CHANGE-DETECTION IN WESTERN KENYA – THE DOCUMENTATION OF FRAGMENTATION AND DISTURBANCE FOR KAKAMEGA FOREST AND ASSOCIATED FOREST AREAS BY MEANS OF REMOTELY-SENSED IMAGERY

T. Lung, G. Schaab *

Department of Geoinformation, Karlsruhe University of Applied Sciences, Moltkestr. 30, D-76133 Karlsruhe, Germany, gertrud.schaab@fh-karlsruhe.de

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ABSTRACT:

In order to understand causes and effects of disturbance and fragmentation on flora and fauna, a time series on land cover change is needed as basis for the BIOTA-East Africa project partners working in western Kenya. For 7 time steps over the past 30 years Landsat data were collected for Kakamega Forest and its associated forest areas. Preprocessing involved georeferencing and radiometric corrections. In a first step the time series is evaluated via a threshold analysis distinguishing between "forest" and "non-forest". Even though a temporally changing pattern of forest losses and replanting is observed, in total no major change in forest-covered area is revealed. Therefore, a supervised multispectral classification is performed distinguishing between classes at the ecosystem level. Ground truthing for the historical imagery is done with the help of maps showing vegetation types or land cover. Actual land cover verification is based on amateur photographs taken from an aeroplane as well as on terrain references. For classification the maximum-likelihood decision rule is applied considering bands 3, 4, 5, 7 plus 7/2 for TM/ETM+ imagery and 1, 2, 3 and 4 for MSS-data, repectively. If available, scenes from both the rainy and dry seasons are made use of. From planned 17 land cover classes 12 can be realized, of which 6 belong to forest formations. A shortcome is that plantation forest of *Maesopsis eminii* (planted mixed in with other indigenous tree species) cannot be separated. Nevertheless, the classification results form a solid basis for a consistent and detailed evaluation of forest history between 1972 and 2001. Analyses presented include graphs of change in land cover class areas over time as well as such allowing for true change detection with transitions between the different classes.

1. INTRODUCTION

Detecting land cover and its changes is needed in order to understand global environmental change. Of particular interest are the effects of tropical rain forest fragmentation which varies regarding intensity and extent. The increase in fragmentation is related either to natural or human sources (e.g. WADE et al., 2003; Geist & Lambin, 2001). Both influence biodiversity, which is known to be immensely rich in tropical forests (Gaston, 2000). In general, the BIOTA (Biodiversity Monitoring Transect Analysis in Africa) project, funded by the German Ministry of Education and Research (BMBF), analyses changes in African biological diversity related to land cover and environmental changes with the aim to develop recommendations for a sustainable biodiversity management (see www.biota-africa.org). The research acticities of BIOTA-East Africa (see Köhler, 2004) are currently focusing on Kakamega Forest and fragments close by, located in western Kenya. Information retrieval regarding land cover change and thus forest fragmentation and disturbance is performed for the wider area of Kakamega Forest and associated forest areas (see Figure 1). Here, the results of satellite data analysis form a major contribution of geo-information processing for documenting anthropogenic influences on these rain forests over time. They will allow the different biological and/or ecological subprojects of BIOTA-East Africa to conclude on changes in forest ecosystems or biodiversity related to global change. With the study sites spread over a relatively small area there is the need and the chance to offer rather detailed information, both in space and time.

2. THE STUDY AREA

Kakamega Forest is known to be the species-richest forest in Kenya. It inhabits a large number of rare animals and even some endemic plant species (KIFCON, 1994). The forest is sourrounded by small forest fragments which might have been connected to the main forest in former times. The Nandi Forests are of comparable size but placed on an escarpment some 200 to 300 m higher in elevation. There has been an ongoing debate wether all these left forest islands have once formed one larger forest area if not even have belonged to the congo-guinean rain forest belt (see e.g. Kokwaro, 1988). The forests are placed in one of the world's most densely populated rural areas (Blackett, 1994: mean population density of 600 inh./km^2) which is intensily used for subsistence agriculture. Due to continualy increas-

