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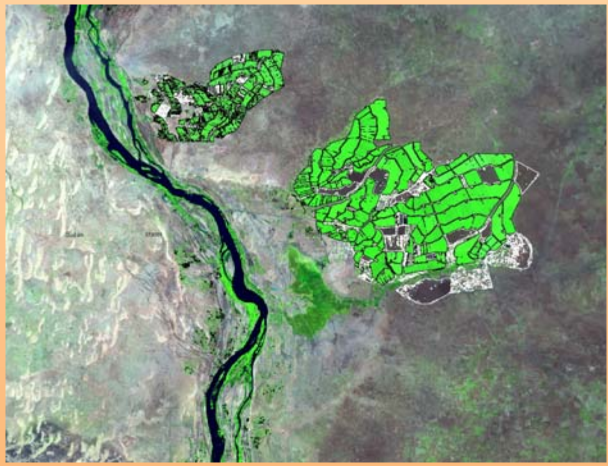
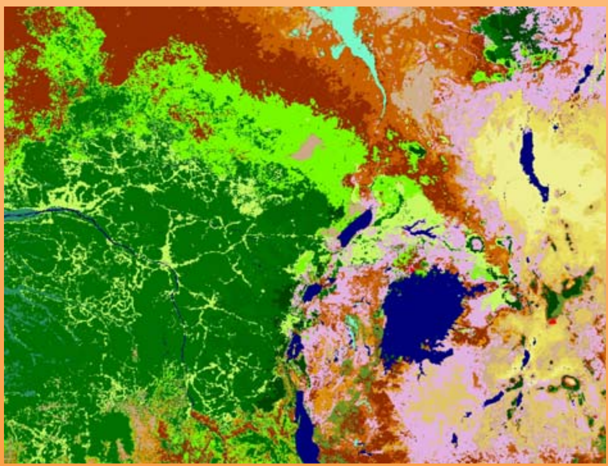
MONITORING LAND COVER DYNAMICS IN SUB-SAHARAN AFRICA

H.D. Eva, A. Brink and D. Simonetti





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The cover page photos by Michel Massart and Hugh Eva. The other insets show a Landsat ETM satellite image of Sudan, and detail from the GLC 2000 map of Africa.

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MONITORING LAND COVER DYNAMICS IN SUB-SAHARAN AFRICA

A pilot study using Earth observing satellite data from 1975 and 2000

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Institute for Environment and Sustainability
Joint Research Centre of the European Commission

Key Questions

What have been the main land cover changes in sub-Saharan Africa over the last 25 years?

Over the last 25 years a number of major disturbances have effected sub-Saharan Africa – civil disturbances, drought, population increases and global market pressures. These have all contributed in direct and indirect ways to a modification of the region's land cover, with natural ecosystems giving way to managed areas.

What are the impacts of such land cover changes?

Such large changes in land cover have repercussions at many levels. The replacement of natural vegetation by agriculture increases the land surface albedo which, it is argued, will accentuate the magnitude and duration of drought. Exposing fragile soils to long periods of insolation can lead to erosion and leaching of nutrients. The natural vegetation lost also contributes to greenhouse gas production. The loss of biodiversity in the region can be argued to be proportional to the loss and fragmentation of natural vegetation. On a socio-economic level the reduction of natural resources can lead to environmental refugees and even conflict.

Why use satellite data used to estimate land cover change?

National statistics on land cover are not always available and are rarely up to date. Where they do exist they are collected and aggregated in different fashions and may target different users. Hence their utility at wider scales is limited. The Earth observing capacities of high spatial resolution satellites make them a valuable tool for estimating land cover classes over large areas, providing a repeatable, independent assessment tool with a consistent methodology.

What are the methodological improvements that should be made to such a study?

The current study is based on a stratified sample of satellite images spread across sub-Saharan Africa. We seek to assess if this sample is sufficient to produce valid statistics on land cover change, and if so at what accuracy. We also wish to know if the image processing and interpretation techniques are adequate.

Why has the JRC carried out this work?

The JRC has a long history of monitoring tropical ecosystems from space. The exploitation and transformation of such data into meaningful information for policymakers forms a key part of the JRC's mission, to support the conception, development, implementation and monitoring of European Union policies.

How does this work serve the long-term goals of the European Union?

The European Union has clear policy lines dedicated to improving natural resource management in Africa and also targets specific environmental issues such as climate change, logging, land degradation and loss of biodiversity. Up-to-date information on environmental resources, food availability/demand, and on potential crisis situations are necessary for targeting aid and development actions. At the same time, such information can serve as a feedback as to the success of supportive measures to national and regional bodies.

Main Findings - Environmental

The main land cover dynamic has been the conversion of natural vegetation to agricultural lands

Our study shows that Africa has lost 16% of its forests and 5% of its woodlands and grasslands over the 1975 to 2000 period, equating to over 50,000 km^2 per year of natural vegetation. The majority of this has been converted to agricultural lands. West Africa has seen the most change.

Despite the expansion, the agricultural domain is more crowded than 25 years ago

The percentage increase in sub-Saharan Africa's population is greater than that of the expansion of agricultural lands. Agricultural lands have increased by 57% over the last 25 years. The area covered by agriculture increased from 215 Mha in 1975 to 338 Mha in 2000, which gives an annual rate of 2.3%. Meanwhile the annual average rural population increase has been 2.7% over the period. This implies that the rural domain is 20% more crowded than it was 25 years ago.

Natural pastures have been reduced in extent while livestock levels have risen

The reduction of natural pastures combined with the increase in livestock levels means that there is on average 40% less available pasture per head of cattle than 25 years ago.

The on-going dynamic can lead to environmental refugees and conflict

On a socio-economic level the reduction of natural pastures and woodlands combined with the increases in human and livestock populations means more competition for less and for poorer quality fuel woods, for grazing and for agricultural lands. This raises the risk of potential conflict, especially in periods of environmental stress, such as drought. Protected areas can accentuate the problem, as access to pastoralists is denied, leaving them little choice but to enter the agricultural domain with their cattle during the migration season.

The role of protected areas is even more crucial than ever – but they are becoming more isolated and vulnerable

A consequence of the ongoing dynamic is the importance of protected areas as 'refuges'. However, they are becoming 'island refuges' and their viability is less certain, both functionally and possibly politically. With dwindling regional natural resources available they become targets for poaching, illegal grazing, for invasion by farmers and as sources of scarce fuel wood. Under future scenarios, local and regional politicians may find it difficult to justify their existence. The JRC is currently developing a system to prioritise and monitor protected areas across Africa.

Climate change scenarios point to a worsening situation

It is clear that climate change constitutes a potential threat to future environmental security and threatens to increase the magnitude of environmental refugees and potential conflict situations.

Land degradation is occurring in areas outside the Sahel

This study was not designed to cover desertification processes, nevertheless, barren lands have increased in the Sudanian region, probably as a result of over-exploitation.

Better spatial data bases are required at national to regional levels

These is a clear requirement for better spatial databases at national and regional levels on a range of natural and socio-economic variables; population, land use, land suitability, water resources, transhumance. These databases need to be interoperable so that trans-national studies can be undertaken. Standardised inventories of natural resources and of agricultural production are required at regular intervals.

Main findings – Development policy

Due to the significant reduction of available land for agriculture, a priority of Rural Development policy should be oriented to increase yields through an intensification of agriculture and integration with animal husbandry

Our study shows that the current agricultural domain has reached its potential limits in some regions and that the food security can be ensured only by an augmentation of the production per hectare. However, the agricultural intensification should be carefully conducted in order to avoid soil degradation, excesses of mineral fertilisers and pesticides, and to limit water over-exploitation. A close integration of agriculture and cattle-ranching is highly recommended for increasing the overall productivity of the agro-system and restoring degraded lands.

The activities related to the adaptation to climate change should be concentrated in the most sensitive areas

From our study, the Sahelian belt and the Afromontane domain are the ecoregions with the biggest land availability problems. They are also the ecoregions that will suffer from climate change with more frequent droughts for the Sahel, and a lack of resilience in mountainous regions. These phenomena are aggravated by the albedo increase due to agricultural encroachment. Adaptation to climate change should therefore be focused on these regions, where there is a high potential impact and the current situation is already unfavourable.

The success of conservation by a network of protected areas should be subject to a sound assessment and management of natural resources at a regional level

Protected areas, though playing a key-role in the conservation of biological resources, can lead to conflict situations when they disturb traditional pastoral activities, especially in regions where the forage availability is limited by the disappearance of fallows. Paradoxically, well managed protected areas may suffer from a higher vulnerability due to their isolation. The management of protected areas should be considered at a regional scale through the development of integrated landscape policies and increased attention to ecological corridors. A careful assessment of the natural resources benefits by all the stakeholders is necessary before engaging any protected area mechanism.

Development policy needs to address the drivers of conflict – amongst which available land and access to natural resources figure strongly

Insufficient resources and insecurity are among the main drivers of migrations which in themselves can be sources of new conflicts. The links between land cover changes, resources reduction and migrations need to be further explored. Meanwhile, there is a necessity to foresee specific support – including at the regional level – to programs encouraging ‘concerted and shared management of natural resources’. Particular attention must be paid to potential transhumance related conflicts: negotiated definition of paths, stocking areas and periods should be encouraged, as undertaken by the EC ‘ECOPAS/Park W’ program.

The significant reduction in the capacity of rural areas and cities to satisfy energy requirements needs to be addressed at all levels, and requires institutional changes and improvements

The continued erosion of fuel wood sources points to the necessity to develop and implement medium and long term local, regional and national energy plans. In the most affected areas, such as West Africa, the north of Central Africa and the Horn of Africa, there should be a drive to increase the use of renewable energies. There is a need to support plantation and regeneration schemes as well as maintaining and developing environmental education programs.

To ensure that environmental sustainability can be achieved, 'environmental and natural resource' issues must be fully integrated into development policies and processes

Increased population and agricultural pressure, together with insufficient attention to natural resources and environmental concerns is rapidly affecting Africa's environmental sustainability, with particular effects and implications on the poorest. There is an urgent necessity to intervene in the most critical areas with *ad hoc* 'conservation and sustainable use programs, as well as to ensure the systematic integration of 'environment and natural resources issues' into policies and programs. This includes when development aid is channelled through general budget support and sector budget support.

Main Findings – Technical

The use of a sample of high resolution satellite data was found to be appropriate for land cover change mapping at regional and continental levels

The results show that for the main ecosystems studied land cover change estimates are statistically valid. It is clear that for sub-regional and national studies a higher number of samples are required.

The use of high resolution satellite data was found to be appropriate for identifying the broad land cover classes mapped

For the basic land cover classes mapped the Landsat Thematic Mapper satellite data were found to be appropriate for most regions. Two thematic classes, water and barren, though relatively easily addressed on single date imagery, are difficult to quantify due to seasonal variations. The use of the Landsat MSS data for the 1975 estimate was on the generally satisfactory, but for some fragmented classes their lower spatial resolution led to loss of definition.

The sampling stratification – modifications are required

The use of an ecological map (White/UNESCO, 1981) for stratification was justified on the basic assumption that land cover is generally similar within these strata. However, as these strata are generally large and cross many national boundaries and regional economic zones, land cover changes may vary strongly within the strata. As well as this, interpreting and analysing the impacts of land cover changes across ecological zones is difficult as the required ancillary and validation data are not usually available at these levels, and are indeed difficult to aggregate from national statistics. For a number of smaller ecoregions, the sampling level, whilst providing a 1% area sample does not give enough sample units. The sampling strata is inappropriate for measuring permanent water bodies as these are not distributed equally throughout the zones. For assessing desertification, the two date approach is not adequate as seasonal changes require a higher temporal sampling.

The image processing techniques - modifications are required

Within the study we used single date unsupervised classification. The land cover estimates were then derived from the difference in the two dates. Recent advances in commercially available software lead us to believe that using a segmentation approach on a two-date composite image, combined with a supervised classification would be more appropriate. This approach would also have the benefit of allowing analysis by land parcel units.

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1. Introduction

Over the last 25 years sub-Saharan Africa, with its abundant natural resources, has been subjected to a series of major disturbances, both 'natural' and man-made; drought, civil disturbances, large population increases and the impacts of 'globalization'. Each of these has had implications for land-use requirements, with subsequent impacts on natural vegetation cover, biodiversity, socio-economic stability and food security. The modification of the vegetation cover, with a predominant clearing of natural vegetation, may have a long-term impact on sustainable food production, freshwater- and forest resources, the climate and last but not least human welfare (Foley *et al*. 2005).

In many developing countries populations are heavily dependant on freshwater, forests croplands and fisheries (Homer-Dixon and Blitt 1998) to which we should add pastures. Shortages in these sectors can give rise to increased poverty, environmental refugees (Jacobson, 1988) and even conflict. Some authorities have even suggested a new age of insecurity (Homer-Dixon, 1991), the so-called "neo-Malthusian" theory. There is a growing body of literature on environmental scarcity and conflict (Raleigh and Urdal, 2005, Urdal, 2005) which reflects not only current concerns but that of future scenarios based on climate change prediction and its subsequent impact on water resources, land degradation and food production. Just how much land cover change has occurred over the last 25 years is not entirely clear – as reliable statistics are hard to come by (see section 1.3).

Our study aims to use an independent method to quantify the areal extent of four broad land cover classes: forests, natural non-forest vegetation, agriculture and barren areas, at two key dates 1975 and 2000. We hope to demonstrate that such an approach can give consistent and repeatable results for natural resource assessment, valid at sub continental levels, and propose improvements to the methodology. Due to the limited availability of satellite data our study does not cover 'desertification' processes, which require multi-temporal analysis so as to remove possible seasonal and inter-annual effects.

The approach uses the mapping capacity of high spatial resolution Earth observing satellites which have been operating since the early 1970s. Such satellite data have been employed for monitoring agriculture since the mid 1970s (Curtis, 1978). While the data, such as that available from the Landsat Thematic Mapper, are appropriate for the mapping task they have a restricted coverage both in time and in space. To cover the full sub-Saharan region 1200 such scenes would be required, with important cost implications, both in image acquisition and processing. A standard technique adopted in land cover inventories, is therefore to use a sampling strategy across the target area (*e.g.* Achard *et al.* 2002). We therefore aimed to acquire two sets of samples, one 'historical', targeted at 1975 and a second 'recent', targeted at the year 2000. The advantages of cost and speed in producing the estimates, is counterbalanced by the availability of estimates at aggregated levels and the lack of a cartographic product showing the spatial distribution of the land cover change.

