Detection and Analysis of Land cover Dynamics in Moist Tropical Rainforest of South Cameroon

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To my parents:
Margaret and Julius Shu Ngongnjoh.

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Acronyms

CIDA	Canadian International Development Agency
CITES	Convention on International Trade in Endangered species
FAO	Food and Agricultural Organization of the United Nations
GEF	Global Environmental Facility of the World Bank
GIS	Geographical Information System
GPS	Global Positioning System
GWZ	Gerard Wijima & Zonen (Wijima- Douala S.A.R.L)
HEVECAM	Hévéa du Cameroun
HFC	La Forestière de Campo
LMR	Logistic Multiple Regression
MINEF	Ministry of Environment and Forests
NFAP	National Forestry Action Programme
NRS	Natural Resource Science Department
NTFP	Non Timber Forest Product
ONADEF	Office National de Développement des Forêts
OTU	Operational Technical Unit
PACBCM	Projet d'Aménagement et de Conservation de la Biodiversité de Campo Ma'an
SNV	Netherlands development organization
SOCAPALM	Société Camerounaise de Palmeraies
UFA	Unité Forestière d'Aménagement
UNCED	United Nations Conference on Environment and Development

Abstract

Keywords:
Biophysical factors, Land cover dynamics, Forest management, Moist Tropical rainforest, Maximum Likelihood Classifier, Logistic Multiple regression, Spatial Models

The dynamics of the vegetative cover of the Operational Technical Unit (OTU) Campo Ma'an are still poorly understood. This study investigated land cover dynamics in the OTU Campo Ma'an in two sub periods; from 1985-1991 and 1991-2001. Remote Sensing and GIS tools were used to detect and quantify land cover change. Change detection was based on a time series analysis of Landsat TM satellite data of April 2001, February 1991 and the existing land cover map of 1985 produced from aerial photo interpretation at a scale of 1:200 000. Supervised classification of satellite images through Maximum Likelihood Classifier discriminated four land cover classes and confirms the usefulness of Landsat TM as a data source in mapping land cover in a moist tropical rainforest. The analysis of time series data revealed six important land cover changes which occurred during the past 16 years in the OTU. The rate of land cover change was observed to vary across the sub periods and a general decline of forest cover was observed over the study period. The study also shows an increase in the area coverage of agro-industrial plantations. Forest regrowth measured as the conversion of open forest to dense forest was observed to double in the second period. Spatial models based on logistics multiple regression revealed biophysical and human factors that influence expansion of agro-industrial plantations, deforestation and forest regrowth in the OTU. This further permitted forecasting of critical forest areas prone to change in the near future. The land cover change results and spatial models developed in this study are useful in supporting forest management efforts. Land cover change analysis permitted the identification of areas were forest conversion is occurring and areas vulnerable to change in the future. This information if used in conjunction with information on the spatial distribution of species habitats permits the identification of biodiversity "hotspots"; thereby helping planners in the prioritisation of conservation efforts.

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1 Introduction

1.1 Background

Tropical rainforests cover more than sixty countries and constitute the most valuable ecosystem of the planet, containing 50 to 90 % of animal and vegetal species on Earth (CIDA, 2001; Kuntz *et al*, 1999; Mertens, 1999). They represent over 57 % of global forest cover and are home to over 500 million people who live in or at the edge of the tropical rainforest, depending on its products for their economic needs of food, shelter as well as their cultural and spiritual traditions (CIDA, 2001). Central and West Africa's 200 millions hectares of contiguous tropical rainforest are the second largest remaining humid tropical forest in the world after the Amazon basin (Mertens, 1999). 8000 plant species of which 80 % are endemics have been reported to occur in this region (Sayer *et al,* 1992 in Gemerden *et al,* 2002). This high level of biodiversity and their role in climate regulation is certainly the major indication of their importance at the global scale (Mertens, 1999). The value and importance of the tropical rainforest to different people is as varied as the diverse goods and functions it provides (Sonne, 2001).

In recent times, the tropical rainforest has been under tremendous human induced and natural changes. Changes in the forest cover generally imply either a conversion or a modification (Mather, 1987). These processes are described as deforestation and degradation respectively. Despite growing concerns and the recognition of the ecological, social and economic importance of tropical moist forests, disagreements exist about the extent and mechanisms of tropical deforestation due to differences in estimation methods and in definition (Serneels, 2001).

Human intervention in forests environments as they struggle to satisfy basic livelihood demands is generally accepted as the main trigger behind forest conversion in tropical areas (CIDA, 2001; Mertens, 1999; Myers, 1991). The current rate of deforestation is alarming. Tropical deforestation reached an average annual extent of 15411 million hectares between 1981 and 1990, representing 0.8 % annual rate of deforestation (FAO, 1995., 1997); and remains a critical issue given its present rate and a widespread consensus regarding its implications for the global carbon cycle and biodiversity (Walker *et al*, 2002).

Though it is difficult to produce accurate figures of deforestation in Cameroon, some studies have however pointed to an alarming rate of forest disappearance. FAO (1995) report shows an annual deforestation rate of 0.6 % in Cameroon. Another study by GFW (2002) indicates that 2 million hectares of forest were lost in Cameroon between 1980 and 1995. Ndoye and Kaimowitz (2000) in Sunderlin *et al* (2001) estimated that the annual deforestation rate in Cameroon ranges between 80 000 and 200 000 hectares.

Forest cover conversion in general and the conversion of tropical rainforest cover in particular have severe global long-term economic and social consequences. Major environmental problems accruing from forest cover change are changes in global climate, habitat degradation and unprecedented species extinction (Southworth *et al*, 2001; Vance *et al*, 2002). These are all major issues of global importance. As a result, of these negative consequences of forest loss to the global environment, the international community is increasingly committed to seeking ways to curb tropical rainforest conversion, in order to minimize global environmental problems. Wise use and sustainable management of forest resources has been encouraged as one of the means of curbing current rates of rainforest disappearance. In this regard, several international cooperation agreements have been signed by world leaders to enforce these commitments. Some include the Convention on International Trade in Endangered species (CITES, 1973), The Ramsar Convention on Wetlands (1971), The World Commission on Environment and Development in Oslo (1987) and the United Nations Conference on Environment and Development (UNCED) at Rio de Janeiro (1992). A high point in international interest was reached in the Rio de Janeiro conference which devoted a full chapter entitled "Combating Deforestation" of its agenda 21 to the issue of forest conservation and development (Mertens, 1999).

In keeping with International agreements, many world governments are devoting efforts in the development of strategies and policies, which favour sustainable use, protection and management of natural resources. In Cameroon, recent degradation of the forest and international concerns about environmental issues motivated the government to revise its forestry policy with the view of promoting sustainable management and wise use of the forest resources (Mertens, 1999; Mertens *et al*, 2000). This initiative led to the creation of institutions such as Office National de Développement des forêts (ONADEF) in 1990 and the Ministry of Environment and Forests (MINEF) in 1992. Also, a new national forestry law was enacted in 1994 that lead to the creation of a National Forestry Action Program (NFAP) in 1995. This programme has as mandate (i) the establishment of mechanisms for the protection of the forest heritage, participation in safeguarding the environment and preserving biodiversity in Cameroon (ii) increase participation of local people in forest conservation so as to raise living standards (iii) develop forest resources with the view of increasing GDP while conserving production potential of fuel wood, timber, non timber forest products and wildlife (iv) ensure resource renewal through regeneration, reforestation with a view to sustaining land potential (v) revitalize the forestry sector by setting up an efficient institutional system that involves all parties concerned with the management of the sector (Mertens, 1999; Mertens *et al*, 2000).

Within this framework, a joint initiative of the Global Environmental Facility (GEF) and the government of Cameroon lead to the creation in 1995, of the Campo Ma'an Biodiversity Conservation Project. This Project is one of several conservation projects recently created in Cameroon. Its principal mission is (i) to enhance the conservation of the unique biodiversity of Campo Ma'an forest of South Cameroon (ii) promote sustainable management of production forest (iii) promote sustainable socio-economic development of the local communities based on harmonious relationship with their environment (Matthews *et al*, 2000; PACBCM, 2000). The Global Environmental Facility of the World Bank provides financial support while the execution of the project is by Tropenbos International, Dutch Cooperation for Development (SNV) and the government of Cameroon through its Ministry of the Environment and Forests (MINEF).

1.2 Research Problem

The intervention unit of the Campo Ma'an Biodiversity Conservation project is known as the Operational Technical Unit (OTU). This management unit has a unique and characteristic heterogeneous landscape pattern resulting from past and present land use practices which have modified the original landscape over time and space. The extent and quality of the vegetative cover of the OTU is seriously being affected by these past and present multiple land uses.

The expansion of plantation agriculture, commercial timber logging, shifting cultivation take place at an elevated scale within the OTU and have been generally cited as the main causes of forest cover change in South Cameroon (Sunderlin *et al*, 2000; Tchouto, 2002). Although this is an established fact, the extent to which these activities are affecting the natural vegetation cover of the intervention zone of the Campo Ma'an Project over time and space is still poorly understood.

Unfortunately, the development of management policies for the OTU has hitherto relied on the assessment of the existing resource potential and socio-cultural life of the indigenous communities of the region while neglecting studies involving changes in the land cover. In this respect, a socio-economic study was carried out by Annaud & Carriere (2000), which revealed the social level and cultural practices of the communities; including their perception and use of forest resources. In a separate study, Tchouto (2002) assessed the vegetation composition of the OTU Campo Ma'an and highlighted the major vegetation types of the area including their characteristics. Other research work; Matthews & Matthews (2000), Anye (2002) and Sonné (2001) documented the status of the fauna, avifauna and non-timber forest products (NTFPS) of the OTU.

Despite this ongoing effort, an information gap still exists in our understanding of the spatio- temporal dynamics of the vegetation cover, their impact on landscape attributes such as biodiversity and efficient tools that can be used for monitoring the dynamics of the land cover in this heterogeneous environment.

The importance of investigating land cover dynamics as a baseline requirement for sustainable management of natural resources has been highlighted by many researchers involved in global change studies (Brandon *et al*, 1998; Chen, 2002; Jansen *et al*, 2002; Mertens, 1999; Mertens *et al*, 2000; Petit *et al*, 2001; Primack, 1993; Read *et al*, 2002; Serneels, 2001; Serneels *et al*, 2000). These scientists have argued that a more focused management intervention requires information on the rates and the impacts of land cover change as well as the distribution of these changes in space and over time.

Also, the importance of spatial models as useful tools for describing processes of land cover change in quantitative terms and for testing our understanding of these processes have been highlighted. Models of land cover change can be aimed at predicting the spatial pattern of changes – addressing the question "where land cover change take place?" or the rate of change-addressing the question "at what rate are land cover changes likely to progress?". These two questions have been referred to as the location issues versus the quantity issue (Pontius & Schneider, 2001 in Serneels, 2001). The spatial prediction of land use or land cover changes only requires an understanding of the proximate causes of the changes. The projection of the future rate of change is a more difficult task because it requires the good understanding of the underlying driving forces of the change (Reibsame *et al*, 1994 in Serneels, 2001). Driving forces are sometimes remote in space or in time from the observed changes, and often involve macro-economic transformations and policy changes that are difficult to anticipate (Serneels, 2001). Spatial modeling of land cover change processes should aim at addressing at least one of the following questions: (i) which environmental and cultural variables contribute most to an explanation of land cover changes: why?; (ii) which locations are affected by land cover changes: where?; and (iii) at what rate is land cover change progressing: when? (Mertens *et al*, 2000). Empirical, statistical models such as regression models are mainly an explanatory tool to test for the existence of links between driving forces and land cover change. They can explain why land cover changed in the past (Serneels, 2001). Spatial statistical models, combining remote sensing, GIS and multivariate mathematical models concentrate on the spatial distribution of landscape elements and on changes in landscape patterns. Based on a set of proximate causes, these models can be used to predict where land cover changes are likely to occur in the near future. Good documentation currently exists on the application of spatial models, deforestation process (Lambin, 1997; Mertens *et al*, 2000) and land cover change in the tropics (Lambin, 1997).

In this research, three main information gaps in the context of the OTU Campo Ma'an are addressed. (i) the capacity of Landsat TM data for mapping land cover in a highly dynamic tropical rainforest environment (ii) investigation of the evolution of the of land cover over time and space and (iii) the development of spatial models for predicting the probability of land cover change based on their determining biophysical and human factors.

The main aim of the research is to generate spatial information on land cover dynamics and provide spatially explicit tools useful for anticipating areas where land cover changes will likely occur in the near future. Such projections will help planners to design mitigation measure in advance or to better focus management priorities to areas that prove vulnerable to the identified land cover changes.

1.3 Specific research objectives

The specific objectives of this research are:

- To investigate the potential of landsat satellite imagery as a source of data for mapping land cover change in a moist tropical rainforest.
- To identify and quantify the major changes in land cover in the study area during the period 1985-1991 and 1991-2001.
- To investigate if the rates of land cover change in the sub periods of this study are different and why.
- To develop a model to predict land cover changes based on their determining biophysical and human factors.
- To investigate if biophysical and human factors which might determine land cover change in the study area are consistent in both sub periods.
- To produce land cover maps and maps depicting areas at risk of undergoing changes in the future.

1.4 Research questions:

- What land cover classes in a moist heterogeneous rainforest can be discriminated from Landsat TM remote sensing data?
- What land cover changes have occurred during the past sixteen years?
- Is there a difference in land cover change between the period 1985- 1991 and 1991-2001?
- How is land cover change distributed over the research area?
- What biophysical factors determine land cover changes in the study area?

- Are biophysical and human factors which might determine land cover change in the study area consistent for the sub periods of the study?
- Which areas are vulnerable to change in the near future?

1.5 Hypotheses:

- Land cover dynamics in a moist tropical rain forest can be detected from Landsat TM remote sensing data.
- There is no difference in the rate of land cover change between the period 1985-1991 and 1991-2001.
- There is no relationship between land cover change and biophysical and human factors.
- Biophysical and human factors which might be responsible for land cover change are not consistent in the sub periods.

2 Study area

2.1 Location

This research was carried out in the OTU (Operational Technical Unit) of the Campo Ma'an Biodiversity Conservation Project situated in South Cameroon. It is located in South and Southeast of the town of Kribi, between latitude 2°10' -2° 60'N and longitude 9° 53'-10° 57' E. The OTU Campo Ma'an covers an area of 710.000 hectares. This study covers the Western part of the OTU, with an area of 4109.95 hectares. It is bounded to the west by the Atlantic Ocean coastline from the Ntem to the Lobe estuaries, to the north by the Kribi-AkomII- Ebolowa main road up to the village of Asok I. The Cameroon -Equatorial Guinea border forms the southern limit of the study area. To the Southeast, it is bounded by the Campo and Ma'an sub- divisional boundary up to the village of Ebianemeyong on the eastern border of the Campo Ma'an National Park. It falls partly between three administrative units; namely: Campo sub-division, Kribi and Akom II sub-divisions.

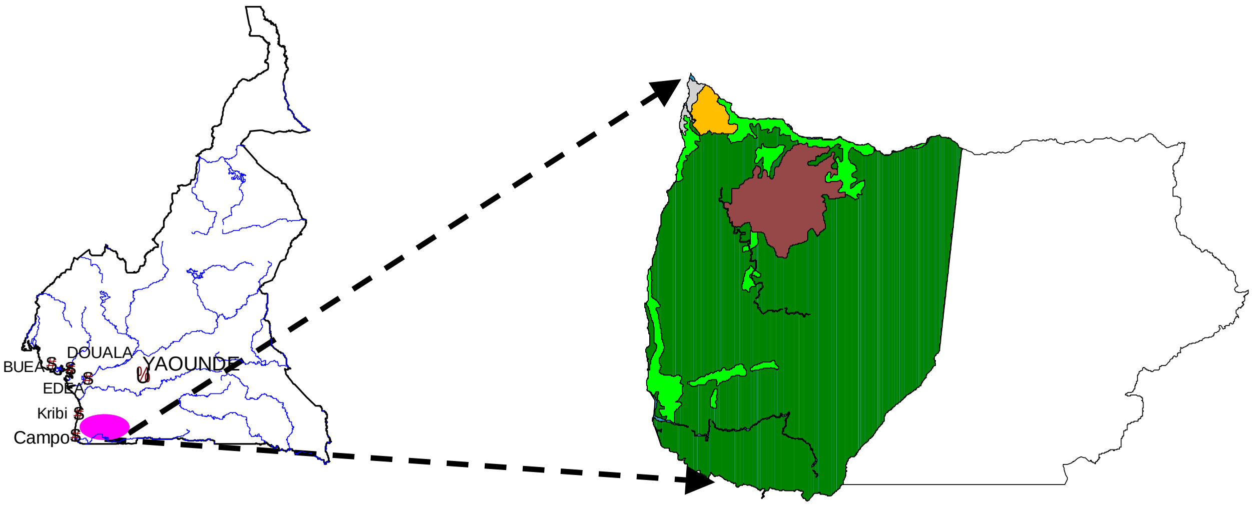


Figure 1: Location of the study area

2.2 Geology and soils

The OTU of the Campo Ma'an Project is situated on the Precambrian Basement Complex, which are the most important and extensive geological formations in Cameroon (Gemerden van *et al*, 1999;

Tchouto, 2002). A large part of this basement complex consist of metamorphic rocks such as gneisses, schists, migmatites, quartzites as well as old volcanic intrusions (Franqueville, 1973 cited in Tchouto, 2002). Soils formed from these metamorphic rocks are acidic and poor in nutrients. The Campo basin to the South west of the study area also has sedimentary rocks of the cretaceous period (Tchouto, 2002). Three major soil types are wide spread in the area; deep moderately drained yellowish brown tropical clay soils (Ultisols), deep well drained, reddish brown tropical clay soils (Oxisols), and grayish alluvial soils restricted to alluvial plains and valley bottoms (Inceptisols), based on (USDA Soil Taxonomy, 1998 cited in: van Gemerden and Hazeu, 1999).

Topographically, the western part of the study area is generally lowland with altitudinal range between 0 and 500masl. The terrain is more variable towards the east with undulating to highly mountainous areas with steeply descending slopes.

2.3 Climate

The climate is equatorial, classified as humid tropical, characterized by two rainy seasons and a short and long dry season. Humid seasons extend from September to November and from April to May. Drier seasons are from December to March and from June to August. According to the Classification system of Köppen (1936) the climate of the area is classified as humid tropical (Aw). Such a climate has a mean temperature in the coldest month of 18°C, average annual temperatures of 25ºC with little variation between years and at least one distinct dry season. Annual rainfall varies from 1719 mm to 22836 mm. Temperatures and rainfall varies from the West (along the coast) towards the East. Presumably this is due to the shading effects of a belt of mountainous terrain towards the east.

2.4 Hydrography

The OTU has a dense drainage system network consisting of streams and rivers, which all empty into the Atlantic Ocean. The Ntem and Lobe form the main river basins in the area. The Ntem and Lobe are fast flowing rivers on a rocky bed with many rapids and waterfalls. The Lobe is the most fascinating as it empties into the Atlantic Ocean through a waterfall, which is one of the prominent tourists attractions in the area. Other rivers include river Bongola, Biwome, Njo'o, Nye'ete and Mvila. This dense drainage network is as a result of the dominant humid climatic conditions throughout the year.