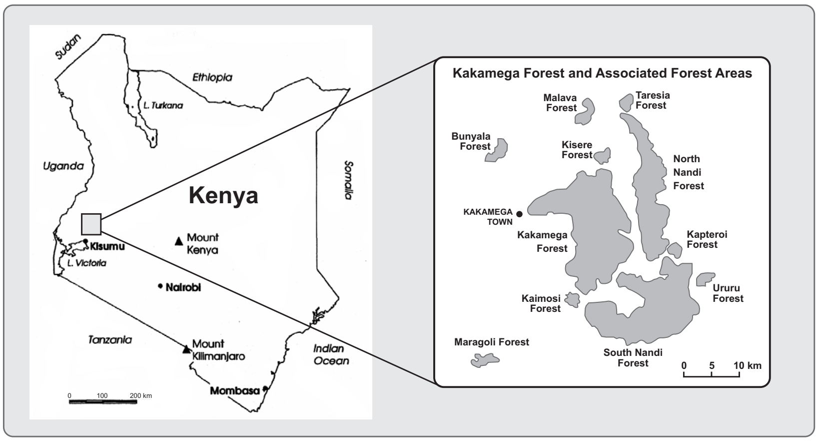

Figure 1: Location of the study area and the different forests covered by remote sensing analyses in western Kenya (34°37'5" – 35°9'25" east of Gr., 0°32'24" north – 0°2'52" south of the equator)

* corresponding author

ing population numbers the pressure on the forests is growing. For the local people the forests play an important role in satisfying their daily needs (e.g. fire wood, house building material; see Kokwaro, 1988). Other legal as well as illegal activities since the early colonial time at the beginning of the 20th century till today have resulted in forest degradation (Mitchell, in print). Only small patches of intact forest are left. The heaviliy disturbed Kakamega Forest is said to have been reduced to ca. 120 km² in 1980 (Kokwaro, 1988). KIFCON (1994) estimated the offtake of fuel wood as ca. 100,000 m^3 per year.

3. MATERIALS AND METHODS

3.1 Data and software

Landsat satellite imagery was ordered with the aim to reach back as far as possible as well as to cover the time period in regular intervals. The achieved time series encompasses 7 time steps between 1972 and 2001 with roughly one image every fifth year. For the time steps 1972, 1975, 1980, 1995 und 2001 two for most parts cloudless scenes from the dry and the rainy season are available. This allows for taking seasonal variation in vegetation patterns into account. For the remaining time steps (1984 und 1989) only a single scene from the dry season is at hand for classification. The scenes were detected by different Landsat sensors, resulting in specific characteristics regarding their spatial as well as radiometric resolutions. The data of the first three time steps (1972, 1975 und 1980) originate of LANDSAT-MSS (Multispectral Scanner). The image material for 1984, 1989 und 1995 were derived by LANDSAT-TM (Thematic Mapper), whereas the data from 2001 were collected by LANDSAT-ETM+ (Enhanced Thematic Mapper Plus). Due to the fact that the data was ordered in system-corrected format, the MSS-data had been resampled to 60 x 60 m^2 spatial resolution, that is a multiple of the 30 x 30 m^2 TM/ETM+ data resolution.

For digital image processing of the remotely-sensed imagery including a supervised multispectral classification ERDAS Imagine 8.5 is used. This software includes the module ATCOR 3 for correcting atmospheric and terrain effects. For analysing the classification results use is made of ArcGIS 8.3 that supports GIS overlay functionality with due accuracy.

3.2 Preprocessing

Preprocessing of the satellite imagery envolves the exact georeferencing of the various scenes by means of topographic map sheets in 1:50,000 scale which are the most actual ones available but have not been updated since 1970. Here a precision of one pixel or better (i.e. less than 30 m) is envisaged. Next, the scenes are clipped for an area of 60 km by 65 km (UTM 36 N: 680,000 – 740,000 E by -5,000 – 60,000 N; ellipsoid Clarke 1880, datum Arc 1960 New). Atmospheric as well as terrain shading effects are corrected via ATCOR 3 based on a digital terrain model which was derived from the 1:50,000 topo maps contours. For an improved visual interpretation of the scenes on the screen a piece-wise linear transformation (via breakpoints) is applied for band combination 5/4/3 (TM, ETM+) and 2/4/1 (MSS), respectively. Further, in all scenes with clouds these areas are masked-out and if available replaced by the information of the second scene of the particular time steps, i.e. by the pixel values of six (TM, ETM+) or four (MSS) spectral bands.