1.1. Africa – recent drivers and impacts

Africa's total land area is about 29.6 million sq km which represents 20 percent of the Earth's surface. Over 65 percent of it is arid or semi-arid (of which 43 percent is extreme desert) about 22 percent is under forest, and only 21 percent is suitable for cultivation (FAOSTAT, 2006). The topography ranges from tropical islands to high mountains, plateau and plains. Climates vary widely, from the warm tropics with high annual rainfall in the Congolian region to the cool tropics in the Afromontane eco-region to the warm tropics with very little rainfall in the Sahelian belt. This diversity is reflected in a wide variety of landscapes which include many biologically rich and unique eco-regions, such as the tropical forests, montane forests, grasslands and coral reef fringed islands (UNEP, 2005).

Africa's population in 2001 was about 812,603 million people. With the highest birth-rate of any continent – 2.4 percent compared to a world average of 1.3 percent – the population is projected to grow to two billion by 2050. About 60 percent of the population live in rural areas and 55 percent of the economic active population is dependant on agriculture, but annual urban growth rates at nearly 4 percent are the most rapid in the world and nearly twice the global average (FAOSTAT, 2006).

Economies are mainly based on primary products or natural resources. Economic performance has been poor - per capita GDP growth rate for sub-Saharan Africa was 4.3 percent in 2001 and 3.2 percent in 2002 and nearly 50 percent of the people in sub-Saharan Africa live with less than one dollar a day. This is reflected also in the human development index, where 29 African countries are classified as low. Main consequences are poverty, malnutrition and diseases. The United Nations Food and Agricultural Organization (FAO) estimates that malnutrition has remained nearly constant over the last 25 years, diminishing by only 2 % from 33 to 31 % prevalence of under nourishment in total population (FAOSTAT, 2006).

Major diseases like HIV/AIDS and malaria have a major impact on social development, economic growth and health systems. For example, in South Africa the impact of HIV/AIDS over the next decade is estimated to be 0.4 percent of Gross Domestic Product. In some countries, such as Zambia and Botswana, 20 % or more of the adult population is believed to be infected with HIV/AIDS. Furthermore, malaria causes between 1.5 and 2.7 million deaths a year, 90 percent of them are children under five (UNAIDS, 2006).

The pressure on Africa's environment (which is mainly the result of population growth that has exceeded the capacity of natural resources to meet expanding human needs with the current technology) results in loss of forests, animal and plant species, land degradation, increasing water shortages and declining water quality. The conversion of land to agriculture associated with poor land management practices causes land degradation and erosion processes. About 25 percent of the land is subject to water erosion and 22 percent to wind erosion and desertification affects over 45 percent of the land area of which 55 percent at high to very high risk (UNEP, 1992). Water stress and scarcity are endemic in 14 of the 53 African countries and water quality is deteriorating while water-related diseases are increasing. Africa has only 9 percent of global renewable freshwater resources and the average water availability per person is far less than the global average (FAO AQUASTAT). It is estimated that around 6,000 people a day die as a result of poor hygiene and contaminated water and about 3 million annually as a result of water-related diseases (UNEP 2005). The land degradation and water stress are exacerbated by a high variability in rainfall resulting often in prolonged droughts, followed by periods with intense rainfall which often cause severe flooding.

Prolonged and widespread droughts occurred in 1973 and 1984, when almost all African countries were affected, and again in 1992, when all southern African countries experienced extreme food shortages. In 1973 alone, drought killed 100,000 people in the Sahel. On the other hand, in 1998 many parts of East Africa experienced record rainfall, up to ten times the usual amount, and disastrous flooding (Gommes and Petrassi, 1996). Millions of Africans require refuge from these disasters. These environmental refugees - people who can no longer gain a secure livelihood in their homelands because of environmental problems, together with associated problems of population pressures and profound poverty – were estimated to be at least 25 million in 1995. When compared or even added to the 27 million traditional refugees - people fleeing political oppression, religious persecution and ethnic troubles – we see the impact this process can have on the already numerous conflicts in Africa (Myers, 2001). Environmental refugees and traditional refugees have often to settle on marginal areas where some face social tensions with new neighbouring communities (OFDA, 2000). In the 1990s, 18 of the 53 African countries were facing main conflicts, which represent almost 40 percent of all global conflicts (UNDP, 2005).

1.2. The policy dimension

Awareness of the potential range of impacts of rapid changes in land cover has led to international concern and calls for action. The United Nations Conference on Environment & Development (UNCED) held in Rio de Janeiro, Brazil, 3 to 14 June 1992 (also known as the Earth Summit) highlighted the protection of natural ecosystems as a key element underpinning economic development. One of the major outcomes of the Earth Summit, the *Agenda 21*, is a global plan of action in every area in which humans impact on the environment. A key component of this action plan, and fundamental to policy support, is the systematic collection of observations relating to forest cover, desertification and degradation processes. (Agenda 21 1992).

Building on the experience of the Rio Earth Summit all national governments and leading development institutions agreed in September 2000 on a global partnership for building a better world - the Millennium Development Goals (MDG). One of the eight MDG goals is to '*ensure environmental sustainability*' (goal 7) where target 9, aims '*to reverse the loss of environmental resources*' with appropriate indicators being the *proportion of land area covered by forest* (indicator 25) and the *proportion of area protected* (indicator 26) within a country. Clearly the latter indicator refers to 'natural areas'. Nevertheless, it is clear that these goals do not take precedence over the primary goal, that is to **"e*radicate extreme hunger and poverty*".**

The European Union has clear policy lines dedicated to improving natural resource management in Africa and targets specific environmental issues such as climate change, logging, land degradation and loss of biodiversity. To support, direct and monitor these actions up-to-date information on environmental resources, food availability/demand, and on potential crisis situations are necessary. At the same time, such information can serve as a feedback as to the success of supportive measures given to national and regional bodies.

1.3. Currently available data

Conventionally, data on forest cover, and on agricultural lands and productivity are available through the Food and Agricultural Organization (FAO) of the United Nations, which collates statistics from the countries themselves, harmonizes and rationalizes them to form global data bases on forests (Forest Resource Assessment – FRA) and on agricultural production (FAOSTAT). While these databases are valuable sources of information, they inevitably suffer from a lack of consistency and completeness both in time and in geographic coverage – relying as they do on the completeness of the national data sources which in some countries are incomplete or out of date. The methods for collecting the data, the actual information collected and aggregation it undergoes may vary markedly between countries, making harmonization and rationalization difficult (see Mathews, 2002, for a similar debate on global forest statistics collected by the FAO). There is therefore a clear need to develop methods to regularly assess and report on key resource extent and condition using robust and repeatable methods.

1.4. The study area

Sub-Saharan Africa encompasses a wide range of climatic and ecological regions resulting in a wide variety of land cover types and dynamics. The area involved is some 1,957 million ha (or 19.57 million square kilometres), which is around two-thirds the continent's land surface. To describe these regions in detail here goes beyond the scope of this work. In brief, the vegetation varies from the humid forests of the central Congo basin to the arid grass and shrub lands of the Sahel. Likewise climatic regimes which are roughly mirrored in the pattern of vegetation differ between the warm tropics with high annual rainfall in the Congolian region to the warm tropics with very little rainfall in the Sahelian belt. Based on the White/UNESCO map our region is subdivided into 14 ecological regions (Table 1) or 'ecoregions'. The differences in area, population, topography, climate and land cover of these ecoregions reflect this diversity.

1.5. Deliverables and applications of the database

In carrying out the exercise we aimed to provide a range of products and deliverables that might serve different aspects of environmental monitoring. Our principle data set consists of over 50 sites for which we obtained geometrically matched high resolution satellite data from two dates. From these a spatial database was created of 511 sub-units of land cover interpretations. These interpretations were used to produce an estimate of the extent of agriculture, forests, natural vegetation and barren areas for sub-Saharan Africa for the years 1975 and 2000 at a continental and at an ecoregion level, with a further estimate of the changes in these classes between these two reference years.

1.5.1. Carbon pool changes

The scientific community has demonstrated the impact of greenhouse gases on the carbon cycle and its consequences for global climate (IPCC, 1997). While emissions from industrial sources can be calculated, it has been pointed out that large uncertainties exist in the estimation of emissions coming from land cover change activities, notably biomass burning and tropical deforestation (Prentice *et al.* 2001). However it is suspected that such activities may contribute as much as 20 percent. The Joint Research Centre's TREES project (Achard *et al*. 2002, 2004), have tried to improve the estimates of emissions due to forest clearance in the humid and dry tropics using remotely sensed data for the 1990s.

1.5.2. Available land

In sub-Saharan Africa land is used predominantly for the production of primary crops, for pasture, cash crops and as a source of fuel wood. As populations rise the amount of land required to meet expanding needs is constantly increasing - a problem that can be accentuated by land degradation and of course land tenure. Data from studies such as this can form one input, along with land suitability, land tenure and population data, into assessing how much land is available for future exploitation, and when (or if) a potential problem on land scarcity will exist. Such problems in land scarcity can give rise to migration and conflict. At the same time the implications on the availability of fuel wood and pastures and the sustainability of protected areas can start to be assessed.

Ecoregion	Area km^2	Predominant land cover	Population 2000	Topography	Climate
GUINEO-CONGOLIAN	2,900,467	Humid tropical forest	114,872,505	mainly level land	warm tropics
ZAMBEZIAN	3,924,240	Dry forests, woodlands and grasslands	70,158,185	mainly level land with sloping land	warm tropics
SUDANIAN	3,641,240	Woodlands and grasslands	112,929,909	mainly level land with sloping land	warm tropics
SOMALIA-MASAI	1,974,420	Grasslands	33,666,625	level land with sloping land	warm tropics
KAROO-NAMIB	667,766	Grasslands	964,032	mainly sloping land with steep land	warm sub-tropics in the North and cool sub-tropics in the South
AFROMONTANE	808,853	Humid forests	87,814,651	mainly steep land	cool tropics
GUINEA-CONGOLIA/ ZAMBEZIA	779,911	Dry forests, woodlands and grasslands	15,168,813	mainly sloping land with level land	warm tropics
GUINEA-CONGOLIA/ SUDANIA	1,225,983	Dry forests, woodlands and grasslands	52,659,006	level land with sloping land	warm tropics
ZANZIBAR-INHAMBANE TONGALAND PONDOLAND	523,547	Coastal ecosystems	32,585,908	mainly level land with sloping land in the North and mainly steep land with sloping land in the South	warm tropics to cool sub-tropics
KALAHARI-HIGHVELD	1,277,340	Grasslands and arid zones	13,298,317	mainly level land with sloping land and some steep land	warm tropics in the North and warm and cool sub-tropics in the South
SAHEL	2,570,970	Grasslands and arid zones	21,557,690	mainly level land	warm tropics
MADAGASCAR	592,139	Dry and humid forests, woodlands and grasslands	14,998,395	mainly steep land with sloping land in the East and mainly sloping land with some level land and steep land in the South	warm tropics with cool tropics in the highlands

Table 1: Ecoregions and their characteristics

1.5.3. Biodiversity indicators

Concern over the loss of biodiversity has been raised in many areas of the world (Myers *et al*. 2000). There are a number of measures of biodiversity which are beyond the realm of remote sensing studies (e.g. numbers of bird or plant species), however it is clear that remote sensing can provide information on the extent of sensitive habitats and current threats. Hence loss or fragmentation of forests and savannahs and increases in barren lands can be used as indicators of biodiversity changes. Within our survey we provide figures for the losses of forests and non-forest natural vegetation.

1.5.4. Climate

The impact of land cover on climate is many-fold, playing a major role on the exchanges in water and heat between the surface and the atmosphere. A key input into climate models is the surface albedo, essentially a measure of the percentage of incoming solar radiation that is reflected from the surface, which in turn is dependant on vegetation type and cover. By assessing the current albedo and distribution of vegetation of sub-Saharan Africa, we can estimate the change that has occurred in this biophysical property over the last 25 years.

Figure 1: The conversion of natural vegetation to agriculture is the overwhelming land cover dynamic in sub-Saharan Africa.

2. Methods and data

2.1. Overview

A sample of 57 study sites were randomly selected from a hexagonal based grid from across sub-Saharan Africa (Figure 2). For each of these sites remotely sensed satellite images from 1975 and 2000, were acquired. Subsets were extracted from the images and classified into five main land cover classes. The proportions of land cover in the sites were then extrapolated to sub-regions, based on the White/UNESCO vegetation map of Africa.

2.2. Satellite data

The historical satellite images come from Landsat Multi-Spectral Scanner (MSS), with a spatial resolution of 80 m and an image swath width of 180 km, and the recent satellite images from the Landsat Thematic Mapper and Enhanced Thematic Mapper, which have a finer spatial definition of 30 m and an image swath width of 180 km. For the majority of sample sites four MSS scenes were downloaded and mosaiced together so as to cover the equivalent area covered by the TM scene as the two reference schemes do not coincide. Image to image geometric referencing was carried out to ensure co-location of the historical and recent images.

Due to incomplete acquisitions and cloud cover, not all sites had images available for the target dates of 1975 and 2000. We therefore selected images as close to these dates as possible and adjusted the area estimates for each sub-set to reference dates of June 1975 and June 2000 by linear interpolation of each land cover class. A total of 57 Landsat TM and 88 Landsat MSS images were used in the study.

2.3. Ancillary data sets used

Ancillary data were used for three specific purposes. Firstly, maps, images and ground-survey photographs were sought to aid in the image interpretation process. Secondly, statistical data were sought as a comparison for our land cover change findings . Thirdly, we sought data on human and livestock population so as to give a general analysis on the implications of our findings in terms of intensity of land use.

2.3.1. Population data

The population statistics (*c.*1975 and 2000) were extrapolated from the database provided by the University of California/UNEP, "African Population Database" (Deichmann, U. 1994 and 1996, Nelson, A. and Deichmann, U. , 2004). The data area available freely from the USGS website http://grid2.cr.usgs.gov/globalpop/africa/: These data were supplemented with national data from the FAO FAOSTAT database.

2.3.2. Forest and agricultural statistics

For comparisons with our findings we used data from the FAO Forest Resource Assessment (FAO 2005) and from the FAO FAOSTAT data base (http://faostat.fao.org/default.aspx).

