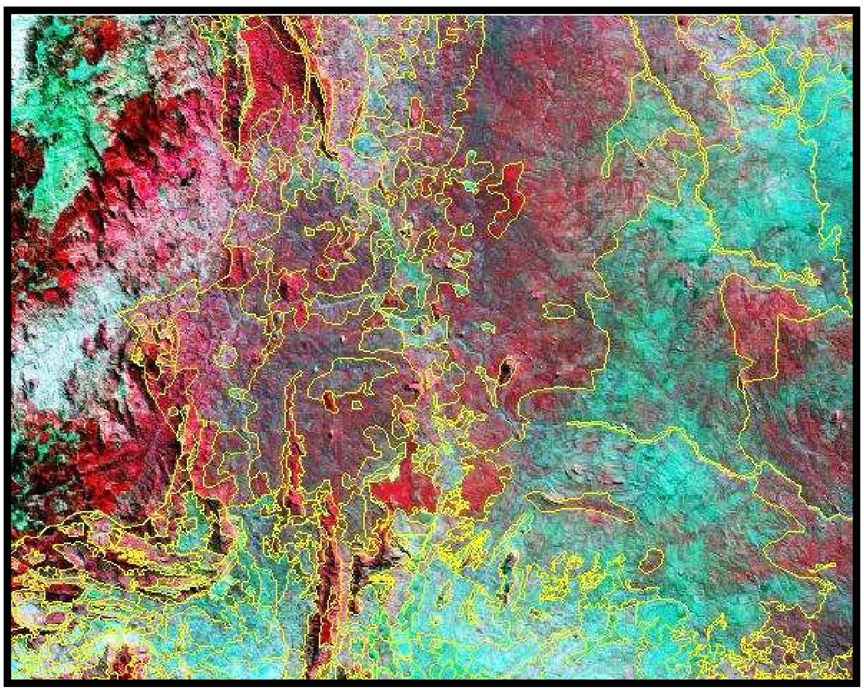
Republic of Italy
Government of Italy

Republic of Mozambique
Ministry of Agriculture

Integrated Assessment of Mozambican Forests

Satellite image interpretation of land-cover types in Manica and Maputo Provinces at nominal scale of 1:250,000 and at National level at nominal scale of 1:1,000,000



Technical Report

February 2006

Agriconsulting S.p.A., Rome, Italy

Technical Report No. 1

INTEGRATED ASSESSMENT OF MOZAMBICAN FORESTS (AIFM) PROJECT

Satellite image interpretation of land-cover types in Manica and Maputo Provinces at nominal scale of 1:250,000 and at National level at nominal scale of 1:1,000,000

Document identity:	AIFM_TechnicalReport_1.1.doc
Version:	1.1
Date:	28-Feb-06
Authors:	Louisa J.M. Jansen, Marco Bagnoli, Sara Chimenti, Angela Dell'Agnello, Marco Focacci, Sinforosa Anna Monaco, Paolo Sorini, Saverio Stoppioni, Ferdinando Urbano
State:	Final
Distribution List:	AIFM Project staff Unidade de Inventario Florestal Direcção Nacional de Florestas e Fauna Bravia Ministero da Agricultura (formerly Ministero da Agricultura e Desenvolvimento Rural)

CCS – Content Change Summary

Version	Rev.	Date	Description	Action (*)	Page
1.0	0.1	21-Feb-06	MADER changed into MINAG	M	Whole document
1.0	0.1	21-Feb-06	Use of "Field orientation"	M	Fig. 19
1.0	0.1	27-Feb-06	Text added	I	Para 1.4 + footnote updated
1.0	0.1	27-Feb-06	Footnote	I	Para 3.3
1.0	0.1	27-Feb-06	Footnote	I	Para 3.5.3
1.0	0.1	27-Feb-06	"Land cover" versus "land cover/use"	I	Para 4.1
1.0	0.1	27-Feb-06	Explanation use of percentage ranges	I	Para 4.5
1.0	0.1	27-Feb-06	User-defined codes placed before table	M	Para 4.5
1.0	0.1	27-Feb-06	Explanation use of percentage ranges	I	Para 4.6
1.0	0.1	27-Feb-06	Reference to TOR-Appendix 2	I	Para 5.2
1.0	0.1	27-Feb-06	"(Semi-) deciduous" and "(semi-) evergreen" use	I	Para 5.2.1
1.0	0.1	27-Feb-06	Reference to TOR text on land-cover change	I	Para 8.4.1
1.0	0.1	27-Feb-06	Figure has changed	R	Fig. 27
1.0	0.1	27-Feb-06	Mozambique geodatabase diagram - 1	R	Para 9.3.2
1.0	0.1	27-Feb-06	Minor text editing	R	Para 11.1
1.0	0.1	27-Feb-06	Minor text editing	R	Para 11.3
1.0	0.1	27-Feb-06	Minor text editing	R	Para 12.4

(*) Action: I=Insert, R=Replace, M=Modify

PROJECT SYNOPSIS

Project Title:	Integrated Assessment of Mozambican Forests (AIFM)
Project Number:	BID Nr. S/000/000/ICB/SERV/C/04
Country:	MOZAMBIQUE
Project Objectives:	1. Assessment of the National Forest Resources: • Assessment of the current status and the predictable future development of country's forest and woodland resources and relate it to management alternatives and national policy programs of the sector; • Explanation of the kind, type and degree of changes which have occurred in land-cover and forest ecosystems in different areas, their foreseen consequences for the human and wildlife conditions, and the measures to be taken to mitigate negative impact of current forest use and improve the living conditions of the local population; • Description of the main environmental components affecting the current state of forest resources and their interactions in order to address use conflicts and regulate future development of the forestry and wildlife sector; • A preliminary assessment of the role of the forestry economy and of the specific degree of degradation of forests resulting from over-exploitation of timber, fuel wood and NFTPs; • Improvement of the DNFFB/UIF technical and operational to carry out and supervise forest resources assessment and monitoring activities; to plan new forest inventories and management plans; to analyze and provide timely and reliable information on the status and changes of national forest resources. 2. Assessment of the Manica and Maputo Provincial Forest Resources. 3. Wildlife assessment in the Chimanimani Reserve (Manica). 4. Assessment of the Forest Resources of the Inchope Region and preliminary study for establishment of a Community Forest Management Plan.
Implementing Agency:	MINAG/DNFFB/UIF, Maputo
Consultant:	Agriconsulting S.p.A.
Address of Consultant:	Via Vitorchiano 123, 00189 Rome, Italy
Date of report:	14 February 2006
Author of report:	Agriconsulting S.p.A.
Reporting period:	April 2005-February 2006

Table of contents

List of Figures

List of Tables

List of Equations

Acknowledgements

The Remote Sensing and Land Cover Classification Expert would like to sincerely thank for their availability to share views and best practices –in alphabetical order–:

- Mr. Giancarlo Carrai, SVALTEC S.r.l. – informatics for architecture and environment, Florence, Italy;
- Mr. Tom Loveland, United States Geological Survey – EROS Data Center, Sioux Falls, USA;
- Mr. Luca Morandini, consultant GIS/IT and statistics, Terni, Italy;
- Messrs. Luca Ongaro and Paolo Sarfatti, Istituto Agronomico per l'Oltremare – Natural Resources, Florence, Italy.
- Mr. Steve V. Stehman, Faculty of Forest and Natural Resources Management – State University of New York, New York, USA; and
- Mr. Alan H. Strahler, Boston University – Center for Remote Sensing, Boston, USA.

Furthermore, the whole team would like to gratefully thank Mr. Giovanni Preto for his continuous interest in how the work evolved and its results.

Acronyms

AIFM	Integrated Assessment of Mozambican Forests Project
ASTER	Advanced Spaceborn Thermal Emission and Reflection Radiometer (sensor onboard the Terra satellite)
CEF	Forestry Research Centre
CENACARTA	Centro Nacional de Cartografia e Teledetecção National Centre of Cartography and Remote Sensing
CSIR-SAC	Council for Scientific and Industrial Research - Satellite Application Centre
DINAGECA	Direcção Nacional de Geografia e Cadastro National Directorate of Geography and Cadastre
DNFFB	Direcção Nacional de Florestas e Fauna Bravia National Directorate of Forests and Wildlife
EDC	EROS Data Center (of the USGS)
FAO	Food and Agriculture Organization of the United Nations
FCC	False Colour Composite (combination of 3 bands of a satellite image)
GIS	Geographic Information System
GLCF	Global Land Cover Facility of the University of Maryland
GOFC-GOLD	Global Observation of Forest Cover-Global Observation of Land Dynamics
GTOS	Global Terrestrial Observation Strategy
GTZ	Gesellschaft für technische Zusammenarbeit (German bi-lateral co-operation)
IAO	Istituto Agronomico per l'Oltremare of the Italian Ministry of Foreign Affairs
IGBP	International Geosphere Biosphere Programme
IGN	Institut Géographie National (France)
IHDP	International Human Dimensions Programme on Global Change
INIA	Instituto Nacional de Investigação Agronómica National Institute for Agricultural Research
IUSS	International Union of Soil Sciences
EDP	Electronic data processing
ETM+	Enhanced Thematic Mapper (sensor onboard the LANDSAT 7 satellite)
LCCS	FAO/UNEP Land Cover Classification System
LUCC	Land Use and Cover Change programme element of the IGBP/IHDP
MINAG	Ministero da Agricultura (formerly Ministero da Agricultura e Desenvolvimento Rural (MADER)) Ministry of Agriculture
MODIS	Moderate-resolution Imaging Spectro-radiometer (onboard the Terra satellite)
NDVI	Normalized Difference Vegetation Index
NASA	US National Aeronautics and Space Administration
NOAA	US National Oceanic and Atmospheric Administration
NTFP	Non-Tree Forest Product
RMSE	Root-Mean-Square Error
SLC	Scan Line Corrector
SPFFB	Servico Provincial de Florestas e Fauna Bravia Provincial Service of Forests and Wildlife
SRTM	Shuttle Radar Topography Mission
TM	Thematic Mapper (sensor onboard the LANDSAT 5 satellite)
UEM	Universidade Eduardo Mondlane
UIF	Unidade de Inventario Florestal Forest Inventory Unit
UNEP	United Nations Environmental Programme
USGS	United States Geological Survey

1 INTEGRATED ASSESSMENT OF MOZAMBICAN FORESTS

1.1 Objectives of the project

The purpose of the Integrated Assessment of Mozambican Forests (AIFM) project is the assessment and monitoring of the extent, state and changes of Mozambican forests and wooded lands in a timely and accurate manner. AIFM will be sufficiently flexible that the implementing agency *Direcção Nacional de Florestas e Fauna Bravia* (DNFFB) can integrate the inventory design into existing forest resources inventories (e.g., Sofala, Cabo Delgado, Zambezía and Inhambane), planned management plans and other environmental studies carried out by national and international institutions in the country. Four major interventions and their outputs are briefly outlined below.

1. Assessment of the National forest resources

- Assessment of the current status and the predictable future development of the Country's forest and woodland resources.
- Explanation of the kind, type and degree of change that have occurred in land cover and forest resources in different areas, their foreseen consequences, and the measures to be taken to mitigate negative impacts of current forest and pasture use and to improve the living conditions of the local population.
- Description of the main environmental components affecting the current state of forest resources and their interactions in order to address use conflicts and regulate future development of the forestry and wildlife sector.
- A preliminary assessment of the role of the forest on the livelihood of local populations (fuel wood, NTFPs, shifting cultivation).
- Improvement of the DNFFB/UIF technical and operational capacity to carry out and supervise resources assessment and monitoring activities, plan forest inventories and management plans, analyse and provide reliable information on status and changes of National forest resources.

2. Assessment of the Manica and Maputo Provincial forest resources

- Setting of the environment for collection and analysis of baseline information within the framework of the national inventorying procedures.
- Establishment of the regional inventory field activities at appropriate intensity in order to test the compatibility of the proposed national methodology at the Province level.

3. Wildlife assessment in the Chimanimani Reserve (Manica)

- Planning and execution of surveys and investigations on wildlife conditions in the Chimanimani reserve.
- Assessment of the feasibility of integrating collected wildlife information into the proposed Mozambican forests inventory system.

4. Forest resources assessment of the Inchope Region and preliminary study for the establishment of a Community Forest Management Plan

- A study on the utilisation patterns of natural resources within the Inchope Forests.
- Assessment of the feasibility of involving local communities and stakeholders in the sustainable management of such resources.
- Contribution to the development of a methodology for implementing participative management plans under similar socio-economic and environmental conditions.

1.2 Background

The present policies of Mozambique emphasize the market-oriented economy, the role of private sector and decentralisation, which are reflected in the forest policies and legislation. This offers challenging opportunities for the development of sustainable management and utilisation of forest resources, in particular as the agricultural sector contributes 24.2% to the GDP (e.g., industry and services contribute 41.2% and 34.6% respectively).

The *Ministero da Agricultura* (MINAG) - *Direcção Nacional de Florestas e Fauna Bravia* (DNFFB) envisages to assess the National forest resources and to set up an inventorying system capable of integrating the forest resources inventorying and monitoring programs carried out at Province level. Two Provinces (e.g., Manica and Maputo) have been selected for evaluating the feasibility of integrating National and Provincial forest inventories into a coordinated information system. Moreover, a preliminary research on the feasibility of community management plans is envisaged in a selected forest area of Inchope (on the border between Manica and Sofala Provinces).

The envisaged forest resources assessment program integrates the data collected at different levels with previously acquired environmental and forestry information. It also improves the DNFFB - *Unidade de Inventario Florestal* (UIF) capacities of assessing and monitoring the ecological and productive conditions of the Mozambican forests, and provides the forest administration (DNFFB and SPFFB) and concerned institutions with an efficient tool for planning forestry sector development and for setting up a strategy for a sustainable use of forest and wildlife resources. That is why the DNFFB decided to take action towards planning and implementing appropriate measures for sustainable use of forest resources.

An assessment of the present land-cover conditions and of the current status of the national forests is to provide the forest administration and other concerned institutions with an up-dated efficient tool for planning and managing land resources. Moreover, it includes also:

- Provision of the required knowledge and expertise for future assessment and monitoring of forest resources;
- Planning and implementation of the sustainable use of forest and wildlife resources at National and Province levels;
- Improvement of the capability of the DNFFB and concerned services of UIF, the Manica and Maputo SPFFB in assessing and monitoring forest resources;
- Acquirement of relevant information and experiences in assessing forest and wildlife resources, which would enable DNFFB to set up sustainable forest management plans in the selected Provinces;
- Setting up of a prototype of community management plans for supporting the sustainable use of forest resources by local dwellers and improve their living conditions.

1.3 Specific remote sensing and land-cover objectives

The land-cover/use assessment, or remote sensing and land-cover component, of the Project provides the baseline data set on which the stratification of the Forest Inventory is based. It is therefore important to stress that this data set is an *intermediate step* in the Forest Inventory procedures. In order to guarantee continuity to the monitoring activities of the Mozambican natural resources, the inventorying system is such that remote sensing interpretation and ground observations can be replicated in future.

Furthermore at National level, the land-cover data will be integrated with available environmental and forest information as well as landform data in order to define so-called Land Units.

The methodology described in this Technical Report has been presented and discussed during the Inception Mission of the Remote Sensing and Land Cover Classification Expert from 3 to 22 May 2005 in Maputo with MINAG, DNFFB, UIF and UEM. It has also been described in the Inception Report. The adopted methodology has been executed in full synergy between UIF and Agriconsulting S.p.A.

The specific remote sensing and land-cover objectives can be summarised as follows:

- Presentation of an overview of occurring land-cover types in Mozambique, their location, extent and distribution.
- Utilisation of up-to-date technologies and international standards in land-cover data collection.
- Exchange of experiences and training on-the-job of the use of remote sensing for land-cover interpretation.

The remote sensing and land-cover component will provide the following results[1]:

1. Documented remotely sensed data derived Provincial land-cover data for Manica and Maputo Provinces (at nominal scale 1:250,000) for the year 2004 outlining the extent, distribution and relationships among different land-cover types in digital format.
2. Documented remotely sensed data derived National land-cover data (at nominal scale 1:1,000,000) for the year 2004-2005 outlining the extent, distribution and relationships among different land-cover types in digital form;
3. Reliable up-to-date land-cover statistics concerning the spatial extent of the different land-cover types at National level and for the two Provinces.
4. Operational implementation of technologies related to remote sensing and land-cover interpretation (e.g., digital image processing, application of international standards) for natural resources monitoring and management at DNFFB/UIF;
5. Inclusion of the land-cover data sets into the Information System at DNFFB/UIF, combining data from AIFM with existing supplementary digital information, which will allow the production of outputs (e.g., maps, tables and reports) and facilitates data exchanges with national and international institutions and services.

1.4 Duration of activities

The activities related to the remote sensing and land-cover interpretation component (Appendix H) started with the Inception Mission of the Remote Sensing and Land Cover Classification Expert from 3-22 May 2005 documented in the Inception Mission report of the expert and the Inception Report.

The remote sensing and land-cover interpretation team in Florence, Italy, started the satellite image interpretations at 1:250,000 nominal scale for Manica and Maputo Provinces in early June and they were finalised after field validation in October and November 2005 respectively. UIF/DNFFB and SPFFB Staff carried out the field orientation and field validation in August-November; the interpretation at 1:1,000,000 nominal scale for Mozambique started in mid-September and was finalised after validation in December 2005. On-the-job training took place in the period 21 November - 14 December 2005 in Florence, Italy, for three UIF Staff members, which also participated in the National level land-cover interpretation.

In the final mission from 15-25 February 2006 a technical workshop was organised at DNFFB in which the results of the remote sensing and land-cover component described in this Technical Report were presented. Reporting took place during the last phase of activities and involved the whole remote sensing and land-cover interpretation team as well as the feedback received from UIF and DNFFB during the final mission resulting in this Technical Report completed in late February 2006.

[1] This Technical Report -to be attached to the AIFM Final Project Report- documents all procedures followed and the results obtained for the remote sensing and land-cover data collection at Province and National levels.

2 EXECUTIVE SUMMARY

Not chaos-like, together crushed and bruised,
But, as the world harmoniously confused:
Where order in variety we see,
And where, though all things differ, all agree.

Alexander Pope, Windsor Forest

This Technical Report documents the assessment of land-cover types in the context of the Integrated Assessment of Mozambican Forests (AIFM) Project. This land-cover/use assessment provides the National administration and other concerned institutions with an updated efficient tool for planning, management and monitoring of the natural resources. Interpretation of remotely sensed satellite images is a tool that provides an overview of land-cover types over vast areas at a certain moment in time. The three land-cover data sets produced (Manica Province, Maputo Province and Mozambique) have been organised in three geodatabases together with the ancillary data used. The land-cover data sets are used as baseline data for the Forest Inventory stratification, being the main aim of the production of these data sets within the Project context, in addition to being available to future agricultural and environmental applications.

The present Report describes the approaches and procedures followed and standard methodologies applied in the AIFM remote sensing and land-cover component. These methodologies can be repeated in future to guarantee continuity of the monitoring activities of the natural resources in Mozambique.

Remote sensing and land-cover interpretation

LANDSAT 5 TM images have been processed for interpretation purposes using orthorectified LANDSAT 7 ETM+ images, downloaded free of charge from Internet, as the basis for interpretation. A multiple view approach was selected combining multi-stage (i.e. data about the terrain are collected from multiple altitudes), multi-spectral (i.e. data are acquired simultaneously in several spectral bands) and multi-temporal sensing (i.e. data about the terrain is collected at different dates). In the interpretation process various levels of complexity were encountered, from a simple direct recognition of objects to the inference of site conditions. Success in image interpretation varies with the training and experience of the interpreter, the nature of the objects or phenomena being interpreted and the quality of the images being utilised. In general, the most capable image interpreters have keen powers of observation coupled with imagination and a great deal of patience. The process of convergence of evidence to successfully increase the accuracy and detail of the land-cover interpretations was applied. Guaranteeing spatial and thematic coherence of the interpretations, carried out by a team of interpreters, is important in order to create a homogeneous high quality product. The applied minimum mapping units are $1km^2$ for the 1:250,000 nominal scale interpretations (Province level) and $16km^2$ for the 1:1,000,000 nominal scale interpretation (National level).

Land-cover classification and legend

The AIFM land-cover legends were created using the FAO/UNEP Land Cover Classification System (LCCS) -version 2- that allows a standardised, systematic definition of classes using a set of parameters tailored to the specific land-cover feature being described. The automatically generated standard LCCS coding is assigned to the land-cover classes of the AIFM legend in order to allow harmonisation and standardisation of the final products in the broader context of natural resources management and regional planning. In Manica Province 31 and in Maputo Province 33 different land-cover classes were identified and at National level 20 land-cover types were distinguished. There is a direct link between the classes at Province and National level.

Validation and accuracy assessment

A statistical validation was performed for all data sets. The georeferencing accuracy of the data sets for Manica Province, Maputo Province and at National level resulted in an average RMSE of 19.3m, 15.6m and 20.7m respectively, corresponding to less than one pixel (e.g., a LANDSAT pixel is 30m). These georeferencing errors should be combined with those of the imagery used for image-to-image georeferencing, i.e. LANDSAT images with a RMSE of less than 50m. Thus, the positional accuracy in case of error propagation results in a RMSE of approximately 2.1-2.4 pixels at both Province and National levels. The thematic accuracies of the land-cover data for Manica Province, Maputo Province and Mozambique are 87.0% (KHAT=0.84), 86% (KHAT=0.85) and 86.0% (KHAT=0.83) respectively, thereby fulfilling the TOR requirement of being at least 85%. The positional and thematic accuracy assessment results allow the use of these data sets for applications with nominal scales of 1:250,000 at Province level and 1:1,000,000 at National level.

Applications

Several applications, though not requested by the TOR, have been made with the collected land-cover data to illustrate possible future uses:

1. The Province level data (1:250,000 nominal scale) have been incorporated into the National level data set (1:1,000,000 nominal scale) using a series of decisions in order to systematically group polygons that fall below the minimum mapping unit defined while conserving the maximum amount of land-cover information possible.
2. An evaluation of two possible approaches to the estimation of the percentage forested area in mixed classes (i.e. polygons that consist of a forest class and another class) was made. The use of NDVI was compared to Unsupervised Classification. The conclusion stresses the caution with which such techniques might be applied.
3. Semantic data harmonisation was applied using two land-cover/use legends produced in previous projects. The FAO/UNEP Land Cover Classification System – Translator Module was used as a tool. This semantic harmonisation of data allowed the comparison of the different classes as used in the various data sets. Comparison of the land-cover statistics is, however, not recommended.
4. A land-cover change study was completed for Manica Province analysing the changes in the period 1990-2004 in order to detect the prevalent change dynamics processes. The conclusions indicate that there is a general change of forests into closed to open forested areas with cultivation, or into cultivated areas. The rates of change are very high and give reason to concern for natural resources management.
5. The use of satellite remote sensing techniques for identifying and monitoring burnt areas and the recurrent occurrence of fires, as well as to collect statistics, is demonstrated.

Land-cover/use geodatabase

The remote sensing and land-cover component is completely integrated in the general framework of the AIFM Project, but it had also some individual requirements. Therefore, a dedicated geodatabase for this specific component was developed in order to structure and organise the data from the very beginning of operational activities so as to have a flawless data production, storage, integration and analysis chain. This resulted in the land-cover/use assessment geodatabase constructed in such a way that UIF/DNFFB can use it as a framework to build upon and include new land-cover and other data sets in future.

The geodatabase is structured around five key thematic and functional groups: (1) Land Cover, (2) Field Sample Data, (3) Ancillary Data, (4) Work Management and (5) Satellite Data. Not only the produced land-cover data sets are included but also all digital ancillary data that was used. Furthermore, a complete metadata description is associated to all data layers, according to the ISO 19115 standard. The created geodatabase can be used for the production of a range of outputs and applications, in addition to facilitating data exchange with national and international institutions and services.

3 REMOTE SENSING

3.1 Introduction

Remote sensing systems that measure energy naturally available are called passive sensors. These sensors can only be used when the naturally occurring energy is available and this can only take place during the time when the sun is illuminating the Earth. Energy that is naturally emitted (e.g., thermal infrared) can be detected day or night. Active sensors provide their own source of illumination. The sensor emits radiation directed towards the target to be investigated; the radiation reflected from that target is detected and measured by the sensor. Both passive and active sensors detect, through the measurement of different parameters, the behaviour of electromagnetic radiation after its interaction with the Earth's surface.

The result of a remote sensing application is improved considerably when taking a *multiple-view* approach (Lillesand and Kiefer, 2000). For the AIFM land-cover interpretation this involves *multi-stage* sensing wherein data about the terrain are collected from multiple altitudes, i.e. high-resolution satellite data is analysed in combination with low altitude data (e.g., topographic maps, roads and rivers, forest types data) and ground observations. Furthermore, it involves *multi-spectral* sensing whereby data are acquired simultaneously in several spectral bands. When the signals recorded in the multiple bands are analysed in combination with each other, more information becomes available than if a single band would be analysed or multiple bands would be analysed independently. The multiple-view approach involves also *multi-temporal* sensing where data about the terrain is collected at different dates (e.g., dry and wet season). Multi-temporal sensing uses changes occurring with time as discriminants of ground conditions. More information is obtained by the multiple-view approach than by any single view.

In any approach to applying remote sensing, not only the right combination of data acquisition and data interpretation techniques must be selected, but the right mixture of remote sensing with conventional techniques must also be identified. Remote sensing is a tool, it is not an end in itself. Like any tool it has its limitations. In the context of the Project, use has been made of several passive sensors as will be described in the following paragraphs.

3.2 Actual problems with LANDSAT images

The LANDSAT satellites have repetitive, circular, sun-synchronous, near-polar orbits, providing full coverage between 81°N and 81°S. The sensors always scan the ground at satellite nadir. The sun-synchronous orbit means that all acquisitions over a given area occur at the same time, giving consistent shadows for the time of year. A LANDSAT track is 183km wide. The repeat cycle for LANDSAT 5 and 7 is 16 days. LANDSAT 7 was launched on 15 April 1999 and orbits 8 days behind LANDSAT 5, launched 1 March 1985. The characteristics of the LANDSAT bands are given in Table 1. LANDSAT 5 carries the Thematic Mapper (TM) sensor, whereas LANDSAT 7 carries the Enhanced Thematic Mapper (ETM+) sensor.

Table 1. Characteristics of LANDSAT 5 and 7

Satellites	LANDSAT 5 and 7							
Sensors	TM and ETM+							ETM+
Spectral bands	1	2	3	4	5	6	7	8
Wavelength[2] (µm)	45-52 (blue)	52-60 (green)	63-69 (red)	76-90 (NIR)	1.55-1.75 (MIR)	10.42-12.50 (TIR)	2.08-2.35 (MIR)	52-90 (Panchromatic)
Pixel size (m)	30	30	30	30	30	120 (TM) 60 (ETM+)	30	15
Orbit	16 days / 705 km							

[2] NIR=Near infrared, MIR=Middle infrared, TIR=Thermal infrared.

Originally managed by the US National Aeronautics and Space Administration (NASA), the responsibility of the LANDSAT program was transferred in 1983 to the National Oceanic and Atmospheric Administration (NOAA).

In the TOR (dated October 2004) and Technical Proposal it is stated that "*satellite image interpretation will be carried out on geo-corrected LANDSAT 7 images or equivalent*" without considering that the U.S. LANDSAT Program is affected by a series of anomalies and failures of the available instruments on-board the LANDSAT 5 and 7 satellites.

The LANDSAT 7 ETM+ scenes with an acquisition date after May 2003 are affected by the scan line corrector (SLC) anomaly. This means, in practice, that the post May 2003 images come with gaps, i.e. in various parts data is missing. Though the USGS-EROS Data Center (EDC) with the help of NASA has become proficient in applying "gap filling" methods using other LANDSAT scenes to fabricate useful LANDSAT 7 data sets (pers. comm. T. Loveland, USGS/EDC) with this method the baseline date for consistent and systematic data collection and subsequent analysis is lost, i.e. the LANDSAT scenes do no longer reflect solely the spectral values of their acquisition date but they are a mixture of these spectral values with those from earlier dates used to fill the gaps. However, if LANDSAT 7 ETM+ is no longer an option, one can fall back on LANDSAT 5 TM scenes where it not that these experience a failure of the LANDSAT 5 recorders. LANDSAT 5 scenes can only be directly broadcasted to a ground receiving station (http://landsat.usgs.gov/grounds.html). The ground receiving station of the Council for Scientific and Industrial Research - Satellite Application Centre (CSIR-SAC), near Pretoria in the Republic of South Africa, is collecting the LANDSAT 5 TM data for the region and covers the whole of Mozambique (http://www.csir.co.za) (Figure 1). In November 2005 also the LANDSAT 5 TM was affected by an anomaly and reception of images was suspended until late January 2006.

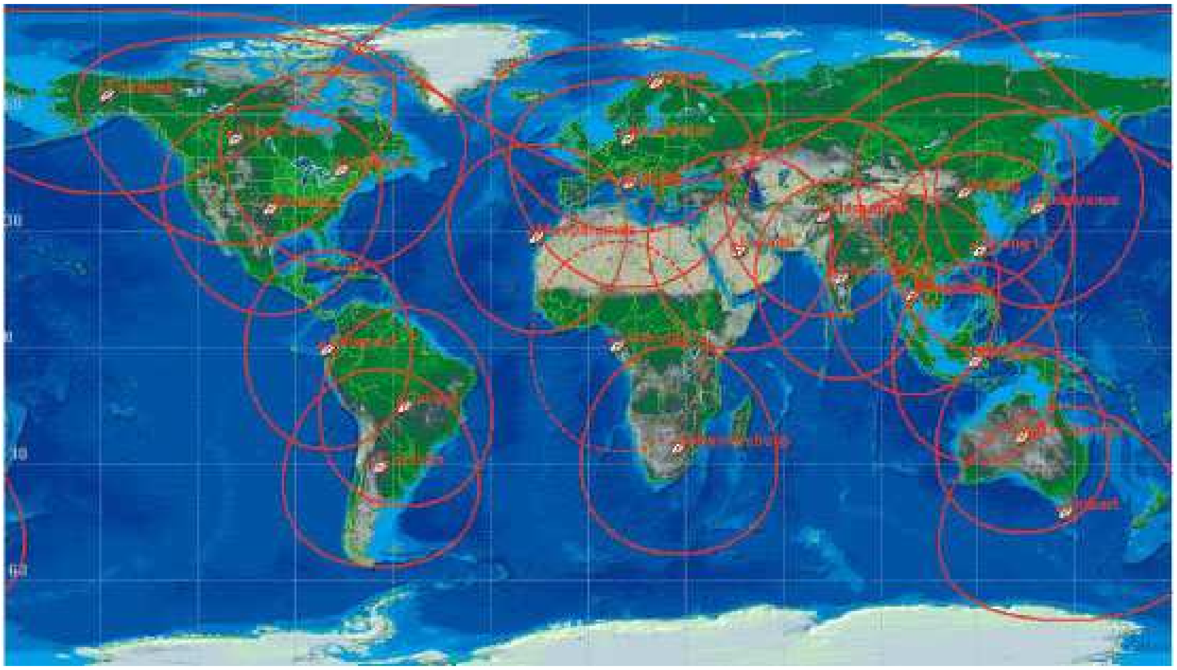
In Mozambique, the focal point for acquisition of satellite imagery is the *Centro Nacional de Cartografia e Teledetecção* (CENACARTA).

From the CSIR-SAC Main Catalogue those images have been selected that have:

- Zero or minimum cloud cover and minimum terrain shadowing; and
- Maximum spectral differences in order to distinguish clearly the different land-cover types. Past experience shows that acquisition dates in the period April-July, corresponding to late wet season and early dry season, offer maximum contrast among the various vegetation types. One should keep in mind, however, that there are variations from year-to-year related to rainfall variability.

The selection of images for the land-cover interpretations at Province level according to the above-mentioned criteria did not pose any problems. However, for the National level interpretation for certain areas no cloud free images were available as will be discussed in the following two paragraphs.

Figure 1. LANDSAT worldwide coverage



3.3 *Images acquired for data collection at Province level*

The nominal scale of 1:250,000 to be used at Province level correspond with the use of LANDSAT imagery in order to obtain the required level of land-cover information. Table 2 gives an overview of the scenes that have been selected based on the above-described criteria for the Manica and Maputo Provinces, where data will be collected at nominal scale 1:250,000. The selection of satellite images is based upon the criteria described in the previous paragraph and attention has been paid to select images from the same acquisition date whenever possible. The result is that the LANDSAT images of the same path in the Province are from the same date and those from a neighbouring path from another date.

All seven bands of the LANDSAT 5 TM were acquired at level 1G processing with Cubic Convolution re-sampling in format BSQ (Band Sequential)[3].

Table 2. LANDSAT 5 TM scenes for the land-cover data collection in the Provinces

Province	Path – Row number		Acquisition date (YYYY-MM-DD)	Cloud coverage
Manica	168	75	2004-06-15	0000
	168	74	2004-06-15	0000
	168	73	2004-06-15	0000
	168	72	2004-06-15	0000
	168	71	2004-06-15	1100
	167	75	2004-07-10	0000
	167	74	2004-07-26	0000
Maputo	168	78	2004-07-17	0000
	168	77	2004-07-17	0000
	167	79	2004-05-23	0000
	167	78	2004-05-23	0000
	167	77	2004-05-23	0000

[3] CENACARTA is gratefully thanked for having made available the LANDSAT 5 TM images for the Provinces at the special Government price rate as part of the yearly quota of satellite images provided to Government.

3.4 Images acquired for data collection at National level

The nominal scale of 1:1,000,000 to be used at National level does not correspond with the use of LANDSAT imagery that are widely used for land-cover data collection in scales ranging from 1:50,000 to 1:250,000. If LANDSAT would be used at the (pixel) resolution of 30m the interpretation would contain much more detail than required at a nominal scale of 1:1,000,000.

More suitable remote sensing images would be those from the Moderate-resolution Imaging Spectro-radiometer (MODIS) onboard the Terra platform that come in many bands of which the bands 1 to 7 are related to land applications and that have a resolution of 250 or 500m (Table 3). The MODIS instrument provides high radiometric sensitivity (12 bit) in 36 spectral bands ranging in wavelength from 0.4 µm to 14.4 µm. The responses are custom tailored to the individual needs of the user community and provide exceptionally low out-of-band response. Two bands have a nominal resolution of 250m at nadir, with five bands at 500m, and the remaining 29 bands at 1km. A ±55-degree scanning pattern at the EOS orbit of 705km achieves a 2,330km swath and provides global coverage every one to two days.

Table 3. Characteristics of MODIS

Satellite	TERRA						
Sensors	MODIS						
Spectral bands	1	2	3	4	5	6	7
Wavelength (nm)	620 - 670	841 - 876	459 - 479	545 - 565	1230 - 1250	1628 - 1652	2105 - 2155
Pixel size (m)	250		500				
Orbit	705 km, 10:30 a.m. descending node (Terra) or 1:30 p.m. ascending node (Aqua), sun-synchronous, near-polar, circular						

However with a pixel resolution of 500m the context of the land cover is lost to a great extent and visual interpretation of land-cover types becomes an impossible task. Therefore LANDSAT 5 TM images were also selected for the National level land-cover data collection (see also paragraph 3.8.5).

LANDSAT images acquired at National level cover a wider period than those selected for the two Provinces because of availability of suitable images (Table 4). During the interpretation of the LANDSAT images for the two Provinces, images of the preferred acquisition period April-July in 2005 had become available. Images of this period were preferred above those outside this period in 2004 because of the better image characteristics to distinguish the different vegetation types. The selection is based upon the following decision criteria in order of application:

- Preferred acquisition period April-July in 2004 and cloud free;
- Preferred acquisition period April-July in 2005 and cloud free;
- Acquisition period outside preferred period of 2004 and cloud free;
- Acquisition period outside preferred period of 2005 and cloud free;
- Acquisition period outside preferred period in 2004 with partial cloud cover; and
- Acquisition period outside preferred period in 2005 with partial cloud cover.

Whenever possible the images of the same path were selected from the same pass-over of the LANDSAT in order to minimise differences in image characteristics (e.g., atmospheric disturbances). Thus images of the same LANDSAT path are closer in acquisition dates than between different LANDSAT paths. Image selection for the northern part of the country proved to be difficult because of consistent cloud coverage of the area, therefore the choice was limited to those images available from the CSIR-SAC Main Catalogue.

The LANDSAT 5 TM images for the National level interpretation have been re-sampled/degraded from a pixel size of 30m into a pixel size of 120m for land-cover type interpretation and 210m for delineation of the polygons in order to loose detail in the image that does not serve the scale of interpretation required (for a detailed explanation see paragraphs 3.8.5 and 5.5.2). This combination of pixel resolutions allows on-screen visual interpretation without losing too much of the contextual information, whereas the interpreter can always go back to the original images with a pixel resolution of 30m in case of doubt.

Table 4. LANDSAT 5 TM scenes for the land-cover data collection at National level

Path – Row number		Acquisition date (YYYY-MM-DD)	Cloud cover
170	71	2004-07-31	0000
170	70	2004-07-31	0000
169	71	2004-08-09	0000
169	70	2004-08-09	0000
169	76	2004-07-24	0000
169	75	2004-07-24	0000
168	76	2004-06-15	0000
168	70	2005-06-02	0000
168	69	2005-09-06	0100
168	68	2005-09-06	1100
167	76	2004-05-23	0000
167	73	2004-07-26	0000
167	72	2004-07-26	0000
167	71	2004-07-26	1201
167	70	2004-07-26	2112
167	69	2004-10-30	2222
167	68	2004-05-07	3323
166	77	2005-07-22	0000
166	76	2004-06-01	2000
166	75	2005-07-22	1112
166	73	2004-11-08	0000
166	72	2004-10-07	0001
166	71	2005-07-22	0000
166	70	2005-06-20	0000
166	69	2004-06-17	0000
166	68	2004-06-17	0000
165	72	2004-07-28	0009
165	71	2005-07-15 2005-06-13	2222 4410
165	70	2005-07-15	0000
165	69	2005-05-12	0200
165	68	2004-05-09	1111
165	67	2004-05-09	3010
164	72	2004-07-28	0009
164	71	2004-10-09	0200
164	70	2004-08-22	1111
164	69	2004-08-06	2030
164	68	2004-08-06	2020
164	67	2004-08-06	9920

3.5 Image processing

The land-cover interpretation has been primarily based on LANDSAT 5 TM images of the years 2004-2005. These images were acquired through CENACARTA from CSIR-SAC. The imagery arrived in seven non-georeferenced ".DAT" files, one for each band. It is necessary to elaborate these raw data in ERDAS Imagine in order to transform them in the proper format for image interpretation using ArcGIS software. This process is subdivided in three steps: (1) conversion form the ".DAT" format to the ".IMG" format; (2) creation of a single ".IMG" file (layer stack) containing all the seven LANDSAT 5 TM bands; and (3) georeferencing in the appropriate coordinate system (e.g., UTM36 South or UTM37 South, datum WGS84).

The processed images ready for interpretation were given a name in a systematic manner using: (1) the LANDSAT path and row numbers (e.g., 167077), the date of the image (e.g., in the format day-month-year), the source (e.g., CSIR standing for CSIR-SAC) and the sensor (e.g., where 5 stands for LANDSAT 5 TM) resulting in the complete name of the above example as 167077_23052004_CSIR5.

3.5.1 Import images to IMG format

The LANDSAT 5 TM images were received on CD-ROM media type in binary (BSQ) format. Each of the seven bands of each LANDSAT 5 TM scene has been imported in ERDAS format (.IMG) using the option "Generic binary", 5960 row and 6920 columns, no header (Figure 2). All information (e.g., date of acquisition, number of rows and columns, etc.) concerning the image can be found in the file "header.dat" that can be opened easily by an editor (e.g., notepad).

The import process has been partially automated (e.g., the parameters have been saved using the command "save options" and recovered through the command "load options"), and by creating a batch file (command "batch"). The path and the name of the output files of all bands of each scene are automatically composed (Figure 3).

Figure 2. Import of the LANDSAT 5 TM generic binary data

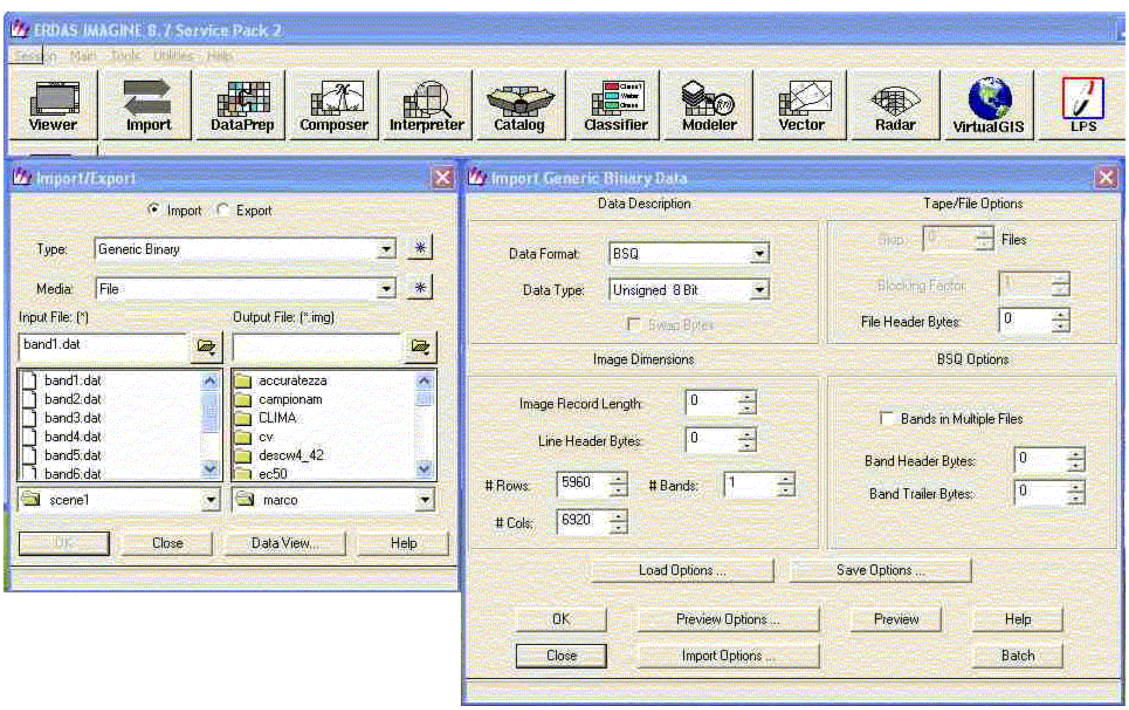
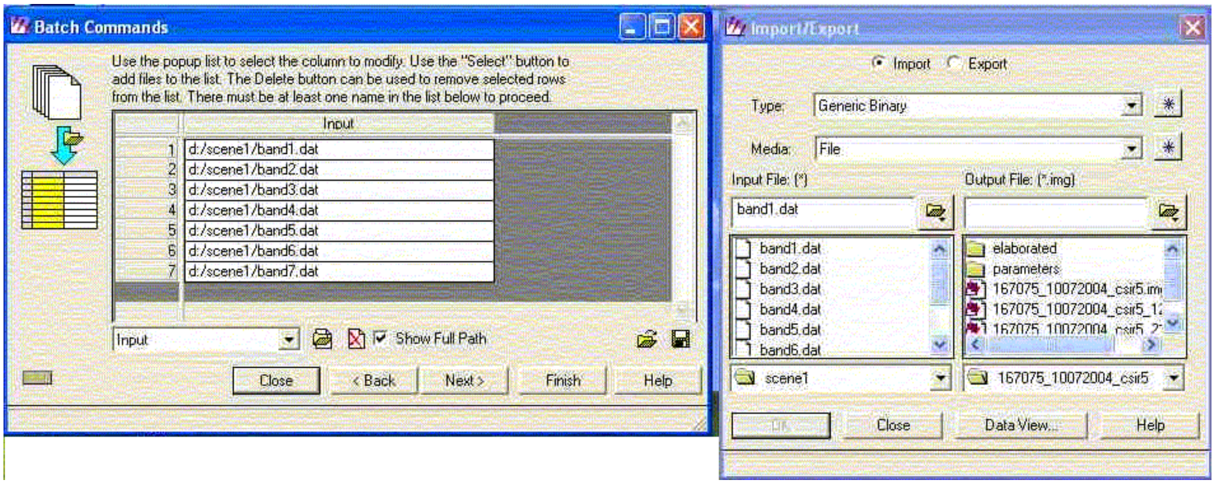


Figure 3. Batch commands used for import of the images

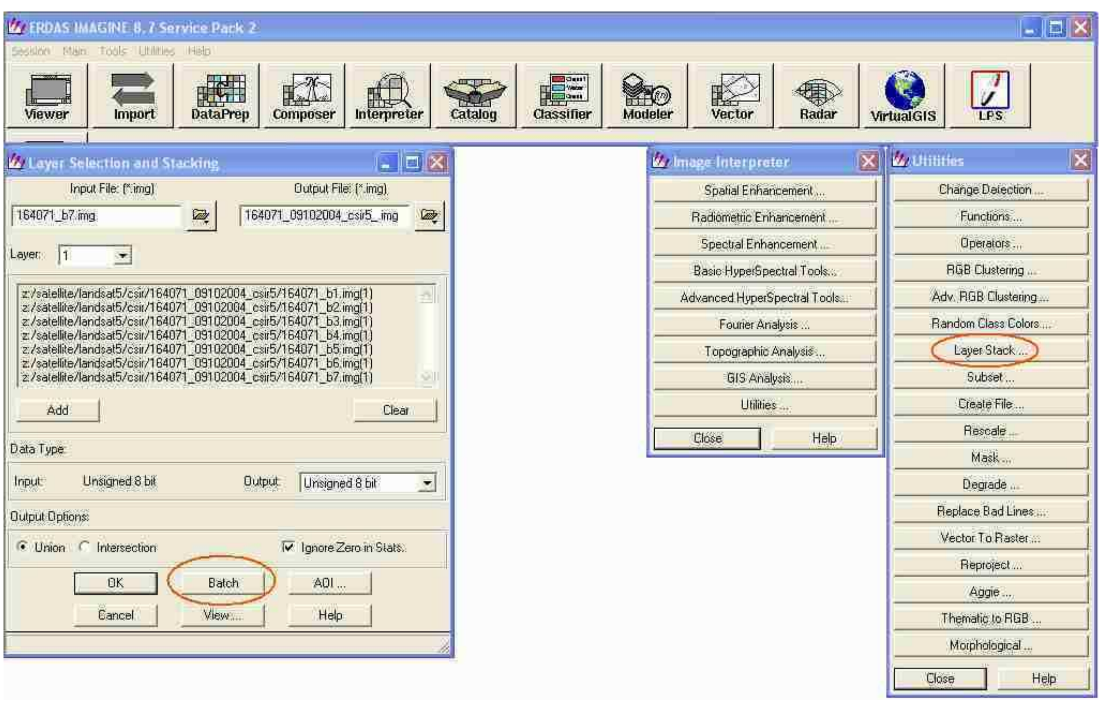


3.5.2 Layer stack

In order to have the possibility to make different False Colour Composites (FCC), all the 7 bands of each LANDSAT 5 TM scene have been loaded in a unique file (.IMG). This operation is called in ERDAS "Layer stack" (command INTERPRETER/UTILITIES/LAYER STACK) (Figure 4). This file format can be visualised in ArcGIS and the satellite image interpreter is free to select each time the three bands for the FCC combination one considers the most suitable for the features one is detecting, delineating and classifying. For this process again a batch file was prepared created by the program that records the commands and the input and output files (e.g., click on the "batch" button).

The first batch file (.BCF) created, that is a text file, has been copied and edited substituting the name and the path of the input and output files. This operation has been replicated for each scene processed.

Figure 4. Layer selection and stacking



3.5.3 Georeferencing

Georeferencing is the process of assigning real-world coordinates (e.g., projection and datum) to geographic data to tie it to the Earth. The projection coordinate systems that were used are Universal Transverse Mercator (UTM) projection zone 36S with datum WGS84 (spheroid WGS84) and Universal Transverse Mercator (UTM) projection zone 37S with datum WGS84 (spheroid WGS84), according to the zone of the image.

The first option to perform georeferencing on raw LANDSAT 5 TM images was the collection of Ground Control Points (GCP) using the available topographic maps at 1:50,000 and 1:250,000 scale from the *Direcção Nacional de Geografia e Cadastro* (DINAGECA). Evaluation of the quality of the topographic maps and the type of area to be georeferenced led to the abandonment of this method. The topographic maps at nominal scale 1:250,000 have not been updated since the 1960s. In the georeferencing process it would be important to find intersections of roads, roads and rivers, roads and railways and the like, in order to assign coordinates. With a difference of more than 45 years between the date of the topographic maps and today one can easily imagine that this may lead to doubtful results, especially since many developments have taken place in the country[4]. Moreover, since the number of LANDSAT scenes to be handled was considerable, an alternative providing the required positional precision and not consuming too much time was desirable. The solution adopted was an image-to-image georeferencing process using the NASA's Global Orthorectified LANDSAT Data Set as reference (Tucker et al., 2004). These images from around the year 2000 have a documented positional accuracy of less than 50m Root-Mean-Square Error (RMSE) that is adequate for the interpretation aims of the Project and these images are free of charge available on Internet from the Global Land Cover Facility of the University of Maryland (http://glcf.umiacs.umd.edu/). Since this data set provides a global coverage, the adopted approach can be used anywhere on Earth (see paragraph 3.6 for more details).

The registration between the raw LANDSAT 5 TM images and the GLCF georeferenced LANDSAT 7 ETM+ images was performed using the ArcGIS 9 module "Georeferencing". For each image, about 15 control points were collected. ArcGIS was selected for this phase because of the on-the-fly reprojection function that permits to overlap the two images step-by-step. This facilitates identification of new Ground Control Points (GCP) and greatly reduces the time needed to collect such points (Figure 5).

The rectification was executed using ERDAS Imagine 8.7. The ground control points were imported form the ".TXT" file generated with ArcGIS and a first order polynomial transformation was used (Figure 6). The Root-Mean-Square Error (RMSE) accepted ranged between 15.5-23.4m in Manica Province (19.3m on average) and 11.7-19.7m in Maputo Province (15.6m on average) where the land-cover interpretation was executed at a detailed level, and between 7.3-51.8m (20.7m on average) for the images used for the National level land-cover interpretation executed at a much coarser scale (see Appendix A for the complete overview of the georeferencing accuracy). Keeping in mind that a LANDSAT pixel corresponds with 30m, this means that at the Province level the error was always much smaller than one pixel, whereas at National level the error was at most less than two pixels. These georeferencing errors should be combined with those of the imagery used for image-to-image georeferencing, i.e. LANDSAT images with a RMSE of less than 50m (Tucker et al., 2004). Therefore, the resulting georeferencing accuracy varies between 2.1-2.4 pixels.

The nearest neighbour re-sampling method was used to keep the spectral reflectance values as similar as possible to the original ones.

[4] During the Final Mission of the Remote Sensing and Land Cover Classification Expert discussion with staff from CENACARTA confirmed the great difficulty with which georeferencing has to deal with in Mozambique because of the available topographic maps.

Figure 5. Georeferencing image-to-image collecting GCPs in ArcGIS with “auto adjust” option

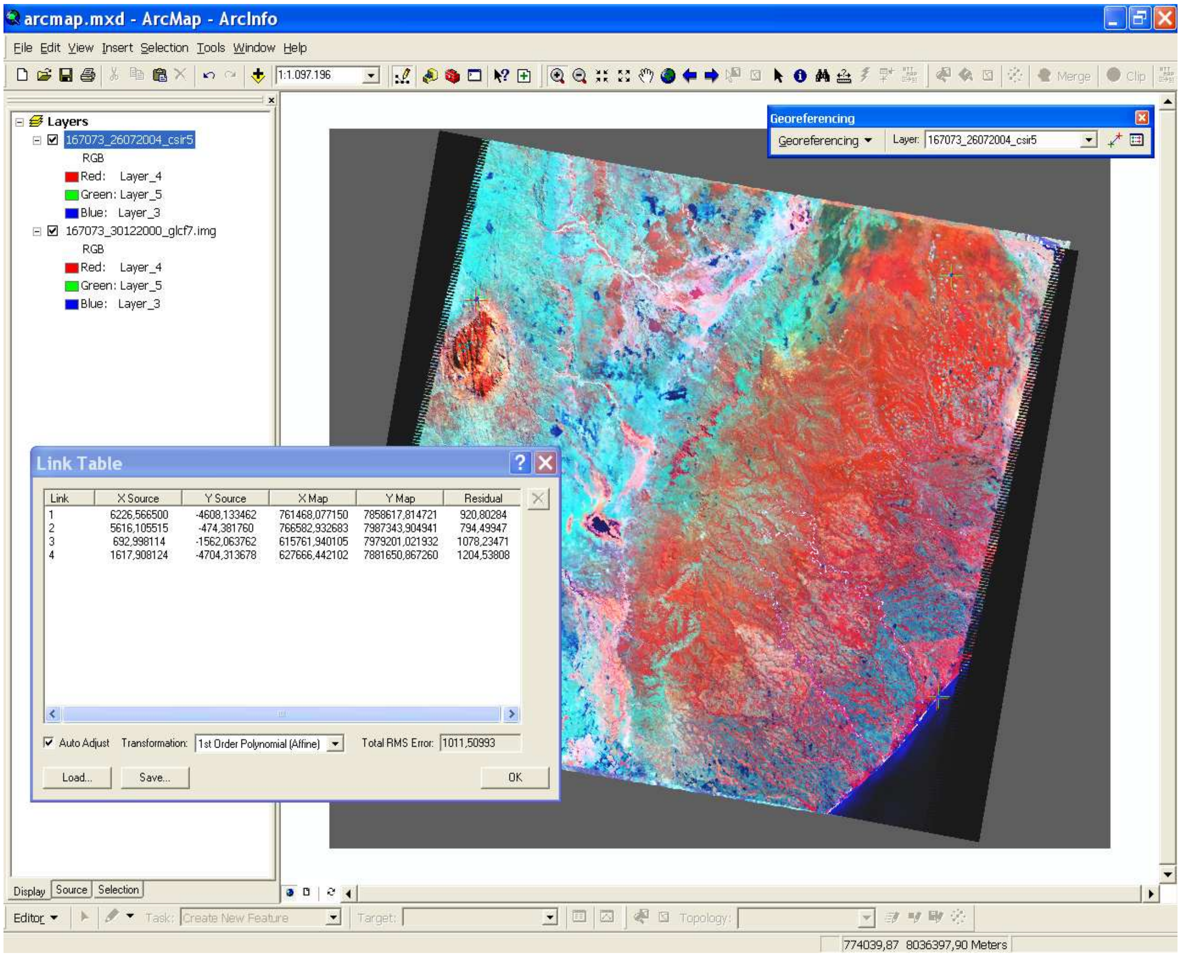
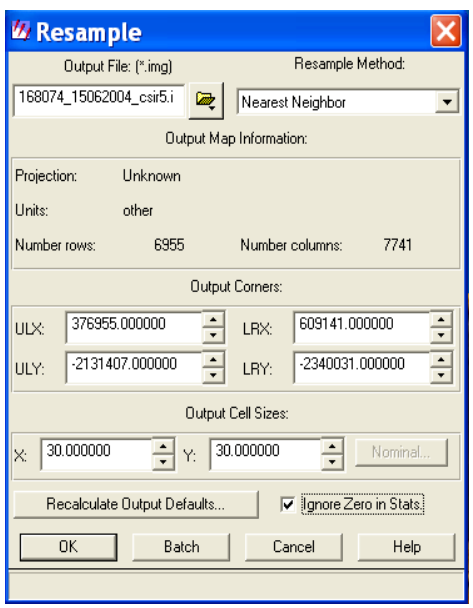


Figure 6. Georeferencing image-to-image with resample parameters

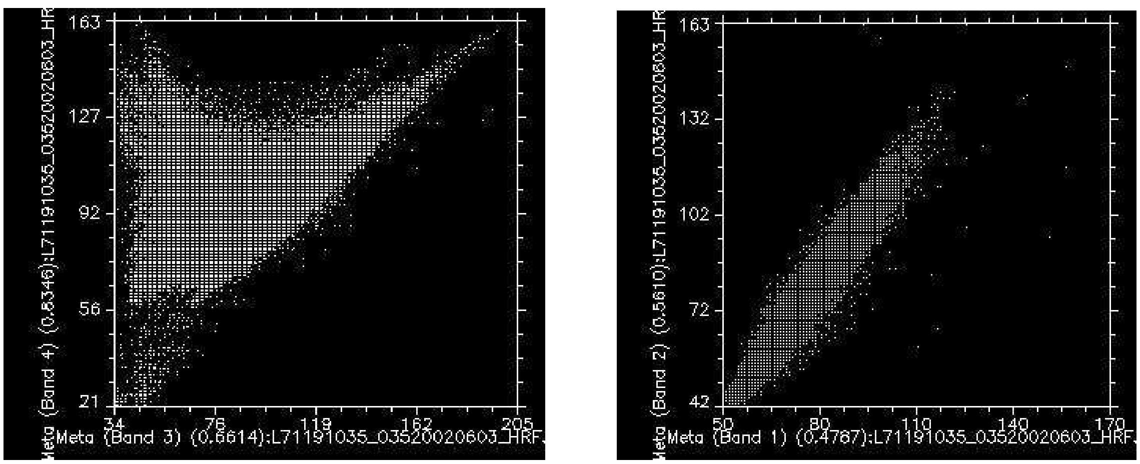


3.5.4 False colour composite

When working with multi-spectral data, the choice of bands to be combined for displaying will be a critical step in the image analysis process, since it affects directly the type and amount of information that can be visually extracted from the image. Since the true colour representation is possible only with the composition of bands 1, 2 and 3 of LANDSAT images (each primary colour is associated to the corresponding spectral band, obtaining something similar to what is seen by the human eye), one speaks more generally about False Colour Composite (FCC) indicating any composition of three different spectral bands associated to the three primary colours of the display device (there is no relationship between spectral bands represented on-screen and the colours used for their representation). In order to select the most meaningful band combination for production of FCC to be used, a preliminary analysis should be performed for each image on the original bands, to check the degree of correlation between the different bands: a high correlation between bands indicates they share elements of information in common, that is to say some degree of redundancy in the information they carry.

Figure 7 gives two examples of scatter plots of highly correlated and uncorrelated bands respectively.

Figure 7. Band 1 versus band 2 scatter plot (left) and band 3 versus band 4 scatter plot (right)



As one could expect, both bands 2 and 3 are weakly correlated with band 4, while the highest correlation is found for bands falling in the visible range (bands 1, 2 and 3) and in the middle infrared range (bands 5 and 7). The selection of the most suitable bands must, however, take into account not only the correlation coefficients between bands but also the type of information to be extracted through interpretation.

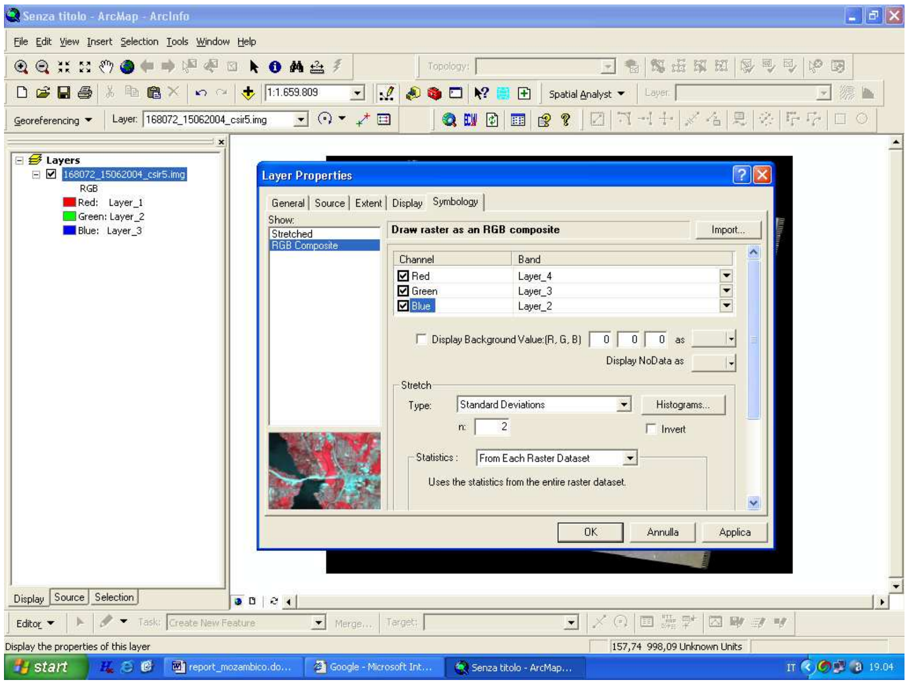
In general one can assume that:

- Vegetation discrimination is enhanced through the incorporation of data from one of the mid IR bands (bands5 and 7) (Please note that the AIFM Project used mainly band 5); and
- Different combinations of any one visible (band 1 to 3), one near-IR (band 4) and one mid IR (band 5 to 7) band are very useful (Please note that the AIFM Project mainly used RGB=432 and RGB=453).