2.5 Vegetation

The vegetation of the OTU is mostly lowland moist tropical rainforest. The main vegetation type is part of the domain of the humid evergreen forest, which belongs to the Atlantic Biafran District and Atlantic Littoral District. The Atlantic Biafran District is dominated by Atlantic Biafran forest rich in Caesalpiniaceae, while the Atlantic Littoral district forest type is limited to the coastal areas and dominated by *Sacoglottis gabonensis* and other coastal indicators (Tchouto, 2002). There are pockets of mangrove forest at the Ntem estuary and a good number of wetlands and seasonally inundated forests are wide spread over the study area.

2.6 Fauna

According to (Matthews *et al*, 2000), the OTU Campo Ma'an Project is one of the most important areas in Africa in terms of the diversity of primates. They have reported the presence of 47 species of large and medium sized mammals in this area. These comprise 18 species of primates, 11 species of ungulates and 12 species of carnivores. Prominent ones are forest elephants (*Loxodonta africana cyclotis*), buffalos (*Syncerus caffer nanus)*, gorillas (*Gorilla gorilla*), chimpanzees (*Pan troglodytes*), leopards (*Panthera pardus*), and giant pangolins (*Manis gigantea*). 23 wildlife species occurring in the area are listed in the 2000 IUCN Red list of threatened species (Matthews *et al*, 2000). Amongst these are black colobus (*Colobus satanus*), red-capped mangabey (*Cercocebus torquantus*), mandrill (*Papio sphinx*), gorilla, chimpanzee, forest elephants, leopards and African manatee.

The avifauna life of the OTU is also very rich and diverse. The 2000 and 2001 birds inventory results showed that 307 bird species belonging to 59 families are present in this area. Of this number, 6 species are restricted –range species that define the Cameroon and Gabon lowlands endemic birds areas (Anye, 2002)

2.7 Population

The OTU of the Campo Ma'an Project is sparsely populated with about 10 inhabitants/km^2. Recent population census (Annaud *et al*, 2000) indicates that over 59,199 people live within the OTU of the Campo Ma'an Project; distributed in 119 villages. In terms of ethnicity, seven ethnic groups namely: Batanga, Mabea, Mvae, Yassa, Ntumu, Bulu and Bagyleli or Bakola pygmies are identified. Also, people from other parts of Cameroon, have been attracted into this region to work in the plantations and timber logging companies contributing to its population increase.

2.8 Infrastructure

The main administrative headquarters (Kribi, Akom II, Campo and Ma'an) are linked by major loose surface roads, which are accessible for most of the year. Apart from these, there exist minor roads and village footpaths, which link agro-plantations, logging concessions and also connecting villages. Electricity supply is limited to the major towns and settlements owned by plantations and logging companies. Many communities depend largely on fuel wood as their major source of energy.

2.9 Economic activities and Tourism

The tourism potential of the OTU is high; ranging from a long, clean sandy beach along the coast of the Atlantic Ocean to fascinating waterfalls such as the Lobe. The diverse plants, wildlife, aquatic life, and diverse human cultures offer good tourists attractions. The main economic activities carried out within the OTU include plantation agriculture and timber logging. SOCAPALM and HEVECAM are multinational companies involved in growing palm trees and rubber trees respectively, while HFC and GWZ are involved in timber logging. Agro-industrial plantations and timber logging companies offer the highest employment opportunities to the local communities and have motivated an influx of people from other parts of the country into the OTU. The local people practice slash and burn farming, fishing, hunting and gathering as means of securing their basic livelihood. The most important food crop cultivated here is cassava or manioc scientifically known as *Manihot esculenta.* Cassava forms the main stable food of all the communities and only the surplus is sold in nearby towns.

A palm tree nursery

A 5 year old rubber tree plantation

Figure 2: Some economic activities in the study area.

3 Materials and Methods

This research used GIS and Remote Sensing techniques. The advent of GIS and Remote Sensing offers greater possibilities for land cover mapping and is described by many researchers as a new and most useful tools for quantitatively measuring land cover change at landscape scale (Lunettaa *et al*, 2002; Pandey, 2000; Petit *et al*, 2001). Due to the success of Remote Sensing and GIS tools in land cover mapping and land cover change detection elsewhere, its use was solicited in this research. The activities carried out during this research included: satellite image interpretation for land cover mapping, field sampling for validation of land cover mapping results and for qualitative description of land cover classes, spatio-temporal analysis of land cover dynamics, investigating which biophysical and human factors influence land cover dynamics in the study area and finally prediction of the probability of land cover change based on their determining biophysical and human factors.

3.1 Land cover mapping

Land cover mapping was aimed at realizing land cover maps for the years 1985, 1991 and 2001 with the same level of generalization. The maps of different years were important for the time series analysis of land cover change. Land cover mapping was achieved through reclassification and recoding of an existing land cover map of 1985, an interpretation of Landsat TM satellite images of February 1991 and April 2001. Field survey to validate satellite image interpretation results was carried out from 10 September to 20 October 2002.

3.1.1 Satellite image processing and classification

Landsat TM satellite images were georeferenced to the coordinates system of the study area (WGS84, projection: UTM zone 32) using a topographic map which was produced in 2001 at a scale of 1:200000. An image-to-image registration technique in the Integrated Land and Water Information System (ILWIS) software was used to georeference satellite images. Ground control points (GCP) taken at road crossings using a GPS (set in UTM) were used to check accuracy of the georeference. The satellite images and other maps used in this research were projected to a common coordinate system and resample to the same spatial resolution. Visual interpretation of satellite images was enhanced through the use of linear stretching and principal component analysis in lLWIS software. Clouds and cloud shadows present on images used for this study were reduced through masking techniques in Erdas Imagine software.

Two main steps were followed in land cover mapping. First unsupervised image classification was carried out prior to field visit, in order to determine strata for ground truthing. Final land cover maps of 1991 and 2001 were produced by combining supervised image classification techniques and on screen digitizing of some land cover classes based on their textural characteristics. This was necessary because field visit revealed that some land cover classes overlapped in spectral reflectance values, but were very distinctively different on the basis of their textural characteristics.

Supervised classification based on the Maximum likelihood classifier algorithm was used in the classification of the 1991 and 2001 satellite images. This was based on 134 training sets. Expert knowledge was used in selecting 134 points on spots at good distances away from those visited during field work. The sample points collected during fieldwork were all used for validating classification results. Land cover classes which showed an overlap in spectral information but could be discriminated based on textural characteristics were digitized on screen, polygonized, rasterized and merged with the others using MapCalc conditional functions in ILWIS.

The 1985 land cover map was reclassified and recoded to the same classes as those obtained from the other two maps. All maps were produced at a scale of 1:750000. Data collected during field visit was used in the qualitative description of the characteristics of land cover classes and in the validation of classification results. Validation of image classification was based on a test set of 134 sample points. Land cover classes such as subsistent crop fields overlapped with bare soil and edges of cloud shadows. In masking out clouds and shadows, water bodies were equally lost because of similar reflection with shadows. Therefore, final land cover mapping did not include the class bare soil, water and subsistent crop fields.

3.1.2 Field sampling design

Field sampling was necessary for validating land cover interpretation results from satellite images, for qualitative description of the characteristics of each land cover class and land use. The sampling technique used in this research was stratified random sampling. This technique was chosen because prior to field visit an automated classification of satellite images was carried out in which different classes of land cover were obtained. These classes were considered to represent different strata and the different land cover classes put together represented the population.

Random points were generated in MS Excel and sample points were distributed proportionally according to the area size of each land cover class. During fieldwork however, some adjustments were made where it was impossible to access some randomly selected points. This research adopted the plot size of Tchouto (2002); rectangular plots of size 50 X 20m. Primary data was generated from 198, but only 134 points were used due to later adjustment in the study area and the number of classes that were retained in the final land cover maps. The land use, land cover and structural description which were important primary data collected at each sample location are presented on appendix 5.

Table 1: The distribution of sample plots in the different land cover classes.

Land cover class	Area (ha)	Number of plots
Dense forest	186000	50
Open forest	5300	30
Rubber tree plantation	41500	47
Palm tree plantation	6900	35
Total	239700	162

3.1.3 Description of Land cover classes

The dense forest class represents natural evergreen forest or moist deciduous forest, wetlands including coastal mangroves. It is the dominant land cover class within the OTU. The general tree height ranges between 10m and 40 m tall, the crown cover percentage is generally above 60 %. More than 70 % of the trees observed in this class were primary species meaning that this class represents the stable stage of the forest succession of the area. It also has some of the most valuable, especially ecologically and commercially important timber species. Some dominant tree species in this class are *Lophira alata, Sacoglottis gabonesis, Erythrophleum ivorensis, Piptadeniastrum africana, Raphia hookerii, Rhizophora racemosa, Coeloncaryon preussi, Desbordesia glaucescens* and many species of the Caesalpiniaceae plant family. In terms of land use, this land cover class was observed to be under multiple usage. Areas assigned as production forest were observed to have past selective logging activity. Other parts are permanent conservation zones with no public access. Another important land use here is illegal hunting and poaching.

The Open forest class corresponds to forest which has undergone modifications from man's influence. It is composed predominantly of secondary vegetation indicative of a recovery stage from past disturbance. It occurs mostly around settlements, along roads or large gaps inside the dense forest; showing some kind of interrelationship between this class and disturbance. The vegetation in this class is of a wide range of growth forms; from early colonizing woody shrubs such as *Chromolaena odorata* to late secondary tree species such as *Anthocleista schweinfurthii*, *Musanga cercropoides*, and *Macaranga spp*. The general height in this class ranges 2m to 25m tall. The crown cover percentage is generally below 60 %. This class is made up largely by farm fallows and other areas which have experienced other forms of forest disturbance. Past land use signs in this class are shifting cultivation and selective logging

The class palm tree plantation and rubber tree plantation refer to a planted palm tree and planted rubber tree estates respectively. Both classes generally have a uniform height and crown cover percentages probably because they are artificially created. The general plants height is between 8-10m and the crown cover percentage are around 60 %. The palm tree and rubber tree plantations are large-scale commercial farms whose produce are destined for export.

The term forest has been employed in this thesis in the context as defined by the 1994 forestry law of Cameroon. The terms low tree layer, medium tree layers and high tree layers used on the data sheets refer to tree height ≤10m and tree height>10m≤25m and >25.

3.1.4 Post classification

A majority filter in ILWIS was used for smoothing the classification results. The accuracy of classification was carried out by means of a confusion matrix generated through GIS overlay of the classified maps and the test samples. The image classification accuracy was further assessed by calculating the Kappa coefficient ‘ $\hat{k}$ ’. The kappa statistics is an estimate of measure of overall agreement between image data and the reference (ground truth) data. Its coefficient fall typically on a scale between 0 and 1, where the latter indicates complete agreement, and is often multiplied by 100 to give a %age measure of classification accuracy. Kappa values are also characterized into 3 groupings: a value greater than 0.80 (80%) represents strong agreement, a value between 0.40 and 0.80 (40 to 80%) represents moderate agreement, and a value below 0.40 (40%) represents poor agreement (Congalton, 1996)

$$\hat{k} = \frac{N\sum_{i=1}^{r} X_{ii} - \sum_{i=1}^{r} X_{i+}X_{+i}}{N^2 - \sum_{i=1}^{r} X_{i+}X_{+i}} = \frac{\theta_1 - \theta_2}{1-\theta_2} \quad \textbf{...Equation 1}$$

Where

$$\theta_1 = \sum_{i=1}^{r} \frac{X_{ii}}{N} \text{ and } \theta_2 = \sum_{i=1}^{r} \frac{X_{i+}X_{+i}}{N^2}$$

X_{i+} is the sum of the ith row, X_{+i} is the sum of the ith column, and X_{ii} is the count of observations at row i and column i, ‘r’ is the number of rows and columns in the error matrix, while N is the total number of observations in the error matrix.

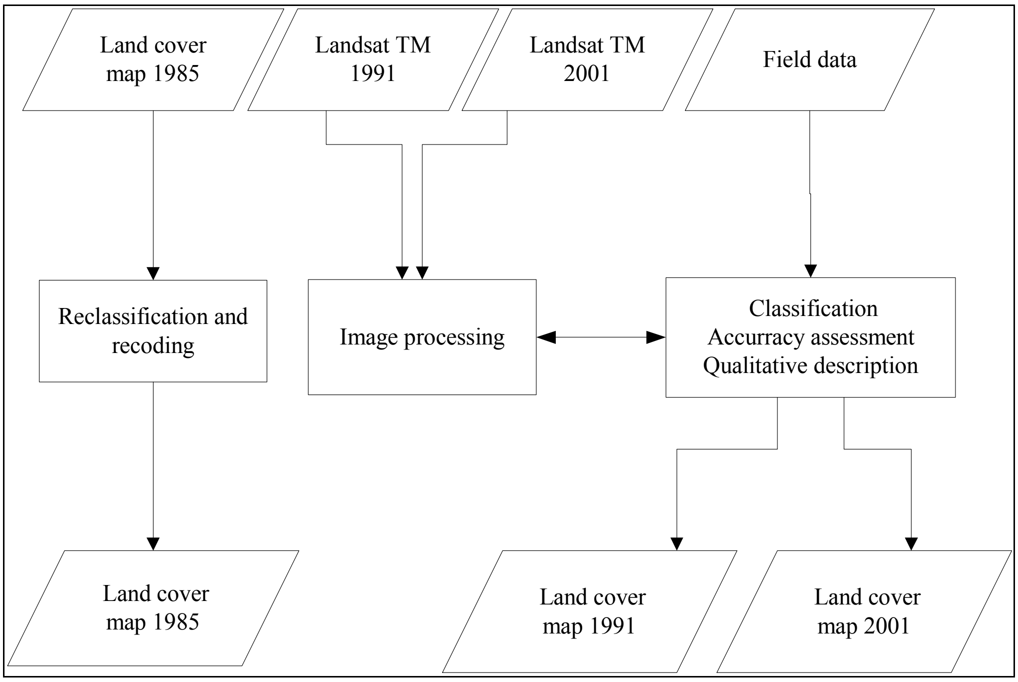


Figure 3: A summary of land cover mapping procedure

3.2 Land cover change detection, qualification and quantification

Land cover change detection is the process of identifying differences in the state of an object or phenomenon by observing it at different times. Essentially, land cover change detection involves the ability to quantify temporal effects using multitemporal data sets. Remotely sensed data obtained from earth orbiting satellites is an important data source for land cover change detection because of repetitive coverage at short intervals and consistent image quality (Singh, 1989).

The objective of analyzing the spatio- temporal dynamics of the land cover was to monitor the evolution of the natural vegetation cover of the study area. This was based on post classification comparison of independently classified land cover maps of 1985, 1991 and 2001 (Section 3.1). The technique used for change detection was GIS overlay in ILWIS. In this technique, the out put table from the overlay of maps of the different dates was used to qualify and quantify the land cover changes. Land cover changes were investigated for the sub periods 1985-1991 and 1991-2001. This was to determine if there is a difference in the rate, the trends and the factors that cause land cover change in the two periods.

The images available for this study had cloud problems. This was particularly problematic with the 1991 image because 23 % of the image was affected by clouds; meaning a loss of an equivalent amount of information on this map. But because of the interest of this research in finding out if there is a difference in trend and rate of land cover dynamics in the two periods, this image could not be excluded from the study. A compromise was to exclude 23 % of information from the other two maps, at points corresponding to cloud and cloud shadow areas in the 1991 map. This permitted the achievement of the following (i) that all three maps used in change analysis had the same amount of information in the beginning (ii) a verification by how much dominant clouds presence on one of the maps could have affected change detection results. The following MapCalc conditional statement in ILWIS was used to exclude the cloud spots on the 1991 map from the 1985 and 2001 maps.

A= IFNOTUNDEF (landcovermap1991,landcovermap1985)
B= IFNOTUNDEF (landcovermap1991,landcovermap2001)
Where:
A is the new 1985 land cover map excluding cloud and cloud shadow areas, B is the new 2001 land cover map excluding cloud and cloud shadow areas.

Though, there was no great difference in the quantitative results obtained before and after exclusion of cloud and cloud shadows areas, subsequent analyses were based on the second quantitative change results (.i.e after exclusion of clouds and cloud shadows). In change quantification, only changes assessed to be important in terms of their magnitude and realism were considered in the analysis.

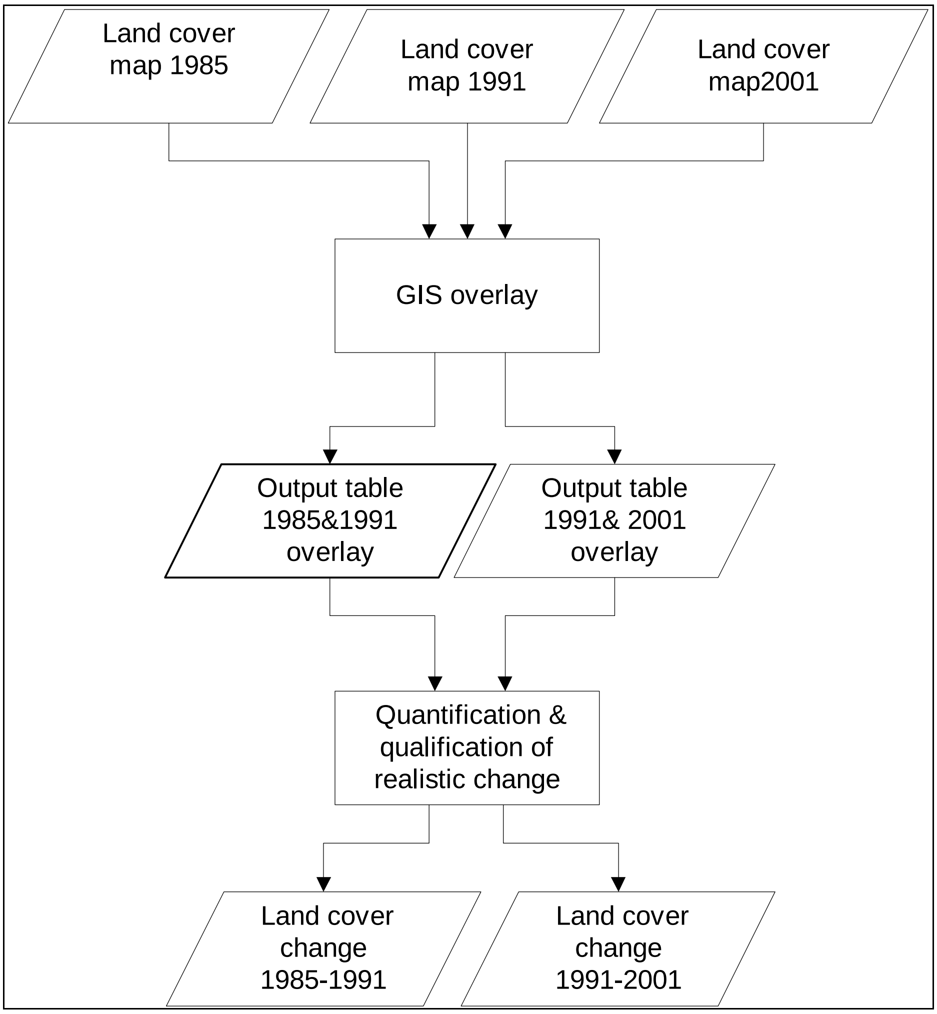


Figure 4: A summary of land cover change detection procedure

3.3 Statistical analysis and spatial modeling

Spatial models are important for analyzing the relationship between location specific parameters and land cover change and offer the opportunity to predict areas where land cover change would likely occur in the future (Serneels, 2001). In this study, the relationship between the main land cover changes and biophysical and human factors was investigated statistically. The objective of this investigation was to associate land cover change to their determining biophysical and human factors in the study area. Based on these factors, probability surface maps for the main land cover changes were generated for the study area. This also permitted the generation of maps depicting areas prone to change in the near future.