2.3.3. Livestock data

The totals of livestock by ecoregion were derived using the 'Cattle density for Africa' map

(2004) available through the FAO GeoNetwork website (http://www.fao.org/geonetwork), showing the continental cattle distribution. The data were aggregated to obtain the proportions of cattle in each country by ecoregion. These proportions were then multiplied by the livestock figures from country totals for 1975 and 2000 reported by FAO FAOSTAT database. Supplementary information were taken from FAO (Seré *et al.* 1996) and ILCA publications (International Livestock Centre for Africa, Addis Ababa, Ethiopia) (Coppock (ed.). 1994, ILCA 1993).

2.4. Land cover classes

The land cover classes assessed are of a broad nature, mainly to accommodate the interpretation process for such a large region. The *forest* class includes closed evergreen, semi-evergreen and dry deciduous forests. Unlike national ground based inventories, the use of remote sensing limits us to assigning classes where at least 40% of the surface is covered by our target class. This contrasts with FAO statistics, where forest classes are those with greater than 10% forest cover. Tree, shrub and grass savannahs and shrub lands are in the *non-forest vegetation* class. The class *barren* includes very sparse grasslands (or pseudo-steppe), bare soil and rocks. As we excluded the deserts from the White/UNESCO 'Sahel', Karoo-Namib and Somalia-Masai strata, care is needed in using these data as an indication of 'desertification'. Monitoring desertification requires multi-temporal image acquisitions, which within the scope of our study was not possible. The class *agriculture* relates to the agricultural domain - irrigated and rain-fed croplands, smallholdings and plantations. In certain circumstances, man-made pastures will be classified under this heading. This occurs predominantly where in the Sahel and Sudanian regions, where arid shrub lands have been cleared for grazing. Natural pastures (in fact a land-use term) will be classified under *non-forest vegetation*.

While the class 'water' was included in the interpretation it is not reported in the assessment as firstly, changes between in water areas between the recent and historical images may be related to seasonal factors rather than long-term changes, and secondly, the large water bodies of sub-Saharan Africa are not equally distributed across the region. The inland waters are dominated by a few large bodies, the Volta, Lakes Chad and Victoria and the great Lakes, limited in their distribution. A special sampling scheme would be required to assess their current areal extent. Similarly, urban areas are not reported in the statistics.

2.5. Stratification plan

The sampling framework consists of a tessellation of hexagons across the study area (Richards *et. al*. 2000, Boschetti *et al*. 2006). A post-sampling stratification was applied using a modified version of the White/ UNESCO vegetation map of Africa, targeting a sampling rate of 1% in each of the strata.

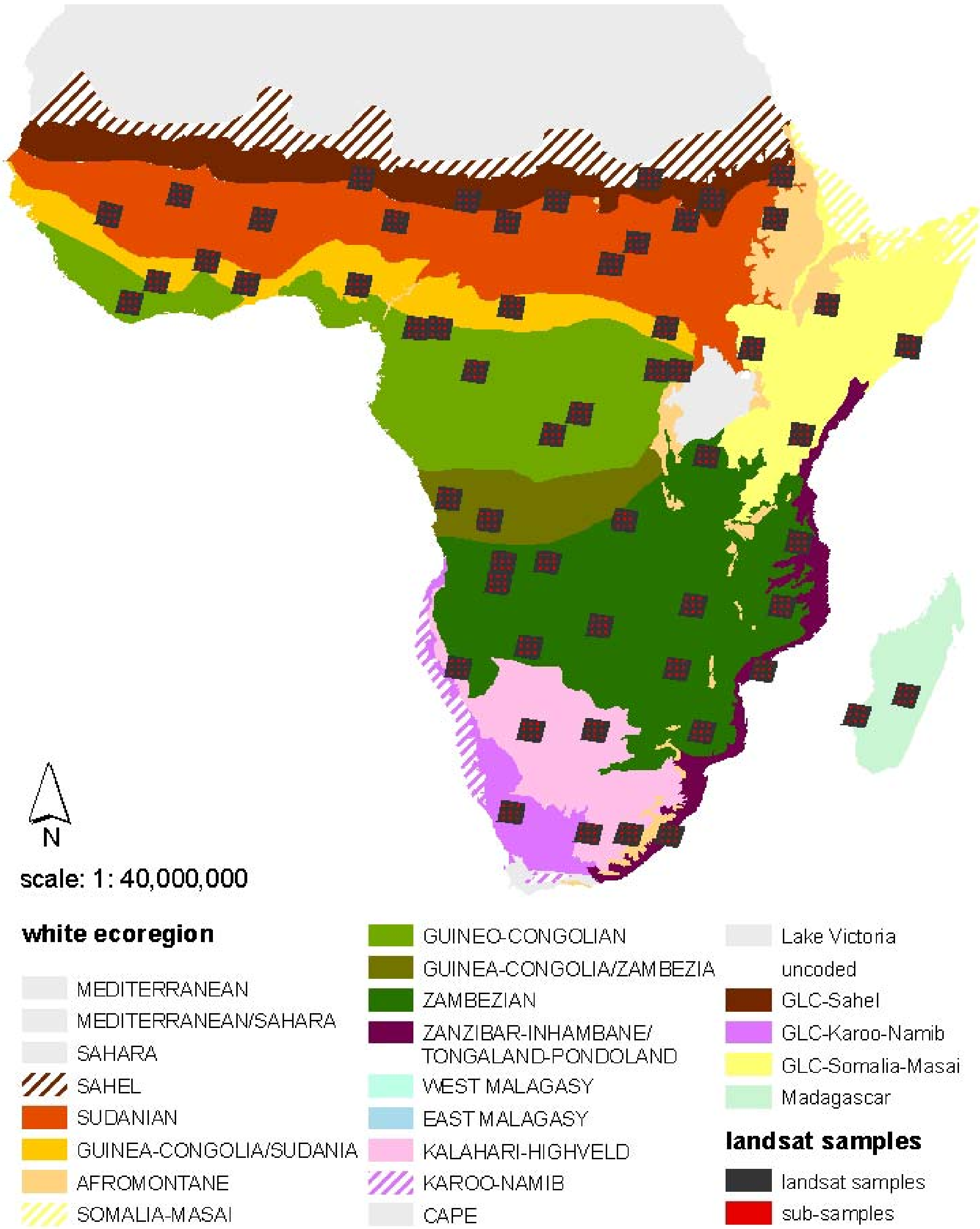

Figure 2: Ecoregion stratification and sample sites

The White/UNESCO map was modified in two ways: one, aggregating small, irregularly shaped strata for which this type of satellite data is inappropriate and two, masking out areas found to be desert on the recent GLC 2000 land cover map (Mayaux *et al.* 2004), but included in the vegetated strata on the original UNESCO map. A sample of 57 hexagons was selected and the nearest satellite Landsat TM scene from the World Reference Series (WRS) II grid to the centre of the hexagon selected. From each of the Landsat scenes nine sub-scenes of 20 by 20 km were extracted and used to assess the land cover.

2.6. Image interpretation

The use of sub-scenes, as opposed to the full scene, was undertaken so as to improve the variance of the estimates and to reduce errors which occur in full scene classification. As a result the area interpreted for the study was 1% of the sub-Saharan region with a total of 511 boxes being assessed. Examples of these subsets are shown in Figures 4-7.

The sub-scenes were independently classified into 30 spectral classes using a statistical unsupervised clustering algorithm (ISODATA) and then visually interpreted into the four main land cover classes (forests, non-forest vegetation, agriculture and barren) along with water and 'no data' (clouds / missing area). For each of the available 511 boxes the proportions of land cover at the two reference dates are calculated. The minimum mapping unit was set at the pixel level.

The image interpretation was carried out in an inter-dependant way, using both images (historical and recent) to classify the land cover. In this way we aimed to minimise errors in assigning a stable class differently on the two images, *e.g.* on the recent image as closed forest (hence *forest* class) and on the historical image open forest (hence *non-forest vegetation* class).
The interpretation was carried out using a set of national vegetation maps, AfriCover (http://www.africover.org/index.htm), on-line digital databases and photographs, agricultural statistics and expert knowledge. The Google Earth online resource was also found to be of use in providing some supporting information in areas where very fine resolution data was available.

To assess the impact on area estimates derived from sensors with different spatial resolutions, we degraded a random sample of 10% of our TM sub-scenes to the MSS resolution and compared the areas classified. An R^2 value of 0.98 at first seems to demonstrate that no major differences occur due to the different spatial resolution (Figure 3). However, examination of the scatter plot shows that this is dependant on percentage cover, with high and low covers being correlated with medium covers having greater variance. It is also clear that for a number of circumstances Landsat MSS data will not detect elements where landscape units fall below 100m. Such areas which may appear 'fragmented' in the Landsat TM classification (e.g. forests with logging), will appear homogeneous in the Landsat MSS classification. The main effect of this generalisation will be to overestimate block classes in the 1975 classifications.

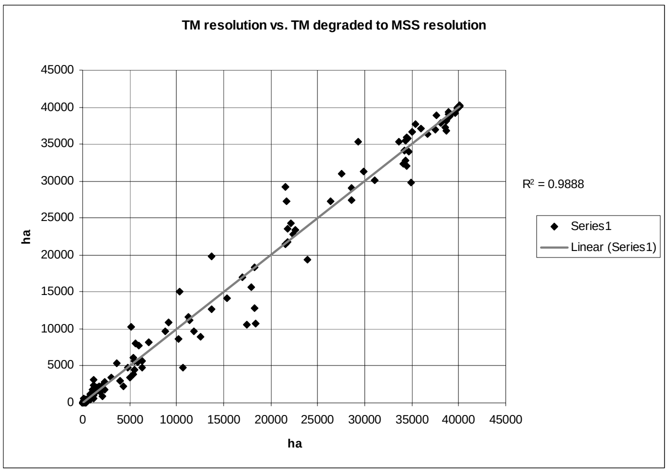

Figure 3: Relationship between MSS and TM area estimates

2.7. Generation of regional results

For our two reference years, 1975 and 2000, the area of each of the four land cover classes and its standard error are calculated per ecoregion by *Direct Expansion* using the formulae given by Gallego and Delincé (1991). The changes between the two dates are reported and the data are then aggregated to the sub-Saharan levels.

For our two reference years, 1975 and 2000, the area of each of the four land cover classes and its standard error are calculated per eco-region using the Horvitz-Thompson Direct Expansion Estimator. The application and utility of the direct expansion method has been tested in various studies, i.e. Gallego and Delincé (1991a), Gallego and Delincé (1991b), Taylor and Eva (1993) and Deppe (1998). The estimator for each land cover class 'c' is the mean proportion 'y' per sample unit, for the sample units contained within each eco-region total area.

This is given by:

$$\bar{y}_c = \frac{1}{n}\sum_{i=1}^{n} y_{ic}$$

where n is the number of sample units and y_{ic} is the proportion of land cover for a particular class in the i^{th} sample unit. The total class area Z_c is obtained from:

$$Z_c = D.\bar{y}_c$$

where D is the total area of the study region. The standard error $S.E.(Z_c)$ is calculated as follows:

$$S.E.(Z_c) = D.\sqrt{\left(1-\frac{n}{N}\right)\frac{1}{n(n-1)}\sum_{i=1}^{n}\left(y_{ic}-\bar{y}_c\right)^2}$$

where N is the total population of sample units from which the sample was drawn and is equal to the study area divided by the area of individual sample units. The 95% confidence intervals, $C.I._{95\%}$, are calculated from:

$$C.I._{95\%} = Z_c \pm 1.96 S.E.(Z_c)$$

The changes between the two dates are reported and the data are then aggregated to the sub-Saharan level.

The significances of the changes by ecoregion are tested using the *t-test* (Annex) to establish if the mean estimate (in this case for area of a particular land cover) is significantly different from two estimates (one 1975, the other 2000) using paired samples.

3. Results

3.1. Sub-Saharan Africa's land cover in the year 2000

Our estimates for sub-Saharan Africa's land cover in the year 2000 show that 17.3 % of the region was under agriculture, 18.8 % forests, 60.8 % non-forest vegetation, 2.5 % barren and under 1% water (Table 2). These figures correspond closely to those of the most up-to-date land cover map of the region (Mayaux *et al*. 2004) also produced from satellite data from 2000, all be it of a different spatial resolution (SPOT VGT 1km data). The largest differences between these two estimates is for agriculture (2.5 %).

	Agriculture (000 ha)	*Forest (000 ha)*	*NF veg. (000 ha)*	*Barren (000 ha)*	*Total (000 ha)*
AFROMONTANE	26,762	865	54,178	488	82,437
GUINEA-CONGOLIA/SUDANIA	28,944	26,365	65,178	49	124,950
GUINEA-CONGOLIA/ZAMBEZIA	987	17,645	60,712	-	79,487
GUINEO-CONGOLIAN	36,988	243,393	14,226	45	295,611
KALAHARI-HIGHVELD	7,942	-	119,538	2,436	130,185
KAROO-NAMIB	280	-	37,279	11,810	49,446
MADAGASCAR	14,616	8,756	34,258	1,976	60,350
SAHEL	39,615	800	92,226	516	134,449
SOMALIA-MASAI	18,674	5,140	125,265	26,443	175,699
SUDANIAN	97,864	18,531	251,242	2,603	371,110
ZAMBEZIAN	49,755	43,709	300,515	3,111	399,953
ZANZIBAR-TONGO-COAST	16,261	2,388	34,468	-	53,359
TOTAL	338,688	367,593	1,189,086	49,477	1,957,035
PERCENT	17.3	18.8	60.8	2.5	100.0
GLC 2000	330,300	363,800	1,211,000	48,300	
DIFFERENCE FROM GLC 2000	2.5	1.0	-1.9	2.4	

Table 2: Sub-Saharan land cover for the year 2000

The distribution of sub-Saharan land cover (Table 3) shows the Sudanian region to contain the most agriculture, while the majority of the forests lie within the Guineo-Congolian region.

