PART I. SUMMARY AND ABSTRACT FORM

1) Title

Using High-Definition Satellite Imagery to Assess the Loss of Ecotone Habitats in the Congo Basin

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22,620.00

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None

7) Abstract

The transition zone between forest and savanna (ecotone) in Central Africa plays an important role in biological divergence and likely speciation. This region is a dynamic habitat mosaic that is influenced by both anthropogenic impacts, such as forest conversion to agriculture, logging, fire, and the introduction of exotic species, and environmental factors including historic and current climate, soils and geomorphology. The main objective of this study is to understand the characteristics of changes in the ecotone region by using remote sensing and mapping techniques. We used high-resolution radar data and multitemporal Landsat images to measure the rate and the characteristics of changes of the ecotone vegetation in Cameroon.

PART II. MAIN PORTION OF TECHNICAL REPORT

1) Original Objectives

The original objective was to use satellite imagery to measure the rate of loss and degradation of ecotone habitats surrounding the Guinea-Congo rainforest block using radar image data collected since 1992, and optical data gathered since the 1970's (Landsat TM).

2) Project Results

BACKGROUND

The junction between forest and savanna vegetation types in west and central Africa marks the boundary separating two structurally and floristically different types of vegetation. The ecotone is formed by long-term and large-scale historical climate changes and a more recent shorter-term and smaller scale anthropic intervention by burning and agricultural practices (Longman and Jenik 1992). In addition to climate and anthropic factors, soil and geomorphology are other factors that influence the species composition and communities in this region (Backéus 1992). At a local level, both current and historical environmental and anthropogenic factors interact to influence the dynamics of the forest-savanna ecotone in the West and Central African lowlands. A major change in forest communities and forest extent in this region occurred during an arid event between 3000-2500 BP or, as extended as 4200-1300 BP (Maley 1987, Maley 1991, Maley 1992, Maley 1996, Vincens et al. 1999). During this period, the forest contracted and the resulting forest configuration, at a gross level, is observed at present (Vincens et al. 1999). Nonetheless, the climate has become progressively wetter since this period, and currently many areas that are savanna should be able to support forest (Aubréville 1966). In general, areas with annual rainfall above 1200-1400 that falls during eight or more months of the year usually can support forest (Aubréville 1966, Happi 1998). In the ecotone region of Cameroon, rainfall is around 1400 (e.g., Bertoua 1584 mm; Bafia, 1480mm; Yoko, 1633mm) with 2-4 months when no rain falls. Though these data suggest that rainfall should be sufficient to support forest, soil water retention may also be an important factor influencing forest regeneration (Swain et al. 1976). A relationship has been observed between soil type and geomorphology and vegetation in several ecotone areas (Adejuwon 1971, Latham and Dugerdil 1970, Cole 1986, Swain et al. 1976). However, when soil type was overlaid with forest vegetation in the Cameroon ecotone little relationship was noted (Happi 1998). In summary, data on present and historical climate and other abiotic conditions indicate that current vegetation patterns reflect historical climate and not current climatic conditions; the role of other abiotic factors in shaping vegetation patterns is also important, but to a lesser extent.

Human activities, especially fire, likely have had a major impact on the maintenance of savanna, which limits forest regeneration into savanna habitats (Hori 1986, Boulvert 1990). Nonetheless, even though they have been present in the ecotone in Cameroon since between 7000-5500 BP (Clist 1990), humans are unlikely responsible for the vast land transformations that occurred in Cameroon and across Africa about 3000 B.P. (Vincens et al. 1999, Reynaud and Maley 1994, but see Boulvert 1990). As stated above, these changes were most likely caused by climate. However, humans have played an important role in maintaining savanna habitat. Without human influence, especially fire, forest regeneration into savanna would likely proceed at a faster rate (Menaut et al 1990, Miége 1966 but see Spichiger and Pamard 1973). For example, Happi (1998) found that areas with higher population densities had lower rates of forest regeneration. Forest regeneration has been detected in various sites across West and Central Africa (Happi 1998, Dauget and Menaut 1992, Gautier 1989, Boulvert 1990 and Schwartz et al. 1996b). In Cameroon, Happi (1998) compared remote-sensing data for a period of 40 years (1950-1990) and determined that forest was encroaching over the savanna landscape at a rate of 0.6 to 2 m a year.

Other anthropogenic factors influencing land-cover change in the ecotone include cutting of gallery forest for agriculture, thinning of forest for wood, and cattle grazing. Cutting of gallery forests for agriculture may lead to an extension of savanna and open areas, especially near towns. Cattle can penetrate into the gallery forests in the savanna landscape and alter the structure of the forest. Further, cattle and agriculture can lead to soil erosion, which may alter the suitability for open areas to be recolonized. Hence, a variety of anthropogenic factors interact to influence the vegetation in the ecotone in Cameroon.

Research conducted in Central Africa and Australia has found that transitional habitats (or ecotones) between rainforest and savanna or dry forest play an important role in divergence and likely speciation (Smith et al. 1997, Schnieder et al. 1999). However, ecotones are not as species rich as central rainforest areas. A top priority of conservation programs is the preservation of areas of high biodiversity. Implicit in this approach is the belief that, by preserving areas of high species diversity, the evolutionary and ecological processes that sustain biodiversity are also protected. Unfortunately, there is little scientific evidence to suggest that regions of high biodiversity, which are generally in the central rainforest, are the same regions were new species are generated. In fact, there is strong evidence that transitional habitats, such as ecotones (areas where two habitats, such as forest and savanna, meet), which lie outside the central rainforest, are areas of evolutionary dynamism (Smith et al. 1997, Smith et al. 2000). Thus, conservation efforts that focus solely on preserving areas of high biodiversity may inadvertently ignore regions where evolutionary novelty and innovation arise. In ecotone regions, such as in Cameroon, dynamic parameters such as the rate of loss of forest patches and gallery forests near villages and the rate of forest expansion in the ecotone region are poorly understood. The dynamic parameters also influence the structural characteritics of vegetation and the process of biomass and carbon accumulation or loss in these transitional regions.

Given the complex and dynamic nature of the ecotone and the biological and evolutionary importance of this area, we examined how land-cover has changed over the past 30 years over an area of the savanna-forest ecotone in central Cameroon. Our first evidence of changes of land cover and land use in Cameroon was from a recent study by Saatchi et al. (2000). In this study, the classification of radar images of 1995 and its comparison with existing vegetation maps of 1970s showed a major part of the evergreen and semi-deciduous forests of the southeastern Cameroon and areas of the ecotone have been either deforested or fragmented (Figure 1). However, there were also evidence of increased woodland and forest cover in the ecotone region of Cameroon (Saatchi et al., 2000). To validate these results, we used Landsat data from the mid-70's to the present to study the changes of land cover in areas suggested by the analysis of radar images.

The utility of these remote-sensing data to evaluate land-cover change has recognized by many scientists because in many regions satellite remote sensing may be the only feasible method to determine rates and potential causes of land-cover change (e.g., Saatchi et al. 1997; Guerra et al. 1998). The change detection methodology developed in this paper for Landsat data allows us to determine the existing land cover types and their changes over a period of 30 years. For the period of mid-90s where no Landsat images were available, we have used the land cover maps derived from radar images of 1995 to follow the changes of land cover types in the region. Given this background of information, our final objective in this study was to focus on the analysis of historical Landsat data over known sites in order understand the vegetation dynamics in the forest-savanna boundary.

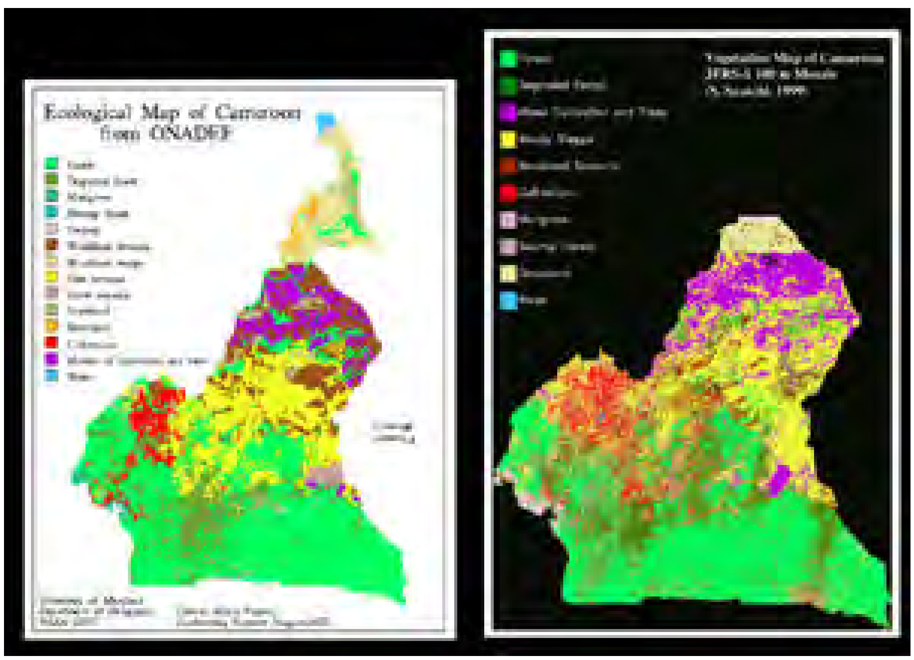


Figure 1. Comparison of radar based vegetation classification map (left) with the ecological map of Cameroon based on visual interpretation of 1970s Landsat images.