A great deal of personal preference is involved in band-colour combinations for interpretation purposes, and for specific applications other combinations could be optimum.

The false colour composite RGB=432 (colour infrared composite) and the false colour composite RGB=453, composed in the classical Red-Green-Blue sequence, have been found the most suitable and efficient for detection of different land-cover types in Mozambique at Province and National level (Figure 8). These FCC allowed an acceptable distinction of all features to be interpreted: forests, woodlands and aquatic vegetation (e.g., mangrove forests) could be differentiated from features such as shrublands, grasslands, cultivated areas, built-up areas and bare areas.

Figure 8. Drawing raster as RGB composite

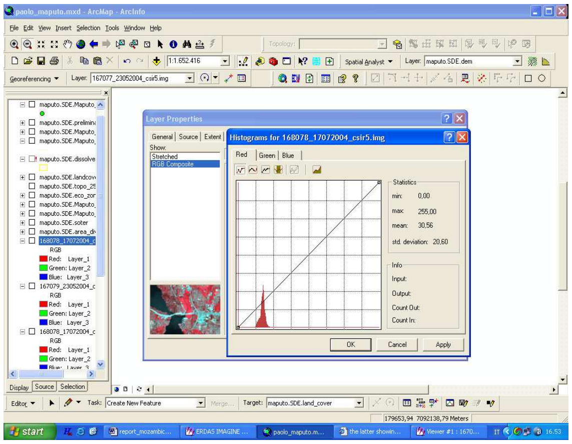


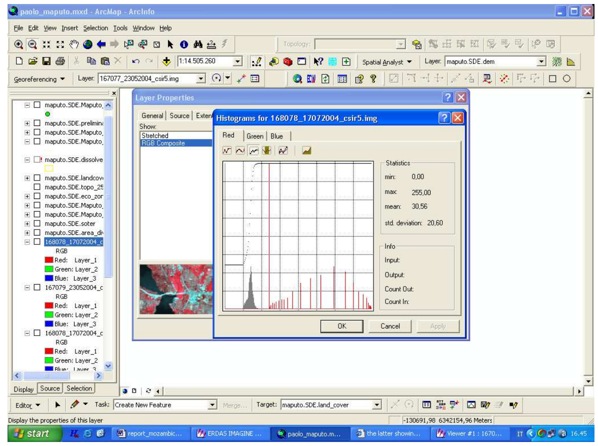
3.5.5 Contrast stretching

Image display devices often operate over a range of 256 grey levels, i.e. the maximum number represented in 8-bit computer encoding. Sensor data in a single image rarely extend over this entire range because under normal conditions it is unlikely that the full dynamic range of the sensor is used. As a consequence satellite images are often dark and lacking in contrast simply because all digital numbers of their pixels fall only into a small portion of the available range (e.g., from 47 to 145). In other words, the tonal information in the scene is compressed into a small range of display values reducing the interpreter's ability to discriminate radiometric details as few details can be seen on such images. If the narrow range of brightness values typically present in an input image could be expanded to fit the full range of available values then the contrast between the dark and light areas of the images would be improved. This is what is done when a contrast stretching operation is performed. The result is an output image accentuating the contrast between features of interest to enhance the image analysis.

A careful analysis of histogram characteristics of each original band in the image is a crucial step for a good image enhancement. As a matter of fact determining the optimal contrast stretching parameters for a specific spectral band, depend on the histogram shape. The shape of the image histogram for a certain spectral band is very interesting as it conveys a lot of information about the spectral characteristic of the objects contained in the image. Figure 9 shows the histogram of the original and enhanced band 4 of a LANDSAT 5 TM image.

Figure 9. Histogram of original band 4 (left) and histogram of enhanced band 4 (right)





The contrast-stretching phase starts with the analysis of the original band histogram. One main challenge encountered in setting up the optimal stretch is represented by strong differences in spectral behaviour of different surfaces in some parts of Mozambique, for example forested areas compared to the coastal dune area close to Maputo District (e.g., the latter showing very high reflectance values in the right tail of the histogram).

Linear and non-linear automatic stretches were used. Sometimes several types of manual stretches were applied that provided better results than the automatic stretches.

The comparison between different enhancements was performed:

- By visual analysis of full resolution image sub-samples and evaluation of the information contents of the resulting image.
- By analysis of the new histograms and evaluation of the relative amount of saturated pixels.

3.5.6 3D visualisation of images

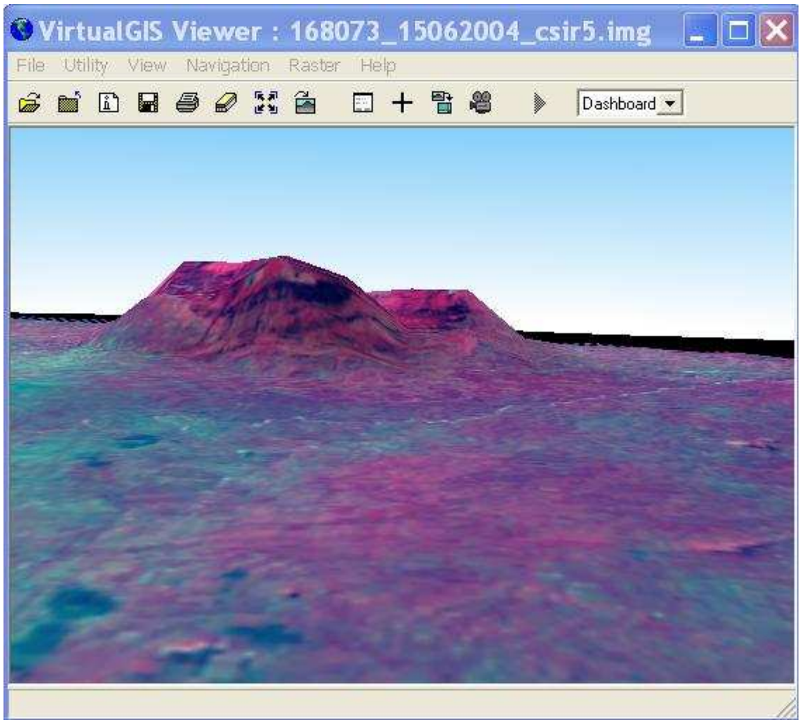
3D viewing of remote sensed images can provide insights that would not be readily apparent from a planimetric map of the same data, leading to a better understanding of the patterns in the images and how they relate to the shape of the Earth's surface.

Some relationships between the surface texture and the shape of the terrain will be apparent when images are shown in perspective. For example, instead of inferring the presence of a valley from the configuration of contour lines on the topographic maps, you can actually see the valley floor and slopes (Figure 10).

Images can be rendered in 3D by defining their z values. If one has the availability of a Digital Elevation Model (DEM) for the area, one can use the values in the model as z values for the image. The 3D representations of the different LANDSAT 5 TM images were elaborated by setting the base height from a digital elevation model (DEM) of Mozambique with a resolution of 90m.

For displaying images in 3D ArcGIS 3D Analyst or ERDAS Virtual GIS were used having a set of tools for analysis and visualisation of 3D data. 3D Analyst adds a specialised 3D viewing application ArcScene, which allows one to navigate and interact with the GIS data.

Figure 10. 3D Rendering in Arc Scene



3.6 Ancillary images used

Land-cover interpretation is a complex task that involves spatial, temporal and spectral analysis. It is compulsory to have satellite images acquired at different seasons and different years to explore all these aspects in the best possible way. Nowadays, various international projects offer the opportunity to download free of charge from Internet a large set of remote sensed data. A search on Internet for all the satellite images available with a relevant resolution was performed. These ancillary data were integrated in the information system developed to support the land-cover interpretation and analysis. This has led to the creation of a repository with a large data set that has been extensively used, improving considerably the land-cover interpretation quality. These images are available to UIF/DNFFB for future use on natural resource management (see also Chapter 9).

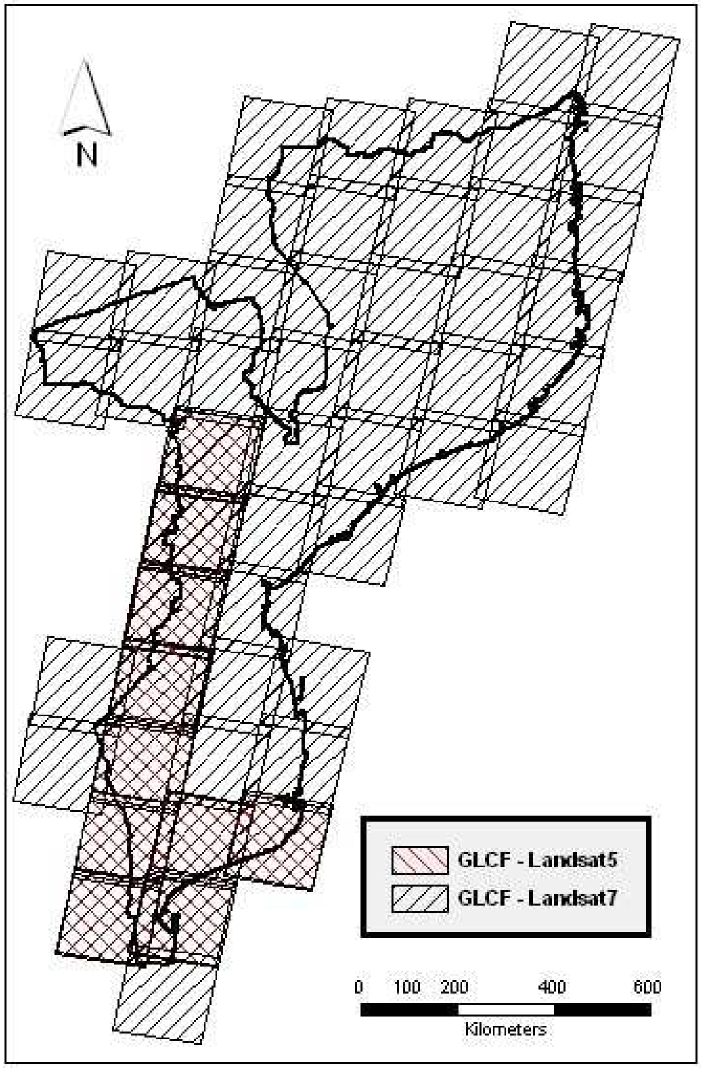
In the next paragraphs, a short description of the ancillary data is presented. In Appendixes C and D it is explained how to acquire and process these data.

3.6.1 LANDSAT 5 TM and LANDSAT 7 ETM+ from GLCF

NASA has sponsored the creation of an orthorectified and geodetically accurate global land data set of LANDSAT images from around 1970 (that have not been used in the AIFM Project), circa 1990 and circa 2000, to support the international scientific community. These data are central to the study of the history of the land-surface state. These data comprise high accurate scene-to-scene within and among-date registration. The process of orthorectification eliminates or minimises mis-registration errors using ground control points associated with an elevation model (accuracy between 30m and 1 km) (Tucker et al., 2004). Once these images were orthorectified and geodetic coordinates were assigned, all data underwent a process of independent evaluation for data quality and geo-positional accuracy. Only TM and ETM+ data with a Root-Mean-Square Error (RMSE) of less than 50m and MSS data with a RMSE of less than 100m were accepted (Tucker et al., 2004). The data are available from the University of Maryland's Global Land Cover Facility (GLCF) (http://glcf.umiacs.umd.edu/index.shtml).

The images are provided in a standard GeoTIFF format with a UTM projection (Please note that Mozambique is partly in UTM zone 36 and partly in zone 37), using the WGS84 datum. Each scene is provided with the bands as separate files (7 bands for TM, 8 for ETM+). All these bands are available for downloading and the original pixel values are affected only by the pre-processing elaborations related to the orthorectification process thus they can be used for many different types of analysis.

Figure 11. LANDSAT images acquired from GLCF



In Manica and Maputo Provinces, two or three images -depending on the availability- of the same scene from LANDSAT 7 ETM+ (circa 2000) were downloaded to comprise the seasonal variability of land cover and one scene from LANDSAT 5 TM (circa 1990s) to analyse long-term temporal changes. For the National level, just one image per scene was downloaded because of the less detailed level of land-cover interpretation required and the subsequent impossibility to analyse in detail a considerable number of satellite images. Table 5 provides an overview of the LANDSAT images obtained from GLCF (the file name convention mentioned earlier was strictly followed). In Figure 11 the geographic distribution of these LANDSAT images is presented. Appendix C provides the instructions on how to download and process these images. At the web site http://landsat.gsfc.nasa.gov one finds more information on the U.S. LANDSAT Programme.

Table 5. LANDSAT images from the Global Land Cover Facility and available for future application

164067_18052001_glcf7	167068_01122001_glcf7 167068_21081990_glcf5	168073_19121999_glcf7 168073_25042000_glcf7 168073_30061992_glcf5 168073_31082000_glcf7
164068_07121999_glcf7	167069_11062002_glcf7	
164069_31052000_glcf7	167070_26052002_glcf7	
164070_02052001_glcf7	167071_26052002_glcf7	
164071_05072001_glcf7	167072_22081999_glcf7	
164072_07092001_glcf7	167073_30122000_glcf7	168074_11051991_glcf5 168074_25042000_glcf7 168074_31082000_glcf7
165067_22052000_glcf7	167074_07052001_glcf7 167074_01031991_glcf5	
165068_12052002_glcf7	167075_07052001_glcf7 167075_01031991_glcf5	168075_15062001_glcf7 168075_16101999_glcf7 168075_25061990_glcf5
165069_15072002_glcf7	167076_07052001_glcf7	
165070_15072002_glcf7	167077_02081989_glcf5 167077_07052001_glcf7	
165071_24081999_glcf7		168076_12062000_glcf7 168076_25061990_glcf5
165072_24081999_glcf7	167078_07052001_glcf7 167078_23071991_glcf5	
166068_30062000_glcf7		168077_25061990_glcf5 168077_30052001_glcf7
166069_30062000_glcf7	167079_07052001_glcf7 167079_23071991_glcf5	
166070_08112001_glcf7		168078_25061990_glcf5 168078_30052001_glcf7
166071_08112001_glcf7	168068_31082000_glcf7	
166072_19072001_glcf7	168069_31082000_glcf7	169070_05052001_glcf7
166073_16072000_glcf7	168070_17072001_glcf7	169071_21072000_glcf7
166075_06072002_glcf7	168071_01072001_glcf7	169075_03062000_glcf7
166076_01062001_glcf7	168072_01072001_glcf7 168072_11051991_glcf5 168072_13081999_glcf7	169076_21052001_glcf7
166077_01062001_glcf7 166077_21041989_glcf5		170070_31052002_glcf7
		170071_16082001_glcf7

3.6.2 LANDSAT images from CENACARTA

Some LANDSAT images from circa 2000 were made available by CENACARTA. Table 6 provides an overview of these images using the established file name convention.

These images are in UTM36s Datum Tete. They have been used as ancillary data with the on-the-fly reprojection function of ArcGIS, taking into account the possible accuracy errors due to the approximate reprojection.

Table 6. LANDSAT images from CENACARTA

167075_21082001_dinageca7	168072_09112002_dinageca7	168075_17111999_dinageca7
167078_13072001_dinageca7	168073_01072001_dinageca7	168077_31082000_dinageca7
168071_29081999_dinageca7	168074_17111999_dinageca7	168078_18062002_dinageca7

3.6.3 LANDSAT mosaic MrSID

Orthorectified LANDSAT Thematic Mapper Mosaics are mosaics of about 20 LANDSAT images each. They are delivered in a compressed format and cover the whole world in two data sets covering two periods, i.e. the 1990’s and circa 2000. These mosaics are created from the NASA LANDSAT images available at GLCF. In these mosaics, band 7 (mid-infrared light) is displayed as Red, band 4 (near-infrared light) is displayed as Green and band 2 (visible green light) is displayed as Blue. Mosaics of circa 2000 (i.e. from ETM+ images) were fused with the panchromatic band resulting in a resolution of 15m. In order to maximise the information of each mosaic, EarthSat has applied a contrast stretch. After that files were compressed in the MrSID format that ArcGIS can read directly.

The mosaics are very useful as they provide a synoptic view of a large area without having to load many LANDSAT images at once. The files are quite small compared with the original images (about 50 Mb for mosaics of the 1990's and 250 for mosaics of circa 2000) because they contain just three enhanced bands and they are heavily compressed. For the same reason, as the quality is lower than the original bands and just three bands are available, they should *not* be used for land-cover interpretation.

The complete coverage of Mozambique has been acquired both for the 1990’s and circa 2000. The download process is easy and can be explored at https://zulu.ssc.nasa.gov/mrsid/ were mosaics are also available. Table 7 provides a summary of the LANDSAT mosaics collected (the name is made of UTM zone, average latitude, reference date and source being MrSID).

Table 7. MRSID mosaics used and available for future application

36010s_1990_MRSID	36025s_1990_MRSID
36010s_2000_MRSID	36025s_2000_MRSID
36015s_1990_MRSID	37010s_1990_MRSID
36015s_2000_MRSID	37010s_2000_MRSID
36020s_1990_MRSID	37015s_1990_MRSID
36020s_2000_MRSID	37015s_2000_MRSID

3.6.4 ASTER images

The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) is an advanced multi-spectral imager that was launched on board NASA’s Terra spacecraft in December 1999. ASTER was built by a consortium of the Japanese Government, industry and industry groups. The VNIR subsystem is specifically equipped with a backward viewing telescope for high-resolution stereoscopic observation in the along-track direction that allows the generation of Digital Elevation Models (DEM) from near-infrared nadir viewing and backwards-viewing bands processing. The ASTER data products are provided at various levels of pre-processing, some of them routinely produced (e.g., radiometric and geometric system corrections, decorrelation stretch) while others are only executed upon demand (e.g., brightness temperature, emissivity, surface reflectance, surface radiance, DEM). ASTER data contribute to a wide range of applications such as vegetation and land-cover (change), geology and soils, land surface climatology, volcanoes, hydrology. The downloaded ASTER images have level IIb correction.

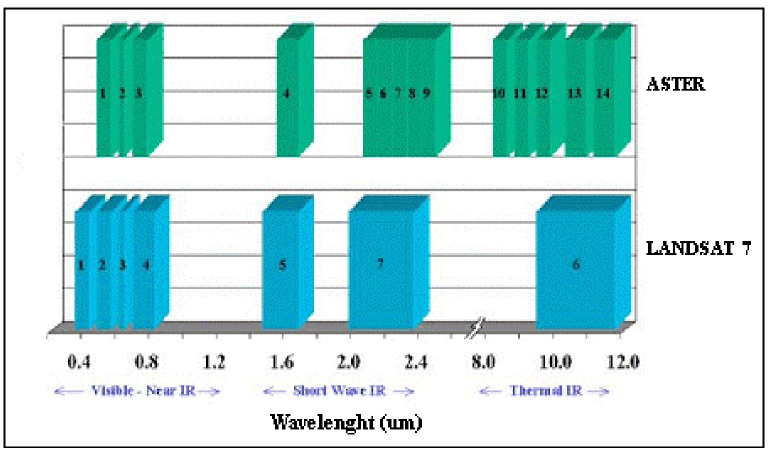
ASTER covers a wide spectral region with 14 bands from the visible to the thermal infrared with high spatial, spectral and radiometric resolution (Table 8). The spatial resolution varies with wavelength: 15m in the visible and near-infrared (VNIR), 30m in the short-wave infrared (SWIR), and 90m in the thermal infrared (TIR), as illustrated by Figure 12. Each ASTER scene covers an area of approximately 60x60km. The images are already georeferenced but the accuracy is low (e.g., around 100-250m), thus **these images were *never* used to assess the geometry of any land-cover polygon**.

The resolution of 15m for three bands (corresponding to bands 2, 3 and 4 of LANDSAT) allows recognition of features and patterns with high spatial definition. ASTER images cover the whole world and they are available on Internet. The number of available images is regularly updated. The process to acquire ASTER scenes is described in detail in Appendix D. For more information on ASTER images see the web site http://asterweb.jpl.nasa.gov/ .

Table 8. Characteristics of ASTER

Satellite Sensor	TERRA ASTER													
Spectral bands[5]	VNIR			SWIR						TIR				
	1	2	3N & 3 B	4	5	6	7	8	9	10	11	12	13	14
Wavelength (µm)	0.52-0.60	0.63-0.69	0.78-0.86	1.60-1.70	2.145-2.185	2.185-2.225	2.235-2.285	2.295-2.365	2.360-2.430	8.125-8.475	8.475-8.825	8.925-9.275	10.25-10.95	10.95-11.65
Pixel size (m)	15			30						60				
Orbit	16 days / 705 km													

Figure 12. Wavelengths of LANDSAT and ASTER bands



ASTER images were used as a valuable support to define land-cover classes inside the polygons delineated using the LANDSAT 5 TM images in Manica and Maputo Provinces at 1:250,000 nominal scale. They were especially used to observe land cover in a season not covered by other images and to discover spatial patterns hidden in the LANDSAT images.

At National level, where the nominal scale for land-cover interpretation was 1:1,000,000, ASTER images were used for validation of the land-cover interpretation (see paragraph 6.3).

The file naming convention adopted is similar to the one used for LANDSAT images. To facilitate data management of these images, the name of each ASTER image is given by the path and row of the LANDSAT in which it falls, the date of the image and a number from 1 to 9 (Figure 13) to identify the approximate position inside the LANDSAT image (Please note that a LANDSAT scene covers an area about 9 times bigger than an ASTER). A suffix "_b" was added in case of two ASTER images at the same location.

[5] VNIR=Visible near infrared, SWIR=Short-wave infrared, TIR=Thermal infrared.

Figure 13. Codes of an ASTER image position inside the LANDSAT image

1	**2**	**3**
4	**5**	**6**
7	**8**	**9**

A complete coverage of ASTER has been collected for Maputo Province, and one covering around 60% of Manica Province (Figure 14 and Table 9).

Figure 14. Overview of downloaded ASTER images

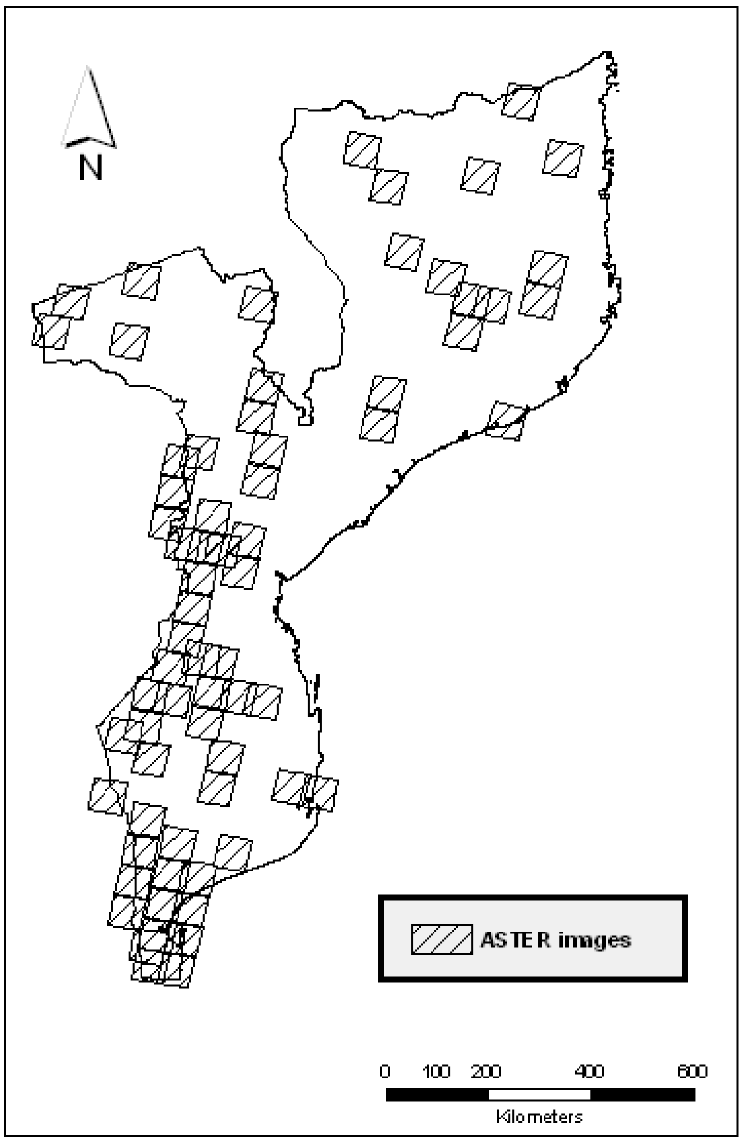


Table 9. List of downloaded ASTER images

165068_16072000_aster_q4	167075_11022005_aster_q7	168073_18022005_aster_q7
165069_17032005_aster_q3	167075_21112003_aster_q8	168073_31082000_aster_q5
165070_10032005_aster_q6	167076_11022005_aster_q1	168073_31082000_aster_q8
165070_10032005_aster_q9	167076_21112003_aster_q5	168074_31082000_aster_q2
165070_24082005_aster_q7	167076_21112003_aster_q8	168074_31082000_aster_q5
165070_30112000_aster_q8	167077_11022005_aster_q4	168074_31082000_aster_q8
165071_24082005_aster_q1	167077_11022005_aster_q7	168075_15012005_aster_q6
165072_26032005_aster_q3	167077_21112003_aster_q8	168075_18022005_aster_q8
166069_04052005_aster_q3	167077_30102001_aster_q6	168075_19032004_aster_q5
166070_13052003_aster_q1	167078_11022005_aster_q1	168075_31082000_aster_q9
166070_24032005_aster_q6	167078_11022005_aster_q4	168076_02052005_aster_q1
166071_20022005_aster_q8	167078_11022005_aster_q7	168076_05122003_aster_q7
166072_20022005_aster_q5	167078_21112003_aster_q2	168076_18022005_aster_q2
166076_04022005_aster_q8	167078_21112003_aster_q8	168076_19032004_aster_q5
166076_08032005_aster_q7	167079_21112003_aster_q2	168077_31082000_aster_q2
167069_09092000_aster_q2	168070_31082000_aster_q8	168077_31082000_aster_q5
167069_21112003_aster_q2	168071_22102004_aster_q9	168077_31082000_aster_q8
167069_27112002_aster_q2	168072_02052000_aster_q7	168078_10052001_aster_q6
167069_28092001_aster_q2	168072_03222005_aster_q8	168078_31082000_aster_q2
167072_11022005_aster_q7	168072_22102004_aster_q3	169070_25052000_aster_q8
167073_11022005_aster_q1	168073_02052000_aster_q1	169071_25052000_aster_q4
167074_11022005_aster_q1	168073_02052000_aster_q4	170070_29082000_aster_q8
167075_07032002_aster_q9	168073_05122000_aster_q6	170071_30092000_aster_q1
167075_11022005_aster_q1	168073_11022005_aster_q6b	

3.6.5 MODIS

The Moderate Resolution Imaging Spectroradiometer (MODIS) is a key instrument onboard the Terra (EOS AM) and Aqua (EOS PM) satellites, viewing the entire Earth's surface since 18 December 1999. The MODIS instrument provides high radiometric sensitivity (12 bit) in 36 spectral bands ranging in wavelength from 0.4µm to 14.4µm. Two bands have pixels at a nominal resolution of 250m at nadir, with five bands at 500m, and the remaining 29 bands at 1km. A ±55-degree scanning pattern at the EOS orbit of 705 km achieves a 2,330km swath and provides global coverage every one to two days (see http://modis.gsfc.nasa.gov/ for more information about MODIS). The file for the two bands at 250m resolution is about 250 MB and the file for the seven bands at 500m resolution is about 150 MB (both available in ".HDF" format from http://edcimswww.cr.usgs.gov/).

There are many products based on MODIS available on Internet. One of the most interesting is MODIS 250m 16-day Composites. It uses the Normalised Difference Vegetation Index (NDVI) to give an estimation of vegetation biomass each two weeks so that it is possible to follow the temporal dynamics of vegetation. With the use of MODIS it is also possible to estimate the temperature of the Earth surface (e.g., in case of fires).

As discussed previously, the possibility of using MODIS for land-cover interpretation at the nominal scale of 1:1,000,000 was examined with the combination of the two bands at 250m resolution (corresponding to band 3 and band 4 of LANDSAT) and a band at 500m resolution (corresponding to band 2 of LANDSAT). Since these results were not satisfactory because of the coarse resolution and the loss of contextual information of land-cover types, it was decided not to use MODIS data for land-cover interpretation. However, one MODIS data set has been included in the geodatabase for documentation purposes and may be used in any future suitable application.

3.7 Ancillary data used

Land cover is the product of the interaction between many factors, both anthropic and natural, thus it is very important to analyse ancillary data other than remotely sensed images. These additional data facilitate the understanding of land dynamics and bring the abstraction that is inherent to land-cover interpretation closer to the real world.

In the following paragraphs the set of ancillary data used in the land-cover interpretation process is described. These data are organised inside the geodatabase (see Chapter 9).

3.7.1 Topographic maps

Topographic maps are a fundamental instrument for collection of land information, as they provide a wide range of information (e.g., roads, villages, morphology, etc.) in the form of a coded and georeferenced representation of the Earth's surface. As discussed before, topographic maps in Mozambique are generally outdated for current needs thus they should not be used for georeferencing purposes but they remain a valuable source of information. The topographic maps have been used together with other ancillary data in order to be able to better locate one self on the satellite images.

The complete cover of Manica and Maputo Provinces was available at 1:50,000 and 1:250,000 scale. No other topographic maps for the rest of Mozambique were available during the land-cover interpretation phase. The original maps, in hard copy format, were georeferenced in the UTM36s or UTM37s projection with datum Tete. These maps were scanned and reprojected to datum WGS84 by DINAGECA. Figure 15 shows the topographic maps used.

3.7.2 DEM

A Digital Elevation Model (DEM) is a representation of the topography of the Earth in digital format, which is by coordinates and numerical descriptions of altitude. The information is stored in raster format. It is an important type of information to evaluate land cover and land use as both are often linked to terrain morphology.

For land-cover interpretation, the digital elevation model from the Shuttle Radar Topography Mission (SRTM) was used. It has a resolution of 90m and a standard quality (see http://srtm.usgs.gov/ for details) that satisfy the objectives of the land-cover interpretation.

The SRTM is a research effort that obtained elevation data on a near-global scale to generate the most complete high-resolution digital topographic database of the Earth to date. SRTM consisted of a specially modified radar system that flew onboard the Space Shuttle Endeavour during an 11-day mission in February 2000. To acquire topographic (elevation) data, the SRTM payload was equipped with two radar antennas. One antenna was located in the Shuttle's payload bay, the other on the end of a 60m mast that extended from the payload bay once the Shuttle was in space. The technique employed is known as interferometric Synthetic Aperture Radar. Figure 16 illustrates a detail of the DEM for Manica Province.

Raw SRTM data can be downloaded from the web site http://srtm.usgs.gov/. There are some "holes" because of small areas with unknown values. Recently, a new version of the global DEM has been delivered with an improved quality and fewer "no data" holes. This new version was delivered towards the end of the land-cover interpretation phase, therefore the first version was used with interpolated values to cover the "no data" areas. The corrected version is available at the web site http://srtm.csi.cgiar.org/.

The DEM is divided in different zones, consequently it was mosaicked and reprojected. Negative values have been converted to 0 because in Mozambique they are just disturbances caused by water, as verified for all values smaller than -5. Values between -5 and 0 can be considered inside the instrumental error range. The DEM for the whole of Mozambique was produced, plus the DEMs for Manica and Maputo Provinces. The DEM was used to obtain slope and hill-shade (see paragraphs 3.8.1 and 3.8.2).

Figure 15. Topographic maps used for land-cover interpretation

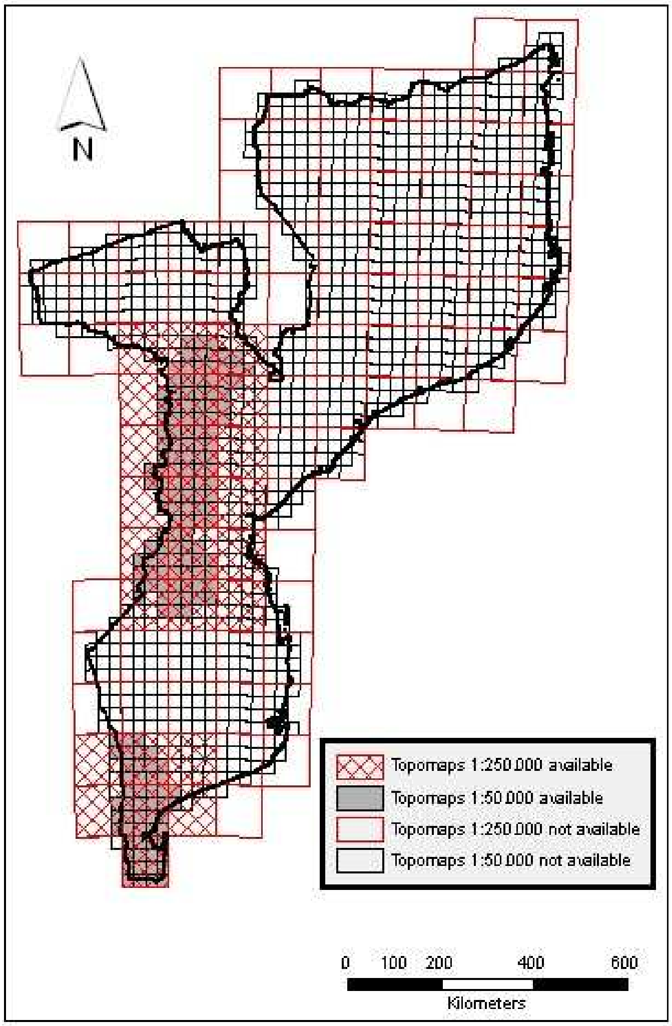
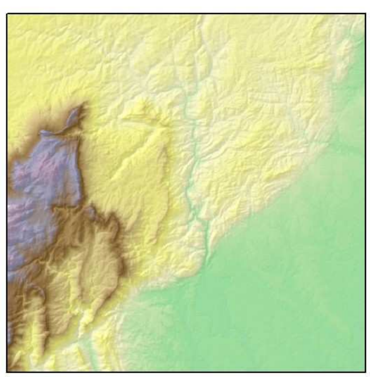


Figure 16. A detail of DEM draped on the hill shade in Manica Province



3.7.3 Data from the IGN/CENACARTA/DINAGECA Joint Venture project

A contribution to facilitating satellite image interpretation has been provided by the land-cover/use data set created by the IGN/CENACARTA/DINAGECA Joint Venture in the framework of the Rural Rehabilitation Project (1996-1999) (IGN/CENACARTA/DINAGECA, 1999). The aim of this project was to produce a land-cover data set for the whole of Mozambique by the visual interpretation of high-resolution satellite images complemented with field surveys. These data, initially only available in paper format, have been converted to digital format in 1998 (Table 10). The land-cover/use data are described in some more detail in paragraph 8.3 as well as how they were used by the remote sensing and land-cover component of the AIFM Project.

Table 10. IGN/CENACARTA/DINAGECA land-cover/use data sets characteristics

GIS database	Data owner /custodian	Scale	Source	Source year	Production year	Extent
Land-cover/use	DINAGECA/ CENACARTA	1:250,000	LANDSAT TM	1995/1997	1998/1999	National

This database contains also a so-called "*Simplified Topographic Base*" (layer) that includes the main information of the classic 1:250,000 paper topographic maps. This information was updated with the help of satellite images and GPS field survey (the last update of the paper maps took place in the mid 1970s). The final product consists of one homogenous database covering the whole territory (1:250,000) plus additional separate databases for eight selected districts at a more detailed level (1:50,000). These spatial data sets, using Clarke 1866 ellipsoid with Tete Datum, have been reprojected to UTM36 South Datum WGS84.

These data comprise:

- Administrative boundaries: Provinces and Districts (Please note that part of the area of Inhambane at the coast is missing);
- Urban settlements: cities and villages;
- Transportation network: roads (that were updated in Manica and Maputo Provinces) and railways;
- Hydrographical network, i.e. rivers and lakes; and
- National parks.

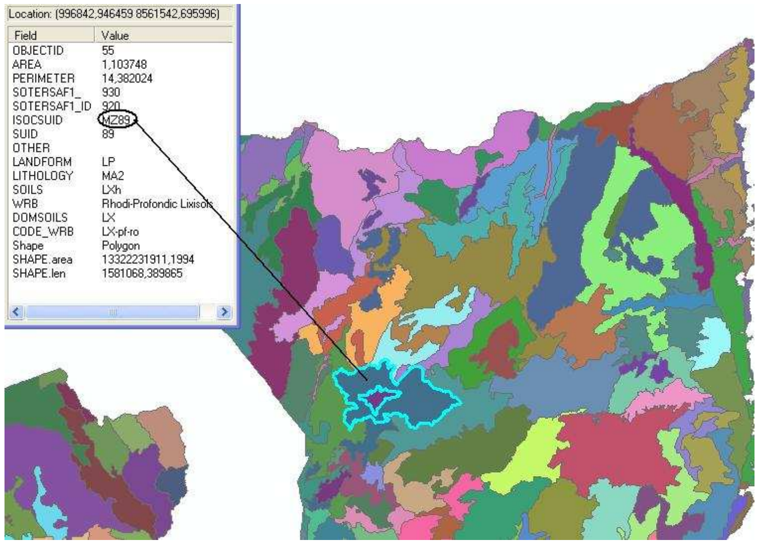
A detailed description of the data set is provided by IGN/CENACARTA/DINAGECA (1999).

3.7.4 Soils and terrain digital databases (SOTER)

SOTER is a uniform methodology, endorsed by the Food and Agriculture Organization of the United Nations (FAO), the United Nations Environmental Programme (UNEP) and the International Union of Soil Sciences (IUSS), for storing and handling digital soils and terrain data. It uses current and emerging information technology to establish a World Soils and Terrain Database, containing digitised map units and their attribute data. The main function is provision of the necessary data for improved mapping and monitoring of changes of world soils and terrain resources. This methodology allows mapping and characterisation of areas of land with a distinctive pattern of landform, lithology, surface form, slope, parent material and soils. Tracts of land characterised in this way are called SOTER units.

For Mozambique the SOTERSAF has been used (FAO/ISRIC, 2003) that is the specific Soil and Terrain database covering eight countries in Southern Africa. Each SOTER unit (Figure 17) thus represents one unique combination of terrain and soil characteristics and in the geographic database has a unique identifier, called SOTER unit-ID (SUID).

Figure 17. A detail of the SOTER map in Niassa Province



3.7.5 Vegetation map of Africa (Ecozones)

The UNESCO/AETFAT/UNSO Vegetation Map of Africa was published in 1983 (White, 1983). The original product comprises three map sheets at a scale of 1:5,000,000. The Vegetation Map of Africa is a compilation of various existing map sources from different regions or countries.

These data were used mainly for an approximate identification of Miombo and Mopane vegetation zones and for analysis of macro-ecological zones for the land-cover interpretation at 1:1,000,000 nominal scale. However, the precision of these data -compared to the 1:1,000,000 nominal scale land-cover interpretation- is only sufficient to provide a broad and general idea of vegetation zones.

3.8 Products derived from various data types

3.8.1 Hill shade

The hill-shade function obtains the hypothetical illumination of a surface by determining illumination values for each cell in a raster. It does this by setting a position for a hypothetical illumination source and calculating the illumination values of each cell in relation to neighbouring cells. The hill-shade values were elaborated using the SRTM DEM that has a resolution of 90m. It was used to enhance the visualisation of satellite images and DEM, using transparency that provides a visual account of the morphological patterns behind the images.

3.8.2 Slope aspect

The slope function calculates the maximum rate of change between each cell and its neighbours. The lower the slope value the flatter the terrain, whereas the higher the slope value the steeper the terrain. Slope was calculated as degree of slope. It was elaborated using the SRTM DEM. Together with the DEM and hill shade, this information was used to explore relationships between landscape morphology and land cover. It also served in the delineation of so-called land units (see relevant AIFM Project Report).

3.8.3 NDVI

The Normalized Difference Vegetation Index (NDVI calculated as NIR-RED/NIR+RED) is a non-linear transformation of the visible (red) and near-infrared bands of satellite information. NDVI is defined as the difference between the visible (red) and near-infrared (NIR) bands, over their sum. The NDVI is an alternative measure of vegetation amount and condition. It is associated with vegetation canopy characteristics such as biomass, leaf area index and percentage of vegetation cover. NDVI was calculated for the whole of Manica Province, mosaicking the NDVI index calculated using band 3 and band 4 of each LANDSAT scene. It was mainly used to identify natural vegetated areas inside mixed areas (e.g., where shifting cultivation is dominant) (see also paragraph 8.2).

3.8.4 LANDSAT 5 TM mosaics at Province level

In order to have a quick overview of the LANDSAT image coverage in the two Provinces that can be used for illustration purposes, a mosaic of all the scenes used for the interpretation in Manica and Maputo Provinces was made. Images comprising just three bands (RGB=432) and using a stretching in order to create a homogeneous look was merged into a single mosaic. These mosaics were used to check internal data consistency and for exploration of similar areas during the interpretation phase. These mosaics should *not* be used for interpretation purposes.

3.8.5 LANDSAT 5 TM at degraded resolution

For the National level, two different LANDSAT 5 TM products have been prepared for interpretation purposes:

1. LANDSAT 5 TM with a pixel size of 210m instead of the original 30m (each resampled pixel is the mean of a window of seven by seven original pixel values) used as baseline data for the interpretation at National level;
2. LANDSAT 5 TM with a pixel size of 120m (window of four by four pixels) as auxiliary data for interpretation purposes.

The command to use in the ERDAS Imagine software is INTERPRETER/UTILITIES/DEGRADE. A batch file was created by the program that records the commands and the input and output files clicking on the “batch” button as described earlier in paragraph 3.5.2. Similar to the “layer stack” process, the first batch file (.BCF) made has been copied and edited substituting the name and the path of the input and output files. This operation has been replicated for each scene processed.

4 LAND-COVER CLASSIFICATION

4.1 Introduction

The land-cover classes as they were used in previous Forest Inventories have been revised by UIF in order to better reflect what they find on the ground and what one can distinguish on satellite imagery (MADEBRAS/FUPEF/MADEMO, 1981; Saket, 1994; Saket et al., 1995). Their new nomenclature has been crosschecked with existing materials and the TOR; subsequently the classes of this nomenclature have been “translated” at UIF into the required FAO/UNEP Land Cover Classification System (Di Gregorio and Jansen, 2000). The use of the FAO/UNEP LCCS for codification of land cover provides a link to an international standard that has been applied in various Eastern African countries. The definition of the classes in LCCS has been fine-tuned during the interpretation process and based upon the field validation results (e.g., description of the land-cover types and photographs taken).

The objective of the land-cover data collection is to include the detail of the Forest Type classes as far as possible corresponding with those provided in Appendix 2 of the TOR, although a number of criteria are being used in the TOR that cannot be detected on the images (e.g., plant species, altitude and climate) but only with the use of additional data sources. The Forest Type classes have been complemented by classes describing other land-cover types (e.g., cultivated areas, built-up areas, water bodies and bare surfaces). Throughout this Technical Report the use of the term “land cover” is preferred as what one can identify on satellite images refers to the “(*bio) physical features one can observe on the surface of the Earth*” (Di Gregorio and Jansen, 2000). The use of “land cover/use” is justified by having included shifting cultivation that refers to a land *use* (see also paragraph 4.3).

4.2 LCCS structure and methodology

The set of diagnostic criteria for the parametric classification approach followed in the Land Cover Classification System (LCCS) developed by FAO is based upon examination of criteria commonly used in existing classifications that identify and describe land cover in an impartial, measurable and quantitative manner (Di Gregorio and Jansen, 2000; Jansen and Di Gregorio, 2002).

As described in detail in Di Gregorio and Jansen (2000) and Jansen and Di Gregorio (1998 and 2002), the developed approach to classification aims at a logical and functional hierarchical arrangement of the classifiers, thereby accommodating different levels of information, starting with broad-level classes that allow further systematic subdivision into more detailed subclasses. At each level the defined classes are mutually exclusive. Criteria used at one level of the classification are not to be repeated at other levels. The increase of detail in the description of a class is linked to the increase in the number of classifiers used. In other words, the more classifiers are added, the more detailed the class. The class boundary is then defined either by the different number of classifiers, or by the presence of one or more different types of classifiers. Emphasis is not given to the class name obtained, the traditional method, but to the set of classifiers used to define this land-cover class.

Many current classification systems are not suitable for mapping and subsequently monitoring purposes (Jansen and Di Gregorio, 1998). In the developed parametric approach, the use of diagnostic criteria and their hierarchical arrangement to form a land-cover class, are a function of geographical accuracy. The arrangement of classifiers will assure at the highest levels of the classification, i.e. the most aggregated levels, a high degree of geographical accuracy.

Land cover should describe the whole observable (bio) physical environment and is, thus, dealing with a heterogeneous set of classes. Evidently, a forest is defined with a set of classifiers different from those to describe snow-covered areas. Therefore, the definition of classes by classifiers is not using the same set of classifiers for description of every class because it would be impractical. In the new approach, the classifiers are tailored to each of the eight major land-cover features identified (Figure 18).

Figure 18. The eight major land-cover categories of LCCS -grouped under the primarily vegetated and primarily non-vegetated area distinction- with their set of classifiers to form classes in hierarchical order (roman figures) followed by the specific technical attribute (e.g., Crop Type) (Jansen and Di Gregorio, 2002)

PRIMARILY VEGETATED AREAS

Cultivated and Managed Terrestrial Areas

I. A. Life Form of Main Crop
B. Spatial Aspect - Field Size
B. Spatial Aspect - Field Distribution
II C. Crop Combination
III D. Cover-Related Cultural Practices

S. Crop Type

Cultivated Aquatic or Regularly Flooded Areas

I. A. Life Form of Main Crop
B. Spatial Aspect - Field Size
B. Spatial Aspect - Field Distribution
II C. Water Seasonality
III D. Cover-Related Cultural Practices
IV E. Crop Combination

S. Crop Type

(Semi) Natural Terrestrial Vegetation

I. A. Life Form and Cover of Main Stratum
B. Height of Main Stratum
C. Macropattern
II D. Leaf Type
E. Leaf Phenology
III F. Stratification:
2nd Layer: Life Form, Cover, Height
3rd Layer: Life Form, Cover, Height

T. Floristic Aspect

(Semi) Natural Aquatic or Regularly Flooded Vegetation

I. A. Life Form and Cover of Main Stratum
B. Height of Main Stratum
II C. Water Seasonality
III D. Leaf Type
E. Leaf Phenology
IV F. Stratification:
2nd Layer: Life Form, Cover, Height

T. Floristic Aspect

Environmental Attributes

Available attributes to most major land cover types: Landform, Lithology, Soils, Climate, Altitude.
Available attributes depending on major land cover type: Erosion, Crop Cover, Salinity, Scattered Vegetation.

PRIMARILY NON-VEGETATED AREAS

Artificial Surfaces and Associated Areas

I. A. Surface Aspect

A. Built-Up Object

Bare Areas

I. A. Surface Aspect
II. B. Macropattern

M. Soil Type/N. Lithology

Artificial Waterbodies, Snow and Ice

I. A. Physical Status
B. Persistance
II. C. Depth
D. Sediment Load

V. Salinity

Natural Waterbodies, Snow and Ice

I. A. Physical Status
B. Persistance
II. C. Depth
D. Sediment Load

V. Salinity

According to the general concept of an *a priori* classification, it is fundamental to the system that all combinations of the classifiers are accommodated in the system independent of scale and tools used to identify objects (e.g., human eye, statistics, aerial photographs or satellite remote sensing). By tailoring the set of classifiers to the land-cover feature, appropriate combinations of sets of predefined classifiers can be made without the likelihood of impractical combinations of classifiers. Two distinct land-cover features having the same set of classifiers may differ in the hierarchical arrangement of these classifiers in order to ensure a high geographical accuracy.

Having all pre-defined classes included in the system is the intrinsic rigidity of this type of classification. However, it is the most effective way to produce standardisation of classification results between user-communities. The disadvantage is that in order to be able to describe any land cover occurring anywhere in the world in a consistent way, a huge number of pre-defined classes are needed and that users should describe a specific land-cover feature in a similar way. This led to the development of the application software that assists users in determination of classifiers in a stepwise selection procedure that aggregates classifiers to obtain the land-cover class.

4.3 Land cover versus land use

Land *cover* is defined in the FAO/UNEP LCCS as the "(*bio) physical features one can observe on the surface of the Earth*" (Di Gregorio and Jansen, 2000). Land *use* is defined as "*the type of human activity taking place at or near the surface*" (Cihlar and Jansen, 2001). The remote sensing and land-cover component of the AIFM Project has adopted and applied these two definitions

Land cover can be a cause, constraint or consequence of a certain land use. Land use is determined by natural, economic, institutional, cultural and legal factors. In general, possible land-uses are limited by (bio) physical constraints. These include climate, topography, soils and the geological substrate, presence or availability of water and the type of vegetation. Agricultural practices differ from one region to another and different types of land uses are practised on the same type of land in different areas, depending on the history, local traditions and way of life, apart from the (bio) physical constraints (Cihlar and Jansen, 2001). The location of an area with respect to other land-use types, such as residential and industrial areas, is also an important factor. Economic incentives as part of policy can affect land-use and land-cover patterns.

The understanding of the interactions between land cover and land use in their spatial and temporal appearances is fundamental to comprehension of land-cover and land-use change dynamics. Changes in land use and management have their impact on land cover, being the expression of human activities (see also paragraph 8.4).

4.4 Analysis of classification requirements

The design of a single common reference system to be used for all land-cover classifications suitable throughout Mozambique has been recommended. However at UIF, a new nomenclature was developed taking into account the lessons learnt in the past and considering the possibility to distinguish these classes using satellite remote sensing. During the Inception Mission this reference system was finalised and translated into the FAO/UNEP Land Cover Classification System[6] (LCCS) standard (version 2). This standard has been applied in 10 Eastern African countries and several Eastern and Central European Countries and in the Community of Independent States. The land-cover classes defined in Appendix 2 of the TOR show a clear emphasis on detailed definition of (semi-) natural vegetated areas (e.g., closed and open forests (woodlands)) and much less emphasis on agricultural areas, bare areas, artificial surfaces and water bodies.

[6] The FAO/UNEP Land Cover Classification System has been endorsed by the Land Use and Cover Change (LUCC) programme element of the International Geosphere Biosphere Programme (IGBP) and International Human Dimensions Programme on Global Change (IHDP).

In the context of the AIFM Project and with the aim of standardisation the land-cover definition of the FAO/UNEP LCCS was adopted. Appendix A gives an overview of the distinctions made in LCCS based upon specific criteria and the definition of land-cover categories as well as the land-cover domains defined at the third level.

A detailed description of the characteristics to be used in the definition of the land-cover classes has been provided in Appendix 2 of the TOR. These characteristics comprise:

- Canopy cover thresholds set at 70, 40 and 10 percent corresponding with the terminology closed, open and sparse;
- Height, with trees being defined as being taller than 5m and shrubs smaller than 5m when mature;
- Leaf type distinguishing (semi-) broadleaved and evergreen plants;
- Further subdivision of forests, woodlands, thickets and shrublands based upon species composition of the vegetation, climatic conditions, physiography and altitude.
- Arboriculture should be distinguished based upon its land *use*, i.e. production of wood/timber or production of fruits and nuts;
- Proximity of certain forest formations to water courses (e.g., along the coast or along rivers).

The term "forests" as used in LCCS refers to closed stands of (semi-) natural trees. In Mozambique the term "forests" is defined as: "*cobertura vegetal capaz de fornecer Madeira ou produtos vegetais, albergar a fauna e exercer um efeito directo ou indirecto sobre o solo, clima ou regime hidrico*" (*Lei de Florestas e Fauna Bravia* 10/99 Capitulo 1 (Disposiçoes Gerais) - Artigo 1 (definições), MADER/DNFFB, 1999). Thus the definition as commonly used in Mozambique is wider and refers to the following in LCCS:

- Forests, i.e. stands of trees with a closed canopy cover (more than 70%) belonging to the (Semi-) natural vegetation both terrestrial or aquatic/regularly flooded.
- Woodlands or Open forests, i.e. stands of trees with a canopy cover ranging between 40-70% belonging to the (Semi-) natural vegetation both terrestrial or aquatic/regularly flooded.
- Planted stands of trees belonging to the Tree crops within the Cultivated terrestrial areas (A11).

Upon request of UIF during the Inception Mission, the class "Shifting cultivation" was added to the legend. Shifting cultivation describes a land *use* rather than a land cover. However, given the importance of the shifting cultivation practice in large parts of the rural areas of the country two classes were created: (1) one in which the natural vegetated areas were dominant, and (2) one in which the cultivated fields prevailed (see paragraph 5.2.5). In order to distinguish the aspect "shifting", use of several images covering the same area in different years was needed in order to establish if fields were abandoned after a couple of years and new fields appeared in different locations or whether fields remained basically in the same location in which case the aspect "shifting" did not apply. Another reason for inclusion of "shifting cultivation" is to be able to describe the process in which a forest is "invaded" by human agricultural activities, first on a temporary basis but with continued pressure on the resources and/or increased population pressure these activities gain a more permanent character. In historical National land-cover data sets the "shifting cultivation" aspect has never been included (e.g., Saket 1994; Saket et al., 1995; IGN/CENACARTA/DINAGECA, 1999).

The correspondence of some pre-set criteria with LCCS is not always 100 percent as will be shown in the examples provided in Table 11 and Table 12.

Table 11. Threshold values for canopy cover description

	Thresholds canopy cover (in percentages)		
	TOR	FAO/UNEP LCCS	
Closed	More than 70	More than 65	
Open	70-40	65-15	65-40
	Less than 40		40-15
Sparse	Less than 10	Less than 15	

A difference of 5 percent in the thresholds for canopy cover is insignificant because no one will be able to establish this type of difference in the field. Since the use of LCCS is specified in the TOR, one can assume that such small differences between these threshold values are acceptable.

Table 12. Threshold values for definition of trees and shrubs

	Thresholds height (m)	
	TOR	FAO/UNEP LCCS
Trees	More than 5	More than 3
Shrubs	Less than 5	Less than 5

Height is a complicated parameter because trees and shrubs grow and their height increases with time. The threshold values defined in general apply to a fully developed tree or shrub. In LCCS trees are defined by the combination of height and physiognomic appearance as having "*a single, well-defined stem*" whereas shrubs are "*without any defined main stem*" (Ford-Robertson, 1971). Furthermore, the height range of 3-5m in LCCS can be either trees or shrubs; definition follows the rule that "*a woody plant with a clear physiognomic aspect of trees can be classified as trees even if the height is lower than 5m but more than 3m*". In the AIFM land-cover interpretation approach the distinction between tree and shrub applied is the threshold value of 5m as defined in the TOR.

The criterion leaf type as defined in the TOR corresponds completely with LCCS. Whenever possible, available multi-temporal images (e.g., wet and dry season) have been used to help the distinction between "(semi-) evergreen" and "(semi-) deciduous".

Arboriculture is considered the cropping of trees with management practices and as such falls in a different LCCS land-cover category than (semi-) natural vegetation but causes no difficulty as above described. Homogeneous tree stands in areas showing sharp edges usually indicate arboriculture.

Species composition is a characteristic that cannot be inferred from satellite imagery but can be observed during the field survey. Convergence of evidence of spectral signatures and terrain knowledge may give the interpreter an idea of the type of species to be expected. Also the use of available (digital) ancillary data concerning vegetation types may assist the interpreter. Proximity to water courses can be identified on the image if the water courses are big enough to show on the LANDSAT imagery and more important if these forest formations have a size of at least the minimum mapping unit or when smaller if they can be accurately delineated.

It is possible to obtain land-*use* information in addition to land cover when interpreting satellite imagery (Cihlar and Jansen, 2000). While land cover is based primarily on spectral data content, which makes the successful use of digital image analysis possible, land-use information benefits from other aspects of the data including pattern, shape, context, size, shadows, etc. This contextual information may be efficiently extracted using visual analysis. A skilled interpreter, familiar with the land cover and use types in the area, can obtain this important additional land-use information and may thus be able to identify land-use boundaries within the image (assuming that the latter are suitably enhanced for optimal viewing).

Given the above-described pre-set conditions and considerations for legend definition, the preliminary land-cover classes were defined. The developed legend has been discussed with the Recipient and inventory experts during the Inception Mission of the Remote Sensing and Land Cover Classification Expert, thus well before its application and it was approved in the Inception Report.

During the interpretation phase the preliminary legend was in constant evolution:

- Classes were added whenever image characteristics were such that an already existing class did not apply, ancillary data supported this impression and discussions within the interpretation team resulted in the formation of a new class; and
- Existing classes were fine-tuned in their definition based upon discussions within the interpretation team.

In this manner the full expertise of the interpretation team was used in order to define a set of classes that can be distinguished based upon the satellite image characteristics and available ancillary data. At the same time definitions of classes became more precise in order to highlight their land-cover characteristics.

Each classification, even when build on a reference system such as LCCS, has to keep in account the operational context in which it will be used (e.g., the scale of working and the specific study area) as described before. As a result, the initial accommodation of the classification requirements in a legend has resulted in two specific legends: one for the so-called Province level, i.e. for the land-cover interpretation of Manica and Maputo Provinces; and one for the National level. These legends are described in more detail in paragraphs 4.5 and 4.6.

Correlation with other existing classifications becomes a matter of "translating" the existing classes back into the classifiers of the system (see paragraph 8.3 for an application). Comparison of individual classes, as well as the used classifiers forming this class, becomes feasible. However, to be able to translate existing classes, documentation is needed on the criteria used. Individual class names are insufficient for any meaningful translation (Jansen, 2004a and 2004b).

4.5 Land-cover legends at Province level

In the FAO/UNEP LCCS, *classification* is defined as "*an abstract representation of the situation in the field*" and *legend* is defined as "*the application of a classification in a specific area using a defined mapping scale and specific data set*" (Di Gregorio and Jansen, 2000). Thus, in the case of the AIFM Project, LCCS was used to extract a set of land-cover classes to be used at two different nominal scales using on-screen visual interpretation of LANDSAT 5 TM satellite images. The general legend created for the nominal scale of 1:250,000 to be used at Province level contains only a subset of land-cover classes of which some have been used in Manica Province, others were used in Maputo Province, and some occur in other Provinces. Table 13 shows the general subset of classes.

Application of any of the classes of this subset to land-cover interpretation at Province level resulted in:

- A land-cover polygon with a single dominant land-cover class with a percentage of 100%; or
- A land-cover polygon with a mixture of two land-cover classes, a so-called mixed class having a dominant and secondary land-cover class, in which case the percentage of the *dominant* class needs to be specified with the following percentage ranges available: (1) 50-74%; and (2) 75-99%. The complementary percentage range for the secondary class is automatically assumed to be 25-50% in case of (1) and 1-25% in case (2).

Mixed classes, consisting of a dominant and secondary land-cover class, have been used when more than one land-cover type was identified on the satellite image in the delineated polygon and these two classes could not be separated spatially or one of the two components would fall below the threshold set for minimum mapping unit (see paragraph 5.6).

Preliminary discussions with UIF/DNFFB/MINAG on the contents of the legend to be used at Province level led to the creation of a set of classes based upon the physiognomic-structural approach advocated by the FAO/UNEP LCCS. This initial set of mainly classes describing vegetation types has been complemented with classes describing other land-cover types. This legend has been continuously adjusted and fine-tuned during the land-cover interpretation of Manica and Maputo Provinces, both at the preliminary interpretation phase and the finalisation of the interpretations based upon the field survey data collected and photographs taken, resulting in the two specific legends for the two Provinces shown in Table 33 and Table 34 that also show the land-cover statistics further discussed in paragraph 11.1. The final legends have been translated by UIF in Portuguese (Appendix E).