	Agriculture	*Forest*	*NF veg.**	*Barren*
AFROMONTANE	7.9	0.2	4.6	1.0
GUINEA-CONGOLIA/SUDANIA	8.5	7.2	5.5	0.1
GUINEA-CONGOLIA/ZAMBEZIA	0.3	4.8	5.1	-
GUINEO-CONGOLIAN	10.9	66.2	1.2	0.1
KALAHARI-HIGHVELD	2.3	-	10.1	4.9
KAROO-NAMIB	0.1	-	3.1	23.9
MADAGASCAR	4.3	2.4	2.9	4.0
SAHEL	11.7	0.2	7.8	1.0
SOMALIA-MASAI	5.5	1.4	10.5	53.4
SUDANIAN	28.9	5.0	21.1	5.3
ZAMBEZIAN	14.7	11.9	25.3	6.3
ZANZIBAR-TONGO-COAST	4.8	0.6	2.9	-
TOTAL	100.0	100.0	100.0	100.0

** NF veg. = non-forest vegetation*

Table 3: Distribution of land cover (%) by ecoregion for the year 2000

The variations in land cover within region (Table 4) show the areas with the highest proportion of agriculture are the Afromontane the Sahel and the Zanzibar-Tongo Coast. Six of the twelve regions have important proportions of agricultural domains (*i.e.* > 20%) the Afromontane region (32%), the Zanzibar-Tongo Coastal region (30%) the Sahel (29%) the Sudanian (26%) Madagascar (24%) and Guinea-Congolia/Zambezia (23%). Karoo-Namib (23%) and Somalia-Masai (15%) have significant barren areas. Our use of the GLC 2000 map to reduce desert areas has influenced the latter figures. The Guineo-Congolian zone is dominated (82%) by the Congo basin forest while in the other regions, non-forest natural vegetation dominates.

	Agriculture	*Forest*	*NF veg.**	*Barren*
AFROMONTANE	32.5	1.1	65.8	0.6
GUINEA-CONGOLIA/SUDANIA	24.0	22.0	53.0	0.9
GUINEA-CONGOLIA/ZAMBEZIA	1.3	22.2	76.4	0.0
GUINEO-CONGOLIAN	12.6	82.4	4.9	0.1
KALAHARI-HIGHVELD	6.2	0.1	91.9	1.9
KAROO-NAMIB	0.6	0.0	75.4	23.9
MADAGASCAR	24.5	14.8	57.1	3.6
SAHEL	29.7	0.8	68.8	0.6
SOMALIA-MASAI	10.7	3.0	71.3	15.1
SUDANIAN	26.4	5.1	67.8	0.8
ZAMBEZIAN	12.6	11.1	75.3	1.0
ZANZIBAR-TONGO-COAST	30.6	4.6	64.7	0.1

** NF veg. = non-forest vegetation*

Table 4: Proportion of land cover (%) within each ecoregion for the year 2000

3.2. Land cover changes for Sub-Saharan Africa – 1975 to 2000

The most dramatic changes in land cover of the period have been the increase (57%) of agricultural lands. The area covered by agriculture increased from 215 Mha in 1975 to 338 Mha in 2000, which gives an annual rate of 2.3 % (Table 5). This has occurred at the expense of forests and non-forest natural vegetation, contributing 55% and 45% respectively to the total, and equates to some 5.2 Mha (52,000 km^2) of natural vegetation lost a year. In total this means that sub-Saharan Africa has lost some 130 Mha of natural vegetation (forests and non-forests) over the last 25 years, amounting to 8% of the total, some 16% of her forests and 5% of her non-forest natural vegetation. The data on changes in 'barren' areas, only relate to the non-arid zones. Desertification is therefore not indicated in the changes.

	Agriculture (000 ha)	*Forest (000 ha)*	*NF veg. (000 ha)*	*Barren (000 ha)*
Land cover 1975	215,274	438,917	1,247,980	42,912
SE	13,132	28,530	31,200	6,866
Land cover 2000	338,688	367,593	1,189,086	49,477
SE	19,305	24,261	32,105	11,380
Total increase	123,414	-71,324	-58,894	6,565
Average annual increase	4,937	-2,853	-2,356	263
Average annual (%) change*	2.3	-0.7	-0.2	0.6

**** Calculated as a percentage of the 1975 land cover***

Table 5: Land cover changes in Sub-Saharan Africa between 1975 and 2000

This dynamic of agricultural expansion at the expense natural vegetation loss is seen almost all over the sub-Saharan region (Table 6), with the exception of the Guinea-Congolian / Zambezian region, where the some abandonment was observed in the Angolan scenes – probably due to civil disturbance. In terms of the major changes, the Sudanian region accounts for over one quarter (26%) of the total increase in agriculture land, and as a consequence the largest proportion loss of natural vegetation (36% of the total). The highest proportional losses of land cover are in forest areas, with almost all regions losing more than 20% of their 1975 forest cover. The largest forest losses occur outside the humid forests of the Congo basin forest, which accounts for only 16% of the total forest loss, despite accounting for more that 80% of the sub-continent's forest area. Four regions account for around 80% of this change, Guineo-Congolian (16%), Sudanian (19%), Guinea-Congolia / Sudania (20%) and Zambesian (24%).

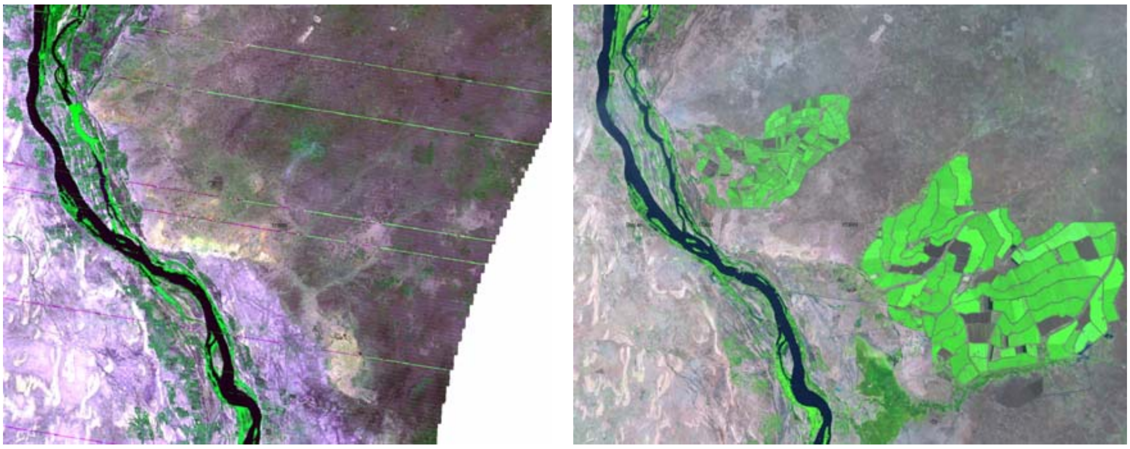

Figure 4: Agricultural expansion is the main driving force of land cover change. These images from the Sudan, show the increase in irrigated crops between 1972 (left) and 2000 (right) along the Nile river.

	Forest (ooo ha)	***NF veg. (ooo ha)***	***Forest (%)*****	***NF Veg.* (%)*****	***Total (%)*****
AFROMONTANE	-1,524	-5,744	-63.8	-9.6	-11.7
GUINEA-CONGOLIA/SUDANIA	-14,108	303	-34.9	0.5	-13.1
GUINEA-CONGOLIA/ZAMBEZIA	-4,173	5,078	-19.1	9.1	1.2
GUINEO-CONGOLIAN	-11,477	-4,787	-4.5	-25.0	-5.9
KALAHARI-HIGHVELD	-	-1,097	-	-0.9	-0.9
KAROO-NAMIB	-	-668	-	-1.8	-1.8
MADAGASCAR	-4,530	-3,210	-34.1	-8.6	-15.3
SAHEL	-1,057	-17,182	-56.9	-15.7	-16.4
SOMALIA-MASAI	-3,706	-11,136	-41.9	-8.2	-10.2
SUDANIAN	-13,388	-21,138	-41.9	-7.8	-11.3
ZAMBEZIAN	-16,979	2,970	-28.0	1.0	-3.9
ZANZIBAR-TONGO-COAST	-382	-2,284	-13.8	-6.2	-6.7
TOTAL	-71,325	-58,894	-16.2	-4.7	-7.7

**** NF veg. = non-forest vegetation***
***** Calculated as a percentage of the 1975 land cover***

Table 6: Changes in natural vegetation cover between 1975 and 2000.

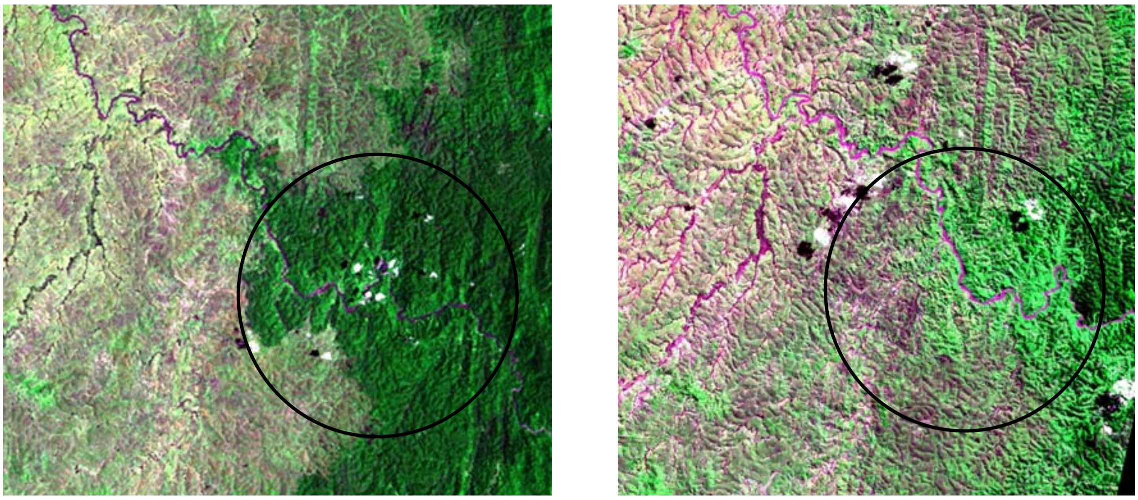

Figure 5: Forest changes have been one of the most important. Here we see the depletion and degradation of forest in Madagascar between 1972 (left) and 2001 (right). Each image is 20km by 20 km .

	Agriculture (000 ha)	*Forest (000 ha)*	*NF veg. * (000 ha)*	*Barren (000 ha)*
AFROMONTANE	286	-61	-230	5
GUINEA-CONGOLIA/SUDANIA	567	-564	12	-1
GUINEA-CONGOLIA/ZAMBEZIA	-22	-167	203	0
GUINEO-CONGOLIAN	662	-459	-191	2
KALAHARI-HIGHVELD	28	0	-44	14
KAROO-NAMIB	8	0	-27	25
MADAGASCAR	301	-181	-128	-10
SAHEL	699	-42	-687	-4
SOMALIA-MASAI	440	-148	-445	154
SUDANIAN	1,299	-536	-846	70
ZAMBEZIAN	563	-679	119	8
ZANZIBAR-TONGO-COAST	105	-15	-91	0
AVERAGE ANNUAL CHANGE	4,937	-2,853	-2,356	263
TOTAL CHANGE - 25 YEARS	123,413	-71,325	-58,894	6,565

** NF veg. = non-forest vegetation*

Table 7: Average Annual changes in land cover (000 ha) between 1975 and 2000

The losses in natural non-forest vegetation are dominated by the Sudanian (36%), Somalia-Masai (19%) and Sahel (29%), which in terms of proportion of the 1975 land cover this equates to 8%, 8% and 16 % respectively. The only significant increases in barren areas are seen in the Sudanian, Karoo-Namib, and Somalia-Masai regions, which account for over 80% of the changes. However, as noted in the introduction, some areas more sensitive to desertification (e.g. northern Sahel) do not fall within the study.

	Agriculture	Forest	NF veg *	Barren
AFROMONTANE	1.3	-3.8	-0.4	1.1
GUINEA-CONGOLIA/SUDANIA	2.6	-1.7	0.0	-1.4
GUINEA-CONGOLIA/ZAMBEZIA	-1.7	-0.9	0.4	0.0
GUINEO-CONGOLIAN	2.3	-0.2	-1.2	6.8
KALAHARI-HIGHVELD	0.4	0.0	0.0	0.7
KAROO-NAMIB	4.2	0.0	-0.1	0.2
MADAGASCAR	2.8	-1.7	-0.4	-0.5
SAHEL	2.3	-3.2	-0.7	-0.7
SOMALIA-MASAI	3.4	-2.2	-0.3	0.6
SUDANIAN	1.6	-2.2	-0.3	4.1
ZAMBEZIAN	1.3	-1.3	0.0	0.3
ZANZIBAR-TONGO-COAST	0.7	-0.6	-0.3	0.0
AVERAGE	**2.3**	**-0.7**	**-0.2**	**0.6**

Table 8: Annual rates of changes (%) in land cover between 1975 and 2000

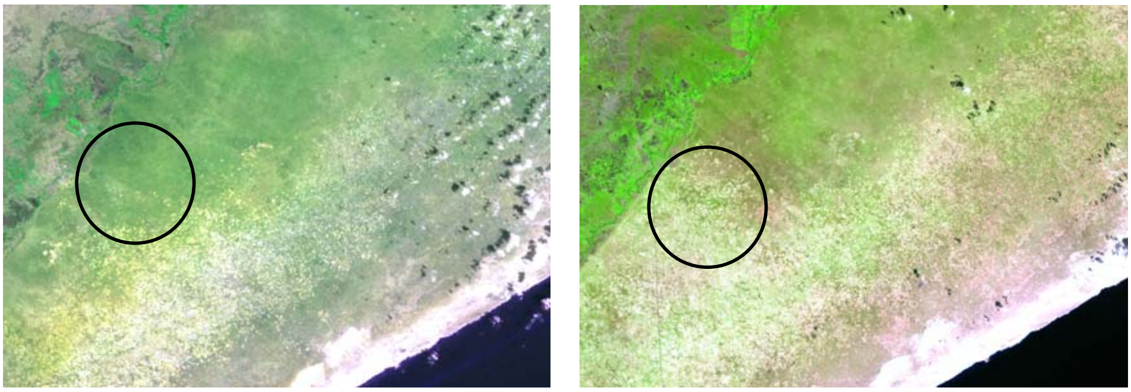

Figure 6: Agricultural expansion and intensification along the coast of Somalia. The agriculture is seen as the white area inland, natural vegetation green and brown.