3.3.1 Generation of independent variables

Land cover change in the OTU Campo Ma'an might be caused by human activities. Therefore, biophysical factors that guide human decision on land utilization were considered important for analysis in relation to land cover change. These spatially explicit biophysical and human variables were calculated as maps using GIS tools (Table 2). Then an ILWIS table was created in which the values for each variable for all sample points were digitally extracted from the maps. This was achieved by introducing the ILWIS MapCalc expression below on the command line of the table created in ILWIS and columns with the sample point numbers and various biophysical variables were progressively generated.

A=Mapvalue (B, Pntcrd(C, %K))
Where:
A is the column name of the variable of interest, Mapvalue is an ILWIS expression referring to value of a variable to be extracted at any point on the map, B is the map name of the variable, Pntcrd is an ILWIS expression, which means point coordinates, C is the point map of field samples, %K is an ILWIS expression which means values of the variable should be extracted for all the locations specific by the point coordinates on the point map.

Table 2: Biophysical variables and techniques used in their derivation

Adapted from (Murwira, 2000).

Data set	**Derived variable**	**Technique used to derive variable**
Soil map,	Soil type	ILWIS GIS MapCalc function
Contours map	DEM, slope, aspect	ILWIS GIS MapCalc function
Road map Drainage map Settlements map	Distance to road Distance to river Distance to settlements	ILWIS GIS Distance function
Zonation map	Conservation	Selecting park polygon and converting to new shapfile in Arcview GIS

3.3.2 Generation of dependent variables

The major land cover changes obtained from change detection (Section 3.2) were categorized into the following classes: expansion of agro-industrial plantations (meaning a change which was due to increase in all plantation areas), deforestation (referring to changes that led to a loss in the dense forest cover) and forest regrowth (referring to a change from the open forest class to the dense forest class). The land cover change maps were overlaid on field sample points and the type of change that had occurred on each location were recorded. This information was then brought together on a common table containing the dependent and the independent variables. This data set was introduced to the relevant software for analyzing statistically the relationship between biophysical and human factors and the three major land cover changes.

3.3.3 Statistical method

Logistic multiple regression techniques in SYSTAT statistical package was used to investigate the relationship between biophysical and human factors and the three land cover changes mentioned above. This was based on a sample size of 164 samples. Exploration of biophysical data by means of histogram plots preceded the analysis. This revealed a skewed distribution of all biophysical variables considered for the analysis. However, from literature (Florent, 2002; Moore *et al*, 1998), it was revealed that transformation of the skewedly distributed variables is not necessary for logistic multiple regression analysis. This regression technique was chosen for the analysis because of its ability to work with binary or dichototomous variables (Florent, 2002; Iachine, 2002; Mertens, 1999; Mertens *et al*, 2000; Moore *et al*, 1998; Murwira, 2000). The additional advantage of this method is that it works in situations where the dependent variable is categorical and the independent variable is categorical or continuous. The logistic multiple regression (LMR) technique identifies variables important in predicting the probability of an occurrence of the dependent variable because it yields coefficients for each variable based on data derived from samples taken across a study site. The coefficients serve as weights in an algorithm which can be used in the GIS database to produce a map depicting the probability of occurrence of the dependent variable (Narumalani *et al*, 1994). The different land cover changes investigated are binary in nature because they are measured either as present or absent. Also, they constituted the dependent variables in the analysis while biophysical and human factors constituted the independent or explanatory variables. The analysis was carried out for both sub periods of the study to find out if the factors responsible for land cover changes were consistent over time. The analysis followed a stepwise Forward and Backward Wald iterations in SYSTAT statistical package.

The interpretation of model results was based on the probability values, the odd ratio, the t-ratio and logit. The odd ratio is a measure of the association which approximates how much more likely or unlikely it is for the outcome to be present for a set of values of independent variables (Hosmer *et al*, 1989). The probability, the odd ratio and the logit are different ways of expressing the same thing (Menard, 1995 in Mertens, 1999). A significant level (α= 0.05) was used to reject the null hypothesis.

The hypothesis developed to test this relationship (section 1.6) is as follows:

Null hypothesis: There is no relationship between land cover change and biophysical factors X_i

Alternative: There is a relationship between land cover change and biophysical factors X_i

Mathematically expressed as:

H_0: β1= 0

Ha: β1 $\neq$ 0

Where: β1= regression slope and X_i represents all biophysical and human factors considered in this study.

The generic form of the logistic multiple regression model is:

$$\log itp = \log\left[\frac{p}{1-p}\right] = \alpha + \beta_1 X_1 + \beta_2 X_2 + ...\beta_n X_n$$ …………Equation 2

The probability values for the occurrence of the dependent variable can then be quantitatively expressed in terms of the independent variables by:

$$P = \frac{\exp(\alpha + \beta_1 X_1 + \beta_2 X_2 + ...\beta_n X_n)}{1 + \exp(\alpha + \beta_1 X_1 + \beta_2 X_2 + ...\beta_n X_n)}$$ ………………………Equation 3

Where:

P is the probability of the occurrence of the dependent variable, in this case land cover changes, α is the intercept, $\beta_1 \ldots \beta_n$ are slope parameters, $X_1 \ldots X_n$ the predictor or independent variables.

The goodness of fit D^2 (similar to R^2) in conventional statistics was used to assess how well the models predicted the dependent variable. The goodness of fit in a logistic regression is defined as the ratio of the maximized log likelihood. This pseudo R^2 or D^2 is defined as

$$D^2 = 1 - \frac{\log[B]}{\log[c]}$$ ……………………………………………………..Equation 4

that is one minus the ratio of the maximized log likelihood of $\log[B]$ and constant –only- term $\log[c]$ models (Serneels, 2001). Although D^2 ranges in value from 0 to 1, its value tends to be considerably lower than the value of the coefficient of determination R^2 of conventional regression analysis. It should not be judged by the standards of what is normally considered a good fit in conventional regression analysis (Serneels, 2001). Values between 0.2 and 0.4 should be considered to represent a very good fit of the model (Domencich and McFadden, 1975 in Mertens, 1999).

Table 3: Variables used in logistic models

	Variable	type	Unit
Dependent Variables	Deforestation	Binary	0 and1
	Plantation expansion	Binary	0 and 1
	Forest regrowth	Binary	0 and 1
Independent Variables	Distance to settlements	Continuous	M
	Distance to roads	Continuous	M
	Distance to rivers	Continuous	M
	Management effect	Binary	0 and 1
	Soil type	Categorical	1 to 3
	Altitude	Continuous	M
	Aspect	Categorical	1 to 4
	Slope	Continuous	Degrees

3.3.4 Testing for Collinearity of independent variables

Collinearity occurs when an independent variable has a strong association with one or more of the other independent variables in a multiple regression analysis. Where the independent variables are highly correlated it becomes impossible to come up with reliable estimates of their individual regression coefficients (Dallal, 2001). According to Menard (1995) in Mertens (1999), collinearity becomes problematic in a logistic regression model when the coefficient of determinant (r^2) of the collinear independent variables is greater than 0.8. In such a situation, only one of the two collinear variables should be considered in the model.

In order to test for collinearity between the independent variables that were significant for each of the three dependent factors, pair wise correlation analysis of each significant independent variable was performed with the other variables and the values of their coefficient of determinant (r^2) were compared. The coefficient of determinant (r^2) for all correlation analysis of independent variables were less than 0.8 (Table 3). Though some level of dependence could be observed between the explanatory variables, it was not to levels that collinearity could be feared to wreak havoc in the logistic regression models developed for predicting the probability distribution of the dependent variables.

Table 4: Pair wise correlation of significant independent variables

Independent variable 1	Independent variable 2	r^2
Distance from roads	Distance from rivers	0.05
Distance from roads	Altitude	0.29
Distance from rivers	Altitude	0.05

3.4 Prediction and mapping of spatial probability distribution of land cover dynamics

Probability surface maps for plantation expansion, deforestation and forest regrowth were generated on the basis of the spatial models parameters obtained from the LMR results in section 3.3.2. A model each for predicting plantation expansion, deforestation and forest regrowth was built in MS Excel by grafting the significant explanatory variables for each of the three land cover changes in the generic logistic multiple regression model. The models were subsequently exported to ILWIS where predicted probability surface maps of expansion of agro-industrial plantations, deforestation and forest regrowth measured as a change from open forest cover to dense forest cover were generated.

The mapping of the probability surface was based on models which had a better goodness of fit for each of the response variables (expansion of agro-industrial plantations, deforestation and forest regrowth) and the determining biophysical factors in the two sub periods. These maps had a value range between 0 and 1. To expand this range, they were converted percentages. The resulting maps were sliced to categorize the probability surface into low, medium and high probabilities. Areas with medium and high probabilities were considered critical areas for land cover change. Slicing was based on the following criteria: <20% = low probability, 20-50% = Medium probability, >50% = High probability.

3.5 Quantitative assessment and mapping of future risk zones

In order to map areas prone to plantation expansion and deforestation in the future, GIS overlay of the probability surface maps and the land cover map of 2001 was carried out. The probability for future deforestation was retained for those pixels which fell within the medium or high probability classes for deforestation, but were still forest by 2001. Similarly, the probability for future expansion of plantation areas were retained for those pixels which fell within the medium and high probability classes for plantation expansion, but had not had this activity occurring by 2001. Further more, the areas of the medium and high probability classes and the total forest cover remaining in 2001 were used to calculate the percentage of forest area at risk of deforestation in the future. The percentage of forest at risk of plantation encroachment was similarly calculated. The quantitative assessment and mapping of future risk of deforestation and plantation encroachment was based on the assumption that the forest areas characterize by medium and high probability form the concentration of the spatial attributes associated with the observed land cover changes and it is presumed that the same factors responsible for change today will continue to play a role in the dynamics of the land cover in the near future.

3.6 Validation of spatial probability models

The degree of performance of the models was tested by overlaying the predicted probability surface maps of each land cover change and the land cover map of 2001 which indicated the current or observed land cover classes. The proportions of the area observed as plantations on the 2001 map and also predicted in the medium and high probability classes were calculated. Similarly, the proportions of the areas observed under deforestation and forest regrowth and also predicted within the medium and high probability classes of these phenomena were also calculated. These results were used as an indication to say how well the models were able to predict the changes. This was based on a threshold set at 50 % at which model results were judged as good or poor.

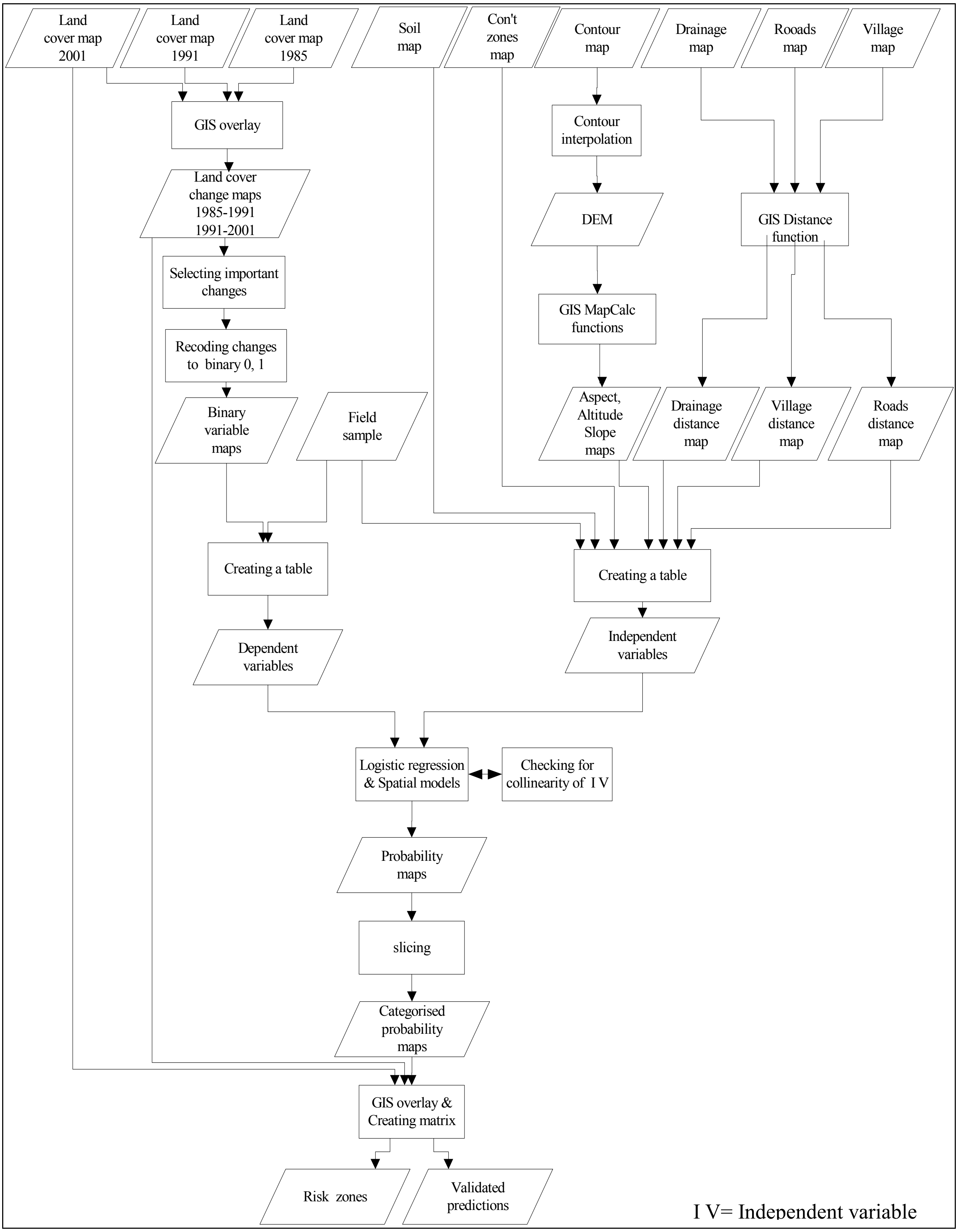


Figure 5: A summary of land cover dynamics analysis and modeling

3.7 Materials

Table 5: Secondary data used in the research

(Source PACBCM)

Secondary data	Year
Landsat TM satellite images	1991 and 2001
Topographic map (1:200 000)	1976 and 2001
Land cover map (1:200 000)	1985
Road map (1:200 000)	2001
Drainage map (1:200 000)	2001
Settlements map (1:200 000)	2001
Soil map (1:200 000)	2001
Digitised contour lines	2001

3.8 Software

Table 6 : Softwares used in the research

Software	Used for
ILWIS 3.1, ERDAS 8.5, Arc View 3.2a	Image processing and classification
MS Excel	Data entering
SYSTAT 7.0.1, SPSS10.1	Statistical analysis
MS Word, Endnote,	Word processing
MS Visio	Flowcharts

4 Results

4.1 Land cover mapping

Two land cover classes were discriminated based on spectral characteristics of satellite images. These included: dense forest and open forest. Agro-industrial plantation areas and open natural forest areas showed an overlap in their spectral reflectance and could not be separated on the basis of this characteristic. The plantation areas however, showed a good textural difference from open natural forests. This additional characteristic was utilized and four land cover classes were finally discriminated on the 2001 and 1991 landsat TM satellite images; dense forest, open forest, palm tree plantation and rubber tree plantation

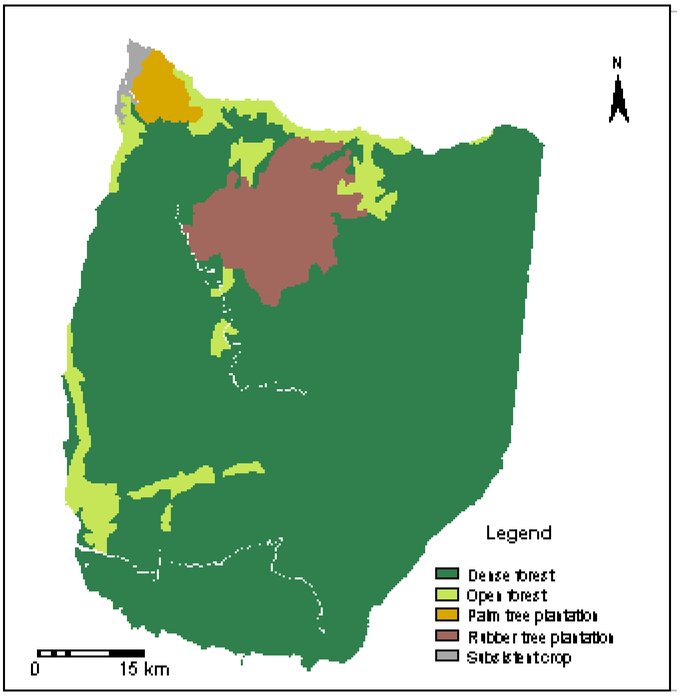


Figure 6: Land cover map of 1985

Obtained from reclassification and recoding of the existing land cover map produced by ONADEF in 1985 from aerial photo interpretation.

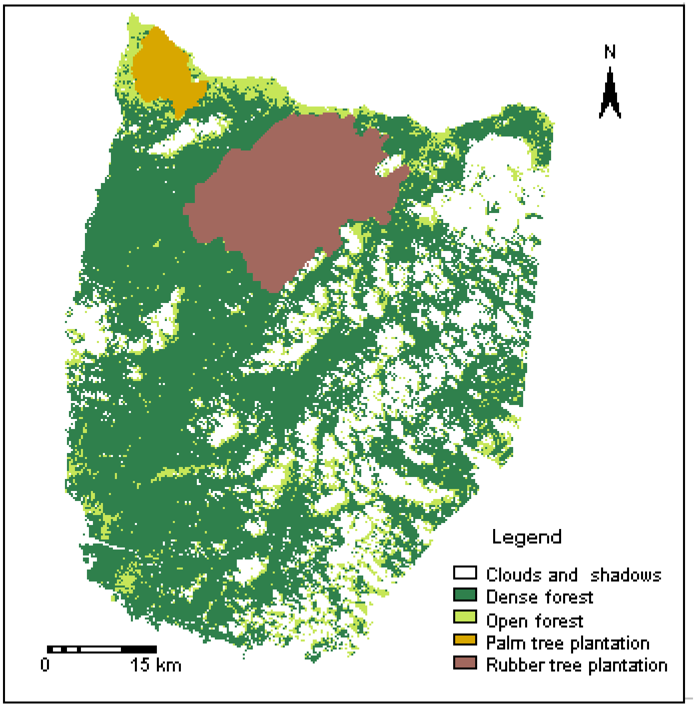


Figure 7: Land cover map of 1991

Obtained from supervised classification of Landsat TM image of February 1991.