METHODOLOGY

Study Area

We chose an area of the ecotone northeast of Yaounde from approximately 5.0° N to 6.0° N latitude and from 11.0° E to 13.0° E longitude (Fig. 2a). This area is covered by Landsat scenes, which have partially cloud free data from the years 1973, 1980, and 2000. The study area includes the town of Tibati in the north, the Reserve de Faune de Pangar et Djerem in the east, and the Sanaga river to the town of Nanga Eboko in the south. According to the ONADEF Ecological Map of Cameroon, the study area falls in a region of forest, woodland savanna and tree savanna (Fig. 2b). The list of Landsat images acquired for the study area is given in Table 1. We chose this region because: 1) it represent a variety of habitats, 2) it includes both areas far from towns and roads where human influence is minimum and areas near human settlements where the ecosystem is affected by land use changes, and 3) there are available remote sensing and ground data. A closer look at the existing vegetation maps (Letouzey, 1968; ONADEF, 1990; Saatchi et al., 2000), shows that the region is covered by the extension of the Guineo-Congolian evergreen forests in its primary, degraded or secondary regeneration formations, gallery forests, woodland savanna with a variety of tree densities, grassland and shrubland savanna. The savannas in this region, stretching north of the semi-deciduous and evergreen forests, are believed to have been created due to the degradation of semi-deciduous forest by human during the recent past (Letouzey, 1968). The population density of this region, apart from the southern part, is sparse and far smaller than the northern savannas. In general, this zone is not used by cattle-rearers as permanent grazing land and only used during the dry seasons for cultivation.

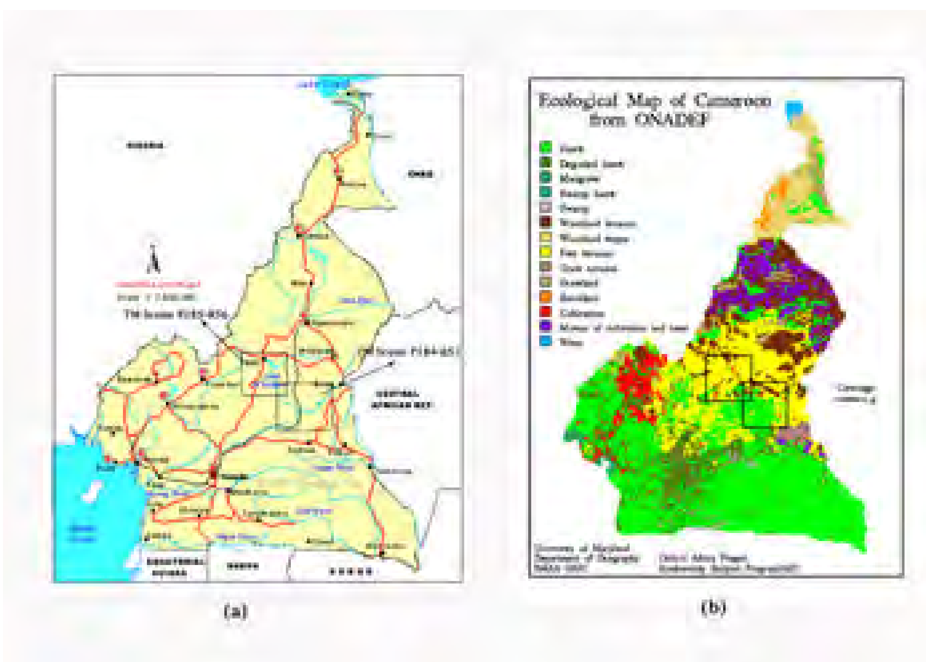


Figure 2. The location of study areas and the Landsat scenes on a) political map of Cameroon, and b) vegetation map of Cameroon.

Table 1. List of Landsat images used in this study.

Path/Row	Sensor	Date
184/56	MSS	1973
184/56	MSS	1977
184/56	MSS	1986
184/56	TM	2000
185/56	MSS	1973
185/56	MSS	1986
185/56	MSS	1986
185/56	TM	1989
185/56	TM	2000

Ground Survey

Based on a series of ground surveys by authors in April, 2000 and field notes compiled by our collaborators in the region, we described 9 vegetation types, which ranged from open savanna to closed gallery forest. The ground survey included three transects about 5 km long within forest-savanna boundary and also recording vegetation types along the roads. Two transects were conducted near the village of Garga Sarali on the road between Beroua and Ndokayo (Bétaré Oya). A third transect was taken north of Ndokayo near the town of Monbal on the road that goes to Garoua Boulai. We took a Geographic Position System (GPS) readings approximately every 500 meters along each transect. We also took GPS along the road between Bertoua and Bétaré Oya at various locations. At each point we described the vegetation and recorded the following data: vegetation height, vegetation cover, dominant plant species, grass or understory layer, and evidence of human activity (burning, cattle, wood extraction). We also took pictures to document the vegetation.

In most sites ground cover was low (<0.5 m; though this may be a seasonal phenomenon) and consisted of grasses or vines including: *Pennicetum* spp., *Emperatus landiga*, and *Chromolina eurdata.* The following is a list of class types with definitions that correspond with the pictures taken during the field survey and given in figure 3.

Burned savanna: recently burned areas with no vegetation and dark ashes.

Grass savanna: almost completely open grass cover.

Thick bush savanna: dense and low bush and shrubs (about 2-5 m in height) with about 70% cover.

Bush savanna: short, less than 5 m tall and in most cases 1 and 2 meters in height with a canopy cover of 30-40% and mixed species composition.

Open mixed wooded savanna: with vegetation height between 2 and 12 m and canopy cover of 5-30%.

Mixed wooded savanna: with vegetation between 2 and 10 m with a canopy cover of 30- 60%.

Closed mixed wooded savanna: tall vegetation with 5 and 12 m in height and a dense canopy cover of 60-90%.

Thick woodland: about 70% canopy cover and with 12 to 20 meters in height and with some scattered forest trees.

Regrowth /disturbed forest: disturbed forest with evidence of logging and many secondary tree species. Alternatively, this vegetation type can be considered regrowth or newly developing forest.

Dense & Gallery forests : dense humid forests and forests that occur in strips along streams or drainages with similar structural complexity as in continuous forest.

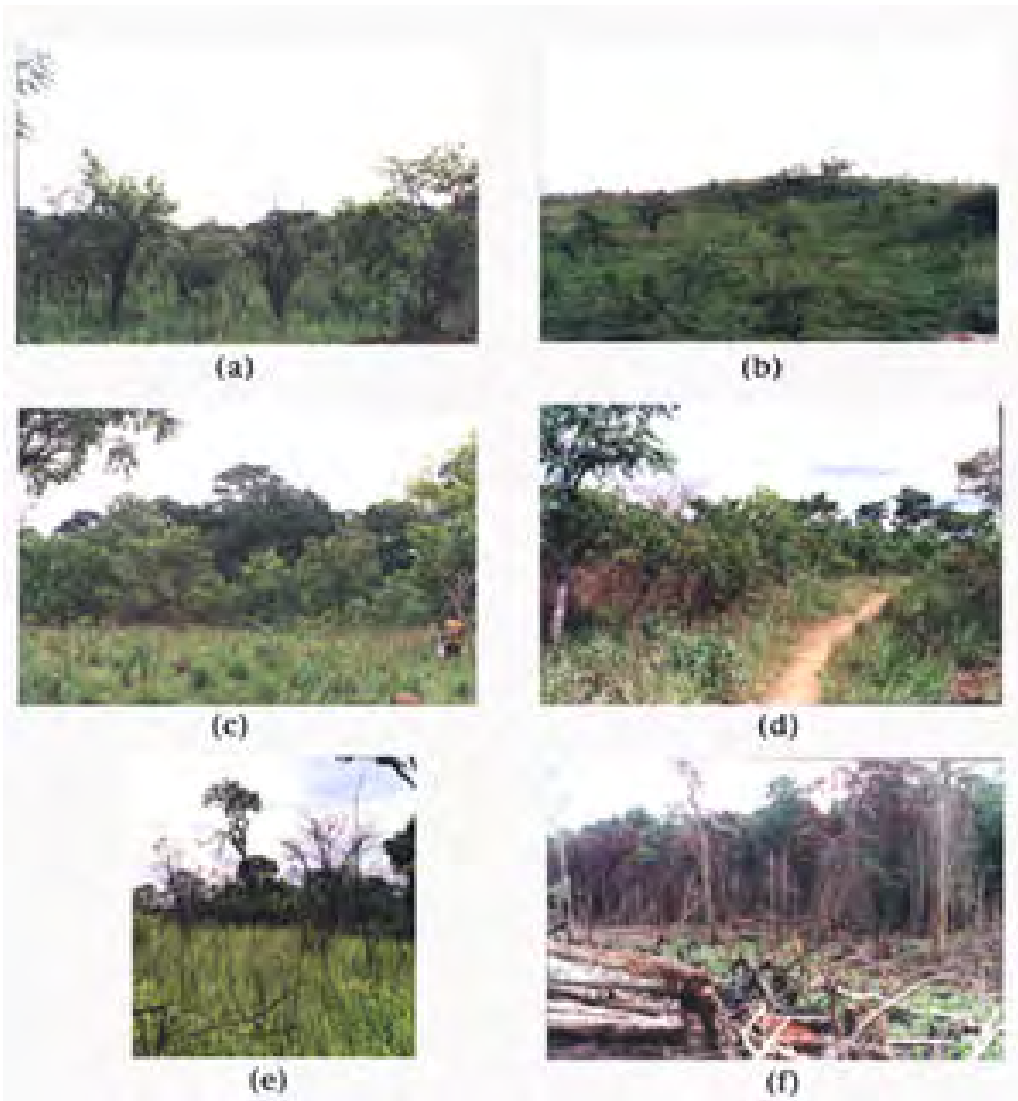


Figure 3. Pictures taken during the field survey representing the land cover types within the study areas: a) Mixed savanna woodland near the town of Betare Oya in western Cameroon, b) Open mixed wooded savanna near the town of Betare Oya in central-west Cameroon, c) Savanna-gallery forest interface near Btare-Oya in western Cameroon, d) Thick bush savanna with almost

complete canopy cover between the towns of Betare Oya and Garoua Boulai in the western Cameroon, e) Burned savanna in the forground and regenerating forest in the background in area where there is considerable forest regrowth near Betare Oya., f) Removal of gallery forest for crop cultivation.