3.3. Comparisons with other statistical sources

Comparisons with the statistics for forests and for agriculture as provided by the FAO are problematic. For forests (FAO Forest Resource Assessment – FRA), the land cover definitions are different from ours, figures are provided by country or by FAO ecoregion (which do not coincide with our ecoregions) and FRA assessment periods are slightly different (1980-1990-2000). Indeed there are difficulties even within the FAO FRA statistics, as the forest definitions for the 1980-1990 period are not the same as those for the 1990-2000 period, making comparisons between 1980 and 2000 almost impossible. The FAO use a far lower threshold (10% forest cover) than us for determining 'forests', hence their estimates are higher, and include a high proportion of, what is for us, 'woodlands' and hence classed as non-forest natural vegetation. The FAO therefore report 644 Mha of forests for sub-Saharan Africa in 2000, compared to our 367 Mha. We note, however, that the FAO forest changes rates (-0.7% for 1980-1990 and -0.78% for 1990-2000) compare with our change rate (-0.71%).

In the agriculture domain, FAOSTAT (2006) report far lower areas of 'arable land', with 127 Mha in 1975 and 153 Mha in 2000 compared to our 215 Mha in 1975 to 338 Mha in 2000. FAO therefore have an increase of 18% over the period, compared to our 57% change. The increases reported by FAO for Primary Crops (49%) and for Permanent Crops (31%) are closer to our figures. What can account for this 50% divergence between our figures and those of FAO? Most probably, our agricultural class refers to the agricultural mosaic, where small-holdings consist of some cereal production, short fallows, cash crops, market gardens and animal enclosures. Increasing populations may be predominantly reflected in the increases in cereal production, not of all land uses.

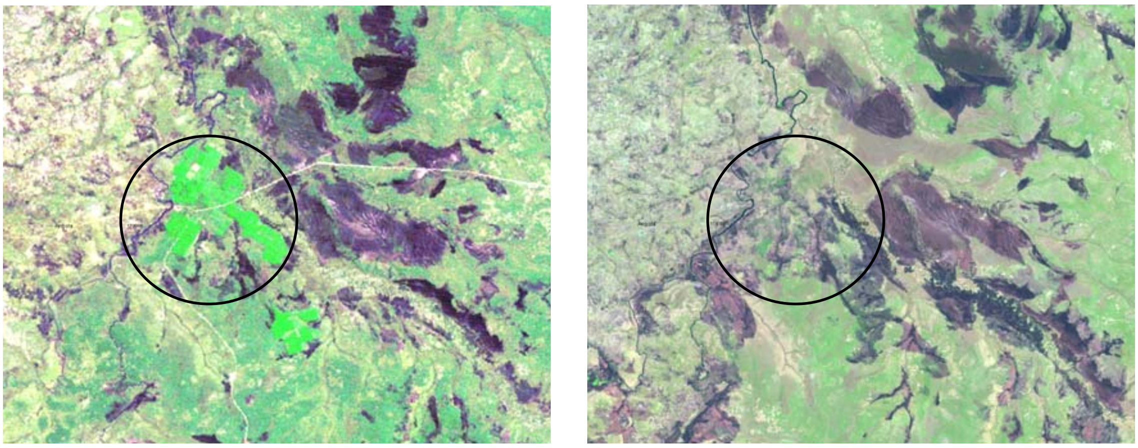

Figure 7: Abandonment of the agricultural zone between the late '70s and 2000 was seen in a number of regions. Here in Angola, even the road crossing the image (left) has disappeared. The black marks are burnt savannahs. Agriculture in the top left of the image (white) has returned to degraded savannahs, and the irrigated area (bright green) is no longer used.

3.4. Results by Economic Zone

Under the fourth Lomé Convention (article 7) concluded between the European Union and the African (Caribbean and Pacific) countries, regional co-operation and integration are given special priority. The European Commission therefore interacts principally with African nations through these regional programmes (Figure 8). The results from the sample unit were re-aggregated by these geographical regions (Table 9). It should however be noted that these figures should be taken as a general indication rather than statistically valid, as the regrouping into different zones will lead to an increase the variance of the estimates. Nevertheless, the regrouping suggests that much of the observed changes have occurred in West Africa.

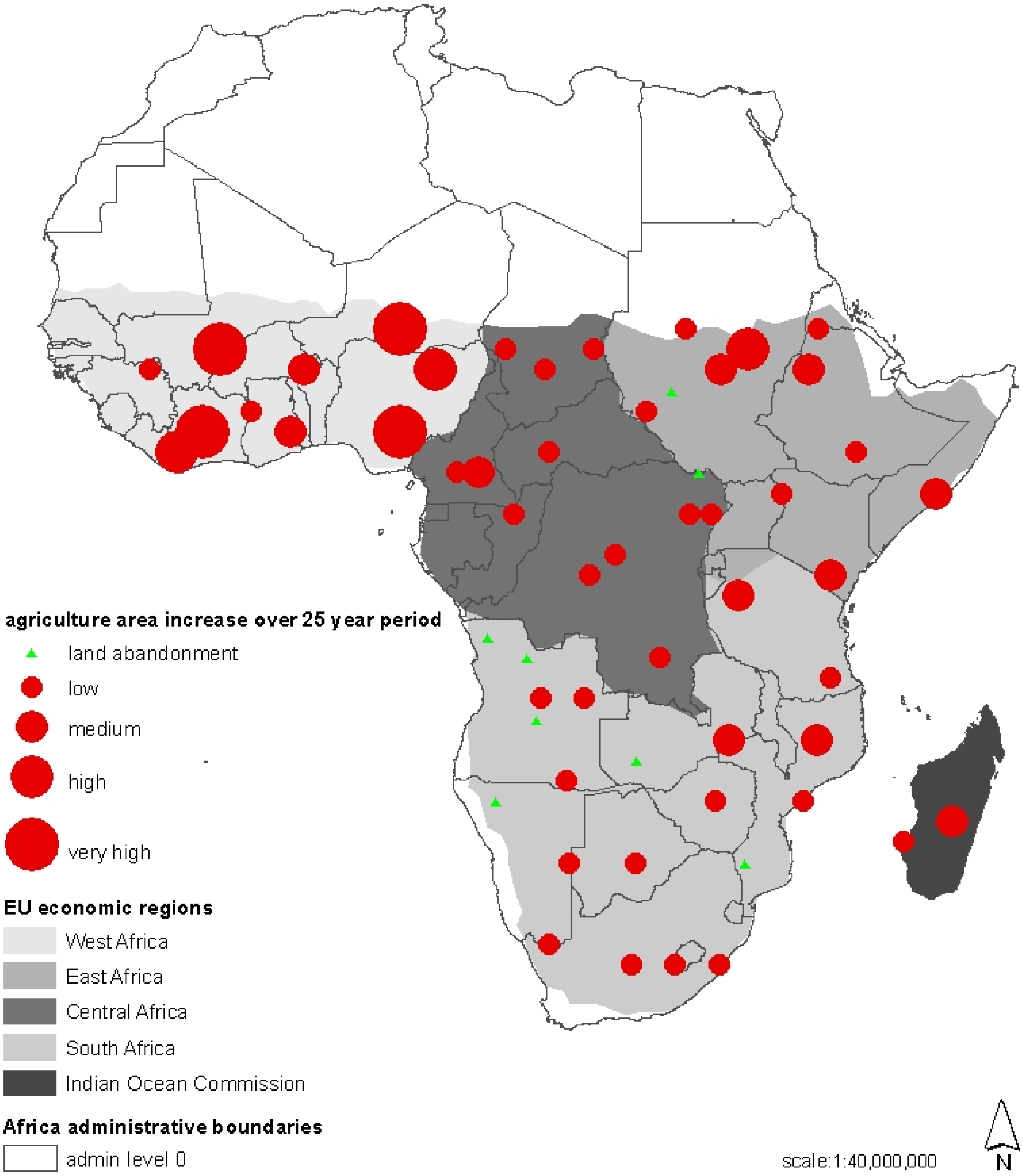

Figure 8: Aggregated sample results showing the relative agricultural increases. Note some areas have seen declines.

Landcover 2000

	Central Africa (000 ha)	East Africa (000 ha)	Southern Africa (000 ha)	West Africa (000 ha)	Madagascar (000 ha)	Total (000 ha)
Agriculture	44,067	56,093	72,388	151,889	14,250	338,687
Forest	222,282	18,640	54,872	62,419	9,379	367,592
NFVeg	201,272	278,544	522,552	152,876	33,841	1,189,085
Barren	888	20,072	23,155	2,541	2,821	49,477

Landcover 1975

	Central Africa (000 ha)	East Africa (000 ha)	Southern Africa (000 ha)	West Africa (000 ha)	Madagascar (000 ha)	Total (000 ha)
Agriculture	33,262	36,348	55,989	82,055	7,620	215,274
Forest	227,678	29,695	72,065	96,352	13,127	438,917
NFVeg	202,263	291,763	525,375	191,676	36,902	1,247,980
Barren	275	17,322	21,214	1,011	3,089	42,912

Changes 1975 to 2000

	Central Africa (000 ha)	East Africa (000 ha)	Southern Africa (000 ha)	West Africa (000 ha)	Madagascar (000 ha)	Total (000 ha)
Agriculture	10,805	19,745	16,399	69,834	6,630	123,413
Forest	-5,396	-11,055	-17,193	-33,933	-3,748	-71,325
NFVeg	-991	-13,219	-2,823	-38,800	-3,061	-58,894
Barren	613	2,749	1,940	1,530	-268	6,565

Table 9: Land cover totals for 2000, 1975 and changes by Regional Economic Groupings (Tanzania has been included in the Southern Africa group).

Figure 9: Changes in land cover in the Sahel are marked, but not always easy to interpret. The area around this town (centre in Sudan, has fields (white) and shrubs (black).

4. Potential impacts

4.1. Available agricultural land – land cover and population

The population of sub-Saharan Africa over the last 25 years has nearly doubled from just over 241 million in 1975 to over 550 million in 2000 (FAOSTAT). The rural proportion of this over the period has fallen from around 80% to 67 %. In such a situation agricultural production must be increased so as to avoid potential famine, either by more efficient farming or by increasing the area of land under production. Importing food would be a further possible mechanism if foreign exchange was possible. As we have seen from sections 3.1 and 3.2 the area under agricultural production has increased by over 55%, and the production of primary crops risen by nearly 50% (FAOSTAT).

	Agriclural land/person (h)		*Available land/person (h) **	
	1975	***2000***	***1975***	***2000***
AFROMONTANE	0.61	0.45	1.9	0.9
GUINEA-CONGOLIA/SUDANIA	0.76	0.81	5.4	2.6
GUINEA-CONGOLIA/ZAMBEZIA	0.29	0.10	14.9	7.7
GUINEO-CONGOLIAN	0.54	0.48	7.2	3.3
KALAHARI-HIGHVELD	1.12	0.88	18.7	13.3
KAROO-NAMIB	0.17	0.43	70.6	57.3
MADAGASCAR	1.80	1.93	12.9	5.7
SAHEL	2.56	2.72	12.9	6.4
SOMALIA-MASAI	0.69	0.82	13.0	5.7
SUDANIAN	1.59	1.28	7.4	3.5
ZAMBEZIAN	1.45	1.05	14.5	7.3
ZANZIBAR-TONGO-COAST	2.38	1.53	6.9	3.5
AVERAGE	1.09	0.91	8.6	4.2

***** Available land is considered as forests, non-forest natural vegetation that could be coverted to agriculture***

Table 10: Rural land availability

There are three consequences of these changes; firstly, the pressure on existing agricultural areas is greater with the average amount of agricultural land per head of rural population falling by 20% from 1.09 to 0.91 hectares – however in certain zones it is far more dramatic. Secondly, the amount of land available for future exploitation is necessarily reduced – on average halved. Thirdly, the forests and non-natural vegetation areas are traditionally areas from fuel wood and other products are collected. This resource is now less than half of that which is was per person 25 years ago. The figures given in Table 10 are the maximum available as, i) not all land 'available' is 'suitable, and ii) not all land 'available' is open to exploitation (e.g. protected areas, land under other ownership). The productive capacity of land resources is determined by climate, soil and landform conditions, and by land-use and -management practices. In view of these constraints the agro-ecological zoning (AEZ) methodology developed by IIASA and FAO (FAO Soils Bulletin 73, 1996 and Fischer *et al.,* 2002) has been applied to estimate the suitable land used and the potential suitable land left for agriculture and pasture. The characterization of these zones is based on combinations of soil, terrain and climatic characteristics which are basic for the supply of water, energy, nutrients and physical support to plants (Fischer *et al*. 2002). For each eco-region FAO's combined climate, soil and terrain-slope constraints dataset has been used to exclude those areas from the suitable land for agriculture which are classified as 100% constrain for agriculture.

We can therefore re-assess our estimates of ‘land available’ for each ecoregion by taking into account only those the areas considered as ‘suitable’ by the FAO AEZ. In this case the amount of land available for future exploitation is obviously reduced (Table 11). Indeed in the case of the Sahel region, the agricultural domain already exceeds the area suitable for cultivation. The figures should be taken as demonstrative, rather than authoritative, but illustrate the trend of the problem, especially in the Afromontane region.

The potentially suitable area has been calculated by subtracting the unsuitable from the total area. The results reveal that the average percentage of potentially suitable area for agriculture for all sub-Saharan Africa is around 60 %, but this varies from nearly a 100 % in Madagascar and over 90 % in the Afromontane region to only 22 % in the Sahel and 4 % in the Karoo-Namib eco-region. These figures together with the agriculture area for the year 2000 assessed through our study, allows to determine the percentage of suitable land used so far and the area of potentially suitable land for agriculture left. In the whole sub-Saharan Africa from the 60 % of suitable area for agriculture nearly 40 % has been exploited already. However, this figure is influenced by two extreme values, the Sahel region, where over 100 % of the suitable area has been already utilized and on the other hand the Guinea-Congolia/Zambezia eco-region, where only 2 % of the suitable land has been used so far. Removing these two extremes the total suitable land for agriculture used so far in sub-Saharan Africa amounts to about 30 %.

Figure 10: Overstocking of cattle may produce further environmental degradation.