The general legend should be considered the starting point for any subsequent land-cover interpretation at the same nominal scale, i.e. 1:250,000, for any of the other Provinces in Mozambique. It provides a framework for systematic definition of land-cover classes. Each time out of this general legend the set of classes relevant to a specific Province can be filtered. In this way the systematic use of the same approach to creation of classes and their codification is warranted. This will enhance compatibility and comparability of resulting land-cover data sets in future, thus facilitating especially land-cover change dynamics analysis and environmental monitoring.

User-defined LCCS codes in the legend of the 1:250,000 nominal scale satellite interpretation are:

- Zs01 = Sugarcane.
- Zt01 = *Brachystegia* spp.
- Zt02 = *Androstachys johnsonii.*
- Zt03 = *Colophospermum mopane.*
- Zt04 = *Avennia marina*, *Ceriops tagal*, *Rhyzophora mucronata.*
- Zt05 = *Mimusops* spp., *Diospyrus rotundifolia*, *Brachylaena discolor*, *Euclea racemosa*, *Sideroxylon inerme.*
- Zt06 = *Aphloia myrtifolia*, *Maesa lanceclata*, *Curtisia faginea*, *Rawolfia inebrians*, *Canopharngia stapfiana*.

Table 13. Final legend for the land-cover data collection at Province level at 1:250,000 nominal scale[7]

LC categories Level III	LC domains Level IV	LC group Level V	LCCS Code LCCS standard name	User code User name	Additional remarks
A11. Cultivated and managed terrestrial areas	**Tree crops**		10495-1--S6W7 Permanently cropped area with rainfed broadleaved evergreen tree crop(s) Crop type: Fruits & nuts Crop cover: Closed > (70-60)% (Plantation(s))	1TCF Tree crops	These includes cashew, coco, mango, etc.
			10495-S10 Permanently cropped area with rainfed tree crop(s) Crop type: Wood & timber	1TCW Forest plantations	Includes crops like *Eucalyptus* (fuel wood) and Pine (industrial use). Fuel wood plantations are found close to the three biggest urban centres. Plantations of *Casuarina* spp. have been planted to stabilise dunes and are nowadays used by the population for fuel wood and timber.
	Shrub crops		10567-1-S0804W7 Permanently cropped area with rainfed broadleaved evergreen shrub crop(s) Dominant crop: Beverage - Tea (*Camellia sinensis* (L.) O.K.) Crop cover: Closed > (70-60)% (Plantation(s))	1SCT Tea plantations	

	Field crops (Herbaceous and shrubs)		11498 // 11494
			Rainfed herbaceous crop(s) // Rainfed shrub crop(s)
			11500 // 11495
			Irrigated herbaceous crop(s) // Irrigated shrub crop(s)
				1FCR
				Rainfed crops
				1FCI
				Irrigated crops
					These crops comprise tobacco and cotton, but also self-sufficiency crops like cassava, etc.

	Mixed class		10786 / 21446 Scattered clustered small-sized field(s) of rainfed herbaceous crop(s) / Closed to open trees	1CXF Shifting cultivation with open to closed forested areas[8]	Mixed class of fields cultivated for a number of years surrounded by open to closed forests.
A12. (Semi-) natural terrestrial vegetation	**Woody vegetation**		20068-15048-Zt05 Semi-evergreen closed woody vegetation Floristic aspect: *Mimusops* spp., *Diospyrus rotundifolia*, *Brachylaena discolor*, *Euclea racemosa*, *Sideroxylon inerme*	2DEC Coastal dense woody vegetation	Woody vegetation type found always along the coast, inland from the mangroves; linked to sandy soils.
			20110-15048-Zt05 Semi-evergreen open woody vegetation Floristic aspect: *Mimusops* spp., *Diospyrus rotundifolia*, *Brachylaena discolor*, *Euclea racemosa*, *Sideroxylon inerme*	2DEO Coastal open woody vegetation	Woody vegetation type found always along the coast, inland from the mangroves; linked to sandy soils.
	Forests	**(Semi-) evergreen[9]**	20089 // 20089-15048 Broadleaved evergreen trees // semi-evergreen trees	2FE Broadleaved (semi-) evergreen closed forest	This class remains unspecified at species level and is identical in its structural-physiognomic description of the vegetation as classes 2FEG, 2FEA and 2FEM.

[7] In **bold** the regrouping of classes at the 85% overall thematic accuracy level requested by the TOR.

[8] If the cultivated fields are surrounded by a vegetation dominated by shrubs, a mixed class should be made consisting of "Rainfed crops" (1HCR) with either Shrubland (=open shrubs) or Thicket (=closed shrubs). If the shrub vegetation is dominant it should be mentioned as the first class in such a mixed class.

[9] Evergreen indicates perennial plants that are never entirely without green foliage (Ford-Robertson, 1971). More than 75 percent of the area of the polygon must be covered by evergreen vegetation. Semi-Evergreen applies to a combination of broadleaved evergreen and broadleaved deciduous, with broadleaved evergreen being the dominant leaf phenology and broadleaved deciduous being more than 25 percent.

LC categories Level III	LC domains Level IV	LC group Level V	LCCS Code LCCS standard name	User code User name	Additional remarks
			20089-L2P10Zt06 // 20089-15048-L2P10Zt06 Broadleaved evergreen trees // semi-evergreen trees Major land class: Sloping land Altitude: 1000 -1500 m Floristic aspect: *Aphloia myrtifolia*, *Maesa lanceclata*, *Curtisia faginea*, *Rawolfia inebrians*, *Canopharngia stapfiana*	2FEM Closed broadleaved (semi-) evergreen mountainous forest	Owing to their high altitude (>1300m a.s.l.) and their mean annual rainfall (>1400mm) in additional to their inaccessibility this forest type has a rich flora.
			20089-13180-L11 Semi-evergreen high forest Major land class: Level land, plain	2FEG Gallery forest	This type of forest may be flooded for some time due to peak flows in the river regime.
			20089-Zt02 Broadleaved evergreen forest Floristic aspect: *Androstachys johnsonii*	2FEA Mecrusse dense	
		(Semi-) deciduous[10]	20090 // 20090-15048 Broadleaved deciduous trees // Semi-deciduous trees	2FD Broadleaved (semi-) deciduous closed forest	This class remains unspecified at species level and is identical in its structural-physiognomic description of the vegetation as classes 2FDC and 2FDB.
			20090-O1O11Zt03 // 20090-15048-Zt03 Broadleaved deciduous trees // Semi-deciduous trees Floristic aspect: *Colophospermum mopane*	2FDC Mopane dense	
			20090-O1O11Zt01 // 20090-15048-Zt01 Broadleaved deciduous trees // Semi-deciduous trees Floristic aspect: *Brachystegia* spp.	2FDB Miombo dense	This vegetation type can have 2 to 3 layers.
	Woodlands (Open forests)	**(Semi-) evergreen**	20131 // 20131-15048 Broadleaved evergreen // semi-evergreen woodland	2WE Broadleaved (semi-) evergreen open forest	This class remains unspecified at species level and is identical in its structural-physiognomic description of the vegetation as classes 2WEM and 2WEA. The class may or may not have a second layer of shrubs.
			20131-L2P10Zt06 // 20131-15048-L2P10Zt06 Broadleaved evergreen // semi-evergreen woodland Major land class: Sloping land Altitude: 1000 -1500 m Floristic aspect: *Aphloia myrtifolia*, *Maesa lanceclata*, *Curtisia faginea*, *Rawolfia inebrians*, *Canopharngia stapfiana*	2WEM Open broadleaved (semi-) evergreen mountainous forest	This forest type is open because of edaphic reasons or human interferences. The latter occurs especially at foot slopes in combination with fertile, rich and deep soils used for cultivation. If natural it is part of a vegetation gradient.
			20131-Zt02 Broadleaved evergreen woodland Floristic aspect: *Androstachys johnsonii*	2WEA Mecrusse open	The class may or may not have a second layer of shrubs.

[10] Deciduous describes the phenology of perennial plants that are leafless for a certain period during the year (Ford-Robertson, 1971). Leaf shedding usually takes place simultaneously in the connection with the unfavourable season (UNESCO, 1973). More than 75 percent of the polygon should be covered by deciduous vegetation. Semi-deciduous applies to a combination of broadleaved deciduous and broadleaved evergreen, with the leaf phenology broadleaved deciduous being dominant and broadleaved evergreen being more than 25 percent.

LC categories Level III	LC domains Level IV	LC group Level V	LCCS Code LCCS standard name	User code User name	Additional remarks
		(Semi-) deciduous	20132 // 20132-15048 Broadleaved deciduous woodland // Semi-deciduous woodland	2WD Broadleaved (semi-) deciduous open forest	This class remains unspecified at species level and is identical in its structural-physiognomic description of the vegetation as classes 2WDC and 2WDB. The class may or may not have a second layer of shrubs.
			20132-Zt03 // 20132-15048-Zt03 Broadleaved deciduous woodland Floristic aspect: *Colophospermum mopane*	2WDC Mopane open	The class may or may not have a second layer of shrubs.
			20132-Zt01 // 20132-15048-Zt01 Broadleaved deciduous woodland Floristic aspect: *Brachystegia* spp.	2WDB Miombo open	The class may or may not have a second layer of shrubs.
	Thickets	(Semi-) evergreen	20152 // 20152-15048 Broadleaved evergreen thicket // Semi-evergreen thicket	2TE Broadleaved (semi-) evergreen thicket	This class is typical in more arid areas. Furthermore, it is found in the vicinity of villages where it often constitutes a regrowth of abandoned cultivated fields.
		(Semi-) deciduous	20153 // 20153-15048 Broadleaved deciduous thicket // Semi-deciduous thicket	2TD Broadleaved (semi-) deciduous thicket	This class is typical in more arid areas. Furthermore, it is found in the vicinity of villages where it often constitutes a regrowth of abandoned cultivated fields.
	Shrublands	(Semi-) evergreen	20173 // 20173-15048 Broadleaved evergreen shrubland // Semi-evergreen shrubland	2SE Broadleaved (semi-) evergreen shrubland	Emergent trees may occasionally occur. This class is typical for areas with poor and/or shallow soils and low rainfall. Furthermore, it occurs as regrowth in areas of shifting cultivation or following fierce bush fires.
		(Semi-) deciduous	20174 // 20174-15048 Broadleaved deciduous shrubland // Semi-deciduous shrubland	2SD Broadleaved (semi-) deciduous shrubland	Emergent trees may occasionally occur. This class is typical for areas with poor and/or shallow soils and low rainfall. Furthermore, it occurs as regrowth in areas of shifting cultivation or following fierce bush fires.
	Grasslands		21270 Herbaceous vegetation with trees 21273 Herbaceous vegetation with shrubs 21318 Open herbaceous vegetation with shrubs	2GCT Tree savanna 2GCS Shrub savanna 2GOS Open shrub savanna	Very occasionally trees can be found as well.
	Mixed class		21446 / 10786 Closed to open trees / Scattered clustered small-sized field(s) Of rainfed herbaceous crop(s)	2FXC Closed to open forested areas with shifting cultivation	Mixed class of closed to open forests with fields cultivated for a number of years.
A23. Cultivated aquatic or regularly flooded areas	Graminoid crops		3003-L11L5S0308 Continuous field(s) of graminoid crops Major land class: Level land, plain, Slope class: Flat to almost flat Dominant crop: Cereals-Rice (*Oryza* spp.)	3GCO Rice crop	

LC categories Level III	LC domains Level IV	LC group Level V	LCCS Code LCCS standard name	User code User name	Additional remarks
A24. (Semi-) natural aquatic or regularly flooded vegetation	**Forests**	Evergreen	40499-4891-L11L5Zt04 Broadleaved evergreen forest on permanently flooded land (with daily variations) Major land class: Level land, Slope class: Flat to almost flat Floristic aspect: *Avennia marina*, *Ceriops tagal*, *Rhyzophora mucronata*	4FEP Mangrove dense	
	Woodlands	Evergreen	40155-4891-L11L5Zt04 Broadleaved evergreen woodland on permanently flooded land (with daily variations) Major land class: Level land, plain, Slope class: Flat to almost flat Floristic aspect: *Avennia marina*, *Ceriops tagal*, *Rhyzophora mucronata*	4WEP Mangrove open	There is a second layer of regrowth of the trees.
			40162 Broadleaved evergreen woodland on temporarily flooded land	4WET Woodland on temporarily flooded land	
	Shrublands		40053 Open shrubs on temporarily flooded land	4SET Open shrubs on temporarily flooded land	
	Herbaceous vegetation		42348-60686 Closed to open herbaceous vegetation on temporarily flooded land	4HVT Herbaceous vegetation temporarily flooded	This vegetation type occurs in depressions where water remains stagnant temporarily leading to an abundant growth of herbaceous plants.
			42347-60686 Closed to open herbaceous vegetation on permanently flooded land	4HVP Herbaceous vegetation permanently flooded	This vegetation type occurs in depressions where water remains stagnant permanently.
			40083 Sparse herbaceous vegetation on temporarily flooded land	4HVS Tandos	This peculiar vegetation type occurs only in Sofala Province (Marromeu). Presence of termite mounds.
B15. Artificial surfaces and associated areas			5001 Built-up area(s)	5BU Built-up areas	This class includes urban, industrial and associated areas.
B16. Bare areas	Consolidated bare areas		6002 Bare rock and/or coarse fragments	6BR Bare rocks	
	Un-consolidated bare areas		6005 Bare soil and/or other unconsolidated material(s)	6BS Bare soils	This class includes all sorts of bare soils, including the salty soils separating mangroves from other vegetation.
			6009 Shifting sands / Dune(s)	6SS Dunes	This class includes dunes where vegetation is rare or absent.
B27. Artificial water bodies	Artificial water bodies		7002 Artificial perennial water bodies	7WB Artificial water bodies	
B28. Natural water bodies	Natural water bodies		8002 Perennial natural water bodies	8WB Natural water bodies	

4.6 Land-cover legend at National level

This legend was prepared for application at the specific nominal scale of 1:1,000,000 for the whole country, thus the classes in this legend are all classes that were expected to be present in the country and that have been used in the data collection with the exception of Shrub crops (1SC). This class was surprisingly not found at the specified scale. This may be related to the fact that any Shrub crops present in the country do not cover a large enough area as defined by the minimum mapping unit or they do not cover a large enough area within a delineated polygon to be mentioned as part of a mixed class. Comparison of the National level legend with the Province level legend will immediately demonstrate that the level of detail in the class definition at National level is much less and that this is applicable for all classes in order to have a balance in the level of detail of the included classes.

The main difference between the land-cover interpretation at Province and National levels has been that the type of satellite imagery requested by the TOR, i.e. LANDSAT, is very suitable for land-cover interpretation at the 1:250,000 nominal scale but quite unsuitable at 1:1,000,000 nominal scale as LANDSAT satellite imagery contains too much detail. The amount of detail in the used LANDSAT 5 TM imagery was reduced by degrading the pixel resolution from 30 to 210m, as described earlier, in order to delineate polygons that contain an amount of information matching the requested nominal scale of 1:1,000,000. Furthermore, the occurrence of so-called mixed classes at the National level increases dramatically and therefore these mixed classes can be composed of three land-cover classes of the legend (instead of two classes as used at the Province level).

The land-cover legend developed for the National level is based upon the regrouping of classes of the Province level at the accuracy level of 85% (Table 14). This means that classes were regrouped in order to generalise the type of land-cover to be distinguished and as a logical consequence this reduces the amount of detail of the classes delineated at the requested coarser scale. In order to be consistent this had to be done for all land-cover categories in a similar manner resulting, for instance, in the loss of information of where Dunes are localised in the country that comprise an important ecological habitat. However, this type of information can be easily tracked and recuperated using GIS operations to select from the final land-cover data set those polygons with the Bare areas (6BA) label located at a certain distance from the sea.

Application of any of the classes of the National level legend to land-cover interpretation resulted in:

- A land-cover polygon with a single dominant land-cover class with a percentage of 100%; or
- A land-cover polygon with a mixture of up to three land-cover classes, so-called mixed class with a dominant, secondary and (if present) tertiary land-cover class, in which case the percentage of each of the classes needed to be specified with the following percentage ranges available: (1) 0-24%; (2) 25-49%; (3) 50-74%; and (4) 75-99% (Please note the difference in approach compared with the Province level).

It is important to note that there is a direct and strong relation present between the different legends used at the two different nominal scales and that the structural-physiognomic approach at definition of classes is identical. Table 15 shows the relationships between the legends at Province and National levels. This facilitates using the coarser scale classes as basis for any more detailed delineation of classes in future and establishes logical and functional linkages between the two resulting data sets. Land-cover classes at the Province level can thus easily be generalised into the National level classes.

The statistics at National level are shown in Table 35 and discussed in paragraph 11.1.

Table 14. Final legend for the land-cover data collection at National level at the nominal scale of 1:1,000,000[11]

LC categories Level III	LC domains Level IV	LC group Level V	LCCS Code LCCS standard name	User code User name	Additional remarks
A11. Cultivated and managed terrestrial areas	**Tree crops**		10001 Tree crop(s)	1TC Tree crops	
	Shrub crops		10013 Shrub crop(s)	1SC Shrub crops	
	Field crops (generic)		10025 // 10013 Herbaceous crop(s) // Shrub crop(s)	1FC Field crops	
	Mixed class		10786 / 21446 Scattered clustered small-sized field(s) of rainfed herbaceous crop(s) / Closed to open trees	1CXF Shifting cultivation with open to closed forested areas[12]	Mixed class of fields cultivated for a number of years surrounded by closed to open forests.
A12. (Semi-) natural terrestrial vegetation	Forests	**(Semi-) evergreen**[13]	20089 // 20089-15048 Broadleaved evergreen trees // Semi-evergreen trees	2FE (Semi-) evergreen forest	
		(Semi-) deciduous[14]	20090 // 20090-15048 Broadleaved deciduous trees // Semi-deciduous trees	2FD (Semi-) deciduous forest	
	Woodlands (Open forests)	**(Semi-) evergreen**	20131 // 20131-15048 Broadleaved evergreen // Semi-evergreen woodland	2WE (Semi-) evergreen woodlands	
		(Semi-) deciduous	20132 // 20132-15048 Broadleaved deciduous woodland // Semi-deciduous woodland	2WD (Semi-) deciduous woodlands	
	Thickets		20018 Closed shrubs (Thicket)	2TK Thickets	
	Shrublands		20022 Open shrubs (Shrubland)	2SL Shrublands	
	Grasslands		21454 Herbaceous closed to open vegetation	2GL Grasslands	.
	Mixed class		21446 / 10786 Closed to open trees / Scattered clustered small-sized field(s) of rainfed herbaceous crop(s)	2FXC Closed to open forested areas with shifting cultivation	Mixed class of closed to open forests with fields cultivated for a number of years.

[11] In **bold** the regrouping of classes at the 85% overall thematic accuracy level

[12] If the cultivated fields are surrounded by a vegetation dominated by shrubs, a mixed class should be made consisting of "Rainfed crops" (1HCR) with either Shrubland (=open shrubs) or Thicket (=closed shrubs). If the shrub vegetation is dominant it should be mentioned as the first class in such a mixed class.

[13] Evergreen indicates perennial plants that are never entirely without green foliage (Ford-Robertson, 1971). More than 75 percent of the area of the polygon must be covered by evergreen vegetation. Semi-Evergreen applies to a combination of broadleaved evergreen and broadleaved deciduous, with broadleaved evergreen being the dominant leaf phenology and broadleaved deciduous being more than 25 percent.

[14] Deciduous describes the phenology of perennial plants that are leafless for a certain period during the year (Ford-Robertson, 1971). Leaf shedding usually takes place simultaneously in the connection with the unfavourable season (UNESCO, 1973). More than 75 percent of the polygon should be covered by deciduous vegetation. Semi-deciduous applies to a combination of broadleaved deciduous and broadleaved evergreen, with the leaf phenology broadleaved deciduous being dominant and broadleaved evergreen being more than 25 percent.

LC categories Level III	LC domains Level IV	LC group Level V	LCCS Code LCCS standard name	User code User name	Additional remarks
A23. Cultivated aquatic or regularly flooded areas			0006 Cultivated aquatic or regularly flooded area(s)	3AC Cultivated aquatic or regularly flooded areas	
A24. (Semi-) natural aquatic or regularly flooded vegetation	**Forests**	Evergreen	40499-4891-L11L5Zt04 Broadleaved evergreen forest on permanently flooded land (with daily variations) Major land class: Level land, Slope class: Flat to almost flat Floristic aspect: *Avennia marina*, *Ceriops tagal*, *Rhyzophora mucronata*	4FF Mangrove dense	The code: Zt04 = Avennia marina, Ceriops tagal, Rhyzophora mucronata.
	Woodlands		40046 // 40047 Woodland on permanently flooded land // Woodland on temporarily flooded land	4WF Aquatic or regularly flooded woodlands	
	Shrublands		41897 // 41983 Closed to open shrubs on permanently flooded land // Closed to open shrubs on temporarily flooded land	4SF Aquatic or regularly flooded shrublands	
	Herbaceous vegetation		42347 // 42348 Closed to open herbaceous vegetation on permanently flooded land // Closed to open herbaceous vegetation on temporarily flooded land	4HF Aquatic or regularly flooded herbaceous vegetation	This vegetation type occurs in depressions where water remains stagnant temporarily leading to an abundant growth of herbaceous plants.
B15. Artificial surfaces and associated areas			5001 Built-up area(s)	5BU Built-up areas	This class includes urban, industrial and associated areas.
B16. Bare areas			0011 Bare area(s)	6BA Bare areas	
B27. Artificial water bodies	Artificial water bodies		7002 Artificial perennial water bodies	7WB Artificial water bodies	
B28. Natural water bodies	Natural water bodies		8002 Perennial natural water bodies	8WB Natural water bodies	

Table 15. Relation between the Province and National level legends

Classes in the legend at Province level		Classes in the legend at National level	
User name	User code	User name	User code
Tree crops	1TCF	Tree crops	1TC
Forest plantation	1TCW		
Tea plantation	1SCT	Shrub crops	1SC
Rainfed field crops	1FCR	Field crops (herbaceous and shrub crops)	1FC
Irrigated field crops	1FCI		
Shifting cultivation with open to closed forested areas	1CXF	Shifting cultivation with forest	1CXF
Coastal dense woody vegetation	2DEC	(Semi-) evergreen forests & woody vegetation	2FE
Broadleaved (semi-) evergreen closed forest	2FE		
Mecrusse dense	2FEA		
Gallery forest	2FEG		
Closed broadleaved (semi-) evergreen mountainous forest	2FEM		
Broadleaved (semi-) deciduous closed forest	2FD	(Semi-) deciduous forests	2FD
Miombo dense	2FDB		
Mopane dense	2FDC		
Coastal open woody vegetation	2DEO	(Semi-) evergreen woodlands & open woody vegetation	2WE
Broadleaved (semi-) evergreen open forest	2WE		
Mecrusse open	2WEA		
Open broadleaved (semi-) evergreen mountainous forest	2WEM		
Broadleaved (semi-) deciduous open forest	2WD	(Semi-) deciduous woodlands	2WD
Miombo open	2WDB		
Mopane open	2WDC		
Broadleaved (semi-) evergreen thicket	2TE	Thickets	2TK
Broadleaved (semi-) deciduous thicket	2TD		
Broadleaved (semi-) evergreen shrubland	2SE	Shrublands	2SL
Broadleaved (semi-) deciduous shrubland	2SD		
Tree savanna	2GCT	Grasslands	2GL
Shrub savanna	2GCS		
Open shrub savanna	2GOS		
Closed to open forested areas with shifting cultivation	2FXC	Forest with shifting cultivation	2FXC
Rice crops	3GCO	Cultivated aquatic or regularly flooded areas	3AC
Mangrove dense	4FEP	Aquatic or regularly flooded forests	4FF
Mangrove open	4WEP	Aquatic or regularly flooded woodlands	4WF
Woodland on temporarily flooded land	4WET		
Open shrubs on temporarily flooded land	4SET	Aquatic or regularly flooded shrublands	4SF
Herbaceous vegetation permanently flooded	4HVP	Aquatic or regularly flooded herbaceous vegetation	4HF
Herbaceous vegetation temporarily flooded	4HVT		
Tandos	4HVS		
Built-up areas	5BU	Built-up areas	5BU
Bare rocks	6BR	Bare areas	6BA
Bare soils	6BS		
Dunes	6SS		
Artificial water bodies	7WB	Artificial water bodies	7WB
Natural water bodies	8WB	Natural water bodies	8WB

5 INTERPRETATION METHODOLOGY

5.1 Introduction

When one looks at remotely sensed images, various objects of different sizes and shapes can be seen. When one can identify what one sees on such an image and communicate this information to others, one is practising *image interpretation*. The images contain raw image data; when processed by a human interpreter's brain these become usable information (Lillesand and Kiefer, 2000) Image interpretation is best learned through experience of viewing many remotely sensed images according to the requirements of specific applications. While viewing an image, the image interpreter systematically examines the image and other supporting materials such as maps. Based on the study of available materials, an interpretation is made as to the physical nature of objects or phenomena appearing in the images. The level of complexity can vary from simple recognition of objects on the Earth's surface to the derivation of detailed information regarding complex interactions between Earth surface and subsurface features. Success in image interpretation varies with the training and experience of the interpreter, the nature of the objects or phenomena being interpreted and the quality of the images being utilised. In general, the most capable image interpreters have keen powers of observation coupled with imagination and a great deal of patience. In addition, a thorough understanding of the phenomenon being studied as well as knowledge of the geographic area under study contributes to the success of the interpretation. For land-cover interpretation a general knowledge of different vegetation types and artificial surfaces coupled with an understanding of the landscape is required.

Elements of image interpretation (Lillesand and Kiefer, 2000) used in the AIFM interpretation process:

- *Shape*, which refers to the general form, configuration or outline of individual objects.
- *Size* of objects should be considered in the context of the image resolution.
- *Pattern* relates to the spatial arrangement of objects.
- *Tone* (or hue) refers to the relative brightness or colour of objects on an image.
- *Texture* is the frequency of the tonal changes on an image.
- *Shadows* are important to interpreters in two opposite ways: (1) the shape or outline of a shadow affords an impression of the profile view of objects (which aids interpretation), and (2) objects within shadows reflect little light and are difficult to discern on an image (which hinders interpretation).
- *Site* refers to the topographic or geographic location and is a particularly important aid in the identification of vegetation types.
- *Association* refers to the occurrence of certain features in relation to others.
- *Resolution* depends on many factors but it always places a practical limit on interpretation because some objects are too small or have too little contrast with their surroundings to be clearly seen.

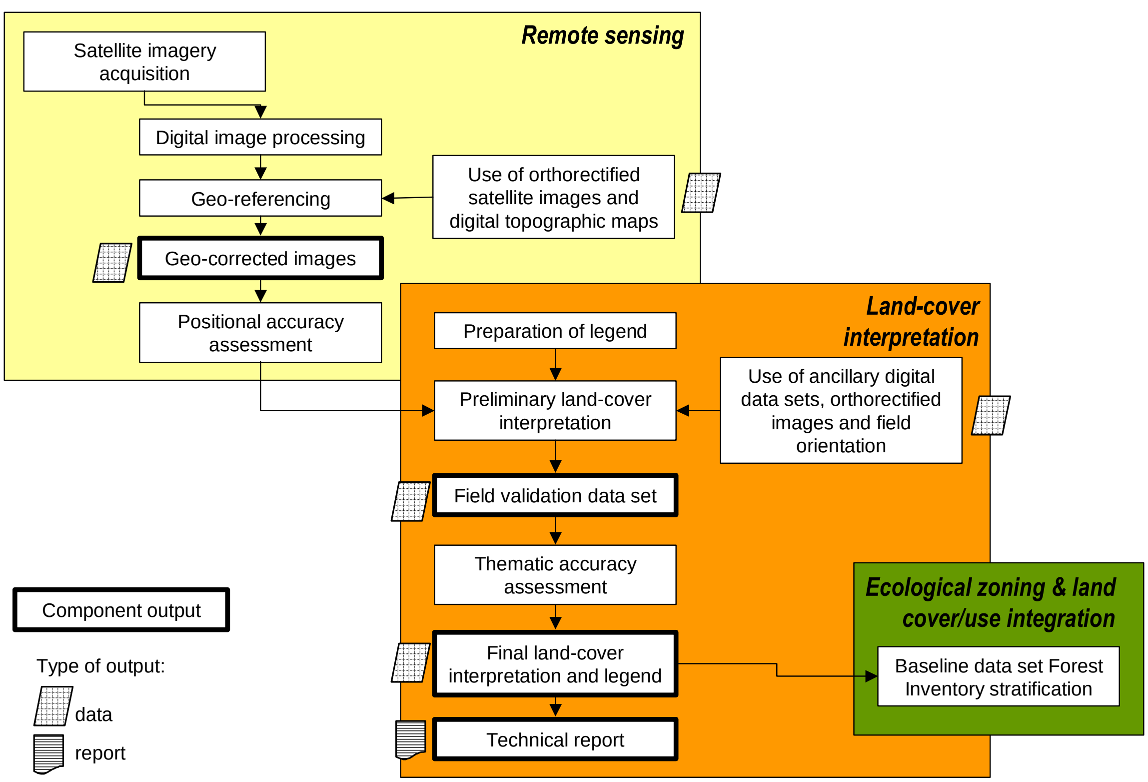
Other factors such as image resolution, image colour balance, etc., also affect the success of image interpretation. As previously mentioned, the interpretation process contains various levels of complexity, from a simple direct recognition of objects (e.g., water surface) in the scene to the inference of site conditions (e.g., different vegetation types having various layers). The interpreter uses the process of *convergence of evidence* to successfully increase the accuracy and detail of the interpretation.

The selected methodology is based upon *on-screen visual interpretation* of LANDSAT 5 TM satellite imagery, using a legend created with the FAO/UNEP LCCS based upon the requirements and experiences of UIF and complemented by field validation. This enables the efficient use of the extremely limited time available within the Project -due to the start of the Project in the field survey season- to produce and validate the land-cover data to be used for the stratification of the Forest Inventory while at the same time using state-of-the-art methodology.

The various steps taken in the image interpretation process are listed here to give an overview of the approach followed (Figure 19):

1. Preliminary phase in which the study area is analysed by studying available ancillary (digital) data and visual navigation through the images according to band combinations that can be created on-the-fly in ArcGIS.
2. Development with the Recipient of the preliminary legend according to the classes described in the TOR using the FAO/UNEP LCCS (Di Gregorio and Jansen, 2000).
3. Preliminary on-screen interpretation, i.e., delineation of polygons and attribution to classes (with the possibility to describe a first dominant class and a secondary class at Province level and the possibility to attribute up to three classes to a single polygon at National level), whereby the interpreters analyse and discuss the land-cover types and identify classes that are more difficult to interpret in order to standardise the approach to interpretation and enhance the internal consistency of the interpretation.
4. Planning of the field orientation, which includes collection of field data in order to better understand the relationships between the satellite images and the ground truth.
5. Adjustment, if necessary, of the preliminary interpretation with the field orientation data.
6. Planning of field validation, which includes preparation of the sampling scheme, identification of sampling sites on the preliminary interpretation and preparation of field survey materials.
7. Execution of field validation, organisation of logistics and collaboration with extra survey staff.
8. Finalisation of the preliminary legend and interpretation based upon the field validation findings and assessment of the interpretation in terms of positional and thematic accuracy.
9. Generation of the final land-cover data sets, preparation of accompanying report and geodatabase.

Figure 19. Overview of the workflow of the remote sensing and land-cover component



5.2 Detection of different classes

The application of the AIFM preliminary legend to visual image interpretation requests a good knowledge of the geographic area. Especially knowledge about the sequence of land covers in the landscape and the type of landscape will help the interpreter. The synergy between UIF and Agriconsulting was therefore of utmost importance.

The visual interpretation process for identification of (semi-) natural vegetation types is generally more complex than that for crop species on agricultural land. As is stated in the TOR Appendix 2, *Natural vegetation boundaries are always problematical, since in effect an artificial boundary is imposed on natural gradients, or progressive changes from one cover type to another. As these boundaries are somewhat problematic, both in terms of* […] *image interpretation and field evaluation, ground cover classes identifying "Forests", "Shrubs", and "T[h]ickets" rely on a relatively high minimum coverage level (40%)*". A complex mixture of various tree species often occupies forested land. Foresters may also be interested in the species composition of under storeys, i.e. the vegetation layers underneath the main canopy, which are generally blocked from view on satellite images by the crowns of the large trees that form the main layer and crown cover. The main image characteristics of shape, size, pattern, shadow, tone and texture -as described earlier- are used in the elimination process in order to determine the vegetation type. Each tree has its own shape and in dense and pure even-aged stands of trees a typical pattern can be recognised on the LANDSAT imagery, however this is extremely rare in Mozambique. When there is a mixture of trees of different and uneven-aged species, visual interpretation becomes much more complicated. Characteristics such as site conditions, geographic location, geomorphologic setting and other environmental factors become key factors in the correct identification of tree stands. Field survey becomes crucial in the validation of the interpretation process.

Permanent crops can be detected by their regular pattern and proximity to built-up areas. Their leaf type can be identified similar to (semi-) natural vegetation. The spectral signature for built-up areas, bare areas and water bodies is so characteristic that they can be easily detected. These classes do not pose any significant problems.

The most difficult aspects to detect and/or to delineate are:

- Appearance of leaf type:
    - The (semi-) deciduous leaf type appears with an great spectral variability on the images;
    - The distinction between (semi-) evergreen and (semi-) deciduous tends to overestimate the presence of (semi-) evergreen vegetation when it is actually (semi-) deciduous;
- Differences in tree and shrub height:
    - The difference between closed forests and thickets, and between open forests and shrubland, as tree or shrub height cannot be derived from satellite imagery;
- Gallery forests; and
- The gradient in the mixture of shifting cultivation or traditional smallholder agriculture with open to closed forests.

These aspects are described in more detail in the following paragraphs.

5.2.1 Differences in leaf type

The differences between the leaf types (semi-) deciduous and (semi-) evergreen with the definitions of the FAO/UNEP LCCS (Di Gregorio and Jansen, 2000) is a tough task in Mozambique. The study of several images covering the same area but from different years and different seasons (e.g., dry and wet season) makes it evident that the spectral reflectance values are very dependent on environmental aspects. Usually a range of spectral values is associated with a single land-cover type. Whereas on a single image part of a forest type vegetation may appear to be (semi-) evergreen, the same area may look decisively different on an image of a different date with the appearance of (semi-) deciduous rather than (semi-) evergreen. One tends to overestimate the presence of (semi-) evergreen when it is actually (semi-) deciduous. Analysis of the literature on vegetation types in Southern Africa makes it clear that there is actually very little real evergreen or semi-evergreen vegetation. Consequently, in the interpretation process most vegetation types that had a different appearance in the same season but in different years have been interpreted as (semi-) deciduous vegetation and very little (semi-) evergreen vegetation types were distinguished.

Furthermore, one tends to underestimate the presence of (semi-) deciduous vegetation, especially in the Mopane and Miombo vegetation types, so that the satellite image interpreters need to be extremely careful not only in defining the leaf type but in particular in estimating the percentage of (semi-) deciduous land-cover classes.

The distinction between deciduous and semi-deciduous and between evergreen and semi-evergreen is extremely difficult both on satellite images and in the terrain; therefore the choice was made to use in a systematic manner the terms (semi-) deciduous and (semi-) evergreen covering the range of deciduous to semi-deciduous and evergreen to semi-evergreen respectively as one finds transitional vegetation zones throughout the country.

5.2.2 Differences in tree and shrub height

As stated before, height is a complicated parameter because trees and shrubs grow and their height increases with time. The threshold values defined in general apply to a fully developed tree or shrub (see also paragraph 4.4). The use of satellite imagery for detection of vegetation types implies that the sensor has always a so-called “bird-eye” view and thus is looking at the leaves of tree and shrub crown canopies without considering height. Definitions based upon the height criterion in order to distinguish trees from shrubs are thus not very pragmatic when using satellite remote sensing.

5.2.3 Forests and woodlands versus thickets and shrublands

Related to the above, one will find that there is confusion between certain classes due to the inability to consider the parameter height. In the physiognomic-structural approach, both thickets and forests have a closed canopy but differ in height, the same is valid for woodlands (open forests) and shrublands that both have an open canopy cover and differ only in height.

Expert knowledge on the occurrence of these vegetation types in the landscape may help in better defining these classes, as well as using various satellite image stretching techniques that may bring to light differences between Forests and Thickets on the one hand, and Woodlands and Shrublands on the other. However, in the assessment of the thematic accuracy of these vegetation types one will always find confusion and therefore one should do everything possible to limit such confusion within acceptable limits in the context of the data collection effort.

5.2.4 Gallery forests

The identification of *Gallery Forests* on the satellite images is considered important in the context of the Project and therefore the cartographic principles have been slightly modified in order to represent this class as much as possible. The elongated branching form of Gallery Forests can be easily identified on the satellite images but often this form cannot be delineated because of the minimum mapping unit defined (see also paragraph 5.6). Consequently, the result will be an *underestimation* of the total area of Gallery Forests.

As this class is considered a particular habitat with a high biodiversity value and an important function in stabilising riverbanks, every effort has been made to delineate this class whenever possible at the nominal scale of 1:250,000.

5.2.5 Shifting cultivation or traditional smallholder agriculture

Agricultural encroachment by *traditional smallholder agriculture* occupies a central position in the debate on tropical deforestation. Shifting cultivators have since long been viewed as the primary agents of deforestation in tropical developing countries (see also Saket, 1994). The implication that agricultural expansion is assumed to be the leading source of tropical deforestation is a hypothesis confirmed by several (case) studies; the common hypothesis that shifting cultivators are viewed as the main agents responsible for forest losses should however be rejected as a *simplification*. An overestimation of the role of *shifting cultivation*, or traditional smallholder agriculture, in tropical deforestation may be due to unclear definitions of what precisely constitutes shifting cultivators or "shifted cultivators", to uncertain estimates and potential political bias. The critical point is that tropical deforestation is driven largely by changing economic opportunities that are linked to other social, political and infrastructural changes. Case study evidence confirms that shifting cultivation alone is never considered to cause deforestation, it occurs along with other agricultural activities and other proximate causes (e.g., wood extraction, expansion of infrastructure) (Geist and Lambin, 2001; Lambin et al., 2001).

The rather broad and unclear defined term "shifting cultivation" can be broken down by more specific and related modes of farming:

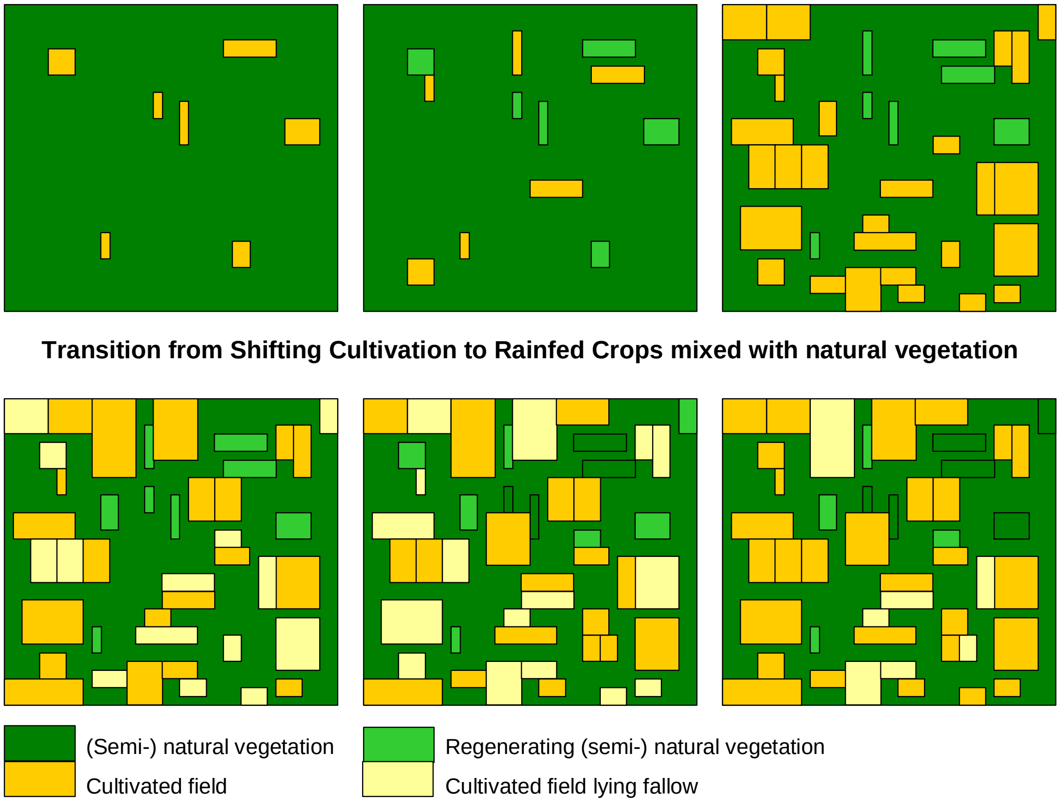
- Colonist shifting cultivation or slash-and-burn agricultural activities; and
- Traditional shifting cultivation or swidden-fallow farming.

The transition from *shifting cultivation* to Rainfed Crops, i.e. the permanent use of cultivated fields, surrounded by (semi-) natural vegetation is described by a series of mixed classes. Shifting cultivation is a term that is related to land *use* instead of land cover; it implies by definition a mixture of forests with cultivated fields. The transition can be described from its initial stage of small fields in a scattered pattern in the forest, to groups of fields in the forest, subsequently the fields do no longer "shift" but remain in the same location surrounded by patches of vegetation. The nature of agriculture changed, i.e. it becomes a system with a more permanent character. A series of classes has been used to describe the various stages that have been identified when cultivation invades natural vegetation (Figure 20):

- "Closed to open forested areas with shifting cultivation" (2FXC) when the forest is dominant in the delineated polygon;
- "Shifting cultivation with open to closed forested areas" (1CXF) when the cultivated fields are dominant in the delineated polygon;
- a mixed class of a Woodland (Open Forest) type and "Rainfed Crops" (1FCR) when the open forest type is dominant in the delineated polygon;
- a mixed class of "Rainfed Crops" (1FCR) with a Woodland (Open Forest) type when the cultivated fields are dominant in the delineated polygon;
- a mixed class of either Thicket or Shrubland with "Rainfed crops" (1FCR) when the vegetation is dominated by shrubs and the shrub vegetation is dominant in the polygon;
- a mixed class of "Rainfed crops" (1FCR) with either Thicket or Shrubland when the cultivated fields are dominant in the polygon.

The distinction of shifting cultivation is only possible with the use of satellite images from previous periods in order to decide whether or not fields shift. Using images of a single year or a single period (e.g., 2004-2005) impede making such a distinction.

Figure 20. Transition from Shifting cultivation to Rainfed crops



5.3 Field orientation

According to the TOR "*Field orientation to allow interpreters to become familiar with the local terrain, vegetation types, land-use systems, etc., prior to image annotation and land-cover mapping would be performed*." However, due to the fact that image interpretation was carried out in Italy this was not feasible. In order to better establish the correspondence between the satellite image characteristics and the field, in Manica Province 66 sample sties and in Maputo Province 45 sample sites were selected for which a relevee sheet was prepared (identical to the one used for field validation shown in Appendix F), in English and Portuguese, with sometimes specific questions for the UIF Staff members that collected these field data. These data were extremely valuable for a better understanding and evaluation of the preliminary image interpretation results and led where necessary to adjustments of this interpretation.

5.4 A note on the use of the term "scale"

According to its definition, *scale* is the ratio or relationship between a distance or area on a map and the corresponding distance or area on the ground, commonly expressed as a fraction or ratio. For digital data, there is no defined distance because the visualisation of the geographic objects can be countless. That is why it is not completely correct to use the term "scale" for digital data.

Throughout this report the words "scale", "working scale", "reference scale" or "nominal scale" are used to identify the detailed level of data, i.e., scale of 1:250,000 for Province level and scale of 1:1,000,000 for National level. It was used to indicate in a synoptic way that data comply to the accuracy requirements, detail of classes requested and minimum mapping unit defined for traditional hardcopy maps at those scales and that these are the optimum scales for visualisation and production of hardcopy outputs of these data. Therefore, the term "scale" is used here in a slightly different meaning with respect to its traditional definition. This approach is coherent with the terminology of the TOR.

Before going into the detail of the interpretation protocols used at the various levels of detail, it is important to explain some concepts adopted that concern the use of different “scales”:

- *Working scale* versus *nominal scale*: though the final product at Province level is presented at the nominal scale of 1:250,000, the actual land-cover interpretation took place at the more detailed working scale of approximately 1:100,000; the same for the final product at National level that is presented at the nominal scale of 1:1,000,000 but the actual land-cover interpretation took place at the more detailed working scale of approximately 1:400,000.
- *Nominal scale of ancillary data*: this is the scale at which ancillary data is best represented but in a digital environment display at more detailed scales is possible.

5.5 Interpretation protocols

5.5.1 At Province level

In Manica Province some specific characteristics should be considered:

- The difference between Mopane and Miombo vegetation types. Miombo is present in most of the Province and this (semi-) deciduous forest formation is found where the landscape morphology is undulating to mountainous. Miombo and Mopane have very typical leaf phenologies and on the images they often give the impression of a herbaceous or shrub savanna when leaves are not present and of an evergreen forest when leaves are present. Therefore the correct interpretation of Miombo and Mopane requests a lot of attention and an interdependent approach between images with the best possible contrast stretches. The expert knowledge of the UIF colleagues has been an important input in adjusting the interpretation for these formations though their input arrived at a late stage of the preliminary land-cover interpretation work at National level and for Maputo Province. However, the synergies between these preliminary interpretations and the expert knowledge input have been such that the results have been optimised under the given conditions.
- Savanna vegetation types are present and they are rarely composed of only herbaceous vegetation as shrubs and emergent trees are present.

In Maputo Province:

- There is a lesser amount of forest vegetation types and a major presence of shrub savanna or grass savanna. Remarkable on the images is the presence of burnt areas, some fires even active during satellite image acquisition. The presence of burnt areas hinders the interpretation in terms of land cover because these zones have a much impoverished herbaceous or shrub vegetation although such vegetation can potentially recover and evolve quickly into a secondary vegetation type. Often the forest fires are of a type in which the lower –herbaceous and shrub– strata of the vegetation are burnt and the higher –tree– strata remain intact.
- Water and humid zones are widespread with the presence of water for more than four months per year, i.e. the LCCS threshold for “permanent”.

In Manica and Maputo Provinces the presence of human influences is considerable. This influence is not only concentrated (as is the case with urban centres) but affects the whole area. Even areas far from urban centres and any form of infrastructure seem to be affected.

Mozambique has land-cover types that are not easily distinguished on satellite images. The interpretation results at Province level, the number and type of classes, however, seem to contradict this as large areas are covered by the same land-cover type considering the physiognomic structure of vegetation types. In fact, apart from the forest types at high altitudes, the Gallery Forests and Mangroves, all of which associations that have a precisely defined topographic position or landscape position, forests types can occur over vast areas resulting in large land-cover polygons containing forests types with medium-sized trees that show a canopy cover from open to very open and with broadleaved plants. The confrontation of satellite images of different dates shows a variety in spectral reflectance values that hardly corresponds to such variations on the ground. Sometimes areas show up as having hardly any vegetation while at another date the area seems to be covered by dense forests and vice versa. It is for this reason that the use of various satellite images covering the same area becomes indispensable. Heavy reliance on the spectral reflectance values of just one date would be a misleading approach to the correct interpretation of land-cover types. The texture detectable on the image should be given priority above the often misleading spectral values. This becomes paramount when no images are available of different seasons (e.g., wet and dry season).

Important in addition to the above-mentioned is also the use of different band combinations while interpreting. In particular the use of band combinations RGB=432 and RGB=453. Together with various types of contrast stretching applied, this can result in ulterior information that can be extracted from the satellite image.

Furthermore, the availability of the IGN/CENACARTA/DINAGECA Joint Venture land-cover/use data set has provided a further insight into the relationship between what the interpreter sees on the image and the land-cover type identified. One should keep in mind, however, that this data set is the result of a different approach to land-cover interpretation than the one adopted by the AIFM Project.

Although the most recent LANDSAT 5 TM coverage provided the baseline data set for land-cover interpretation at Province level, also use of LANDSAT 7 ETM+ images was made, both historical data (circa 2000) and more recent images. In some particular cases, especially in the case of burnt areas, use of ASTER images was made. Because of the higher resolution of these images (15m) the risk is to want to detect a level of detail that is not requested. One should note that these free of charge downloadable images are often covered by some clouds.

The remote sensing and land-cover component's geodatabase (see Chapter 9) facilitated access to the data and streamlined the interpretation going from one satellite images to a neighbouring one. The approach to land-cover interpretation is very personal: one can start in one corner of the satellite image and work through it or one can start from a specific identified class.

5.5.2 At National level

As mentioned in paragraphs 3.4 and 3.8.5, the LANDSAT 5 TM images degraded from a pixel size of 30 m into a pixel size of 120m and 210 m for identification respectively delineation of the land-cover polygons, have been used as baseline data for land-cover interpretation at National level.

Thus, the following methodology was applied:

- The land-cover interpretation was carried out using 120m resolution images in order to detect, with a high level of precision, the different land-cover types on the image.
- The 210m resolution images served as a baseline for the digitalisation of land-cover polygons. In this way, the interpreter could use a suitable level of resolution (according to the working scale of 1:400,000) utilising also the precise information obtained from the 30m resolution images.

The interpretation at National level could appear, at first sight, as being much easier than the one at Province level since the working scale allowed more generalisation. Instead, the minimum mapping unit thresholds together with the heterogeneity of certain areas made the interpretation rather more than less complicated. In order to facilitate the interpretation, also at this level any source of ancillary information were used. Compared to the Province level, the use of the DEM and the eco-zones data acquired greater importance as these data provide general information useful at the working scale of the National level.

The most difficult aspects to detect concerned either (semi-) natural vegetation or cultivated areas:

- The (semi-) deciduous formations showed a wide variety in phenology. (Semi-) deciduous forests or woodlands in the dry season appear to be similar to grasslands or even bare areas. The comparison among satellite images from different dates allowed the correct detection of this type of feature. Moreover, even in dry season such formations present a coarser texture than grasslands or shrublands (see also paragraph 5.2).
- The thickets class was rarely used due to the difficulty of discrimination between thickets and shrublands. With the help of the expert knowledge of the UIF Staff members it was possible to adjust the preliminary land-cover interpretation and to re-label many polygons previously classified as shrublands.
- Tree crops in coastal areas may have been easily confused with forested areas. In this case, the IGN/CENACARTA/DINAGECA Joint venture land-cover/use data provided a crucial source of information.
- The RGB=453 band combination enhanced the presence of fires on naturally vegetated areas. A scattered pattern of burnt areas highlighted the presence of "slash-and-burn" agriculture, whereas large and continuous extensions indicated the presence of extensive burning for hunting or pasture purposes. In the latter case, the land cover remained almost unaltered since the fires did not affect permanently the (semi-) natural vegetation.

5.6 Minimum mapping units applied

The *minimum mapping unit* is a concept applied by cartographers when addressing the smallest area that can be shown on a map. This concept is therefore scale-dependent and *not* related to classification. Usually a single polygon area is defined as the smallest possible entity that can be represented in the data set and its size is applied to all classes in the legend. This approach has been superseded by a more flexible approach in which classes that have a specific importance in the context of the data collection effort may also be represented at a polygon size that is smaller than the minimum mapping unit applied.

According to the TOR the following minimum mapping units are defined: "*a minimum mapping unit of 16 km^2 for the National forest and land-cover map (1:1,000,000 i.e. 4,000x4,000m) and of 4 km^2 at 1:250,000 scale*." In practice, the land-cover interpretation team applied a minimum mapping unit of 1km^2 for the 1:250,000 nominal scale interpretation because the difference between the two nominal scales to be applied at Province and National level is factor 16 (i.e. 4x4) and not factor 4. So more detail has been included in the 1:250,000 nominal scale interpretation than requested by the TOR.

In addition, at National level a higher level of detail was reached by setting two different thresholds for the minimum mapping unit. Polygons containing mixed classes maintained a minimum mapping unit of *16 km^2*, whereas a limit of 9 *km^2* was set for single class polygons.

Because the aim of the land-cover data sets in the AIFM Project is provision of the baseline data for the stratification of the Forest Inventory, the identification of Gallery Forests on the satellite images is considered important and therefore the cartographic principles have been slightly modified in order to represent this class as much as possible. The elongated branching form of Gallery Forests will be represented at the 1:250,000 nominal scale when at least a minimum width of 150-200m is present and the total area of the polygon is at least 1km^2, i.e. the minimum mapping unit applied. At National level the width should be at least 1km. If these criteria do not apply the Gallery Forest will be part of a larger polygon and in most cases because of its limited area will not be represented in the class codes of the polygon. The result will be an underestimation of the total area of Gallery Forests.

5.7 Interpretation consistency

Each land-cover polygon of a preliminary interpretation exists of a set of boundaries of which two aspects should be validated:

- The *spatial coherence* of the polygon, i.e. are the boundaries in the appropriate place and has the same logical and functional thinking been applied in a consistent manner in the area of interpretation; and
- The *thematic coherence,* i.e. is the label given to the polygon correctly describing its contents and are other areas with similar features (e.g., spectral signature) described in the same manner.

The interpretation process has been constantly monitored for internal consistency within the layer and between the two Provinces concerning the spatial and thematic consistency as applied by the interpreters. The same accounts for the National level interpretation.

After each phase within the preliminary land-cover interpretation process for Manica and Maputo Provinces, a systematic thorough checking of the coherence and consistency of the land-cover polygons and classes has been executed. Several approaches can be adopted for this type of consistency evaluation. The most appropriate approach in the context of this Project has been a semi-statistic selection of polygons with a one by one evaluation executed by an expert satellite image interpreter. The more people execute the satellite image interpretation, the more important it is to verify that all interpreters follow the same approach from the very beginning and do not diverge with time.

The main consistency results are from the evaluation of a data set covering the whole area of interest (e.g., Province) when consistency is checked before the end of the preliminary interpretation process and before finalising this data set after its validation. A complete overview of the land-cover data covering the area of interest can highlight differences or inconsistencies that would not show up in a partial view. At the same time, harmonisation of class names and class labels -followed by an upgrade of the entire legend- can be performed if necessary.

The land-cover polygons to be checked, and if necessary changed, were highlighted and for each of them a specific note was added for the satellite image interpreter’s use. Figure 21 shows an example of the overall view of the land-cover data for Manica Province with the polygons to be checked in green.

The main inconsistencies detected are the following ones:

- *Similarity*: a line between two areas that have the same land-cover type;
- *Cover value*: wrong estimation of the percentage of the land-cover type; and
- *Cover feature*: wrong identification of the land-cover type.

Two examples are shown and described below. The first one shows an example of similarity, i.e. the same land-cover type. The polygon boundary indicated in yellow has been deleted as it is redundant. The polygon boundaries in blue have remained intact (Figure 22).The second one shows an example of the wrong estimation of the land-cover percentage in the polygon. Two areas with the same specific land-cover type were previously separated because of the estimated percentage of this cover in the polygon (Figure 23). After consistency checking the cover values were considered to be equal and the two polygons were merged.

Figure 21. Complete Manica layer with polygons to be checked in green

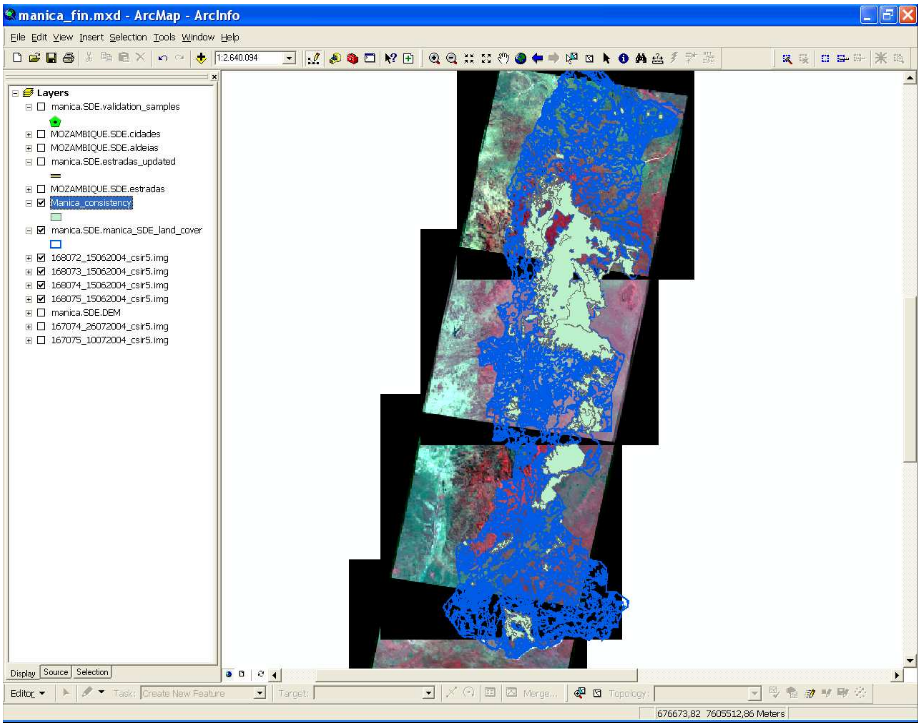


Figure 22. Example of similarity in land-cover interpretation consistency checking

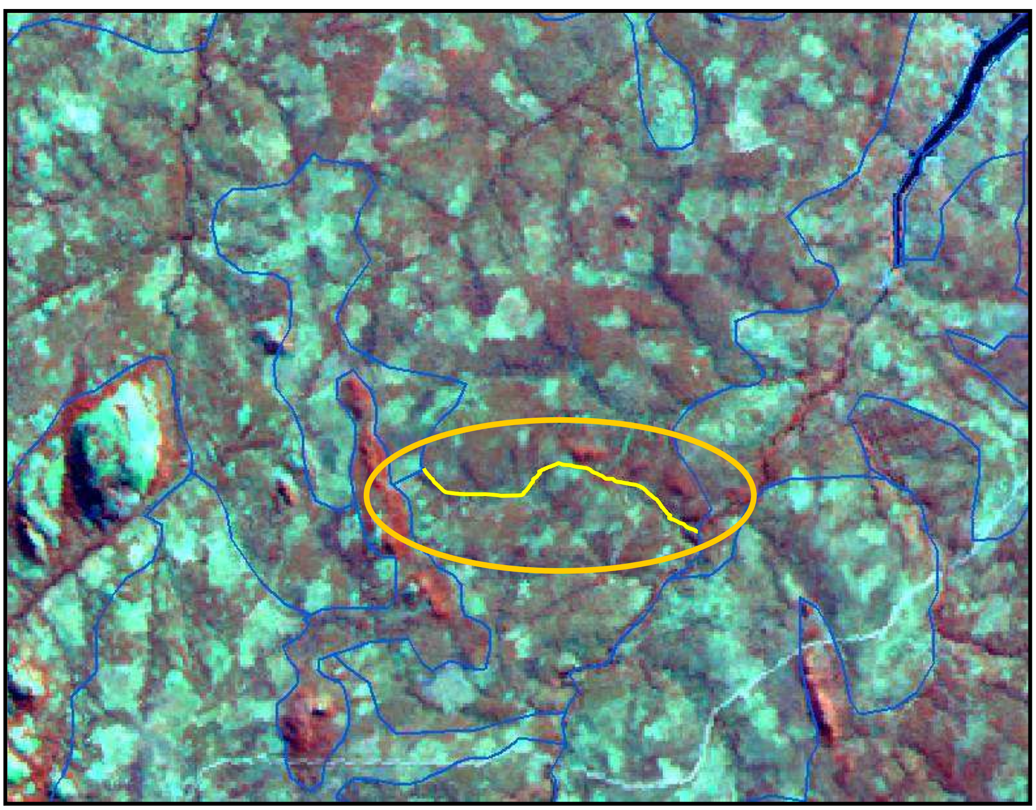
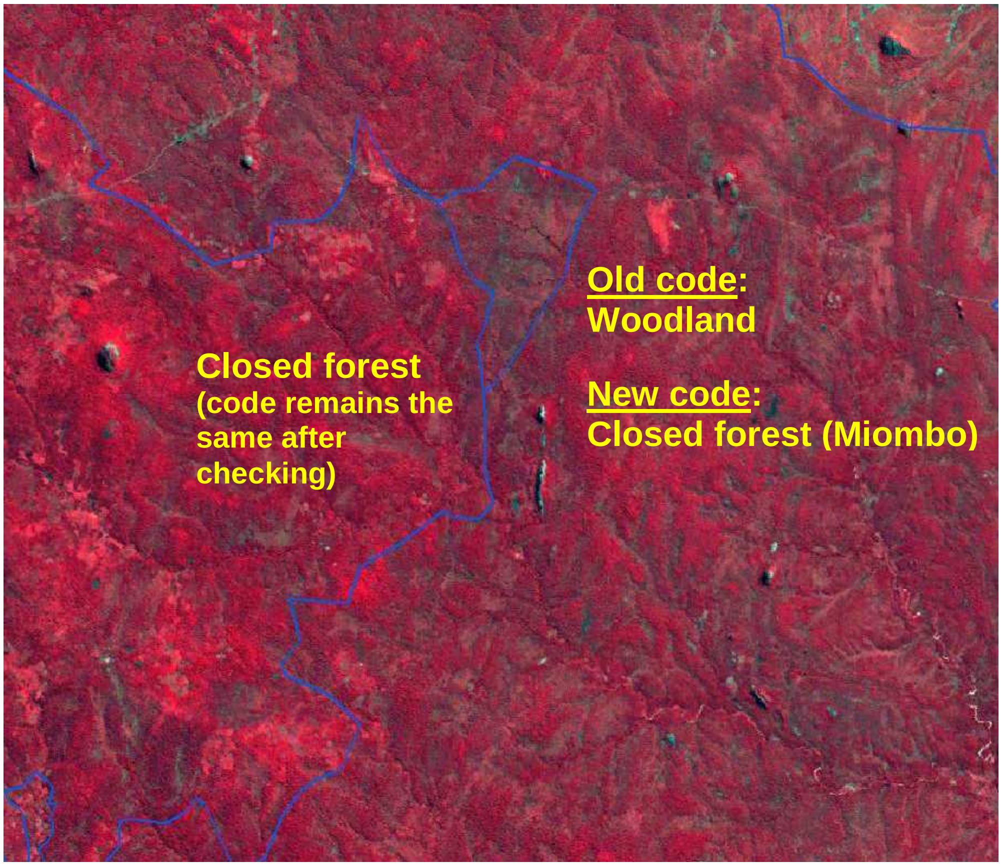


Figure 23. Example of cover value inconsistency in land-cover interpretation consistency checking



6 FIELD VALIDATION

6.1 Introduction

Field data collection is an integral part of and one of the most expensive operations in any study. In general, the more specific a category is, the more ground samples are needed and the more costly the survey becomes. The classes in the legends, therefore, avoid unnecessarily detailed categorisation of land-cover types (i.e. they use similar parameters in their definition) and guarantee robustness and a fairly homogeneous level of accuracy for all interpreted land-cover classes.