In most vegetation types listed above, the species composition are mixed. Tables 2 and 3 show the sites with geographical locations, vegetation types and the species composition. The ground observations and field surveys are identified as T1, T2, and T3 for the three transects, and RD1, and RD2 for the road observations. The main purpose of the field survey was to observe the status of vegetation cover and to collect data that could help interpret and validate remote sensing images.

Table 2. Ground-truth data taken in the ecotone region in Cameroon along 3 transects (T) and 2 different portions of the main road (RD).
See table 2. For full names of plant species.

Transect	Habitat type	Dominant Species
RD1	bush savanna	vitex, term
RD1	bush savanna	anno, brid
RD1	closed mixed wooded savanna	albezia, alchornia, Ceiba, term, trema
RD1	closed mixed wooded savanna	hymen, lann, cross
RD1	closed mixed wooded savanna	
RD1	closed mixed wooded savanna	hymen, cross, pilio, brid, lann, albezia
RD1	mixed wooded savanna	polio, anno, brid, albezia
RD1	mixed wooded savanna	brid, polio, term, lann
RD1	mixed wooded savanna	brid, polio, term, lann, anno
RD1	open mixed wooded savanna	pilio, anno, lann, hymen
RD1	open mixed wooded savanna	
RD1	regrowth forest, highly disturbed	
RD1	regrowth forest, highly disturbed	musanga, albizia, polycias, pycnanthus, antocleist
RD1	regrowth forest, highly disturbed	polycias, maesa, pycnanthus, celtis, albizia
RD1	regrowth forest, highly disturbed	piptad, musanga, albezia, cissus, vitex
RD1	gallery forest edge	Panadanus, uapaca, phoenix
RD1	thick bush savanna	albizia, anno, pilio
RD1	thick bush savanna	pilio, acaica, albizia, brid, eritrina
RD1	town	
RD2	bush savanna	lann, polio, term
RD2	bush savanna	term, anno, hemen, pros
RD2	bush savanna	
RD2	bush savanna	
RD2	bush savanna	
RD2	gallery forest edge	markhamia, vitex, musanga
RD2	gallery forest edge	
RD2	mixed wooded savanna	anno, cross, hymen
RD2	mixed wooded savanna	anno, nauc, hymen, polio, albizia
RD2	open mixed wooded savanna	nauc, pros
RD2	open mixed wooded savanna	anno, polio, brid, pros, albizia
RD2	open mixed wooded savanna	cross, hymen, loph

RD2	open mixed wooded savanna	
RD2	open mixed wooded savanna	
RD2	open mixed wooded savanna	
RD2	thick bush savanna	
RD2	thick bush savanna	
T1	closed mixed wooded savanna	ficus, anno, map, albezia, loph
T1	closed mixed wooded savanna	loph (dominant)
T1	gallery forest edge	uapaca, xylopia, polyscias, lann
T1	gallery forest edge	polycias, chlorophora, albizia, uapaca
T1	gallery forest edge	pycnanthus, uapaca, xylopia, olax, albizia
T1	gallery forest edge	
T1	mixed wooded savanna	pros, cross, brid, hymen, pilio
T1	mixed wooded savanna	pros, cross, brid, hymen, pilio, daniellia
T1	mixed wooded savanna	loph (dominant), anno, cross, hymen, lann
T1	mixed wooded savanna	loph (dominant), anno, cross, hymen, lann, cusso
T1	mixed wooded savanna	vitex, lann (2 spp.), nauc
T1	mixed wooded savanna	
T1	mixed wooded savanna	
T1	mixed wooded savanna	loph (dominant)
T1	mixed wooded savanna	
T1	grass savanna	
T1	grass savanna	
T1	open mixed wooded savanna	hymen, cross, pilio, brid, lann, albezia
T1	open mixed wooded savanna	lann, polio, term
T1	open mixed wooded savanna	
T1	open mixed wooded savanna	
T1	open mixed wooded savanna	
T2	bush savanna	brid, polio
T2	bush savanna	psorospermum
T2	bush savanna	anno, nauc, brid, term
T2	closed mixed wooded savanna	hymen, pysc, albizia, term, nauc, uapaca
T2	mixed wooded savanna	loph, hymen, term, lann, pterocarpus
T2	mixed wooded savanna	pros, syzi, map, loph
T2	mixed wooded savanna	
T2	grass savanna	
T2	grass savanna	
T2	open mixed wooded savanna	
T2	open mixed wooded savanna	
T2	open mixed wooded savanna	
T2	thick woodland	polyscias, syzi, term, fic
T2	thick woodland	harun, term, loph, pros
T2	thick woodland	pros, vitex, brid, term, lann
T3	closed mixed wooded savanna	uapaca, pros, tabern, vitex, albizia
T3	gallery forest edge	albizia, musanga
T3	gallery forest edge	phoenix, uapaka, albezia, pycnanthus
T3	gallery forest edge	uapaca, celtis, musanga, albezia
T3	mixed wooded savanna	nauc, hymen, brid, pilio, anno, term
T3	mixed wooded savanna	albizia, pros, brid, hymen, pilio term
T3	mixed wooded savanna	albizia, musanga

T3	mixed wooded savanna	anno, albizia, nauc, vitex, polio
T3	mixed wooded savanna	anno, albizia, nauc, vitex, polio
T3	mixed wooded savanna	loph, anno, albizia, acacia, brid
T3	mixed wooded savanna	brid, anno, pilio, term, nauc, pros, acacia
T3	grass savanna	acacia
T3	open mixed wooded savanna	acacia, brid, anno, albizia, pilo
T3	open mixed wooded savanna	albizia, anno, pilio
T3	open mixed wooded savanna	brid, anno, pilio
T3	open mixed wooded savanna	brid, polio, term
T3	open mixed wooded savanna	anno, albizia, cassia, vitex, polio

Table 3. Plant species recorded during the field survey. Abbreviations correspond to plants listed in Table 1.

Plant species	**Abreviation**
Forest/Forest second growth	
Polyscias fulva	polyscias
Anthocleista macrophyla	antho
Albizia spp.	albizia
Musanga cecropioides	musanga
Elaeis guineensis	elaeis
Maesa lanceolata	maesa
Pycnanthus angolensis	pycnanthus
Myrianthus arboreus	myrianthus
Celtis spp.	celtis
Persea americana	avacodo
Ceiba pentandra	Ceiba
Trema orientalis	Trema
Alchornea cordifolia	alchornia
Piptadeniastrum africanum	Piptad
Uapaca spp.	Uapaca
Phoenix reclinata	Phoenix
Pandanus candelabrum	Pandanus
Chlorophora excelsa	Chorophora
Pycnanthus anglolensis	pycnanthus
Uapaca togoensis	
Olax subscorpioidae	Olax
Markhamia tomentosa	Markhamia
Canarium schweinfurthii	Canarium
Macaranga spinosa	Macaranga
Savanna	
Albizia spp.	albizia
Terminalia glaucescens	term
Annona senegalensis	anno
Bridelia macrantha	brid
Prosopis africana	pros
Piliostigma thonningii	pilio
Acacia spp.	acacia

Eritrina spp.	eritrina
Lannae spp.	lann
Vitex spp.	vitex
Chromolina eurdata (ground cover)	Chromolina
Emperatus landiga (ground cover)	Emperatus
Hymenocardia acida	hymen
Pennicetum (grass)	Pennicetum
Crossopteryx febrifuga	cross
Uapaca spp	Uapaca
Lophira alata	loph
Maprounea africana	map
Xylopia spp.	xylopia
Proteae elliotii	Progeae
Daniellia oliveri	Daniellia
Cussonia batterii	Cussonia
Nauclae latifolia	nauc
Psorospermum kunztianum	
Syzigium guinesis (spelling check)	syzi
Cisus spp	
Combretum colinum	
Psychotria spp	psyc

Remote-sensing

The multi-temporal Landsat data were used to map the changes of the vegetation over three decades. The lack of more frequently acquired Landsat images for tropical Africa limited the analysis of the dynamics of forest-savanna boundary to the decadal periods. However, since we are interested in the loss or encroachment of forest in the ecotone region to understand the changes in biodiversity and habitat stability, the decadal analysis of the land cover change was adequate. To understand the interannual variabilities in land use changes and their impact on the changes of vegetation in the ecotone region additional data are required. Furthermore, in this analysis, we did not examine the impact of climate and assumed a steady state condition for temperature and rainfall variations. There are however, indications that in the absence of anthropogenic forces, the interannual variability in temperature and rainfall play an active role in shaping the tropical and subtropical savanna ecosystems (Zeng and Neelin, 2000).