	Area (000 ha)	FAO Suitability (000 ha)	Agr. domain (000 ha) 1975	Agr. domain (000 ha) 2000	Rural Population (000) 1975	Rural Population (000) 2000	Available land (ha / pp) 1975	Available land (ha / pp) 2000
AFROMONTANE	82,403	74,914	19,608	26,751	31,977	59,264	1.73	0.81
GUINEA-CONGOLIA/SUDANIA	124,899	76,118	14,760	28,932	19,419	35,538	3.16	1.33
GUINEA-CONGOLIA/ZAMBEZIA	79,454	54,257	1,526	987	5,186	10,237	10.17	5.20
GUINEO-CONGOLIAN	295,489	157,082	20,425	36,973	38,047	77,525	3.59	1.55
KALAHARI-HIGHVELD	130,131	50,243	7,227	7,938	6,454	8,975	6.66	4.71
KAROO-NAMIB	49,425	2,800	91	280	537	651	5.05	3.87
MADAGASCAR	60,325	59,423	7,089	14,610	3,930	7,563	13.32	5.93
SAHEL	134,393	31,610	22,136	39,599	8,648	14,549	1.10	-0.55
SOMALIA-MASAI	175,626	82,625	7,672	18,666	11,159	22,721	6.72	2.81
SUDANIAN	370,956	278,109	65,349	97,823	41,041	76,214	5.18	2.37
ZAMBEZIAN	399,787	328,969	35,659	49,734	24,644	47,348	11.90	5.90
ZANZIBAR-TONGO-COAST	53,337	46,518	13,642	16,254	5,734	10,651	5.73	2.84
TOTAL (average)	1,956,226	1,242,668	215,185	338,548	196,776	371,236	5.22	2.44

Table 11: Suitable agricultural areas and available land per person – note the Sahel has exceeded its potential limits.

4.2. Available pastoral land – land cover and livestock

Similarly, data on livestock levels show the same trend, higher stocking levels. The *natural vegetation* includes forests, which in the case of the Guineo-Congolian region is unsuitable. Note that (Table 12) in the five ecoregions the potential availability of pasture per head of cattle has halved. In many regions cattle raising is migratory, with herds moving to new pastures throughout the dry season, This 'transhumance' faces a number of problems as the agricultural zone expands. Firstly there is less natural pasture available. Secondly due more intensive cultivation, fallow periods are shorter creating larger regions of degraded savannahs with a lower proportion of palatable grasses. Thirdly, conflict situations are more likely to arise with other groups of herders and cultivators. These conflicts can have an added racial element as many of the nomadic groups (e.g. M'bororo, Peul, Fulani, Masai) are often of different ethnic and religious groups from the cultivators . Conflicts between such groups are often reported by relief agencies, popular journals and in the scientific literature (e.g. Obioha, 2005). To avoid conflicts, large populations often migrate, bringing further problems. The role of protected areas can accentuate such conflicts, as they prohibit the passage of herds, forcing them into the agricultural zone.

	All potential grazing lands		*Natural pastures only*	
	1975	***2000***	***1975***	***2000***
AFROMONTANE	29.3	39.0	38.5	57.9
GUINEA-CONGOLIA/SUDANIA	5.6	10.5	6.3	13.8
GUINEA-CONGOLIA/ZAMBEZIA	0.5	0.4	0.5	0.4
GUINEO-CONGOLIAN	0.6	0.8	0.6	1.0
KALAHARI-HIGHVELD	2.6	2.4	2.8	2.5
KAROO-NAMIB	0.8	1.1	0.8	1.1
MADAGASCAR	6.0	7.0	6.8	9.4
SAHEL	8.7	15.8	10.4	22.6
SOMALIA-MASAI	9.3	13.2	9.8	15.0
SUDANIAN	9.1	17.3	11.0	23.6
ZAMBEZIAN	4.5	5.3	5.0	6.1
ZANZIBAR-TONGO-COAST	1.7	2.0	2.3	2.8
TOTAL	6.5	9.9	7.3	12.1

Table 12: Head of cattle per km^2 - 1975 and 2000. "All potential grazing lands" includes the agricultural land, forests and natural vegetation, "Natural pastures" excludes the agricultural lands.

4.3. Wood fuels

Wood-fuels (fuel wood and charcoal) provide between 85 and 99% of household energy requirements in Africa, with a per capita consumption of between 300 and 700kg of wood per year (Brocard *et al.* 1998). This resource is collected almost exclusively from the natural landscapes. With rises in demand, driven by population increases, the natural regeneration rate of this resource may fall short of requirements with existing land use patterns.

The reduction in forests woodlands and shrub savannahs has a direct impact on the capacity of rural areas and cities to satisfy their energy requirements. For example, field survey in and around the Park W (see Annex) shows far lower fractional trees cover and tree species in the degraded savannahs outside the Park, with respect to the Park itself.

4.4. Protected areas

A consequence of the ongoing dynamic is the importance of protected areas as ‘refuges’. However, as they become ‘island refuges’ their viability is less certain, both functionally and politically. With dwindling regional natural resources available they are more vulnerable and become targets for poaching, illegal grazing, for invasion by farmers and as sources of scarce fuel wood. Under future scenarios, local and regional politicians may find it difficult to justify their existence unless they can be shown to benefit local populations. The role of protected areas is even more crucial than ever – but they are becoming more vulnerable (see section 5).

4.5. Climate

The interactions between land surface processes and climate have long been studied (Charney, 1975). A key driving force for local climate is the surface albedo, a measure of the percentage of solar radiation that is reflected back into the atmosphere. The albedo depends directly on the land cover. In a dynamic system, one might expect that different changes in land cover might balance out, leaving the surface albedo more or less stable. Our analysis shows however a more or less unidirectional transition, from different levels of vegetated surfaces to agricultural systems, where for much of the year the land is predominantly bare.

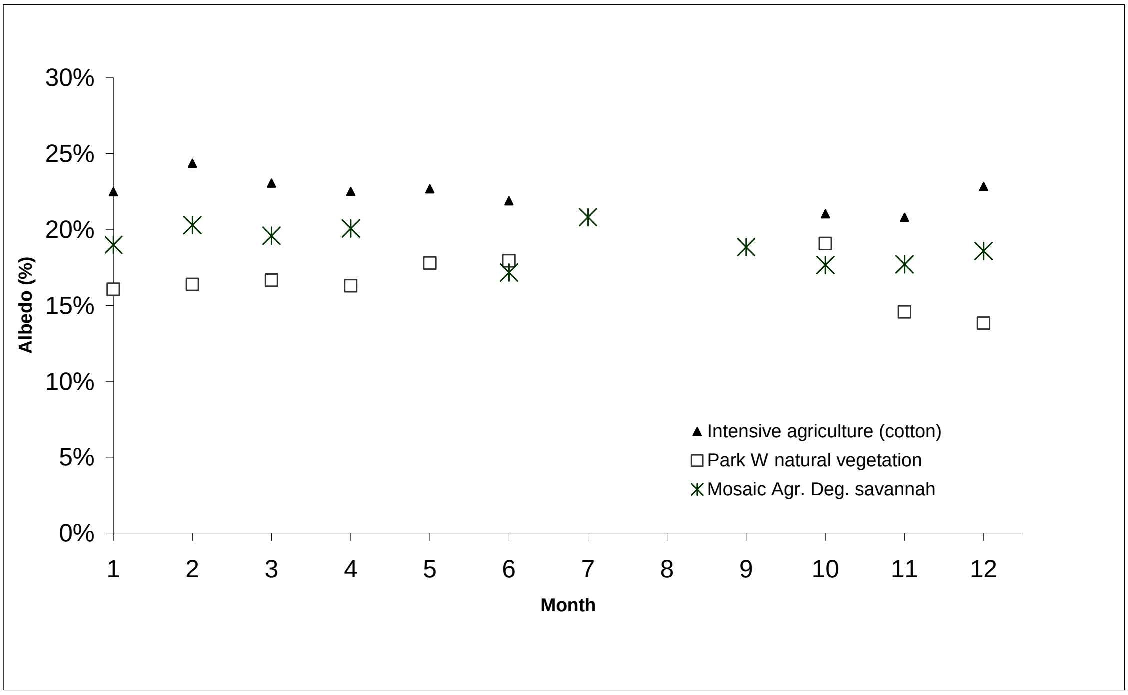

Figure 11: The surface albedo of natural and degraded savannahs and of agricultural lands as measured by Earth Observing satellites (data courtesy of M.Taberner and B.Pinty) .

The impact of land cover change on the surface albedo is demonstrated in Figure 11, where satellite measurement of albedo are recorded for the cotton growing belt in Burkina Faso, for natural savannahs in a protected area (the Transnational Park W) and for degraded savannahs. The agricultural zone albedo varies between 20 and 25% albedo, whereas the natural vegetation between 10 and 17%. Forest ecosystems would have even lower albedos. It is therefore highly likely that the progressive conversion of forests, woodlands and savannahs into agricultural lands is having an impact on the climate system, from local to continental scales.

4.6. Conflict

The sources of conflict across the Sub-Saharan region are well beyond the scope of this work. Never-the-less it is clear that the continued reduction of natural pastures, woodlands and forests will lead in certain areas to increased competition for access to and use of natural resources and land. Analysis of the 1994 tragedy in Rwanda highlights the contribution of land scarcity and environmental degradation as a major driving factor in the process (Percival and Homer-Dixon, 1995). The extent and magnitude of these conflicts will be amplified during periods of environmental stress, as has been noted in a number of regions where during drought periods access to water, land and pasture has been reduced. Future climate change scenarios point to certain areas of Africa having longer and more severe droughts. At the same time, coastal zones will be more prone to flooding, reducing the land available. Data on conflict are difficult to assess quantitatively. In Figure 12 we give an example of conflicts in northern Nigeria, reported by Obioha (2005) from household surveys. By adding the average monthly rainfall deficit from the long-term mean, we can see that the sustained period of drought between 1982 and 1987 probably accentuated conflict situations, mainly amongst pastoralists, and between cultivators and pastoralists.

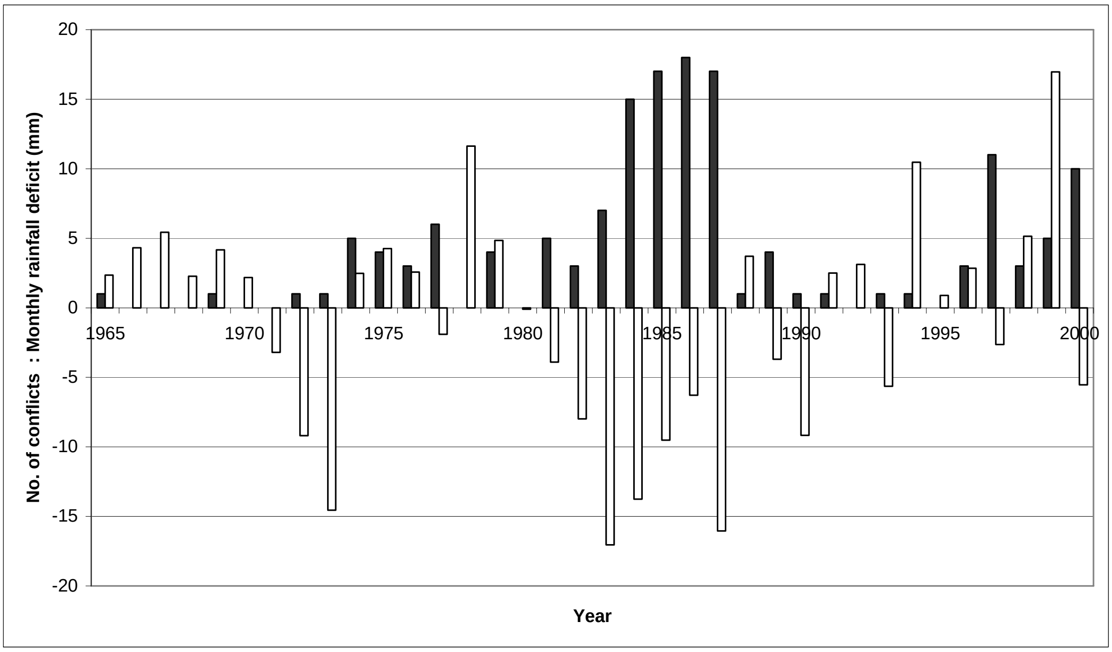

Figure 12: Reported conflicts (black bars) and deviations from the long term average rainfall (white bars) for northern Nigeria. (Source: Obioha 2005)

An assessment of some 37 cases of crises and clashes which took place in Nigeria between 1991 and 2005 (Fasona and Omojola, 2005), judged agriculture and land to be cause of over 35% of the incidence.

4.7. Land cover and fire

As a general observation, we note that the increase in the agricultural mosaic (consisting of arable lands, managed pasture and set-aside) has led to a reduction in the extent of 'wild-fires' and magnitude of biomass burnt. This is a direct consequence of the reduction in areas of natural savannahs and woodlands and the far lower biomass and fuel continuum found in the agricultural zone.

Figure 13: Fire is a common feature in the natural savannahs.

5. Protected area impacts – the example of the Park W complex

5.1. The Park W complex

The Joint Research Centre has for several years had a close co-operation with the ECOPAS project which manages the Park W complex in West Africa. Joint field missions, training and support for GIS and for bush-fire monitoring have been carried out by the JRC (Grégoire *et al*. 2003, Eva *et al*. 2003 & 2004).

In the coarse of this co-operation the JRC has analysed the land cover changes occurring around the Park, and their effect on both people and the local natural resources. The main driving forces of change in the area have been population increase and the adoption of cotton as a cash crop.