One cannot measure any characteristic of the land-cover types everywhere. To find out what the land cover of an area is like one must be satisfied with measurements made in part of it, i.e. on a sample. However, sample information is of little value unless it can be used as a reliable description of the area as a whole. What one wants is information that is truly representative of the area, and a means of sampling that will ensure this, bearing in mind that land cover is variable (Webster and Oliver, 1990).

Before starting a sampling procedure the *target population* needs to be defined (Stehman, 1999). In this case using LCCS we are observing "*the (bio) physical cover of the Earth's surface*" (Di Gregorio and Jansen, 2000) in the form of land-cover polygons. Thus, the field validation has not been limited to forested areas only. Furthermore, LCCS describes any type of land cover with a physiognomic-structural approach, i.e. the overall appearance of the land cover and its spatial distribution, which is the horizontal and vertical arrangement. This applies to all classes. Location of the sampling points in the field is nowadays no problem using the Global Positioning System (GPS) instrument and/or a compass. Bias may be introduced again if the sample area is atypical, unpleasant (e.g., wetland or thorny thicket).

A sampling scheme for field validation was designed (Appendix F) and the information from these sampling sites has formed the basis for the calculation of the overall thematic accuracy of the land-cover interpretations at both nominal scales, as will be discussed in Chapter 7.

6.2 Field survey sampling design at Province level

A sample design should be simple to implement and analyse. This simplicity criterion applies to both the implementation of the design and the analysis of the resulting data. The same criterion also applies to the ease with which auxiliary information can be incorporated into the analysis to improve the precision of the estimates. This auxiliary information may be the land-cover proportions derived from the data (Stehman, 1999). In order to make a field sampling design, one should know how many sample sites should be selected and consequently located. For a random stratified sampling method, the number of sample sites, to be used in the thematic accuracy, can be calculated using the formula of Snedecor and Cochran (1980):

$$N = \frac{(t)^2\, p(1-p)}{E^2}$$

Equation 6-1

where,

- N is the number of observations
- p is the expected accuracy in percentage
- t is the t of the Student's test equals 1.96 if one wants to have a confidence level of 95% in the accuracy estimate
- E is the maximum error in percentage allowed in the estimation.

In the case of the land-cover data collection in the AIFM Project, the estimation error of the accuracy allowed is 5% (E=0.05) and the expected accuracy is 85% (p=0.85), therefore the number of sample locations necessary (N) is 195. For the validation of the land-cover interpretation in Manica Province, 210 sample locations had been selected of which 192 have been collected in the field. For Maputo Province the number of sample locations necessary is the same as for Manica Province as the set of parameters is equal but those selected, due to time constraints, comprised 121 of which 121 have been collected in the field. The response design is recorded for the dominant land-cover class in the polygon.

The land-cover classes have been aggregated at Level IV of the legend, for some land-cover classes Level III or V were used (see paragraph 7.2 and Table 13). A minimum of two samples for each group has been guaranteed, while the distribution of the remaining samples has been defined proportionally to the surface covered by each group in the province using the Neymann formula:

$$Nj = N \frac{Aj}{\sum_{j=1}^{m} Aj}$$

Equation 6-2

where,

- N is the total number of samples to allocate in the Province, Nj is the number of samples for each group (stratum)
- Aj is the total area of polygons belonging to the group (stratum) j
- m is the number of groups.

With the same approach the samples within the group have been distributed, although this was not compulsory, taking into account the area covered by each class as much as possible.

Since there are few roads in large parts of the two Provinces, it was decided for practical reasons (e.g., constraints in available time for executing the field survey), to consider only polygons with at least a portion of them within 2.5km from the main road network as one could assume that such sites are accessible with limited effort and within a reasonable time. For this purpose an update of the digital road network was executed using satellite image interpretation of the LANDSAT 5 TM images. Subsequently, a buffer of 2.5km around the road network was created in ArcGIS. The land-cover polygons (partly) within this buffer were subsequently selected and the statistics of the surfaces covered by the different land-cover domains, groups and classes were produced. In this manner it has been possible to verify the occurrences of the classes inside the buffer area in terms of number of polygons and surface area and then verify their accessibility for the field survey. According to the above-mentioned and explained statistical criteria, the sample sites were located using ArcGIS thereby paying attention to select those sample sites that are representative of the selected class and are not too close to the boundary of the delineated polygon. This is very important as two of the sources of error in the land-cover data sets are georeferencing and mis-registration as part of the positional error (see paragraph 7.1).

6.3 Field survey sampling design at National level

The thematic accuracy assessment at National level has been different from the Province level, as the season in November-December 2005 did not permit a field validation by teams describing sample sites on the ground. Furthermore, one should also consider the costs/benefit ratio if for the validation of a product at a coarse scale covering a very large area (i.e. the whole of Mozambique) field surveying would have been used that would have collected data at a very detailed level. The costs of the transportation of several field survey teams and the detailed level data collected would not weigh up against the benefits. Therefore, during the Inception mission and in the Inception Report, an alternative has been presented that comprises the use of high-resolution satellite images (e.g., ASTER at 15m resolution) in order to validate the 1:1,000,000 nominal scale interpretation.

The assumption in the proposed methodology is that the experiences and knowledge gained at Province level in understanding the spectral values of the images and their relationships with specific land-cover types in the dry and wet season as well as the complementary expert knowledge of the UIF Staff provide the basis on which a validation at National level can be based using again satellite imagery in order to validate a satellite imagery based land-cover interpretation. Without a link to the relationships between satellite image interpretation and field data, such a methodology should *not* be considered.

At the National level, also economic reasons make it a quite cumbersome task to collect ground truth data covering the entire country (e.g., whether strip flights are used or field survey teams on the ground). Therefore, it was decided to use the satellite image interpretation of small areas on ASTER images, having a resolution of 15m, as sample areas in order to validate the degraded LANDSAT 5 TM image based land-cover interpretation (e.g., pixel size of 210m). The level at which the 85% thematic accuracy was to be reached at National level is shown is Table 14.

The selection of sample areas was carried out in three phases:

1. Systematic selection of the LANDSAT frames with more than 70% of the area covering the territory of Mozambique resulting in 30 frames.
2. Random selection of a single ASTER scene for each LANDSAT frame (around nine ASTER scenes correspond to one LANDSAT frame).
3. Stratified random selection of a sample area belonging to a 1x1km grid.

As a result of the phases 1 and 2, a sub-sample of 30 out of approximately 270 ASTER scenes covering Mozambique, was selected. Then a 1km grid of points has been made and overlaid with the land cover. For each point, the attributes of the land-cover class of this location have been loaded.

The number of samples to be used in the thematic accuracy has been calculated with the same formula and approach described earlier in paragraph 6.2. In the case of the land-cover data collection in the AIFM Project, the estimation error of the accuracy allowed at National level was fixed at 4% (E=0.04) and the expected accuracy 85% (p=0.85), as a result the required sample locations (N) are 385.

For the National level the number of sample locations available was 373 (related to the availability of suitable cloud free ASTER images). Their selection was stratified random according to the classes. The distribution of the samples in each stratum has been defined proportionally to the surface covered by each class in the National territory excluding the two Provinces (Maputo and Manica) using the Neymann formula (equation 6.3); then a minimum of 5-10 samples for each class has been guaranteed.

$$Nj = N \frac{Aj}{\sum_{j=1}^{m} Aj}$$

Equation 6-3

where,

- N is the total number of samples to allocate in Mozambique, Nj is the number of samples for each class (stratum)
- Aj is the total area of polygons allocate within the National boundary (excluding the two Provinces Maputo and Manica) belonging to the class (stratum) j
- m is the number of classes.

For each sample point, the interpreters observed approximately a square of 1x1km centred on the point and, considering the context of the polygon at such a coarse scale, judged if the point was correct or not.

7 DATA ACCURACY ASSESSMENT

Before being used in scientific investigations and policy decisions, thematic data sets constructed from remotely sensed data should be subjected to an accuracy assessment that quantify data quality so that data users may evaluate the utility of these data for their intended aim (Stehman and Czaplewski, 1998).

7.1 Positional accuracy assessment

The inclusion of a positional accuracy assessment should be a standard practice in any digital data collection effort. However, the TOR do not require such an assessment. In order to be as complete in the methodology as possible within the available resources of the AIFM Project, the minimum necessary positional accuracy assessment has been executed.

The positional accuracy describes the geometry of an object in the real word with reference to the values of its vertical and horizontal accuracy. Three different steps of verification and validation can be adopted:

1. *Georeferencing* of the LANDSAT satellite images, i.e. the technical solutions for projecting the imagery onto the UTM projection with WGS84 spheroid aiming at providing for each pixel on the image its position on the ground by the means of a tern of coordinates.
2. *Location control*, i.e. the correspondence between the coordinates of any arbitrary chosen point on the image and its position on the ground by the confrontation with better accuracy source data.
3. *Registration*, i.e. the precision of the drawing/digitising system adopted defined as the difference between the same lines when interpretation is repeated of the same feature.

The positional accuracy of the georeferencing of the AIFM digital land-cover data sets for the two Provinces and at National level has been assessed for each LANDSAT 5 TM scene used in the land-cover interpretation. These accuracy values and the number of ground control points (GCP) used are provided in Appendix A. Location control depends on the availability of a better accuracy source but the available topographic maps at 1:50,000 scale produced in the 1960s do not correspond anymore with the ground truth of today and therefore have not been used. The uncertainties with which identical features can be located both on the satellite imagery based interpretation and the topographic maps are too big. The particular on-screen digitising technique of the interpretation has dramatically reduced possible sources of errors in the digitising phase. The only source of error to estimate is the cursor placement and this was set to one pixel at maximum.

7.2 Thematic accuracy assessment

When producing an interpretation of land cover, one wants to make some statement about the correspondence of this interpretation with the reality. The accuracy of an interpretation can be defined as a measure of its agreement with the reality that it represents. However, reality is usually not known (if the land cover would be known, making an interpretation would be a useless exercise). Comparison should thus be made with another representation that has been accepted as being more reliable. In practice, accuracy measurements are indexes of agreement with another representation of reality, generally known only on a sample (Carfagna and Gallego, 1999).

A statistically valid design for estimating accuracy parameters has three parts: (1) the response design specifies which data are to be collected at each sample location; (2) the sampling design specifies the locations at which the response data are to be acquired; and (3) the analysis lays out the formulas and tests to be applied to the observations. Any land-cover data collection without proper validation, whether at global, regional or local scale, remains an untested hypothesis (Stehman and Czaplewski, 1998; Boschetti et al., 2005).

One of the most common means of expressing thematic classification accuracy is the preparation of a classification *confusion matrix*, sometimes called *error matrix* or *contingency table*. The confusion matrix compares on a category-by-category basis, the relationship between known reference data, i.e. the ground truth, and the corresponding results of classification either in the form of pixels, cluster of pixels, polygons or groups of polygons (Lillesand and Kiefer, 2000). On the rows the class codes of the legend are listed, whereas the columns are related to the "true" classification on the ground. On the major diagonal axis of the matrix one will find the correctly classified elements, i.e. the class observed on the ground is the same as recorded in the interpretation.

Several characteristics about classification performance are expressed by the confusion matrix:

- The *overall accuracy* is computed by dividing the total number of correctly classified classes by the total number of elements.
- *Producer's accuracy* results from dividing the number of correctly classified elements in each category (on the diagonal axis) by the number of samples used for that category (the column total of the category). This figure indicates how well samples of the given category are classified.
- *User's accuracy* results from dividing the number of correctly classified elements in each category (on the diagonal axis) by the number of samples that were classified in that category (the row total of the category). This figure indicates the probability that a sample classified into a given category actually represents that category on the ground.
- Classification errors of *omission* (exclusion) or *commission* (inclusion), these are all the non-diagonal elements in the confusion matrix in which omission errors correspond to non-diagonal column elements and commission errors to non-diagonal row elements.

There are three other facets of accuracy assessment (Carfagna and Gallego, 1999; Lillesand and Kiefer, 2000; Boschetti et al., 2005) that are worth mentioning:

- The quality of any accuracy estimate is only as good as the information used to establish the "true" land-cover class present at the sample sites. The accuracy of the reference data may be influenced by factors such as spatial mis-registration, interpretation errors, data entry errors and changes in the land cover between the date of the classified image and the date of the field survey sample.
- The accuracy assessment procedure must be designed to reflect the intended use of the classification. A small cultivated field area misclassified while being surrounded by shrubland might be of little significance if the classification forms the basis of the stratification for a Forest Inventory, as is the case with AIFM, or development of a regional land-use plan; the error might be intolerable if the classification forms the basis for land taxation or for cultivated area financial support.
- Remotely sensed data are normally just a small subset of many possible forms of data resident in an Information System and errors may propagate through multiple layers of information, from topographic maps used for georeferencing to ancillary data used for identification of spectral signatures of land-cover objects.

In the TOR it is specified that an "*accuracy of 85% is required for the eight Level III land-cover types and for the vegetation and forest types at least at level IV (evergreen & deciduous and semi-deciduous forests and grasslands). The same interpretation accuracy is required for the vegetation and forest types at fourth interpretation level.*" However this statement is not correct as the distinction in (semi-) evergreen and (semi-) deciduous in LCCS is made at level V (see Table 13 and Table 14). Furthermore it is stated that "*The surface estimates should have ±10 % error (at 90 % confidence interval)*". The accuracy assessment requirements apply similarly to both Province and National land-cover data sets.

A point that should be made about interpreting classification accuracies is the fact that even a completely random assignment of pixels to classes will produce percentage correct values in the confusion matrix. In fact, such a random assignment could result in a surprisingly good apparent classification result. The so-called *KHAT statistic* or *kappa coefficient* is a measure of the difference between the actual agreement between reference data, i.e. the field survey data, and the interpreted data, i.e. the land-cover polygons, and the chance agreement between the reference data and a random class.

Thus, the KHAT statistic can be defined as:

$$\kappa = \frac{observed\ accuracy - chance\ agreement}{1 - chance\ agreement}$$

Equation 7-1

This statistic serves as an indicator of the extent to which the percentage correct values of a confusion matrix are due to “true” agreement versus “chance” agreement. As true agreement (observed) approaches 1 and chance agreement approaches 0, κ approaches 1 (Mather, 1999; Lillesand and Kiefer, 2000). The KHAT statistic is computed as:

$$\kappa = \frac{N\sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r}(x_{i+} \cdot x_{+i})}{N^2 - \sum_{i=1}^{r}(x_{i+} \cdot x_{+i})}$$

Equation 7-2

where,

- r number of rows in the confusion matrix
- x_{ii} the number of observations in row *i* and column *i* (on the major diagonal)
- x_{i+} total of observations in row *i* (shown as marginal total to right of the matrix)
- x_{+i} total of observations in column *i* (shown as marginal total at bottom of the matrix)
- N total number of observations included in the matrix.

It is advisable to compute both the overall accuracy and KHAT statistic and analyse the resulting values. One of the principal advantages of computing KHAT is the ability to use this value as a basis for determining the statistical significance of any given matrix or the differences between matrices.

7.2.1 At Province level

Table 16 provides an overview of the overall thematic accuracy at aggregated data level for Manica Province, i.e. the aggregation of classes according to the names of the land-cover domains and groups shown in bold in Table 13. A total of 192 observations could be used. The mixed classes (codes 1CXF and 2FXC) composed of shifting cultivation with (semi-) natural vegetation, or vice versa, have not been grouped with other classes. The overall thematic accuracy assessment for Manica Province results in 87%, thereby fulfilling the requirement of the TOR.

In Table 17 the results at individual class level are provided as well in order to provide a better insight to the data user on the potential uses of the land-cover class data. Even at disaggregated data level the overall accuracy with 86.0% fulfils the TOR requirement. Also the User’s and Producer’s accuracies have been calculated (Table 18). It should be clear to the data user that the use of these data at class level is not recommendable for the classes 2FE, 4WE and 4HV. Values for the classes 6BR and 6BS are not provided and also the use of the data for these classes is not recommended.

The KHAT statistic for Manica Province at aggregated data level is 0.84, whereas at individual class level it is 0.85. In both cases the value is relatively close to 1, meaning that chance agreement is limited.

Table 16. Thematic accuracy assessment Manica Province land-cover data at aggregated data level[15]

Land-cover interpretation	Field sample data (ground truth)																	Total samples
Land-cover category (III)	A11			A12									A24		B15	B16	B28	
Land-cover domain (IV)	1TC	1FC		2FE	2FD	2WE	2WD	2TE	2TD	2SD	2GL		4WE	4HV				
Mixed class			1CXF									2FXC						
1TC	3																	3
1FC		13				1									1			15
1CXF			7															7
2FE	1			6	2		2											11
2FD					29													29
2WE						1												1
2WD							54		2			1						57
2TE								1										1
2TD							1		3									4
2SD		1				1				8		1						11
2GL		1			1	1				3	14							20
2FXC												25						25
4WE													1		1			2
4HV		1												1				2
B15															1			1
B16		1				1										0		2
8WB																	1	1
Total samples	4	17	7	5	32	1	62	1	5	11	14	27	1	1	3	0	1	192

Overall thematic accuracy = 87.0% (sum of the diagonal divided by total number of samples) and KHAT statistic = 0.84.

[15] See for the codes used Table 13.

Table 17. Thematic accuracy assessment Manica Province land-cover data at class level[16]

		Field sample data (ground truth)																									Total samples
	Land-cover category (III)	A11			A12																	A24		B15	B16		B28	
	Land-cover class	1TCW	1FCR	1CXF	2FEM	2FE	2FEG	2FD	2FDC	2FDB	2WE	2WD	2WDC	2WDB	2TE	2TD	2SD	2GCT	2GCS	2GOS	2FXC	4WET	4HVT	5BU	6BR	6BS	8WB	
Land-cover interpretation	1TCW	3																										3
	1FCR		13									1												1				15
	1CXF			7																								7
	2FEM				1																							1
	2FE	1				3		2																				6
	2FEG						2					2																4
	2FD							6																				6
	2FDC								2																			2
	2FDB									21																		21
	2WE										1																	1
	2WD											12		1														13
	2WDC												15			2												17
	2WDB													26							1							27
	2TE														1													1
	2TD													1		3												4
	2SD		1									1					8				1							11
	2GCT								1			1						4										6
	2GCS		1														2	1	7									11
	2GOS																1			2								3
	2FXC																				25							25
	4WET																					1		1				2
	4HVT		1																				1					2
	5BU																							1				1
	6BR											1													0			1
	6BS		1																							0		1
	8WB																										1	1
Total samples		4	17	7	1	2	2	8	3	21	1	19	15	28	1	5	11	5	7	2	27	1	1	3	0	0	1	192

Overall thematic accuracy = 86.0% (sum of the diagonal divided by total number of samples) and KHAT statistic = 0.85.

[16] See for the codes used Table 13.

Table 18. Producer's and User's accuracies of the Manica Province land-cover data

Land-cover domains and groups		User's accuracy (%)	Producer's accuracy (%)
1TC	Forest plantations	100.0	75.0
1FC	Rainfed crops	86.7	76.5
1CXF	Shifting cultivation with open to closed forested areas	100.0	100.0
2FE	(Semi-) evergreen forests	54.5	100.0
2FD	(Semi-) deciduous forests	100.0	90.6
2WE	(Semi-) evergreen woodlands (open forests)	100.0	100.0
2WD	(Semi-) deciduous woodlands (open forests)	94.7	87.1
2TE+2TD	Thickets (evergreen and (semi-) deciduous)	80.0	66.7
2SE+2SD	Shrublands (evergreen and (semi-) deciduous)	72.7	72.7
2GL	Grasslands	70.0	100.0
2FXC	Open to closed forested areas with shifting cultivation	100.0	92.6
4WE	(Semi-) evergreen woodland, temporarily flooded	50.0	100.0
4HV	Herbaceous vegetation, temporarily flooded	50.0	100.0
5BU	Built-up areas	100.0	33.3
8WB	Water bodies	100.0	100.0

As the confidence with which each land-cover category of the interpretation has been classified is known, this value can be displayed also cartographically thereby showing the distribution of the confidence values for the whole Province.

The components identified above all contribute toward a convergence of evidence on the validation of a national land-cover product. They allow users to construct error analyses that assess how the weaknesses and strengths of a specific land-cover product used as an information source affect their application (e.g., forest inventory, change analysis and modelling, etc.) (Boschetti et al., 2005).

Table 19 provides an overview of the overall thematic accuracy at aggregated data level for Maputo Province, i.e. the aggregation of classes according to the names of the land-cover domains and groups shown in bold in Table 13. A total of 121 observations could be used. The mixed classes (codes 1CXF and 2FXC) composed of shifting cultivation with (semi-) natural vegetation, or vice versa, have not been grouped with other classes. The overall thematic accuracy assessment for Maputo Province results in 86.0%, thereby fulfilling the requirement of the TOR.

In Table 20 the results at individual class level are provided as well in order to provide a better insight to the data user on how the land-cover data may be used. Even at the disaggregated data level the overall accuracy of 86.0% fulfils the TOR requirement. Again the User's and Producer's accuracies have been calculated (Table 21). It should be clear that from the Producer's point of view, the class 2WE has a low accuracy, for the user however the accuracy of this class is OK. The learning process of land-cover interpretation in Manica Province has contributed to the higher values for User's and Producer's accuracies in Maputo Province.

The KHAT statistic for the overall thematic accuracy assessment for Maputo Province at aggregated data level is 0.83, whereas at individual class level the value is 0.86. In both cases the value is relatively close to 1, meaning that chance agreement is limited.

Table 19. Thematic accuracy assessment Maputo Province land-cover data at aggregated data level[17]

	Field sample data (ground truth)														
Land-cover category (III)	A11		A12									A24		B28	Total samples
Land-cover domain (IV)	1FC		2FE	2FD	2WE	2WD	2TD	2SD	2GL	2GO		4SE	4HV	8WB	
Mixed class		1CXF									2FXC				
Land-cover interpretation															
1FC	13					2									15
1CXF		2													2
2FE			11												11
2FD			2	7											9
2WE					2										2
2WD			1	1		22			1						25
2TD						1	3								4
2SD	1					1		8		1					11
2GC						3		2	25						30
2GO										2					2
2FXC											4				4
4SET												1			1
4HV					1								3		4
8WB														1	1
Total samples	14	2	14	8	3	29	3	10	26	3	4	1	3	1	121

Overall thematic accuracy = 86.0% (sum of the diagonal divided by total number of samples) and KHAT statistic = 0.83.

[17] See for the codes used Table 13.

Table 20. Thematic accuracy assessment Maputo Province land-cover data at class level[18]

		Field sample data (ground truth)																			
	Land-cover category (III)	A11			A12												A24			B28	
	Land-cover class	1FCR	1FCI	1CXF	2FE	2FEG	2FD	2WE	2WD	2WDC	2TD	2SD	2GCT	2GCS	2GOS	2FXC	4SET	4HVT	4HVP	8WB	Total samples
Land-cover interpretation	1FCR	9							2												11
	1FCI		4																		4
	1CXF			2																	2
	2FE				7																7
	2FEG					4															4
	2FD				2		7														9
	2WE							2													2
	2WD				1		1		10												12
	2WDC									12				1							13
	2TD								1		3										4
	2SD	1							1			8			1						11
	2GCT								3			1	11								15
	2GCS											1		14							15
	2GOS														2						2
	2FXC															4					4
	4SET																1				1
	4HVT							1										2			3
	4HVP																		1		1
	8WB																			1	1
Total samples		10	4	2	10	4	8	3	17	12	3	10	11	15	3	4	1	2	1	1	121

Overall thematic accuracy = 86.0% (sum of the diagonal divided by total number of samples) and KHAT statistic = 0.85.

[18] See for the codes used Table 13.

Table 21. Producer's and User's accuracies of the Maputo Province land-cover data

Land-cover domains and groups		User's accuracy (%)	Producer's accuracy (%)
1FC	Rainfed crops	86.7	92.9
1CXF	Shifting cultivation with open to closed forested areas	100.0	100.0
2FE	(Semi-) evergreen forests	100.0	78.6
2FD	(Semi-) deciduous forests	77.8	87.5
2WE	(Semi-) evergreen woodlands (open forests)	100.0	66.7
2WD	(Semi-) deciduous woodlands (open forests)	88.0	75.9
2TE+2TD	Thickets (evergreen and (semi-) deciduous)	75.0	100.0
2SE+2SD	Shrublands (evergreen and (semi-) deciduous)	72.7	80.0
2GL	Grasslands	84.4	93.1
2FXC	Open to closed forested areas with shifting cultivation	100.0	100.0
4SE	(Semi-) evergreen shrublands, temporarily flooded	100.0	100.0
4HV	Herbaceous vegetation, temporarily flooded	75.0	100.0
8WB	Water bodies	100.0	100.0

7.2.2 At National level

At National level the thematic accuracy assessment is executed at the level of aggregation indicated in Table 14. A total of 338 observations could be used for the confusion matrix. The confusion between various (semi-) natural vegetation types (A12) with (Semi-) deciduous forest types is obvious from the matrix. The nominal scale of 1:1,000,000 makes the distinction between the different vegetation types more difficult while at the same time the amount of differences interpreted are related to a single land-cover type.

Table 22 provides an overview of the overall thematic accuracy at aggregated data level for Maputo Province, i.e. the aggregation of classes according to the names of the land-cover domains and groups shown in bold in Table 14. The mixed classes (codes 1CXF and 2FXC) composed of shifting cultivation with (semi-) natural vegetation, or vice versa, have not been grouped with other classes. The overall thematic accuracy assessment for the land-cover data at National level results in 85.0%, thereby fulfilling the TOR requirement.

The KHAT statistic for the overall thematic accuracy assessment for Mozambique is 0.83, meaning that chance agreement is limited, as it should be.

The Users' and Producers' Accuracies are shown in Table 23. The values show that (Semi-) evergreen woodlands, Shrublands and Bare areas should be handled with care from the Users' Accuracy point of view, whereas (Semi-) deciduous woodlands, Grasslands, Forested areas with shifting cultivation should be handled with care from the Producers' Accuracy point of view. Aquatic or regularly flooded shrublands have a low Producers' Accuracy.

Table 22. Thematic accuracy assessment for Mozambique National level at aggregated data[19]

	Validation sample area ("ground truth")																		Total samples
Land-cover category (III)	A11			A12								A24				B15	B16	B28	
Land-cover domain (IV) / Mixed class	1TC	1FC	1CXF	2FE	2FD	2WE	2WD	2TK	2SL	2GL	2FXC	4FF	4WF	4SF	4HF				
Land-cover interpretation																			
1TC	11																		0
1FC		20	4																4
1CXF			17								4								21
2FE				22	1		1				1								25
2FD			1		76		8				3								88
2WE					1	11	1			3									16
2WD							47			5									52
2TK							2	9											11
2SL							5		16						1				22
2GL					6		3		3	12									24
2FXC									1		20								21
4FF												16							16
4WF													6						6
4SF														1					1
4HF														1	19				20
B15																5			5
B16					2												3		5
B28																		5	5
Total samples	0	0	18	22	86	11	67	9	20	20	28	16	6	2	20	5	3	5	338

Overall thematic accuracy = 85.0% (sum of the diagonal divided by total number of samples) and KHAT statistic = 0.83.

[19] See for the codes used Table 14.

Table 23. Producer's and User's accuracies of the Mozambique National level land-cover data

LCCS land-cover categories, domains and groups			User's Accuracy (%)	Producer's accuracy (%)
A11	1TC	Tree crops	100.0	100.0
	1FC	Field crops	83.3	100.0
	1CXF	Shifting cultivation with forested areas	81.0	77.3
A12	2FE	(Semi-) evergreen forests	88.0	100.0
	2FD	(Semi-) deciduous forests	86.4	88.4
	2WE	(Semi-) evergreen woodlands (open forests)	68.8	100.0
	2WD	(Semi-) deciduous woodlands (open forests)	90.4	70.1
	2TK	Thickets (evergreen and (semi-) deciduous)	81.8	100.0
	2SL	Shrublands (evergreen and (semi-) deciduous)	72.7	80.0
	2GL	Grasslands	50.0	60.0
	2FXC	Forested areas with shifting cultivation	95.5	71.4
A24	4FF	Aquatic or regularly flooded forests	100.0	100.0
	4WF	Aquatic or regularly flooded woodlands	100.0	100.0
	4SF	Aquatic or regularly flooded shrublands	100.0	50.0
	4HF	Aquatic or regularly flooded herbaceous vegetation	95.0	95.0
B15		Artificial surfaces and associated areas	100.0	100.0
B16		Bare areas	60.0	100.0
B28		Water bodies	100.0	100.0

8 APPLICATIONS

8.1 From nominal scale 1:250,000 to 1:1,000,000

As the land-cover interpretation of Manica and Maputo Provinces was executed at the nominal scale of 1:250,000, it seemed illogic to execute a new interpretation for these two Provinces at National level though the land-cover interpretation at Province level has a series of characteristics that are quite different from the National level:

- The minimum mapping unit is 100 Ha at Province level and 1600 Ha at National level (but 900 Ha for polygons with a Forest Type class or single class);
- The detail in land-cover class description decreases (see Chapter 4);
- At Province level up to two classes can be distinguished in a delineated polygon, whereas at National level up to three classes can be distinguished with different percentage ranges;
- The scale at which the polygons are drawn is different and consequently the level of detail of their boundaries.

All these aspects should be considered when an attempt at "conversion" of land-cover data from Province to National level is made. Relationships between land-cover classes are quickly established as the legend is hierarchical in nature and classes can be easily converted to those used at National level.

The number of polygons in Manica Province with an area of less than 900 Ha is 1155, with an area between 900-1600 Ha there are 286 polygons, on a total number of 2070. The number of polygons in Maputo Province with an area of less than 900 Ha is 828, with an area between 900-1600 Ha there are 181 polygons, on a total number of 1310. All these small polygons must be aggregated so that no polygon in the National level land-cover data set will fall under the established minimum mapping unit threshold. Such small polygons must therefore be aggregated with adjacent polygons.

Because of the large number of small polygons, a method for a semi-automatic "conversion" from Province to National level was defined. First, land-cover codes have been translated from the Province to the National level legend. In doing so, some polygons adjacent to polygons having similar codes were dissolved. Second, for all remaining polygons with an area smaller then the minimum mapping unit, four levels of similarity have been established between them and the neighbouring polygons. In the first step, small polygons have been dissolved with an adjacent polygon having the same primary land-cover code (if existent). In the second step, small polygons have been dissolved with an adjacent polygon having the second land-cover code equal to their principal land-cover code (if existent). In the third step, small polygons have been dissolved with an adjacent polygon having the principal land-cover code equal to their secondary land-cover code (if existent). In the fourth step, small polygons have been dissolved with an adjacent polygon having the same second land-cover code (if existent). Finally, the remaining small polygons have been dissolved with smaller adjacent polygons, i.e. the smaller adjacent polygon is a criterion followed also in the four steps, to preserve as much as possible the information contained in the small polygons. Once the minimum mapping unit threshold was respected, the three main land-cover codes were associated to the new polygons. They have been calculated using a database linked to both the original polygons at Province level (with the area of each class) and the new polygons at National level, summarizing the area for each code. All these steps have been performed with the support of macros and SQL queries in order to get consistent results in a limited amount of time.

The difference in accuracy with which the polygon boundaries were delineated remains as no modifications were made to smoothen any polygon boundaries. The difference in detail has repercussions for any cartographic representation at a nominal scale of 1:1,000,000 but the advantage is that a higher level of information is preserved for analysis.

8.2 Evaluation of percentage forest in mixed classes

The presence of mixed classes in the legend (e.g., shifting cultivation) and the attribution of two possible classes (principal and secondary) to polygons at Province level, make it impossible in some cases to give an estimation of the area effectively covered by (Semi-) natural vegetation. To overcome this issue, various approaches based on a pixel-by-pixel analysis were tested. This is mainly interesting for evaluation of the percentage of forested area in zones with shifting cultivation since this information permits spatio-temporal comparisons and allows quantification of deforestation rates. Two main methods are described that were tested in order to answer the question posed by UIF if it is possible to quantify forested areas in zones where both forest types and cultivated fields occur.

The two methods tested used a single LANDSAT scene (e.g., 168/73) from Manica Province:

1. Normalized Difference Vegetation Index (NDVI) that is an index computed using LANDSAT bands 4 and 3 and is a measure of vegetative cover (see also paragraph 3.8.3); and
2. Unsupervised Classification, that is the clustering of pixels by their numerical spectral characteristics without supervision, or support, from the human brain.

NDVI has the advantage that it has a "physical meaning", i.e. a measure of vegetative biomass that can be analysed in order to find a specific threshold that separates forest from the other land-cover classes. This kind of approach can be useful in specific land-cover polygons where a strong contrast between covers exists. This happens in shifting cultivation areas when it is necessary to separate forested areas from agricultural field crops. It is *not* very suitable for distinction of (semi-) natural vegetation (e.g., forests and thickets). A threshold can be set to identify different classes. Once such a threshold value is found on an image, it can be re-used on other similar images (with some correction using general spectral statistical analysis), but it is strongly season dependent. This means that it is compulsory to use images of a season where the reflectance response of vegetation is high. The NDVI index was calculated for the whole Province and a threshold was set on the basis of 40 points interpreted visually. For this pilot study only one threshold was set (i.e. forest/non-forest).

The Unsupervised Classification is performed automatically by the ERDAS Imagine software. The software will identify clusters with similar spectral characteristics using the information of all seven LANDSAT bands. Once these clusters are identified, no information about the type of land cover in these clusters is provided and it is up to personal interpretation to detect correspondences between these clusters and land-cover types. This methodology can often better distinguish between different classes, but must be re-interpreted for each scene to be classified. The Unsupervised Classification was computed for areas with mixed classes (masking all other polygons) using three classes: forest, non-forest and uncertain areas. This third class allows allocating pixels to none of the other two classes according to the encountered situation.

Both NDVI and Unsupervised Classification work quite well in areas with shifting cultivation, giving a quite accurate estimate of forested areas present in the polygons. However, in polygons with different types of mixed classes, NDVI is not very efficient while Unsupervised Classification still performs within acceptable limits. The biggest problem concerns areas where Miombo and Mopane are found as these Forest Type classes appear on the satellite image almost as bare areas because of their specific leaf phenology. In these cases, NDVI is completely wrong and Unsupervised Classification has a low performance. In Figure 24, Figure 25 and Figure 26 three situations are illustrated: (1) shifting cultivation with clear contrast between classes; (2) mixed classes with forest, thickets and shrubs; and (3) mixed class with Mopane. Examples of the LANDSAT image (RGB=432), NDVI analysis result and Unsupervised Classification result of the same area is provided for comparison. **A combination of (semi-) automatic methodologies might be used only with extreme caution to estimate the percentage of forested areas in mixed classes on a local basis; however, it remains compulsory to analyse different situations in order to match the models to the variability of the real world.**

Figure 24. Example of forested area with shifting cultivation with clear contrast between classes

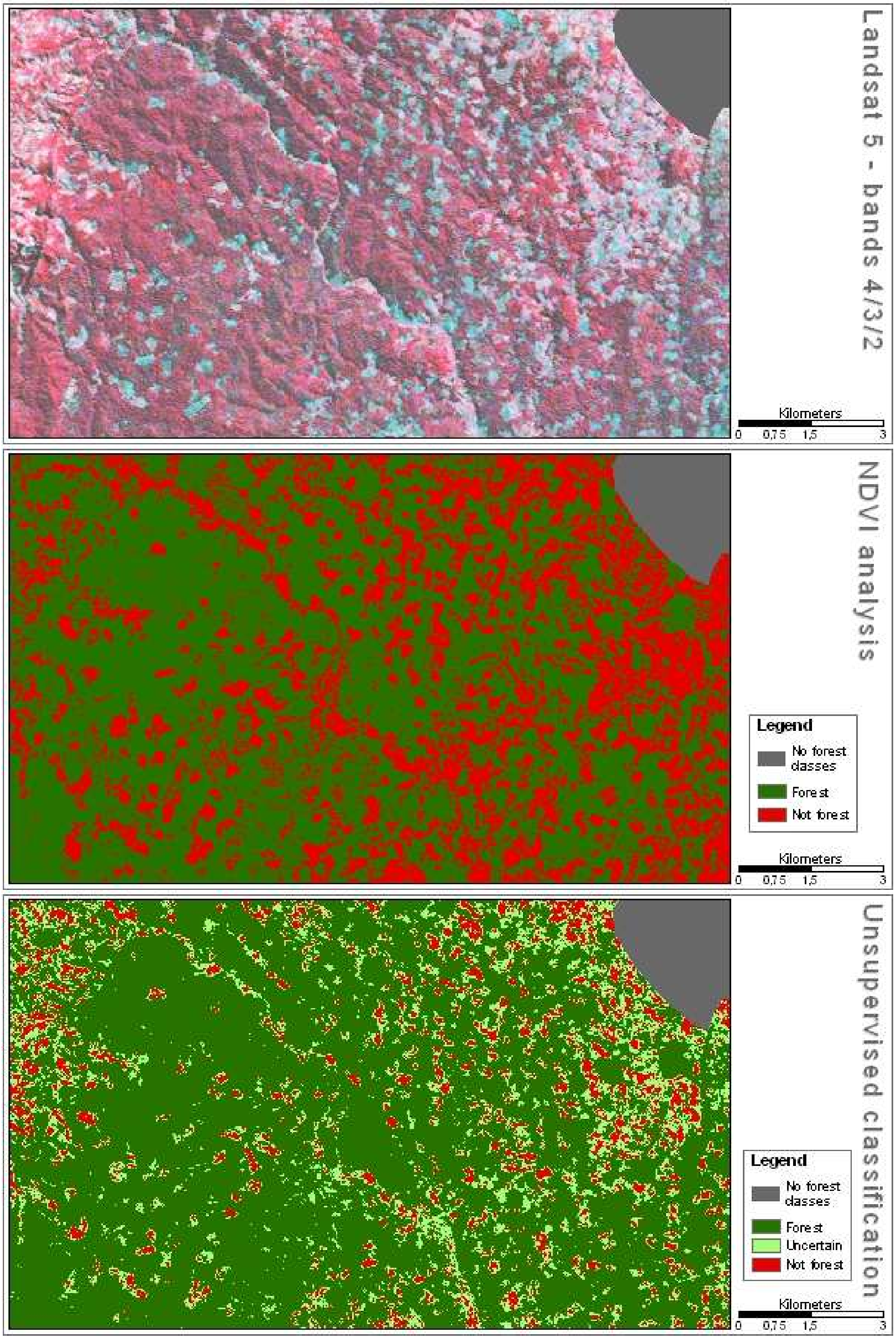


Figure 25. Example of mixed classes with forest, thickets and shrubs

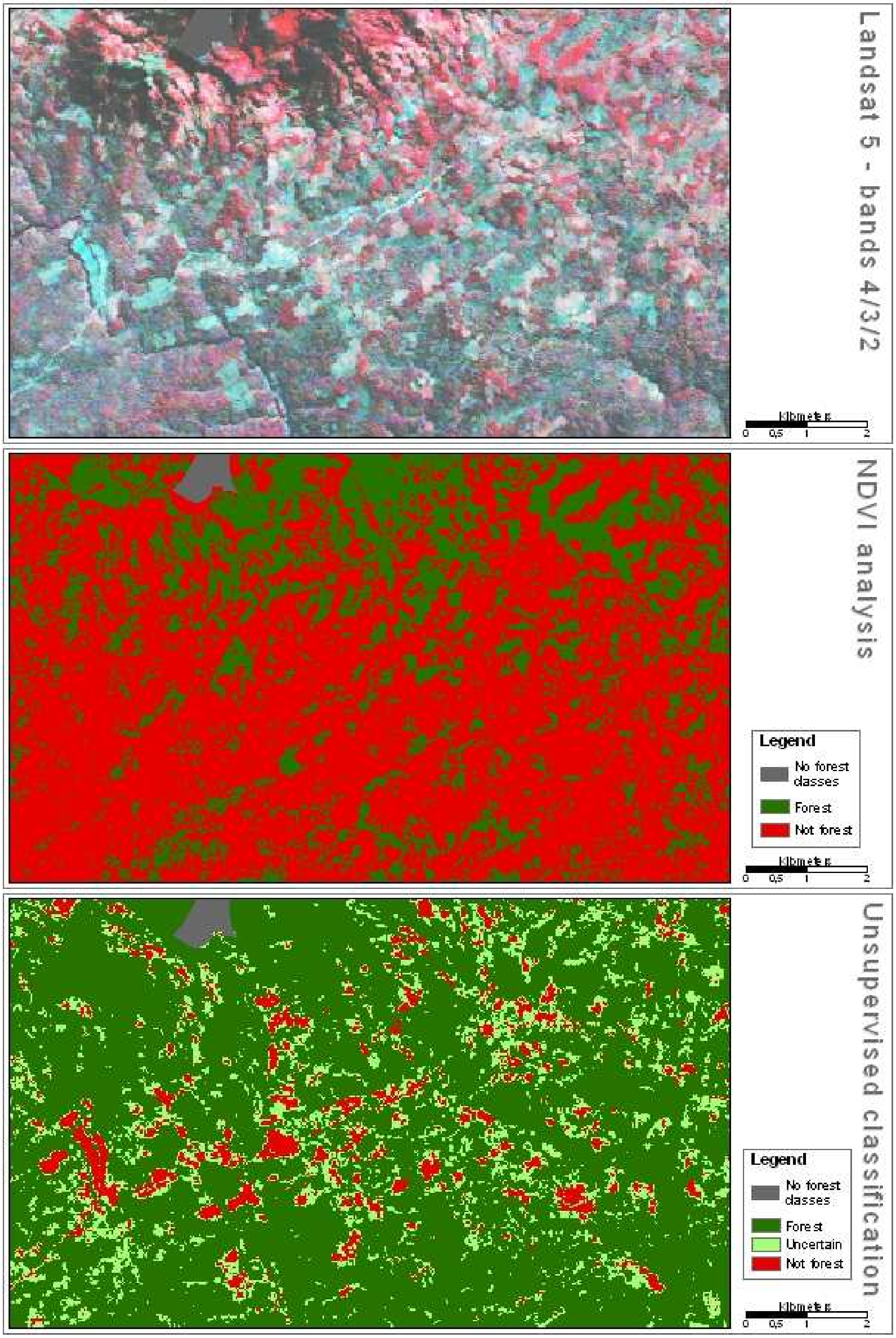
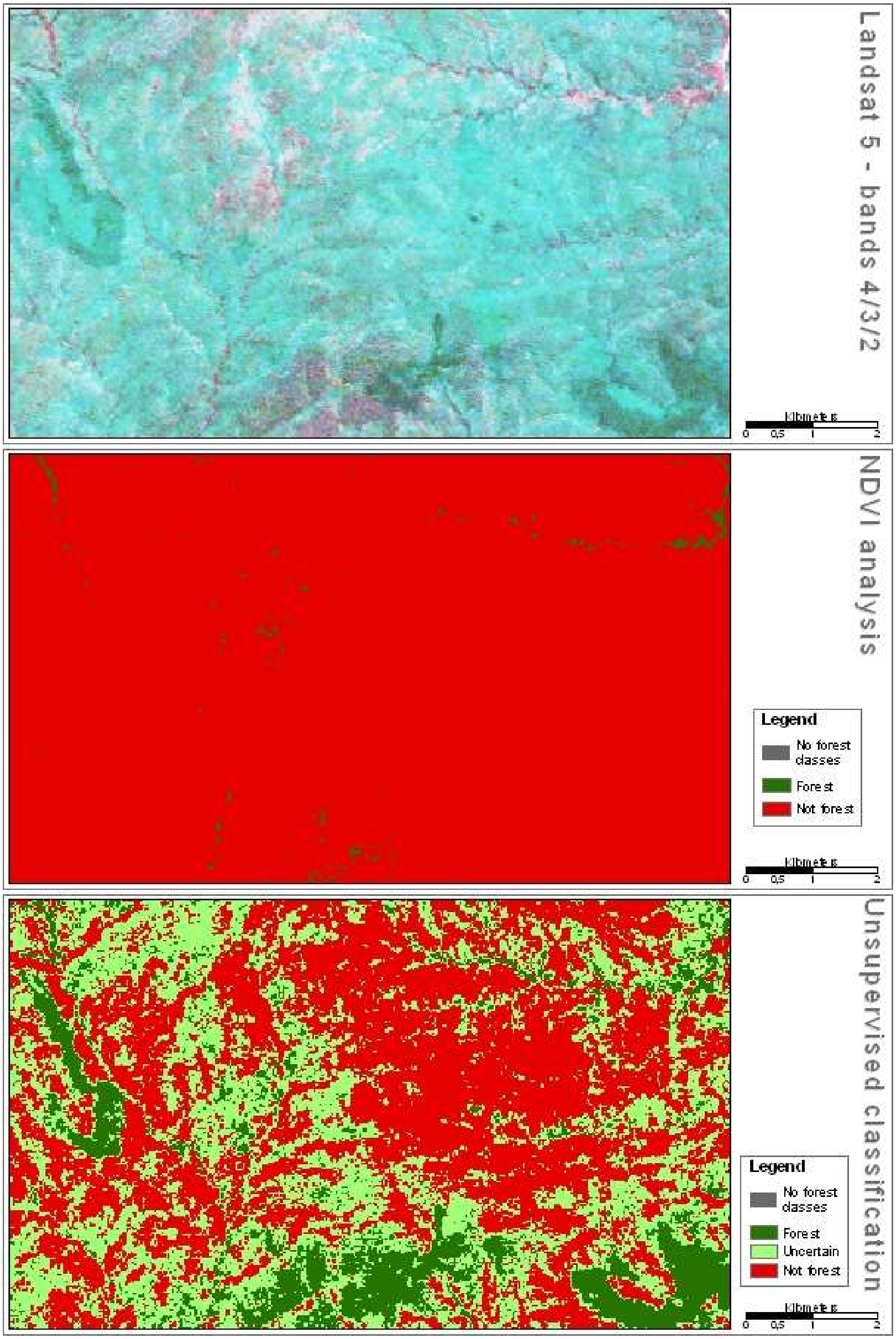


Figure 26. Example of mixed class with Mopane



8.3 Semantic land-cover data harmonisation

Nowadays emphasis is shifting from static land-cover data collection towards more dynamic environmental modelling in order to understand the past, monitor the present situation and to predict future trajectories. Thus, with the growing interest in modelling environmental change, it is important to re-examine existing data sets and attempt to harmonise them in order to make comparisons between countries and to compile time series with which to analyse change dynamics and detect trends (Jansen, 2004a and b; Jansen, 2005; Jansen et al., 2006b).

As basis of a harmonisation strategy, the FAO/UNEP LCCS-Translator Module is recommended by the Global Observation of Forest Cover-Global Observation of Land Dynamics (GOFC-GOLD) and Global Terrestrial Observation Strategy (GTOS) (see www.gofc-gold.uni-jena.de). The LCCS-Translator Module allows harmonisation of the semantic aspects of land-cover data.

The *semantic aspect* of data, and specifically of classification codes, depends not only on the type of coding system or the nomenclature applied, but it depends primarily on the definitions used because these imply the parameters used in the formation of classes. Comparison of these parameters permits determination of whether a change in coding between data sets through a semantic translator will be sufficient for harmonisation. Otherwise it is necessary to reclassify the nomenclatures into a third system, a so-called reference system that functions like a bridge between two data sets; each class in the original data set will find its more or less corresponding class in the reference system. Class descriptions contribute to the definition of boundary conditions that should be applied unequivocally and consistently when establishing correspondence between class sets in order to avoid errors in data interpretation. The level of confidence with which such class correspondence is established is highest when the same parameters have been applied; differences in the applied parameters, and thus in boundary conditions, produce lower confidence levels. Complete correspondence is not always obtainable when harmonising data, thus there is a need to establish rules in order to reach the highest level of confidence possible (Jansen et al., 2006b).

The two main land-cover data sources used as ancillary data in the interpretation process have been translated in the FAO/UNEP LCCS terminology. These data sources comprise:

- The IGN/CENACARTA/DINAGECA Joint Venture land-cover/use legend, is the list of classes used in the project "*Base topografica simplificada & uso e cobertura da terra*" (IGN/CENACARTA/DINAGECA, 1999). For each polygon of the data one can obtain from the data fields up to three land-cover classes identified in the same polygon (Table 24).
- The land-cover legend of the FAO/UNDP project MOZ/92/013 "*Methodology and results of the Forestry Vegetation Mapping at 1:250.000*" (Saket et al., 1995).

Harmonisation of the terminology of these two data sets with LCCS provides the necessary condition for any comparison of the criteria used to define the classes of each data set. It should be clear to any user that each data set is the result of a completely different approach to land-cover interpretation, albeit remote sensing has been the main tool in each of them, and applied methodology. Consequently, the statistics of these data sets should *not* be compared to one another to analyse land-cover changes over time.

Table 24. Data fields and their explanation in the IGN/CENACARTA/DINAGECA data set (1999)

Data fields	Explanation
OCUP1: 1° ocupação da area	Land-cover for first class
ESTA1: estado da cobertura da terra da 1° ocupação	Type of cover for first class
SOLO1: tipo de solo da 1° ocupação	Type of soil for first class
USOA1: eventual uso antigo (campos grandes) da 1° ocup.	Eventual previous use
VEGET1: eventual vegetação particular da 1° ocupação	Specific vegetation for first class
PCT_OCUP1: % da 1° ocupação	First class cover percentage
OCUP2: 2° ocupação da area	Land-cover for second class
ESTA2: estado da 2° cobertura da terra	Type of cover for second class
SOLO2: tipo de solo da 2° cobertura	Type of soil for second class
USOA2: uso antigo da 2° ocupação	Eventual previous use (2nd class)
VEGET2: vegetação particular da 2° ocupação	Specific vegetation for second class
PCT_OCUP2: % da 2° ocupação	Second class cover percentage
OCUP3: 3° ocupação da area	Land-cover for third class
ESTA3: estado da 3° cobertura da terra	Type of cover for third class
SOLO3: tipo de solo da 3° ocupação	Type of soil for third class
USOA3: uso antigo da 3° ocupação	Eventual previous use (3rd class)
VEGET3: vegetação particular da 3° ocupação	Specific vegetation for third class
PCT_OCUP3: % da 3° ocupação	Third class cover percentage
CAMPO: tamanho dos campos do uso da terra	Field crop dimension
CAJU: densidade dos cajueiros no uso da terra	Density of cashew trees
CANA: presença de cultura de cana de açúcar no uso da terra	Presence of sugar cane
COCO: presença de cultura de coqueiros no uso da terra	Presence of coconut trees
CHA: presença de cultura de chá no uso da terra	Presence of tea crops

The land-cover/use classes contained in the OCUP1-2-3 fields can be summarised as shown in Table 25. The use of the data from this data set was restricted to the first set of classes, specifically those contained in the fields (OCUP1, OCUP2, OCUP3) for day by day interpretation use, while some information from other fields has been included in the translation into FAO/UNEP LCCS shown below (Table 26), in the following order of fields OCUP1/VEGET1/CAJU/CANA/COCO/CHA and when the fields CAJU, CANA, COCO and CHA were not present the translation is limited to the fields OCUP1/VEGET1.

The provided LCCS Codes can be imported in the LCCS-Translator Module and the software will automatically provide the LCCS specific standard codes and class names.

Table 25. The IGN/CENACARTA/DINAGECA land-cover/use classes

IGN/CENACARTA/DINAGECA Joint Venture land-cover/use classes (1999) Original land-cover/use legend	
Uso da terra cultivado	
1.	cultivado sequeiro
2.	cultivado regadio
Uso da terra não cultivado	
11.	plantações
12.	zona verde organizada
13.	área habitacional urbanizada
14.	área habitacional semiurbanizada
15.	área habitacional não urbanizada
16.	zona de produção e transporte
17.	salinas
Copertura da terra com limitação edáfica	
101.	solo sem vegetação
102.	pradaria inundável
103.	pradaria inundáda
104.	mangal (localmente degradado)
105.	pradaria degradada inundável
Copertura da terra sem limitação edáfica	
201.	pradaria
202.	arbustos (0.5m<altura<3m)
203.	matagal mèdio (3m<altura<7m)
204.	matagal lato (altura>7m)
205.	matagal aberto (3m<altura<7m)
206.	pradaria arborizada (cc% 10-40)
207.	pradaria com árvores anãs emergentes (cc% 10-40)
209.	floresta de baixa altitude medianamente fechada (cc% 10-40)
210.	floresta de baixa altitude fechada (cc% >70)
211.	floresta sempervirente
Areas de agua	
301.	oceano
302.	albufeira
303.	lago, lagoa natural
304.	rio entre margens
Território fora dos distritos prioritarios	
401.	pais fronteiriço
402.	território nacional fora das áreas tratadas

Table 26. Correspondence between the IGN/CENACARTA/DINAGECA land-cover/use legend (1999) and FAO/UNEP LCCS version 2

IGN/CENACARTA/DINAGECA Joint Venture land-cover/use legend		FAO/UNEP Land Cover Classification System
Code	Class name	LCCS code[20]
1/0	Cultivado Sequeiro (Rainfed Crops)	11498 // 11494
2/0	Cultivado Regadio (Irrigated Crops)	11500 // 11495
11/0	Plantações (Tree Plantations)	10001-W7
1/0/0/0/1/0	Cultivado sequeiro com coqueiros	11371-12602-S0607 // 11356-12602-S0607
1/0/3/0/0/0	Cultivado sequeiro com caju	11371-12602-S0605 // 11356-12602-S0605
1/0/3/0/1/0	Cultivado sequeiro com coquiero e caju	11371-12651-S0605S0607 // 11356-12651-S0605S0607
1/0/4/0/0/0	Cultivado sequeiro / Caju	11371-12614 / 11490-S0605
1/1	Cultivado sequeiro com bambù	11498 // 11494 // 21639-ZT1
101/0	Solo sem vegetação	0011
102/0	Pradaria inundável	42348
103/0	Pradaria inundada	42347
104/0	Mangal (localmente degradado)	40499-4891-L11L5R2Zt04 // 40604-4891-L11L5R2Zt04
105/0	Pradaria degradada inundável	40065 // 40083
13/0	Área habitacional urbanizada	5003-13 // 5003-14
14/0	Área habitacional semiurbanizada	5003-15
15/0	Área habitacional não urbanizada	5003-17
16/0	Zona de produção e trasporte	5003-8 // 5002
17/0	Salinas	5004-2-L11L5
201/0	Pradaria	21454
201/0/0/0/1/0	Pradaria com coqueiros	21454 // 10167-S0607
202/0	Arbustos	21450
202/0/0/0/1/0	Arbustos com coqueiros	21450 // 10167-S0607
202/3	Arbustos com mopane	21450 // 20132-ZT03 // 20132-15048-ZT03
203/0	Matagal medio	20002
203/1	Matagal com bambù	20002 // 21639-ZT1
204/0	Matagal alto	21446-13233
205/0	Matagal aberto	20010
205/0/0/0/1/0	Matagal com coqueiros	20010 // 10167-S0607
205/0/3/0/0/0	Matagal aberto com caju	20010 // 10167-S0605
205/3	Mopane baixo	20132-13342-Zt03
207/0	Pradaria com árvores anãs emergentes	21640 // 20014-4277
206/0	Pradaria arborizada	21640 // 20014-3012
206/3	Pradaria arborizada com Mopane	21640-Zt03 // 20132-3012-Zt03
206/4	Pradaria arborizada com Embondeiros	21640-Zt07 // 20014-3012 // 20014-3012-Zt07
210/0	Floresta de baixa altitude fechada	20006
211/0	Floresta sempervirente	21496-15048
209/0	Floresta de baixa altitude medianamente fechada	20014
209/3	Floresta de baixa altitude medianamente fechada (Mopane)	20802-15048-Zt03
303/0	Lagos, albufeiras	8002-5
304/0	Rio entre margens	8002-1

[20] See the FAO/UNEP LCCS version 2 software and manual, free of charge available and provided to UIF, for standard class names.

Table 27. Correspondence between the Saket land-cover classes and FAO/UNEP LCCS

Saket et al. land-cover legend Code	 Class name	FAO/UNEP Land Cover Classification System LCCS code
MF	*Montane forests*	
MF1	Closed montane forest	20089-15048-P10 // 20089-15048-P11
MF2	Medium closed montane forest	20131-3001-P10 // 20131-3001-P11
MF3	Open montane forest	20131-6011-P10 // 20131-6011-P11
LF	*Low-land forests*	
LF1	Closed low-land forest	20014-1
LF2	Medium low-land forest	20014-3012
LF3	Open low-land forest	20006
T	Thickets	21450-13395
S	Shrub	21450-13476
WG	Wooded grassland	21640 // 21643
M	*Mangroves*	
M1	Closed mangroves	41640-67278-L11L5R2
M2	Sparse mangroves	40604-463-L11L5R2
G	Non-woody vegetation - Grassland	21454 // 11502 // 42349
PF	Man-made forests	11490-S10W7
A	*Agriculture and impact of agriculture on natural vegetation*	
A1	Permanent cropping	11492-S6 // 10026-S0915
A2	Shifting cultivation - Long fallow	11502 / 0003
A3	Shifting cultivation - Short fallow	0003 / 11502
D	Dunes	6009-L11L5
B	Barren land	0011
O	Urban and other areas	5001
W	Water bodies	7001 // 8001

8.4 Land-cover change

8.4.1 Introduction

Land-cover change knowledge has become increasingly important in order to analyse environmental processes and problems. Processes such as deforestation, encroachment of agriculture in forested areas, loss of prime agricultural land and urbanisation, etc., must be understood if living conditions and standards are to be improved or maintained at current levels. Nowadays emphasis is shifting from static land-cover data collection towards more dynamic environmental modelling in order to understand the past, monitor the present situation and to predict future trajectories (Jansen et al., 2003 and 2006a; Jansen and Ndiaye, 2006).