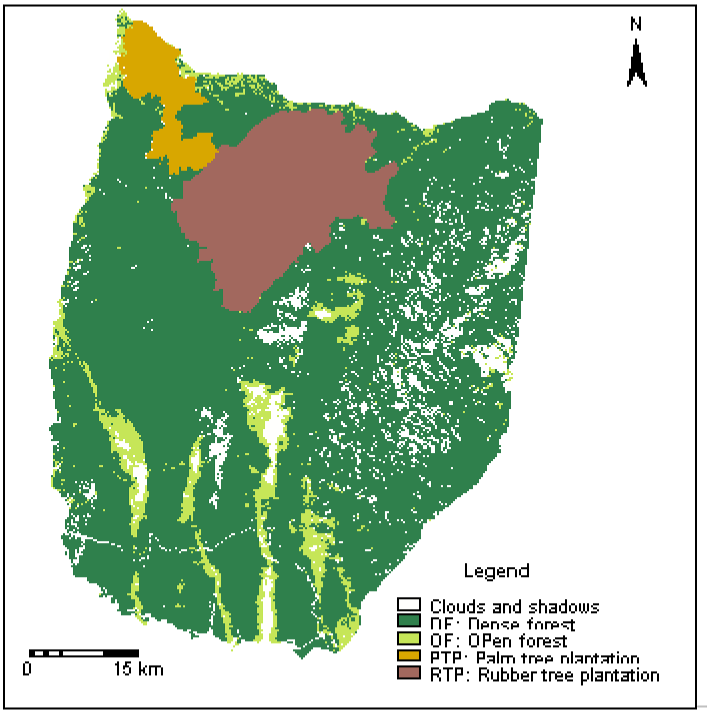


Figure 8: Land cover map of 2001

Obtained from supervised classification of Landsat TM image of April 2001.

4.2 Accuracy assessment

(i) Accuracy assessment based on Confusion matrix

Table 7: The confusion matrix

DF= Dense forest, OF =Open forest, PTP= Palm tree plantation, RTP = Rubber tree plantation

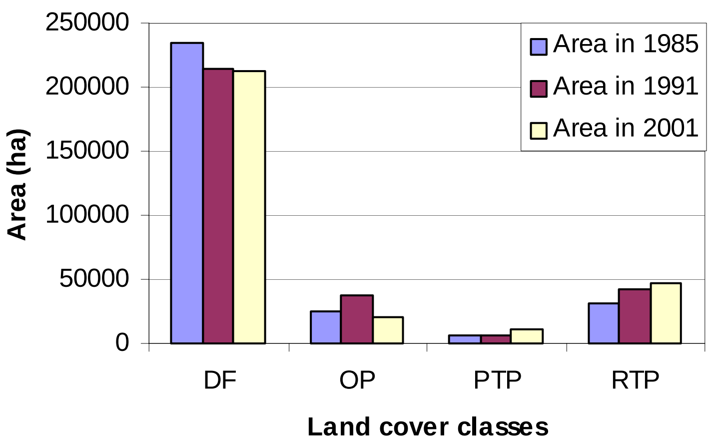
		Reference data					
		DF	OF	PTP	RTP	Total	User accuracy
Classified data	DF	36.0	1.0	1.0	0.0	38.0	0.95
	OP	9.0	24.0	6.0	1.0	40.0	0.60
	PTP	0.0	0.0	30.0	0.0	30.0	1.00
	RTP	0.0	1.0	0.0	25.0	26.0	0.96
	Total	45.0	26.0	37.0	26.0	134.0	
	Producer accuracy	0.80	0.92	0.81	0.96		

The confusion matrix gave an overall accuracy of 85.0% and average accuracy of 87.0 %

(ii) Calculation of Kappa statistics ($\hat{k}$) gave an accuracy 81.0 %

4.3 Land cover change detection qualification and quantification

Land cover change analysis for the sub periods (1985-1991 and 1991-2001) revealed that six important land cover changes were consistent in both sub periods. The results further revealed that the dense forest class decreased in the first period more than in the second period. The open forest class increased in the first period up to 1991 and decreased to 2001 almost to its extend in 1991. The palm tree and rubber tree plantations both showed a steady increase through out the study period.



DF= Dense forest, OF =Open forest PTP= Palm tree plantation, RTP = Rubber tree plantation

Figure 9: Coverage of land cover classes

Table 8: Area coverage and rates of land cover dynamics

Land cover change	1985-1991		1991-2001	
	Area (ha)	Rate (ha/year)	Area (ha)	Rate (ha/year)
Dense forest to Open forest	29372.0	4895.3	15421.6	1542.2
Dense forest to Palm tree plantation	472.0	78.7	3428.1	342.8
Dense forest to Rubber tree plantation	5725.0	954.2	4727.5	472.8
Open forest to Dense forest	13858.1	2309.7	29939.4	2993.9
Open forest to Palm tree plantation	525.8	87.6	828.7	82.9
Open forest to Rubber tree plantation	3953.8	659.0	263.6	26.4

Table 9: Area of land cover classes which did not change during the study.

Land cover class	1985-1991 Area (ha)	% Of 1985 total	1991-2001 Area (ha)	% Of 1991 total
Dense forest	198958.4	85	186077.3	87
Open forest	6525.4	26	5356.3	14
Rubber tree	32001.7	100	41568.6	100
Palm tree	5986.0	100	6961.5	100

This means that the 85 % and 26 % of the original area of the dense forest class and the open forest class respectively did not change in the first period. In the second period, 87 % and 14 % of the dense forest class and the open forest class respectively did not change.

Table 10: land cover changes not considered in the analysis.

Land cover change	1985-1991	1991-2001
	Area (ha)	Area (ha)
Palm tree plantation to Dense forest	2.6	12.4
Palm tree plantation to Open forest	6.7	36.3
Rubber tree plantation to Dense forest	1.6	36.3
Rubber tree plantation to Open forest	1.5	6.8
Subsistent crop to dense forest	323.3	-
Subsistent crop to open forest	1448.0	-
Subsistent crop to palm tree plantation	15.5	-

These changes were not considered in the analysis because of their small magnitudes. Also the class subsistent crop was present on the initial map but not on the subsequent ones hence the evolution of this change could not be monitored.

4.4 The relationship between biophysical and human factors and land cover dynamics

This relationship was established from the interpretation of the logistic multiple regression results; based on the probability values, the odd ratio, the t-ratio, logit and the calculated goodness of fit (D^2) of the model. Values of goodness of fit between 0.2 and 0.4 are considered very good fit for the model (Domencich and McFadden, 1975 in Mertens, 1999). Results revealed by Backward Wald iterations of the independent variables and the separate dependent variables are presented for both sub periods investigated.

Table 11: Biophysical factors significantly related to deforestation (period: 1985-1991)

Biophysical factor	Slope	t- ratio	Odd ratio (e^{b_i})	P-value
Constant	-1.631569	-3.898032		0.000097
Distance to settlements	0.000406	2.763899	1.000407	0.005712
Distance to rivers	-0.001855	-2.645591	0.998147	0.008155

Distance to settlements was positively related to deforestation and distance to rivers was negatively related to deforestation (significance level α=0.05, D^2 =0.043) in the first period.

Table 12: Biophysical factors significantly related to forest regrowth (period: 1985-1991)

Biophysical factor	Slope	t- ratio	Odd ratio(e^{b_i})	P-value
Constant	-2.242795	-7.417719		0.000000
Distance to rivers	0.000115	3.323374	1.000115	0.000889

Distance to rivers was positively related to forest regrowth (significance level α=0.05, D^2 =0.08), and was the only factor influencing forest regrowth in the first period. The expansion of agro-industrial plantations did not show any relationship with biophysical and human factors during the first sub period.

Table 13: Biophysical factors significantly related to deforestation (period: 1991-2001)

Biophysical factor	Slope	t- ratio	Odd ratio(e^{b_i})	P-value
Constant	1.060910	1.095120		0.273464
Altitude	-0.045913	-2.433580	0.955125	0.014950
Distance to roads	0.000505	2.276230	1.000505	0.022832
Distance to rivers	-0.000174	-2.313423	0.999826	0.020699

Altitude and distance to rivers were negatively related to deforestation while distance to roads was positively related to deforestation (significance level α=0.05, D^2 =0.20) in the second period.

Table 14: Biophysical factors significantly related to agro-industrial plantation expansion (period: 1991-2001)

Biophysical factor	Slope	t-ratio	Odd ratio(e^{b_i})	P-value
Constant	1.691279	1.277944		0.201269
Altitude	-0.082191	-2.808086	0.921096	0.004984
Distance to roads	0.000925	3.316035	1.000926	0.000913
Distance to rivers	-0.000991	-2.259134	0.999010	0.023875

Altitude and distance to rivers were negatively related to plantation expansion while distance to roads was positively related to expansion of plantation (significance level α=0.05, D^2 =0.220) in the second period.

Table 15: Biophysical factors significantly related to forest regrowth (period: 1991-2001)

Biophysical factor	Slope	t-ratio	Odd ratio (e^{b_i})	P-value
Constant	-1.935943	-4.688688		0.000003
Distance to roads	-0.002593	-2.110813	0.997411	0.034788
Distance to rivers	0.000078	2.061040	1.000078	0.039299

Distance to roads was negatively related to forest regrowth while distance to rivers was positively related to forest regrowth (significance level α=0.05, D^2 =0.20) in the second period.

4.5 Mapping predicted probability surface of land cover dynamics 1991-2001

Based on their goodness of fit (D^2), the following spatial models were chosen from Section 4.4, for predicting and mapping the probability surface of expansion of agro-industrial plantations, deforestation and forest regrowth.

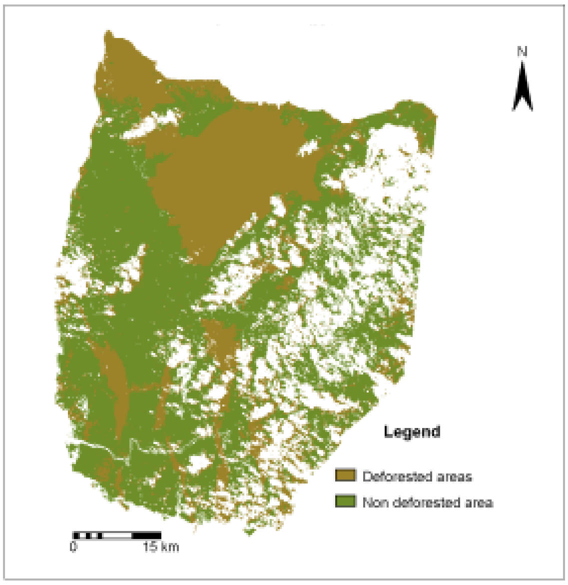
Table 16: Spatial model parameters for predicting deforestation

Biophysical factor	Slope	t- ratio	Odd ratio (e^{b_i})	P-value
Altitude	-0.045913	-2.433580	0.955125	0.014950
Distance to roads	0.000505	2.276230	1.000505	0.022832
Distance to rivers	-0.000174	-2.313423	0.999826	0.020699
Constant	1.060910	1.095120		0.273464

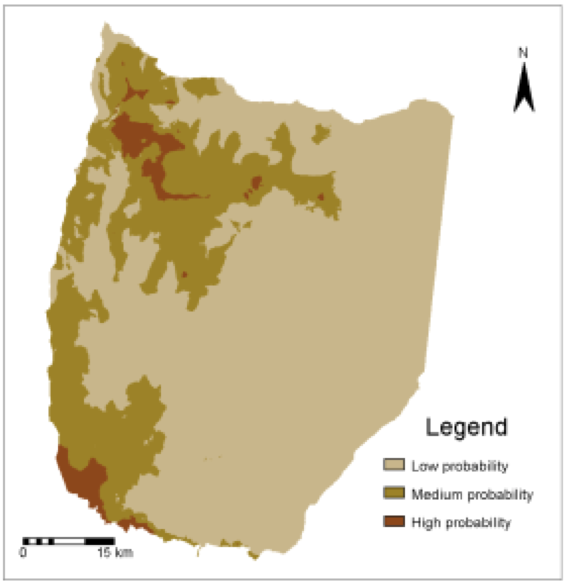
Model:

$$P = \frac{\exp(1.060910-(0.045913*X1)+(0.000505*X2)-(0.000174*X3))}{1+\exp(1.060910-(0.045913*X1)+(0.000505*X2)-(0.000174*X3))}$$

Where: X1=Altitude, X2=Distance to roads, X3=Distance to rivers



Observed deforestation



Predicted probability deforestation Low probability = <20%, Medium probability=20-50% High probability = >50%.

Figure 10: Predicted deforestation

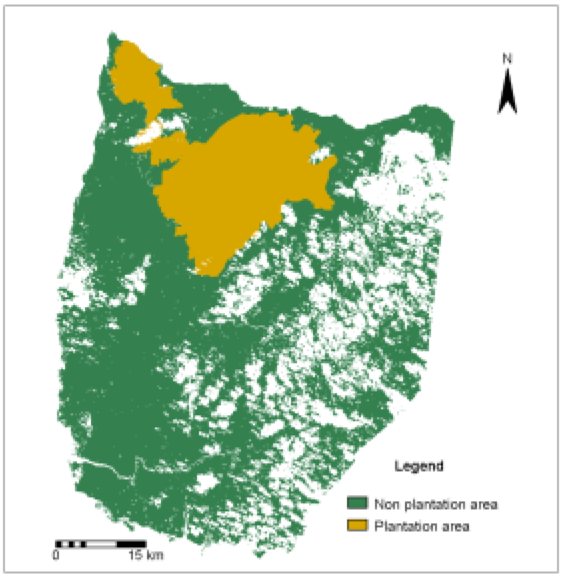
Table 17: Spatial model parameters for predicting expansion of agro-industrial plantation

Biophysical factor	Slope	t-ratio	Odd ratio (e^{b_i})	P-value
Constant	1.691279	1.277944		0.201269
Altitude	-0.082191	-2.808086	0.921096	0.004984
Distance from roads	0.000925	3.316035	1.000926	0.000913
Distance from rivers	-0.000991	-2.259134	0.999010	0.023875

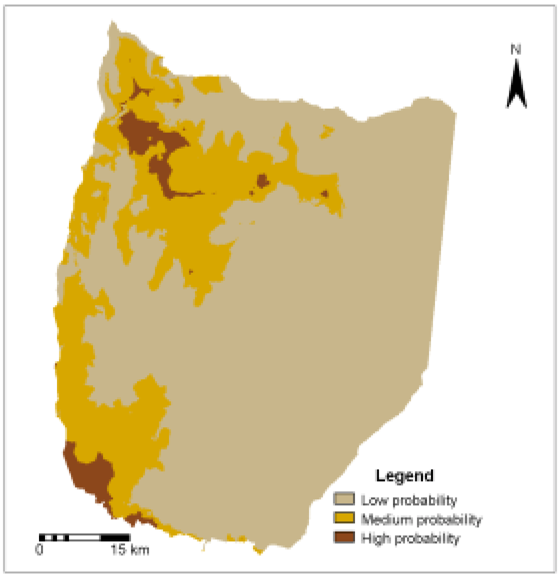
Model:

$$P = \frac{\exp(1.691279 - (0.082191 * X1) + (0.000925 * X2) - (0.000991 * X3))}{1 + \exp(1.691279 - (0.082191 * X1) + (0.000925 * X2) - (0.000991 * X3))}$$

Where: X1=Altitude, X2=Distance to roads, X3= Distance to rivers



Observed plantation expansion



Predicted probability of plantation expansion Low probability= <20%, Medium probability =20-50%, High probability = >50%

Figure 11: Predicted plantation expansion

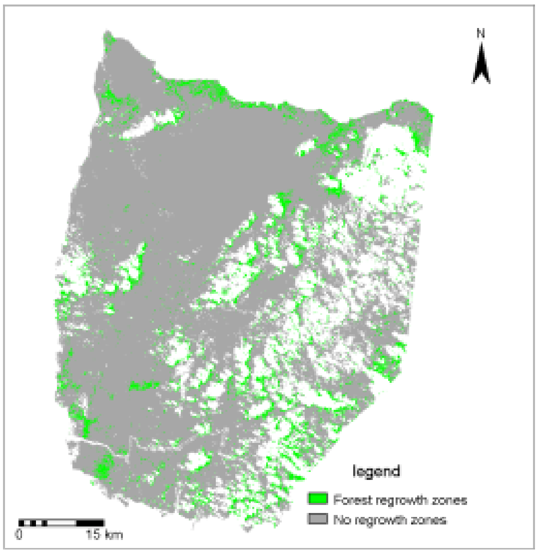
Table 18: Spatial model parameters for predicting forest regrowth

Biophysical factor	Slope	t-ratio	Odd ratio (e^{b_i})	P-value
Constant	-1.935943	-4.688688		0.000003
Distance to roads	-0.002593	-2.110813	0.997411	0.034788
Distance to rivers	0.000078	2.061040	1.000078	0.039299

Model:

$$P = \frac{\exp(-1.935943 - (0.002593 * X1) + (0.000078 * X2))}{1 + \exp(-1.935943 - (0.002593 * X1) + (0.000078 * X2))}$$

Where: X1=distance to roads X2= distance to rivers



Observed forest regrowth

Predicted probability of forest regrowth. Low probability= <20%, Medium probability =20-50%, High probability = >50%

Figure 12: Predicted forest regrowth zones

4.6 Validation of spatial models

Validation of the spatial models was carried as described in section 3.5.1. The validation results are presented (table 19).

Table 19: Validation of spatial models

Predicted probability	Proportion of observed deforestation in 2001	Proportion of observed plantation expansion in 2001	Proportion of observed forest regrowth in 2001
Medium probability	61 %	50 %	9.3 %
High probability	53 %	34 %	9.0 %

4.7 Areas at risk of land cover change in the future

Zones most vulnerable to deforestation and plantation expansion in the future were mapped from selecting the predicted medium and high probability classes for each of these two changes, but where they had not occurred by 2001 (Section 3.6). Also, the percentage forest area at risk of deforestation and plantation encroachment in future in the medium and high probability classes were calculated from a ratio of the area of these probability classes and the total forest area in 2001 (Table 20 & 21).