3.3 Threshold Analysis

The first step towards a classification of the landscape is the threshold analysis aiming at the generation of binary images distinguishing „forest“ from „no forest“. This distinction could be made use of later by performing multispectral classifications independently for these two major land cover classes (Lillesand & Kiefer, 2000). The different spectral channels as well as several vegetation indices (e.g. NDVI, SAVI) are evaluated concerning their suitability. Band 2 and 1 (Green) in the case of TM/ETM+ and MSS, respectively, turned out to be best for separating ”forest“ and ”no forest“ (Lung, 2004). First numbers of forested areas are derived by overlay techniques combining the resulting threshold images and raster layers of the official forest areas (gazetted in the 1930s), the latter derived by digitizing their boundaries from the already mentioned 1:50,000 topo maps. However, even though a temporally changing pattern of forest losses and replanting is observed, in total no major change in forest-covered area is revealed. What is needed for describing forest fragmentation and disturbances in detail is to distinguish between more land cover classes in order to separate near natural forest from secondary forest or even plantation forest. Further, the results of the threshold analysis demonstrate that a truely satisfying separation of “forest” and “no forest” is not possible when considering just one spectral band. Therefore, the subsequent multispectral classification is not to be performed independantly for these two major classes.

3.4 Supervised Classification

The multispectral classification of the Landsat time series starts with the most actual time step (2001) and subsequently goes back till the earliest time step (1972). It makes use of the maximum-likelihood classificator, deriving training areas (several per land cover class whereever possible) from a) different maps with vegetation information, b) amateur photographs taken from an aeroplane in 2001, and c) terrain references. While photographs and terrain references are considered as ground truth for timestep 2001, the vegetation maps (Vegetation map 1:250,000 from 1966, Forest Department forest map 1:10,000 from 1972, KIFCON land cover map 1:25,000 from 1991) are a valuable source for ground truthing in the past. The development of a methodolgy for a best-possible classification based on the satellite imagery of 2001 can be subdivided in three steps: 1) Via signature analysis of the training areas the spectral bands to be considered are evaluated for the dry season image regarding the spectral separation of envisaged 17 land cover classes. Because the ETM+/TM channels 1 und 2 contribute only a very small information amount for distinguishing the desired land cover classes, they are disregarded in the classification process. 2) By adding the rainy season image the classification is improved in particular regarding the separation of grassland and agricultural land. Thus a multiseasonal approach is to be preferred against a monoseasonal approach. 3) A further improvement in the classification results from including the ratio 7/2 (ETM+/TM) as an additional artificial channel. This ratio band showed to be most suitable for differentiating between the vegetation formations (Lung, 2004; see also Hildebrandt, 1996). Having finalized the classification for timestep 2001, the developed methodology is applied as exactly as possible to the data of the other time steps in order to derive comparable results. However, minor modifications are necessary: For time steps with only one satellite image at hand only a monoseasonal classification approach is possible. For classifications of MSS-data other spectral band combinations are to be used due to sensor differences. Also the use of an artificial band did not gain improvements. To summarize, for classifying ETM+/TM-data the bands 3, 4, 5, 7, and 7/2 are used, in the case of MSS-data the bands 1, 2, 3, and 4.

Table 1: Land cover classes distinguished in the supervised Landsat imagery classification process

Class	Description
1. Near natural + old secondary forest	Forest of lowest disturbance level, dense canopy, older than 50 years as well as old secondary forest (30-50 years)
2. Secondary forest	Mid-aged secondary forest of 20-30 years as well as aged *Maesopsis eminii* (originally from Uganda) plantations mixed with indigenous species
3. Bushland / shrubs	Bushed areas interspersed with grasses and herbs plus young (10-20 years) and very young (initial state, younger than 10 years) secondary forest, also early mixed *Maesopsis eminii* plantations
4. Secondary bushland - *Psidium guajava*	Colonization of guava trees (animal-dispersed, e.g. by monkeys)
5. Grassland with scattered trees	Grassland with single bushes or trees
6. Grassland	Grassland, partially of natural origin, partially due to clearings, partly used as meadows, grass used for roof hatching
7. Plantation forest - *Pinus patula*	Plantation of pine trees (originally from Mexico, monocultures), maybe of cypress
8. Plantation forest - *Bischoffia javanica*	Plantation of bischoffia trees (originally from Uganda, monocultures, could be without leaves due to pest)
9. Tea plantation	Tea plantation
10. Agricultural land	Cultivated land of diverse characteristics, highly devided land with trees and bushes along plot boundaries, mainly subsistence agriculture, high percentage of bare ground
11. Water	Water
12. Others	Roads (tarmac or dirt track), rocks, settlements