The importance of land-cover change is stated various times in the TOR as a key objective of "*the purpose of the Integrated Assessment of Mozambican Forests* [Project] *is to assess and monitor the extent, state and* changes *of Mozambican forests and wooded lands in a timely and accurate manner*" and in more detail in Chapter 3 of the TOR as "*explain the kind, type and degree of changes which have occurred in land cover and forest ecosystems in different areas, their foreseen consequences for the human and wildlife conditions, and the measures to be taken to mitigate negative impact of current forest use and improve the living conditions of the local population*" and to "*improve DNFFB/UIF technical and operational* [skills] *to carry out and supervise* […] *monitoring activities*".

The present policies of Mozambique that emphasize the market-oriented economy, the role of private sector and decentralisation are reflected in the forest policies and legislation. This offers challenging opportunities for the development of sustainable management and utilisation of forest resources and underlines the importance of land-cover *change*. In the turmoil of a changing economy, the spatial and temporal dynamics of land-cover are continuously evolving. It is, therefore, important for the Mozambican Government to have accurate and timely information for natural resources management, land-use planning and land-use policy development, as a prerequisite for monitoring and modelling land-use and environmental change and as a basis for land-use statistics. Land-cover change, as one of the main driving forces of (global) environmental change, is central to sustainable development (Meyer and Turner, 1994; Walker and Steffen, 1997; Walker, 1998; Lambin et al., 2000). The quality and quantity of resources at various points in time, the rates by which they have changed, the overall distribution of the land-cover types, etc., should be known to develop strategies to plan a sustainable use of natural resources while preserving biological richness and diversity (Jansen et al., 2006a).

As stated in paragraph 8.3, several land-cover data sets exist in Mozambique but these cannot be compared to one another. Therefore, the key objective of the Manica land-cover change study presented in this report is an inventory of the land-cover changes at the nominal scale of 1:250,000 in Manica in the period 1990-2004, their location, extent and distribution and an understanding of the change dynamics processes in order to provide Government with spatially explicit data and information for a sustainable management of natural resources. This refers to the TOR paragraph 5.1 expected output of "*a general assessment on the current extent, status and kinds of forest ecosystems and land cover/use and relevant changes occurred in different Provinces of the country in the course of the last ten years*". The land-cover change of Manica Province was carried out in addition to the activities specified in the Technical Proposal because it was deemed important to provide an example at Province level of the possible uses of the land-cover data sets produced. The choice of the two years is related to the political and socio-economic developments that took place (e.g., the peace agreement of 1992, the series of macroeconomic reforms combined with political stability since the multi-party elections in 1994), as well as data availability.

The applied change methodology at 1:250,000 nominal scale should *not* be repeated in an identical way to the 1:1,000,000 nominal scale as that data set comprises a higher generalisation level.

Land-cover change has to recognise that changes come in two types: (1) *conversion* from one land-cover category to another (e.g., from cultivated to built-up area); and (2) *modification* within one category (e.g., from forest to woodland, from thicket to shrubland, etc.). These two types of change have implications for the methodology used to describe and classify land cover (Jansen and Di Gregorio, 2002). Conversion implies an evident change, whereas modifications are much less apparent. The latter requires a greater level of detail to be accommodated. With a system based upon class names the latter type of change cannot be captured unless the system contains an ample set of classes.

A similar approach to land-cover change has previously been applied in Albania (Jansen et al., 2003a, 2003b and 2006a), Niger (Mahamadou, 2001; Jansen et al., 2003) and Senegal (Jansen and Ndiaye, 2006). These applications comprise land-cover changes in both rural and urban areas and at nominal scales ranging between 1:100,000 and 1:250,000.

8.4.2 Applied methodology

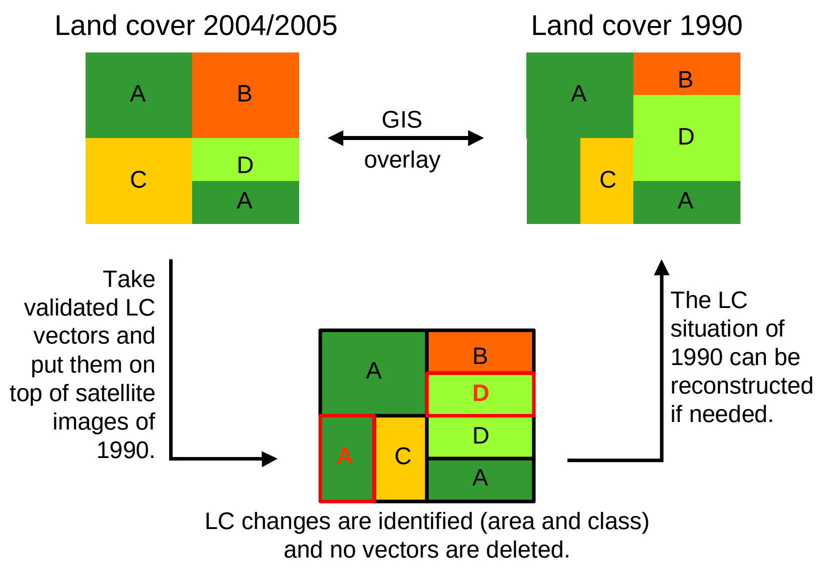
Digital LANDSAT 5 TM was used to produce the baseline interpretation of 2004; the interpretation for 1990 identifies the changes in boundaries and/or class labels respective to 2004. A multi-temporal sensing approach was taken by a simultaneous comparison between images collected at the two dates.

At the level of recording the changes a specific so-called *object-oriented approach* has been applied at the level of the geodatabase. If an existing polygon did change there were three possibilities (Figure 27):

- The shape of the polygon changed in which case the boundaries were adjusted without deleting any existing boundary! In this way a new polygon was created in the database and recorded as changed. This new polygon was given the appropriate class label.
- The shape of the polygon remained unaltered but the class label changed. In this case the new class label was recorded as change.
- Both the shape and the class label of the polygon changed and thus the combined approach of the above described was necessary.

Thus, the land-cover change data set contains *not* the situation of 1990 but the changes respective to 2004. This approach allows the user to reconstruct the land-cover situation in 1990.

Figure 27. The land-cover change geodatabase approach (after Carrai and Jansen, modified)



Due to the working scale and the limited number of images to be used, changes in land-cover percentage were not taken into account. The minimum mapping unit threshold of 100 Ha was generally maintained; polygons with a size of at least 50 Ha were tolerated only in case of being adjacent to polygons having the same land-cover. For elongated features such as rivers and riverine vegetation (e.g., Gallery forest) the minimum polygon width of 200m was preserved.

A land-cover change matrix was produced to analyse the changes. Furthermore, to have a general overview of land-cover change and a better insight into the land-cover change processes, classes belonging to a similar land-cover type were grouped into the LCCS domains, as explained in Table 28. As a final step, an assessment of the distribution and type of land-cover changes within the Districts of Manica Province was executed described in the following paragraph.

8.4.3 Analysis of change results

In Manica Province, a total of 5,441,131Ha or 87.4% did not undergo any land-cover change in the period 1990-2004. This means that 12.6% of the territory did change. Regrouping the land-cover classes helps in better understanding the type of changes that occurred and the processes behind them. At land-cover category and domain levels, the following aspects can be highlighted using the analysis of the change matrix (Table 29):

1. The absolute value of loss/gain of a certain land-cover type;
2. The net percentage of loss/gain; and
3. The weight, inside the change percentages, of each domain.

From Table 29, it is clear that modifications and conversions occurred in particular in those domains belonging to the land-cover categories of Cultivated and managed terrestrial areas (A11), (Semi-) natural terrestrial vegetation (A12) and -to a lesser extent- (Semi-) natural aquatic or regularly flooded areas (A24). From the total change, 51.5% concerned modifications and 48.2% concerned conversions.

Furthermore, one can observe that *modifications* occurred within:

- (Semi-) natural terrestrial vegetation (A12) land-cover category involving 399,746 Ha or 50.8% of total change;
- Cultivated and managed terrestrial areas (A11) land-cover category involving 5,055 Ha or 0.6% of total change; and
- (Semi-) natural aquatic or regularly flooded areas (A24) land-cover category involving 376 Ha or 0.0% of total change.

Conversions occurred where:

- (Semi-) natural terrestrial vegetation became Cultivated and managed terrestrial areas, involving 299,831 Ha or 38.1% of total change; and
- Cultivated and managed terrestrial areas became (Semi-) natural terrestrial vegetation, involving 79,245 Ha or 10.1% of total change.

From this analysis at aggregated data level, it becomes clear that the land-cover types subject to change belong mainly to (Semi-) natural terrestrial vegetation (A12) and Cultivated and managed terrestrial areas (A11), with the first land-cover category more prone to change. Thus, the interest of the land-cover change study has been particularly focused on land-cover changes in the (Semi-) natural terrestrial vegetation to which the major part of the distinguished Forest Types belong.

Table 28. Regrouping of the land-cover classes for the change assessment in Manica Province

Legend at Province level User name	Code	Legend at National level Domain name	Code
Tree crops	1TCF	Tree crops	TC
Forest plantation	1TCW		
Tea plantation	1SCT	Field & shrub crops	FC
Rainfed field crops	1FCR		
Irrigated field crops	1FCI		
Shifting cultivation with open to closed forested areas	1CXF	Shifting cultivation with forest	SF
Coastal dense closed woody vegetation	2DEC	Forests & closed woody vegetation	FO
Broadleaved (semi-) evergreen closed forest	2FE		
Mecrusse dense	2FEA		
Gallery forest	2FEG		
Closed broadleaved (semi-) evergreen mountainous forest	2FEM		
Broadleaved (semi-) deciduous closed forest	2FD		
Miombo dense	2FDB		
Mopane dense	2FDC		
Coastal open woody vegetation	2DEO	Woodlands & open woody vegetation	WO
Broadleaved (semi-) evergreen open forest	2WE		
Mecrusse open	2WEA		
Open broadleaved (semi-) evergreen mountainous forest	2WEM		
Broadleaved (semi-) deciduous open forest	2WD		
Miombo open	2WDB		
Mopane open	2WDC		
Broadleaved (semi-) evergreen thicket	2TE	Thickets & shrublands	TS
Broadleaved (semi-) deciduous thicket	2TD		
Broadleaved (semi-) evergreen shrubland	2SE		
Broadleaved (semi-) deciduous shrubland	2SD		
Tree savanna	2GCT	Grasslands	GR
Shrub savanna	2GCS		
Open shrub savanna	2GOS		
Closed to open forested areas with shifting cultivation	2FXC	Forested area with shifting cultivation	FS
Woodland on temporarily flooded land	4WET	Aquatic or regularly flooded woodlands	WA
Open shrubs on temporarily flooded land	4SET	Aquatic or regularly flooded shrub & herbaceous vegetation	HA
Herbaceous vegetation permanently flooded	4HVP		
Herbaceous vegetation temporarily flooded	4HVT		
Built-up areas	5BU	Built-up areas	BU
Bare rocks	6BR	Bare areas	BA
Bare soils	6BS		
Dunes	6SS		
Artificial water bodies	7WB	Water bodies	WB
Natural water bodies	8WB		

Figure 28 shows the changes between domains in percentages of total change. Thus these percentages do *not* refer to the total area of the Province. One can interpret the following from the change statistics:

- In the Forests (FO) domain a loss of 348,330 Ha (17.8%) occurred: 11.9% was modified into Forest with shifting cultivation (FS) and 3.4 % was converted into Shifting cultivation with forest (SF). The weight of the passage from FO into FS was 67.5%, while the weight of the conversion into SF was 19.0%.
- The loss of Woodlands (WO) was 82,075 Ha (4.4%): 1.1% was modified into FS and 1.6% was converted into field crop (FC). The weight of the conversion into FC was 26.5%.

- Thickets and shrublands (TS) decreased with 10.0%. Although 2.2% and 2.5% was gained from FO and WO respectively, 14.8% was converted into field crops (FC). The weight of this conversion was 86.7%.
- Forest with shifting cultivation (FS) increased with 249,810 Ha (38.1%). As explained above, forests gave the major contribution, i.e. 2.8% was converted into FC.
- Shifting cultivation with forest (SF) increased with 72,245 Ha (26.0%). The most important gains came from the FO and WO domains with 24.3% and 7.9% respectively, whereas 0.9% was converted into field crops.
- Field crops (FC) increased with 150,827 Ha (82.9%); 23.6% was formed by the contribution of grasslands (GR), 10.3% of FS and 15.0% of FO.

From the above, it seems that there is a general change of forests into closed to open forested areas with cultivation. The substantial increase in cultivated areas is especially evident by the 27,411 Ha converted into crops from forests and 18,801 Ha from forest into shifting cultivation, while part of 42,963 Ha coming from grasslands should be considered as a change in land *use* (i.e., the use as pastures) rather than a loss of natural vegetation and thus a land-*cover* change. Few domains, such as Tree crop (TC) or flooded vegetation (e.g., WA, HA) showed no substantial changes.

At the land-cover class level, a particular focus was given to the changes in forested areas in order to analyse what type of forest is more affected by change dynamics in (semi-) natural vegetation as above explained:

- Miombo dense forests (2FDB) decreased with 211,984 Ha being apparently the most affected vegetation type by human pressure. The main part was converted into Forest with shifting cultivation (2FXC) and Shifting cultivation with forest (1CXF).
- Broadleaved (semi-) deciduous closed forests (2FD) and Broadleaved (semi-) evergreen closed forests (2FE) showed a loss of 40,081 Ha and 93,610 Ha respectively, while Closed broadleaved (semi-) evergreen mountainous forest (2FEM) maintained more or less the same extent.
- Gallery forests (2FEG) had an intermediate behaviour since their change was equal to 3,352 Ha.
- Similarly to the Miombo dense forests (2FDB), Miombo open forests showed the highest decrease (50,675 Ha), whereas Broadleaved (semi-) deciduous open forests (2WD) show a decrease of “only” 20,762 Ha.
- Mopane open forests (2WDC) were reduced by 10,631 Ha, while Open broadleaved (semi-) evergreen mountainous forest (2WEM) and Broadleaved (semi-) evergreen open forest (2WE), were not subject to any particular changes.

Figure 29 and Figure 30 show the location of some areas subject to land-cover change in the period 1990-2004 in Manica Province. These figures show clearly that not all areas in the Districts shown are subject to change but some areas are more prone to change than others.

The distribution of land-cover changes in Manica Province is not homogeneous, being more important in the Eastern-Central and Southern part and marginal in the Northern part. The District of Barue was the most affected by land-cover changes (31.5% of the surface), followed by Manica (28.9%) and Mossurize (23.9%), while Macossa, Tambara and Guru remained almost unchanged. In Barue District, the most important phenomenon concerned the loss of forests. In this District 121,676 Ha were modified into Forest with shifting cultivation, and 21,507 Ha and 17,167 Ha respectively were converted into Shifting cultivation with forest and Field crops. In Manica District, although the amount of land-cover change is high (28.9%), no significant trend was detected since changes concerned almost the totality of classes. A particular land-cover change was found in Machaze District where 125,507 Ha have been converted from Shifting cultivation with forest into Forests with shifting cultivation as the result of the progressive abandonment of cotton plantations.

Table 29. Land-cover change matrix for the period 1990-2004 at domain level for Manica Province

		Land-cover domains in 2004													
LCCS category		A11			A12					A24		B15	B16	B27 & B28	Total (Ha)
LC domain		TC	FC		FO	WO	TS	GR		WA	HA	BU	BA	WB	
LC class				SF					FS						
Land-cover domains in 1990	TC	20480	2536	0	0	0	0	0	0	0	0	0	0	0	23016
	FC	0	174697	0	709	135	293	4453	1427	0	0	50	0	0	181764
	SF	0	2519	202150	4655	217	1227	2086	64043	0	0	0	0	0	276897
	FO	0	28120	72005	1575627	13042	3867	4799	255055	0	0	556	0	0	1953071
	WO	0	31058	22755	1254	1750852	1177	14705	48922	0	0	433	0	0	1871156
	TS	0	26017	1841	0	439	142909	0	1679	0	0	0	0	0	172885
	GR	0	47416	2517	1369	751	0	683782	704	0	0	0	0	0	736539
	FS	0	20228	47874	21127	20588	6039	4229	532513	1389	0	546	0	0	654533
	WA	0	0	0	0	0	0	0	0	171118	376	0	0	0	171494
	HA	0	0	0	0	0	0	0	0	0	114258	0	0	0	114258
	BU	0	0	0	0	0	0	0	0	0	0	10184	0	0	10184
	BA	0	0	0	0	0	0	0	0	0	0	0	44528	0	44528
	WB	0	0	0	0	0	0	0	0	0	0	0	0	18033	18033
Total (Ha)		20480	332591	349142	1604741	1786024	155512	714054	904343	172507	114634	11769	44528	18033	6228358

Figure 28. Modifications and conversions in the period 1990-2004 in Manica Province

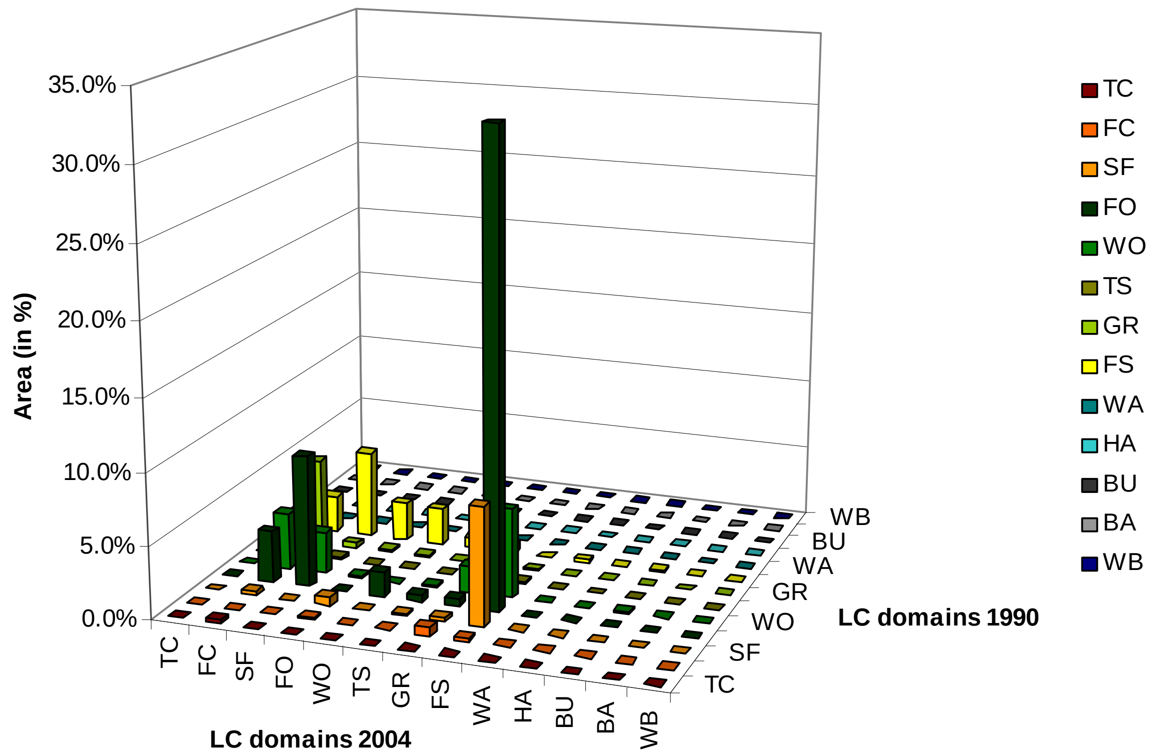


Figure 29. The location of land-cover changes 1990-2004 in the Barue District of Manica Province

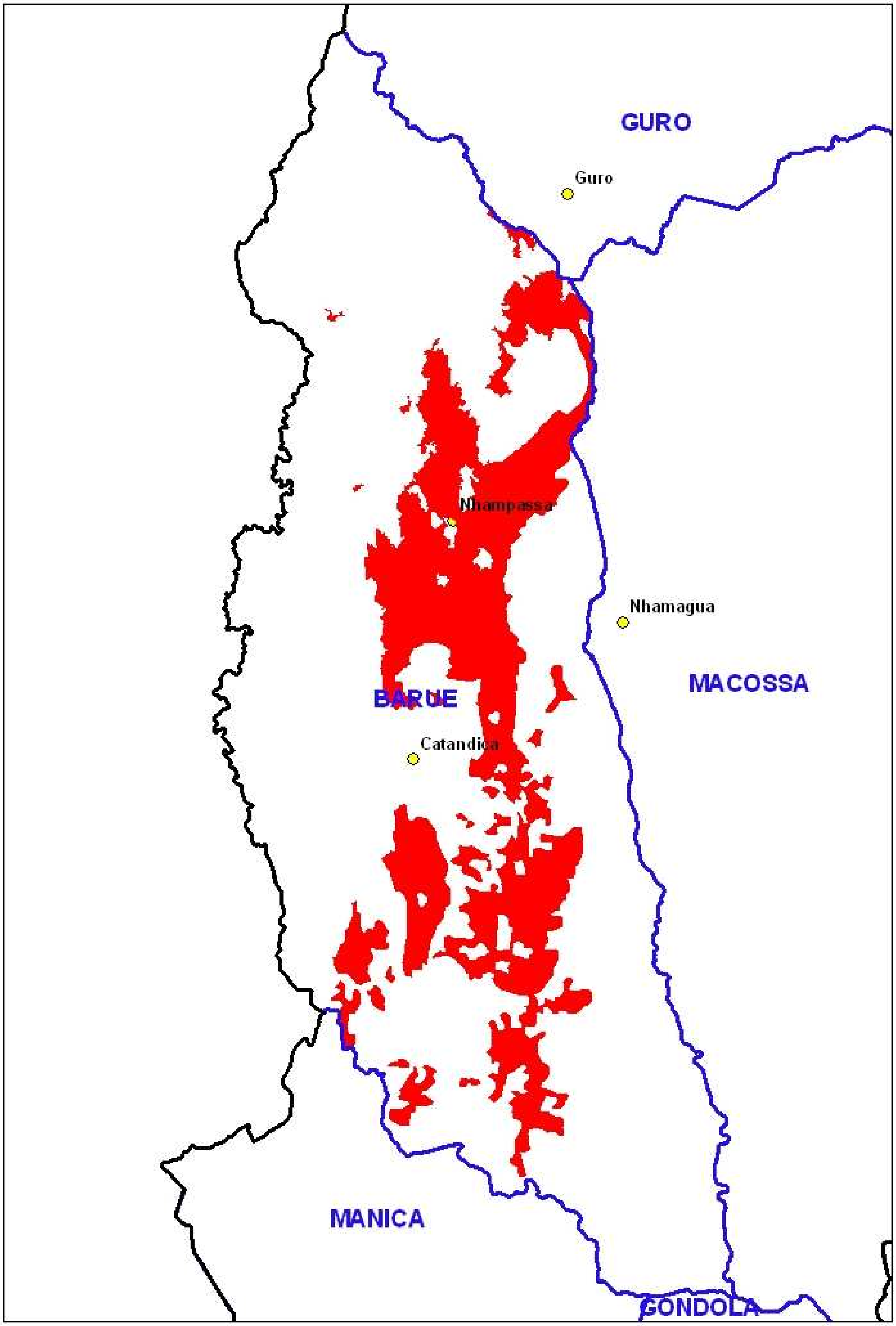
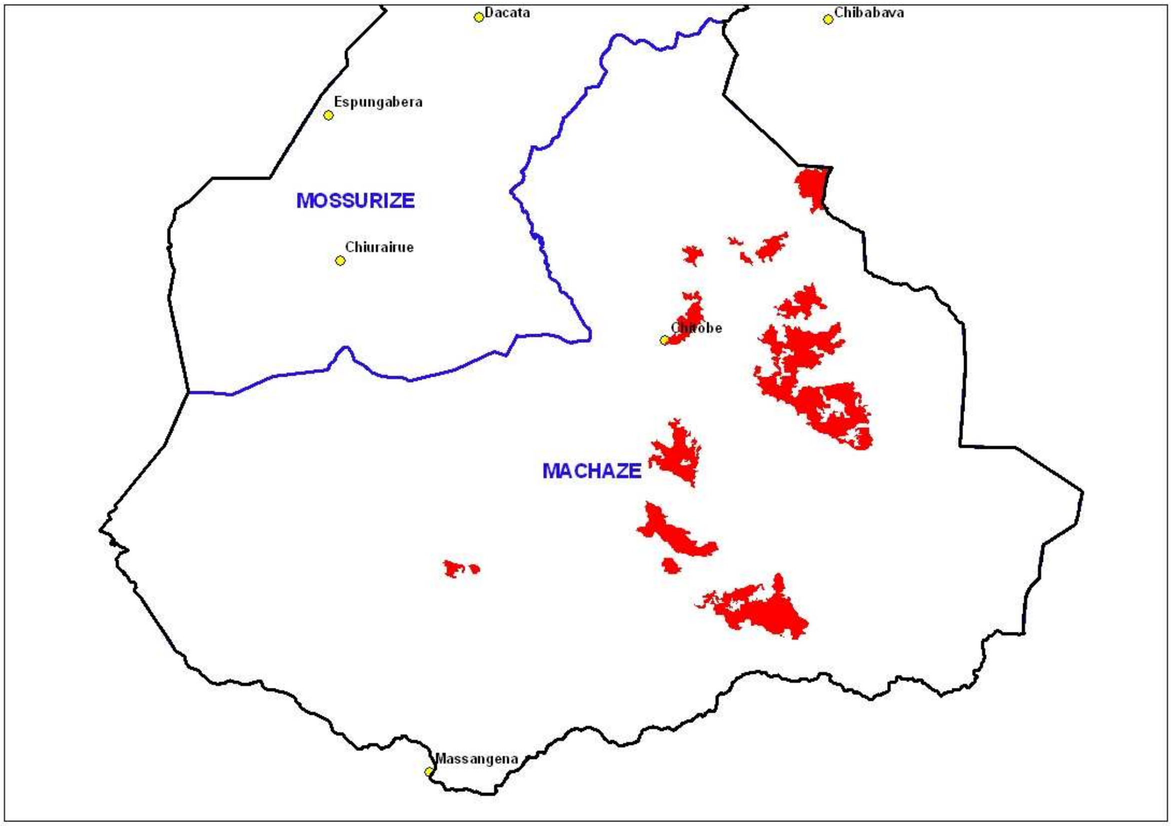


Figure 30. The location of land-cover changes 1990-2004 in the Machaze District of Manica Province



From Figure 31 it becomes clear that the areas with Forests (FO), Tree crops (TC), Thickets & shrublands (TS), Woodlands (WO) and Grasslands (GR) decrease in absolute extent, i.e. irrespective of the territory of Manica Province, with 17.8, 11.0, 10.0, 4.5 and 3.0% respectively. Thus the tree cover has been reduced in the various vegetation types but also as a crop. It also becomes clear, in a more dramatic manner than in previous tables and figures, that the areas with Field crops (FC), Forests with shifting cultivation (FS), Shifting cultivation with forests (SF) and Built-up areas increased considerably with 83.0, 38.2, 26.1 and 15.6% respectively.

The rates of land-cover change on a yearly basis in Manica Province have been calculated for the period 1990-2004 (Table 30). The annual population growth rate of Mozambique according to the World Fact Book 2000 is 1.48% (2005 estimate) and according to the Populations Division and Statistics Division of the UN Secretariat (see www.unstats.un.org) the annual population growth rate in the period 2000-2005 is given as 2.00%. The population growth rate in Mozambique is decreasing since the mid 1990s and more people tend to seek a livelihood in urban centres, consequently the rural population is decreasing. But the rates by which Field Crops (FC), Shifting cultivation with forests (SF) and Forests with shifting cultivation (FS) increase in Manica exceed the overall population growth by far. Thus, these figures should give rise to concern as subsistence agriculture continues to employ the vast majority of the country's workforce (e.g., 81% in agriculture is the 2005 estimate).

The growth rates for (semi-) natural vegetation types (FO, WO, TS and GR) are all negative indicating that in Manica Province these areas decreased and natural resources management is a concern. The rate by which Forests (FO) decrease is inversely proportional to the rate by which the Mozambican population increases (e.g., -1.41% versus 1.48%).

Figure 31. Differences in absolute spatial extent in Manica Province in the period 1990-2004

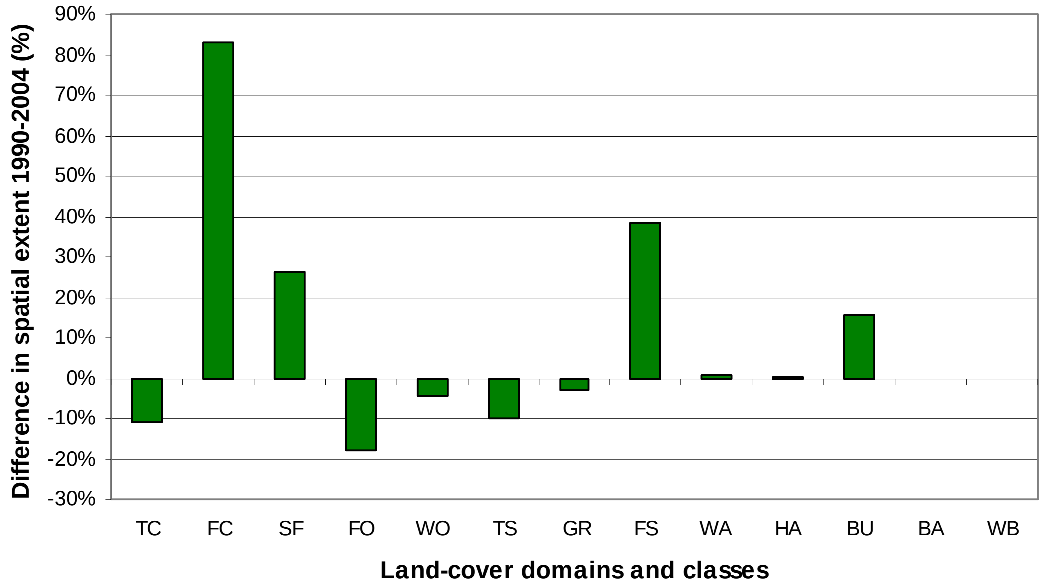


Table 30. The rates of land-cover change per year in Manica Province in the period 1990-2004

LC domain or class	Area in 2004		Area in 1990		Annual rate of change[21]
	Ha	%	Ha	%	%
TC	20480	0.33%	23016	0.37%	-0.82
FC	332591	5.34%	181764	2.92%	4.41
SF	349142	5.61%	276897	4.45%	1.66
FO	1604741	25.77%	1953071	31.36%	-1.41
WO	1786024	28.68%	1871156	30.04%	-0.36
TS	155512	2.50%	172885	2.78%	-0.75
GR	714054	11.46%	736539	11.83%	-0.22
FS	904343	14.52%	654533	10.51%	2.33
WA	172507	2.77%	171494	2.75%	0.07
HA	114634	1.84%	114258	1.83%	0.02
BU	11769	0.19%	10184	0.16%	1.07
BA	44528	0.71%	44528	0.71%	0
WB	18033	0.29%	18033	0.29%	0

[21] For the calculation of the annual rate of change in the period 1990-2004 linear growth has been assumed.

8.5 Burnt area monitoring

Fire is a vital and natural part of the functioning of numerous ecosystems. Humans have used fire for thousands of years as a land management tool. Fire is one of the natural forces that has influenced plant communities over time and as a natural process it serves an important function in maintaining the health of certain ecosystems. However, in the latter part of the twentieth century, changes in the human-fire dynamics have led to a situation where fires are now a major threat to many vegetation types and the biodiversity therein. In forests where fires occur every dry season, tree species exhibit adaptive traits such as thick bark, ability to heal fire scars, resprouting capability and seed adaptations. The ecological importance of these annual fires on forest formations is significant. Fire strongly promotes fire-tolerant species, which replace the species potentially growing in an undisturbed environment.

The aim of this application was to demonstrate the potentiality of remote sensing techniques in order to monitor burnt areas in the sense of carrying out statistics and mapping the phenomenon of recurrent occurrence of fires as especially the latter may give an indication of the frequency of human-fire dynamics are changing or not.

The critical point of the methodology is the availability of multi-temporal satellite images acquired during the “fire” season that is at the end of the dry season. The period ranges from the beginning of September up to the beginning of November, but there is a certain variability from year to year related to the variability in rainfall.

Since the Project could not acquire other LANDSAT 5 TM images for this specific activity, use of the free of charge available ASTER images has been made. The images shown in Table 31, as previously described, have been downloaded and used in this application.

Table 31. ASTER images used

Path – Row number		Position of ASTER image in the TM5 scene	Acquisition date YYYY-MM-DD	Cloud over	
167	79	Top, centre	2000-09-09	1%	T1
167	79	Top, centre	2001-09-28	0%	T2
167	79	Top, centre	2002-11-27	1%	T3

First of all, using ERDAS, a subset of the three images was created using an approximate “AOI” (area of interest), the area that is the intersection of the images T2 and T3.
For each scene, the spectral signatures (see file with .SIG extension in the geodatabase) of different stages of burnt area and of the main land-cover types were independently taken and a Maximum Likelihood (supervised) classification was carried out.

Each supervised classification result has been reclassified in two classes: i.e. Burnt area (code=1) and Burnt area (code=2) (see Table 32) that were converted into the GRID ArcInfo format. Subsequently with ArcGIS a combination of the three grids has been produced. The GRID obtained contains for each pixel three attributes derived from the original grids: “Burnt_area_T1”, “Burnt_area_T2”, “Burnt_area_T3”.

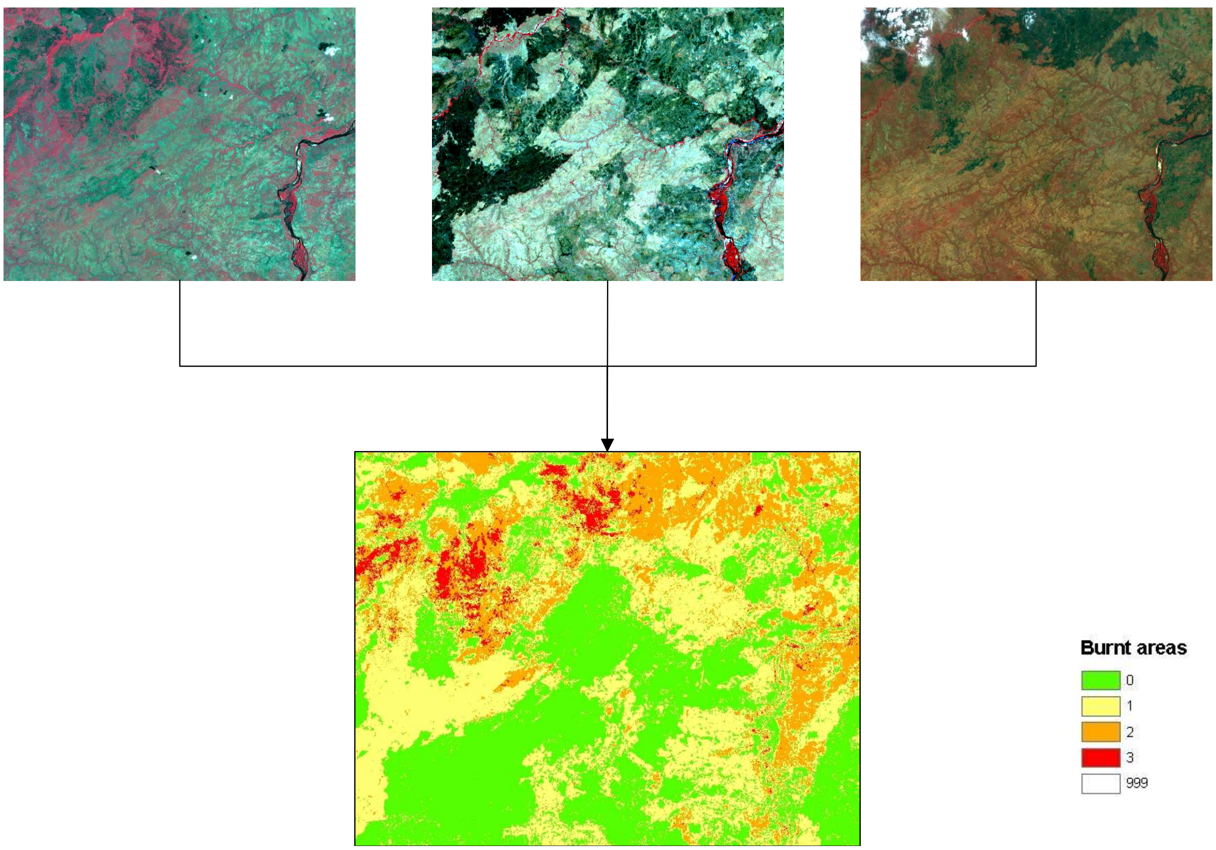
It is very easy to query the table to identify the location and to produce statistics, especially statistics of the type “how many times” and “when the different parts of the images were burnt” (e.g., “Burnt_area_T1”=1, AND “Burnt_area_T2”=1, AND “Burnt_area_T3”=2 means that fires occurred two times on T1 and T2).

Table 32. Explanation of the reclassification codes for burnt areas

"Burn_stat" Code	Description
1	The area comes out burnt in 1 scenes
2	The area comes out burnt in 2 scenes
3	The area comes out burnt in 3 scenes
999	The area is not covered by all three satellite images

The "Burnt_stat" code assists in visualising results and carrying out statistics in a synthetic way. Figure 32 shows an example of the reclassification process and the analysis result for a selected area.

Figure 32. Portion of the same area in the three ASTER images (T1, T2 and T3) and the final reclassification result



9 THE LAND-COVER/USE ASSESSMENT GEODATABASE

9.1 Introduction

The Information System documented in this chapter has been developed inside the framework of the AIFM Project in order to provide an efficient tool for planning a sustainable forestry sector development. The remote sensing and land-cover component has the immediate objective of making available a comprehensive data set of land-cover/use types and related ancillary information as a fundamental tool to support not only the other activities within this Project (e.g., land unit, community forestry) but to support the UIF/DNFFB/MINAG in the long term.

The achievement of this objective is based on a comprehensive Information System able to assist a group of satellite image interpreters in their land-cover type analysis, managing a huge amount of digital data, dealing with the limitations resulting from the Project context and available resources (e.g., timeframe of activities is related to other Project components), data availability and the sustainability after Project completion.

This Information System is strongly geographic oriented. It comprises many components such as geodatabases, satellite image data, a set of procedures and a limited range of applications. This Geographic Information System (GIS) has been developed through a process of data modelling that defines this system step-by-step at different levels of abstraction, from an informal requirements analysis to the physical implementation of the elements.

This chapter provides an overview of the development process performed to build the data model and a detailed description of the AIFM land-cover/use assessment geodatabases at different levels of abstraction. Some basic concepts on geodatabase technology and data modelling are also provided in order to facilitate the introduction of the description of the Information System. These concepts are based upon Ceri et al. (1999), MacDonald (2001), Zeiler (2003) and Arctur and Zeiler (2004).

9.1.1 Geodatabase technology

The ability of GIS technology to integrate different data types and from different sources, to analyse these data and to present results in an appropriate manner for decision and policy making has led to GIS being a common tool across many organisations. This development of GIS in the last couple of years, together with the progress of technology, the new challenges of geographic sciences and the availability of ever larger geographic data sets, made the inefficiency of data storage and management based on flat files evident.

The geodatabase technology overcomes the limits of old systems using relational databases with extensions for storing, querying and manipulating spatial data. A geodatabase provides the possibility to design objects and relations able to capture more closely the behaviour of the real world. The geodatabase is much more than a “manager” of geographic data, it also allows the implementation of sophisticated business logic that, for example, builds relationships between data types (such as topologies and geometric networks), validates data and controls data access. A geodatabase is a complex structure that requires a multi-step process to define a *data model* suitable for the defined aims of a specific project.

9.1.2 Data modelling

Data modelling becomes an obvious issue whenever GIS software is built on top of a geodatabase. Data models lie at the very heart of GIS as they determine the ways in which real world phenomena may best be represented in digital form. The objective of data modelling is to provide a consistent, modular and easy-to-maintain structure where different data types are accommodated.

Database planning is a very important activity in GIS development. It begins with the identification of the needed data and continues to cover several other activities collectively termed as data life cycle, i.e. the identification of data in the needs assessment, inclusion of the data in the data model, creation of the metadata, collection and entry of data into the database, updating and maintenance routines, and, finally, retained according to the appropriate record retention schedule.

The data modelling phase is the most appropriate stage to solve business issues as they can become much harder to face at later stages. Data modelling is based on the fundamental principle of *abstraction*. A system model is created at different levels, starting at the higher abstraction levels and adding more levels with more detail, as more is understood about the system. When complete, the model can be viewed at several levels. The abstraction model starts from the “informal” user’s view of reality and his/her requirements, then passes through an environmental or business model, a data model, a database, to finish with the GIS application. The tools adopted for data modelling are designed to represent in a visual and not proprietary manner the conceptual data requirements of an Information System.

Database design is usually divided into three major activities: (1) conceptual, (2) logical and (3) physical data modelling described in more detail below:

1. The *conceptual data modelling* identifies data content and describes data at an abstract, or conceptual, level. This step is intended to describe what the GIS should be able to do and does not deal with how the GIS will be implemented, leaving the “how” question that is the subject of logical and physical database design. The conceptual design of the GIS also includes identification of the basic GIS architecture (e.g., functions of hardware and GIS software), estimates of usage and scoping the size of the GIS system. All of this is done with reference to the existing data processing environments that should interface with the GIS. Conceptual data models provide a link between realities, as these are perceived by human beings, and the way in which this reality will be represented in the database. It thus formalises human concepts of space and it is a compulsory task as computer systems work through sets of formal rules.
2. The *logical database design* translates the conceptual database model into the data model of a specific software system. The purpose of the logical model is to show the data that the application should store in order to satisfy business requirements. It shows how this data is related and explores any integration requirements with business areas outside the scope of the development project.
3. The *physical database design* is the representation of the logical data model in the schema of the software. The purpose of the physical model is to show how each data element will be implemented and stored in the database.

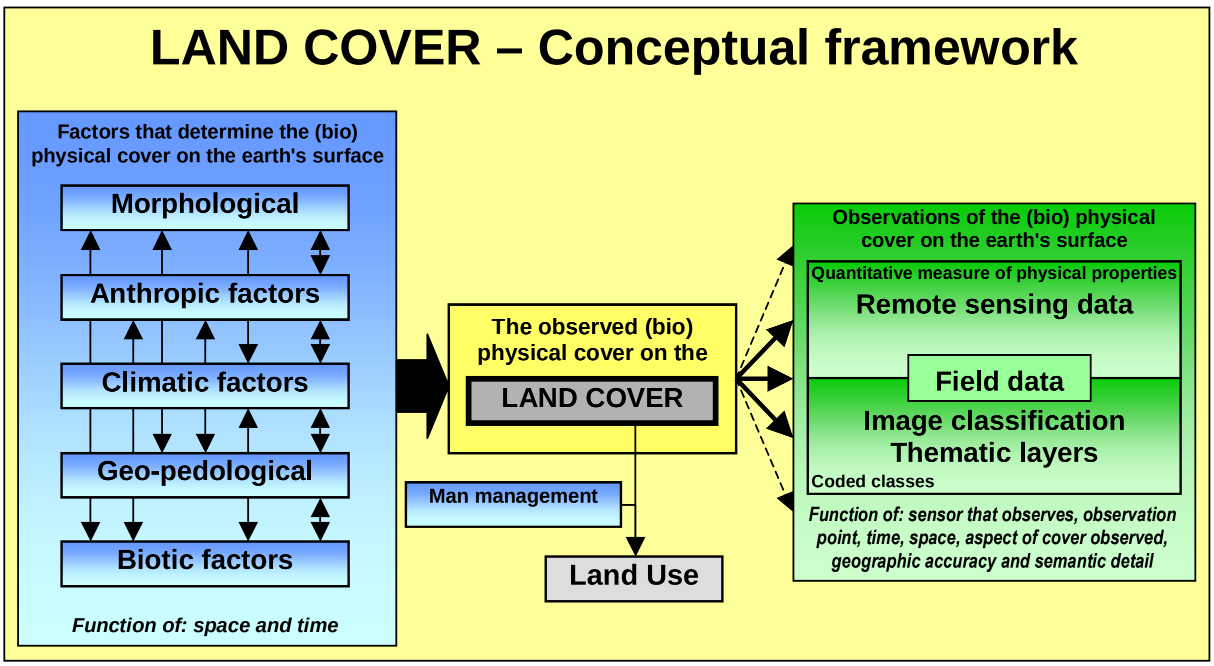
This process finally leads to the definition of a *data model*, whose implementation is focused on a geodatabase that can be tested and subsequently used according to the defined objectives of the Project.

9.1.3 A conceptual framework for land cover

As stated before in paragraph 4.3, land cover is defined as "*the observed (bio) physical cover on the Earth's surface*" (Di Gregorio and Jansen, 2000). Land cover is thus a complex concept that involves both the definition of a set of (bio) physical cover characteristics to be considered and an instrument (e.g., human eye, digital sensor sensible to visible, infrared or thermal wavelengths, etc.) to observe the Earth's surface, together with an observation point (e.g., from a plane or a satellite, ground observation far or close from the point to be observed, etc.).

Therefore, how the observation of the (bio) physical cover on the Earth's surface will look like depends on the instrument(s) used for observation, the time of observation, the location, the set and detail of (bio) physical characteristics observed and the geographic accuracy of the observation. Consequently, there are many possible representations of land cover. Land use is defined as "*the type of human activity taking place at or near the surface*" (Cihlar and Jansen, 2001) so it includes a direct or indirect human activity.

Figure 33. A schematic environmental model of land cover



As shown in Figure 33, a approximate environmental model of land cover can identify five main categories of interdependent factors that determine the (bio) physical cover on the Earth's surface: (1) morphology (e.g., elevation, slope, aspect, etc.); (2) human action (e.g., infrastructures, pollution, agriculture, pasture, urbanisation, etc.); (3) climate (e.g., precipitation, temperature, wind, etc.); (4) soil and geology (e.g., texture, organic carbon, lithology, rock outcrops, etc.); and (5) biotic factors (e.g., vegetation and fauna). All these factors are a function of space and time.

Land-cover data sets are real observations of the (bio) physical cover on the Earth's surface. They can be divided in two broad categories: (1) coded and (2) uncoded representations. Uncoded representations are, for example, satellite images (e.g., LANDSAT, ASTER, MODIS) or vegetation indexes (e.g., NDVI). They provide a quantitative measure of physical properties (e.g., spectral reflectance, temperature, shape, biomass, etc.) of land cover. In coded representations some kind of (bio) physical cover classification system is used. Examples of coded representations are the Vegetation Map of Africa

(White, 1993), topographic maps, the IGN/CENACARTA/DINAGECA Joint Venture land-cover data set (1999), and so on. Data collected in the field can be either coded or uncoded.

This general overview of the land-cover environmental model is helpful as a conceptual framework in which the data model and land-cover/use assessment geodatabase structure have been developed.

The land-cover/use data set required by the AIFM Project is described in the TOR, Technical Proposal and Inception Report, in particular concerning the classes to be incorporated in the land-cover interpretation at the two nominal scales and the thematic accuracy to be reached as well as the sensor to be used. There are many potential methodologies to develop the requested land-cover/use data set. One possible approach could be the definition of a functional relation between land-cover/use classes and the (bio) physical cover genetic factors. But due to the very complex nature of land-cover/use types and the classification requirements of the Project, it would be very hard to define such a model for the whole of Mozambique. Moreover, the data sets available in Mozambique are not always comprehensive, so that this kind of approach is impracticable. Another possible methodology could be the construction of a predictive model based on a statistical relation between the variable one wants to predict (e.g., classes of land-cover/use) and a set of available variables related to land-cover/use. A number of points with known values of the variable to be predicted could be used to calibrate and validate this kind of model. Again, the semantic detail (i.e. classification) required for the Project makes this approach unsuitable and results are likely to be insufficient for an applied Project which main goal is not merely research.

As stated in the TOR, Technical Proposal and Inception Report, the methodology selected and applied for collection of land-cover data for Mozambique at National level and for Manica and Maputo at Province level is on-screen visual interpretation of LANDSAT images of the years 2004/2005 integrated with available digital ancillary data sets, field validation and accuracy assessments (see Chapters 3 to 7). Thus, the purpose is the production of a structure for the Information System supporting and improving the satellite image based land-cover interpretation activities.

9.2 Requirements analysis

9.2.1 General requirements within the AIFM Project context

The general aim of the AIFM Project is stated in the TOR as "*the assessment and monitoring of the extent, state and changes of Mozambican forests and wooded lands in a timely and accurate manner. It must provide an efficient tool for planning forestry sector development and for setting up a strategy for a sustainable use of forest and wildlife resources*".

The remote sensing and land-cover component contributes to this overall goal by developing some specific tools, methodologies and data collection. The specific remote sensing and land-cover objectives are the presentation of an overview of occurring land-cover types in Mozambique, their location, extent and distribution and the utilisation of up-to-date technologies and international standards in land-cover data collection. De facto, it provides the baseline data set on which the stratification of the Forest Inventory is based (see also Chapter 1).

The expected outputs of the remote sensing and land-cover component are provided in paragraph 1.3. The remote sensing and land-cover component is completely integrated in the general framework of the Project, but it has also some individual requirements. Therefore, **it was decided to develop a dedicated geodatabase for this specific component of the Project in order to structure and organise the data from the very beginning of operational activities so as to have a flawless data production, storage, integration and analysis chain**.

The geodatabase described in this chapter is, therefore, focused on the requirements of the remote sensing and land-cover component in order to produce the outputs expected by the Project. The following paragraphs describe the data model used for this specific purpose. The requirements analysis for the AIFM Project will be described in the general data model development (see relevant documentation for a complete description of the AIFM Project data model as this was not available at the time of reporting in this Technical Report).

9.2.2 Specific requirements of the remote sensing and land-cover component

In order to carry out the requirements analysis for the Information System developed in support of the remote sensing and land-cover component and, subsequently, the created geodatabase model, the main purpose of the Information System for this component was defined as accommodating the delineated polygonal land-cover/use units.

The AIFM Project identifies two geographical land-cover interpretation levels: (1) a National level with a legend, a minimum mapping unit and an accuracy referred to a nominal scale of 1:1,000,000, and a (2) Province level with a legend, a minimum mapping unit and an accuracy referred to a nominal scale of 1:250,000. The Province level activities were carried out for two Provinces, i.e. Manica and Maputo, taking into consideration the opportunity to apply the same approach to other Provinces in future. The integration of the two levels of land-cover interpretation into a comprehensive Information System is a key issue in the Project.

The definition of the land-cover/use classes is realised through on-screen interpretation of LANDSAT images of year 2004/2005 by satellite image interpreters. The land-cover interpretations based upon the LANDSAT images are integrated with field survey data (e.g., field orientation and field validation), data describing factors influencing land cover (e.g., human activity, climate, terrain morphology, flora and fauna, soils) and with data on other land-cover aspects that are either coded (e.g., other land-cover data sets having different legends, dates and geographic detail) or uncoded (e.g., satellite images from ASTER, LANDSAT and MODIS covering different years and different seasons). Therefore, a set of information levels must be associated with the land-cover polygons for the Province and National levels.

The required data at Province level are the class of the dominant land cover, the percentage of the dominant class in the delineated polygon, the secondary land-cover class (if present), the percentage of this secondary class in the delineated polygon (if present), the name of the interpreter defining the polygon and its class(es), a unique ID code and any notes. For the National level, the data are the same as at the Province level plus a tertiary land-cover class (if present) and its percentage inside the polygon. It is possible to verify the polygons areas in real time in order to check whether or not the minimum mapping unit areas defined are being respected.

The topological correctness of the land-cover data layer must be assured, i.e. no overlapping areas and no gaps should occur, and the coherence for any obtained products (e.g., land-cover change) and the borders of the study area (e.g., country boundaries).

The system includes a set of digital ancillary data that served the satellite image interpreters in their comprehensive approach to land-cover interpretation described in detail earlier. Finally, the field survey data for field orientation and field validation are part of the System. All these data have been integrated in the Information System that at the same time should be flexible enough to include any further and future data sets.

One of the goals of the Information System is achievement of land-cover change analysis between the selected reference year and other years. The aim is characterisation of not only the actual state, but to highlight land-cover dynamics in the form of change processes. Polygons were changes occurred must be identified. Both the old and the new land-cover codes must be reported. In order to facilitate this type of analysis and to allow continuous monitoring, the polygons with changes must be delineated as stand-alone entities that show the differences with respect to the polygons of the reference land-cover layer (see also paragraph 8.4).

Furthermore, the System must also be a support for the extraction of field samples sites for the Forest Inventory (as was the case for Manica Province were the team not only extracted the sample sites but also carried out an ulterior check of the land-cover type at the selected sample sites) and must allow the production of thematic cartography and standard outputs like tables and diagrams.

Several users simultaneously access the data and, in particular, the System must manage editing sessions by multiple users on the same land-cover layer. The permission accesses to data must be differentiated for different users, i.e. all the ancillary data from external sources must be changed only by the administrator. The disk space resources must be efficiently handled in order to guarantee a flexible and flawless management of all satellite data (approximately 80 gigabyte of data in the case of this Project component) and to allow fast import and export of data.

Given the amount of satellite image data that is available (around 200 images), it is possible to know anywhere in the study area how many and which type of satellite images are available together with a summarised description of the ID code of the image, path in which it is stored, reference date, source, reference system and eventual remarks/notes.

Finally, the System should manage the subdivision of the working area between multiple interpreters and, extremely important, the monitoring of progress of the land-cover interpretation activity.

9.3 Land-cover/use assessment data model

The land-cover/use assessment data model was designed to accommodate all above-described needs taking into account the requirements stated in the TOR and the various limitations (e.g., time, economic resources and sustainability). The main restriction is data availability and data quality. The existing and accessible digital environmental data with a direct relation to the remote sensing and land-cover component are limited to the Joint Venture IGN/CENACARTA/DINAGECA data sets. In order to widen available sources of information, a lot of data was downloaded from Internet (e.g., different types of satellite images, a digital elevation model and some thematic data layers with a resolution of 1km). For all these data layers, the data model defines a suitable structure to organise and manage them in the created geodatabase. The data modelling effort was focused on the key purpose of accommodating land cover and related data layers (e.g., land-cover change, field sample data, forest type information).

No reference data model dedicated to land-cover/use assessment was found in the scientific literature, so this model has been specifically developed in the framework of the Project. It does not attempt to be an exhaustive model on land-cover/use assessment, but a specific tool functional within the objectives and limitations of the Project, though it could be considered a representative example. Its primary goal is assistance to the satellite image interpreters in their land-cover/use assessment in order to produce the high quality land-cover data layers and to integrate these in the general AIFM Information System.

Three geodatabases have been created (i.e. Maputo, Manica and Mozambique), but they are all three based upon the same data model. The Manica geodatabase is the one taken as example for documentation purposes as it is the most comprehensive one and because it has been used in the developed applications documented in Chapter 8. Specific or different features in the other two geodatabases are highlighted in the text.

The geodatabase has been the primary technical tool to perform the land-cover interpretation. The software and hardware were selected to manage such as multi-user environment. The GIS software used is ArcGIS and the database SQL Server. ArcSDE handled the connection between the GIS tools, installed on every computer/workstation, and the geodatabase located on the server (see Technical Proposal for details about hardware and software architecture). This system permits editing of the same data set by multiple users at the same time, thereby increasing the consistency of interpretation between users and overcoming edge-matching problems in areas where different satellite image interpreters are at work. The permission access to data has been set according to the different users. This policy maintained data integrity even with multiple users working on the same geodatabase, with a GIS administrator supervising all data flows and overall data management. The subdivision of the working area between interpreters and the monitoring of the progress of the work have been realised through a data set that was always up-to-date and thus showing to all users the same information.

The geodatabase was designed to enhance the integrity and consistency, both for geometry and semantic attributes, providing some specific tools for validation of features and to distinguish features by default value to avoid as much as possible errors. The attributes of land-cover feature classes and of all other related data sets (described in the various chapters of this Report) were implemented through domains. Control of topologic rules and correction of errors were executed at the end of *every* working day by the GIS administrator of the team in order to keep the data clean at every stage of the progress of the work. A macro was developed to check whether or not the minimum mapping unit was respected and it was executed in real time during interpretation work. Furthermore, a complete metadata description is associated to all data layers, according to the ISO 19115 standard.

A suitable data structure was defined in support of the comprehensive approach of the land-cover interpretation process. Data was placed in different categories according to their thematic/semantic content, topological relations and data access policy. These data sets help data usage and management, leaving flexibility to add new data becoming available during the Project life span, or in future if this System will be further extended to other studies in Mozambique. The data model is considered to be extended to future land-cover/use assessments at Province level for the whole of Mozambique. The integration of multiple-season and multiple-year satellite data with other existing digital supplementary data facilitates the interpretation process; the use of ground truth samples serves a better orientation of land-cover interpretation in the first phase (e.g., field orientation) and the assessment of the data quality (e.g., field validation and accuracy assessments) in the end.

The integration between Province and National levels was realised through a coherent data structure, a subset of ancillary data related to the geographic extent and a hierarchical legend system that ensures a common framework.

The digital elevation model and its related products (e.g., slope and hill shade) have been included in the geodatabase as raster data set, to improve the visualisation performance and to mosaic all files downloaded from Internet. For the same reason, topographic maps have been inserted in the geodatabase as raster catalogues.

A different data management approach was adopted for the satellite images. The land-cover/use assessment component has used 63 LANDSAT 5 TM, 64 LANDSAT 7 ETM+, 71 ASTER and 12 MrSID LANDSAT mosaics. This huge amount of data (approximately 80 gigabyte) was stored in separate files to facilitate image elaboration, exportation and management. All 210 satellite images have been saved in ".IMG" format (except the MrSID mosaic, saved as ".MRSID" format). All images have a name coded according to their location (LANDSAT path and row), date and sensor as explained in Chapter 3. In the geodatabase, a vector data set with the frames of all the images associated to metadata was used to select and retrieve images required by the interpreters. Given the number of images and the Project area, this solution was found the most appropriate (and more pragmatic than storing the satellite images inside the geodatabase).

The geodetic reference system used is UTM 36S WGS84. No official reference system for the AIFM Project was defined at the time the remote sensing and land-cover component became operational, so the most suitable option for this task was selected. Part of Mozambique is in UTM 37S, but a unique reference system was required by the National level data set. The datum WGS84 is used at international level and in particular the images downloaded from Internet have this datum. It was therefore considered a pragmatic choice to adopt this as the standard geodetic system.

In the next pages the Manica, Maputo and Mozambique geodatabases are described and illustrated by a series of graphs. A synthetic description of these structures is provided in the following paragraphs. The reference geodatabase is Manica, differences with the Maputo and/or Mozambique geodatabases are highlighted in the text whenever necessary.