Land Cover Classification

To develop the most recent land cover map of the study area, we chose the Landsat 7 TM images of the two study areas (path 185-row 56, and path 184-row 56) acquired in February of 2000 to perform image classification. In this report, we only discuss the results of the analysis for the Landsat images of path 185-row 56 shown in figure 3. We used standard methods to classify the images and the details of the methodology are reported in a separate paper to be submitted in publication (Saatchi et al., 2001). In the classification process, the cloud and cloud shadow were masked out. A combination of unsupervised and supervised classification were used to generate a map of the study areas with the following 9 classes: open grass savanna, burned savanna, shrub savanna mixed savanna, open woody savanna, closed woody savanna, forest regrowth or disturbed forest, dense forest, urban, and open water. Not all the classes are the same as the ones surveyed during the field campaign. We combined two types of shrub savanna and woody savanna with different densities because Landsat images were not able to separate them. Gallery forest was included in dense or other forest types depending on the vegetation cover. The classification result is shown in figure 4 and the accuracy for each class type is given along with the name in the caption. The accuracy was assessed by choosing independent test sites from field notes and GPS points collected during the field campaign. This land cover map was used in conjunction with change detection technique to assess the dynamics of forest-savanna boundary and the type of vegetation in the ecotone region.

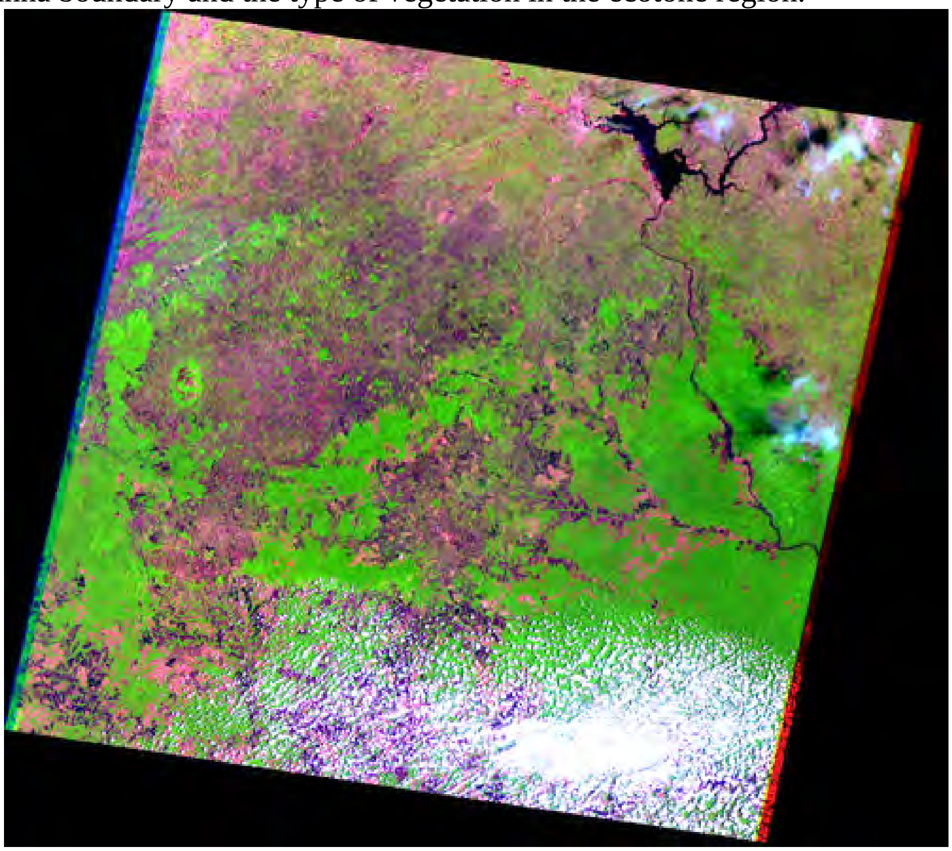


Figure 3. Color composite of bands 5,4,3 of Landsat TM image path 185, row 56 acquired March 15, 2000.

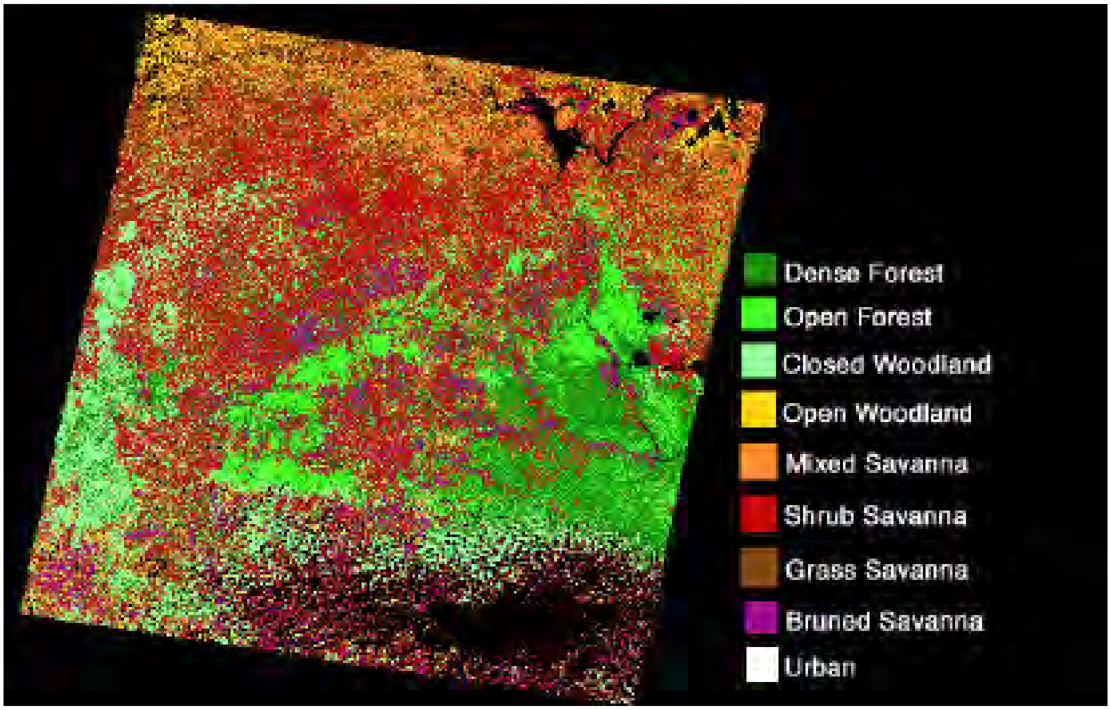
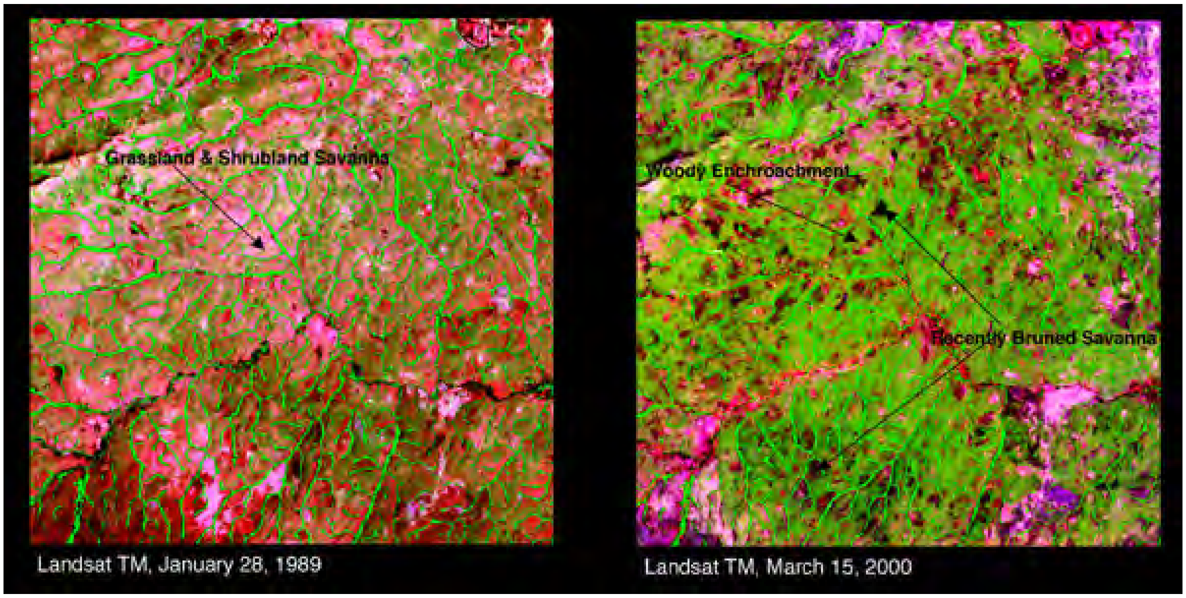