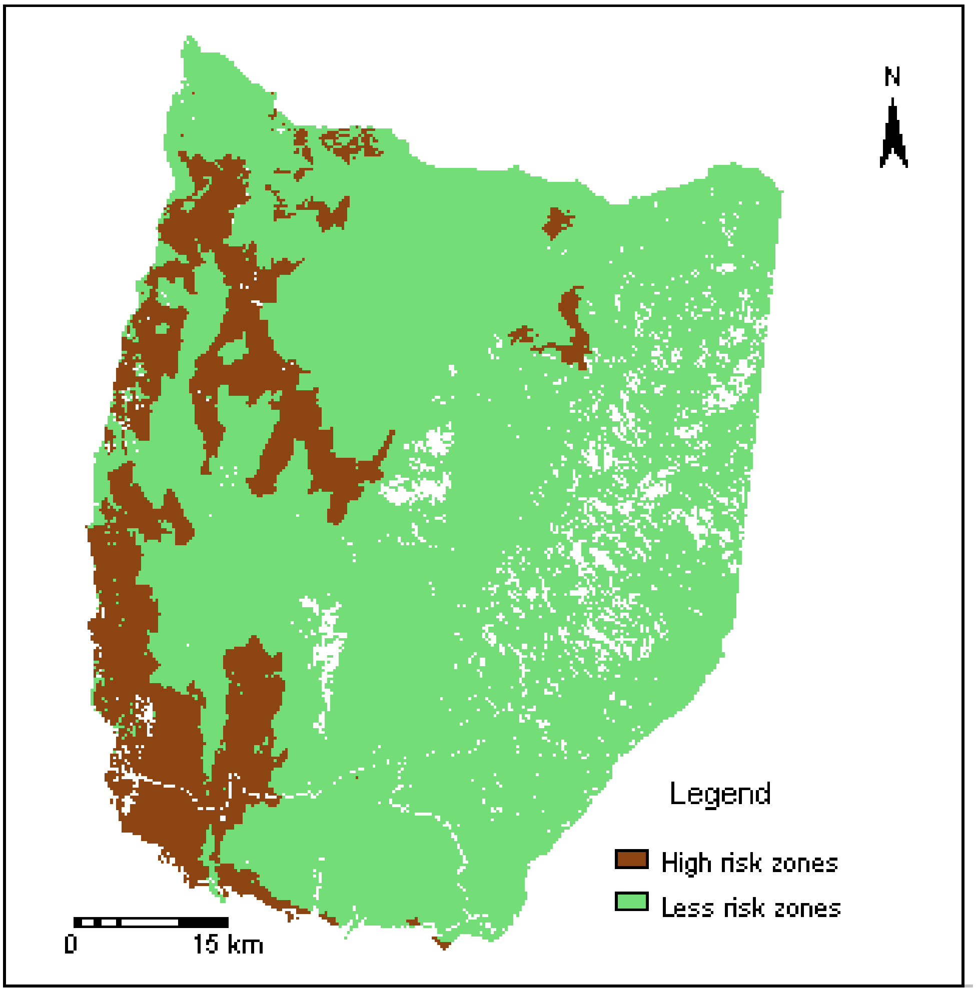


Figure 13: Spatial distribution of future risk zones of deforestation

Table 20: Quantitative assessment of future risk zones of deforestation

Predicted risk zones	Area (ha)	% Forest area at risk
Medium probability	60064.7	28
High probability	6902.2	3

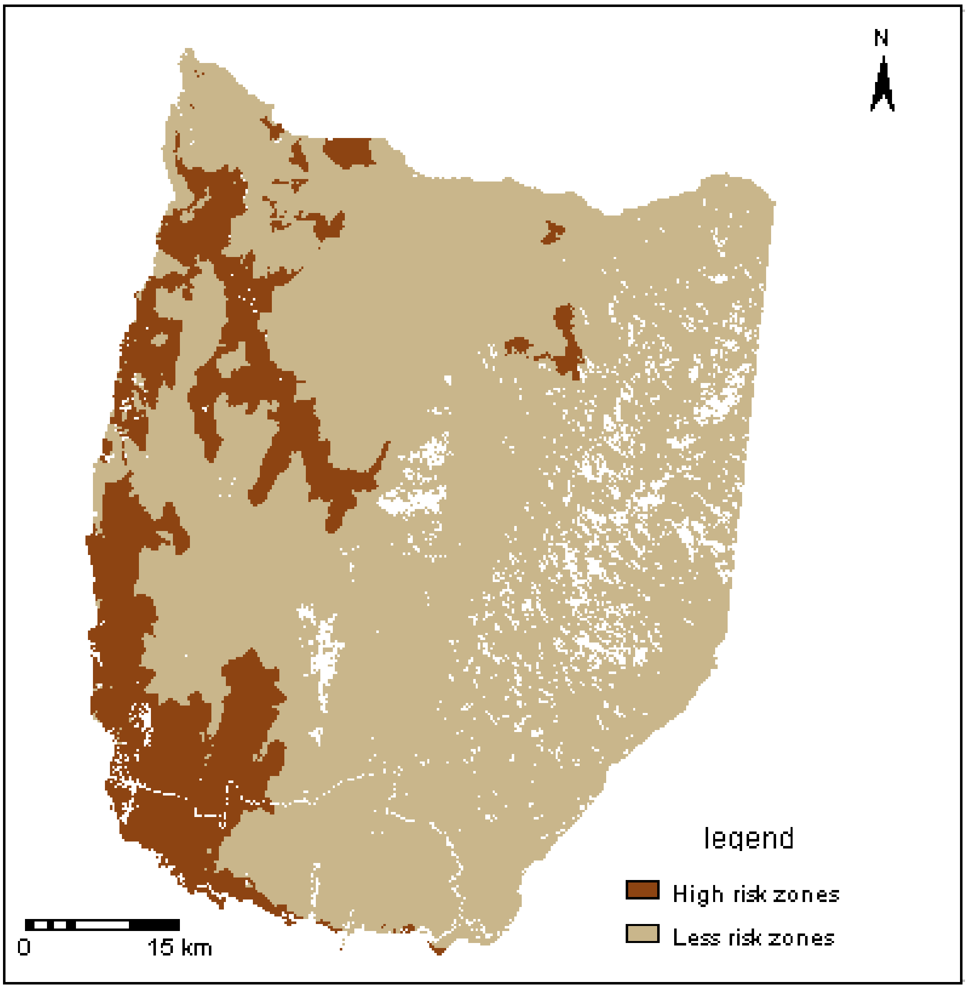


Figure 14: Spatial distribution of future risk zones of plantation expansion

Table 21: Quantitative assessment of future risk zones of plantation expansion

Predicted risk zones	Area (ha)	% Forest area at risk
Medium probability	59744.6	25
High probability	7026.9	3

5 Discussion

5.1 Land cover mapping

Four land cover classes (dense forest, open forest, palm tree and rubber tree plantations) were discriminated from landsat satellite image on the basis of spectral values and textural characteristics. However, it was difficult to separate the open forest class and agro-industrial plantations based on their spectral characteristics. This difficulty is possibly attributed to the similarity in the crown cover percentage of both land cover classes. The open forest class and the agro-industrial plantations both had crown cover percentage generally below 70 %. This similarity in the crown cover percentage offers a similar reflectance surface for both land cover types; thus leading to the overlap in their spectral characteristics. The textural differences exhibited by these land cover classes are due to the regular spacing of the trees in the plantations and also due to the fact that plantations are spatially layout in consecutive regular blocks. Therefore, this regular spatial arrangement of trees in the plantations (which is different from the arrangement of trees in a natural forest) possibly contributes to the textural differences between plantations and modified natural forests.

Also, it was not possible to separate subsistent crop fields from bare soil in the classification. This difficulty to separate these two classes is possibly due to as seasonal influence i.e. the time of imaging. The images used in this research were taken in February and April, months which correspond to the active farming season in this region. In these months, clearing down the forest for new crop fields is a common activity. It is possible that reflectance from dry materials abundantly present in crop fields during this season and from the bare soil will be the same. This possibly explain why crop fields and bare soil could not be discriminated based on their spectral values. The results of the land cover mapping were different from those obtained by Mertens (1999) and Mertens *et al* (2000) who carried out a similar study in a tropical environment. The difference in these results and that of these authors is that in their studies, they were able to discriminate agricultural fields from bare soil. A possible assumption might be a difference in the season for the images for this study and that of these other authors.

The over all accuracy of the classification results from the confusion matrix and the calculation of the Kappa coefficient was 85 and 81 % respectively. These values fall within the range described by Congalton (1996) as strong agreement. These high accuracy results demonstrate that the combined use of the spectral and textural characteristics increased the number of classes in the final classification and also with a good accuracy.

5.2 Land cover dynamics

Results of land cover dynamics for the sub periods of this study revealed six important changes, which were consistent from the first sub period to the second sub period (Table10). From these results, it is observed that the rate of conversion of dense forest to open forest dropped during the second sub period (1991-2001) to about a third the rate in the first sub period (1985 – 1991); from about 4900 hectares per year to about 1500 hectares per year. Palm tree and rubber tree plantations both expanded during the study period, with the rate of expansion of rubber tree plantations in the second period dropping to almost a third its rate in the first period; from 1600 hectares per year to about 500 hectares per year. The difference in land cover change rates between the two periods is presumably due to various renovations in the management policies. The declaration of this zone as an Operational Technical Unit in 1995 set in a good number of control mechanisms on all activities in this area thereby accounting for the drop in rates in the second period.

The observed decline in forest cover and increase in plantations coverage through out the study ties to the fact plantation encroachment is one of the causes of deforestation in the OTU. The expansion of plantation is due to the successful economic rewards from the plantation produce (rubber and palm oil). This has caused not only the existing multinational companies to expand their activities, but also a good number of elites, local individuals and groups are increasing getting involved in this activity. Several assistance schemes set up by multinational companies to local individuals or local initiative groups make the process of starting a plantation fairly easy. Significant among these are free supply of seedlings and marking assistance to aspiring local individuals or local initiative groups. Therefore the growing number of actors in this activity is responsible for its expansion and consequent impact on the natural vegetation. The role of commercial agriculture in modifying the natural forest cover has been documented by other researchers Serneels (2001) discovered that changes in the land cover of the Kenyan Embu highlands was largely due to the introduction of cash crops farming in the area which caused a considerable decrease in the natural vegetation cover.

This study also reveals that land cover change in the study area is not a simple straightforward process, but is highly complex in that one cover class changes to other class and finally change to the original cover again. An example is dense forest changing to open forest and later becoming dense forest again. The complexities of these changes make monitoring the trend of land change cumbersome. The rate of forest regrowth observed in the second period of this study doubled that observed in the first period. This observed rate of forest regrowth is attributed partly to the management effort, which has helped in controlling human influences on the forest cover. Also, the long fallow farming systems practice in this area and the restriction of logging activities to the production forest units known as UFA (Unité Forestière d'Aménagement), probably explain the observed forest regrowth trend.

Conservation effect was considered as one of the parameters in the analysis of land cover dynamics, but it was statistically insignificant in explaining forest regrowth. This observation might have been caused by a limited number of samples collected within the management zones, rather than a suggestion that the effects of management have no impact on the observed rate of forest regrowth.

Despite, the high increase rate of forest recovery, observed in the second period, the study show a continuous decline in forest cover over the study period. This indicates that factors responsible for forest loss outweigh those that stimulate forest recovery.

The results of the land cover change analysis show that the rate at which land cover change occurred in both sub periods is different, therefore the hypothesis that there is no difference in the rate of land cover change in the two periods was rejected.

5.3 Land cover dynamics and biophysical factors

Distance to settlements and distance to rivers were factors associated with deforestation in the first sub period of this study while in the second period, altitude, distance to roads and distance to rivers were important in explaining the process of deforestation. Distance to settlements was positively related to deforestation i.e. the closer to settlements the higher the deforestation effects. This suggests that early deforestation was taking around the settlements. This is possibly deforestation caused by local farming activities in which the forest around the settlements was cleared in the first period for farming purposes.

Surprisingly, distance to settlements, which was significant in the first period, became insignificant in the second period while distance to roads, which was statistically insignificant in the first period, became significant in the second period. This finding suggests that more agricultural activities were concentrated around the settlements during the early period leading to deforestation of the land around the settlements. As time went on, land around the settlements became exhausted and people began to move away from settlements to clear new areas far away from the settlements. In doing so however, the new fields were cleared along existing roads. This is an indication that areas accessible by roads are more prone to being deforested in the recent period. Therefore, accessibility play an important role in recent deforestation process.

Other researchers have supported the importance of accessibility as a factor determining deforestation. Mertens (1999), Mertens and Lambin (2000) discovered that distance to roads was one of the factors important in deforestation in the East province of Cameroon as roads increased access to forest areas by migrants. Serneels (2001) discovered that the extension of wheat farming in the Serengheti-Mara ecosystem was mainly influenced by easy access to the land.

The negative relationship between deforestation and distance to rivers indicates that areas close to rivers have little or no chance of being deforested while forest areas away from rivers are more prone to deforestation. This finding agrees with field observations were forest clearance for plantation agriculture and subsistent farming was concentrated outside the river basins. The explanation for this observation is that river basins within the OTU are permanently water logged or temporally inundated in some places. Such forest is not suitable neither for plantation activities nor subsistent crop farming. Hence they have been avoided by any intense human activities. Thus, the risk of deforestation tends to increase with increasing distance from river basins.

The significance of altitude in the deforestation process can be explained by easy accessibility of low land with heavy machinery. Since the development of plantations is one of the main causes of deforestation, it is assumed that these activities are concentrated on the low plains due to the ease of working with machinery on flat terrain. Also local, farming activities occur in plains because they are easily accessible and less working. Though the western part of the OTU Campo Ma'an is generally of low altitudinal range, this study however reveals that human activities have avoided the isolated highland areas. Therefore, the main human activities associated with deforestation in the OTU notably shifting cultivation, plantation agriculture and timber logging occur at low altitude.

It can be seen from the results that the factors responsible for deforestation are also significant for plantation expansion. This is not a surprising finding because plantation encroachment is one of the causes of natural forest loss; therefore factors significant for deforestation are also associated with expansion of agro-industrial plantations.

Distance to rivers showed a consistent positive relationship with forest regrowth (measured as the conversion of open forest to dense forest) in both sub periods and distance to roads showed a negative relationship with forest regrowth in the second period. The positive relationship between distance to rivers and forest regrowth is not surprising because, forest close to rivers tends to receive limited human interferences and thus has time to recover more than forest away from river basins. The negative association shown by distance to roads and forest regrowth in the second period is also not surprising because areas close to roads are under continuous influences by humans and recovery along roadsides will be a very slow process.

Though the soil quality is one of the most important factors in agricultural activities, hence deforestation, it is not surprising that this factor was not significant in this study. This is because the study area is almost dominated by one soil type (ferralsols) and the other soil types (arenasols and fluvisols) are restricted to a tiny southern tip of the research area (Appendix 2c). Due to the dominance of one soil type over the entire area, statistical relationship could not be established between this factor and the investigated land cover changes.

From the general topography of the study area, it was not surprising that the factors aspect and slope were not statistically significant in explaining the investigated land cover changes. This is because the western part of the UTO is generally flat. Hence, the effects of aspect and slope are less important in determining change. Should this study have included the eastern parts of the OTU as originally anticipated, aspect and slope probably would have become important due to the shielding effects of the high mountains with steeply descending slopes which would probably influence land use decisions.

From these results the null hypothesis that there is no relationship between biophysical and human factors and land cover change was rejected for distance to settlements, distance to rivers, distance to roads and altitude. This hypothesis could not be rejected for aspect, slope soil type and conservation. Furthermore, all the significant biophysical factors except for distance to settlements were consistent for both periods. Therefore, the null hypothesis that biophysical and human factors responsible for change are not consistent in the sub periods was rejected for distance to rivers, distance to roads and altitude. This hypothesis could not be rejected for distance to settlements.

5.4 Spatial prediction of land cover dynamics

The overall explanatory power of the models for predicting the expansion of agro-industrial plantations, deforestation and forest regrowth (Section 4.3) fell within the range described by Domencich and McFadden (1975) in Mertens (1999) as satisfactory for a goodness of fit for logistic multiple regression analysis. The validation of the predicted surface probability maps of deforestation indicated that the areas predicted as having medium and high probability had at least 50 % of the observed deforestation observed in 2001 occurring in those areas. The validation of the surface probability map of plantation expansion showed that 50 % of the observed plantation areas in 2001 fell within areas predicted as medium and 34 % in areas predicted as high. These results indicate that the factors grafted into these two models are important in explaining the occurrence of deforestation as well as plantation expansion. However, from the strength of the relationships and the validation results, it can be seen that though these biophysical factors are important for explaining land cover change, their influence is in conjunction with other more important factors. The validation results for the forest regrowth model showed that less than 50 % of observed forest regrowth areas in 2001 were predicted in the medium and high probability class of the of the predicted maps. This shows a weak performance of the model suggesting that stronger factors apart from those investigated in this study are important in explaining forest regrowth in the area.

Prediction results indicated that about 30 % of the forest cover of 2001 is at risk of conversion in the near future assuming that the same factors continue to play a role in land cover change and nothing happens as a regulating major.

6 Conclusion and recommendation

6.1 Conclusion

From this study, the following conclusions can be made:
Landsat TM data is an important source of data for mapping the dynamics of land cover in a moist tropical rainforest. However, cloud cover can limit the useful of this important data because as high as 23 % of the information on one of the images used in the study was obscured by cloud coverage. Therefore, any possible limitation of landsat TM satellite images in mapping land cover and cover dynamics in a moist tropical rainforest is the effects of clouds.

The availability and use of time series satellite images permitted the detection and quantification of land cover dynamics in the OTU. This has been useful in improving our understanding of past and present changes in the landscape. From the findings of this study, land cover in the OTU cannot be assumed to be a process that takes place at a constant rate in time. The rates varied between the sub periods of this study, but the factors responsible for land cover change were consistent in both periods. Due to the quality of the images that were used in this study, it is feared that a large amount of data was loss. Quantitative values for land cover change are based on cloud free zones only. Therefore these figures may be different if better images entirely free from clouds are used. However, the study is able to identify the main land cover changes and biophysical factors explaining them. The quantitative assessment and spatial location of areas vulnerable to change in future was highlighted in the study. This information hopefully is useful contribution towards management and conservation efforts in the OTU. Also, the goodness of fit of the spatial models, the spatial agreement of predicted medium and high probability areas and observed changes, indicated a satisfactory performance of the deforestation and plantation expansion models. Therefore, the availability of time series satellite imagery data and spatial models are important in forecasting changes in the tropical forest ecosystems and biodiversity. The spatial models, land cover change results in conjunction with maps of species habitats will be useful in identifying critical zones "biodiversity hotspots" thereby helping planners in the prioritizing conservation efforts. This also offers the opportunity for planning ahead because failures in some conservation initiatives stemmed from the fact that appropriate majors were taken at when the situation has already out of hand.

6.2 Recommendation

This study was not able to separate crop fields from bare soils because the time of image capture coincided with the season of forest clearing for new crop fields; thus crop fields and bare soil tend to reflect in the same way. A study interested in mapping crop fields is recommended to bear this seasonal influence in mind. This study predicted and mapped areas vulnerable to change in the future based on selected biophysical and human factors. However, biophysical factors may not be conclusive in determining land cover change in the OTU. Therefore, a possible continuation of this study is to include socio-economic factors, cultural context and political policies related to land use. This will provide a complete insight of the factors responsible for land cover dynamics in the OTU. Furthermore, since the spatial models developed in this study can only answer the "where" and "why" questions related to land cover change, the development of models that answer the "when" and "by how much" questions is recommended as another possible continuation of this study. Knowing where changes might occur and also how much of it is likely to occur offers a better basis for deciding which intervention measures are appropriate and how fast efforts need to be accelerated.