4. RESULTS AND DISCUSSION

Instead of desired 17 classes, on the basis of the available Landsat satellite imagery and the reference data for ground truth verification 12 land cover classes can be realized. A subset of the year 2001 classification is shown for Kakamega Forest in Figure 2. From the 12 land cover classes 6 belong to forest formations. Thus, a differentiation of tropical rain forest in general is possible when classifying Landsat imagery. There has been no need in differentiating the cultivated land surrounding the forested areas. For a more detailed description of the classes see Table 1. Classes 6 to 1 form successional stages, with "Secondary bushland – *Psidium guajava*" standing out because *Psidium guajava* is not a real forest tree species. Areas of class "Near natural + old secondary forest" are likely to have survived over the long term or when representing old secondary forest have regenerated to this final stage of natural succession on areas which have been disturbed by man-kind. Forest plantations can be distinguised as long as they are monocultures and large enough in size to be reprensented by pure pixels. This is the case for *Pinus patula* and *Bischoffia javanica*, but not for *Eucalyptus saligna* and *Cupressus lusitanica*. A shortcome of the classification is that *Maesopsis eminii* plantation cannot be separated due to being planted mixed in with other indigenous tree species. In these cases the spectral signatures are to similar to several secondary forest stages. Forest plantation still hiding in these classes might be later revealed at least for Kakamega Forest by following a rule-based hybrid approach, that involves the Forest Department forest map in 1:10,000 scale as well as visual interpretation of the contrast-enhanced band combination 5/4/3 (ETM+/TM).

4.1 Visual evaluation of the classification

All derived classifications for the seven time steps were visually evaluated in order to judge their accuracy. For the different forest areas or parts of them very distinct developments can be observed. Clear fellings of "Near natural + old secondary forest" und "Secondary forest" in favour of bushland, grassland and agricultural land are obvious all over the area, e.g. for the western arm and the most southern parts of Kakamega Forest (see Figure 2). Other areas, like the middle part or the most western end of Kakamega Forest are characterized by a continous change of forest plantations and their fellings. Along the north-eastern edge of Kakamega Forest regeneration of forest can be noticed in younger times (1994/95 and 2001), shown by grassland with scattered trees or even arrangements of successional stages. And, from 1994/95 onwards in the north-western area colonization of *Psidium guajava* on former grassland or agricultural land are found. Especially in the classification results based on ETM+/TM-data with the higher resolution as compared to MSS-data numerous scattered pixels of the classes "Secondary Forest" and "Bushland / shrubs" are spread throughout the major areas of "Near natural + old secondary forest". This is a an indication for likely disturbance of former prestine forest through selective logging (compare with Mitchell, in print). For South Nandi Forest the portion of interspersed "Bushland / shrubs" pixels is much higher as compared to interspersed "Secondary Forest" pixels. Therefore, here this process of selective logging seems to go still on to a much higher rate as compared to Kakamega Forest, where major disturbances by selecting and felling certain tree species seem to have happened longer ago.