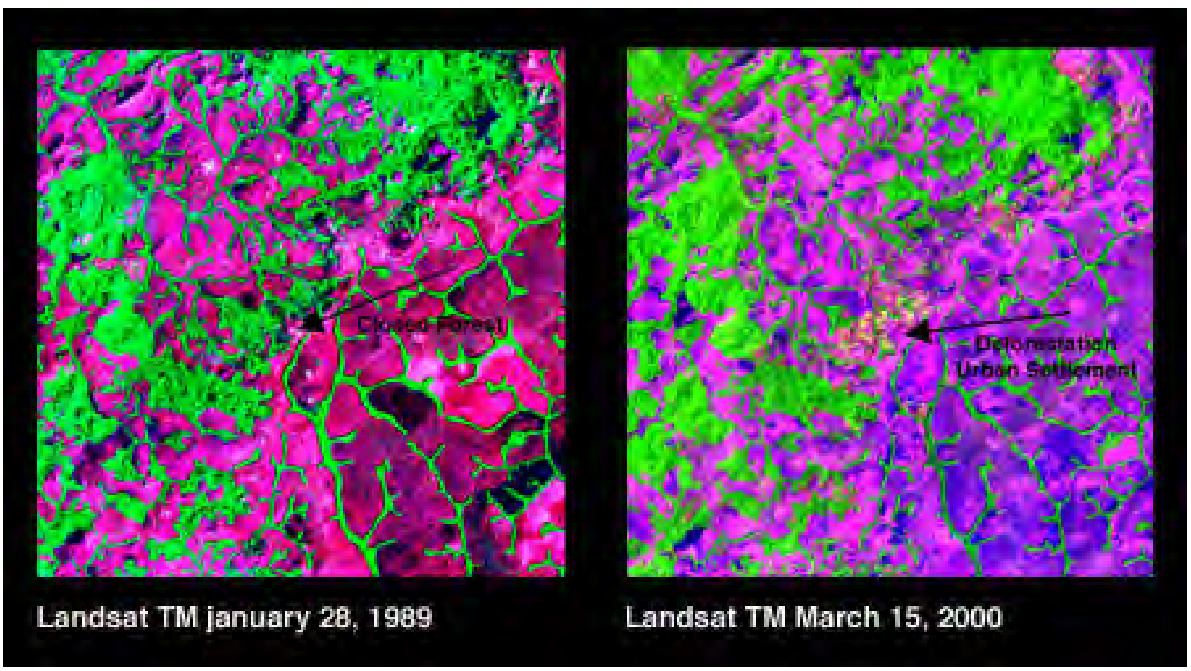
Figure 4. Classification of the Landsat TM image (path 185, row 56). The overall accuracy of classification is 92% with dense forest 94%, open forest 86%, closed woodland 89%, open woodland 93%, mixed savanna 78%, shrub savanna 83%, grass savanna 97%, burned savanna 98%, and urban 88%.

Land cover Change Detection

After classifying the vegetation cover of the study areas for the most recent Landsat image, we used a change detection approach to understand the history of land cover and land use within the study area over the past three decades. The Landsat data acquired over the two study areas covered mid 70s, mid 80s and the beginning of the year 2000. The images were acquired during the same season, so the vegetation was considered to be in the same phenological stage and consequently the spectral data were comparable. As the images were from both MSS (multispectral scanner) and TM (thematic mapper) instruments, we employed a series of post-processing procedures to calibrate the images for radiometric and atmospheric effects. The calibration was performed to extract the surface reflectances from images in order to compare the vegetation spectral characteristics and indices through time (Song et al. 2001). The calibration of images is primarily for automatic change detection approach. Without calibration, the images can be used in a multi-date classification procedure to detect the changes in vegetation cover. Figure 5 shows an example of woody encroachment in savanna in the ecotone region. The images are color composites of TM bands 543 of 1989 and 2000.



(a)



(b)

Figure 5. Comparison of Landsat images over the study area to demonstrate a) the woody encroachment in the Savanna region and b) the deforestation as a result of human development. The images are color composites of bands 5,4,3, of 1989 (left) and 2000 (right) TM images with a matched histogram stretch.

To remove atmospheric effects from the TM data, a simplified atmospheric correction model was used with a standard atmospheric constants for the data acquisition dates, and the given sun elevation angle (ENVI 3.1). This model used the post-launch offsets and gains to produce reflectance images. The lack of information about the atmosphere did not permit a more rigorous calibration of the data. The reflectance images were further calibrated by using coefficients obtained from reflectances of known targets (Roberts, 1999). The MSS data was calibrated by using the ENVI 3.1 procedures for the skewing and aspect ratio correction to remove systematic and geometric distortions. The atmospheric effects on MSS data were calibrated by using the post-launch gain and offset and the generic atmospheric model for the acquisition dates and the sun angle. The calculation of accurate ground reflectances was not possible with these procedures. However, this did not prevent the multi-date analysis of images as the reflectances were inter-calibrated by using the Landsat 7 reflectances of some invariant surface targets as reference.

The relation between the reflectance values obtained from the images and the vegetation spectral characteristics led to the creation of vegetation indices (VI). These indices can be directly related to the green vegetation cover and consequently be used to detect changes in vegetation status and cover. Among the available vegetation indices in the literature, we used three different types that were useful for our purpose. These indices are developed from measurements in red (or visible) and near infrared (NIR) bands and they are based on simple physics: plants reflect less visible light but more NIR radiation compared with non-vegetated surfaces. The visible red wavelengths are absorbed by chloroplasts in vegetation and near infrared wavelengths are strongly reflected due to leaf structural characteristics such as spongy mesophyll, air spaces, etc. The indices are given as follows:

The Normalized Difference Vegetation Index (NDVI) is related the greenness of vegetation and has a fixed range from 0 to 1. This index was shown to be correlated to green biomass, leaf area index and other measures of vegetation greenness (Tucker, 1979; Sellers, 1985). The Modified Simple Ratio (MSR) has a non-linear relation with NIR and Red measurements, is less sensitive to unknown foliage geometrical and optical properties, and is more linearly related to vegetation parameters than NDVI. The NDVI and MSR are both derived from infrared and visible red band ratio that suppresses differential solar illumination effects of slope and aspect orientation (Lillesand and Kiefer 1994). The Modified Soil Adjusted Vegetation Index (MSAVI) tends to reduce the errors caused by optical properties of soil and has a nearly linear relation with plant cover (Huete, 1988). These three indices can provide the best relations with the vegetation cover over the forest-savanna boundary as they enhance the changes of green vegetation cover and reduce the soil impact in areas where vegetation is sparse. We used all three indices for the change detection analysis and evaluated the performance of each. However, in this report, we present the results obtained by using the MSAVI because it is a better indicator of the changes of savanna vegetation. MSAVI is given as follows:

$$MSAVI = \frac{2b_n + 1 - \sqrt{(2b_n + 1)^2 - 8(b_n - b_r)}}{2} \qquad (1)$$

where b_n and b_r is reflectance of near infrared and red bands, respectively. The vegetation index obtained from MSS and TM data from different dates were compared over known invariant targets such as open water, dense tropical vegetation, exposed soil surface, and urban areas. This procedure was performed to insure that changes in vegetation indices were related to changes of surface condition and the vegetation status and not because of radiometric calibration differences. Before calculating the vegetation indices, the visible red and NIR reflectances from all images were adjusted to the reflectances of Landsat 7 by using linear regression models developed from comparing the reflectances over known invariant targets in the scenes. Because of this inter-calibration and our knowledge of land cover types and vegetation characteristics observed in Landsat 7 imagery, the changes in vegetation cover were traced back to the date of the first Landsat MSS data in mid 70s. Figure 6 shows the MSAVI images acquired at different dates of a portion of the study area.