9.3.1 Geodatabase structure

The geodatabase is structured around five key thematic and functional groups: (1) Land Cover, (2) Field Sample Data, (3) Ancillary Data, (4) Work Management and (5) Satellite Data. These groups are represented in the geodatabase diagrams shown in the next pages. The Catalogue view gives an overview of data structure as organised by ArcCatalog. The following is a description of all the geodatabase objects offered by ArcGIS:

- *Feature classes* are collections of geographic features with the same geometry type (such as point, line, or polygon), the same attributes, and the same spatial reference.
- *Domains* (values allowed in a field) on attribute can be set for enforcing data integrity and help data entry.
- *Feature data sets* are collections of feature classes stored together that share the same spatial reference; that is, they have the same coordinate system, and their features fall within a common geographic area. Feature classes with different geometry types may be stored in a feature data set. Feature data sets also have a natural organisational quality, much like a folder or a file system, where feature classes can be organised by category into logical groups. Topologically related feature classes must reside in the same feature data set.
- *Topological associations* are spatial relationships between features that share geometry such as boundaries and vertices. Specific rules can be set to preserve the integrity of these spatial relationships.
- *Tables* are sets of data elements arranged in rows and columns. Each row represents an individual entity, record, or feature, and each column represents a single field or attribute value.
- *Relationships* are associations or links between two objects in a geodatabase. Relationships can exist between spatial objects (features in feature classes), between non-spatial objects (rows in a table), or between spatial and non-spatial objects. They grant referential integrity and model how objects are related to each other.
- *Rasters* are spatial data models that define space as an array of equally sized cells arranged in rows and columns. Each cell contains an attribute value and location coordinates. Unlike a vector structure, which stores coordinates explicitly, raster coordinates are contained in the ordering of the matrix. In a geodatabase rasters can be organised into a raster data set or raster catalogue. In a raster data set, all rasters are merged together in a unique mosaic. Raster catalogue is a collection of raster data sets defined in a table of any format, in which the records define the individual raster data sets that are included in the catalogue. A raster catalogue is used to display adjacent or overlapping raster data sets without having to mosaic them together into one large file.

All these objects have been used in the geodatabase to implement the data model. This is a summary of the geodatabase elements clustered by thematic groups, described in detail in the next sections.

In the "**Land Cover**" functional group four feature classes exist:

1. "Land_cover" (polygons - land-cover assessment layer, the central element of the geodatabase);
2. "Lc_change" (polygons - land-cover change between 2004 and 1990);
3. "Lc_forest_type" (polygons - land-cover polygons classified as forest in "Land_cover", grouped by their forest type); and
4. "Study_area" (polygons - Manica, Maputo and Mozambique boundary, respectively).

They are grouped in the "Land_cover" feature data set for three main reasons: (1) they belong to the same thematic set; (2) they are topologically related; and (3) they share the same geographic reference. "Lc_change" and "Lc_forest_type" feature classes have been developed just for the Manica geodatabase. Topological rules ("Land_cover_Topology") were set to ensure the topological correctness of the elements (no overlapping polygons, no gaps between polygons inside the study area) and the geometric coherence among the different layers. The table "Landcover_Codes", describes the land-cover codes used in the land-cover feature classes.

In the "**Field Samples Data**" functional group two feature classes exist:

1. "Orientation_samples" (points - sample points used for the orientation phase); and
2. "Validation_samples" (points - sample points used for the validation phase).

They are grouped in the "Field_samples" feature data set for two main reasons: (1) they belong to the same thematic set; and (2) they share the geographic reference.
Four tables are part of this group:

- "FS_samples_description" (basic information on data collected in the field about the sample points);
- "FS_site_description" (site information of sample points);
- "FS_cover_description" (description of sample points cover); and
- "FS_table" (list of references to digital photographs taken at the sample points site).

All tables and features classes are linked, as they refer to the same "entity" (sample points). The relationship classes are:

- "FS_orientation_sample" (between "Orientation_samples" and "FS_samples_description");
- "FS_validation_sample" (between "Validation_samples" and "FS_samples_description");
- "FS_sample_site" (between "FS_samples_description" and "FS_site_description");
- "FS_sample_cover" (between "FS_samples_description" and "FS_cover_description"); and
- "FS_sample_photo" (between "FS_samples_description" and "FS_photo").

The orientation and validation phases are different at national level that is why the "Field Samples Data" structure is different in the Mozambique geodatabase. It has one feature class, "Validation_samples", stored in the "ASTER_samples" feature data set.

In the "**Ancillary Data**" functional group several feature classes exist:

1. "Province" (polygons - Province boundaries), "Distritos" (polygons - district boundaries) and "Reservas" (polygons – protected areas, just for Mozambique and Maputo geodatabase) grouped in the "Data_administrative" feature data set;
2. "Grid_50" (polygons - vector catalogue of topographic maps at 1:50,000 scale) and "Grid_250" (polygons - vector catalogue of topographic maps at 1:250,000 scale) grouped in the "Data_topography" feature data set;
3. "Eco_zones" (polygons - ecological zones), "Hidrografia" (lines - hydrography), "Landcover_Dinageca" (polygons – land-cover feature class produced by Joint Venture IGN/CENACARTA/DINAGECA in 1999), "SOTER" (polygons – SOTER feature class) grouped in the "Data_environmental" feature data set; and

4. “Aldeias” (points - villages), “Cidades” (points - cities) and “Estradas” (lines – road network) grouped in the “Data_infrastructures” feature data set.

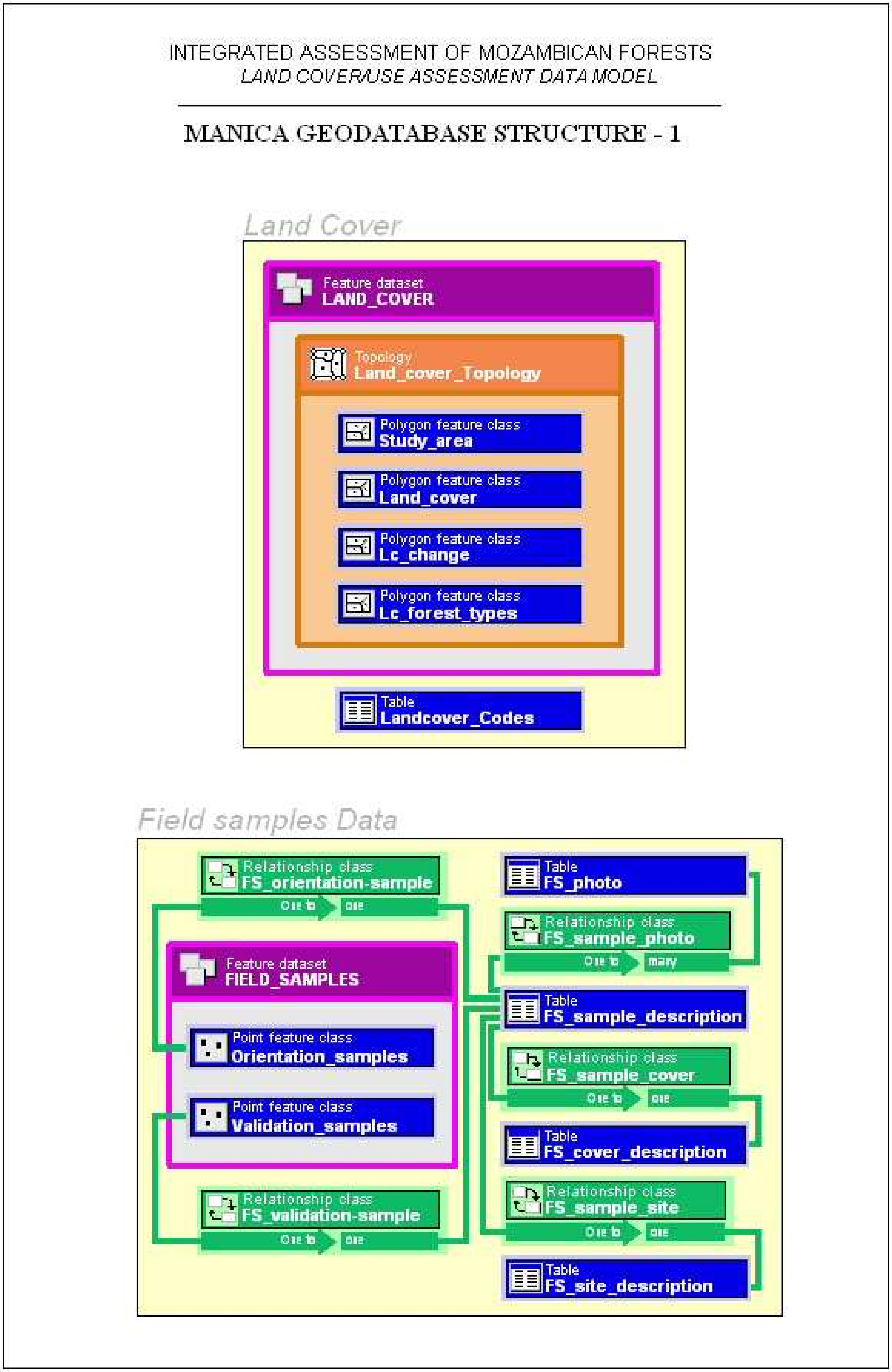
All these data originate from external data sources and they have been used “as they were” (except for “Estradas” that was updated for Manica and Maputo Provinces). They have been grouped in different feature data sets to better organise the access and retrieval of information and to define the same privileges to users and set the geographic reference (reference system and extent).

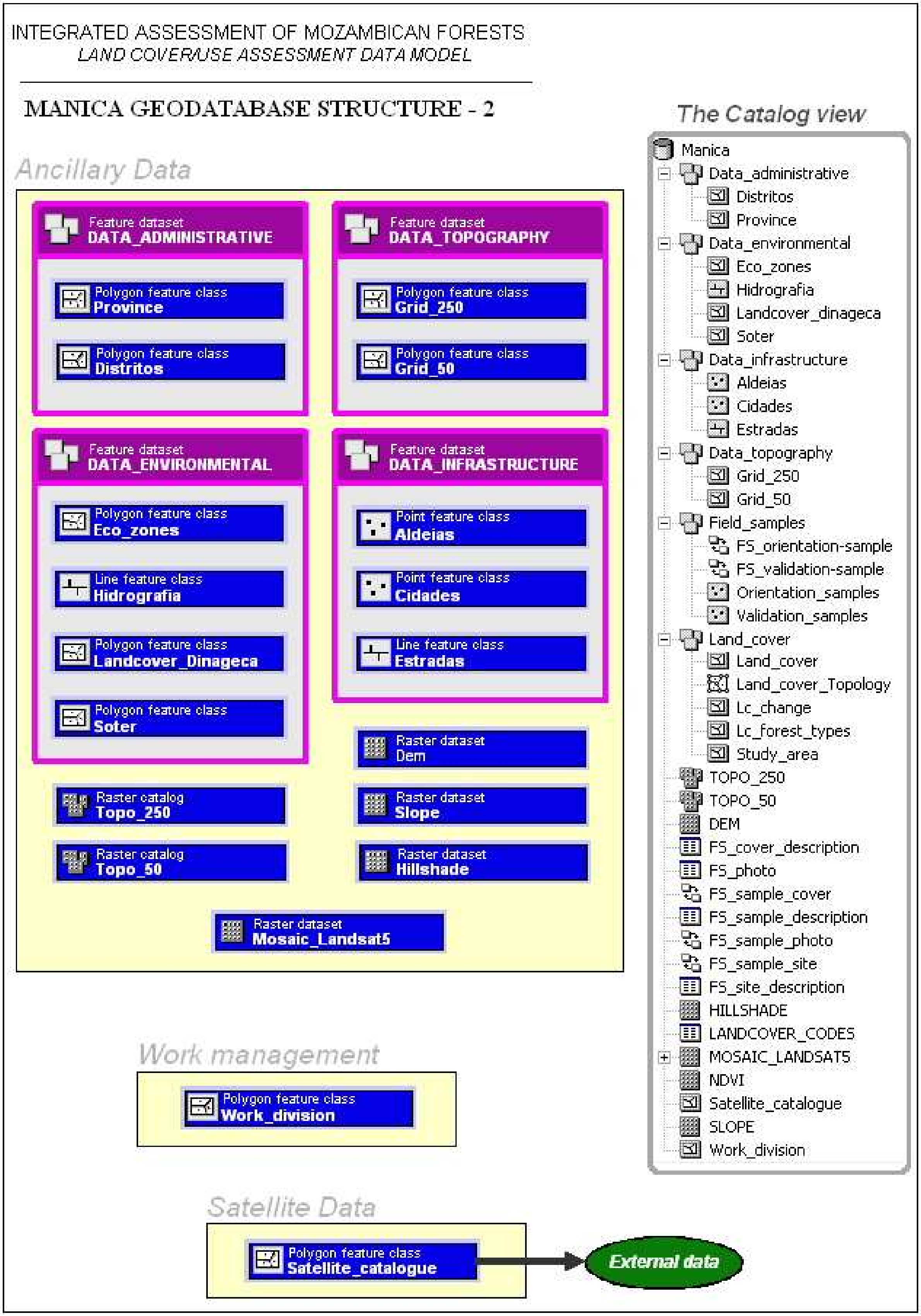
Four raster data sets are present:
1. “DEM” (digital elevation model from SRTM with 90m of resolution);
2. “Slope” (slope computed using “DEM”);
3. “Hillshade” (hill shade simulation computed using “DEM”); and
4. “Mosaic_LANDSAT5” (a mosaic of stretched bands RGB=432 from LANDSAT 5 TM images used for the interpretation, just for Manica and Maputo geodatabases).

The two raster catalogues, “Topo_50” and “Topo_250”, are collections of all the topographic maps. Raster catalogues have been used to preserve the colour maps and to allow overlapping areas. These two raster catalogues are available just for the Manica and Maputo geodatabases.

In the “**Work management**” functional group, the only “Work_division” (polygons) feature class is present.

In the “**Satellite Data**” functional group, the “Satellite_catalogue” (polygons) is a feature class with geographic and semantic metadata, a kind of reference collection to satellite images stored in flat files external to the geodatabases.

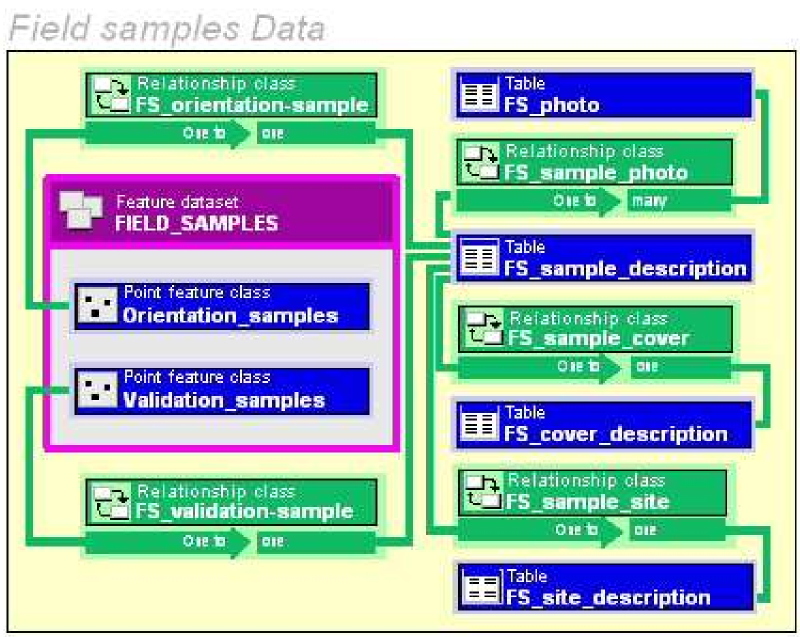

INTEGRATED ASSESSMENT OF MOZAMBICAN FORESTS
LAND COVER/USE ASSESSMENT DATA MODEL
MANICA GEODATABASE STRUCTURE - 1
Land Cover
Feature dataset
LAND_COVER
Topology
Land_cover_Topology
Polygon feature class
Study_area
Polygon feature class
Land_cover
Polygon feature class
Lc_change
Polygon feature class
Lc_forest_types
Table
Landcover_Codes
Field samples Data
Relationship class
FS_orientation-sample
One to one
Feature dataset
FIELD_SAMPLES
Point feature class
Orientation_samples
Point feature class
Validation_samples
Relationship class
FS_validation-sample
One to one
Table
FS_photo
Relationship class
FS_sample_photo
One to many
Table
FS_sample_description
Relationship class
FS_sample_cover
One to one
Table
FS_cover_description
Relationship class
FS_sample_site
One to one
Table
FS_site_description

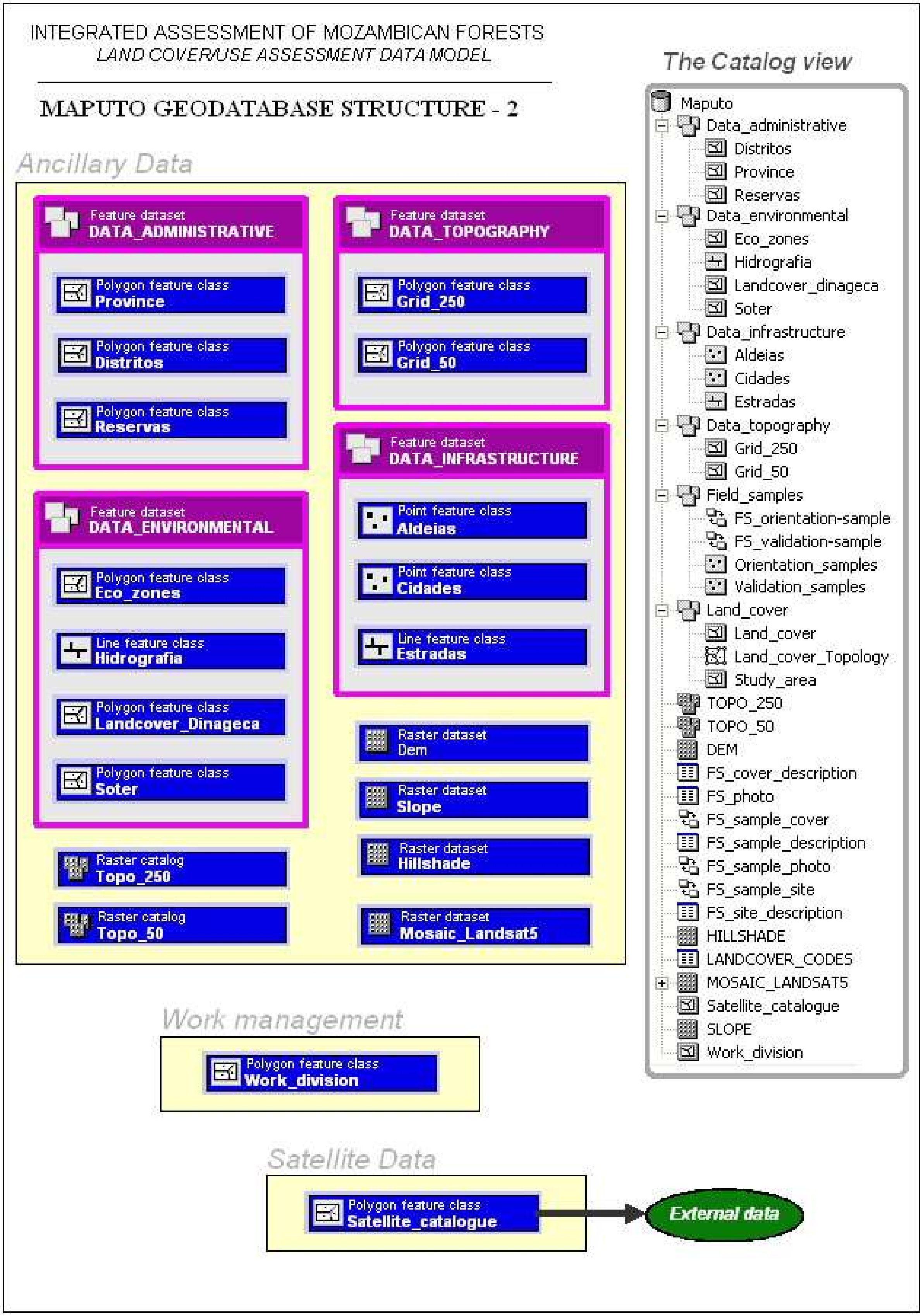

INTEGRATED ASSESSMENT OF MOZAMBICAN FORESTS
LAND COVER/USE ASSESSMENT DATA MODEL
MANICA GEODATABASE STRUCTURE - 2
Ancillary Data
Feature dataset DATA_ADMINISTRATIVE
Polygon feature class Province
Polygon feature class Distritos
Feature dataset DATA_TOPOGRAPHY
Polygon feature class Grid_250
Polygon feature class Grid_50
Feature dataset DATA_ENVIRONMENTAL
Polygon feature class Eco_zones
Line feature class Hidrografia
Polygon feature class Landcover_Dinageca
Polygon feature class Soter
Feature dataset DATA_INFRASTRUCTURE
Point feature class Aldeias
Point feature class Cidades
Line feature class Estradas
Raster dataset Dem
Raster catalog Topo_250
Raster dataset Slope
Raster catalog Topo_50
Raster dataset Hillshade
Raster dataset Mosaic_Landsat5
Work management
Polygon feature class Work_division
Satellite Data
Polygon feature class Satellite_catalogue
External data
The Catalog view
Manica
Data_administrative
Distritos
Province
Data_environmental
Eco_zones
Hidrografia
Landcover_dinageca
Soter
Data_infrastructure
Aldeias
Cidades
Estradas
Data_topography
Grid_250
Grid_50
Field_samples
FS_orientation-sample
FS_validation-sample
Orientation_samples
Validation_samples
Land_cover
Land_cover
Land_cover_Topology
Lc_change
Lc_forest_types
Study_area
TOPO_250
TOPO_50
DEM
FS_cover_description
FS_photo
FS_sample_cover
FS_sample_description
FS_sample_photo
FS_sample_site
FS_site_description
HILLSHADE
LANDCOVER_CODES
MOSAIC_LANDSAT5
NDVI
Satellite_catalogue
SLOPE
Work_division

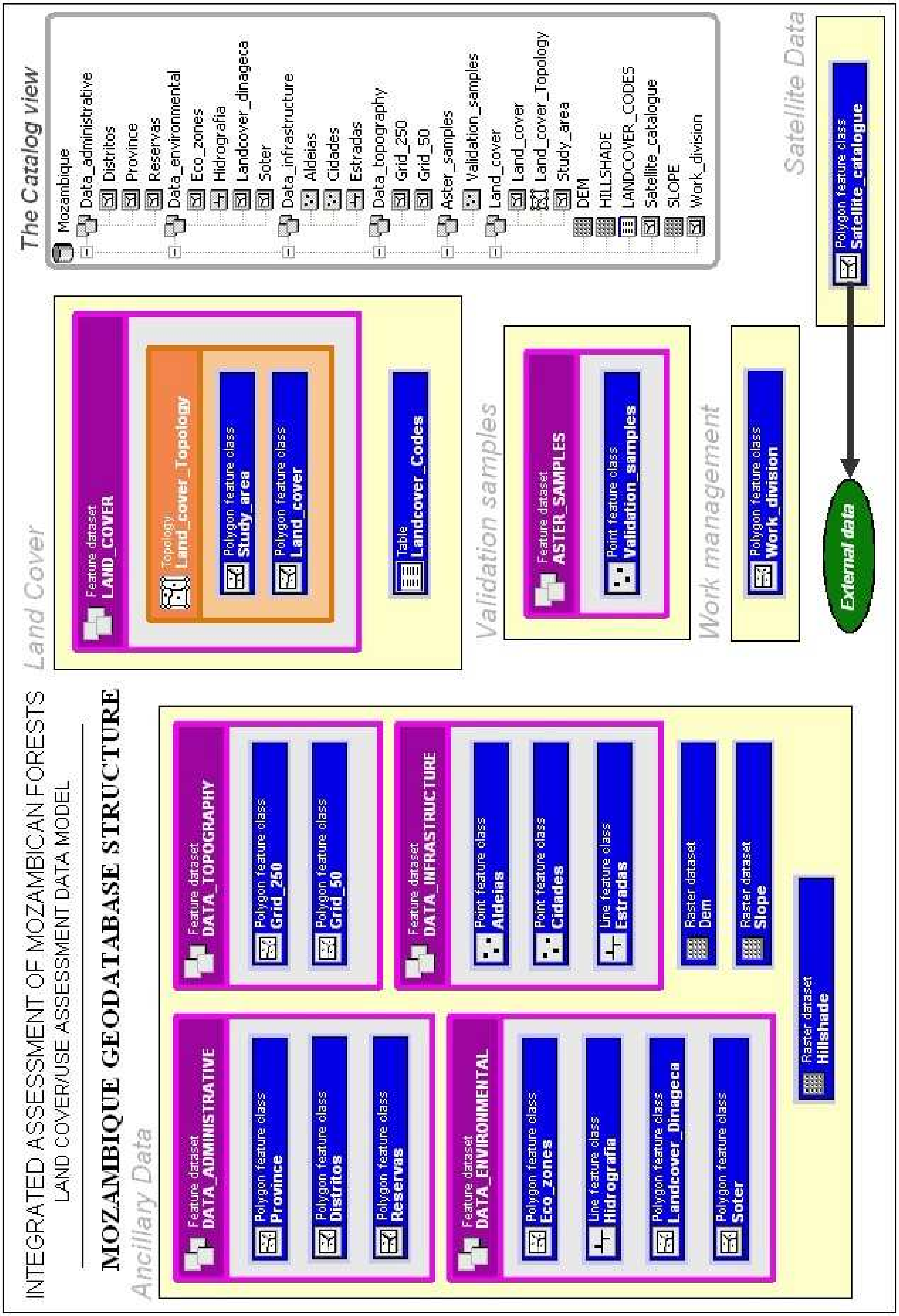
INTEGRATED ASSESSMENT OF MOZAMBICAN FORESTS

LAND COVER/USE ASSESSMENT DATA MODEL

MAPUTO GEODATABASE STRUCTURE - 1




INTEGRATED ASSESSMENT OF MOZAMBICAN FORESTS
LAND COVER/USE ASSESSMENT DATA MODEL
MAPUTO GEODATABASE STRUCTURE - 2
Ancillary Data
Feature dataset DATA_ADMINISTRATIVE
Polygon feature class Province
Polygon feature class Distritos
Polygon feature class Reservas
Feature dataset DATA_TOPOGRAPHY
Polygon feature class Grid_250
Polygon feature class Grid_50
Feature dataset DATA_INFRASTRUCTURE
Point feature class Aldeias
Point feature class Cidades
Line feature class Estradas
Feature dataset DATA_ENVIRONMENTAL
Polygon feature class Eco_zones
Line feature class Hidrografia
Polygon feature class Landcover_Dinageca
Polygon feature class Soter
Raster dataset Dem
Raster dataset Slope
Raster dataset Hillshade
Raster dataset Mosaic_Landsat5
Raster catalog Topo_250
Raster catalog Topo_50
Work management
Polygon feature class Work_division
Satellite Data
Polygon feature class Satellite_catalogue
External data
The Catalog view
Maputo
Data_administrative
Distritos
Province
Reservas
Data_environmental
Eco_zones
Hidrografia
Landcover_dinageca
Soter
Data_infrastructure
Aldeias
Cidades
Estradas
Data_topography
Grid_250
Grid_50
Field_samples
FS_orientation-sample
FS_validation-sample
Orientation_samples
Validation_samples
Land_cover
Land_cover
Land_cover_Topology
Study_area
TOPO_250
TOPO_50
DEM
FS_cover_description
FS_photo
FS_sample_cover
FS_sample_description
FS_sample_photo
FS_sample_site
FS_site_description
HILLSHADE
LANDCOVER_CODES
MOSAIC_LANDSAT5
Satellite_catalogue
SLOPE
Work_division



INTEGRATED ASSESSMENT OF MOZAMBICAN FORESTS
LAND COVER/USE ASSESSMENT DATA MODEL
MOZAMBIQUE GEODATABASE STRUCTURE
Ancillary Data
Feature dataset DATA_ADMINISTRATIVE
Polygon feature class Province
Polygon feature class Distritos
Polygon feature class Reservas
Feature dataset DATA_ENVIRONMENTAL
Polygon feature class Eco_zones
Line feature class Hidrografia
Polygon feature class Landcover_Dinageca
Polygon feature class Soter
Raster dataset Hillshade
Feature dataset DATA_TOPOGRAPHY
Polygon feature class Grid_250
Polygon feature class Grid_50
Feature dataset DATA_INFRASTRUCTURE
Point feature class Aldeias
Point feature class Cidades
Line feature class Estradas
Raster dataset Dem
Raster dataset Slope
Land Cover
Feature dataset LAND_COVER
Topology Land_cover_Topology
Polygon feature class Study_area
Polygon feature class Land_cover
Table Landcover_Codes
Validation samples
Feature dataset ASTER_SAMPLES
Point feature class Validation_samples
Work management
Polygon feature class Work_division
External data
Satellite Data
Polygon feature class Satellite_catalogue
The Catalog view
Mozambique
Data_administrative
Distritos
Province
Reservas
Data_environmental
Eco_zones
Hidrografia
Landcover_dinageca
Soter
Data_infrastructure
Aldeias
Cidades
Estradas
Data_topography
Grid_250
Grid_50
Aster_samples
Validation_samples
Land_cover
Land_cover
Land_cover_Topology
Study_area
DEM
HILLSHADE
LANDCOVER_CODES
Satellite_catalogue
SLOPE
Work_division

9.3.2 Geodatabase description

The Manica, Maputo and Mozambique geodatabases are “containers” of many objects and their relations, whose structure has been described in the previous paragraphs. In the next pages, a series of diagrams provide a detailed description of all feature classes, feature data sets, relationships classes, topological rules, raster data sets, raster catalogues and domains. The Manica geodatabase is again taken as reference.

For a more exhaustive description of the land-cover/use assessment and related feature classes, see the previous paragraphs.

For a more exhaustive description of ancillary data originating from the IGN/CENACARTA/ DINAGECA Joint Venture, see IGN/CENACARTA/DINAGECA (1999).

All feature data sets refer to UTM36 WGS84 within the extension of the study area (e.g., Manica, Maputo and Mozambique respectively).

“DEM”, “Slope” and “Hillshade” raster data sets are cut according to the boundaries of the study areas and have a resolution of 90m. The “Mosaic_LANDSAT5” raster data sets have a resolution of 90m.

The complete description of each layer is given in the metadata contained in the geodatabases, where details are documented and available for consultation (“.XML” versions of the three databases have been created; these can be imported in simple personal geodatabases that use Access instead of SQL Server).

INTEGRATED ASSESSMENT OF MOZAMBICAN FORESTS

LAND COVER/USE ASSESSMENT DATA MODEL

Land Cover - 1

MANICA GEODATABASE DIAGRAM - 1

The land cover / use feature class has been derived by on-screen interpretation of Landsat TM images for the year 2004, using a legend created with the Land Cover Classification System (LCCS) based upon the requirements and experiences of UIF and complemented by field validation. Each polygon can contain up to 2 classes. This is the main layer of the geodatabase.

Simple feature class **Land_cover**

Geometry: Polygon
Contains M values: No
Contains Z values: No

Field name	Data type	Allow nulls	Default value	Domain	Precision	Scale	Length	
OBJECTID	Object ID							
LC	String	No	xxx	LC_classes			5	Dominant land cover
LC_SEC	String	Yes		LC_classes			5	Secondary land cover
NOTE	String	Yes					70	
AUTOR	Short integer	Yes		Operators	0			Photointerpreter who created the data
PERC_1C	Short integer	Yes		Percentage	0			%of the dominant land cover
HECTARES	Long integer	Yes			0			
POLY_ID	Long integer	Yes			0			Polygon identificator
SHAPE	Geometry	Yes						
SHAPE_Length	Double	Yes			0	0		
SHAPE_Area	Double	Yes			0	0		

The study area feature class is used to enforce topological relations.

Simple feature class **Study_area**

Geometry: Polygon
Contains M values: No
Contains Z values: No

Field name	Data type	Allow nulls	Default value	Domain	Precision	Scale	Length
OBJECTID	Object ID						
PROVINCIA	String	Yes					30
HECTARES	Double	Yes			0	0	
SHAPE	Geometry	Yes					
SHAPE_Length	Double	Yes			0	0	
SHAPE_Area	Double	Yes			0	0	

Polygons of land cover / use with a forest component (pure or mixed), classified according to their forest type even when the original code mask this information (e.g. shifting cultivation).

Simple feature class **lc_forest_types**

Geometry: Polygon
Contains M values: No
Contains Z values: No

Field name	Data type	Allow nulls	Default value	Domain	Precision	Scale	Length	
OBJECTID	Object ID							
FOREST	String	Yes					50	Forest type
NOTE	String	Yes					30	
SHAPE	Geometry	Yes						
POLYLC_ID	Long integer	Yes			0			Poly ID of the linked polygon in the land cover layer
SHAPE_Length	Double	Yes			0	0		
SHAPE_Area	Double	Yes			0	0		

Land cover change between 2004 and 1990. Polygons of 2004 can have changes in geometry and/or land cover codes in a parent-child relation with polygons in 1990.

Simple feature class **lc_change**

Geometry: Polygon
Contains M values: No
Contains Z values: No

Field name	Data type	Allow nulls	Default value	Domain	Precision	Scale	Length	
OBJECTID	Object ID							
LC	String	No	xxx	LC_classes			5	Dominant land cover in 2004
LC_SEC	String	Yes		LC_classes			5	Secondary land cover in 2004
PERC_1C	Short integer	Yes		Percentage	0			%of the dominant land cover in 2004
HECTARES	Long integer	Yes			0			
CHANGE	Short integer	Yes		Change	0			Flag for polygons with a change
LC_90	String	Yes	xxx	LC_classes			5	Dominant land cover in 1990
LC_SEC_90	String	Yes		LC_classes			5	Secondary land cover in 1990
PERC_C1_90	Short integer	Yes		Percentage	0			%of the dominant land cover in 1990
POLY_ID1990	Long integer	Yes			0			Poly ID in 1990
POLY_ID2004	Long integer	Yes			0			Poly ID in 2004 (parent-child relation)
SHAPE	Geometry	Yes						
SHAPE_Length	Double	Yes			0	0		
SHAPE_Area	Double	Yes			0	0		

INTEGRATED ASSESSMENT OF MOZAMBICAN FORESTS

LAND COVER/USE ASSESSMENT DATA MODEL

Land Cover - 2

MANICA GEODATABASE DIAGRAM - 2

Coded value domain
Change

Description: *Kind of change*
Field type: *Short integer*
Split policy: *Default value*
Merge policy: *Default value*

Code	Description
1	No change
2	Change

Coded value domain
Percentage

Description: *Percentage of the dominant class*
Field type: *Short integer*
Split policy: *Short integer*
Merge policy: *Default value*

Code	Description
3	100 %
1	50% - 74%
2	75% - 99%

Coded value domain
LC_classes

Description: *Land cover classes*
Field type: *String*
Split policy: *Duplicate*
Merge policy: *Default value*

Code	Description
xx	To be defined
1TCF	Tree crops
1TCW	Forest plantation
2FEG	Gallery forest
2FDC	Mopane dense
2FDB	Miombo dense
2WDC	Mopane open
2WDB	Miombo open
2GCT	Tree savanna
2GCS	Shrub savanna
2GOS	Open shrub savanna
5BU	Built-up areas
6BR	Bare rocks
6BS	Bare soils
7WB	Artificial water bodies
8WB	Natural water bodies
1CXF	Shifting cultivation with open to closed forested areas
2FEM	Closed broadleaved semi-evergreen mountainous forest
2FE	Broadleaved (semi-) evergreen closed forest
2WEM	Open broadleaved semi-evergreen mountainous forest
2WE	Broadleaved (semi-) evergreen open forest with shrubs
2WD	Broadleaved (semi-) deciduous open forest with shrubs
2TE	Broadleaved (semi-) evergreen thicket
2TD	Broadleaved (semi-) deciduous thicket
2SE	Broadleaved (semi-) evergreen shrubland
2SD	Broadleaved (semi-) deciduous shrubland
2FXC	Closed to open forested areas with shifting cultivation
2FD	Broadleaved (semi-) deciduous closed forest
4WET	Woodland temporarily flooded
4SET	Shrubs temporarily flooded
4HVT	Herbaceous temporarily flooded
1FCR	Rainfed crops

Land cover codes of the legend at provincial level, their description and the corresponding code in LCCS classification system

Table
LANDCOVER_CODES

Field name	Data type	Allow nulls	Default value	Domain	Precision	Scale	Length
OBJECTID	Object ID						
CODE	String	Yes					9
DESCRIPTION	String	Yes					64
LCCS_CODE	String	Yes					50

Land_cover_Topology

Cluster tolerance: 0,1

Participating feature classes and ranks

Feature class	Rank
Study_area	1
Land_cover	2
Lc_change	3
Lc_forest_type	3

Topology rules

Origin feature class	Topology rule	Comparison feature class
Land_cover	Must Not Overlap	
Land_cover	Must Not Have Gaps	
Land_cover	Must Be Covered By	Study_area
Land_cover	Area Boundary Must Be Covered By Boundary Of	Lc_change
Land_cover	Must Cover Each Other	Lc_change
Lc_forest_type	Area Boundary Must Be Covered By Boundary Of	Land_cover

INTEGRATED ASSESSMENT OF MOZAMBICAN FORESTS

LAND COVER/USE ASSESSMENT DATA MODEL

Ancillary data - 1

MANICA GEODATABASE DIAGRAM - 3

Villages - from IGN/CENARCARTA/DINAGECA database

Simple feature class
Aldeias

Geometry *Point*
Contains M values *No*
Contains Z values *No*

Field name	Data type	Allow nulls	Default value	Domain	Precision	Scale	Length
OBJECTID	Object ID						
NOME	String	Yes					50
TOTAL	Long integer	Yes			0		
MASCULINO	Long integer	Yes			0		
FEMININO	Long integer	Yes			0		
AGREGADOS	Long integer	Yes			0		
CODIGO_CEN	Double	Yes			0	0	
CODIGO_CENS	String	Yes					14
SHAPE	Geometry	Yes					

Towns - from IGN/CENARCARTA/DINAGECA database

Simple feature class
Cidades

Geometry *Point*
Contains M values *No*
Contains Z values *No*

Field name	Data type	Allow nulls	Default value	Domain	Precision	Scale	Length
OBJECTID	Object ID						
TIPO_TOP	Short integer	Yes			0		
TOPONIMO	String	Yes					50
ID_OPER	Long integer	Yes			0		
SHAPE	Geometry	Yes					

Main roads - from IGN/CENARCARTA/DINAGECA database

Simple feature class
Estradas

Geometry *Polyline*
Contains M values *No*
Contains Z values *No*

Field name	Data type	Allow nulls	Default value	Domain	Precision	Scale	Length
OBJECTID	Object ID						
TIPO_COM	Short integer	Yes			0		
ID_OPER	Long integer	Yes			0		
SHAPE	Geometry	Yes					
SHAPE_Length	Double	Yes			0	0	

Catalog of topographic maps at 1:250,000 scale

Simple feature class
Grid_250

Geometry *Polygon*
Contains M values *No*
Contains Z values *No*

Field name	Data type	Allow nulls	Default value	Domain	Precision	Scale	Length	
OBJECTID	Object ID							
FOLHA	String	Yes					5	Sheet number
NOME	String	Yes					50	Sheet name
PRESENT	String	Yes					3	Maps available to the project
SHAPE	Geometry	Yes						
SHAPE_Length	Double	Yes			0	0		
SHAPE_Area	Double	Yes			0	0		

Catalog of topographic maps at 1:50,000 scale

Simple feature class
Grid_50

Geometry *Polygon*
Contains M values *No*
Contains Z values *No*

Field name	Data type	Allow nulls	Default value	Domain	Precision	Scale	Length	
OBJECTID	Object ID							
ID	Long integer	Yes			0			
PRESENT	String	Yes					3	Maps available to the project
NOTE	String	Yes					20	Notes
SHEET	Long integer	Yes			0			Sheet number
SHAPE	Geometry	Yes						
SHAPE_Length	Double	Yes			0	0		
SHAPE_Area	Double	Yes			0	0		

INTEGRATED ASSESSMENT OF MOZAMBICAN FORESTS
LAND COVER/USE ASSESSMENT DATA MODEL

Ancillary data - 2

MANICA GEODATABASE DIAGRAM - 4

Soils and terrain digital databases (SOTER)

Simple feature class **Soter**

Geometry: Polygon
Contains M values: No
Contains Z values: No

Field name	Data type	Allow nulls	Default value	Domain	Precision	Scale	Length
OBJECTID_1	Object ID						
OBJECTID	Double	Yes			0	0	
SOTERSAF11	Double	Yes			0	0	
ISOCSUID	String	Yes					10
SUID	Double	Yes			0	0	
OTHER	String	Yes					15
LANDFORM	String	Yes					10
LITHOLOGY	String	Yes					10
SOILS	String	Yes					10
WRB	String	Yes					50
DOMSOILS	String	Yes					2
CODE_WRB	String	Yes					16
SHAPE	Geometry	Yes					
SHAPE_Length	Double	Yes			0	0	
SHAPE_Area	Double	Yes			0	0	

The UNESCO/AETFAT/UNSO (White's) Vegetation Map of Africa

Simple feature class **Eco_zones**

Geometry: Polygon
Contains M values: No
Contains Z values: No

Field name	Data type	Allow nulls	Default value	Domain	Precision	Scale	Length
OBJECTID	Object ID						
SHAPE	Geometry	Yes					
TERR_ECOS_	Double	Yes			0	0	
TERR_ECOS1	Double	Yes			0	0	
REALM	String	Yes					3
BIOME	Short integer	Yes			0		
ECO_NUM	Short integer	Yes			0		
ECO_ID	Long integer	Yes			0		
ECO_NAME	String	Yes					99
ECO_SYM	Short integer	Yes			0		
BDI	Short integer	Yes			0		
CURR_STAT	Short integer	Yes			0		
THREAT	Short integer	Yes			0		
FUTR_STAT	Short integer	Yes			0		
PRIOR_STAT	Short integer	Yes			0		
GBL_STAT	Short integer	Yes			0		
G200_REGIO	String	Yes					99
G200_BIOME	Short integer	Yes			0		
G200_STAT	Short integer	Yes			0		
G200_NUM	Long integer	Yes			0		
G200_DLINE	Short integer	Yes			0		
A25	Short integer	Yes			0		
ECO_CODE	String	Yes					16
SHAPE_Length	Double	Yes			0	0	
SHAPE_Area	Double	Yes			0	0	

Hydrography

Simple feature class **Hidrografia**

Geometry: Polyline
Contains M values: No
Contains Z values: No

Field name	Data type	Allow nulls	Default value	Domain	Precision	Scale	Length
OBJECTID	Object ID						
ORDEM	Short integer	Yes			0		
TOPONIMO	String	Yes					50
ID_OPER	Long integer	Yes			0		
SHAPE	Geometry	Yes					
SHAPE_Length	Double	Yes			0	0	

INTEGRATED ASSESSMENT OF MOZAMBICAN FORESTS
LAND COVER/USE ASSESSMENT DATA MODEL

Ancillary data - 3

MANICA GEODATABASE DIAGRAM - 5

Simple feature class
Landcover_dinageca

Geometry: *Polygon*
Contains M values: *No*
Contains Z values: *No*

Field name	Data type	Allow nulls	Default value	Domain	Precision	Scale	Length
OBJECTID	Object ID						
ID_OPER	Long integer	No			0		
OCUP1	Short integer	No			0		
ESTA1	String	No					2
SOLO1	Short integer	No			0		
LMENOR1	Short integer	No			0		
USOA1	String	No					5
VEGET1	Short integer	No			0		
PCT_OCUP1	Short integer	No			0		
OCUP2	Short integer	No			0		
ESTA2	String	No					2
SOLO2	Short integer	No			0		
LMENOR2	Short integer	No			0		
USOA2	String	No					5
VEGET2	Short integer	No			0		
PCT_OCUP2	Short integer	No			0		
OCUP3	Short integer	No			0		
ESTA3	String	No					2
SOLO3	Short integer	No			0		
LMENOR3	Short integer	No			0		
USOA3	String	No					5
VEGET3	Short integer	No			0		
PCT_OCUP3	Short integer	No			0		
CAMPO	String	No					1
CAJU	Short integer	No			0		
CANA	Short integer	No			0		
COCO	Short integer	No			0		
CHA	Short integer	No			0		
SHAPE	Geometry	Yes					
SHAPE_Length	Double	Yes			0	0	
SHAPE_Area	Double	Yes			0	0	

This land-use/cover data set was created by the Joint Venture IGN / CENACARTA / DINAGECA to produce a land-cover data set for the whole of Mozambique (1996-1999) by the visual interpretation of high resolution satellite images completed with field surveys. See the relevant documentation for a complete description of these data.

Administrative boundaries of Manica Province

Simple feature class
Province

Geometry: *Polygon*
Contains M values: *No*
Contains Z values: *No*

Field name	Data type	Allow nulls	Default value	Domain	Precision	Scale	Length
OBJECTID	Object ID						
PROVINCIA	String	Yes					30
HECTARES	Double	Yes			0	0	
SHAPE	Geometry	Yes					
SHAPE_Length	Double	Yes			0	0	
SHAPE_Area	Double	Yes			0	0	

Administrative boundaries of Manica's Districts

Simple feature class
Distritos

Geometry: *Polygon*
Contains M values: *No*
Contains Z values: *No*

Field name	Data type	Allow nulls	Default value	Domain	Precision	Scale	Length
OBJECTID	Object ID						
DISTRITO	String	No					30
PROVINCIA	String	No					30
SHAPE	Geometry	Yes					
SHAPE_Length	Double	Yes			0	0	
SHAPE_Area	Double	Yes			0	0	

INTEGRATED ASSESSMENT OF MOZAMBICAN FORESTS

LAND COVER/USE ASSESSMENT DATA MODEL

Satellite catalogue and work management

MANICA GEODATABASE DIAGRAM - 6

Geographic satellite catalogue with relevant metadata. This feature class is an index to satellite images stored in external files.

Simple feature class
Satellite_catalogue

Geometry *Polygon*
Contains M values *No*
Contains Z values *No*

Field name	Data type	Allow nulls	Default value	Domain	Precision	Scale	Length	
OBJECTID	Object ID							
NAME	String	No					50	Satellite image ID name
ORIGIN	String	Yes					50	Data source
DATE	Date	Yes			0	0	8	Reference date
PROJ_ORIG	String	Yes		Projections			50	Original projection
PROJ	String	Yes		Projections			50	Final projection
PATH	String	Yes					80	Relative path where the image is stored
NOTE	String	Yes					150	
SHAPE	Geometry	Yes						
SENSOR	String	Yes		Categories			30	
RESOLUTION	Float	Yes			0	0		
SHAPE_Length	Double	Yes			0	0		
SHAPE_Area	Double	Yes			0	0		

This feature class represents the division of the study area among interpreters and status progress recorder to monitor the work status and to coordinate the interpretation on the border between interpreters.

Simple feature class
Work_division

Geometry *Polygon*
Contains M values *No*
Contains Z values *No*

Field name	Data type	Allow nulls	Default value	Domain	Precision	Scale	Length	
OBJECTID	Object ID							
NOTE	String	Yes					70	
LANDSAT	String	Yes					50	Landsat scene to be interpreted
AUTOR	Short integer	Yes		Operators	0			Photointerpreter responsible for the scene
STATUS	Short integer	Yes	0	Status	0			Working stage
SHAPE	Geometry	Yes						
SHAPE_Length	Double	Yes			0	0		
SHAPE_Area	Double	Yes			0	0		

Coded value domain
Categories

Description *Data categories*
Field type *String*
Split policy *Default value*
Merge *Default value*

Code	Description
Landsat7	Landsat7
Aster	Aster
MODIS	MODIS
MrSID mosaic	MrSID mosaic
Landsat5	Landsat5

Coded value domain
Projections

Description *Reference systems*
Field type *String*
Split policy *Default value*
Merge *Default value*

Code	Description
UTM 36s WGS84	UTM 36s WGS84
UTM 36n WGS84	UTM 36n WGS84
UTM 37s WGS84	UTM 37s WGS84
UTM 37n WGS84	UTM 37n WGS84
UTM 36s Tete	UTM 36s Tete
UTM 37s tete	UTM 37s tete
Geographic WGS84	Geographic WGS84
Geographic Tete	Geographic Tete
No reference system	No reference system

Coded value domain
Operators

Description *Operator code*
Field type *Short integer*
Split policy *Duplicate*
Merge *Default value*

Code	Description
1	1
2	2
3	3
4	4
5	5
6	6
7	7

Coded value domain
Status

Description *Work status*
Field type *Short integer*
Split policy *Default value*
Merge *Default value*

Code	Description
2	Done
1	Work in progress
0	To be done

INTEGRATED ASSESSMENT OF MOZAMBICAN FORESTS
LAND COVER/USE ASSESSMENT DATA MODEL

Field samples - 1

MANICA GEODATABASE DIAGRAM - 7

Relationship class
FS_orientation-sample

Type *Simple* — Forward label *FS_sample_description*
Cardinality *One to one* — Backward label *Orientation_samples*
Notification *None*

Origin feature class	Destination table
Name *orientation_samples*	Name *FS_sample_description*
Primary key *SAMPLE_ID*	
Foreign key *SAMPLE_ID*	

No relationship rules defined.

Filed samples used for orientation phase

Simple feature class
Orientation_samples

Geometry *Point*
Contains M values *No*
Contains Z values *No*

Field name	Data type	Allow nulls	Default value	Domain	Precision	Scale	Length	
OBJECTID	Object ID							
X_UTM36S	Long integer	Yes			0			X coordinate in UTM36S WGS84
Y_UTM36S	Long integer	Yes			0			Y coordinate in UTM36S WGS84
SHAPE	Geometry	Yes						
PROVINCE	String	Yes					10	Province where the sample is
LC_CLASS	String	Yes		LC_classes			10	Land cover class defined on the field
SAMPLE_ID	String	Yes					50	Sample identificator
SAMPLE_NUMBER	Short integer	Yes			0			Sample number
SAMPLE_PHASE	String	Yes					50	Sample collected during orientation

Table
FS_sample_description

Data on the field samples. Point feature class and descriptive tables are all linked to this table.

Field name	Data type	Allow nulls	Default value	Domain	Precision	Scale	Length	
OBJECTID	Object ID							
SAMPLE_ID	String	Yes					30	Sample identificator
SAMPLE_NUMBER	Double	Yes			0	0		Sample number
SAMPLE_PHASE	String	Yes					17	Sample collected during orientation or validation
PROVINCE	String	Yes					11	Province where the sample is
LC_CLASS	String	Yes					14	Land cover class defined on the field
AUTOR	String	Yes					18	Operator who collected the field data
DATE	Date	Yes			0	0	8	Date of field mission
AREA_HA	Double	Yes			0	0		Hectares evaluated
ACCESSIBILITY	String	Yes					16	
SLOPE	String	Yes					15	
X_UTM36S	Double	Yes			0	0		X coordinate in UTM36S WGS84
Y_UTM36S	Double	Yes			0	0		Y coordinate in UTM36S WGS84
X_LATLON	Double	Yes			0	0		X in geographic coordinates
Y_LATLON	Double	Yes			0	0		Y in geographic coordinates
DISTRICT	String	Yes					25	
NOTES	String	Yes					250	
SAMPLE_POSITION	String	Yes					12	
DISTANCE	Long integer	Yes			0			Distance from the point indicated on the form
ORIENTATION	String	Yes					15	Orintation of the point in respect to the one in the form

Relationship class
FS_validation-sample

Type *Simple* — Forward label *FS_sample_description*
Cardinality *One to one* — Backward label *validation_samples*
Notification *None*

Origin feature class	Destination table
Name *validation_samples*	Name *FS_sample_description*
Primary key *SAMPLE_ID*	
Foreign key *SAMPLE_ID*	

No relationship rules defined.

Filed samples used for validation phase

Simple feature class
Validation_samples

Geometry *Point*
Contains M values *No*
Contains Z values *No*

Field name	Data type	Allow nulls	Default value	Domain	Precision	Scale	Length	
OBJECTID	Object ID							
SHAPE	Geometry	Yes						
X_UTM36S	Long integer	Yes			0			X coordinate in UTM36S WGS84
Y_UTM36S	Long integer	Yes			0			Y coordinate in UTM36S WGS84
LC_VALIDATED	String	Yes		LC_classes			10	Land cover class defined on the field
LC_PREDICTED	String	Yes		LC_classes			10	Land cover class from fotointepretation
PROVINCE	String	Yes					10	Province where the sample is
SAMPLE_ID	String	Yes					30	Sample identificator
SAMPLE_NUMBER	Short integer	Yes			0			Sample number
SAMPLE_PHASE	String	Yes					20	Sample collected during validation

INTEGRATED ASSESSMENT OF MOZAMBICAN FORESTS
LAND COVER/USE ASSESSMENT DATA MODEL

Field samples - 2

MANICA GEODATABASE DIAGRAM - 8

Site description around the sample points.

Table
FS_site_description

Field name	Data type	Allow nulls	Default value	Domain	Precision	Scale	Length
OBJECTID	Object ID						
SAMPLE_ID	String	Yes					255
SAMPLE_NUMBER	Long integer	Yes			0		
SAMPLE_PHASE	String	Yes					30
VEGETATED	String	Yes					30
TERRESTRIAL	String	Yes					30
AQUATIC	String	Yes					10
CULTIVATED	String	Yes					10
CULTIVATED_PRINC	String	Yes					10
CULTIVATED_SEC	String	Yes					10
NATURAL	String	Yes					10
NATURAL_PRINC	String	Yes					10
NATURAL_SEC	String	Yes					10
URBAN	String	Yes					10
URBAN_PRINC	String	Yes					10
URBAN_SEC	String	Yes					10
BARE	String	Yes					10
BARE_PRINC	String	Yes					10
BARE_SEC	String	Yes					10
WATER	String	Yes					10
WATER_PRINC	String	Yes					10
WATER_SEC	String	Yes					10
HOMOGENITY	String	Yes					255
SEASONAL_TREES	String	Yes					255
SEASONAL_SHRUBS	String	Yes					20
SEASONAL_HERBS	String	Yes					20
SEASONAL_CULTIVATED	String	Yes					20
CANOPY_COVER	String	Yes					20
TREES_SPECIES	String	Yes					150

Relationship class
FS_sample_photo

Type *Composite* — Forward label *FS_photo*
Cardinality *One to many* — Backward label *FS_sample_description*
Notification *Forward*

Origin table: Name *FS_sample_description*; Primary key *SAMPLE_ID*; Foreign key *SAMPLE_ID*
Destination table: Name *FS_photo*

No relationship rules defined.

Table
FS_sample_description

Field name	Data type	Allow nulls	Default value	Domain	Precision	Scale	Length
OBJECTID	Object ID						
SAMPLE_ID	String	Yes					30
...	...	...	...	...	...	...	...

Relationship class
FS_sample_site

Type *Composite* — Forward label *FS_site_description*
Cardinality *One to many* — Backward label *FS_sample_description*
Notification *Forward*

Origin table: Name *FS_sample_description*; Primary key *SAMPLE_ID*; Foreign key *SAMPLE_ID*
Destination table: Name *FS_site_description*

No relationship rules defined.

Index to photos taken around the sample points.

Table
FS_photo

Field name	Data type	Allow nulls	Default value	Domain	Precision	Scale	Length
OBJECTID	Object ID						
SAMPLE_ID	String	Yes					16
SAMPLE_NUMBER	Double	Yes			0	0	
SAMPLE_PHASE	String	Yes					16
PHOTO_ID	String	Yes					22
PHOTO_LINK	String	Yes					24

INTEGRATED ASSESSMENT OF MOZAMBICAN FORESTS

LAND COVER/USE ASSESSMENT DATA MODEL

Field samples - 3

MANICA GEODATABASE DIAGRAM - 9

Table
FS_sample_description

Field name	Data type	Allow nulls	Default value	Domain	Precision	Scale	Length
OBJECTID	Object ID						
SAMPLE_ID	String	Yes					30
...	...	...	...	...	...	...	...

Relationship class
FS_sample_cover

Type *Composite*
Cardinality *One to one*
Notification *Forward*
Forward label *FS_cover_description*
Backward label *FS_sample_description*

Origin table
Name *FS_sample_description*
Primary key *SAMPLE_ID*
Foreign key *SAMPLE_ID*

Destination table
Name *FS_cover_description*

No relationship rules defined.

Table
FS_cover_description

Field name	Data type	Allow nulls	Default value	Domain	Precision	Scale	Length
OBJECTID	Object ID						
SAMPLE_ID	String	Yes					20
SAMPLE_NUMBER	Double	Yes			0	0	
SAMPLE_PHASE	String	Yes					30
TREES_LEV1_COVER	Long integer	Yes			0		
TREES_LEV1_HEIGHT	Long integer	Yes			0		
TREES_LEV1_LEAF_TYPE	String	Yes					30
TREES_LEV1_LEAF_PHENOLOGY	String	Yes					30
TREES_LEV2_COVER	Long integer	Yes			0		
TREES_LEV2_HEIGHT	Long integer	Yes			0		
TREES_LEV2_LEAF_TYPE	String	Yes					30
TREES_LEV2_LEAF_PHENOLOGY	String	Yes					30
TREES_LEV3_COVER	Long integer	Yes			0		
TREES_LEV3_HEIGHT	Long integer	Yes			0		
TREES_LEV3_LEAF_TYPE	String	Yes					30
TREES_LEV3_LEAF_PHENOLOGY	String	Yes					30
SHRUBS_LEV1_COVER	Double	Yes			0	0	
SHRUBS_LEV1_HEIGHT	Double	Yes			0	0	
SHRUBS_LEV1_LEAF_TYPE	String	Yes					25
SHRUBS_LEV1_PHENOLOGY	String	Yes					25
SHRUBS_LEV2_COVER	Double	Yes			0	0	
SHRUBS_LEV2_HEIGHT	Double	Yes			0	0	
SHRUBS_LEV2_LEAF_TYPE	String	Yes					20
SHRUBS_LEV2_PHENOLOGY	String	Yes					20
GRAMINOIDS_COVER	Double	Yes			0	0	
GRAMINOIDS_HEIGHT	Double	Yes			0	0	
COVER_ESTIMATION	String	Yes					20
PRIM_CULTIV_LIFEFORM	String	Yes					20
PRIM_CULTIV_CROP_NAME	String	Yes					30
SEC_CULTIV_LIFEFORM	String	Yes					30
SEC_CULTIV_CROPNAME	String	Yes					30
AVERAGE_FIELD_SIZE	Double	Yes			0	0	
FIELD_DISTRIBUTION	String	Yes					255
CULTIVATION_PERIOD	String	Yes					50
CULTIVATION_TIME_FAC_R	String	Yes					20
WATER_SUPPLY	String	Yes					20
URBAN_VEGETATION	String	Yes					20
BARE_SOILS	String	Yes					20

Land cover description around the sample points.