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Appendix

Appendix1a: Output table from GIS overlay of 1985 and 1991 land cover maps

Before clouds and cloud shadow exclusion

Clm	Landcovermap1985	Landcovermap1991	NPix	Area	Area_ha
DF * DF	Dense forest	Dense forest	2325917	2093325300	209332.5
DF * OP	Dense forest	Open forest	344766	310289400	31028.9
DF * PTP	Dense forest	Palm tree plantation	5313	4781700	478.2
DF * RTP	Dense forest	Rubber tree plantation	63612	57250800	5725.1
OP * DF	Open forest	Dense forest	159865	143878500	14387.9
OP * OP	Open forest	Open forest	73725	66352500	6635.3
OP * PTP	Open forest	Palm tree plantation	5842	5257800	525.8
OP * RTP	Open forest	Rubber tree plantation	43931	39537900	3953.8
RTP * DF	Rubber tree plantation	Dense forest	18	16200	1.6
RTP * OP	Rubber tree plantation	Open forest	17	15300	1.5
RTP * RTP	Rubber tree plantation	Rubber tree plantation	355574	320016600	32001.7
PTP * DF	Palm tree plantation	Dense forest	29	26100	2.6
PTP * OP	Palm tree plantation	Open forest	75	67500	6.8
PTP * PTP	Palm tree plantation	Palm tree plantation	66562	59905800	5990.6
SC * DF	Subsistent crop	Dense forest	3952	3556800	355.7
SC * OP	Subsistent crop	Open forest	17113	15401700	1540.2
SC * PTP	Subsistent crop	Palm tree plantation	220	198000	19.8

After clouds and cloud shadow exclusion

.clm	ladcover1985	ladcover1991	NPix	Area	Area_ha
DF * DF	Dense forest	Dense forest	2210649	1989584100	198958.4
DF * OP	Dense forest	Open forest	326356	293720400	29372
DF * PTP	Dense forest	Palm tree plantation	5244	4719600	472
DF * RTP	Dense forest	Rubber tree plantation	63611	57249900	5725
OP * DF	Open forest	Dense forest	153979	138581100	13858.1
OP * OP	Open forest	Open forest	72504	65253600	6525.4
OP * PTP	Open forest	Palm tree plantation	5842	5257800	525.8
OP * RTP	Open forest	Rubber tree plantation	43931	39537900	3953.8
RTP * DF	Rubber tree plantation	Dense forest	18	16200	1.6
RTP * OP	Rubber tree plantation	Open forest	17	15300	1.5
RTP * RTP	Rubber tree plantation	Rubber tree plantation	355574	320016600	32001.7
PTP * DF	Palm tree plantation	Dense forest	29	26100	2.6
PTP * OP	Palm tree plantation	Open forest	74	66600	6.7
PTP * PTP	Palm tree plantation	Palm tree plantation	66511	59859900	5986
SC * DF	Subsistent crop	Dense forest	3592	3232800	323.3
SC * OP	Subsistent crop	Open forest	16089	14480100	1448
SC * PTP	Subsistent crop	Palm tree plantation	172	154800	15.5

Appendix1b: Output table from GIS over lay of 1991 and 2001 land cover maps

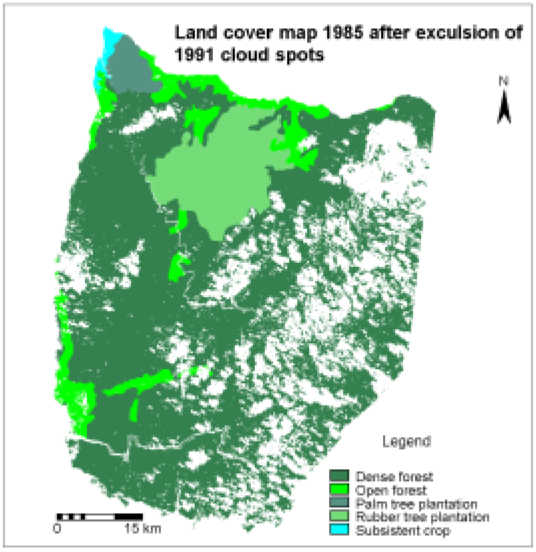
Before clouds and cloud shadow exclusion

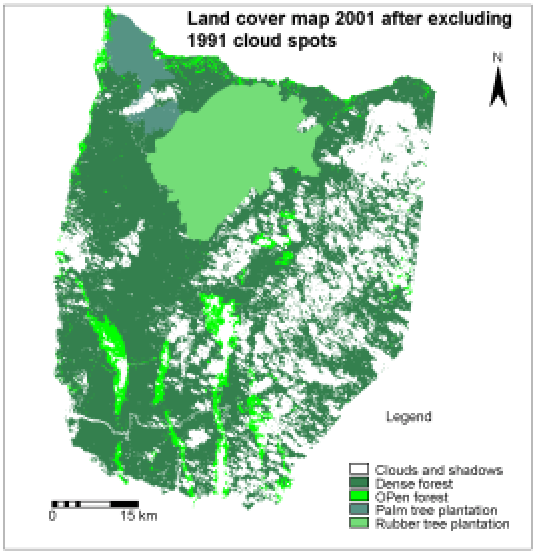
Clm	Landcovermap1991	Landcovermap2001	NPix	Area	Area_ha
DF * DF	Dense forest	Dense forest	2067525	1860772500	186077.3
DF * OF	Dense forest	Opens forest	171351	154215900	15421.6
DF * Cl	Dense forest	Clouds and shadows	51355	46219500	4621.9
DF * RTP	Dense forest	Rubber tree plantation	52528	47275200	4727.5
DF * PTP	Dense forest	Palm tree plantation	38090	34281000	3428.1
OP * DF	Open forest	Dense forest	332660	299394000	29939.4
OP * OF	Open forest	Open forest	59514	53562600	5356.3
OP * Cl	Open forest	Clouds and shadows	13600	12240000	1224
OP * RTP	Open forest	Rubber tree plantation	2929	2636100	263.6
OP * PTP	Open forest	Palm tree plantation	9208	8287200	828.7
PTP * DF	Palm tree plantation	Dense forest	138	124200	12.4
PTP * OF	Palm tree plantation	Open forest	403	362700	36.3
PTP * Cl	Palm tree plantation	Clouds and shadows	1	900	0.1
PTP * PTP	Palm tree plantation	Palm tree plantation	77350	69615000	6961.5
RTP * DF	Rubber tree plantation	Dense forest	403	362700	36.3
RTP * OF	Rubber tree plantation	Open forest	75	67500	6.8
RTP * RTP	Rubber tree plantation	Rubber tree plantation	461873	415685700	41568.6
RTP * PTP	Rubber tree plantation	Palm tree plantation	1092	982800	98.3

After clouds and cloud shadow exclusion

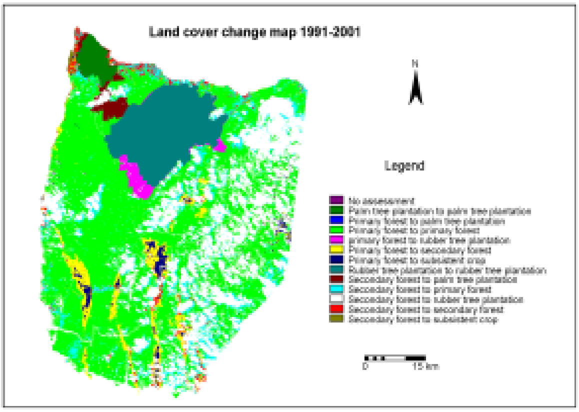
.clm	landcover1991	landcover2001	NPix	Area	Area_ha
DF * DF	Dense forest	Dense forest	2067525	1860772500	186077.3
DF * OF	Dense forest	OPen forest	171351	154215900	15421.6
DF * Cl	Dense forest	Clouds and shadows	51355	46219500	4621.9
DF * RTP	Dense forest	Rubber tree plantation	52528	47275200	4727.5
DF * PTP	Dense forest	Palm tree plantation	38090	34281000	3428.1
OP * DF	Open forest	Dense forest	332660	299394000	29939.4
OP * OF	Open forest	OPen forest	59514	53562600	5356.3
OP * Cl	Open forest	Clouds and shadows	13600	12240000	1224
OP * RTP	Open forest	Rubber tree plantation	2929	2636100	263.6
OP * PTP	Open forest	Palm tree plantation	9208	8287200	828.7
PTP * DF	Palm tree plantation	Dense forest	138	124200	12.4
PTP * OF	Palm tree plantation	OPen forest	403	362700	36.3
PTP * Cl	Palm tree plantation	Clouds and shadows	1	900	0.1
PTP * PTP	Palm tree plantation	Palm tree plantation	77350	69615000	6961.5
RTP * DF	Rubber tree plantation	Dense forest	403	362700	36.3
RTP * OF	Rubber tree plantation	OPen forest	75	67500	6.8
RTP * RTP	Rubber tree plantation	Rubber tree plantation	461873	415685700	41568.6
RTP * PTP	Rubber tree plantation	Palm tree plantation	1092	982800	98.3

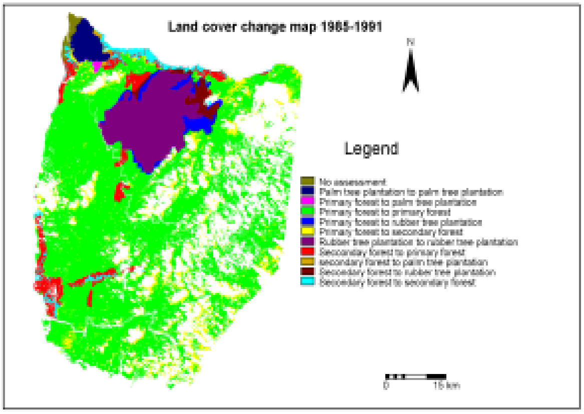
Appendix 2a:Land cover maps of 1985 and 2001 after exclusion of 1991 clouds and shadows spots



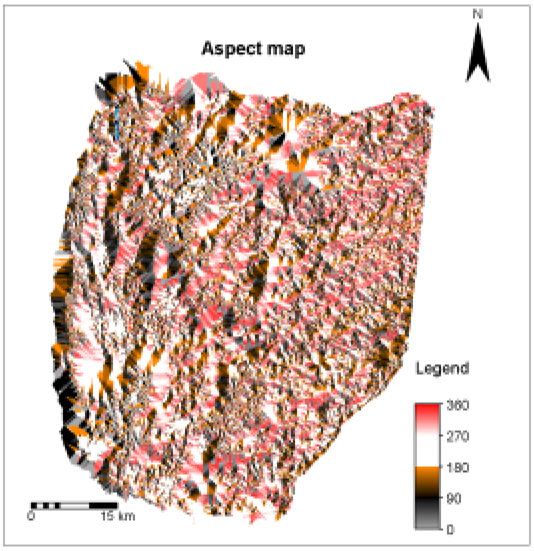


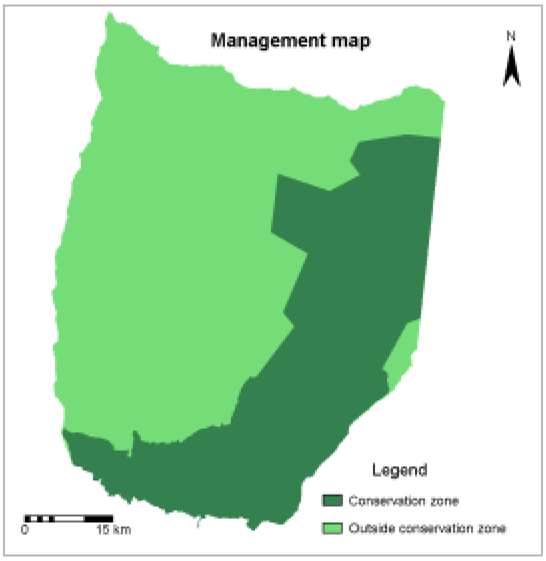
Appendix 2b: Land cover change maps of 1985-1991 and 1991-2001

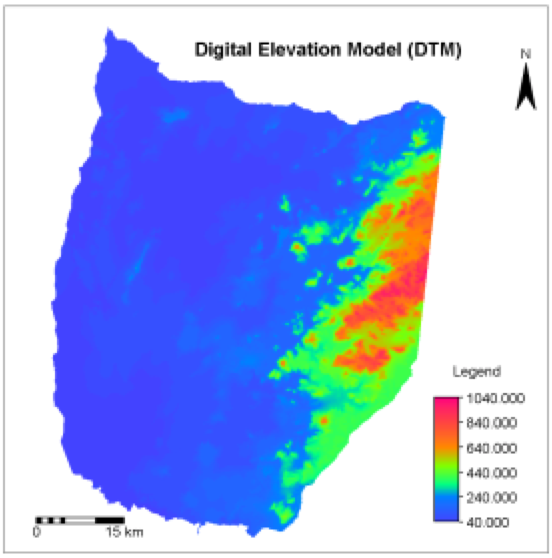


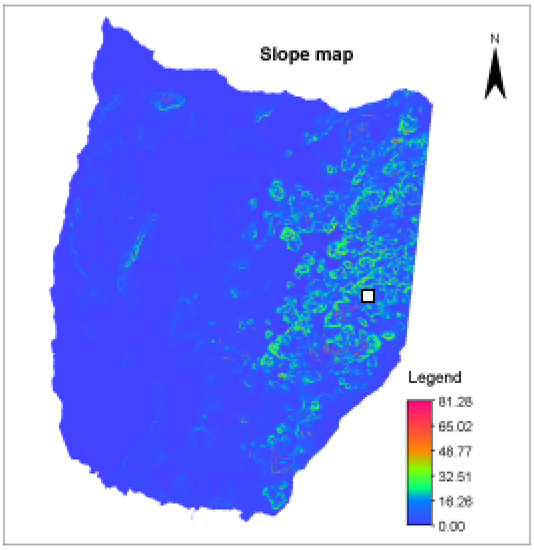


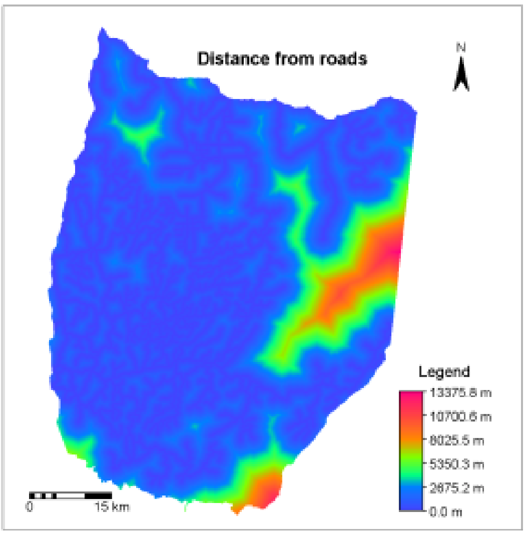
Appendix 2c: Maps of biophysical variables

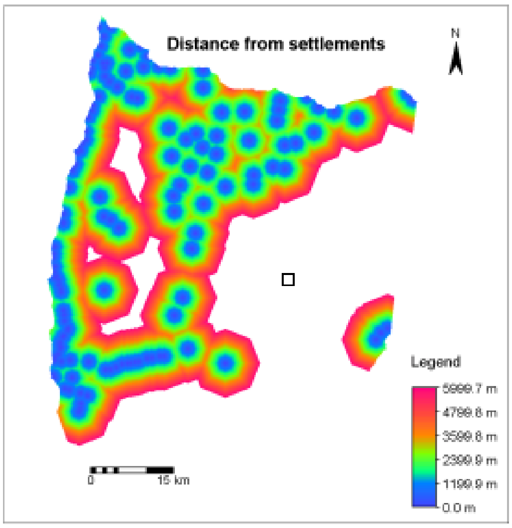


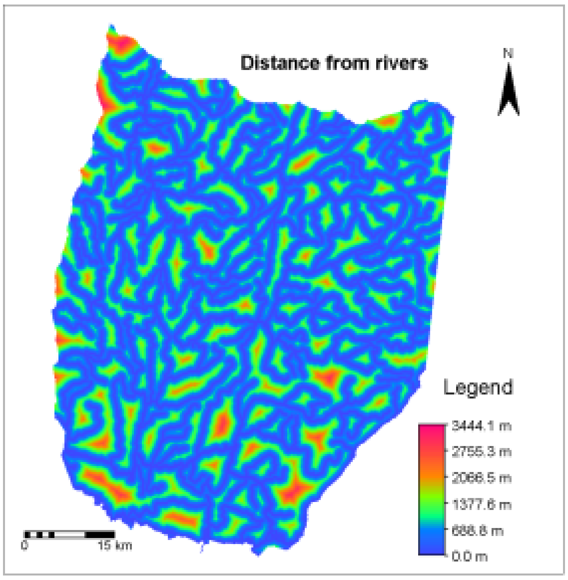


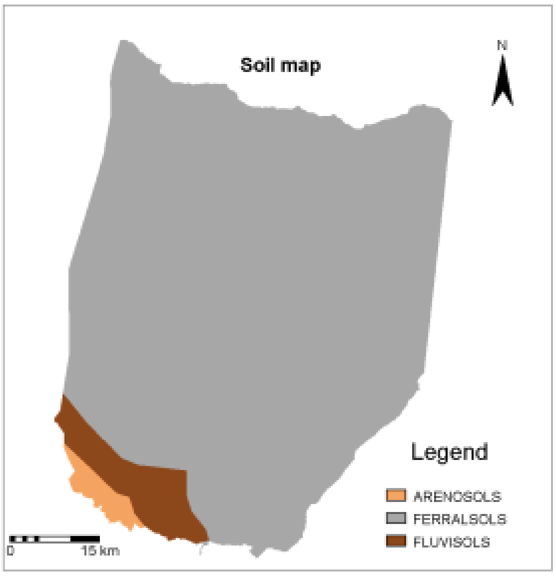









Distance from rivers
N
Legend
3444.1 m
2755.3 m
2066.5 m
1377.6 m
688.8 m
0.0 m
0
15 km


Soil map
N
Legend
ARENOSOLS
FERRALSOLS
FLUVISOLS
0
15 km

Appendix 3. Biophysical variables that were not significantly related to major land cover change during the sub period of investigation 1985-1991

Appendix3a: Biophysical factors that were not significantly related to expansion of agro-industrial plantations.

Biophysical factor	P-value
Altitude	0.507586
Aspect	0.978625
Conservation	0.973139
Distance from roads	0.973139
Distance from rivers	0.432557
Distance from settlements	0.942331
Soil type	0.991238
Slope	0.917927
Constant	0.964613

Appendix 3b: Biophysical factors that were not significantly related to deforestation

Biophysical factor	P-value
Altitude	0.501863
Aspect	0.061822
Conservation	0.259651
Distance from roads	0.064255
Slope	0.324454
Soil type	0.976582

Appendix 4. Biophysical variables that were not significantly related to major land cover change during the sub period of investigation 1991-2001

Appendix 4a: Biophysical factors that were not significantly related to expansion of agro-industrial plantations.