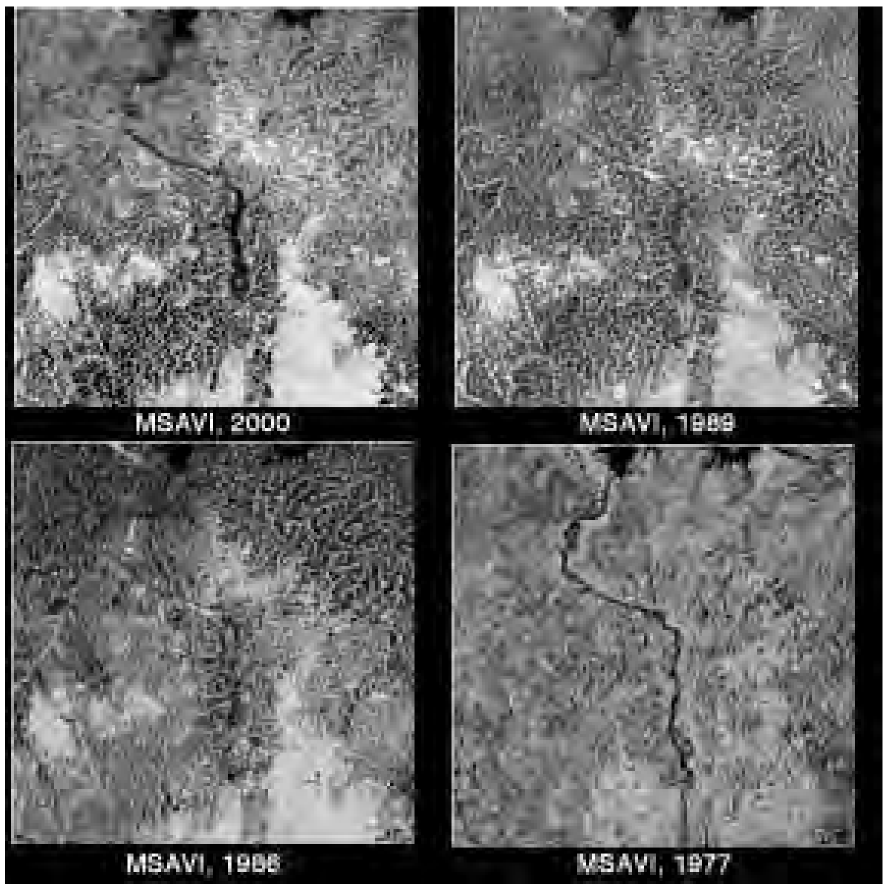


Figure 6. Changes in vegetation cover from 1977 to 2000 as demonstrated by MSAVI. The loss of ecotone vegetation due to savanna burning and agricultural practices can be observed in lower left corner of the images. The upper left corner of the images shows vegetation loss up to 1989 and woody encroachment from 1989 to 2000.

After cross calibration of MSAVI, the quantitative changes of vegetation cover can be detected. Figure 7 shows that MSAVI can separate all classes represented in figure 4 based on the stages of plant succession. With regard to mainly the herbaceous vegetation types (grass and shrub savanna), the index differs based on the density of vegetation and their ligneous cover proportion. It is also observed that the index is stronger for secondary and open forest than in the dense and mature forest. This can be associated to the strong leaf biomass of secondary forest, which in turn causes higher reflection in the NIR channel.

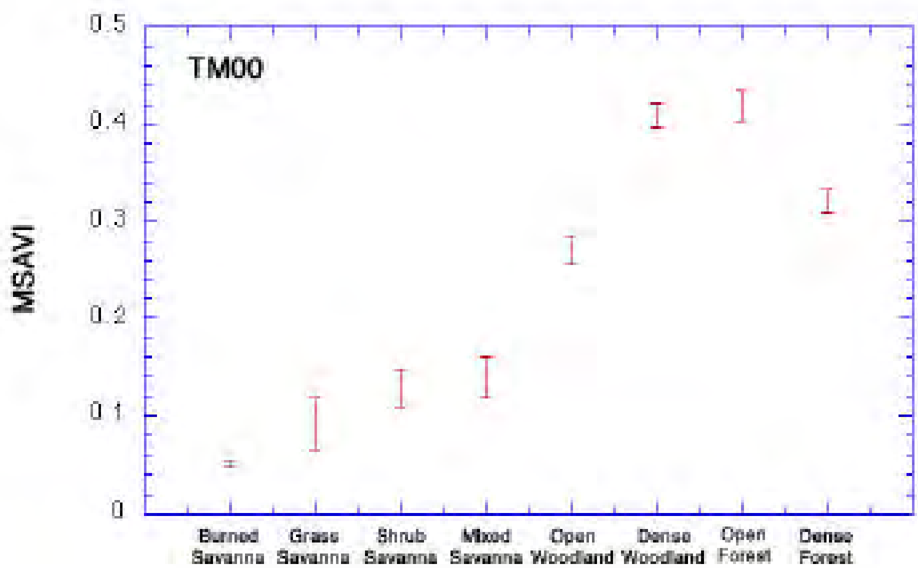


Figure 7. Mean and standard deviation of MSAVI signatures of vegetation types. Except for grass and shrub savanna, MSAVI can differentiate vegetation types.

To detect the changes in MSAVI over the entire landscape, we created normalized difference or ratio images as given by equation (2). Because of similar acquisition geometry, the ratio type relation enhances the variations of the vegetation index by reducing any possible multiplicative effects such as spectral calibration and any topographical effects on reflectances and indices. The ratio images were assumed to be directly related to the actual vegetation changes. These changes can be quantified by several methods (Singh, 1989; Guerra et al. 1998). The change images between two consecutive dates of MSAVI can be obtained by:

$$change - index = \frac{MSAVI_2 - MSAVI_1}{MSAVI_2 + MSAVI_1} \qquad (2)$$

where the subscripts for MSAVI represents the two dates of images. We produce these change images for the 2000-1989, 1989-1986, and 1986-1977 dates. The frequency histogram of the change image between 1989 and 2000 is shown in figure 8. In this histogram, most of the unchanged pixels are grouped around the mean value of zero while modified pixels are in the two positive and negative extremes. The right part of the histogram represents the pixels showing a positive biomass evolution (e.g.. woody encroachment), whereas the left part represents the loss of vegetation biomass. Because the image change histogram has a normal distribution, the value of standard deviation ±1 can be used as the threshold to separate the stable pixels from the modified pixels. We applied this procedure to every two consecutive years of Landsat data to distinguish changes between 1977 to 1986, 1986 to 1989, and 1989 to 2000. This process was repeated for all three indices in order to examine whether changes were related were dependent on soil, vegetation cover, and leaf greenness and structure.

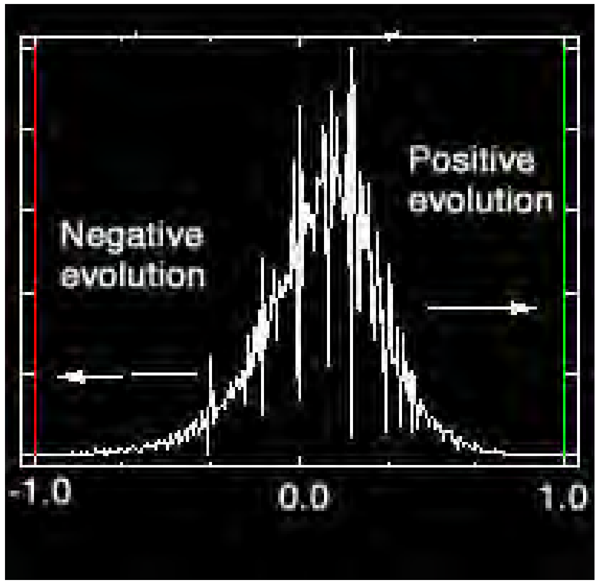


Figure 8. Histogram of the change image based on the normalized difference between the 2000 and 1989 MSAVI images. The arrows indicate the modified pixels and the threshold were fixed at ±1 standard deviation.

Interpretation of Vegetation Changes

The result of the change detection between 2000 and 1989 TM images based on the normalized difference MSAVI images is shown in figure 9. This result shows the spatialisation of the changes over the entire image. Each color or digital number represents the evolution of vegetation types from 1989 to 2000. The dark areas correspond to the areas of no change between the two dates. These areas are primarily the central regions of dense forests and woodlands that are either in national parks or reserves, or far away from human settlements. The identification of these changes is only possible when the image in figure 9 is compared with the classification map shown in figure 4. As images are registered and georeferenced the changes shown in figure 9 can be overlapped pixel-by-pixel on the vegetation map. The results can be summarized as follows:

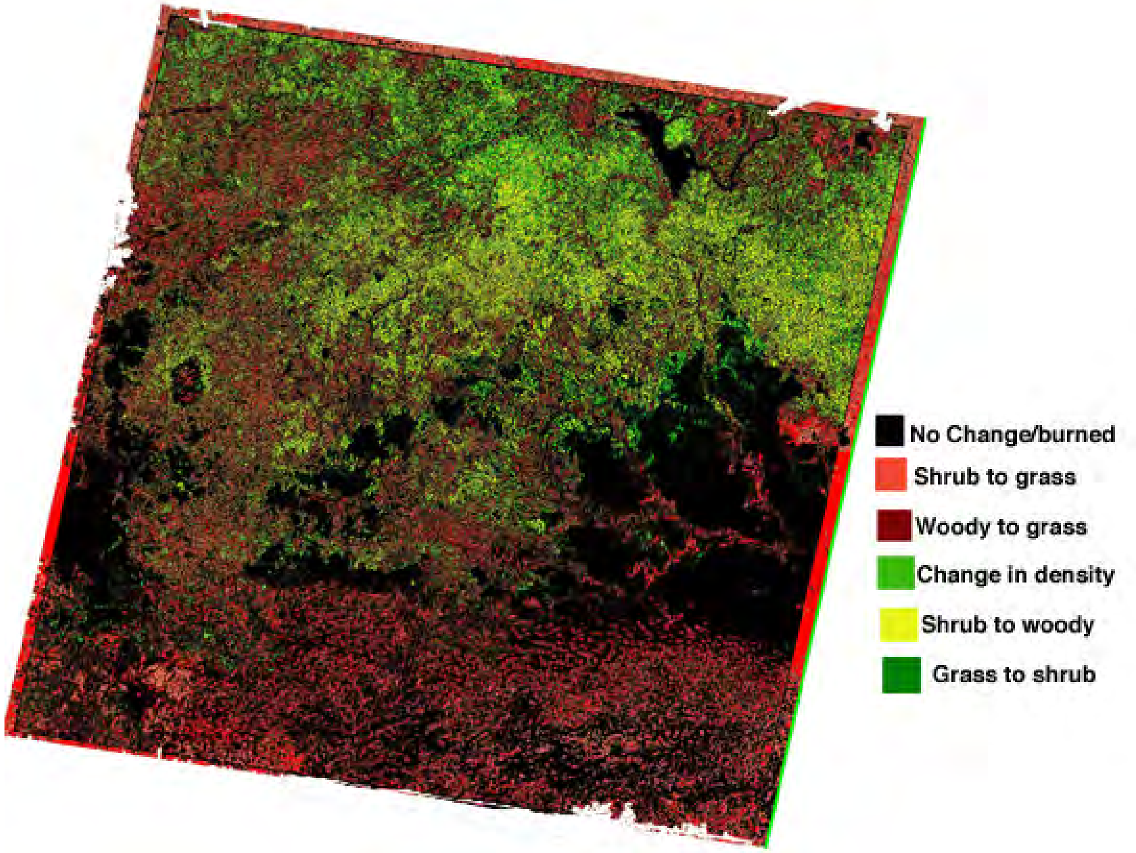


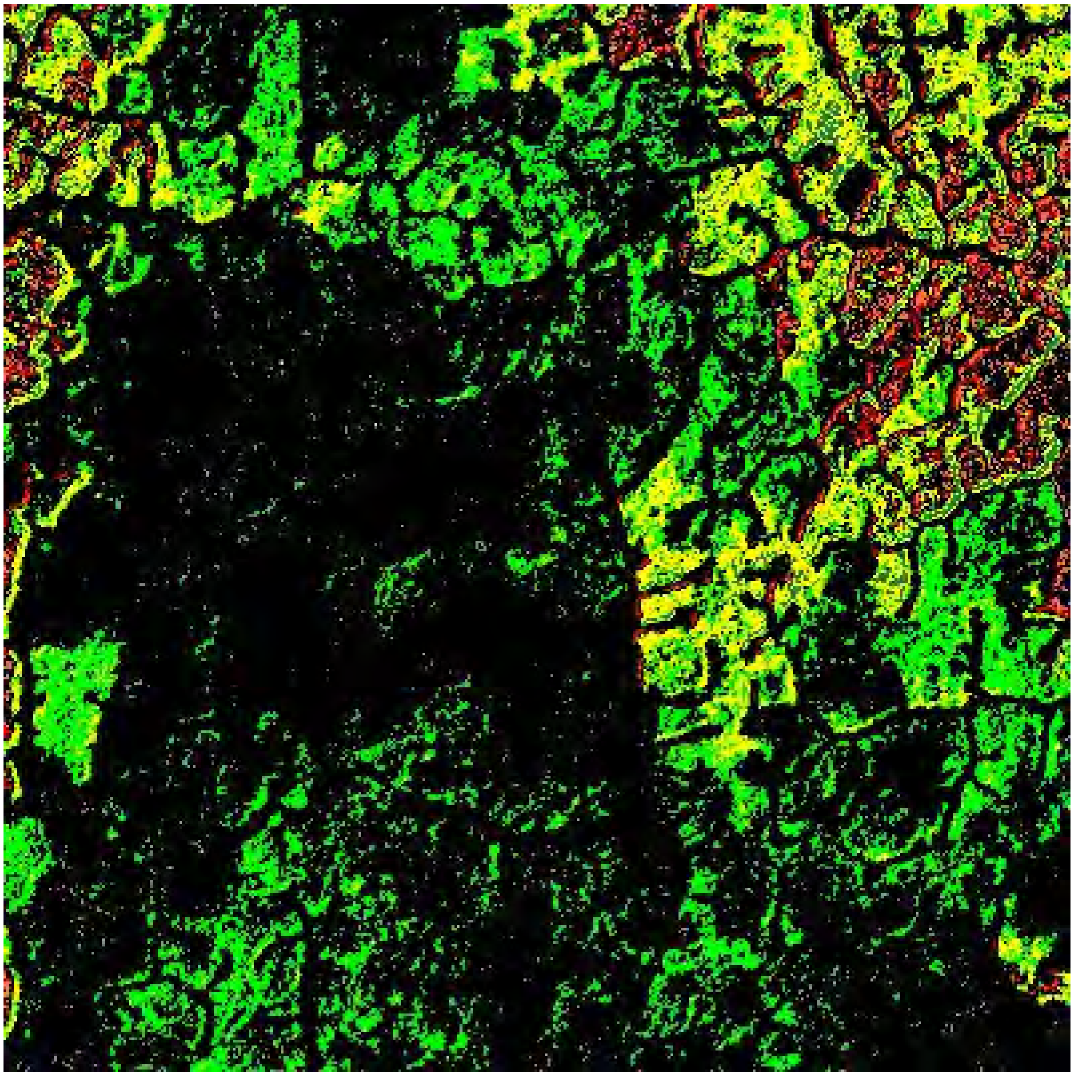
Figure 9. Land cover change map showing the evolution of vegetation types between 1989 and 2000. The dark areas represent no change between two dates regardless of the land cover type.

1. The loss of ecotone vegetation appears at the edges of gallery forests and in areas near human settlements. This loss is often in thinning the gallery forests by removing trees and making use of the moisture availability for cultivation. The edges of gallery forests can also be disturbed due to the exposure to human and cattle movement. Because these changes are mainly attributed to human impact, they can vary interannualy. However, a large percentage of changes (more than 20% of entire area changed from 1977 to 2000) is due to continuous loss of biomass. The area extent of these changes cannot be determined accurately because they are located within few pixels along the edges of gallery forests. The uncertainty is due to the misregisteration in images and the fact that the 60-80 m resolution of MSS images were resampled to 30 m resolution of TM images.

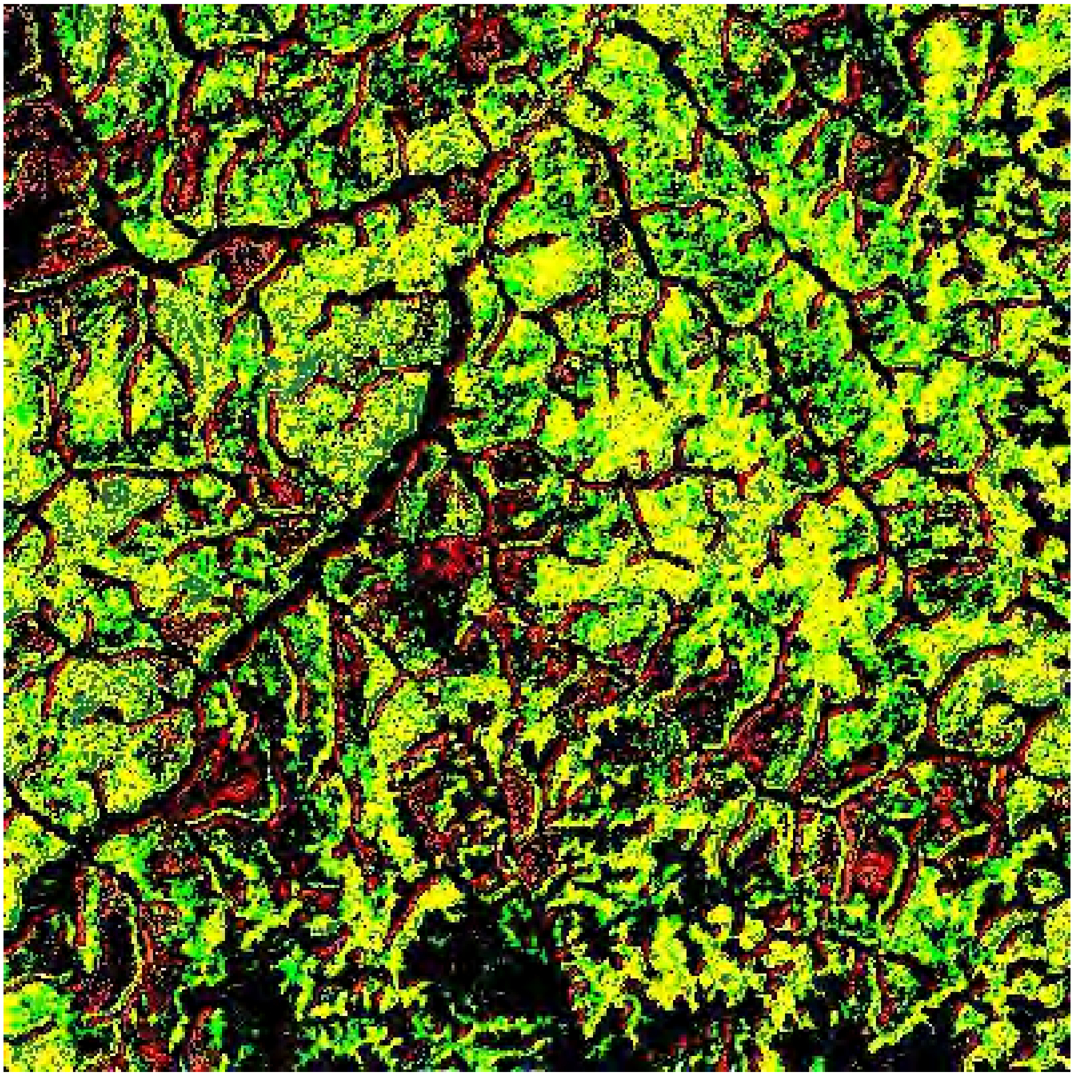
In order to show the relationship between vegetation loss and human impact, we computed the Euclidean distance between each pixel of change to the nearest clusters of pixels identified as urban class (roads and settlements). The result of this calculation shows that 67% of pixels of vegetation loss between 2000 and 1989 occur within 5 km from an urban class. The same calculation between 1989 and 1977 images shows a much higher correlation (82%). The analysis of Landsat images and the vegetation indices shows that a large part of the ecotone region was disturbed between 1977 and 1989. The MSAVI images in figure 6 shows the continuous thinning of the ecotone vegetation in the lower left corner of the images from 1977 to 1989 with some areas of abandonment from 1989 to 2000.