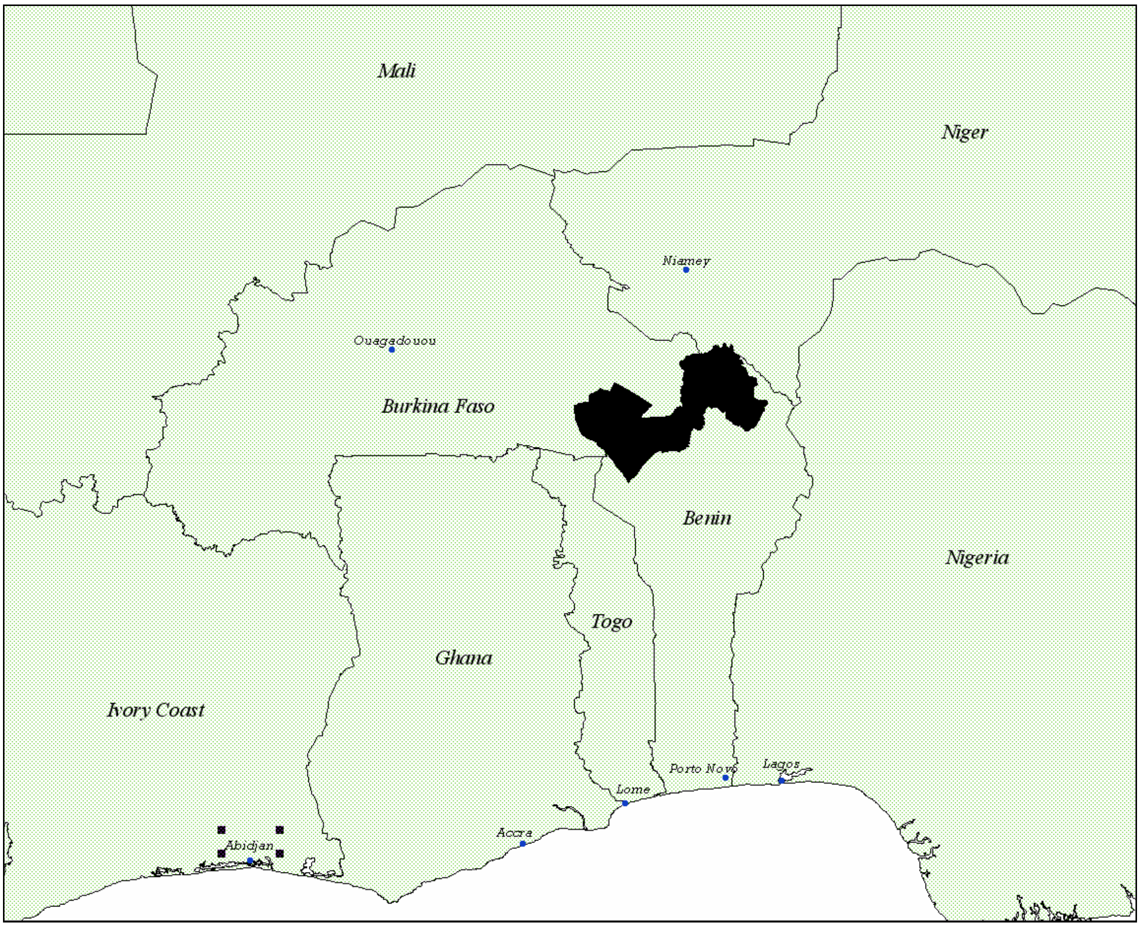

Figure 14: The location of the WAP complex, consisting of the Transnational Park W, Arli and Pendjari. The complex crosses the frontiers of Burkina Faso, Benin and Niger.

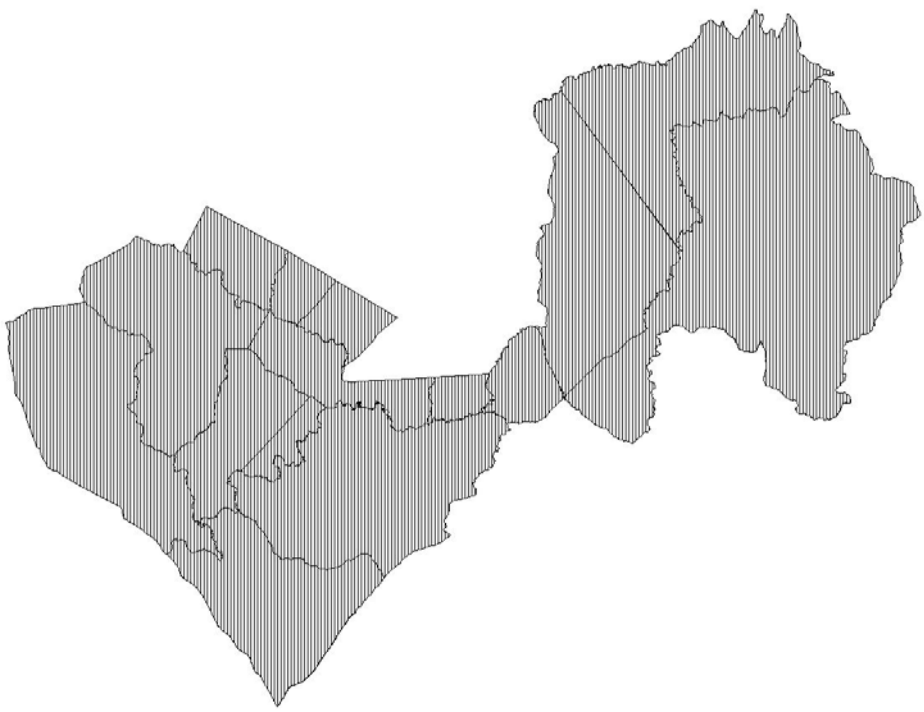

Figure 15: The WAP complex, composed of protected areas, faunal reserves and hunting concessions.

5.2. The land cover changes around the Park W 1975 to 2000

Using satellite data from early 1970's and 2000's, the main areas of change around the Park W, Arli and Pendjari complex can be assessed. We processed satellite data in the 20 km buffer zone around the parks limits. Some of the most striking areas of changes are in the north of Benin, where the so-called 'Cotton belt' has markedly changed the natural vegetation over the last 20 years. To the northeast of the park on the northern side of the Niger river, much of the natural vegetation (*brousse tigrée*) has been depleted by an increase in the agricultural and closed pastural areas.

	1975 (km^2)	***2002 (km^2)***	***Increases (%)***
Agriculture - Intensive	*2813*	*4997*	*78*
Agriculture - Mosaic	*3600*	*5644*	*57*
Degraded savannahs	*3281*	*4264*	*30*
Savannahs	*10059*	*4924*	*-51*

Table 13: Land cover changes around the WAP complex

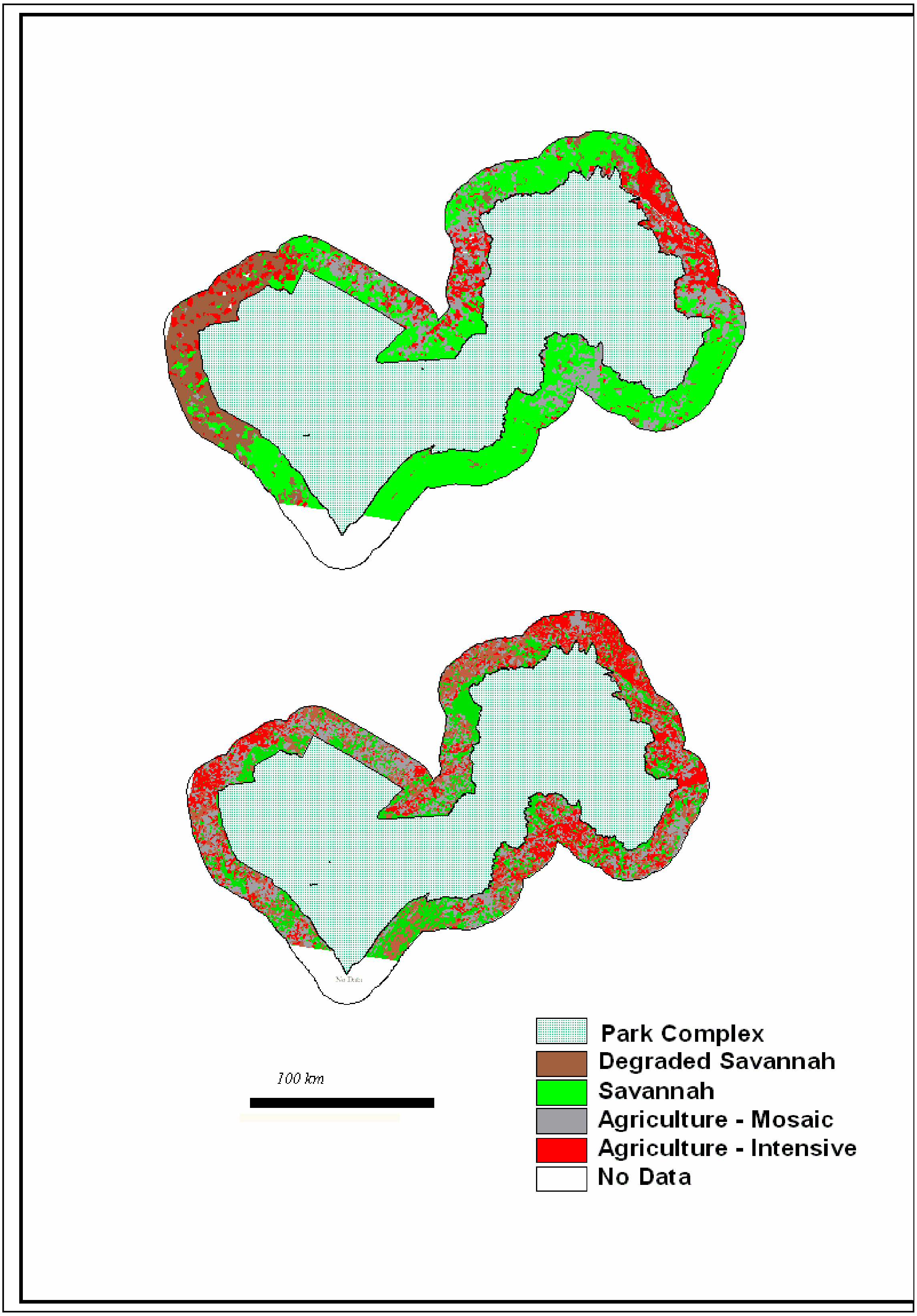

Figure 16: Land cover changes between 1975(top) and 2000(bottom) in a 20 km buffer zone around the WAP complex. Percentage change is calculated over the 1975 area.

5.2.1. Implications for biodiversity

The land cover changes occurring around the Park W have a number of impacts on biodiversity within the Park itself. The JRC carried out a study on the buffer zone around the Park W complex (Clerici *et al.* 2006). Over the last 25 years the physical isolation of the Park has increased, so that it is now almost completely surrounded by a continuum of agricultural lands with implications for its genetic pool and increases in potential contact between humans and wildlife. For predators such as large carnivores this may results in conflict situations with human-induced mortality occurring. There may also be change in the balance of species in the contact area, where degraded vegetation may favour external competitors. In the event of a major perturbation in populations, re-colonisation becomes more difficult.

5.2.2. Impact on the natural vegetation outside the Park

To observe the differences between vegetation composition and biomass levels inside the Park W and in the savannahs and rural complex outside the Park, the JRC in collaboration with the technical staff of ECOPAS, carried out a field mission in November 2004. Four transect were made, two within the Park and two outside, but within the same ecological zone (rainfall / soils). Each transect was approximately 500m long with a sampling unit every 50m. At each sampling unit, an inventory of tree, shrub and herbaceous species was made, recording only the presence (not number) of ligneous plants within a 20m radius of the sample site. To assess the biomass, five sub samples (each of area 0.24 m^2) were used, using a centre sample and four samples at 5 m distance from the centre, one at each of the compass points. At each sample point all herbaceous and litter material were collected and weighed. A sample of this (wet) matter was weighed, and retained for later drying. To obtain the dry weight biomass, the samples were oven-dried in the IRD laboratories at Ouagadougou.

Within the Park 32 different tree species were found while sampling 22 sites; outside the Park 14 species were found in the same number of plots (Annex). The number of shrub species was found to be equal, with 43 different species found inside the Park and 42 outside (Annex). Herbaceous biomass levels were significantly different, with an average of 7.7 t/ha dry mass inside the Park (S.D. 4.6) as opposed to 3.2 t/ha (S.D. 2.0) in the agricultural domain.

The equality in the number of shrub species outside the Park to that found inside the Park may reflect the lower level and intensities of fires outside the park – allowing the growth of woody vegetation.

5.2.3. Implications for the Park and for the local population

As the availability of natural resources around the Park reduces, the Park itself becomes a target both as the sole repository of natural resources. As shown above, the Park holds far higher levels of fuel-wood, of forage and obviously of bush-meat. As a result, poaching, illegal cattle grazing etc. are potentially constant pressures on the Park.

6. Assessment of the methodology

6.1. Sampling levels

A major challenge for a successful assessment of the scales of land cover change and the interpretation of these changes is to adopt an appropriate sampling scheme, which both increases the accuracy of the exercise and is useful for decision makers, land resource managers and environmental scientists. The sampling scheme adopted for this study is based on ecoregions. The logic for this was the fact that we wished to measure land cover at two different dates. Within the ecoregions, random samples were selected. The advantage of this sampling scheme is that we are assessing generally similar land covers within each strata, and we might expect the land cover changes at least to be of a similar nature. However, as these ecoregions are large and cross a number of countries this assumption may not be valid. The disadvantages are that i) a number of land cover classes are not randomly distributed across the continent, or even within a strata – notably water and urban areas, and ii) most analysis requires the use of supporting statistical data, which themselves are not available at these ecosystem levels. The main sources of data are national inventories. These data are hard to re-aggregate to ecosystem levels.

Finally for the European Commission, much analysis is done in regional economic blocks, which again do not correlate to ecoregions. A more effective sampling strategy, already employed for forest inventory (Duveiller *et al.* 2007) is to have far more samples in a regular grid.

6.2. Spatial scales of the satellite data

For the basic land cover classes mapped the Landsat Thematic Mapper satellite data were found to be appropriate for most regions. Two thematic classes, water and barren, though relatively easily addressed on single date imagery, are difficult to quantify due to seasonal variations. The use of the Landsat MSS data for the 1975 estimate was on the generally satisfactory, but for some fragmented classes the lower spatial resolution led to loss of definition. This would compromise efforts to determine fragmented classes.

6.3. Digital classification techniques

Within the study we used single date unsupervised classification. The land cover estimates were then derived from the difference in the two dates. Recent advantages in commercially available software lead us to believe that using a segmentation approach on a two-date composite image, combined with a supervised classification would be more appropriate. This approach would also have the benefit of allowing analysis by land parcel units. At the same time a development of a library of land cover spectral signals would help to create a first pass set of interpretations.

6.4. Interpretations in thematic labelling

The development of a network of local experts to help in the interpretation and validation of classes should form part of any new project. This would enhance the viability and also the speed of any study, and much time was dedicated within the current work to assessing the nature of land cover classes.