Biophysical factor	P-value
Aspect	0.539936
Distance from rivers	0.162415
Distance from settlements	0.067201
Conservation	0.948628
Soil type	0.996383
Slope	0.258937

Appendix 4b: Biophysical factors that were not significantly related to deforestation

Biophysical factor	P-value
Aspect	0.788008
Conservation	0.949982
Distance from village	0.850541
Slope	0.544394
Soil type	0.990455

Appendix 5a: Forest structure data

plot ID	Date	Location	UTME	UTMN	LC	LU	HC%	MC%	LC%	AC%
NR1	13/10/2002	Nlozok	616208.70	312745.60	RTP	CA	0	70	0	23.3
NR2	12/10/2002	Hevecam	617673.30	307881.70	RTP	CA	0	70	0	23.3
NR3	12/10/2002	Hevecam	622256.10	309058.70	RTP	CA	0	80	0	26.7
NR4	12/10/2002	Hevecam	621586.30	304981.40	RTP	CA	0	80	0	26.7
NR5	12/10/2002	Hevecam	621360.30	307856.80	RTP	CA	0	30	0	10.0
NR6	12/10/2002	Hevecam	618852.50	292974.80	RTP	CA	0	70	0	23.3
NR7	12/10/2002	Hevecam	618715.70	289043.10	RTP	CA	0	80	0	26.7
NR8	12/10/2002	Hevecam	617514.30	285541.70	RTP	CA	0	80	0	26.7
NR9	30/09/2002	Ipono	594175.60	258087.70	RTP	CA	0	90	0	30.0
NR10	11/10/2002	Zingui	634704.30	307711.00	RTP	CA	0	90	0	30.0
NR11	11/10/2002	Zingui	634313.30	307692.80	RTP	CA	0	90	0	30.0
NR12		Hevecam	618536.82	303725.79	RTP	CA	0	90	0	30.0
NR13		Hevecam	618931.61	303712.80	RTP	CA	0	90	0	30.0
NR14		Hevecam	613666.49	287760.30	RTP	CA	0	90	0	30.0
NR15		Hevecam	614488.56	288413.31	RTP	CA	0	90	0	30.0
NR16		Hevecam	613235.19	294010.34	RTP	CA	0	90	0	30.0
NR17		Hevecam	609745.13	294814.49	RTP	CA	0	90	0	30.0
NR18		Hevecam	626039.89	295878.38	RTP	CA	0	90	0	30.0
NR19		Hevecam	625106.24	297133.29	RTP	CA	0	90	0	30.0
NR20		Hevecam	622728.11	298073.26	RTP	CA	0	90	0	30.0
NR21		Hevecam	624418.45	302095.14	RTP	CA	0	90	0	30.0
NR22		Hevecam	624296.14	309620.37	RTP	CA	0	90	0	30.0
NR23		Hevecam	625052.70	310165.97	RTP	CA	0	90	0	30.0
NR24		Hevecam	617957.93	303329.44	RTP	CA	0	90	0	30.0
NR25		Hevecam	618634.70	305601.06	RTP	CA	0	90	0	30.0
NR26		Hevecam	611288.57	300757.13	RTP	CA	0	90	0	30.0
NR27	30/09/2002	Bibabimvoto	601167.30	261002.80	OF	FF	0	30	90	40.0
NR28	26/09/2002	Grand Batanga	598889.00	316120.00	OF	FF	0	5	100	35.0
NR29	13/10/2002	Nlozok	616565.40	315034.40	OF	FF	0	0	100	33.3
NR30	13/10/2002	Bidou III	613196.20	315056.00	OF	FF	0	0	90	30.0
NR31	13/10/2002	Bidou III	613021.00	314923.50	OF	FF	0	0	95	31.7
NR32	12/10/2002	Dougongomo	601695.00	315170.60	OF	FF	60	20	70	50.0
NR33	14/10/2002	Nlende	605177.50	321160.40	OF	FF	0	60	75	45.0
NR34	5/10/2002	Etonde FFng	592104.10	270937.40	OF	FF	10	70	70	50.0
NR35	13/10/2002	Nlende	606198.60	319859.60	OF	FF	0	30	80	36.7
NR36	13/10/2002	Lendi	607405.80	319307.70	OF	FF	0	0	100	33.3
NR37	29/09/2002	Mintom Centre	594212.00	262914.00	OF	FF	0	95	90	61.7
NR38	5/10/2002	Etonde Nigeria	592581.70	271200.60	OF	FF	0	0	80	26.7
NR39	30/09/2002	Bibabimvoto	601166.30	261005.90	OF	FF	0	30	80	36.7
NR40	6/10/2002	Dipikar Island	606293.80	249787.10	OF	FF	10	40	60	36.7
NR41	30/09/2002	Biba	597542.20	260305.50	OF	FF	0	70	60	43.3
NR42	30/09/2002	Ipono	594871.20	258002.90	OF	FF	0	10	90	33.3
NR43	30/09/2002	Bibabimvoto	601178.00	261270.80	OF	FF	0	50	70	40.0
NR44	4/10/2002	Bongola	606985.00	256944.00	OF	FF	0	20	60	26.7
NR45	27/09/2002	Boussibilinga II	598086.00	304428.00	OF	FF	0	85	80	55.0
NR46	30/09/2002	Ipono	594974.00	257938.00	OF	FF	0	0	100	33.3
NR47	26/09/2002	Nlende Bide	598556.40	307451.40	OF	FF	0	90	0	30.0

NR48	26/09/2002	Eboundja	600695.30	309414.50	OF	FF	0	0	100	33.3
NR49	10/10/2002		684596.00	308956.80	OF	FF	0	10	70	26.7
NR50	8/10/2002	Ebiameneyong	651624.80	267055.80	OF	FF	5	50	80	45.0
NR51	30/09/2002	Ipono	595320.80	260229.20	OF	FF	0	20	80	33.3
NR52	7/10/2002	CMNP	625502.80	261559.10	OF	FF	20	10	70	33.3
NR53	25/09/2002	Dougongomo	602457.00	312785.00	OF	FF	60	20	70	50.0
NR54	25/09/2002	Lobe	600894.00	316323.00	OF	FF	0	0	95	31.7
NR55	26/09/2002	Eboundja	600813.00	309604.00	OF	FF	0	0	90	30.0
NR56	26/09/2002	Eboundja	600302.00	309829.00	OF	FF	0	0	100	33.3
NR57	11/10/2002	Efoulan I	641612.70	306581.30	OF	FF	0	0	100	33.3
NR58	10/10/2002	AFFn	704801.00	290889.00	OF	FF	0	0	100	33.3
NR59	4/10/2002	Bibabimvoto	600359.00	259042.00	OF	FF	0	60	60	40.0
NR60	26/09/2002	Eboundja	599944.00	311221.00	OF	FF	30	80	10	40.0
NR61	26/09/2002	Eboundja	599682.00	310765.00	OF	FF	0	0	90	30.0
NR62	25/09/2002	Lobe	599644.00	317577.00	SC	SCF	n.a	n.a	n.a	n.a
NR63	14/10/2002	Bidou I	608934.10	316939.80	SC	SCF	n.a	n.a	n.a	n.a
NR64	12/10/2002	Hevecam	617517.30	302543.40	SC	SCF	n.a	n.a	n.a	n.a
NR65	28/09/2002	Ebodje	592069.10	283069.50	SC	SCF	n.a	n.a	n.a	n.a
NR66	27/09/2002	Boussibilinga II	597259.00	301737.00	SC	SCF	n.a	n.a	n.a	n.a
NR67	26/09/2002	Eboundja	599792.00	311267.00	SC	SCF	n.a	n.a	n.a	n.a
NR68			603046.26	319135.92	SC	SCF	n.a	n.a	n.a	n.a
NR69			602554.60	319196.09	SC	SCF	n.a	n.a	n.a	n.a
NR70			602097.58	320369.27	SC	SCF	n.a	n.a	n.a	n.a
NR71			602219.67	322497.42	SC	SCF	n.a	n.a	n.a	n.a
NR72			603742.79	322316.27	SC	SCF	n.a	n.a	n.a	n.a
NR73			604501.17	321684.42	SC	SCF	n.a	n.a	n.a	n.a
NR74			609119.12	316733.61	SC	SCF	n.a	n.a	n.a	n.a
NR75			608929.70	316667.39	SC	SCF	n.a	n.a	n.a	n.a
NR76			611819.49	315240.95	SC	SCF	n.a	n.a	n.a	n.a
NR77			613160.25	315236.27	SC	SCF	n.a	n.a	n.a	n.a
NR78			614101.43	314119.10	SC	SCF	n.a	n.a	n.a	n.a
NR79			614215.42	314021.03	SC	SCF	n.a	n.a	n.a	n.a
NR80			616241.52	313800.48	SC	SCF	n.a	n.a	n.a	n.a
NR81			616255.77	313997.13	SC	SCF	n.a	n.a	n.a	n.a
NR82			616381.49	313523.61	SC	SCF	n.a	n.a	n.a	n.a
NR83			619074.58	314160.31	SC	SCF	n.a	n.a	n.a	n.a
NR84			619462.44	313860.32	SC	SCF	n.a	n.a	n.a	n.a
NR85			620166.03	314067.42	SC	SCF	n.a	n.a	n.a	n.a
NR86			620368.86	313733.55	SC	SCF	n.a	n.a	n.a	n.a
NR87			620727.99	311970.95	SC	SCF	n.a	n.a	n.a	n.a
NR88			592744.17	280180.72	SC	SCF	n.a	n.a	n.a	n.a
NR89			593367.75	277892.63	SC	SCF	n.a	n.a	n.a	n.a
NR90			592406.66	277354.30	SC	SCF	n.a	n.a	n.a	n.a
NR91			591994.41	273407.88	SC	SCF	n.a	n.a	n.a	n.a
NR92			592722.73	259869.85	SC	SCF	n.a	n.a	n.a	n.a
NR93			593136.77	259826.27	SC	SCF	n.a	n.a	n.a	n.a
NR94			592571.86	260333.55	SC	SCF	n.a	n.a	n.a	n.a
NR95	6/10/2002	Lobe	595597.00	253454.00	DF	OT	0	30	0	10.0
NR96	13/10/2002	Kilombo I	606786.80	309504.70	DF	OT	0	5	30	11.7
NR97	13/10/2002	Kilombo I	606787.80	309508.40	DF	OT	0	5	30	11.7
NR98	13/10/2002	Wjima	610196.10	315654.80	DF	OT	80	0	80	53.3

NR99	14/10/2002	Nlende	605582.60	320488.00	DF	OT	0	30	80	36.7
NR100	12/10/2002	Ngock	634504.90	297810.00	DF	OT	0	10	100	36.7
NR101	12/10/2002	Hevecam	615598.60	304419.00	DF	OT	0	30	100	43.3
NR102	28/09/2002	Ebodje Beyo	593508.90	290551.60	DF	OT	0	70	5	25.0
NR103	5/10/2002	Melabe	593647.80	272124.60	DF	OT	0	70	10	26.7
NR104	11/10/2002	Elon	638527.60	309713.10	DF	OT	0	60	70	43.3
NR105	29/09/2002	Mintom Biba	599209.10	266248.40	DF	CON	20	70	30	40.0
NR106	6/10/2002	Lobe	615672.00	276010.00	DF	CON	20	70	30	40.0
NR107	7/10/2002	Road to Nkoelon	628552.00	262161.00	DF	CON	20	70	30	40.0
NR108	7/10/2002	CMNP	608950.00	263347.00	DF	SL	0	40	60	33.3
NR109	7/10/2002	Road to Nkoelon	623966.00	263121.00	DF	SL	50	40	10	33.3
NR110	7/10/2002	CMNP	606092.00	261087.00	DF	SL	0	50	30	26.7
NR111	26/10/2002	Eboundja	601404.60	310106.20	DF	OT	0	60	40	33.3
NR112			612477.35	273743.94	DF	OT	0	60	40	33.3
NR113			612616.70	250393.04	DF	SL	10	70	15	31.7
NR114			624053.79	239295.77	DF	OT	10	40	20	23.3
NR115			620513.47	251847.84	DF	OT	10	40	30	26.7
NR116			631027.16	252598.82	DF	CON	0	70	40	36.7
NR117			635211.18	247985.67	DF	OT	60	40	50	50.0
NR118			646188.78	270246.85	DF	CON	60	0	50	36.7
NR119			646027.81	269837.83	DF	CON	50	30	10	30.0
NR120			646879.37	268939.34	DF	OT	30	60	10	33.3
NR121			647348.73	270273.67	DF	CON	0	70	30	33.3
NR122	13/10/2002	Kilombo II	611253.40	308923.10	DF	CON	50	30	10	30.0
NR123	29/09/2002	Mintom Biba	597806.00	259938.00	DF	CON	65	20	30	38.3
NR124	30/09/2002	Mintom	595522.00	263745.00	DF	CON	40	30	60	43.3
NR125	14/10/2002	Lobe	611400.50	292862.00	RTP	CON	35	70	70	58.3
NR126	14/10/2002	Lobe	611638.50	293041.80	RTP	CON	40	60	30	43.3
NR127	8/10/2002	Abang II	654816.50	272676.70	DF	OT	0	70	60	43.3
NR128	6/10/2002	Mabiogo	596676.30	251909.90	DF	OT	30	50	20	33.3
NR129	6/10/2002	Mabiogo	596469.70	252149.90	DF	CON	60	50	5	38.3
NR130	6/10/2002	Dipikar Island	605706.90	252359.30	DF	CON	55	50	15	40.0
NR131	5/10/2002	Melabe	598005.40	275018.60	DF	OT	0	60	40	33.3
NR132	5/10/2002	Melabe	594285.90	275504.60	DF	SL	30	60	30	40.0
NR133	30/09/2002	Nyamelande	595849.30	256504.50	DF	SL	30	70	10	36.7
NR134	4/10/2002	Bongola	606404.60	252980.20	DF	SL	30	70	20	40.0
NR135	27/09/2002	Boussibilinga II	601110.90	304322.00	DF	SL	30	70	10	36.7
NR136	27/09/2002	Boussibilinga II	598739.60	304581.60	DF	SL	30	70	20	40.0
NR137	27/09/2002	Boussibilinga II	598739.60	304581.60	DF	SL	30	70	20	40.0
NR138	27/09/2002	Bebera	597231.80	300091.90	DF	SL	30	70	20	40.0
NR139	28/09/2002	Ebodje	594734.70	282421.20	DF	SL	30	70	20	40.0
NR140	28/09/2002	Agok	600386.20	285266.80	DF	SL	30	70	20	40.0
NR141	5/10/2002	Etonde Nigeria	591270.50	272501.60	DF	SL	30	70	10.00	36.7
NR142	27/09/2002	Boussibilinga II	597577.00	301320.00	DF	SL	30	70	20	40.0
NR143	28/09/2002	Lolabe	596654.80	292057.20	DF	SL	30	70	30	43.3
NR144	28/09/2002	Lolabe	596664.10	292024.70	DF	SL	30	70	10	36.7
NR145	29/09/2002	Ipono	594281.20	259409.10	DF	SL	30	70	10	36.7
NR146	4/10/2002	Bibabimvoto	604183.00	258262.00	DF	SL	30	70	10	36.7
NR147	30/09/2002	Ipono	Bare soil	timber park	BP	SL	0.00	0.00	0	0.0
NR148	5/10/2002	Etonde FFng	594405.00	268597.00	OF	FF	0	0	100	33.3
NR149	13/10/2002	SOCAPALM	605531.90	318833.30	BP	RS	0	0	0	0.0

NR150	14/10/2002	SOCAPALM	608878.70	316162.70	BP	RS	0	0	0	0.0
NR151	14/10/2002	SOCAPALM	608901.10	316170.90	BP	RS	0	0	0	0.0
NR152	26/09/2002	Grand Batanga I	598590.00	315298.00	BP	RS	0	0	0	0.0
NR153			591511.98	260906.79	BP	BS	0	0	0	0.0
NR154			592083.60	260581.29	BP	BS	0	0	0	0.0
NR155			591476.78	261660.89	BP	BS	0	0	0	0.0
NR156			593348.83	266456.61	BP	BS	0	0	0	0.0
NR157			610470.94	316074.64	BP	BS	0	0	0	0.0
NR158			612695.22	315511.64	BP	BS	0	0	0	0.0
NR159			613143.66	315503.78	BP	BS	0	0	0	0.0
NR160			613949.78	315480.31	BP	BS	0	0	0	0.0
NR161			608519.49	317541.76	OF	FF	30	80	10	40.0
NR162			601471.99	323377.37	BP	BS	0	0	0	0.0
NR163			600176.99	321988.51	OF	FF	30	80	10	40.0
NR164			600843.02	320392.84	BP	BS	0	0	0	0.0
NR165			600150.09	316988.27	BP	BS	0	0	0	0.0
NR166			599498.92	309410.64	BP	BS	0	0	0	0.0
NR167			598289.15	307314.67	OF	FF	30	80	10	40.0
NR168			597904.09	306381.87	OF	FF	30	80	10	40.0
NR169			597806.45	304128.00	OF	FF	30	80	10	40.0
NR170			597933.95	304580.81	OF	FF	30	80	10	40.0
NR171			597032.12	301854.71	OF	FF	30	80	10	40.0
NR172			597303.75	302004.54	OF	FF	30	80	10	40.0
NR173			597089.88	295848.47	OF	FF	30	80	10	40.0
NR174			595772.39	293749.61	OF	FF	30	80	10	40.0
NR175	14/10/2002	SOCAPALM	606818.80	318262.50	PTP	CA	0	80	0	26.7
NR176	13/10/2002	Kilombo II	610322.80	303192.20	PTP	CA	0	0	20	6.7
NR177	13/10/2002	Kilombo II	610825.90	304048.70	PTP	CA	0	0	20	6.7
NR178	13/10/2002	Kilombo II	605259.00	305049.00	PTP	CA	0	0	20	6.7
NR179	13/10/2002	Kilombo II	605243.10	305063.60	PTP	CA	0	0	50	16.7
NR180	13/10/2002	Wjima	609838.40	313429.60	PTP	CA	0	80	0	26.7
NR181	13/10/2002	Wjima	610444.20	313780.70	PTP	CA	0	80	0	26.7
NR182	13/10/2002	Wjima	610301.20	314307.90	PTP	CA	0	80	0	26.7
NR183		Wjima	607347.18	302908.47	PTP	CA	0	80	0	26.7
NR184		Wjima	607756.19	304008.12	PTP	CA	0	80	0	26.7
NR185		Wjima	608748.55	303961.18	PTP	CA	0	80	0	26.7
NR186		Wjima	609432.48	302767.66	PTP	CA	0	80	0	26.7
NR187		Wjima	606334.51	307444.32	PTP	CA	0	80	0	26.7
NR188		Wjima	607531.11	308754.13	PTP	CA	0	80	0	26.7
NR189		Wjima	607191.89	312410.60	PTP	CA	0	80	0	26.7
NR190		Wjima	608624.38	312343.29	PTP	CA	0	80	0	26.7
NR191		Wjima	609066.92	312142.13	PTP	CA	0	80	0	26.7
NR192		Wjima	609791.07	312584.67	PTP	CA	0	80	0	26.7
NR193		Wjima	603601.17	318239.92	PTP	CA	0	80	0	26.7
NR194		Wjima	603923.02	319218.87	PTP	CA	0	80	0	26.7
NR195		Wjima	605720.00	317354.84	PTP	CA	0	80	0	26.7
NR196		Wjima	605827.28	315571.26	PTP	CA	0	80	0	26.7
NR197		Wjima	605720.00	314818.66	PTP	CA	0	80	0	26.7
NR198		Wjima	605746.82	317554.36	PTP	CA	0	80	0	26.7
NR199		Wjima	605698.03	317297.20	PTP	CA	0	80	0	26.7
NR200		Wjima	607642.90	307377.35	PTP	CA	0	80	0	26.7