INTEGRATED ASSESSMENT OF MOZAMBICAN FORESTS

LAND COVER/USE ASSESSMENT DATA MODEL

Integration

MAPUTO GEODATABASE DIAGRAM

Ancillary Data

Simple feature class
Reservas

Geometry: *Polygon*
Contains M values: *No*
Contains Z values: *No*

Field name	Data type	Allow nulls	Default value	Domain	Precision	Scale	Length
OBJECTID	Object ID						
TIPO_RES	Short integer	Yes			0		
TOPONIMO	String	Yes					50
SHAPE	Geometry	Yes					
SHAPE_Length	Double	Yes			0	0	
SHAPE_Area	Double	Yes			0	0	

Natural protected areas - from IGN/ CENARCARTA/DINAGECA database

Land Cover

Land_cover_Topology

Cluster tolerance: 0,1

Participating feature classes and ranks

Feature class	Rank
Study_area	1
Land_cover	2

Topology rules

Origin feature class	Topology rule	Comparison feature class
Land_cover	Must Not Overlap	
Land_cover	Must Not Have Gaps	
Land_cover	Must Be Covered By	Study_area

Simple feature class
Land_cover

Geometry: *Polygon*
Contains M values: *No*
Contains Z values: *No*

Field name	Data type	Allow nulls	Default value	Domain	Precision	Scale	Length
OBJECTID	Object ID						
LC	String	No	xxx	LC_classes			5
LC_SEC	String	Yes		LC_classes			5
AUTOR	Short integer	Yes		Operators	0		
SHAPE	Geometry	Yes					
PERC_1C	Short integer	Yes		Percentage	0		
HECTARES	Long integer	Yes			0		
POLY_ID	Long integer	Yes			0		
SHAPE_Length	Double	Yes			0	0	
SHAPE_Area	Double	Yes			0	0	

Simple feature class
Study_area

Geometry: *Polygon*
Contains M values: *No*
Contains Z values: *No*

Field name	Data type	Allow nulls	Default value	Domain	Precision	Scale	Length
OBJECTID	Object ID						
PROVINCIA	String	No					30
HECTARES	Double	No			0	0	
SHAPE	Geometry	Yes					
SHAPE_Length	Double	Yes			0	0	
SHAPE_Area	Double	Yes			0	0	

Table
LANDCOVER_CODES

Field name	Data type	Allow nulls	Default value	Domain	Precision	Scale	Length
OBJECTID	Object ID						
CODE	String	Yes					9
DESCRIPTION	String	Yes					64
LCCS_CODE	String	Yes					50

Coded value domain
LC_classes

Description: *Land cover classes*
Field type: *String*
Split policy: *Duplicate*
Merge policy: *Default value*

Code	Description
xxx	To be defined
1TCF	Tree crops
1TCW	Forest plantation
2FBG	Gallery forest
2FDC	Mopane dense
2WDC	Mopane open
2GCT	Tree savanna
2GCS	Shrub savanna
2GOS	Open shrub savanna
5BU	Built-up areas
6BR	Bare rocks
6BS	Bare soils
7WB	Artificial water bodies
8WB	Natural water bodies
1CXF	Shifting cultivation with open to closed forested areas
2FE	Broadleaved (semi-) evergreen closed forest
2WE	Broadleaved (semi-) evergreen open forest with shrubs
2WD	Broadleaved (semi-) deciduous open forest with shrubs
2TE	Broadleaved (semi-) evergreen thicket
2TD	Broadleaved (semi-) deciduous thicket
2SE	Broadleaved (semi-) evergreen shrubland
2SD	Broadleaved (semi-) deciduous shrubland
2FXC	Closed to open forested areas with shifting cultivation
2FD	Broadleaved (semi-) deciduous closed forest
4WET	Woodland temporarily flooded
4HVT	Herbaceous temporarily flooded
1FCR	Rainfed crops
1FCI	Irrigated crops
2DBC	Coastal dense forest
2DBO	Coastal open forest
4FEP	Mangrove dense
4HVP	Herbaceous permanently flooded
4WEP	Mangrove open
6SS	Dunes
4SET	Shrubland temporarily flooded

INTEGRATED ASSESSMENT OF MOZAMBICAN FORESTS

LAND COVER/USE ASSESSMENT DATA MODEL

Integration

MOZAMBIQUE GEODATABASE DIAGRAM - 1

Land Cover

Simple feature class
Land_cover

Geometry: *Polygon*
Contains M values: *No*
Contains Z values: *No*

Field name	Data type	Allow nulls	Default value	Domain	Precision	Scale	Length	
OBJECTID	Object ID							
LC_PRI	String	No	xxx	LC_classes			5	Dominant land cover
LC_SEC	String	Yes		LC_classes			5	Secondary land cover
LC_TER	String	Yes		LC_classes			5	Tertiary land cover
NOTE	String	Yes					70	
AUTOR	Short integer	Yes		Operators	0			Photointerpreter who created the data
SHAPE	Geometry	Yes						
LC_PRI_PER	Short integer	Yes		Perc_class	0			% of the dominant land cover
LC_SEC_PER	Short integer	Yes		Perc_class	0			% of the secondary land cover
LC_TER_PER	Short integer	Yes		Perc_class	0			% of the tertiary land cover
HECTARES	Long integer	Yes			0			
POLY_ID	Long integer	Yes			0			Polygon identificator
SHAPE_Length	Double	Yes			0	0		
SHAPE_Area	Double	Yes			0	0		

Coded value domain
Percentage

Description: *Percentage of the dominant class*
Field type: *Short integer*
Split policy: *Default value*
Merge policy: *Default value*

Code	Description
1	0% - 24%
2	25% - 49%
3	50% - 74%
4	75% - 99%
5	100%

Simple feature class
Study_area

Geometry: *Polygon*
Contains M values: *No*
Contains Z values: *No*

Field name	Data type	Allow nulls	Default value	Domain	Precision	Scale	Length
OBJECTID	Object ID						
SHAPE	Geometry	Yes					
SHAPE_Length	Double	Yes			0	0	
SHAPE_Area	Double	Yes			0	0	

Table
LANDCOVER_CODES

Field name	Data type	Allow nulls	Default value	Domain	Precision	Scale	Length
OBJECTID	Object ID						
CODE	String	Yes					9
DESCRIPTION	String	Yes					64
LCCS_CODE	String	Yes					50

Coded value domain
LC_classes

Description: *Land cover classes*
Field type: *String*
Split policy: *Duplicate*
Merge policy: *Default value*

Code	Description
xxx	To be defined
1TC	Tree crops
1SC	Shrub crops
1FC	Field crops
1CXF	Shifting cultivation with forest
2FE	(Semi-) Evergreen forests
2FD	(Semi-) Deciduous forests
2WE	(Semi-) Evergreen woodlands
2WD	(Semi-) Deciduous woodlands
2TK	Thickets
2SL	Shrublands
2GL	Grasslands
2FXC	Forest with shifting cultivation
3AC	Cultivated aquatic or regularly flooded areas
4WF	Aquatic / regularly flooded woodlands
4SF	Aquatic / regularly flooded shrublands
4HF	Aquatic / regularly flooded herbaceous vegetation
5BU	Built up areas
6BA	Bare areas
7WB	Artificial waterbodies
8WB	Natural waterbodies
4FF	Mangrove dense

Land_cover_Topology Cluster tolerance: 1

Participating feature classes and ranks

Feature class	Rank
Study_area	1
Land_cover	2

Topology rules

Origin feature class	Topology rule	Comparison feature class
Land_cover	Must Not Overlap	
Land_cover	Must Not Have Gaps	
Land_cover	Must Be Covered By	Study_area

INTEGRATED ASSESSMENT OF MOZAMBICAN FORESTS
LAND COVER/USE ASSESSMENT DATA MODEL

Integration

MOZAMBIQUE GEODATABASE DIAGRAM - 2

Validation samples

Simple feature class **Validation_samples**

Geometry: Point; Contains M values: No; Contains Z values: No

Point samples taken on Aster images used for validation phase

Field name	Data type	Allow nulls	Default value	Domain	Precision	Scale	Length	Description
OBJECTID	Object ID							
LC_PRI	String	Yes		LC_classes			5	Dominant land cover of the LC polygon containing the sample
LC_SEC	String	Yes		LC_classes			5	Secondary land cover of the LC polygon containing the sample
LC_TER	String	Yes		LC_classes			5	Tertiary land cover of the LC polygon containing the sample
LC_VALIDATED	String	Yes		LC_classes			10	Land cover class defined on the Aster image
ASTER	String	Yes					50	
SHAPE	Geometry	Yes						
X_UTM36S	Double	Yes			0	0		X coordinate in UTM36S WGS84
Y_UTM36S	Double	Yes			0	0		Y coordinate in UTM36S WGS84
POLYLC_ID	Long integer	Yes			0			Identificator of the LC polygon containing the sample
CONFIRMED	String	Yes					5	Validation result of the photointerpretation

Ancillary Data

Simple feature class **Reservas**

Geometry: Polygon; Contains M values: No; Contains Z values: No

Natural protected areas - from IGN/ CENARCARTA/DINAGECA database

Field name	Data type	Allow nulls	Default value	Domain	Precision	Scale	Length
OBJECTID	Object ID						
TIPO_RES	Short integer	Yes			0		
TOPONIMO	String	Yes					50
SHAPE	Geometry	Yes					
SHAPE_Length	Double	Yes			0	0	
SHAPE_Area	Double	Yes			0	0	

10 ON-THE-JOB TRAINING

Together with DNFFB/UIF training needs were identified included in the on-the-job training programme conducted in the period 21 November - 14 December 2005 in Florence, Italy, for three UIF Staff members. As an evident technical level within UIF is present, the focus of the training was on:

- Emphasis on the remote sensing and land-cover interpretation process, the steps to take, the crosschecks to be executed, the continuous quality checking (both of the land-cover types identified as on the spatial characteristics of the data layer), etc., was a key issue.
- The importance of the selection of the period for image acquisition and the resulting type of image with its spectral characteristics were demonstrated using the available imagery.
- Working with different LANDSAT band combinations, digital image processing, mosaicking, and working with images from different seasons to extract the maximum amount of information.
- The advantages and disadvantages of visual image interpretation versus automatic classification (using the example described in paragraph 8.2).
- The visual interpretation of land cover at National level using the degraded LANDSAT images.
- Design of a sampling scheme for field validation and subsequently calculation of thematic accuracy of the interpretation (using the example of Manica Province described in paragraph 6.2 and 7.2.1 as the field validation data for Maputo Province had not yet arrived in Florence and the design at National level was under discussion).
- The different approach to field validation adopted at National level with the explanation that at the nominal scale of 1:1,000,000 the use of detailed field survey information becomes a matter of costs/benefit analysis in a season in which field surveying is anyhow impossible (November-December) and an area would be involved that would mean high costs of transportation of any field survey teams the alternative of using a different, more detailed type of free of charge downloadable satellite images becomes an optimal solution for the level of detail required even in the accuracy assessment at such a nominal scale.
- Feedback of field validation data into the interpretation in order to finalise it as well as the use of expert knowledge into the preliminary National level interpretation (i.e. the procedure of field orientation was not used at National level).
- Interpretation issues and level of information within the land-cover polygons at 1:250,000 versus 1:1,000,000 nominal scales (this was extensively discussed and it was explained why certain classes, for example coastal dunes, with a too detailed level of information were not included in the National level interpretation though they can be extracted with GIS procedures) (see also paragraph 8.1).
- Visits to a limited number of selected institutes/organisations in Italy dealing with remote sensing applications to examine state-of-the-art applications (e.g., the Istituto Agronomico per l'Oltremare of the Italian Ministry of Foreign Affairs (IAO) and IBIMET national research centre).

In addition to the agreed focus on the points mentioned above, the on-the-job training comprised also the downloading of satellite images from Internet (described in Appendices C and D), a detailed explanation of the FAO/UNEP LCCS version 2 for definition of classes (see Chapter 4) and for semantic data harmonisation (see paragraph 8.3), the explanation of the approach to land-cover change adopted for Manica Province (see paragraph 8.4) and a possible approach to monitor burnt areas (see paragraph 8.5). A special session was organised in order to explain the importance of a well-structured and organised geodatabase not only during the remote sensing and land-cover interpretation but also for facilitating work in the long term (see Chapter 9). During the on-the-job training more hands-on experience in the use of both ERDAS Imagine and ArcGIS was obtained.

11 RESULTS AND CONCLUSIONS

11.1 The resulting land-cover data sets

Three land-cover data sets have been produced using on-screen visual interpretation of LANDSAT 5 TM satellite images of the period 2004-2005 using several ancillary data sets. A multiple-view remote sensing approach was taken combining multi-stage, multi-spectral and multi-temporal sensing. In the interpretation process various levels of complexity were encountered, from a simple direct recognition of objects to the inference of site conditions. The process of convergence of evidence to successfully increase the accuracy and detail of the land-cover interpretations was used.

The applied minimum mapping units are $1km^2$ for the 1:250,000 nominal scale interpretations and $16km^2$ for the 1:1,000,000 nominal scale interpretation. The difference in requested minimum mapping unit at Province level, $1km^2$ versus the $4km^2$ mentioned in the TOR, is due to the difference between the two nominal scales that is a factor 16 and not 4. Consequently, more detail has been included in the two data sets at Province level. In addition, at National level a higher level of detail was reached by setting two different thresholds for the minimum mapping unit: (1) polygons containing mixed classes maintained a minimum mapping unit of 16 km^2; and (2) a minimum mapping unit of 9 km^2 was set for single class polygons.

The resulting data sets for Manica Province, Maputo Province and Mozambique have a positional accuracy with a RMSE in the range of 15.5-23.4m (19.3m on average), 11.7-19.7m (15.6m on average) and 7.3-51.8m (20.7m on average) per LANDSAT scene, corresponding with an average error of less than one pixel (LANDSAT has a pixel of 30m) at both Province and National levels. This is the minimum error possible as a pixel is the smallest element of the LANDSAT image. These georeferencing errors should be combined with those of the imagery used for image-to-image georeferencing, i.e. LANDSAT images with a RMSE of less than 50m. Thus, the positional accuracy in case of error propagation results in a RMSE of approximately 2 pixels at both Province and National levels. The thematic accuracies of the land-cover data for Manica Province, Maputo Province and Mozambique are 87.0% (KHAT=0.84), 86.0% (KHAT=0.85) and 86.0% (KHAT=0.83) respectively, thereby fulfilling the TOR requirement of being at least 85%. The positional and thematic accuracy assessment results allow the use of these data sets for applications with nominal scales of 1:250,000 at Province level and 1:1,000,000 at National level.

The timeframe for the satellite image interpretation and execution of field surveys was limited by the availability of the favourable dry season. Field surveys for field orientation and field validation purposes could be executed for the two Provinces (with 111 and 313 field observations respectively), but when the National level interpretation was undertaken the Project found itself in the unfavourable wet season. Considerations of the costs/benefits of field surveys covering the whole of Mozambique using a nominal scale of 1:1,000,000 should be balanced against one another. Therefore at National level no further field surveys were executed but 338 observations on ASTER images having 15m resolution served as validation data. Another very important aspect is that any Forest Inventory can only start once the land-cover data set is finalised according to the quality criteria defined in the TOR because it is the baseline data set for stratification. Even though the time schedule was very tight, the completion of the Manica Province land-cover data set permitted the execution of the Forest Inventory in that Province by late 2005. The completion of the data sets for Maputo Province and at the National level in a timely manner by December 2005 permits the Forest Inventory in 2006 the full use of the dry season for survey.

Table 33. Land-cover statistics of 2004 for Manica Province

LCCS Land-cover category	Land-cover class: User code	Land-cover class: User name	Class in mixed land-cover types [22]: as primary land cover (Ha)	Class in mixed land-cover types [22]: as secondary land cover (Ha)	Class as pure land-cover type (Ha)	Total of the class in mixed and pure land-cover types (Ha)	Total area relative to provincial surface (%)
A11. Cultivated and managed terrestrial areas	1TCF	Tree crops	0	3,126	0	3,126	0.03
	1TCW	Forest plantations	21,362	0	21,362	21,362	0.22
	1SCT	Tea plantations	0	0	0	0	0.00
	1FCR	Rainfed field crops	335,469	193,721	74,169	529,190	5.57
	1FCI	Irrigated field crops	0	0	0	0	0.00
	1CXF	Shifting cultivation with open to closed forested areas	353,241	1,311	272,227	354,552	3.73
A12. (Semi-) natural terrestrial vegetation	2DEC	Coastal dense woody vegetation	0	0	0	0	0.00
	2DEO	Coastal open woody vegetation	0	0	0	0	0.00
	2FEM	Closed broadleaved (semi-) evergreen mountainous forest	75,601	8,664	70,757	84,265	0.89
	2FE	Broadleaved (semi-) evergreen closed forest	160,212	56,161	123,793	216,373	2.28
	2FEG	Gallery forest	163,281	107,559	63,184	270,840	2.85
	2FEA	Mecrusse dense	0	0	0	0	0.00
	2FD	Broadleaved (semi-) deciduous closed forest	364,123	89,552	175,138	453,675	4.77
	2FDC	Mopane dense	72,677	66,606	45,163	139,283	1.47
	2FDB	Miombo dense	768,079	172,519	152,514	940,598	9.90
	2WEM	Open broadleaved (semi-) evergreen mountainous forest	30,754	3,823	12,626	34,577	0.36
	2WE	Broadleaved (semi-) evergreen open forest with shrubs	27,877	5,973	8,788	33,850	0.36
	2WEA	Mecrusse open	0	0	0	0	0.00
	2WD	Broadleaved (semi-) deciduous open forest with shrubs	199,089	170,692	86,414	369,781	3.89
	2WDC	Mopane open	713,276	110,577	377,065	823,853	8.67
	2WDB	Miombo open	814,937	639,041	318,748	1,453,978	15.30
	2TE	Broadleaved (semi-) evergreen thicket	4,613	10,128	592	14,741	0.16
	2TD	Broadleaved (semi-) deciduous thicket	11,680	125,608	2,301	137,288	1.44
	2SE	Broadleaved (semi-) evergreen shrubland	3,983	2,740	2,158	6,723	0.07
	2SD	Broadleaved (semi-) deciduous shrubland	136,468	494,073	22,620	630,541	6.63
	2GCT	Tree savanna	291,857	229,419	123,345	521,276	5.49

[22] The calculation of the area statistics in case two classes compose a so-called mixed class has been systematically set at 60% of the polygon area for the dominant land-cover class and 40% of the polygon area for the secondary land cover. This approach is identical to the one applied by the FAO AFRICOVER project.

LCCS Land-cover category	Land-cover class: User code	User name	Class in mixed land-cover types [22]: as primary land cover (Ha)	as secondary land cover (Ha)	Class as pure land-cover type (Ha)	Total of the class in mixed and pure land-cover types (Ha)	Total area relative to provincial surface (%)
	2GCS	Shrub savanna	316,385	443,245	85,054	759,630	7.99
	2GOS	Open shrub savanna	105,946	97,276	39,735	203,222	2.14
	2FXC	Closed to open forested areas with shifting cultivation	894,799	4,190	705,415	898,989	9.46
A23. Cultivated aquatic or regularly flooded areas	3GCO	Rice crops	0	0	0	0	0.00
A24. (Semi-) natural aquatic or regularly flooded vegetation	4FEP	Mangrove dense	0	0	0	0	0.00
	4WEP	Mangrove open	0	0	0	0	0.00
	4WET	Woodland temporarily flooded	171,748	79,086	125,885	250,834	2.64
	4SET	Shrubland temporarily flooded	73,676	5,580	4,775	79,256	0.83
	4HVT	Herbaceous temporarily flooded	42,670	106,696	10,045	149,366	1.57
	4HVP	Herbaceous vegetation permanently flooded	0	0	0	0	0.00
	4HVS	Tandos	0	0	0	0	0.00
B15. Artificial surfaces and associated areas	5BU	Built-up areas	11,502	0	8,251	11,502	0.12
B16. Bare areas	6BR	Bare rocks	27,119	6,675	4,901	33,794	0.36
	6BS	Bare soils	17,896	30,623	1,182	48,519	0.51
	6SS	Dunes	0	0	0	0	0.00
B27. Artificial water bodies	7WB	Artificial water bodies	9,533	0	9,533	9,533	0.10
B28. Natural water bodies	8WB	Natural water bodies	8,500	10,553	5,396	19,053	0.20

Table 34. Land-cover statistics of 2004 for Maputo Province

LCCS Land-cover category	Land-cover class: User code	Land-cover class: User name	Class in mixed land-cover types [23]: as primary land cover (Ha)	Class in mixed land-cover types [23]: as secondary land cover (Ha)	Class as pure land-cover type (Ha)	Total of the class in mixed and pure land-cover types (Ha)	Total area relative to provincial surface (%)
A11. Cultivated and managed terrestrial areas	1TCF	Tree crops	136	0	2,099	2,235	0.10
	1TCW	Forest plantations	0	0	2,858	2,858	0.12
	1SCT	Tea plantations	0	0	0	0	0.00
	1FCR	Rainfed field crops	71,407	36,672	86,194	194,272	8.48
	1FCI	Irrigated field crops	24,131	3,462	30,562	58,155	2.54
	1CXF	Shifting cultivation with open to closed forested areas	0	0	46,775	46,775	2.04
A12. (Semi-) natural terrestrial vegetation	2DEC	Coastal dense woody vegetation	0	4,031	0	4,031	0.18
	2DEO	Coastal open woody vegetation	466	633	633	1,732	0.08
	2FEM	Closed broadleaved (semi-) evergreen mountainous forest	0	0	0	0	0.00
	2FE	Broadleaved (semi-) evergreen closed forest	13,228	0	43,762	56,990	2.49
	2FEG	Gallery forest	4,952	280	31,453	36,685	1.60
	2FEA	Mecrusse dense	0	0	0	0	0.00
	2FD	Broadleaved (semi-) deciduous closed forest	12,909	2,228	110,620	125,757	5.49
	2FDC	Mopane dense	2,798	37,988	0	40,786	1.78
	2FDB	Miombo dense	0	0	0	0	0.00
	2WEM	Open broadleaved (semi-) evergreen mountainous forest	0	0	0	0	0.00
	2WE	Broadleaved (semi-) evergreen open forest with shrubs	9,725	4,948	18,952	33,624	1.47
	2WEA	Mecrusse open	0	0	0	0	0.00
	2WD	Broadleaved (semi-) deciduous open forest with shrubs	70,932	47,821	108,929	227,682	9.94
	2WDC	Mopane open	119,923	77,109	65,998	263,030	11.49
	2WDB	Miombo open	0	0	0	0	0.00
	2TE	Broadleaved (semi-) evergreen thicket	5,494	1,410	7,152	14,056	0.61
	2TD	Broadleaved (semi-) deciduous thicket	8,100	3,716	15,579	27,395	1.20
	2SE	Broadleaved (semi-) evergreen shrubland	194	0	3,862	4,056	0.18
	2SD	Broadleaved (semi-) deciduous shrubland	104,567	90,528	56,868	251,964	11.00

[23] The calculation of the area statistics in case two classes compose a so-called mixed class has been systematically set at 60% of the polygon area for the dominant land-cover class and 40% of the polygon area for the secondary land cover. This approach is identical to the one applied by the FAO AFRICOVER project.

LCCS Land-cover category	Land-cover class		Class in mixed land-cover types [23]		Class as pure land-cover type (Ha)	Total of the class in mixed and pure land-cover types (Ha)	Total area relative to provincial surface (%)
	User code	User name	as primary land cover (Ha)	as secondary land cover (Ha)			
	2GCT	Tree savanna	188,018	25,254	84,693	297,965	13.01
	2GCS	Shrub savanna	37,686	84,887	114,135	236,708	10.34
	2GOS	Open shrub savanna	7,963	2,383	4,558	14,904	0.65
	2FXC	Closed to open forested areas with shifting cultivation	0	273	98,659	98,932	4.32
A23. Cultivated aquatic or regularly flooded areas	3GCO	Rice crops	0	0	0	0	0.00
A24. (Semi-) natural aquatic or regularly flooded vegetation	4FEP	Mangrove dense	664	0	4,572	5,236	0.23
	4WEP	Mangrove open	0	386	0	386	0.02
	4WET	Woodland temporarily flooded	13,798	2,029	19,941	35,768	1.56
	4SET	Shrubland temporarily flooded	1,753	0	4,267	6,020	0.26
	4HVT	Herbaceous temporarily flooded	11,845	46,326	28,949	87,120	3.80
	4HVP	Herbaceous vegetation permanently flooded	6,240	5,568	9,648	21,456	0.94
	4HVS	Tandos	0	0	0	0	0.00
B15. Artificial surfaces and associated areas	5BU	Built-up areas	10,321	5,126	20,881	36,328	1.59
B16. Bare areas	6BR	Bare rocks	0	0	0	0	0.00
	6BS	Bare soils	203	4,077	1,910	6,190	0.27
	6SS	Dunes	827	1,761	3,475	6,063	0.26
B27. Artificial water bodies	7WB	Artificial water bodies	0	208	7,216	7,424	0.32
B28. Natural water bodies	8WB	Natural water bodies	10,861	3,964	22,270	37,095	1.62

Table 35. Land-cover statistics of 2004-2005 for Mozambique

LCCS land-cover category	Land-cover class[24] User code	User name	Area (Ha)	(%)
A11. Cultivated and managed terrestrial areas	TC	Tree crops	1,900,528	2.43
	1SC	Shrub crops	0	0.00
	1FC	Field crops	6,002,813	7.67
	1CXF	Shifting cultivation with forests	3,555,343	4.55
A12. (Semi-) natural terrestrial vegetation	2FE	(Semi-) evergreen forests	5,440,814	6.96
	2FD	(Semi-) deciduous forests	16,013,101	20.47
	2WE	(Semi-) evergreen woodlands	936,229	1.20
	2WD	(Semi-) deciduous woodlands	15,295,665	19.55
	2TK	Thickets	1,039,777	1.33
	2SL	Shrublands	8,276,292	10.58
	2GL	Grasslands	7,407,510	9.47
	2FXC	Forests with shifting cultivation	5,405,275	6.91
A23. Cultivated aquatic or regularly flooded areas	3AC	Cultivated aquatic or regularly flooded areas	14,772	0.02
A24. (Semi-) natural aquatic or regularly flooded vegetation	4FF	Aquatic or regularly flooded forests	335,520	0.43
	4WF	Aquatic or regularly flooded woodlands	832,335	1.06
	4SF	Aquatic or regularly flooded shrublands	437,045	0.56
	4HF	Aquatic or regularly flooded herbaceous vegetation	2,169,887	2.77
B15. Artificial surfaces and associated areas	5BU	Built-up areas	1,168,422	1.49
B16. Bare areas	6BA	Bare areas	947,669	1.21
B27. Artificial water bodies	7WB	Artificial water bodies	33,278	0.04
B28. Natural water bodies	8WB	Natural water bodies	1,009,149	1.29

[24] In case of so-called mixed classes the area statistics have been calculated using 40%, 30% and 30% of the area of the polygon respectively for the dominant, secondary and tertiary land-cover class that composes such a mixed class. This calculation is conform the FAO AFRICOVER approach.

The data sets comprise a legend defined with the FAO/UNEP Land Cover Classification System, an international standard (Di Gregorio and Jansen, 2000). The defined set of classes includes those of the TOR-Appendix 2 and goes beyond, as non-vegetated land-cover classes have also been included. Although not requested by the TOR, for each class identified also the percentage of this class in the polygon is specified. In Manica Province 31 different land-cover classes were differentiated and in Maputo Province 33 different classes. At National level 20 classes were differentiated.

This Technical Report, accompanying the three land-cover data sets produced in digital format, outlines the extent, distribution and relationships between different land-cover types. Reliable up-to-date land-cover statistics concerning the spatial extent of the different land-cover types at National level and for the two Provinces were obtained.

In Manica Province, the land-cover is dominated by (Table 33):

1. Miombo forests (open and closed) with a 25.2% of total cover of the Province;
2. Savanna (Tree and Shrub) with 13.5% of total cover of the Province;
3. Shifting cultivation with 13.2% of total cover of the Province; and
4. Mopane forests (open and closed) with 10.1% of total cover of the Province.

In Maputo Province, the land-cover is dominated by (Table 34):

1. Savanna (Tree and Shrub) with 24.0% of total cover of the Province;
2. Mopane (Open and dense) with 13.3% of total cover of the Province;
3. Open forest with shrubs with 11.4% of total cover of the Province; and
4. Shrubland with 11.2% of total cover of the Province.

Mozambique is a country where (Semi-) deciduous forests are dominant covering 20.5% of the country, followed by (Semi-) deciduous woodlands with 19.6% (Table 35). Shrublands with 10.6%, Grasslands with 9.5% and Field crops with 7.7% of total cover follow at lower frequencies. If one combines the two classes Shifting cultivation with forests (1CXF) and Forests with shifting cultivation (2FXC), the total area where one finds a combination of forests and cultivation amounts to 11.5% and is thus substantial.

Comparisons of statistics on either land cover or land-cover change with previous data sets (Saket et al., 1995; IGN/CENACARTA/DINAGECA, 1999) ***are not recommended*** **for the simple reason that although all these data sets used remote sensing, their class sets (i.e. legends) are very different**. For the first time classes like Shifting cultivation with open to closed forests (1CXF) and Open to closed forests with shifting cultivation (2FXC) have been delineated in order to have spatially explicit data on areas where a mixture of forest uses and agricultural uses is found. The land-cover change application has been specially developed to allow UIF/DNFFB to use satellite data of previous periods to delineate the changes from the period that occurred before, thereby going back in time. One should be aware, though, that by going back in time uncertainties in the data would increase, as one cannot validate the change interpretations in the field. In the international scientific literature, the attribution of the process of deforestation to shifting cultivators is seen as a simplification. Case study evidence confirms that shifting cultivation alone is never considered to cause deforestation, it occurs along with other agricultural activities and other proximate causes (e.g., wood extraction, expansion of infrastructure) (Geist and Lambin, 2001; Lambin et al., 2001).

In the three created land-cover data sets there are several classes that are very similar in their physiognomic-structural description and they are only distinguished at the level of certain plant species that are characteristic. Examples are, for instance, Broadleaved (semi-) deciduous closed forest, Mopane closed and Miombo closed, as well as Broadleaved (semi-) deciduous open forest, Mopane open and Miombo open.

Table 36 shows an example of comparison of three similar classes at the LCCS classifier level. This example illustrates that the only difference between these three classes is the use of the classifier “floristic aspect”. This means that on satellite images these classes having the same leaf type and leaf phenology *cannot* be distinguished from one another, this is only possible with the use of ancillary data and/or expert knowledge of the terrain.

Table 36. Comparison of similar land-cover classes at LCCS classifier level

LCCS Classifiers used	2FD Broadleaved (semi-) deciduous closed forest	2FDC Mopane dense	2FDB Miombo dense
Life form	A3. Trees	A3. Trees	A3. Trees
Cover	A10. Closed (≥ 70%)	A10. Closed (≥ 70%)	A10. Closed (≥ 70%)
Height	B2. ≥ 5m	B2. ≥ 5m	B2. ≥ 5m
Macropattern	-	-	-
Leaf type	D1. Broadleaved	D1. Broadleaved	D1. Broadleaved
Leaf phenology	E2. Deciduous – (E4. semi)	E2. Deciduous – (E4. semi)	E2. Deciduous – (E4. semi)
Floristic aspect	-	*Colophospermum mopane*	*Brachystegia* spp.

If the data sets contain polygons that are labelled with one of these three classes and one would find after a field visit that this class label should be different (which in the above example would only be the case if the “floristic aspect” has been identified wrongly as the class 2FD remains at a more generic level or one would want to add “floristic aspect” to class 2FD in which case it should become either 2FDC or 2FDB), then the data set can of course be adjusted to better reflect the ground truth. One should keep in mind, however, that (1) the land-cover interpretation is based upon examination of *areas* and not of a single sample *point*; and (2) that such a change will *not* have any effect on the thematic accuracy assessment at aggregated data level as these classes in this accuracy assessment were already grouped. The data quality at aggregated data level is thus not affected.

11.2 Operational implementation of methodologies

Operational implementation of state-of-the-art technologies related to remote sensing and land-cover interpretation included the interpretation of land-cover types in a fully digital environment with multiple interpreters working at the same time on the same land-cover interpretation (see Appendix G for the team composition). The remote sensing process included everything from image acquisition, to georeferencing, image enhancement, creating FCC images for interpretation purposes, the use of multiple images and available digital ancillary data sets.

However, the application of remote sensing techniques cannot produce reliable results if there is not an investment made in establishing the relationships between what one visually can interpret on-screen and what one observes in the field. Therefore, two types of field surveys were executed. Field orientation established a better understanding between the spectral reflectance values of the satellite images and the ground truth during interpretation, whereas the field validation confronted the interpretation with the ground truth in order to assess the thematic accuracy of the interpretation. These field surveys contributed to the high quality of the resulting land-cover data sets.

The adopted procedures strengthen the existing UIF capacity to monitor natural resources. All methodologies and standards applied have been part of the on-the-job training conducted in the context of the Project and they can be replicated in future by UIF/DNFFB. In this Technical Report detailed explanations are provided of all the steps taken in the remote sensing and land-cover interpretation component in order to function, if necessary, as a kind of manual.

11.3 The land-cover/use assessment geodatabase

The remote sensing and land-cover component is completely integrated in the general framework of the Project, but it had also some individual requirements. Therefore, it was decided to develop **a dedicated geodatabase for this specific component of the Project in order to structure and organise the data from the very beginning of operational activities so as to have a flawless data production, storage, integration and analysis chain**. This resulted in the so-called land-cover/use assessment geodatabase.

This geodatabase was the primary technical tool to perform the land-cover interpretations. The software and hardware were selected to manage a multi-user environment. The GIS software used is ArcGIS and the database SQL Server. ArcSDE handled the connection between the GIS tools, installed on every computer/workstation, and the geodatabase located on the server.

The geodatabase is structured around five key thematic and functional groups: (1) Land Cover, (2) Field Sample Data, (3) Ancillary Data, (4) Work Management and (5) Satellite Data. Not only the produced land-cover data sets are included but also all digital ancillary data that was used. Furthermore, a complete metadata description is associated to all data layers, according to the ISO 19115 standard.

The land-cover/use geodatabase can be imported using the ".XML" file by either creating an empty geodatabase using ArcSDE for the multi-user environment or by using ArcCatalog for creation of a personal geodatabase in a stand-alone environment. In the files handed over to UIF/DNFFB, there is also a "light" version of the three geodatabases that does not contain the raster images.

The land-cover/use assessment geodatabase has been constructed in such a way that UIF/DNFFB can use it as a framework to build on and include new land-cover and other data sets in future. The created geodatabase can be used for the production of a range of outputs (e.g., maps, tables and reports) and applications (e.g., land-cover change, burnt area monitoring, environmental modelling, etc.) and facilitates data exchanges with national and international institutions and services.

12 RECOMMENDATIONS

12.1 The resulting land-cover data sets

It is strongly recommended in order to be able to monitor the occurrence of land-cover types, their location, extent and distribution over time **to stick to a well-defined methodology that should be systematically applied at regular intervals**. The use of available free of charge downloadable satellite imagery from the Internet was made with the main objective that such a procedure could be adopted also in future.

The use of the three created land-cover data sets should not remain limited to providing the baseline data for the Forest Inventory of the AIFM Project. Land cover is a subject that is relevant in many environmental and agricultural applications and studies. **The value of these data sets is related to the frequency and intensity of their use**. It is therefore of prime importance that these data will be shared, as those who will ultimately benefit from its use are the people in Mozambique.

The option to use on-screen visual interpretation to collect land-cover data at the 1:1,000,000 nominal scale using LANDSAT satellite images should be revisited for a number of reasons:

- LANDSAT satellite images have a pixel resolution of 30m that is suitable for delineation of land-cover polygons when working at nominal scales ranging from 1:50,000 to 1:250,000.
- There are various problems with the LANDSAT program and the availability of this type of imagery in the long term has become uncertain.
- If LANDSAT images would be no longer an option, there are others types of satellite imagery (e.g., multi-spectral data from SPOT with 20m resolution, ASTER with 15m, IKONOS with 4m, etc.) that however all have a pixel resolution of less than 30m meaning that the level of detail on these images is even greater than on the LANDSAT images.
- The nominal scale of 1:250,000 is well adapted for Province level applications. These data can be scaled to 1:1,000,000 nominal scale if and when needed.

12.2 Operational implementation of methodologies

The adopted procedures strengthen the existing UIF capacity to monitor natural resources. All methodologies and standards applied were part of the on-the-job training conducted and they can be replicated in future by UIF/DNFFB. The real test whether or not the implemented procedures, standards and methodologies are operational will come after closure of the AIFM Project. Therefore during the life span of the Project, it is recommended to keep a continuous intensive dialogue going between the UIF/DNFFB/MINAG and Agriconsulting S.p.A.

12.3 The land-cover/use assessment geodatabase

The land-cover/use assessment geodatabase has been constructed in such a way that UIF/DNFFB can use it as a framework to build on and include new land-cover and other data sets in future. **It is strongly recommended that in the general AIFM geodatabase replication of data sets already included in the created and delivered land-cover/use assessment geodatabase is avoided as it would lead to unnecessary multiplication of data volumes**.

Data management is an essential part of any data collection effort and **it is strongly recommended not to wait until data has been collected but to project an Information System, or once one is established its possible modifications, before data collection in order to have a perfect data flow from collection until the analysis phase**. Projection of an Information System, its design and testing well in advance of its operational use will save a lot of time and effort in order to deliver the requested products at the agreed moment of delivery.

12.4 Correspondence between Forest Inventory and land-cover data sets

Correspondence between the Forest Inventory data and the three land-cover data sets may bring discrepancies to light that should be avoided although these data sets are the result of different methodologies and scales. It should be understood that it is unrealistic to expect a 100% correspondence between these data sets due to the different objectives with which they were created.

It is recommended to make an ulterior check of the land-cover type of the Forest Inventory sampling sites. This is the more important at National scale where up to three land-cover classes may be found in a single land-cover polygon, but one should not exclude -considering the scale of this data set- that more than three land-cover types may be present. Therefore, it is important to check on the original LANDSAT satellite images with 30m resolution if the selected sample site corresponds with a land-cover type of interest to the Forest Inventory. Such an ulterior crosscheck has also been executed for the selection of sample sites in Manica Province by the remote sensing and land-cover interpretation team in Florence once they had made a preselection of sample sites. As this team has completed its tasks in the context of the AIFM Project, it is now up to UIF to perform the same role.

The data resulting from the Forest Inventory should also be crosschecked with the land-cover interpretations, as the level of detail of the Forest Inventory data is greater in addition to having been always actually measured in the field. One should keep in mind however that the Forest Inventory collect detailed data at sample points, whereas land-cover data is based upon examination of areas. The proposed solution is that the Forest Inventory data only overrule the land-cover class derived at a smaller scale when there is ample proof that the whole area is reflected by the Forest Inventory sample. But this crosschecking can only take place once the data sets have been collected and therefore needs to be scheduled in the final phase of the AIFM Project. This crosscheck should include once more the on-screen visual interpretation in order to decide whether or not a polygon label needs to be adjusted.

REFERENCES

Arctur, D., Zeiler, M., 2004. Designing geodatabases: case studies in GIS data modelling. ESRI Press, Redlands, California, USA.

Boschetti, L., Foody, G.M., Friedl, M.A., Hansen, M.C., Herold, M., Mayaux, P., Morisette, J.T., Stehman, S.V., Strahler, A.H., Woodcock, C.E., 2005. Global land-cover validation: recommendations for evaluation and accuracy assessment of global land-cover maps. EC Joint Research Centre, Ispra, Italy.

Carfagna, E., Gallego, F.J., 1999. Thematic maps and statistics. Land cover and land-use information systems for European Union policy needs, Proceedings of the seminar, Luxembourg 21-23 January 1998. European Commission, Theme 5 (Agriculture and Fisheries). Office for Official Publications of the European Communities, Luxembourg. Pp. 111-121.

Ceri, S., Atzeni, P., Paraboscho, S., Torlone, R., 1999. Basi di dati. McGraw-Hill Publishers, Milan, Italy.

Cihlar, J., Jansen, L.J.M., 2001. From land cover to land use: a methodology for efficient land-use mapping over large areas. *The Professional Geographer* 53(2): 275-289.

Di Gregorio, A., Jansen, L.J.M., 2000. Land Cover Classification System (LCCS): classification concepts and user manual. FAO, Rome. (Incl. CDROM with software application)

Ford-Robertson, F.C. (Ed.), 1971. Terminology of forest science, technology practice and products. Society of American Foresters, Washington D.C.

Geist, H.J., Lambin, E.F., 2001. What drives tropical deforestation. A meta-analysis of proximate and underlying causes of deforestation based on subnational case study evidence. LUCC Report Series No. 4., Land Use and Cover Change (LUCC) programme element of the International Geosphere Biosphere Programme (IGBP) and International Human Dimensions Programme on Global Change (IHDP), Louvain-la-Neuve.

IGN/CENACARTA/DINAGECA Joint Venture, 1999. Land-use/land-cover legend.

Jansen, L.J.M., 2004a. Global land cover harmonisation: report of the UNEP/FAO expert consultation on strategies for land cover mapping and monitoring, 6-8 May 2002, Artimino, Italy. In: Groom, G. (Ed.), 2004. Developments in strategic landscape monitoring for the Nordic countries. Nordic Council of Ministers. ANP 705: 75-90.

Jansen, L.J.M., 2004b. Thematic harmonisation and analyses of Nordic data sets into Land Cover Classification System (LCCS) terminology. In: Groom, G. (Ed.), 2004. Developments in strategic landscape monitoring for the Nordic countries. Nordic Council of Ministers. ANP 705: 91-118.

Jansen, L.J.M., 2005. Harmonisation of land-use class sets to facilitate compatibility and comparability of data across space and time. 12th CEReS International Symposium on Remote sensing – Maximization of the use of satellite data for understanding the Earth environment, 13-14 December 2005, Center for Environmental Remote Sensing (CEReS), Chiba University, Chiba, Japan. 26p.

Jansen, L.J.M., Carrai, G., Morandini, L., Cerutti, P.O., Spisni, A., 2003a. Analysis of the spatio-temporal and semantic aspects of land-cover/use dynamics. Technical report 2. World Bank Albanian National Forest Inventory (ANFI) project. AGROTEC S.p.A. Consortium, Rome. 40p.

Jansen, L.J.M., Carrai, G., Morandini, L., Cerutti, P.O., Spisni, A., 2006a. Analysis of the spatio-temporal and semantic aspects of land-cover/use change dynamics 1991-2001 in Albania at national and district levels. *Environmental Monitoring & Assessment*, in print.

Jansen, L.J.M., Cerutti, P.O., Spisni, A., Carrai, G., Morandini, L., 2003b. Interpretation of remote sensing imagery for land-cover/use mapping. Technical report 1. World Bank Albanian National Forest Inventory (ANFI) project. AGROTEC S.p.A. Consortium, Rome. 62p.

Jansen, L.J.M., Di Gregorio, A., 1998. The problems of current land cover classifications: development of a new approach. Land cover and land-use information systems for European Union policy needs, Proceedings of the seminar, Luxembourg 21-23 January 1998. European Commission, Theme 5

(Agriculture and Fisheries). Office for Official Publications of the European Communities, Luxembourg. Pp 93-102.

Jansen, L.J.M., Di Gregorio, A., 2002. Parametric land cover and land-use classifications as tools for environmental change detection. *Agriculture, Ecosystems & Environment* 91(1-3): 89-100.

Jansen, L.J.M., Groom, G.B., Carrai, G., 2006b. Semantic data harmonisation of land-cover class sets using the FAO/UNEP Land Cover Classification System - Translator Module (LCCS-TM). Submitted to *Int. J. of Applied Earth Observation and Geoinformation*.

Jansen, L.J.M., Mahamadou, H., Sarfatti, P., 2003. Land cover change analyses: an application in Niger using the FAO/UNEP Land Cover Classification System (LCCS). *Journal of Agriculture and Environment for International Development* 97(1-2): 47-68.

Jansen, L.J.M., Ndiaye, D.S., 2006. Land-cover change dynamics 1978-1999 of (peri-) urban agriculture in the Dakar region. Submitted to *Journal of Agriculture and Environment for International Development.*

Kleinn, C., 2003. A national strategy for forest inventories in Mozambique. Consulting report Sustainable Forest Management Project, MADER/DNFFB/UIF, 28 August 2003, Maputo.

Lambin, E.F., Rounsevell, M.D.A., Geist, H.J., 2000. Are agricultural land-use models able to predict changes in land-use intensity? *Agriculture, Ecosystems and Environment* 82: 321-331.

Lambin, E.F., Turner, B.L., Geist, H.J., Agbola, S.B., Angelsen, A., Bruce, J.W., Coomes, O.T., Dirzo, R., Fischer, G., Folke, C., George, P.S., Homewood, K., Imbernon, J., Leemans, R., Li, X., Moran, E.F., Mortimore, M., Ramakrishnan, P.S., Richards, J.F., Skånes, H., Steffen, W., Stone, G.D., Svedin, U., Veldkamp, T.A., Vogel, C. and Xu, J., 2001. The causes of land-use and land-cover change: moving beyond the myths. *Global Environmental Change* 11: 261-269.

Lillesand, T.M., Kiefer, R.W., 2000. Remote sensing and image interpretation. Fourth edition. John Wiley & Sons, New York.

MacDonald, A., 2001. Building a geodatabase. ESRI Press, Redlands, California, USA.

MADEBRAS/FUPEF/MADEMO, 1981. Inventário florestal. Vol. 1. Desenvolvimento florestal da provincia do Niassa. Curitiba.

MADER/DNFFB, 1999. Lei de Florestas e Fauna Bravia 10/99. Maputo.

Mahamadou, H., 2001. Étude diachronique des changements de couverture des terres au Niger (scène de Mayahi) des années 1990 à 1999. Gestion des ressources naturelles et sécurité alimentaire au Niger – interprétation des images satellitales pour la cartographie de couverture des terres. Istituto Agronomico per l'Oltremare (IAO)/Centre régional Agrhymet/Cooperazione italiana, Florence.

Mather, P.M., 1999. Computer processing of remotely sensed images - An introduction. Second edition. John Wiley & Sons, New York.

Meyer, W.B., Turner, B.L. (Eds.), 1994. *Changes in land use and land cover: a global perspective*. Cambridge University Press, Cambridge, UK.

Saket, M., 1994. Report on the updating of the exploratory national forest inventory. FAO/UNDP MOZ/92/013 Project document, July 1994. MADER/DNFFB/UIF, Maputo. 77p.

Saket, M., Taquidir, M.A., Banze, C.J.A., 1995. Methodology and results of the forestry vegetation mapping at 1:250,000. FAO/UNDP MOZ/92/013 Project document, September 1995. MADER/DNFFB/UIF, Maputo. 41p.

Snedecor, G.W., Cochran, W.G., 1980. Statistical Methods. Seventh edition. Iowa State University Press. Ames, Iowa, USA. 507p.

Stehman, S.V., 1999. Basic probability sampling designs for thematic map accuracy assessment. *Int. J. Remote Sensing*, 20(12): 2423-2441.

Stehman, S.V., Czaplewski, R.L., 1998. Design and analysis for thematic map accuracy assessment: fundamental principles. *Remote Sensing of Environment* 64: 331-344.

Thompson, M., 2004. Training on the use of remote sensing systems for forest inventories. Final consultancy report, version 1.0, 29 February 2004, Mozambique Forest Inventory Project, MADER/DNFFB/UIF, Maputo. Geo Terra Image Pty Ltd, South Africa. 57p.

Tucker, C.J., Grant, D.M., Dykstra J.D., 2004. NASA's global orthorectified LANDSAT data set. *Photogrammetic Engineering & Remote Sensing* 70(3): 313-322.

Walker, B., 1998. GCTE and LUCC – a natural and timely partnership. *LUCC Newsletter* 3. pp 3-4.

Walker, B., Steffen, W., Canadell, J., Ingram, J. (Eds.), 1997. The terrestrial biosphere and global change: implications for natural and managed ecosystems. Synthesis volume. *IGBP Book Series* 4. Cambridge University Press, Cambridge, UK.

Webster, R., Oliver, M.A., 1990. Statistical methods in soil and land resource survey. Spatial information systems. Oxford University Press, UK.

Wild, H., Fernandes, A. (Eds.), 1968. Flora Zambesiaca, Vegetation map of the flora zambesiaca area. M.O. Collins (Pvt) Ltd. Publ., Salisbury, Rhodesia.

White, 1983. The vegetation of Africa. A descriptive memoir to accompany the UNESCO/ AETFA/UNSO vegetation map of Africa. UNESCO *Natural Resour. Res*. 20: 1-356.

Zeiler, M., 2003. Modelling our world. ESRI Press, Redlands, California, USA.

Appendix A. Georeferencing accuracy

Area	LANDSAT Path	LANDSAT Row	Number of GCP	RSME (m)	Error at level of pixel
Manica Province	168	75	14	18.96	0.63
	168	74	12	22.25	0.74
	168	73	15	21.68	0.72
	168	72	16	23.41	0.78
	168	71	15	17.33	0.58
	167	75	15	15.49	0.52
	167	74	13	15.69	0.52
Maputo Province	168	78	17	17.69	0.59
	168	77	14	12.02	0.40
	167	79	15	17.09	0.57
	167	78	13	19.66	0.66
	167	77	13	11.67	0.39
Rest of the country	170	71	15	15.96	0.53
	170	70	15	21.64	0.72
	169	71	15	16.01	0.53
	169	70	17	19.65	0.66
	169	76	15	14.85	0.50
	169	75	15	13.90	0.46
	168	76	14	15.15	0.50
	168	70	16	20.58	0.69
	168	69	15	34.62	1.15
	168	68	15	15.96	0.53
	167	76	14	13.45	0.45
	167	73	15	12.99	0.43
	167	72	15	20.18	0.67
	167	71	15	26.18	0.87
	167	70	13	25.95	0.87
	167	69	23	16.71	0.56
	167	68	15	28.30	0.94
	166	77	15	13.88	0.46
	166	76	18	15.33	0.51
	166	75	8	8.95	0.30
	166	73	9	18.46	0.62
	166	72	17	14.74	0.49
	166	71	14	18.58	0.62
	166	70	13	23.18	0.77
	166	69	14	22.36	0.75
	166	68	15 [25]	47.49	1.58
	165	72	12	16.19	0.54
	165	71	15	51.82	1.73
	165	70	13	25.65	0.85
	165	69	14	24.75	0.83
	165	68	15	31.87	1.06
	165	67	11	17.81	0.59
	164	72	6	13.20	0.44
	164	71	10	14.88	0.50
	164	70	15	27.92	0.93
	164	69	10	7.31	0.24
	164	68 [26]			
	164	67 [27]			

[25] This LANDSAT scene was georeferenced using a second order polynomial.
[26] This LANDSAT scene was not received by Agriconsulting S.p.A. before 23 December 2005.
[27] This LANDSAT scene was not received by Agriconsulting S.p.A. before 23 December 2005.

Appendix B. Land-cover classification using FAO/UNEP LCCS

The FAO/UNEP Land Cover Classification System (LCCS), endorsed by the Land Use and Cover Change (LUCC) project of the International Geosphere Biosphere Programme (IGBP) and International Human Dimensions Programme on Global Change (IHDP), has been designed with two main phases, the *Dichotomous Phase* and the *Modular-Hierarchical Phase*. In the latter, land-cover classes are created by the combination of sets of pre-defined classifiers. These classifiers are tailored to each of the eight major land-cover types. The definitions of the distinctions at the various levels are provided in the table below (Di Gregorio and Jansen, 2000).

Dichotomous phase: first-level distinction based on the criterion of "*presence of vegetation*"

A. Primarily Vegetated Areas

This class applies to areas that have a vegetative cover of at least 4% for at least two months of the year. This cover may consist of the life forms *Woody* (Trees, Shrubs), *Herbaceous* (Forbs, Graminoids) or a combination of them, or consist of Lichens/Mosses (only when other life forms are absent). A separate cover condition exists for Lichens/Mosses that can be only applied if this life form contributes at least 25% to the total vegetative cover.

B. Primarily Non-Vegetated Areas

This class includes areas that have a total vegetative cover of less than 4% for at least 10 months of the year, or an absence of Woody or Herbaceous life forms and with less than 25% cover of Lichens/Mosses.

Dichotomous phase: second-level distinction based on the criterion "*edaphic condition*"

A1. Terrestrial Primarily Vegetated Areas

The vegetation is influenced by the edaphic substratum.

B1. Terrestrial Primarily Non-Vegetated Areas

The cover is influenced by the edaphic substratum.

A2. Aquatic or Regularly Flooded Primarily Vegetated Areas

The environment is significantly influenced by the presence of water over extensive periods of time. The water is the dominant factor determining natural soil development and the type of plant communities living on its surface. Includes marshes, swamps, bogs and all areas where water is present for a substantial period regularly every year. This class includes floating vegetation.

B2. Aquatic or Regularly Flooded Primarily Non-Vegetated Areas

The environment is significantly influenced by the presence of water over an extensive period of time each year.

Dichotomous phase: third-level distinction based on the criterion "*artificiality of cover*"

A11. Cultivated and Managed Terrestrial Area

Areas where the natural vegetation has been removed or modified and replaced by other types of vegetative cover of anthropogenic origin. This vegetation is artificial and requires human activities to maintain it in the long term. In between the human activities, or before starting crop cultivation, the surface can be temporarily without vegetative cover. Its seasonal phenological appearance can be regularly modified by humans (e.g., tillage, harvest, and irrigation). All vegetation that is planted or cultivated with an intent to harvest is included in this class (e.g., wheat fields, orchards, rubber and teak plantations).

A12. (Semi-) Natural Vegetation

Natural vegetated areas are defined as areas where the vegetative cover is in balance with the abiotic and biotic forces of its biotope. Semi-natural vegetation is defined as vegetation not planted by humans but influenced by human actions. These may result from grazing, possibly overgrazing the natural phytocenoses, or else from practices such as selective logging in a natural forest whereby the floristic composition has been changed. Previously cultivated areas which have been abandoned and where vegetation is regenerating are also included. The secondary vegetation developing during the fallow period of shifting cultivation is a further example. The human disturbance may be deliberate or inadvertent. Hence semi-natural vegetation includes vegetation due to human influences but which has recovered to such an extent that species composition and environmental and ecological processes are indistinguishable from, or in a process of achieving, its undisturbed state. The vegetative cover is not artificial, in contrast to classes A11 and A24, and it does not require human activities to be maintained long term.

A23. Cultivated Aquatic or Regularly Flooded Areas

Areas where an aquatic crop is purposely planted, cultivated and harvested, and which is standing in water over extensive periods during its cultivation period (e.g., paddy rice, tidal rice and deepwater rice). In general, it is the emerging part of the plant that is fully or partly harvested. Other plants (e.g., for purification of water) are free-floating. They are not harvested but they are maintained. This class excludes irrigated cultivated areas.

A24. (Semi-) Natural Aquatic or Regularly Flooded Vegetation

Areas that are transitional between pure terrestrial and aquatic systems and where the water table is usually at or near the surface, or the land is covered by shallow water. The predominant vegetation, at least periodically, comprises hydrophytes. Marshes, swamps, bogs or flats where drastic fluctuations in water level or high concentration of salts may prevent the growth of hydrophytes are all part of this class. The vegetative cover is significantly influenced by water and dependent on flooding (e.g., mangroves, marshes, swamps and aquatic beds). Occasionally flooded vegetation within a terrestrial environment is not included in this class. *Natural Vegetated Aquatic* habitats are defined as biotopes where the vegetative cover is in balance with the influence of biotic and abiotic forces. *Semi-Natural Aquatic* vegetation is defined as vegetation that is not planted by humans but which is influenced directly by human activities that are undertaken for other, unrelated purposes. Human activities (e.g., urbanization, mining and agriculture) may influence abiotic factors (e.g., water quality), affecting species composition. Furthermore, this class includes vegetation that developed due to human activities but which has recovered to such an extent that it is indistinguishable from its former state, or which has built up a new biotope which is in balance with the present environmental conditions. A distinction between Natural and Semi-Natural Aquatic Vegetation is not always possible because human activities distant to the habitat may create chain reactions that ultimately disturb the aquatic vegetative cover. Human activities may also take place deliberately to compensate for effects as noted above with the aim of keeping a "natural" state.

B15. Artificial Surfaces and Associated Areas

Areas that have an artificial cover as a result of human activities such as construction (cities, towns, transportation), extraction (open mines and quarries) or waste disposal.

B16. Bare Areas

Areas that do not have an artificial cover as a result of human activities. These areas include areas with less than 4% vegetative cover. Included are bare rock areas, sands and deserts.

B27. Artificial Water bodies, Snow and Ice

Areas that are covered by water due to the construction of artefacts such as reservoirs, canals, artificial lakes, etc. Without these the area would not be covered by water, snow or ice.

B28. Natural Water bodies, Snow and Ice

This class refers to areas that are naturally covered by water, such as lakes, rivers, snow or ice. In the case of rivers, the lack of vegetation cover is often due to high flow rates and/or steep banks. In the case of lakes, their geological origin affects the life conditions for aquatic vegetation. The following circumstances might cause water surfaces to be without vegetation cover: depth, rocky basins, rocky and/or steep shorelines, infertile washed-in material, hard and coarse substrates.

Each of the above-described eight categories is further subdivided in so-called "Structural Domains".

Modular-hierarchical phase: fourth-level distinctions	

A11. Cultivated and Managed Terrestrial Areas	**Tree crops**
	Shrub crops
	Herbaceous crops: further subdivided into
	    Graminoid crops
	    Non-graminoid crops
	Managed lands

A12. (Semi-) Natural Terrestrial Vegetation	**Forests** **Woodlands** **Thickets** **Shrublands** **Grasslands** **Sparse vegetation** **Lichens/Mosses**
A23. Cultivated Aquatic or Regularly Flooded Areas	**Aquatic or regularly flooded graminoid crops** **Aquatic or regularly flooded non-graminoid crops**
A24. (Semi-) Natural Aquatic or Regularly Flooded Vegetation	**Aquatic or regularly flooded forests** **Aquatic or regularly flooded woodlands** **Aquatic or regularly flooded closed shrubs** **Aquatic or regularly flooded open shrubs** **Aquatic or regularly flooded grasslands** **Aquatic or regularly flooded sparse vegetation**
B15. Artificial Surfaces and Associated Areas	**Built-up areas** **Non built-up areas**
B16. Bare Areas	**Consolidated areas** **Unconsolidated areas**
B27. Artificial Water Bodies, Snow and Ice	**Artificial water bodies** **Artificial snow** **Artificial ice**
B28. Natural Water Bodies, Snow and Ice	**Natural water bodies** **Snow** **Ice**

In the FAO/UNEP LCCS (Di Gregorio and Jansen, 2000) a number of terms are used for which the definitions are given below in order to avoid confusion between these definitions -followed in this Technical Report- and the interpretation of certain quite common terms.

Canopy cover in LCCS is defined as follows: "*The cover can be considered as the proportion of a particular area of the ground, substrate or water surface covered by a layer of plants considered at the greatest horizontal perimeter level of each plant in the layer*". A distinction is made between Closed (more than 60-70 percent), Open (from (70-60 percent) to (20-10 percent)) and Sparse (less than (20-10) percent)".

Aquatic vegetation: Areas that are transitional between pure terrestrial and aquatic systems and where the water table is usually at or near the surface, or the land is covered by shallow water. The predominant vegetation, at least periodically, comprises hydrophytes. Marshes, swamps, bogs or flats where drastic fluctuations in water level or high concentration of salts may prevent the growth of hydrophytes are all part of this class.

Bare areas: This class describes areas that do not have an artificial cover resulting from human activities. These areas include areas with less than four percent vegetative cover. Included are bare rock areas and sands

Built-up areas: These are characterized by the substitution of the original (semi-) natural cover or water surface by an artificial, often impervious, cover. This artificial cover is characterized by a long cover duration (more than one year).

Forests: (Semi-) natural vegetation dominated by Closed trees (shrubs or herbaceous may be present).

Grasslands: (Semi-) natural vegetation dominated by Closed or Open herbaceous, graminoids or forbs (trees and/or shrubs may be present but only with sparse cover).

Herbaceous crops: Cultivated area dominated by Herbaceous crops. The cover duration is limited to the harvest stage.

Managed lands: Vegetated areas that are enclosed by any kind of urban construction. These areas form isolated patches within the urban area.

Shrublands: (Semi-) natural vegetation dominated by Open shrubs (trees can be present, but only with sparse cover; herbaceous may be present).

Thickets: (Semi-) natural vegetation dominated by Closed shrubs (trees can be present but only with sparse cover; herbaceous may be present).

Tree crops: Cultivated area dominated by Tree crops. The plants often form a distinct block and are often planted in a regular spacing/pattern (e.g., orchards, nursery stock). In general, the duration of the crop cover lasts many years.

Water bodies:

- Artificial water bodies applies to areas that are covered by water due to the construction of artefacts such as reservoirs, canals and artificial lakes, etc. Without these the area would not be covered by water, snow or ice.
- Natural water bodies applies to areas that are naturally covered by water such as lakes and rivers.

Woodlands: (Semi-) natural vegetation dominated by Open trees (shrubs or herbaceous may be present).

Appendix C. How to download LANDSAT 5 TM and 7 ETM+ images

The Global Land Cover Facility (GLCF) at the University of Maryland hosts an image archive that has LANDSAT TM, LANDSAT ETM+ and other satellite images available for most of the world for downloading (Figure 34). The address for the GLCF is: http://landcover.org/.

Figure 34. GLCF home page

Once you enter the GLCF site, click on the Data & Products link at the top of the page. This page has links to all of the data sources available through the archive. To locate LANDSAT imagery, click the LANDSAT link. Here one will find an overview of the different LANDSAT sensors (e.g., MSS, TM and ETM+). More technical information about the imagery can be found in the links on the left side of the web page. The LANDSAT data in the GLCF archive can be accessed through a web interface, or directly through an FTP server. Although a web interface is the easiest manner to find imagery for a particular area of interest, the FTP server often contains additional images that are not available through the web interface. To search for LANDSAT data through the web interface, click the Download LANDSAT in Web Interface link at the top of the page.

Three different options for searching are then presented:

- Choose a "Map Search" to find imagery based on an interactive world map.
- If you know the Path/Row of an image, you can search using these numbers directly.
- Click the Map Search link to enter the interactive map server.