So far only a visual judgement regarding the quality of the classifications is possible. What is still missing is an accuracy assessment via error matrices opposing the classification results with field reference data. Getting such reference data for all the different time steps as covered in the time series seems to be a big if not unsoluble effort. But at least for the most actual timestep (2001) such an assessment should be possible and is aimed at, as within BIOTA-East access to aerial photography of the year 2000 is sought for. For the moment the evaluation is based on the available ground truth reference data as well as on interpreting the likelyhood of correct assignement to land cover classes by putting the results of the single time steps in their cronical order. This allows to point out typical trends but also likely misclassifications. In general, the separation of grassland and agricultural land is critical because their spectral distinction depends highly on date of image acquisition, i.e. is correlated to the development stages of the field crops. Because in this area a large variation of crops is cultivated by the local people with up to three harvests per year depending on the changing pattern of rainy and dry seasons (Jätzold & Schmidt, 1982) it seems to be almost impossible to recommend certain times of the year to be covered by imagery. However, the classification result is improved when a multiseasonal approach is followed based on at least two scenes which represent different stages in the cultivation cycle. This seems to be not the case for the 1975 imagery even though two scenes had been ordered with the intention to cover dry and rainy seasons. Also difficulties arouse concerning the distinction of *Pinus patula* plantations and the land cover class “Near natural + old secondary forest“. As *Pinus patula* is an exotic species in Kenya, apart from forest plantations no further pixels of that class are expected. A reason for the occurrence of such pixels scattered throughout the class ”Near natural + old secondary forest“ (1) could be that despite preprocessing minor shading effects due to the variable terrain have still some influence. But also young pine plantation show similar spectral reflection as class 1. Further inaccuracies are introduced in the areas where masked-out clouds have been replaced by the image information of the second scene. Overall, the classification results for the time step 1994/95 is judged to be the most accurate, followed by the time step 2001. The quality for 1989 and 1984 is less because only one scene (dry season) is at hand and thus monoseasonal processing had to be performed. The classifications of MSS-data are of poorer quality due to their coarser spatial resolution of 60 x 60 m^2 as well as their lower number in spectral channels (e.g. mid infrared not covered). Within the results based on MSS-data the classification of 1972/73 seems to be best, followed by the reults of the time steps 1975 and 1979/80. In spite of drawbacks regarding differentiated information for detailed studies, MSS-data allows to get back in time as far as the early 1970s. Just making use of ETM+/TM-data would limit time series to the past 20 years.

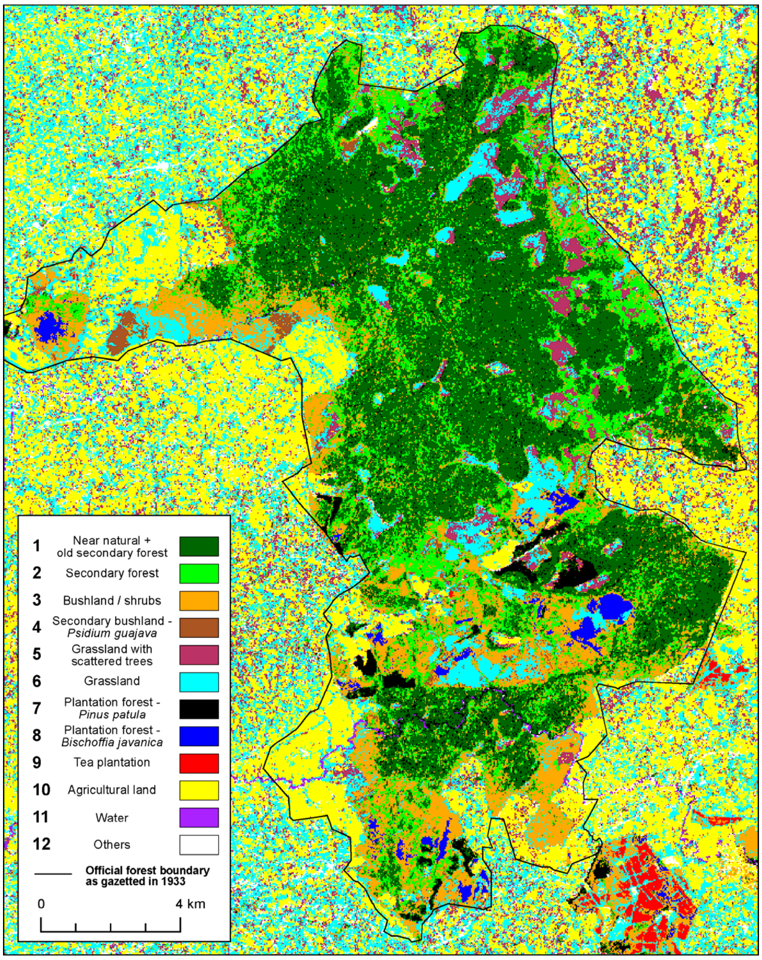

Figure 2: Landsat ETM+ land cover classification result of 2001 for the subset of Kakamega Forest, displayed together with the official forest boundary as gazetted in 1933.