2. Figure 4 shows a large area of savanna that has been colonized by woody vegetation. The woodland expansion occured between the gallery forests and in most cases far away from any human settlements. The vegetation change map in figure 9 shows that a large area of shrubs and woody encroachment in the northern part of the scene. The main cause of the encroachment of woodland in grassland savanna region can be attributed to a variety of factors such as: 1) minimum or no human impact, 2) availability of moisture, and 3) changes in rainfall patterns. The changes of tree and grass ratios in savanna regions in particular closer to the transitional ecotone region have been debated among the scientists. One explanation formulated by Hancock, 1944 in the much drier region of East Africa in Sudan suggests that there are always grass and tree periods in savanna landscapes. Following plagues of grass hoppers or dry years, grassed may set no seed, thus rendering the land free of grass fires, which favors the establishment of trees. We do not know whether the areas of positive and negative evolution of vegetation over this region is due to the above factor. Availability of frequent Landsat images and extensive ground survey can resolve this issue. An alternative explanation can be directly related to the rainfall patterns and soil type. In areas dominated by clay soils (i.e. vertisols) near the edges of tropical forests, the possibility of expansion of trees is much higher as clay soils tend to have higher capacity to hold water at a suction greater than sandy soil. Further ground truth data over the study area will help to identify environmental and anthropogenic factors that cause the changes in ecotones.

A high resolution map of the area of the shrub and woody encroachment is shown in Figure 10. Figure 10a shows an area on the north eastern boundary of the Reserve de Faune de Pangar et Djerem. The recolonization of forest in this area occurred both through the progress of the forest front in the savanna and through the invasion from the skirt to the center of the forest. Figure 10b shows the vegetation recolonization in areas between the gallery forest where the possible reduction of fire frequency and agricultural practices have caused the replacement of grass with dense shrubs and shrublands with woody savanna trees. A similar analysis of Euclidean distances from the pixels with woody encroachment to pixels of urban class suggests that only 46% of these pixels are within the 5 km from urban class. Although, this number is lower than 67% obtained for areas of negative changes, it does not completely explain the cause of woody encroachment. In general, the total area of urban classes from 1989 to 2000 has increased over the entire image.



(a)



(b)

Figure 10. High resolution land cover change map showing in detail the evolution of land cover and land use. The color caption is the same as in figure 9. The recolonization and changes of secondary vegetation to dense forest in (a) occur both at the front edge and within the forest (dark areas). The encroachment of woody savanna between the gallery forests are shown in (b). Changes around the gallery forest may also have been caused by misregisteration of two images.

3. The areas that have experience minimum changes from 1977 to 2000 are areas of dense forest and closed woodlands. Although this may not be the case in other regions, in our study area, these vegetation types create the most stable habitats. The only treat to these areas is the gradual fragmentation due to forest logging. Figure 11 shows an area near the city of Bertoia where the degradation of forests near the forest savanna boundary is caused by logging and thinning of vegetation.

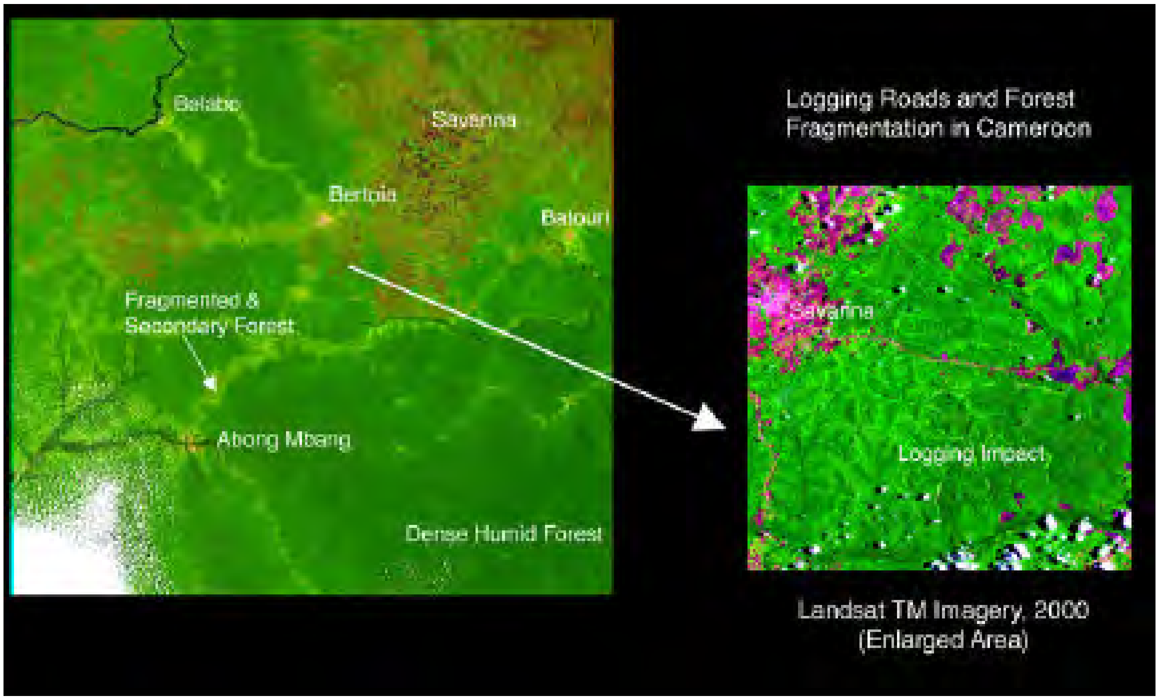


Figure 11. Forest fragmentation due to road development and logging. The image on the right site is at the boundary of forest-savanna south of Bertoia.

Conclusion

In this study, we demonstrated that the relationship between vegetation types and various vegetation indices could be used to monitor the dynamics of forest-savanna boundary with multi-date remote sensing data. The interpretation of multi-date spectral data in terms of vegetation physiognomy, structure, and composition as well as land use provides the best tool to understand the vegetation dynamics. The methodology used in this study enabled us to trace the patterns of land cover change for 30 years where Landsat imagery was available. The radiometric calibration and cross calibration of images, the use of cross-calibrated vegetation indices, and the land cover classification of images were important elements in understanding the changes in Landsat data. The lack of more frequent data sets did not allow a thorough analysis of land cover and land use change their possible causes. Such analysis requires a change detection technique that can incorporate data sets from various sources (a fusion approach). For example, the combination of Landsat and radar images provides a better time series observation of the landscape. We intend to use a fusion approach using multi-date classification to use images from both sensors in change detection analysis.

The methods developed in this study can be extrapolated for monitoring forest-savanna vegetation changes in humid tropics.

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3. Conservation Impact

There is increasing interest in how habitats are changing over time as a result of human and climatic impacts. In this study we provided quantitative estimates of the spatial patterns of ecotone change. Because little attention has been paid to ectones, the rate of loss of forest patches and gallery forests that make up the matrix of the ectone is poorly known. Further, forest expansion is a poorly understood phenomena which has obvious conservation and economic impacts.

4. Local Involvement

We have made an effort, and will continue to do so, to discuss our project with as many individuals and governmental and non-governmental organizations as possible so that our results will be useful for a wide variety of projects.

5. Training and Environmental Education
None proposed.

6. Distribution of the Project Results/Recommendations
Some places/people in Cameroon for final report dissemination:

Herbier National du Cameroun – Dr. Achoundong

Office National de Developpement des Forets – Jerome Momo

Union Europeenne – Jaap Schoorl

Wildlife Conservation Society

World Wildlife Fund for Nature

Projets Forets Communautaires – Phillipe Azuel, Marc Dethier

Conservation International

ORSTOM - Jean Maley

Duncan Thomas

7. List of works

Saatchi, S., C.H. Graham, and T. Smith. Evaluating land-cover change in the Cameroon forest-savanna ecotone. In prep.

8. List of Materials

None proposed.

B. RECOMMENDED PROJECT FOLLOW-UP

There are several projects that could follow this project. One project is an extensive botanical study that would provide more detail to plant species compositions. For example, in the west side of the study area *Uapaca* sp. and *Lophira lanceolata* dominated savanna woodlands were detected, while on the east side savanna woodlands tended to be mixed. A second useful area for study would be to further examine the mechanism of forest expansion and use this information to predict the pattern of forest expansion in the future. A final study would be to expand the present study to examine land-cover change across a larger area in the Congo basin to determine if the patterns of ecotone change in Cameroon are consistent to those in a larger region.