On the Map Search page, you will see a world map, you can choose the type of imagery you are interested in finding on the left, and click the Update Map button to see the areas where images are available in red (Figure 35). Use the magnifying glass tool on the map to zoom in to your area of interest. Please note that there are tabs above the map for searching based on Path/Row, Lat/Long, Place Name, Draw (trace a search area polygon) and Map Layers (select other map layers to be viewed). Once you have identified your area of interest, use the select tool (arrow with plus sign) to select one or more tiles. You will see the number of images available below the map (Figure 36).

Click Preview and Download to see the available LANDSAT images for the selected area.

Figure 35. Earth Science Data Interface (ESDI)

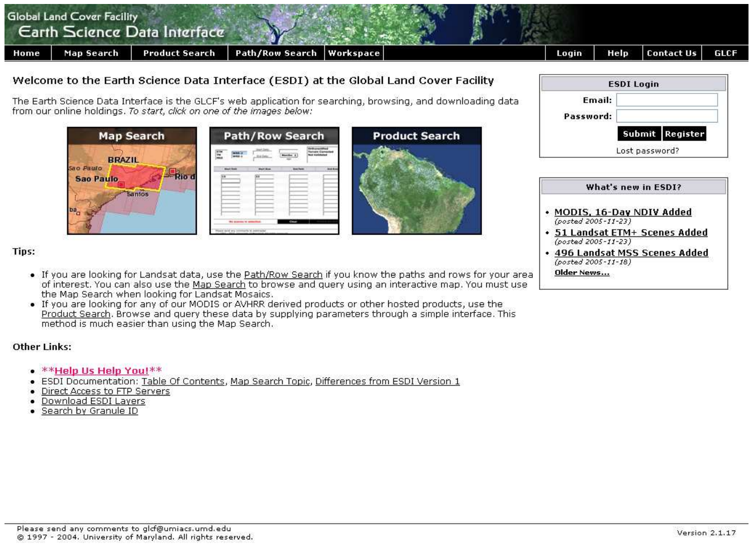
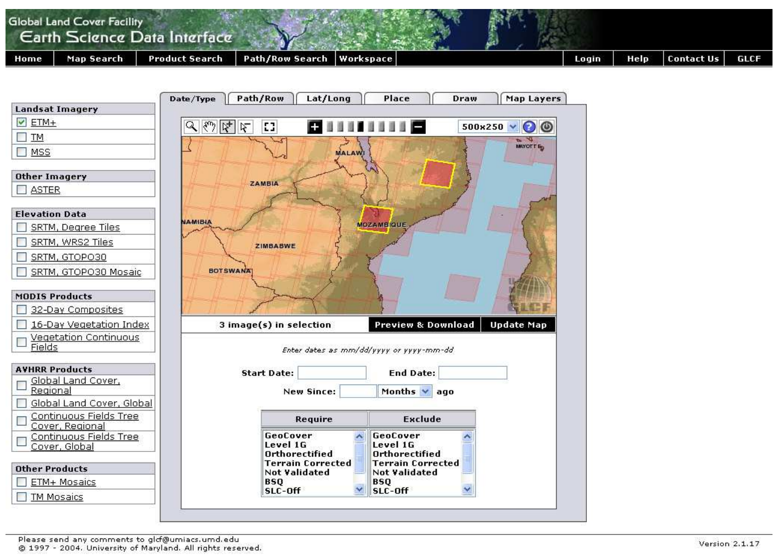


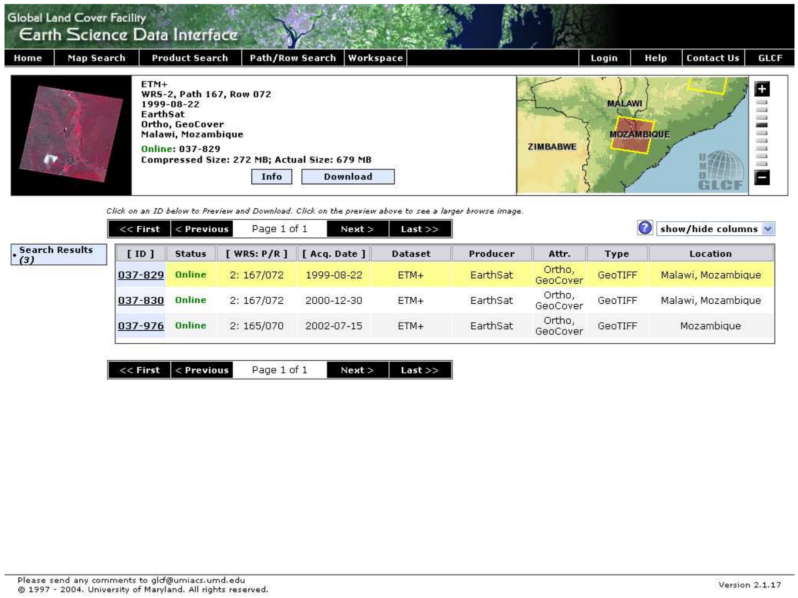
Figure 36. LANDSAT images in selection



Among the search results, additional information about the images is available including the Path /Row identifiers and the date the images were acquired (Figure 36 and Figure 37). The Path/Row is a unique identifier used to index LANDSAT imagery known as the World Reference System (WRS). There are two WRS versions. WRS 1 is used for the first three LANDSAT satellites (from 23 July 1972 to 16 July 1982) and WRS 2 is used for subsequent LANDSAT satellites. Click the Download link to download the image files.

Each of the LANDSAT bands is compressed and the file names end with the ".GZ" extension. These files are compressed using the gZip format and can be uncompressed using most any decompression software. Most of the images are in the GeoTIFF format.

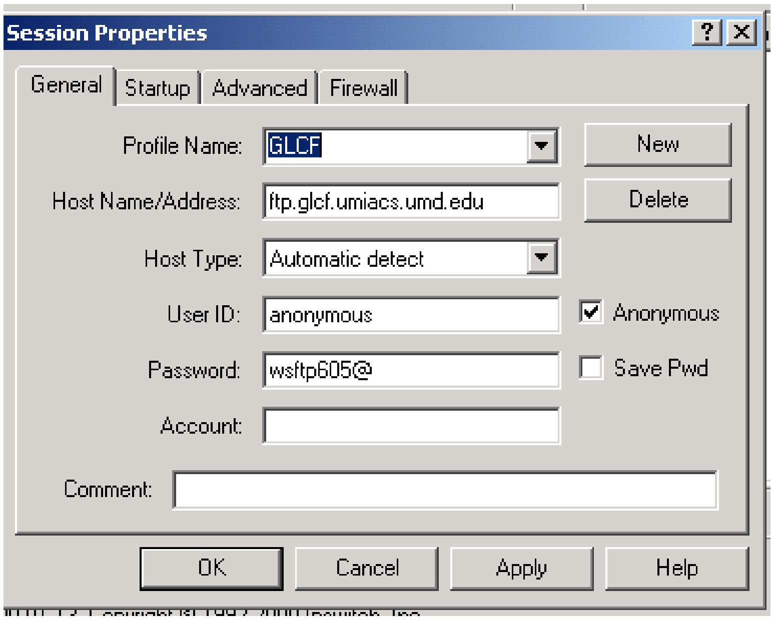
Figure 37. Search results.



The individual image bands will need to be composed together into a single file. Instructions for compositing LANDSAT bands can be found in paragraph 3.6.2 of this Technical Report. Each band is noted by ".NN#" where "#" is the band number. For example the file name "p006r24_5t920615_nn4.tif.gz" represents a LANDSAT TM band 4 image for path 6, row 24, acquired on June 15, 1992. In some directories you will see a band 8 and that is the 15m panchromatic ETM band. Bands 61 and 62 are the high and low gain thermal bands corresponding to LANDSAT ETM band 6. Files with an ".MET" extension are metadata files that can be viewed in a text editor and contain valuable information regarding the specifications of the image.

Once the path and row number for the scene(s) one is interested in are known, they can be downloaded directly (with a maximum of three at a time, a downloader software can be used to automate large amounts of bands). Another option is to use GLCF's FTP server (Figure 38). To access the server, point your web browser or favourite ftp client to: ftp.glcf.umiacs.umd.edu. If you are using a web browser type in this URL: ftp://glcf.umiacs.umd.edu/. Navigate to GLCF =>LANDSAT =>WRS2 (or WRS1 if you are looking for older imagery) and then select the directory that represents the path for your scene. Next, select the directory that represents the row for your scene. Within the "row" directory you will see one directory for each LANDSAT image that is available. If the directory name has the word "orthorectified" in it that means the image has been orthorectified as part of the GeoCover project. Inside the image directory you will find ".JPEG" preview images for the scenes. Preview images are useful to see if the scene will meet the user needs (e.g., correct area of interest, cloud cover) without having to download the entire image. Copy the image files from the server to your desktop and refer to the paragraphs above for information on the file formats.

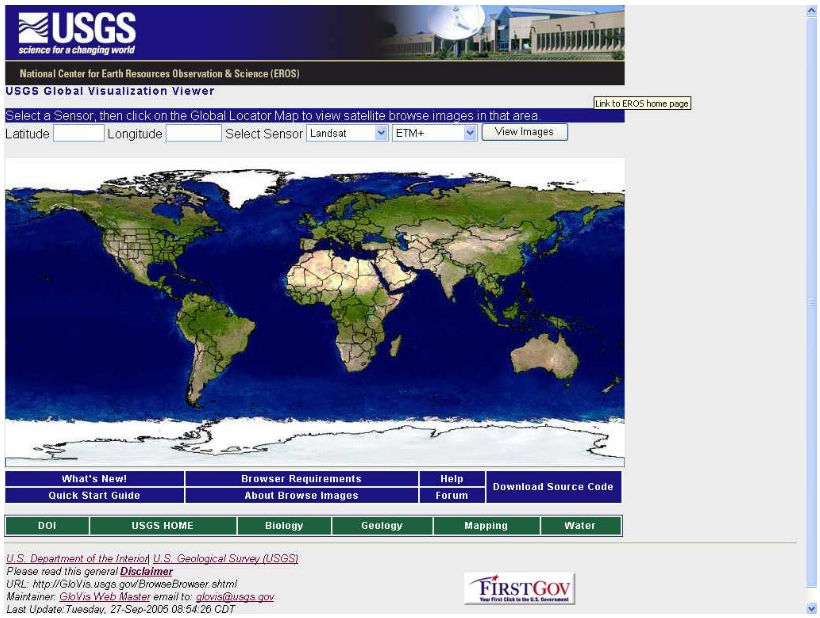
Figure 38. FTP server



Appendix D. How to download ASTER images

Through the web site http://lpdaac.usgs.gov/aster/glovis.html is possible to check which ASTER scenes are available[28] and find their ID (Figure 39). The USGS Global Visualization Viewer (GLOVIS) is a quick and easy online search and order tool for selected satellite data, including ASTER Level IIB images. When you first open GLOVIS, you will see the Global View: a MODIS image of the world. Clicking on the map selects an area of interest, and displays colour browse images for the sensor you have selected.

Figure 39. USGS Global Visualization Viewer



Just select the desired sensor and click on the region you want to investigate. The system will show you the images available in the selected frame; you can choose frame dimension (1000, 400 or 90 miles), the sensor, additional layers, cloud cover limits (Figure 40). Once one has defined any constraints, available images can be browsed trough **Prev Scene** and **Next Scene** (date acquisition order). Trough the arrows you can jump from one scene to the adjacent one. Clicking with the right key of the mouse, a useful and user-friendly menu appears. Pay attention that also *scene ID* can be copied from the metadata list.

If you want to buy this image trough USGS, select Add in the bottom left of the page, then finally, Order. At the moment, it is not possible to order ASTER free of charge from this web site. To obtained ASTER free of charge, see the previous methodology to find your *scene ID*. Once you have copied it, go to http://edcimswww.cr.usgs.gov/pub/imswelcome and enter as a guest (you can also become a registered user if you like) (Figure 41). Select sensor ASTER and in the **Choose Data Set List** highlight both ASTER IIb registered radiance at the sensor v002 and ASTER IIb-registered radiance at the sensor v003 and then OK. In the **Choose a Data Search Type** frame, select **Data Granule ID Search** (Figure 42). Paste the *scene ID* in the window **Enter one Data Granule ID per line** and then select **Start Search**.

[28] In February 2006 information was received that it was no longer possible to download free of charge ASTER images.

Figure 40. ASTER image in selection

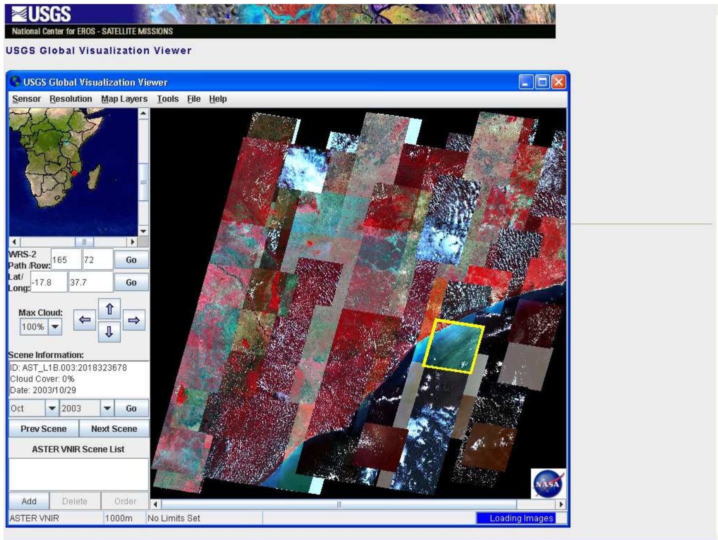


Figure 41. Earth Observing System Data Gateway.

Once the system has found your image, it will show you the following image attributes:

- Image ID
- Checking the little white square in the Select column, you can be confirmed of image geographic position trough the option show map coverage and then zoom in up to 16X
- Image price and attributes
- Image Quick look
- Receive, trough ftp, an image portion having a higher resolution than the quick look
- Special Processing, if available
- Start and Stop Image acquisition Date
- Average Cloud Cover
- Image Center Point

Figure 42. Search creation.

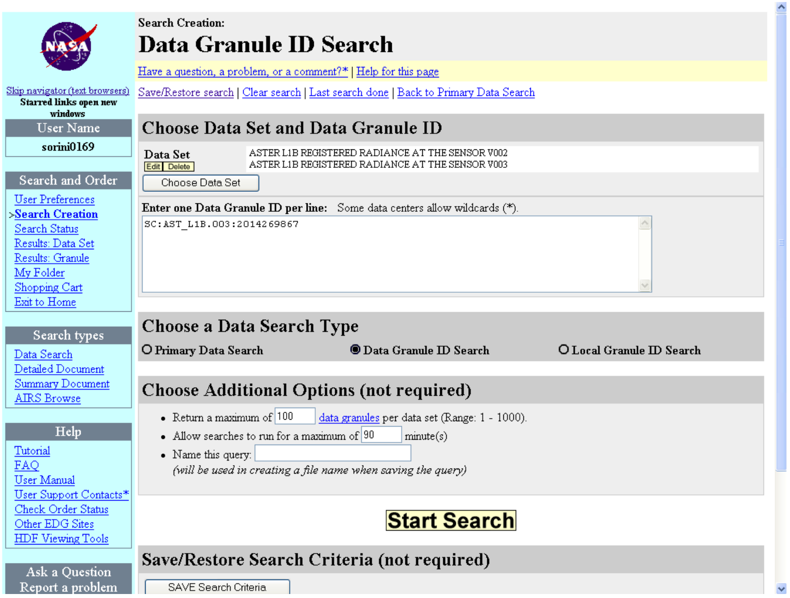
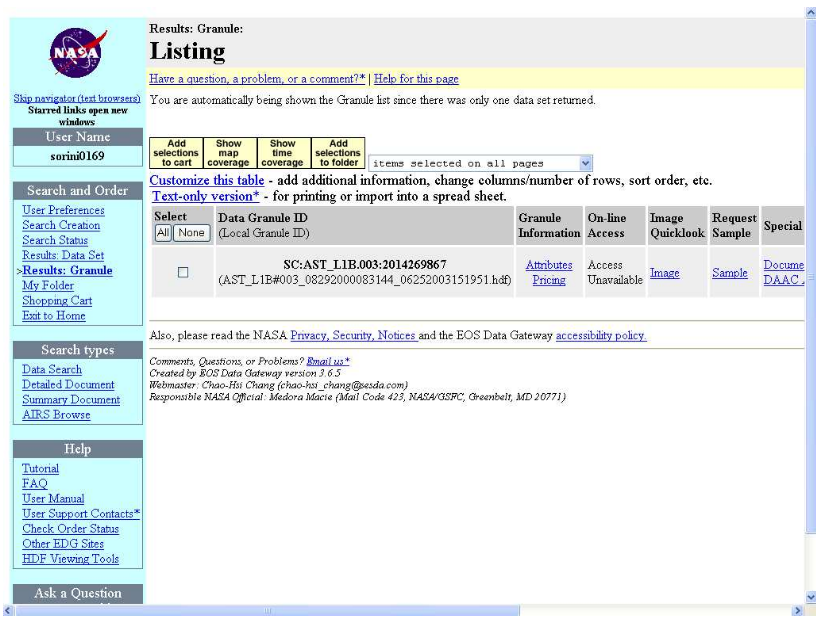


Figure 43. Search results



Once you are sure to be interested to acquire the image, start the obtaining procedure through **Add selections to cart**. In the **Order Options** column, select **Choose Options**. **Option 9: AST_07 (ASTER On-Demand L2 Surface Reflectance) V003** provides you, for free, reflectance value of the first 9 ASTER bands registered by NASA parameters. Select how you want to receive the image, **FTP PULL** if options 9 has been chosen, and then select **Ok! Accept my choice.** Select **Go to step 2: Order Form** and fill the fields with your personal data. This step is not necessary if you have previously registered yourself as a registered user. Select **Submit Order Now.** You will receive first an email confirming that your order is going to be processed and then a second email with FTP information (Figure 43).

You have one week to complete the download after you receive the second email and 24 hours since you start the download. You will be allowed to download three files:

- *File.hdf0 (**reflectance** of bands 1-2-3) 184,196 Mb*
- *File.hdf1 (**reflectance** of thermal bands 4-5-6-7-8-9) 76,961 Mb*
- *File.hdf.met (image metafile, can be open with Wordpad) 60 Kb*

Since full option 9 has a size of about 260 MB, high-speed connection and FTP software are highly recommended. The ".HDF" format can be imported to other common formats like ".TIF" and re-projected with specific software. If this file format is not supported by the software in use, HEG (http://newsroom.gsfc.nasa.gov/sdptoolkit/HEG/HEGHome.html) can be used. It is a free of charge tool made available by NASA. The georeferencing quality is quite low, i.e. 100-250m accuracy error, thus often a georeferencing process is required.

Appendix E. Land-cover legends in Portuguese

Translated legend used at the Province level at the 1: 250,000 nominal scale:

User code	User name	Additional remarks	LCCS standard name
1TCF	Cultivos Arboreas	Inclui Caju, coco, manga, etc	Area de cultivo permanente com cultivos arboreas de folha larga de sequeiro Tipo de cultura: Frutos de suco/ Amendoas Cobertura de cultivo: Fechado > (70-60)% (Plantaçoes)
1TCW	Plantaçôes Florestais	Inclui Eucalyptus (combustivel lenhoso), Pinheiros (uso industrial). Plantaçoes para cpmbustiveis lenhosos sao encontradas perto dos maiores centros urbanos. Plantaçoes de *Casuarins spp.* Foram plantadas para estabilizar as dunas. Actualmente usada pela populaçao para lenha e madeira.	Area Permanente de plantaçoes florestais Tipo de produto: Madeira/lenha
1SCT	Plantaçoes de Cha		Area de cultivo permanente com cultivos Arbustivos de folha larga de sequeiro Cultura dominante: Cha (*Camellia sinensis* (L.) O.K.); Cobertura de cultivo: Fechado > (70-60)% (Plantaçoes)
1FCR	Cultivos de sequeiro	As culturas sao constituidos por tabaco e algodao, bem como mandioca usada para a subsistencia.	Cultivos herbaceo de sequeiro // Cultivos arbustivos de sequeiro
1FCI	Cultivos de regadio		Cultivos herbaceo de regadio // Cultivos arbustivos de regadio
1CXF	Agricultura itinerante/Florestas	Classes mistas de campos cultivados por alguns anos, dentro e areas de florestas fechadas a abertas.	Pequenos campos de cultivos herbaceous de sequeiros nao uniformemente distribuidos
2DEC	Vegetaçao arborea/arbustiva costeira densa	Vegetaçao arborea encontrada ao longo da costa, no interior a partir dos mangais; associados a solos arenosos	Vegetaçao arborea/arbustiva fechada sempre verde Floristic aspect: *Mimusops* spp., *Diospyrus rotundifolia*, *Brachylaena discolor*, *Euclea racemosa*, *Sideroxylon inerme*
2DEO	Vegetaçao arborea/arbustiva costeira aberta	Vegetaçao arborea encontrada sempre ao longo da costa, no interior a partir dos mangais; associados a solos arenosos	Vegetaçao arborea/arbustiva aberta sempre verde Floristic aspect: *Mimusops* spp., *Diospyrus rotundifolia*, *Brachylaena discolor*, *Euclea racemosa*, *Sideroxylon inerme*
2FEM	Floresta densa sempre verde de montanha	Pertencem a altitudes elevadas (>1300m a.n.m.a.m.), e um percipitaçao media anual (>1400mm). Adicionalmente, este tipo de floresta possui uma rica flora.	Arvores sempre verde de folha larga Maior class: Montanhosa (1000-1500 m) Floristic aspect: *Aphloia myrtifolia*, *Maesa lanceclata*, *Curtisia faginea*, *Rawolfia inebrians*, *Canopharngia stapfiana*
2FE	Floresta densa sempreverde	Esta classe permanece nao especificada a nivel de espécies e a descriçao da sua estrutura fisionomica è identica as classes 2FEG, 2FEA e 2FEM.	Arvores sempre verde de folha larga
2FEG	Florestas de galeria	Este tipo de floresta pode ser inundada por algum tempo devido aos picos dos regimes das inondaçoes dos rios.	Floresta alta sempre verde de folha larga Maior class: Plano
2FEA	Mecrusse denso		Floresta sempre verde de folha larga Floristic aspect: *Androstachys johnsonii*
2FD	Floresta densa (sem-) decidua	Estas classes continuam nao especificadas a nivel de espécies e a sua descriçao estrutural fisionomica é identical a das classes 2FDC e 2FDB.	Arvores de folha larga deciduas // Arvores de folha semi-deciduas
2FDC	Mopane denso		Arvores de folha larga deciduas // Arvores de folha larga semi-deciduas Climate: Tropics - Dry semi-arid Floristic aspect: *Colophospermum mopane*

User code	User name	Additional remarks	LCCS standard name
2FDB	Miombo denso	Este tipo de vegetaçao pode ter dois a tres estratos;	Arvores de folha larga deciduas // Arvores de folha larga semi-deciduas Floristic aspect: *Brachystegia* spp.
2WEM	Floresta aberta (semi-) sempre verde de montana	Este tipo de floresta é aberta por razoes edaficas ou interferencias humanas. Este ultimo ocorre especialmente na parte baixa das montanhas em combinaçao com solos ferteis e profundos usados para cultivos. Quando natural faz parte de um gradiente de vegetaçao.	Floresta aberta de folha larga sempre verde Maior class: Montanhosa (1000-1500 m) Floristic aspect: *Aphloia myrtifolia*, *Maesa lanceclata*, *Curtisia faginea*, *Rawolfia inebrians*, *Canopharngia stapfiana*
2WE	Floresta aberta (semi-) sempre verde	Esta classe continua nao especificada a nivel de espécies e a sua descriçao estrutural fisionomica é identica a das classes 2WEM, 2WEF e 2WEA. A classe pode ou nao ter um segundo estrato de arbustos.	Floresta aberta de folha larga sempre verde // Floresta aberta de folha larga semi-sempre verde
2WEA	Mecrusse aberto	A classe pode ou nao ter um segundo estrato de arbustos.	Floresta aberta de folha larga sempre verde Floristic aspect: *Androstachys johnsonii*
2WD	Floresta (semi-) deciduas aberta	Esta classe continua nao especificada a nivel de espécies e descriçao da sua estrutura fisionomica é identica a das classes 2WDC e 2WDB. A classe pode ou nao ter um segundo estrato de arbustos.	Floresta aberta de folha larga sempre verde // Floresta aberta de folha larga semi-sempre verde
2WDC	Mopane aberto	A classe pode ou nao ter um segundo estrato de arbustos.	Floresta aberta de folha larga decidua Floristic aspect: *Colophospermum mopane*
2WDB	Miombo aberto	A classe pode ou nao ter um segundo estrato de arbustos.	Floresta aberta de folha larga decidua Floristic aspect: *Brachystegia* spp.
2TE	Matagal (semi-) sempre verde	Esta classe é tipica em areas aridas. É igualmente encontrada nas zonas proximas das vilas, onde constituem regeneraçao em campos cultivados abandonados.	Matagal de folha larga sempre verde
2TD	Matagal (semi-) deciduo	Esta classe é tipica em areas aridas. É igualmente encontrada nas zonas proximas das vilas onde constituem regeneraçao em campos cultivados abandonados.	Matagal de folha larga decidua
2SE	Arbustos (semi-) sempre verde	Podem ocorrer arvores emergentes. Esta classe é tipica das areas com solos pobre e superficiais e de baixa precipitaçao. Ocorre igualmente como regeneraçao em areas de agricultura itinerante ou seguindo queimadas descontroladas.	Areas de arbustos sempre verde de folha larga // Areas de arbustos sempre verde de folha larga
2SD	Arbustos (semi-) deciduos	Podem ocorrer arvores emergentes. Esta classe é tipica das areas com solos pobre e superficiais e de baixa precipitaçao. Ocorre igualmente como regeneraçao em areas de agricultura itinerante ou seguindo queimadas descontroladas.	Areas de arbustos deciduos de folha larga // Areas de arbustos semi-sempre verde de folha larga
2GCT	Pradaria arborea		Vegetaçao de herbaceas com arvores
2GCS	Pradaria arbustiva	Ocasionalmente pode se encontrar arvores.	Vegetaçao de herbaceas com arbustos
2GOS	Pradaria arbustiva aberta		Vegetaçao de herbaceas com arbustos abertos
2FXC	Floresta com agricultura itinerante	Classe mista de florestas fechada a aberta com campos cultivados por um periodo de tempo.	Cobertura de arvores densa a aberta / Pequenos campos de cultivos herbaceous de sequeiros nao uniformemente distribuidos
3GCO	Campos de arroz		Campos continuos de gramineas Maior class: Plano; Classe de montanha: Plano a quase plano Dominant crop: Cereals - Rice (*Oryza* spp.)
4FEP	Mangal denso		Floresta sempre verde em terrenos permanentemente inundados (com variaçoes diarias) Maior class: Plano; Classe de montanha: Plano a quase plano Floristic aspect: *Avennia marina*, *Ceriops tagal*, *Rhyzophora mucronata*

User code	User name	Additional remarks	LCCS standard name
4WEP	Mangal Aberto	Existe um Segundo estrato de arvores em regeneraçao.	Floresta aberta sempre verde em terrenos permanentemente inundados (com variaçoes diarias)) Maior class: Plano; Classe de montanha: Plano a quase plano Floristic aspect: *Avennia marina*, *Ceriops tagal*, *Rhyzophora mucronata*
4WET	Floresta aberta temporariamente inundada		Floresta aberta sempre verde em terrenos temporariamente inundados
4SET	Areas arbustivas abertas temporariamente inundadas		Arbustos abertos em terrenos temporariamente inundados
4HVT	Vegetaçao herbacea temporariamente inundada	Este tipo florestal ocorre em depressoes onde a agua pernanece estagnada temporariamente levando para um crescimento abundante de plantas herbaceas.	Vegetaçao herbacea fechada em terrenos temporariamente inundados
4HVP	Vegetaçao herbacea permanente inundada	Este tipo florestal ocorre em depressoes onde a agua pernanece estagnada permanentemente.	Vegetaçao herbacea fechada em terrenos permanentemente inundados
4HVS	Tandos de Marromeu;	Este tipo de vegetaçao peculiar ocorre somente na provincia de sofala (Marromeu). Presenca de morro de Muché.	Vegetaçao herbacea dispersa em terrenos temporariamente inundados
5BU	Areas habitacionais	Esta classe inclui areas de urbanas, industrial e associadas.	Areas habitacionais
6BR	Rochas sem vegetaçao		Rochas sem vegetaçao
6BS	Solos sem vegetaçao	Esta classe inclui todo o tipo de solo sem vegetaçao, incluindo solos salinos separando os mangais de outros tipos de vegetaçao.	Solos sem vegetaçao e/ou outros materiais nao consolidados
6SS	Dunas	Esta classe inclui as dunas onde a vegetaçao é rara ou ausente.	Dunas
7WB	Corpos de agua artificiais		Corpos de agua artificiais
8WB	Corpos de agua naturais		Corpos de agua naturais

Translated legend used at the National level at the 1:1,000,000 nominal scale:

User code	User name	Additional remarks	LCCS standard name
1TC	Cultivos Arboreas/Plantações Florestais		Cultivos arboreos (frutos e amendoas)/ Madeira/lenha
1SC	Cultivos arbustivos		Cultivos Arbustivos
1FC	Campos cultivados	Descriçao geral dos campos cultivados	Cultivos herbaceos // cultivos arbustivos
1CXF	Agricultura Itinerante con florestas	Classes mistas de campos cultivados por alguns anos, dentro e areas de florestas fechadas a abertas.	Pequenos campos de cultivos herbaceous de sequeiros nao uniformemente distribuidos
2FE	Floresta (semi-) sempre verde		Arvores sempre verde de folha larga // Arvores semi-sempre verde de folha larga
2FD	Floresta (semi-) decidua		Arvores de folha larga deciduas // Arvores de folha larga deciduas semi-deciduas
2WE	Floresta aberta (semi-) sempre verde		Floresta aberta de folha larga sempre verde // Floresta aberta de folha larga semi-sempre verde
2WD	Floresta aberta (semi-) decidua		Floresta aberta de folha larga // Floresta aberta de folha larga semi-decidua
2TK	Matagal		Arbustos Fechados (Matagal)
2SL	Areas arbustivas		Arbustos abertos
2GL	Pradaria	.	Vegetaçao herbaceas fechadas a aberta
2FXC	Floresta fechada a aberta com agricultura itinerante	Classe mista de florestas fechada a aberta com campos cultivados por um periodo de tempo.	Cobertura de arvores densa a aberta / Pequenos campos de cultivos herbaceous de sequeiros nao uniformemente distribuidos
3AC	Campos cultivados em areas regularmente inundadas		Campos cultivados em areas regularmente inundadas
4FF	Mangal denso		Floresta sempre verde em terrenos permanentemente inundados (com variaçoes diarias) Maior class: Plano; Classe de montanha: Plano a quase plano Floristic aspect: *Avennia marina*, *Ceriops tagal*, *Rhyzophora mucronata*
4WF	Floresta aberta em areas regularmente inundadas		Floresta aberta em areas permanente ou temporariamente inundadas
4SF	Arbustos em areas regularmente inundadas		Vegetaçao arbustiva fechada a aberta em terrenos pernamente e temporariamente inundados
4HF	Vegetaçao herbacea regularmente inundada	Este tipo florestal ocorre em depressoes onde a agua pernanece estagnada temporariamente levando para um crescimento abundante de plantas herbaceas.	Vegetaçao herbacea fechada a aberta em terrenos pernamente e temporariamente inundados
5BU	Areas habitacionais	Esta classe inclui areas de urbanas, industrial e associadas.	Areas habitacionais
6BA	Areas sem vegetaçao		Areas sem vegetaçao
7WB	Corpos de agua artificiais		Corpos de agua artificiais
8WB	Corpos de agua naturais		Corpos de agua naturais

Appendix F. Land-cover field data sheet and explanation

FIELD SURVEY DATA SHEET:	***Integrated Assessment of Mozambican Forests***

A. GENERAL INFORMATION

RELEVEE Nº	
AREA NAME	
LOCATION	
OBSERVER	
DATE	
TIME	
RELEVEE SIZE	(in m^2 or ha)

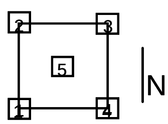
FIELD SAMPLE COORDINATES

N or S	East

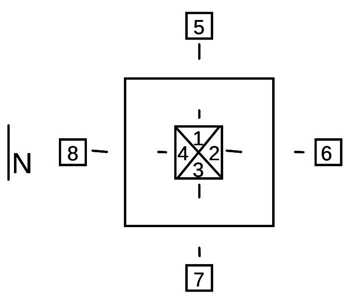
ACCESSIBILITY

- ☐ Very Good
- ☐ Good
- ☐ Medium
- ☐ Bad

On the spot	Observing the spot from a distance
Indicate Relative Position of Coordinates	Distance from viewpoint to observed point ____ (m)
	The bearing of the observed point ____ (º)



FIELD PHOTOGRAPHS



Relative Position of photograph

Film Roll Nº	

Photo Shot Nº	Position

GENERAL LANDFORM

Slope

- ☐ Flat to Gently Sloping Terrain (0 - 7 %)
- ☐ Gently Sloping to Moderately Sloping (8 - 3 %)
- ☐ Sloping to Moderately Steep, Undulating to Rolling terrain (14 - 20 %)
- ☐ Steep to Very steep, Rolling to Hilly Terrain (21 - 55 %)
- ☐ Extremely Steep Terrain, Steeply Dissected Hilly and Mountainous Terrain (56 - 140 %)

B. GENERAL LAND COVER INFORMATION

LAND COVER

- General Land Cover Type
  Relevee Site

A.	Vegetated	Non-Vegetated
		Two Mixed Major Land Cover Aspects
B.	Terrestrial	

- Specific Land Cover Type

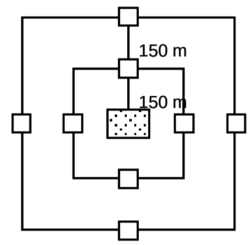
	Single Major Land Cover Aspect	Most Important	Second
Cultivated			
Natural / Semi-Natural			
Built Up			
Bare			
Artificial Water Body			
Inland Water			

AREA LANDCOVER HOMOGENITY (Applicable if on spot)

Land Cover Homogeneous for more than 300 m around the sample area :

Yes

No



LAND COVER SEASONAL ASPECTS

	Natural / Semi-Natural Vegetation				Cultivated Fields			
	dry	green	flowering	fruits	ploughed	initial stage	full mat. stage	harvested
TREES								
SHRUBS								
HERBS								

C. SPECIFIC LAND COVER INFORMATION

NATURAL AND SEMI-NATURAL VEGETATION

		Level	Cover	Height	Leaf Type: Broad	Leaf Type: Needle	Leaf Type: Aphyllous	Leaf Phenology: Evergreen	Leaf Phenology: Deciduous
WOODY									
	Trees	1							
		2							
		3							
	Shrubs	1							
		2							
HERBACEOUS									
	Graminoids								
	Forbs								

Cover Estimation of vegetation Visual Instrumental Other

Total canopy cover: ______ %.

3 most frequent species: ____________________

CULTIVATED TERRESTRIAL AREA AND MANAGED LAND

- Life Form of ***MAIN CROP***

	Leaf Type		Leaf Phenology			
	Broad	Needle	Evergreen	Deciduous	Fruit Trees	Plantation
☐ Trees	☐	☐	☐	☐	☐	☐
☐ Shrubs	☐	☐	☐	☐		
☐ Herbaceous						
☐ Graminoids						
☐ Other						

- Crop Name : ____________

- Life Form of ***SECOND CROP***

	Leaf Type		Leaf Phenology			
	Broad	Needle	Evergreen	Deciduous	Fruit Trees	Plantation
☐ Trees	☐	☐	☐	☐	☐	☐
☐ Shrubs	☐	☐	☐	☐		
☐ Herbaceous						
☐ Graminoids						
☐ Other						

- Crop Name : ____________

- Average Field Size ____________ (m^2 or ha)

- Field Distribution
  - ☐ Bordering Fields
  - ☐ Distance between fields
    - ☐ < average field size
    - ☐ = 1 to 3 X average field size
    - ☐ = 3 to 9 X average field size
    - ☐ > 9 X average field size

- Cultivation period
  - ☐ main crop, during two or more different periods within same year
  - ☐ second crop in same period as main crop
  - ☐ second crop in different period as main crop
  - ☐ second crop starts during active period main crop

- Cultivation Time Factor
  - Time lap between two consecutive active periods
    - ☐ =<1 year
    - ☐ 1 to 4 years
    - ☐ > 4 years

- Water Supply / Irrigation
  - ☐ Not Irrigated
  - ☐ Supplementary Irrigation
    - ☐ Postflooding
    - ☐ Surface
    - ☐ Sprinkler
    - ☐ Drip
    - ☐ Other ____________

- Life Form MANAGED LAND
  - Urban Vegetated Area
  - Area covered by trees is
    - ☐ > 40 %
    - ☐ between 20 % and 40 %
    - ☐ < 20 %

BARE AREAS

- ☐ Consolidated
  - ☐ Bare Rock
  - ☐ Gravel, Stones and Boulders
  - ☐ Hardpans
- ☐ Unconsolidated
  - ☐ Bare Soil
  - ☐ Loose and shifting sands
    - ☐ Stony (5 - 40 %)
    - ☐ Very Stony (40 - 80 %)
- ☐ Dunes
  - ☐ Barchans
  - ☐ Parabolic
  - ☐ Longitudinal
    - ☐ Saturated
    - ☐ Unsaturated

This field survey data sheet is based upon the one that was used by the FAO AFRICOVER Project.

FIELD SURVEY DATA SHEET: *Integrated Assessment of Mozambican Forest*

INFORMACAO GERAL

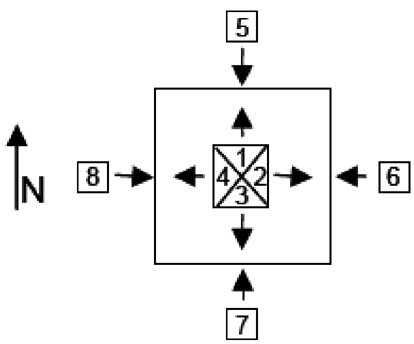
Notas: «NOTE»
Localizaçao do ponto: «SITE»

PONTO NÚMERO	«ID»
PROVINCIA	«PROVINCIA»
DISTRITO	«DISTRITO»
ANOTADOR	
DATA	
HORA	
TAMANHO DA ÁREA OBSERVADA (ha)	

COORDENADAS GPS UTM 36 S	Sul «Y_UTM36S» Este «X_UTM36S»
Accesibilidade do ponto	☐ Muito boa ☐ Boa ☐ Media ☐ Mala

☐ **La observaçao foi feita no ponto**	☐ **La observaçao nao foi feita no ponto**
	Distancia da o ponto (metros):
	Rumo (graus):

FIELD PHOTOGRAPHS



Relative Position of photograph

LISTA DAS FOTOGRAFIAS		
NUMERO DA FOTO	POSICAO	NOME DO FILE

TOPOGRAFIA

DECLIVE	☐ PLANO O QUASE PLANO (0 – 7%)
	☐ SUAVEMENTE ONDULADO A ONDULADO (8 – 13%)
	☐ FORTEMENTE ONDULADO (14 – 20%)
	☐ ESCARPADO A MUITO ESCARPADO (21 – 55%)
	☐ EXTREMAMENTE ESCARPADO (56 –140%)

INFORMACAO GERAL SOBRE A COBERTURA DO SOLO

COM VEGETACAO	**SEM VEGETACAO**
TERRESTRE	**AQUATICO**

Tipo de cobertura	Um solo tipo de cobertura		Dois tipos de cobertura	
			Tipo principal	Tipo secundario
Cultivos	☐	☐	☐	☐
Natural ou semi-natural	☐	☐	☐	☐
Areas urbanas	☐	☐	☐	☐
Solo descoberto	☐	☐	☐	☐
Cuerpos de agua atrificiais	☐	☐	☐	☐
Agua	☐	☐	☐	☐

O tipo de cobertura è homogeneo numa area de mais de 300 metros?

☐ Sim	☐ Nao

VEGETACAO

	Vegetaçao natural ou semi-natural				Campos cultivados			
	Secos	Verdes	Com flores	Com frutos	Arado	Estado inicial	Maduro	Colheitado
Arvoles	☐	☐	☐	☐	☐	☐	☐	☐
Arbustos	☐	☐	☐	☐	☐	☐	☐	☐
Ervas	☐	☐	☐	☐	☐	☐	☐	☐

C. INFORMACAO ESPECIFICA DA COBERTURA DO SOLO

1. (FLORESTA OU OUTRA VEGETAÇÃO NATURAL)				Tipo de folhas			Fenologia das folhas	
	Estrato	Cobertura (%)	Altura (metros	Latifolidas	Agulheras	Afilas	Sempreverdes	Deciduas
Arvoles	1			☐	☐	☐	☐	☐
	2			☐	☐	☐	☐	☐
	3			☐	☐	☐	☐	☐
Arbustos	1			☐	☐	☐	☐	☐
	2			☐	☐	☐	☐	☐
Ervas								
Graminaceas								
Forbs								

Estiamçao da cobertura:	☐ Visual	☐ Instrumental	☐ Outra

Cobertura total de copas (%):

As 3 especies mas frequentes:

2. (PLANTAÇOẼS FLORESTAIS OU ÁREAS DE AGRICULTURA)

Cultivo principal	Tipo de folhas		Fenologia das folhas			
	Latifoliadas	Agulheras	Sempreverde	Deciduas	Arvoles de fruta	Plantaçoes florestais
☐ Arvoles	☐	☐	☐	☐	☐	☐
☐ Arbustos	☐	☐	☐	☐		
☐ Herbaceas	Nome do cultivo:					
☐ Graminoides						
☐ Outro						

Cultivo secundario	Tipo de folhas		Fenologia das folhas			
	Latifoliadas	Agulheras	Sempreverde	Deciduas	Arvoles de fruta	Plantaçoes florestais
☐ Arvoles	☐	☐	☐	☐	☐	☐
☐ Arbustos	☐	☐	☐	☐		
☐ Herbaceas	Nome do cultivo:					
☐ Graminoides						
☐ Outro						

Dimençoes da machamba (m2 ou ha):

Distribuçao espacial

Tem campos vecinhos?	☐ Sim	☐ Nao

Si tem campos vezinhos qual è o seu tamanho?

☐ = 1 a 3 vezes	☐ = 3 a 9 vezes	☐ >9 vezes

Periodo do cultivo

☐ Cultura principal durante dois ou mais periodos no mesmo ano	☐ Cultura secundaria no mesmo periodo que a cultura principal	☐ Cultura secundaria en um periodo diferente que cultura principal	☐ Cultura secundaria comienza quando a cultura principal està ativa

Diferencia entre dois periodos acivos	☐ =< 1 ano	☐ 1 a 4 anos	☐ > 4anos

Irrigaçao

☐ Irrigado	☐ Nao irrigado

No caso de areas urbanas com vegetaçao:
La area cubierta con arvoles es

☐ 40%	☐ entre 20% e 40	☐ <20%

3. SOLO DESCOBERTO

☐ Consolidado	☐ Nao consolidaao	☐ Dunas

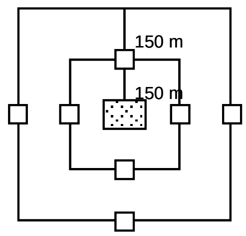
COMENTÁRIOS GERAIS:

Guide on how to make a field observation

1. Localise the position of the field sample site using the GPS. Look around to see if the sample site is representative for the area. If yes, proceed. If no, look for a sample site close by that is representative.

   Servir-se do GPS para localizar a posição dos pontos de levantamento e verificar que o ponto seja rappresentativo de uma area mais grande.

2. The area that is most suitable for a sampling site should be homogeneous for at least 300m from the point selected (see figure):



   Individuar a zona mais apropriada para fazer o levantamento: tem que ser homogénea no minimo 300 metros a volta do ponto seleccionado (ver ficha).

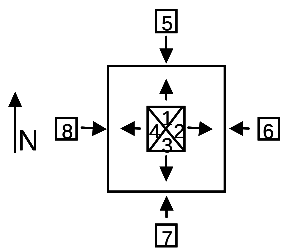
3. When taking photographs avoid taking people or areas that are of no interest to the field survey (e.g., roads, houses, etc.) or areas that are too close to objects that obscure the horizon as one can see in the photograph below that is an example of how one should *not* take a photo.

   Tirar as fotografias procurando de evitar de enquadrar pessoas o areas sem interesse (estradas, casas) ou perto de coisas que podem esconder o horizonte, como na imagem:

4. When making photos, look to position yourself in a manner and in a point from where you can take several photos in different directions as indicated below. Take the photos in the main wind directions as indicated on the field survey sheet:
   - Photo 1 is taken to the North, Photo 2 to the East, etc.
   - Photos 5, 6, 7 and 8 should be taken, when possible, from a certain distance from the sample site and should provide an overview from outside the area described of the sample site.

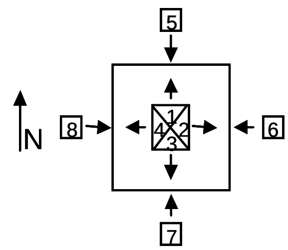
Tirar as fotografias estando em pontos de onde se pode ver o mais possível a volta. Tirar as fotografias apontando para os quatros pontos cardinais, como indicado na ficha: a foto n°1 tem que ser tirada na difracção norte, ecc. As fotos 5,6,7,8 têm que ser tirada, quando possível, a distancia do ponto central para o centro (do exterior para o interior).

FIELD PHOTOGRAPHS



Relative Position of photograph

Fotografias do campo



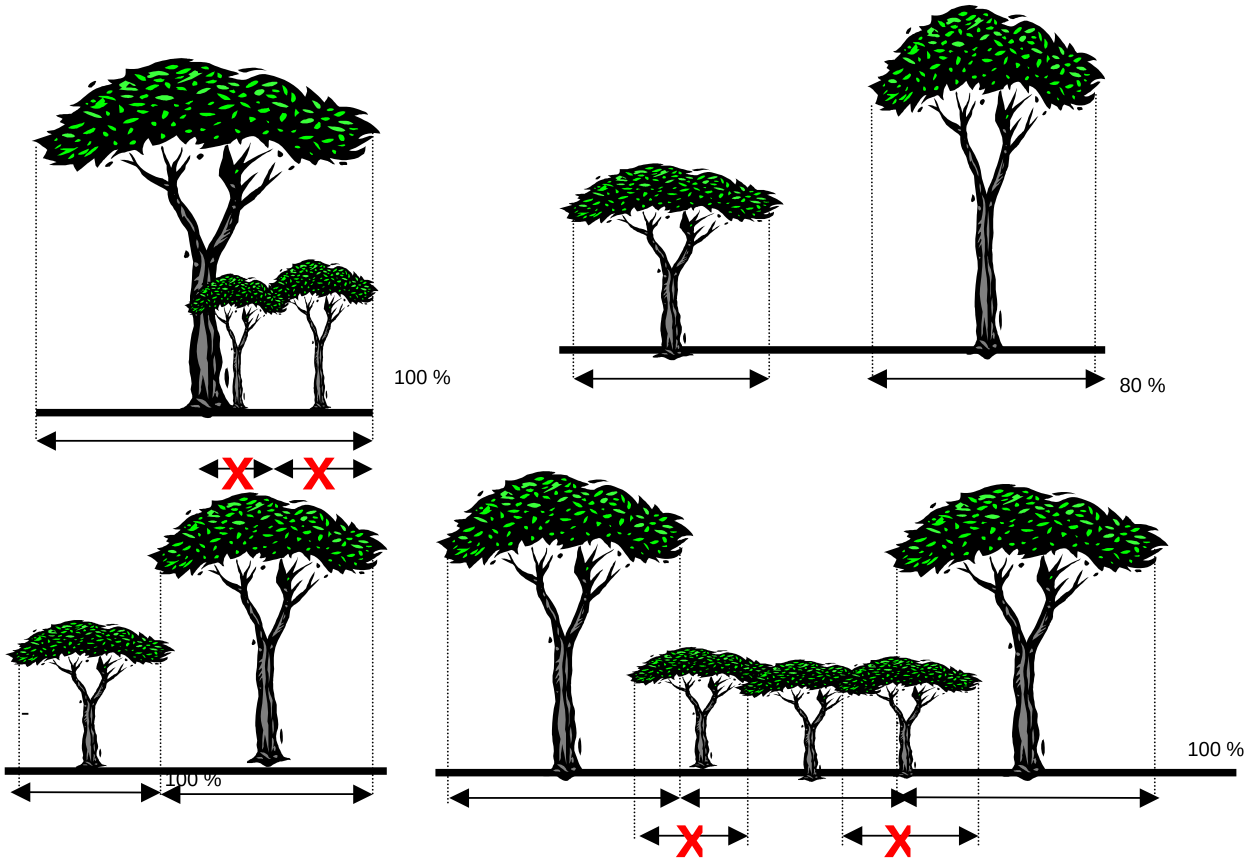
Posições relativas das fotografias

5. Example of a photo well-taken (don't forget to show the sample site number):
   Exemplo de image bem feita:

6. Collect with care the information on the vegetation, with particular attention to the height and crown canopies.

   Preencher exactamente as informações sobre a vegetação, prestando muita atenção as alturas e à cobertura.
7. If there are more layers of vegetation, define the **overall canopy cover** (for trees only, or for shrub only when trees are completely absent). So one should take the sum of all relevant layers but this should *not* result in a figure bigger than 100% (in the examples consider only the ground surface where the shadow of the *highest* crown canopy would fall).

   Se ha mais layers de vegetação, definir a ***cobertura total*** *(para os arvores ou para os arbustos se não houver arbores) sem fazer a soma aritmetica das percentagens dos layers (não se considera a copertura do layer inferior se esta coberta por um layer superior). A cobertura total não pode ser por isso mais do 100%.*



8. Describe at least the three most frequent tree species; if no trees are present describe the three most frequent shrub species.

   Descrever no minimo as 3 especies de arbores mais frequentes e se não ha arbores, as tres especies mais frequentes de arbustos.

Appendix G. Remote sensing & land-cover team

The activities related to the remote sensing and land-cover interpretation component of the AIFM Project resulting in the 1:250,000 nominal scale land-cover data sets for Manica and Maputo Provinces and the 1:1,000,000 nominal scale National land-cover data set described in this report were carried out by the following persons:

Name Short Curriculum vitae	Main activities
Louisa J.M. Jansen She graduated in Agricultural and Environmental Sciences at the University of Wageningen, The Netherlands, in 1991. She worked as lecturer and researcher on the application of remote sensing and GIS for water resources surveys and soils at the International Institute for Aerospace Survey and Earth Sciences (ITC, The Netherlands). She developed methodologies to collect land-use information from land-cover data (Kenya and Lebanon) and covered subjects like land-use planning, erosion/land degradation, land evaluation and classification at the FAO Land and Water Development Division (several Sub-Saharan African countries). She is author of the FAO/UNEP Land Cover Classification System. Her extensive experiences in remote sensing and GIS applications comprise environmental change dynamics and land degradation for the Dutch Royal Tropical Institute (Mali), natural resources evaluation and food security for the Italian Ministry of Foreign Affairs (Niger and Senegal), land-cover/use inventory for agricultural land reform (Romania and Moldova), land-cover data harmonisation for the Nordic Council of Ministers of Environment (Denmark, Estonia, Norway and Sweden), coastal area management for UNEP (Malta), environmental change dynamics for the World Bank (Albania) and land-use policy for the EU Phare programme (Albania).	• Overall management/co-ordination remote sensing and land-cover component • Training on the use of land-cover data, classification and legend, use of LCCS, accuracy assessments, land-cover change analysis • Selection of LANDSAT 5 TM images • Writing, overall co-ordination and editing of Technical Report
Marco Bagnoli He graduated in Forest Sciences at the University of Florence, Italy, in 1988, and specialised in Remote Sensing and Natural Resources Evaluation at the Istituto Agronomico per l'Oltremare[29] (IAO). He did research on the use of remote sensing for detection of deforestation in tropical areas and in this context participated in FAO projects (e.g., Bhutan and Iran). His extensive experience in satellite remote sensing and GIS comprises applications related to land cover/vegetation, forestry (e.g., regional forest inventories), land-use (planning) and land-unit mapping while working for various private companies, the Italian Ministry of Environment and the EC Joint Research Centre. He covered the Middle East, Asia and Latin America for EURIMAGE, he worked on the use of remote sensing for natural resources evaluation for the Italian Ministry of Foreign Affairs (Angola) and on setting up a GIS for land-use planning for the Italian ONG Crocevia (Palestine Territories).	• Land-cover interpretation LANDSAT 5 TM 2004 for the Provinces (June-Oct. 2005) • Land-cover interpretation LANDSAT 5 TM 2004/2005 for the National coverage (Sept.-Dec. 2005) • Land-cover change Manica Province (Nov. 2005) • Documentation of remote sensing protocols and burnt area monitoring application

[29] Istituto Agronomico per l'Oltremare of the Italian Ministry of Foreign Affairs, Via A. Cocchi 4, 50131 Florence, Italy (web site: http://www.iao.florence.it).

Sara Chimenti She graduated in Geological Sciences at the University of Pisa, Italy, in 2004, and specialised in Geomatics and Natural Resources Evaluation at the Istituto Agronomico per l'Oltremare (IAO). She is an expert in geochemistry and has worked at the operational centre of Stromboli Island providing scientific information on vulcanology to visitors.	• Land-cover interpretation LANDSAT 5 TM 2004 for the Provinces (July-Oct. 2005) • Land-cover interpretation LANDSAT 5 TM 2004/2005 for the National coverage (Sept.-Dec. 2005) • Land-cover change Manica Province (Nov. 2005) • Documentation of used ancillary data and metadata
Angela Dell'Agnello She graduated in Forest Sciences at the University of Florence, Italy, in 1982, and specialised in Remote Sensing and Natural Resources Evaluation at the Istituto Agronomico per l'Oltremare (IAO). She gained extensive experience in forest inventories, forest change assessments and land-cover/vegetation data collection using satellite remote sensing while working for various regional forest inventories and vegetation surveys with extensive field campaigns, the FAO Forest Resources Assessment projects (FRA90 and FRA2000), the data consistency assessment (geometric and thematic validation) of the TREES project (e.g., tropical forest belt covering Africa, Asia and Latin America) and the FAO Africover project (land-cover data collection in the Democratic Republic of Congo and overall evaluation of data consistency in nine Eastern African countries). She has also been involved in data collection for wildlife applications. She has also considerable experience in teaching in the fields of environment and natural resources.	• Land-cover interpretation LANDSAT 5 TM 2004 for the Provinces (June-Oct. 2005) • Land-cover interpretation LANDSAT 5 TM 2004/2005 for the National coverage (Sept.-Dec. 2005) • Land-cover change Manica Province (Nov. 2005) • Documentation of interpretation protocols
Marco Focacci He graduated in Forest and Environmental Sciences at the University of Florence, Italy, in 2002 and specialised in Geomatics and Natural Resources Evaluation at the Istituto Agronomico per l'Oltremare (IAO). He worked for the Italian ONG MAIS on the implementation of agroforestry systems and reforestation (Guatemala) and for the Guatemalan Government on forestry policy. He has also experience in teaching in the field of environmental education.	• Land-cover interpretation LANDSAT 5 TM 2004/2005 for the National coverage (Oct.-Dec. 2005) • Land-cover change Manica Province (Nov. 2005) • Documentation of interpretation protocols and land-cover change Manica Province
Sinforosa Anna Monaco She graduated in Agronomic Sciences at the University of Perugia, Italy, in 1991. She gained considerable experience in the use of aerial photo interpretation with a range of Italian private companies in the context of the EC Common Agricultural Policy (e.g., subventions related to production of milk, olive oil, annual crops, tree crops and vineyards) and she worked for the EU LUCAS (Land Use Cover Assessment) project.	• Land-cover interpretation LANDSAT 5 TM 2004 for the Provinces (June-Oct. 2005) • Land-cover interpretation LANDSAT 5 TM 2004/2005 for the National coverage (Sept.-Dec. 2005) • Land-cover change Manica Province (Nov. 2005) • Documentation of interpretation protocols

Paolo Sorini He graduated in Tropical and Subtropical Agricultural Sciences at the University of Florence, Italy, in 1997 and specialised in Geomatics and Natural Resources Evaluation at the Istituto Agronomico per l'Oltremare (IAO). His experience covers remote sensing and GIS as he was involved in the realisation of an information system dedicated to international co-operation at IAO and worked on the mapping of natural resources for agricultural use and planning in a UNDP/FAO project (Libya). He has also worked as volunteer providing humanitarian aid in Eastern Europe (Croatia, Czech Republic and Poland).	• Land-cover interpretation LANDSAT 5 TM 2004 for the Provinces (July-Oct. 2005) • Land-cover interpretation LANDSAT 5 TM 2004/2005 for the National coverage (Sept.-Dec. 2005) • Land-cover change Manica Province (Nov. 2005) • Documentation of remote sensing protocols and the downloading of LANDSAT and ASTER images
Saverio Stoppioni He graduated in Geological Sciences at the University of Genoa, Italy, in 1998 and specialised in Remote Sensing and Natural Resources Evaluation at the Istituto Agronomico per l'Oltremare (IAO). He gained considerable experience in satellite remote sensing and GIS while working for the FAO Africover project (land-cover data collection in Sudan and the Democratic Republic of Congo) where he was also involved in database management, overall evaluation of data consistency (nine Eastern African countries) and in the FAO Asiacover project he was involved in the translation of Southeast Asian land-cover legends with the FAO/UNEP Land Cover Classification System methodology; he worked on land-cover data quality for a FAO project (Egypt) and on the improvement of coastal land degradation monitoring for an EU project (Lebanon and Syria).	• Land-cover interpretation LANDSAT 5 TM 2004 for the Provinces (July-Oct. 2005) • Land-cover interpretation LANDSAT 5 TM 2004/2005 for the National coverage (Sept.-Dec. 2005) • Land-cover change Manica Province • Internal data consistency checking • Updating and documentation of the land-cover legends • Semantic land-cover data harmonisation and documentation
Ferdinando Urbano He graduated in Environmental and Land Planning Engineering at the Polytechnic University of Milan, Italy, in 1999 and specialised in Geomatics and Natural Resources Evaluation at the Istituto Agronomico per l'Oltremare (IAO). He gained considerable experience in GIS and satellite remote sensing while working on environmental management and human rights for the Portuguese NGO INDE (Guinea Bissau, Timor East and Portugal), protected areas and land-cover change for the Italian Ministry of Foreign Affairs (Niger), the creation of a water resources management system for the Italian NGO LVIA (Tanzania) and the development of environmental models to map desertification risk at the Italian National Soil Conservation Institute. He has also experience in teaching in the field of GIS applications for rural development.	• Land-cover interpretation LANDSAT 5 TM 2004 for the Provinces (June-Oct. 2005) • Data modelling and design plus documentation • Geodatabase development and management • Satellite images elaboration • GIS data management
In the period 18 November - 14 December 2005 the team was joined by: **Carla Cuambe (UIF)** **Jaoquim Armando Macuácua (UIF)** **Pachis Mugas (UIF)**	• Training on the adopted remote sensing and land-cover interpretation methodology • Expert knowledge input into the LANDSAT 5 TM 2004/2005 land-cover interpretation at National level and Maputo Province

Appendix H. Schedule of executed activities

Activities land-cover/use assessment	2005								2006	
	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.
A. Satellite image selection and acquisition:										
- For Manica and Maputo Provinces at 1:250,000 nominal scale	■									
- For the national level at 1:1,000,000 nominal scale			■	■	■					
B. Satellite image interpretation and land-cover legend:										
- For Manica and Maputo Provinces at 1:250,000 nominal scale	■	■	■	■						
- For the national level at 1:1,000,000 nominal scale					■	■	■	■		
C. Ground verification and accuracy assessments:										
- For Manica and Maputo Provinces at 1:250,000 nominal scale						■	■			
- For the national level at 1:1,000,000 nominal scale								■		
D. Land-cover data entry into the geodatabase:		■	■	■	■	■	■	■		
E. Crosscheck of land-cover data with Forest Inventory data:										
- For Manica and Maputo Provinces at 1:250,000 nominal scale									■	
- For the national level at 1:1,000,000 nominal scale										
F. Training in remote sensing and land-cover data collection:							■	■		
Technical reporting								■	■	■
Workshop to present results RS & LC component										■