7. Conclusions and recommendations

7.1. Land cover dynamics and the implications

The ongoing process of land cover change in sub-Saharan Africa can be monitored and quantified using Earth observing satellites. This dynamic has been shown to be largely a conversion of natural vegetation to agricultural lands, with less and less land available for future exploitation, and shorter fallow periods. This trend has implications on the available natural resources (land, water, fuel-wood, pastures) for the poorest. The technical capacity to put in place a permanent land-cover monitoring system at different levels, from national to continental, exists. However, for effective use in policy development and analysis such a system needs to be accompanied by regional analyses using a of range of physical (e.g. meteorological) and socio-economic data.

7.2. EU environmental policy support

To improve our understanding of what is occurring to sub-Saharan Africa's natural resources and what the implications for the local population of such changes are, the European Union could help in encouraging more African scientists and decision makers to take part in the environmental monitoring process.

Our study gives some ideas as to where priorities may be made in development support – increasing agricultural production, fuel security, avoiding conflict that arises from natural resource depletion, and making environmental sustainability part of the development process. Indeed, many of these themes are already taken into account. However, studies such as ours help to focus where geographically priorities lay by theme, and point to the need to improve our spatial analysis of land cover and socio-economic trends.

7.3. Protected areas

The role of protected areas is one of the corner stones of conservation strategies. There is an urgent need to review the conservation status and threats to parks across Africa, so as to mobilise resources and support for their sustainable futures. To do this conservation priorities need to be set. The JRC is developing a pilot system to objectively define the indices of conservation priorities for 741 protected areas across Africa and to monitor their status (Hartley *et al.* 2007). Such information can act as a crucial input into environmental aid policies and actions.

7.4. Future requirements to the method

The use of Earth observing satellite data to monitor and regularly document land cover change has been shown to be largely effective. Higher sampling schemes and improved image processing techniques would enable national studies to be carried out. Both of these are feasible. The sampling approach needs to be accompanied by a full-cover analysis with lower spatial resolution satellite data (e.g. 300 m) so that spatial analysis can be carried out at regional levels. For the monitoring of water bodies, a specific scheme may need to be devised. Desertification also requires a specific scheme, where the long term variations can be discerned from the short term seasonal fluctuations.

7.5. Future data requirements

This study has touched on a few of the potential consequences that land cover change posses in Africa. However, the quality of readily available data sources at continental, regional and even national levels, make such analyses tenacious. There is a need therefore to identify key information requirements, potential sources and methods to aggregate and rationalise them.

Information requirements depend on the end-users. For EU policy makers this may range from climate change impacts on the regional economic production to land-use change as a driver of conflict. Key elements difficult to obtain at the national to regional levels are land-suitability, land tenure, population distributions and trans-humance.

8. Annexes

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8.2. Species composition and biomass levels in and around the Park W.

The collection of biomass and species inventories were carried out in collaboration with the project ECOPAS and the University of Parma during field survey in 2004. Four transects were performed, two in the Park W and two in the agricultural domain. The species inventories were carried out by Joël Bama and Philippe Tamini. The different colours of the sample sites represent the four transects carried out.

TREE SPECIES

	Park W savannah												Agriclutural Domain										Park W savannah										Agriclutural Domain											
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44
Acacia																												x																
Adansonia digitata						x													x		x																							
Afrormosia laxiflora										x																																		
Afzelia africana												x															x																	
Albizia chevalieri																																												
Annona senegalensis																																												
Anogeissus	x			x						x	x						x	x				x											x	x			x	x	x	x	x			
Balanites aegyptiaca	x																																											
Bombax							x	x			x									x			x					x	x	x	x	x												
Burkea																							x							x	x	x												
Butyrosp			x	x					x	x		x											x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x		x	x	x
Cadaba farinosa																																												
Cassia sieberiana																																												
Cissus quadrangularis																																												
Comb gluti	x		x							x																																		
Comb micra																																												
Comb nigri			x																																									
Crossopt									x																			x			x													
Daniellia oliveri																														x														
Detarium			x																																									
Dichrostachys																																												
Diospyros mespiliformis																																												
Entada																																												
Feretia																																												
Flueggea virosa (Securinega virosa)																																												
Gardenia																																												
Grewia																																												
Guiera																																												
Hymenocardia acida																																												
Isoberlinia																																		x										
Khaya senegalensis																								x		x	x	x	x															
Lannea								x	x								x	x		x	x		x		x	x	x					x	x				x		x	x	x			
Lonchocarpus laxiflorus						x																																						
Maytenus sen.																																												
Nauclea latifolia																																												
Pericopsis																																												
Piliostigma																																												
Prosopis																			x	x																								
Pseudocedrela kotschyi																																												
Pteleopsis																																												
Pteleopsis suberosa										x																																		
Pterocarpus		x															x	x			x		x	x	x	x	x	x	x	x		x		x	x						x			
Sclerocarya birrea					x	x	x	x											x	x																								
Securinega																																												
Sterculia				x	x		x		x	x	x	x										x				x	x									x	x				x			x
Stereospermum kunthianum																																												
Strychnos spinosa																																												
Tamarindus		x			x				x																										x	x			x	x				
Terminalia avicennioides										x		x														x				x														
Xeroderris sthulmannii																														x	x													
Ximenia Americana																																												
Ziziphus mauritiana	x																																											
Ziziphus mucronata																																												
Ziziphus spina-christi																																												

SHRUB SPECIES

	Park W savannah												Agriclutural Domain										Park W savannah										Agriclutural Domain											
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44
Acacia	x		x		x	x	x	x									x	x	x	x	x	x	x		x		x						x	x	x	x	x	x	x	x	x	x	x	x
Adansonia digitata																																												
Afrormosia laxiflora																																		x					x					
Afzelia africana																																												
Albizia chevalieri																								x																				
Annona senegalensis																																		x		x						x		x
Anogeissus		x			x																						x						x		x	x	x	x	x		x	x	x	x
Balanites aegyptiaca	x										x																														x			
Bombax											x																			x														
Burkea																																x												
Butyrosp																						x			x	x		x		x	x	x		x			x	x		x	x	x		x
Cadaba farinosa																														x														
Cassia sieberiana																																											x	
Cissus quadrangularis																			x																									
Comb gluti	x			x	x	x	x	x	x		x	x					x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x
Comb micra	x		x		x						x	x					x	x		x	x	x				x	x	x	x	x	x	x			x		x			x	x		x	x
Comb nigri			x		x		x	x	x		x	x					x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x		x					x	x		x	x
Crossopt				x																			x	x			x	x	x		x	x	x				x	x	x					
Daniellia oliveri																																												
Detarium																							x		x									x	x	x		x	x					
Dichrostachys																																						x	x				x	
Diospyros mespiliformis					x																									x					x								x	
Entada																																												
Feretia			x		x		x	x			x														x					x			x		x		x	x	x		x	x		
Flueggea virosa (Securinega virosa)																													x															
Gardenia																											x									x	x			x		x		
Grewia		x		x							x	x						x	x	x	x													x		x	x	x		x		x	x	
Guiera																																												
Hymenocardia acida						x																																						
Isoberlinia																																			x	x						x	x	x
Khaya senegalensis																												x																
Lannea																		x			x								x									x						
Lonchocarpus laxiflorus																					x																							
Maytenus sen.																																				x	x		x			x	x	x
Nauclea latifolia																												x																
Pericopsis																																												
Piliostigma										x																x		x	x	x					x							x	x	x
Prosopis																																												
Pseudocedrela kotschyi																															x													
Pteleopsis																																												
Pteleopsis suberosa												x																												x				
Pterocarpus																																										x		
Sclerocarya birrea																			x																									
Securinega																																				x							x	x
Sterculia																						x			x				x															
Stereospermum kunthianum								x										x															x											
Strychnos spinosa								x	x																														x		x			
Tamarindus																		x												x									x		x			
Terminalia avicennioides																														x					x									x
Xeroderris sthulmannii																																												
Ximenia Americana										x		x					x							x						x											x			
Ziziphus mauritiana	x																																		x						x	x	x	
Ziziphus mucronata																																												
Ziziphus spina-christi																													x															

HERBACEOUS SPECIES

	Park W savannah												*Agriclutural Domain*										*Park W savannah*										*Agriclutural Domain*											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**	**41**	**42**	**43**	**44**
Andropogon	1	9	3	5	1	1		1	9	9	1	1											8	10	9	10	10	10	10	10	10	10												
Bulbostylis		1		x			2																																			x		
Diheteropogon sp.	3							x																																				
Euphorbia forskalii																																												
Loudetia			7	5	9	8	8	9	1		9	9					2		4	5	1	4	2										10	10	10	10	10	10	10	10	10	10	10	10
Microchloa indica																																												
Pennisetum pedicellatum																	8	7	5		5	3			1												x							
Rottoboellia exalatata																																												
Spermacoce stachydea	6																																											
Tripogon minimus																																												
Other						1				1								3	1	5	4	3																						
herbaceous biomass t/ ha	5	6	4	5	0	6	5	4	12	12	2	9	5	6	0	0	4	6	4	2	0	4	13	14	8.1	17	13	5	9.3	0.4	11	8.3	6.6	4.1	1.2	5.3	4.3	3.8	2.6	1.9	3.5	2.2	1.4	2.2

8.3. Standard errors and t-tests.

Significance of changes at the continental and the ecoregion levels are reported in Tables 14 and 15. Here the two tailed, paired t-test is performed to see if for each class the reported change is significant. If the t-value is greater than the critical value, the change is a statistically significant one. We see that at the sub-Saharan level, all changes, except 'water' , are significant. At the regional levels the significance varies, partly due to small changes, and partly due to low sampling levels.

	Agriculture	***Forest***	***NF veg.***	***Barren***	***Water***
Samples	*511*	*511*	*511*	*511*	*511*
t critical two-tail	*1.96*	*1.96*	*1.96*	*1.96*	*1.96*
t-value	*9.1*	*8.5*	*3.3*	*3.2*	*0.12*

Table 14: Significance of changes at the sub-Saharan level

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Region	*Land cover*	*mean 75*	*mean 00*	*n samples*	*Paried t*	*Critical t*	*Significant?*
GUINEO-CONGOLIAN	*Agriculture*	2,779	5,009	69	3.85	1.99	T
	Barren	1	6	69	1.42	1.99	F
	Forest	34,662	32,961	69	2.43	1.99	T
	NFveg.	2,586	1,927	69	2.96	1.99	T
	Water	176	130	69	1.09	1.99	F
ZAMBEZIAN	*Agriculture*	3,557	4,975	106	3.22	1.98	T
	Barren	291	311	106	0.37	1.98	F
	Forest	6,050	4,371	106	5.76	1.98	T
	NFveg.	29,851	30,051	106	0.40	1.98	F
	Water	311	286	106	0.57	1.98	F
SUDANIAN	*Agriculture*	7,020	10,648	94	5.76	1.99	T
	Barren	93	283	94	2.03	1.99	T
	Forest	3,427	2,016	94	3.81	1.99	T
	NFveg.	29,248	27,336	94	2.26	1.99	T
	Water	61	95	94	2.08	1.99	T
SOMALIA-MASAI	*Agriculture*	1,651	4,018	30	2.55	2.04	T
	Barren	4,857	5,689	30	2.25	2.04	T
	Forest	1,903	1,106	30	2.13	2.04	T
	NFveg.	30,349	27,881	30	3.11	2.04	T
	Water	42	38	30	0.23	2.04	F
KAROO-NAMIB	*Agriculture*	72	227	13	1.02	2.16	F
	Barren	8,906	9,560	13	2.01	2.16	F
	Forest	-	-	13	-	2.16	-
	NFveg.	30,864	30,179	13	2.16	2.16	F
	Water	185	62	13	1.88	2.16	F
AFROMONTANE	*Agriculture*	8,850	12,071	14	2.20	2.14	T
	Barren	166	220	14	0.82	2.14	F
	Forest	1,078	390	14	1.32	2.14	F
	NFveg.	27,035	24,438	14	1.78	2.14	F
	Water	59	60	14	0.06	2.14	F
GUINEA-CONGOLIA/ZAMBEZIA	*Agriculture*	776	497	19	1.31	2.09	F
	Barren	-	-	19	-	2.09	-
	Forest	11,093	8,887	19	2.07	2.09	F
	NFveg.	28,287	30,577	19	1.73	2.09	F
	Water	258	72	19	1.08	2.09	F
GUINEA-CONGOLIA/SUDANIA	*Agriculture*	4,771	9,269	52	4.61	2.01	T
	Barren	23	16	52	1.35	2.01	F
	Forest	13,077	8,443	52	3.89	2.01	T
	NFveg.	20,961	20,873	52	0.07	2.01	F
	Water	1,540	1,414	52	2.13	2.01	T
KALAHARI-HIGHVELD	*Agriculture*	2,223	2,442	37	1.18	2.03	F
	Barren	638	749	37	1.23	2.03	F
	Forest	-	-	37	-	2.03	-
	NFveg.	37,092	36,757	37	1.65	2.03	F
	Water	75	83	37	0.55	2.03	F
SAHEL	*Agriculture*	6,593	11,794	38	4.06	2.02	T
	Barren	184	154	38	1.71	2.02	F
	Forest	553	238	38	2.03	2.02	T
	NFveg.	32,573	27,458	38	3.94	2.02	T
	Water	125	384	38	1.88	2.02	F
ZANZIBAR-TONGO-COAST	*Agriculture*	7,530	9,010	17	(1.45)	2.1	F
	Barren	-	-	17	-	-	-
	Forest	1,528	1,323	17	0.84	2.1	F
	NFveg.	23,742	21,931	14	1.23	2.2	F
	Water	105	135	15	(0.90)	2.1	F
MADAGASCAR	*Agriculture*	4,944	9,356	14	(2.58)	2.2	T
	Barren	1,416	1,265	14	0.59	2.2	F
	Forest	8,419	5,606	14	2.52	2.2	T
	NFveg.	23,742	21,931	14	1.23	2.2	F
	Water	171	476	12	(2.09)	2.2	F

Table 15: Significance of changes at the ecoregion levels (T=true / F=false)

European Commission

EUR 22498 EN – DG Joint Research Centre, Institute for Environment and Sustainability

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Authors: H.D.Eva, A.Brink and D. Simonetti
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Abstract
This document describes a pilot project undertaken to estimate the magnitude, characteristics and potential impacts of land cover changes that have occurred in sub-Saharan Africa over the last 25 years (1975-2000). The work will serve as a basis for further, more detailed, studies on particular ecosystems, notably the tropical forests and on selected countries.

EUROPEAN COMMISSION
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