4.2 Areas within Official Forest Boundaries

Because the forest areas are giving priority in the BIOTA-East project, numerical analysis is concentrating on these area. Here, the areas within the official forest boundaries as gazetted in the 1930s are assessed. For Kaimosi Forest and Maragoli Forest no administrative forest boundary is shown on the topo maps 1:50,000. Therefore they are not included in this analysis. Thus, for 9 of the 11 forest areas (see Figure 1) the areas covered by the different land cover classes are derived for all time steps. As an example, for Kakamega Forest considerable changes in “Near natural + old secondary forest” (1) and “Secondary Forest” (2) over time are revealed: 15,000 ha of class 1 and 2 in 1972 (compare Kokwaro, 1988: 14,300 ha in 1972) and 12,200 ha in 2001. This means a 20% loss in forest area over the past 30 years. By just looking at “Near natural + old secondary forest” a similar loss is observed: 8,500 ha in 2001 as compared to 10,500 ha in 1972.

All numbers are presented via bar charts to visualize typical trends in changes of forest formations over time for each forest. For several of the forest areas very pronounced opposed dynamics regarding the land cover classes “Near natural + old secondary forest“, “Secondary Forest“ and “Bushland / shrubs“ are observed. For an example see the graph for South Nandi Forest in Figure 3. Here, the area

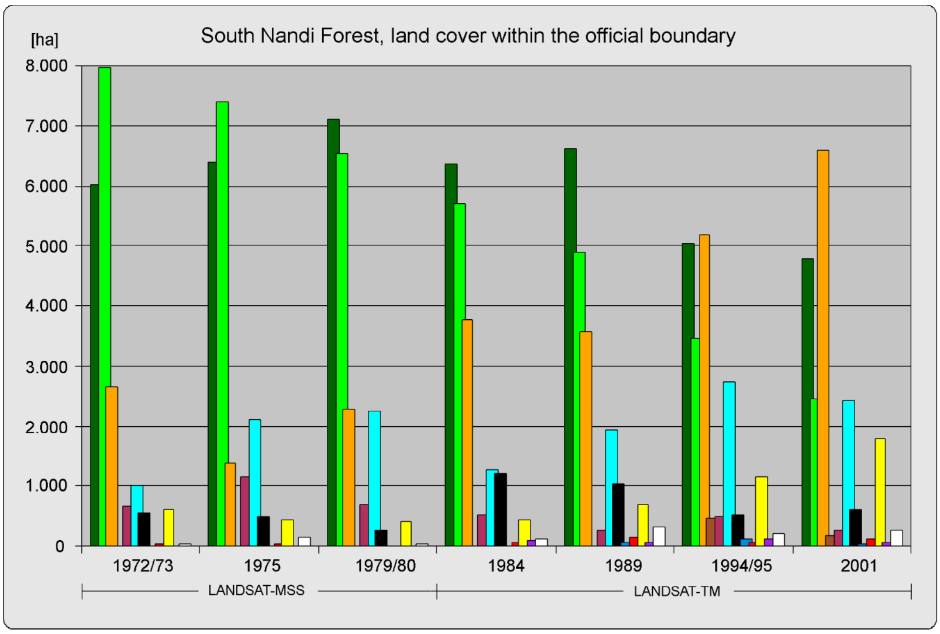

Figure 3: Land cover 1972 – 2001 for South Nandi Forest, area [in ha] within official forest boundary (for colours see Figure 2)

covered by “Near natural + old secondary forest“ and “Secondary forest“ is generally decreasing while the area of “Bushland / shrubs“ is continously increasing since 1975. South Nandi Forest is marked by a tremendous loss of forested area: 15,000 ha of class 1 and 2 in 1972 as compared to 7,200 ha in 2001. The rather sudden increase in “Bushland / shrubs“ area between 1979/80 and 1984 can be disputed regarding its height. The steep step in the numerical values is more likely a result of change in sensor systems used. Small island areas of bushland found as gaps within forest formations due to selective logging are not detected by MSS because of its coarser resolution as compared to ETM+/TM and therefore „disappear“ in the forest classes.