Appendix 5b: Floristic composition

plot ID	UTME	UTMN	*Dorminant tree species*		
NR1	616208.70	312745.60	*Hevea brasilensis*		
NR2	617673.30	307881.70	*Elaeis guineensis*		
NR3	622256.10	309058.70	*Hevea brasilensis*		
NR4	621586.30	304981.40	*Hevea brasilensis*		
NR5	621360.30	307856.80	*Hevea brasilensis*		
NR6	618852.50	292974.80	*Hevea brasilensis*		
NR7	618715.70	289043.10	*Hevea brasilensis*		
NR8	617514.30	285541.70	*Hevea brasilensis*		
NR9	594175.60	258087.70	*Hevea brasilensis*		
NR10	634704.30	307711.00	*Hevea brasilensis*		
NR11	634313.30	307692.80	*Hevea brasilensis*		
NR12	618536.82	303725.79	*Hevea brasilensis*		
NR13	618931.61	303712.80	*Hevea brasilensis*		
NR14	613666.49	287760.30	*Hevea brasilensis*		
NR15	614488.56	288413.31	*Hevea brasilensis*		
NR16	613235.19	294010.34	*Hevea brasilensis*		
NR17	609745.13	294814.49	*Hevea brasilensis*		
NR18	626039.89	295878.38	*Hevea brasilensis*		
NR19	625106.24	297133.29	*Hevea brasilensis*		
NR20	622728.11	298073.26	*Hevea brasilensis*		
NR21	624418.45	302095.14	*Hevea brasilensis*		
NR22	624296.14	309620.37	*Hevea brasilensis*		
NR23	625052.70	310165.97	*Hevea brasilensis*		
NR24	617957.93	303329.44	*Hevea brasilensis*		
NR25	618634.70	305601.06	*Hevea brasilensis*		
NR26	611288.57	300757.13	*Hevea brasilensis*		
NR27	601167.30	261002.80	*Harungana madagascariensis*	*Musanga cercropoides*	*Anthocleista schweinfurthii*
NR28	598889.00	316120.00	*Musanga cercropoides*	*Macaranga spinosa*	*Anthocleista schweinfurthii*
NR29	616565.40	315034.40	*Alchornea cordifolia*	*Chromolaena odorata*	*Macaranga spinosa*
NR30	613196.20	315056.00	*Harungana madagascariensis*	*Macaranga spinosa*	*Anthocleista schweinfurthii*
NR31	613021.00	314923.50	*Harungana madagascariensis*	*Macaranga spinosa*	*Anthocleista schweinfurthii*
NR32	601695.00	315170.60	*Pycnanthus angolensis*	*Uapaca guineensis*	*Albizia adianthifolia*
NR33	605177.50	321160.40	*Harugana madagascariensis*	*Uapaca guineensis*	*Anthocleista schweinfurthii*
NR34	592104.10	270937.40	*Gilbertiodendron dewevrei*	*Scyphocephalium mannii*	*Symphonia globulifera*
NR35	606198.60	319859.60	*Albizia zygia*	*Musanga cercropoides*	*Xylopia aethiopica*
NR36	607405.80	319307.70	*Chromolaena odorata*		
NR37	594212.00	262914.00	*Harugana madagascariensis*	*Musanga cercropoides*	*Chromolaena odorata*
NR38	592581.70	271200.60	*Alchornea cordifolia*	*Musanga cercropoides*	*Macaranga spinosa*
NR39	601166.30	261005.90	*Harungana madagascariensis*	*Musanga cercropoides*	*Macaranga spinosa*
NR40	606293.80	249787.10	*Musanga cercropoides*	*Calpocalyx heitzii*	*Anthocleista schweinfurthii*
NR41	597542.20	260305.50	*Uapaca sp*	*Alchornea floribunda*	*Lacosperma secundiflorum*
NR42	594871.20	258002.90	*Musanga cercropoides*	*Chromolaena odorata*	*Alchornea cordifolia*
NR43	601178.00	261270.80	*Anthocleista schweinfurthii*	*Macaranga spinosa*	*Harungana madagascariensis*
NR44	606985.00	256944.00	*Musanga cercropoides*	*Calpocalyx heitzii*	*Harungana madagascariensis*
NR45	598086.00	304428.00	*Erythrophleum ivorensis*	*Musanga cercropoides*	*Sacoglottis gabonensis*
NR46	594974.00	257938.00	*Alchornea cordifolia*	*Chromolaena odorata*	
NR47	598556.40	307451.40	*Macaranga spinosa*	*Anthocleista schwein-furthii*	*Harungana madagascariensis*
NR48	600695.30	309414.50	*Macaranga spinosa*		

NR49	684596.00	308956.80	*Chromolaena odorata*	*Anthocleista schwein-furthii*	*Harungana madagascariensis*
NR50	651624.80	267055.80	*Anthocleista schweinfurthii*	*Caloncoba glauca*	*Pycnanthus angolensis*
NR51	595320.80	260229.20	*Harungana madagascariensis*	*Musanga cercropoides*	*Lacosperma secundiflorum*
NR52	625502.80	261559.10	*Erythrophleum ivorensis*	*Lophira alata*	*Calpocalyx heitzii*
NR53	602457.00	312785.00	*Pycnanthus angolensis*	*Uapaca guineensis*	*Albizia adianthifolia*
NR54	600894.00	316323.00	*Chromolaena odorata*	*Anthocleista schwein-furthii*	*Triumferta cordifolia*
NR55	600813.00	309604.00	*Musanga cercropoides*	*Macaranga spinosa*	*Harungana madagascariensis*
NR56	600302.00	309829.00	*Macaranga spinosa*	*Anthocleista schwein-furthii*	
NR57	641612.70	306581.30	*Chromolaena odorata*	*Alchornea cordifolia*	*Triumferta cordifolia*
NR58	704801.00	290889.00	*Chromolaena odorata*		
NR59	600359.00	259042.00	*Musanga cercropoides*	*Macaranga spinosa*	*Harungana madagascariensis*
NR60	599944.00	311221.00	*Musanga cercropoides*	*Macaranga spinosa*	*Harungana madagascariensis*
NR61	599682.00	310765.00	*Macaranga spinosa*	*Alchornea cordifolia*	*Anthocleista schweinfurthii*
NR62	599644.00	317577.00	*n.a*		
NR63	608934.10	316939.80	*n.a*		
NR64	617517.30	302543.40	*n.a*		
NR65	592069.10	283069.50	*n.a*		
NR66	597259.00	301737.00	*n.a*		
NR67	599792.00	311267.00	*n.a*		
NR68	603046.26	319135.92	*n.a*		
NR69	602554.60	319196.09	*n.a*		
NR70	602097.58	320369.27	*n.a*		
NR71	602219.67	322497.42	*n.a*		
NR72	603742.79	322316.27	*n.a*		
NR73	604501.17	321684.42	*n.a*		
NR74	609119.12	316733.61	*n.a*		
NR75	608929.70	316667.39	*n.a*		
NR76	611819.49	315240.95	*n.a*		
NR77	613160.25	315236.27	*n.a*		
NR78	614101.43	314119.10	*n.a*		
NR79	614215.42	314021.03	*n.a*		
NR80	616241.52	313800.48	*n.a*		
NR81	616255.77	313997.13	*n.a*		
NR82	616381.49	313523.61	*n.a*		
NR83	619074.58	314160.31	*n.a*		
NR84	619462.44	313860.32	*n.a*		
NR85	620166.03	314067.42	*n.a*		
NR86	620368.86	313733.55	*n.a*		
NR87	620727.99	311970.95	*n.a*		
NR88	592744.17	280180.72	*n.a*		
NR89	593367.75	277892.63	*n.a*		
NR90	592406.66	277354.30	*n.a*		
NR91	591994.41	273407.88	*n.a*		
NR92	592722.73	259869.85	*n.a*		
NR93	593136.77	259826.27	*n.a*		
NR94	592571.86	260333.55	*n.a*		
NR95	595597.00	253454.00	*Rhizophora racemosa*		
NR96	606786.80	309504.70	*Alchornea cordifolia*	*Macaranga spinosa*	

NR97	606787.80	309508.40	*Parkia bicolor*	*Macaranga spinosa*	*Anthocleista schweinfurthii*
NR98	610196.10	315654.80	*Hallea stipulosa*	*Lacosperma secundiflo-rum*	
NR99	605582.60	320488.00	*Raphia hookerii*	*Uapaca guineensis*	*Zanthoxyllum heitzii*
NR100	634504.90	297810.00	*Musanga cercropoides*	*Zanthoxyllum heitzi*	
NR101	615598.60	304419.00	*Coeloncaryon preussii*		
NR102	593508.90	290551.60	*Rhizophora racemosa*	*Manikara lacera*	
NR103	593647.80	272124.60	*Hallea stipulosa*	*Raphia*	*Coeloncaryon preussi*
NR104	638527.60	309713.10	*Uapaca guineensis*	*Pycnanthus angolensis*	*Potherandia micrantha*
NR105	599209.10	266248.40	*Uapaca guineensis*	*Pycnanthus angolensis*	*Potherandia micrantha*
NR106	615672.00	276010.00	*Uapaca guineensis*	*Pycnanthus angolensis*	*Potherandia micrantha*
NR107	628552.00	262161.00	*Uapaca guineensis*	*Pycnanthus angolensis*	*Potherandia micrantha*
NR108	608950.00	263347.00	*Uapaca guineensis*	*Sacoglottis gabonensis*	*Coeloncaryon preussi*
NR109	623966.00	263121.00	*Pterocarpus soyauxii*	*Erythrophleum ivorensis*	*Coula edulis*
NR110	606092.00	261087.00	*Canarium schweinfurthii*	*Sacoglottis gabonensis*	
NR111	601404.60	310106.20	*Coula edulis*	*Lophira alata*	
NR112	612477.35	273743.94	*Coula edulis*	*Lophira alata*	
NR113	612616.70	250393.04	*Scorodophleus zenkerii*	*Piptadeniastrum afri-canum*	*Erythrophleum ivorensis*
NR114	624053.79	239295.77	*Desbordesia glaucescens*	*Piptadeniastrum afri-canum*	*Sacoglottis gabonensis*
NR115	620513.47	251847.84	*Desbordesia glaucescens*	*Piptadeniastrum afri-canum*	*Aphanocalyx cymetroides*
NR116	631027.16	252598.82	*Desbordesia glaucescens*	*Calpocalyx heitzii*	*Lophira alata*
NR117	635211.18	247985.67	*Sacoglottis gabonensis*	*Calpocalyx heitzii*	*Erythrophleum ivorensis*
NR118	646188.78	270246.85	*Sacoglottis gabonensis*	*Desbordesia glaucescens*	*Coula edulis*
NR119	646027.81	269837.83	*Pycnanthus angolensis*	*Stuadtia Kamerunensis*	
NR120	646879.37	268939.34	*Erythrophleum ivorensis*	*Calpocalyx heitzii*	*Pycnanthus angolensis*
NR121	647348.73	270273.67	*Lophira alata*	*Sacoglottis gabonensis*	*Pycnanthus angolensis*
NR122	611253.40	308923.10	*Pycnanthus angolensis*	*Coeloncaryon preussii*	*Pterocapus soyauxii*
NR123	597806.00	259938.00	*Uapaca guineensis*	*Lophira alata*	*Sacoglottis gabonensis*
NR124	595522.00	263745.00	*Pycnanthus angolensis*	*Tetraberlinia bifoliata*	*Aphanocalyx cymetroides*
NR125	611400.50	292862.00	*Sacoglottis gabonensis*	*Desbordesia glaucescens*	*Piptadeniastrum africanum*
NR126	611638.50	293041.80	*Sacoglottis gabonensis*	*Desbordesia glaucescens*	*Pycnanthus angolensis*
NR127	654816.50	272676.70	*Erythrophleum ivorensis*	*Dialium pachyphyllum*	*Coeloncaryon preussi*
NR128	596676.30	251909.90	*Pycnanthus angolensis*	*Sacoglottis gabonensis*	*Desbordesia glaucescens*
NR129	596469.70	252149.90	*Sacoglottis gabonensis*	*Dialium dinklagei*	*Tetraberlinia bifoliata*
NR130	605706.90	252359.30	*Sacoglottis gabonensis*	*Dialium dinklagei*	*Tetraberlinia bifoliata*
NR131	598005.40	275018.60	*Eribroma oblonga*	*Uapaca guineensis*	*Terminalia superba*
NR132	594285.90	275504.60	*Sacoglottis gabonensis*	*Desbordesia glaucescens*	*Calpocalyx heitzii*
NR133	595849.30	256504.50	*Eribroma oblonga*	*Uapaca guineensis*	*Terminalia superba*
NR134	606404.60	252980.20	*Sacoglottis gabonensis*	*Desbordesia glaucescens*	*Calpocalyx heitzii*
NR135	601110.90	304322.00	*Sacoglottis gabonensis*	*Desbordesia glaucescens*	*Calpocalyx heitzii*
NR136	598739.60	304581.60	*Sacoglottis gabonensis*	*Desbordesia glaucescens*	*Calpocalyx heitzii*
NR137	598739.60	304581.60	*Sacoglottis gabonensis*	*Desbordesia glaucescens*	*Calpocalyx heitzii*
NR138	597231.80	300091.90	*Sacoglottis gabonensis*	*Desbordesia glaucescens*	*Calpocalyx heitzii*
NR139	594734.70	282421.20	*Sacoglottis gabonensis*	*Desbordesia glaucescens*	*Calpocalyx heitzii*
NR140	600386.20	285266.80	*Sacoglottis gabonensis*	*Desbordesia glaucescens*	*Calpocalyx heitzii*
NR141	591270.50	272501.60	*Sacoglottis gabonensis*	*Desbordesia glaucescens*	*Calpocalyx heitzii*
NR142	597577.00	301320.00	*Sacoglottis gabonensis*	*Desbordesia glaucescens*	*Calpocalyx heitzii*
NR143	596654.80	292057.20	*Sacoglottis gabonensis*	*Desbordesia glaucescens*	*Calpocalyx heitzii*

NR144	596664.10	292024.70	*Sacoglottis gabonensis*	*Desbordesia glaucescens*	*Calpocalyx heitzii*
NR145	594281.20	259409.10	*Sacoglottis gabonensis*	*Desbordesia glaucescens*	*Calpocalyx heitzii*
NR146	604183.00	258262.00	*Sacoglottis gabonensis*	*Desbordesia glaucescens*	*Calpocalyx heitzii*
NR147	Bare soil	timber park	*n.a*		
NR148	594405.00	268597.00	*Alchornea cordifolia*	*Chromolaena odorata*	
NR149	605531.90	318833.30	*n.a*		
NR150	608878.70	316162.70	*n.a*		
NR151	608901.10	316170.90	*n.a*		
NR152	598590.00	315298.00	*n.a*		
NR153	591511.98	260906.79	*n.a*		
NR154	592083.60	260581.29	*n.a*		
NR155	591476.78	261660.89	*n.a*		
NR156	593348.83	266456.61	*n.a*		
NR157	610470.94	316074.64	*n.a*		
NR158	612695.22	315511.64	*n.a*		
NR159	613143.66	315503.78	*n.a*		
NR160	613949.78	315480.31	*n.a*		
NR161	608519.49	317541.76	*Musanga cercropoides*	*Macaranga spinosa*	*Harungana madagascariensis*
NR162	601471.99	323377.37	*n.a*		
NR163	600176.99	321988.51	*Musanga cercropoides*	*Macaranga spinosa*	*Harungana madagascariensis*
NR164	600843.02	320392.84	*n.a*		
NR165	600150.09	316988.27	*n.a*		
NR166	599498.92	309410.64	*n.a*		
NR167	598289.15	307314.67	*Musanga cercropoides*	*Macaranga spinosa*	*Harungana madagascariensis*
NR168	597904.09	306381.87	*Musanga cercropoides*	*Macaranga spinosa*	*Harungana madagascariensis*
NR169	597806.45	304128.00	*Musanga cercropoides*	*Macaranga spinosa*	*Harungana madagascariensis*
NR170	597933.95	304580.81	*Musanga cercropoides*	*Macaranga spinosa*	*Harungana madagascariensis*
NR171	597032.12	301854.71	*Musanga cercropoides*	*Macaranga spinosa*	*Harungana madagascariensis*
NR172	597303.75	302004.54	*Musanga cercropoides*	*Macaranga spinosa*	*Harungana madagascariensis*
NR173	597089.88	295848.47	*Musanga cercropoides*	*Macaranga spinosa*	*Harungana madagascariensis*
NR174	595772.39	293749.61	*Musanga cercropoides*	*Macaranga spinosa*	*Harungana madagascariensis*
NR175	606818.80	318262.50	*Elaeis guineensis*		
NR176	610322.80	303192.20	*Elaeis guineensis*		
NR177	610825.90	304048.70	*Elaeis guineensis*		
NR178	605259.00	305049.00	*Elaeis guineensis*		
NR179	605243.10	305063.60	*Elaeis guineensis*		
NR180	609838.40	313429.60	*Elaeis guineensis*		
NR181	610444.20	313780.70	*Elaeis guineensis*		
NR182	610301.20	314307.90	*Elaeis guineensis*		
NR183	607347.18	302908.47	*Elaeis guineensis*		
NR184	607756.19	304008.12	*Elaeis guineensis*		
NR185	608748.55	303961.18	*Elaeis guineensis*		
NR186	609432.48	302767.66	*Elaeis guineensis*		
NR187	606334.51	307444.32	*Elaeis guineensis*		
NR188	607531.11	308754.13	*Elaeis guineensis*		
NR189	607191.89	312410.60	*Elaeis guineensis*		
NR190	608624.38	312343.29	*Elaeis guineensis*		
NR191	609066.92	312142.13	*Elaeis guineensis*		
NR192	609791.07	312584.67	*Elaeis guineensis*		
NR193	603601.17	318239.92	*Elaeis guineensis*		
NR194	603923.02	319218.87	*Elaeis guineensis*		

NR195	605720.00	317354.84	*Elaeis guineensis*		
NR196	605827.28	315571.26	*Elaeis guineensis*		
NR197	605720.00	314818.66	*Elaeis guineensis*		
NR198	605746.82	317554.36	*Elaeis guineensis*		
NR199	605698.03	317297.20	*Elaeis guineensis*		
NR200	607642.90	307377.35	*Elaeis guineensis*		

Appendix 5c: Field data sheet

Sheet Header

Sam #………… Plot #………… Plot size…………….. Date………
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Alt………Slope…..….Aspect………….. (UTM) N………...….E……….…… Location…………..…….
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Observers………………………………………………………………………..

Site description

Cover type	Land use	Structure	E.Cover %	E. Ht
		High tree layers		
		Medium tree layer		
		Low tree layer		
Humidity				
Additional info				

Plot data Trees> 10cm dbh

Species Scientific name	Local /common name	DBH		Number of Individuals	Seedlings cover % 1-2 m	Seedlings cover % 2-4m