4.3 Change-Detection-Analysis

In some cases the extent of forest is reaching across the official forest boundaries. In order to consider these forested areas also, the forest cover as marked on the topo maps in 1:50,000 scale (based on aerial photography from 1967) are digitized. The digitized forest cover is overlayed by the official forest boundaries from the 1930s (GIS-functionality Union) and the result buffered by 1 km. The derived area extent is in total used for a complex change-detection-analysis. Thus on the one hand it is ensured, that also the widest extent of forest formations within the complete time series is considered in analysis. On the other hand, the mass of the cultivated land surrounding the forest areas with its difficulties of in particular distinguishing between agricultural land and grassland is excluded. This area is of no importance for the current research objectives of the BIOTA project.
While when looking at the areas enclosed by official forest boundaries area sizes covered by the land cover classes were derived for every single forest area and time step individually, for analysis of the buffered forest areas the total area delineated is assessed by directly comparing each two time steps. Via the local GIS-function Combine a matrix is generated that assigns an unique value for every possible combination of the 12 land cover classes. Not only the classifications of the neighbouring time steps (1972/73 compared to 1975, 1975 to 1979/80, etc.) are evaluated but also the complete time series in three time steps (1972/73 to 1989 and 1989 to 2001) as well as its start directly with its end (1972/3 to 2001, see Figure 4). Besides change matrices again diagrams have been prepared. For each land cover class two bars are placed in one another. The broader bar in the back represents the area covered by that land cover class for the latter of the two compared time steps. The narrow bar in the front reveals the portions of the land cover classes by which that area was covered at the earlier time step of the two under consideration. The unchanged portion is always displayed as the lowest part of the bar. Above that base the areas that have changed the land cover class are found. For deriving the total area covered by a certain land cover class at the earlier time step, the portions (which are still absolute values) of this class within the different narrow bars are to be added.
Via these diagrams statements regarding both quantity and direction of changes in land cover are possible. Some peculiarities which can be attributed to classification difficulties attract attention. For the two classes 6 (“Grassland“) und 10 (“Agricultural land“) a high proportion of the other land cover class is shown for the earlier time step (see inner bar). The diagram thus reveals areas which change between either being covered by agricultural land or by grassland. This confirms the conclusion made earlier, that areas classified as grassland (in particular along the edges of the forest areas) are to some extent more likely areas used for agriculture. For the class „Others“ the unchanged proportion is rather low but the portions of „Grassland” and „Agricultural land“ for the earlier time step are in contrast quite large. This is to be interpreted that the areas covered by that class changes over time which is most unlikely because e.g. roads and settlements contributing to this class “Others“ are not expected to change positions to a large extent.

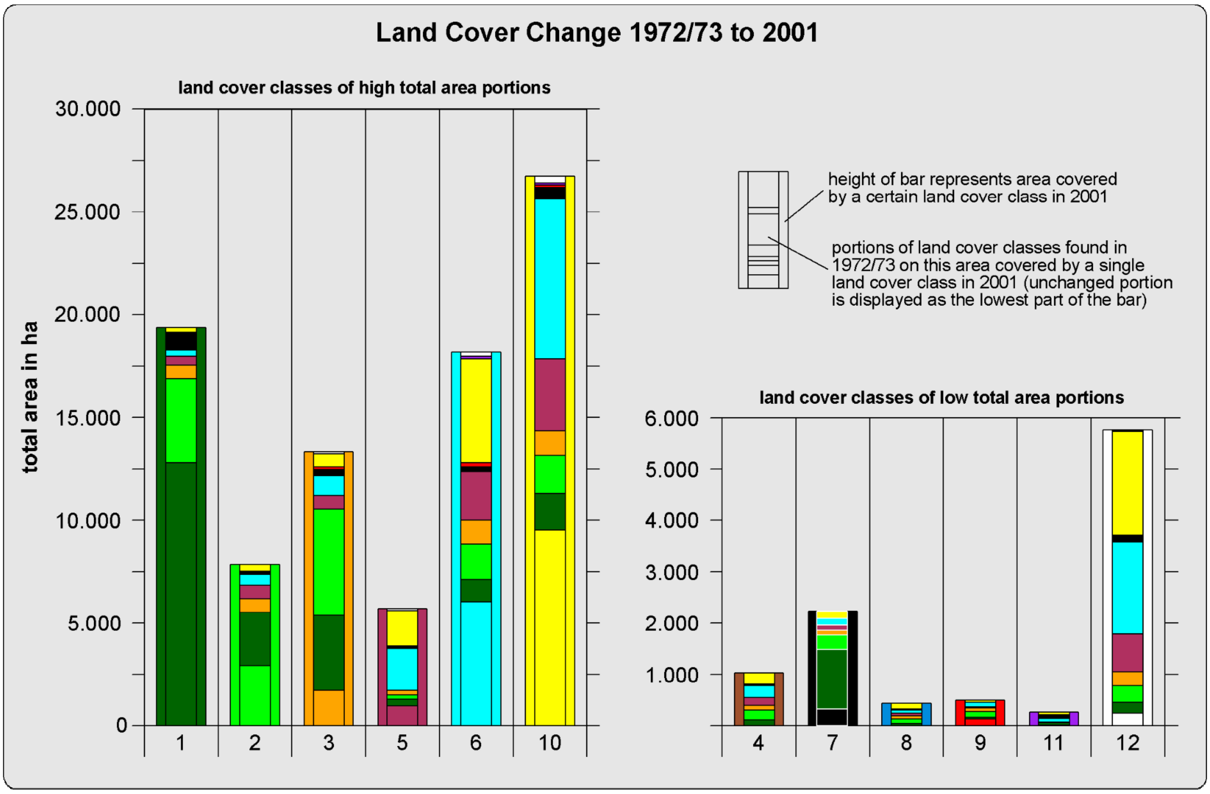

Figure 4: Land cover changes 1972/73 to 2001 for total area of Kakamega Forest and associated forest areas buffered by 1km (for colours see Figure 2)

Especially when comparing the results of the first and the last time step of the time series (Figure 4) regarding the class “Bushland / shrubs“ (3), very high portions of the land cover classes 1 (“Near natural + old secondary forest“) and 2 (“Secondary forest“) for the earlier time slice are revealed, pointing at major forest loss. When looking at the diagramms comparing the neighbouring time steps (not shown here), the unchanged portion of class 3 is always relatively low. This allows to suspect that bushland does not stay bushland for long, but either regenerates to secondary forest or is further cleared and thus changes to grassland or agricultural land. Similar fluctuating dynamics can be noticed for the class “Secondary forest“ (2), but here the largest portion of the changed classes is always “Near natural + old secondary forest“ (1). This could be due to misclassifications because of spectral similarities between pixels making up the classes 1 and 2. But portions of land cover class 1 (for 1972/73) in class 2 (2001) can also be related to forest loss if these have been compensated for by such forest plantations that could not be distinguished from the „natural“ forest formations as in the case of e.g. *Maesopsis eminii*. As can be seen from Figure 4 forest loss has mainly occurred in favour of bushland (3), grassland (6) and agricultural land (10). Whereas the also high portions of class 1 (“Near natural + old secondary forest“) in class 2 (“Secondary forest“) and 7 (“Plantation forest – *Pinus patula*“) have to be interpreted with care, as discussed above.

5. CONCLUSION AND OUTLOOK

The classification of Landsat imagery for 7 time steps between 1972 and 2001 aimed at a homogeneous (unlike Brooks et al., 1999) as well as dense (unlike ICRAF, 1996 with only 2 time steps) time series for documenting land cover change in the wider Kakamega Forest area in order to contribute to biodiversity research and management (compare Schaab et al., 2002). For the first time such a consistent land cover time series for Kakamega Forest and its associated forest areas is now available which is differentiating between forest formations and covers the past 30 years.

The results reveal distinct pattern in land cover change and thus regarding disturbance and fragmentation for the different forest areas considered. In total a decrease in forest area is observed due to clear fellings of larger areas as well as due to selective logging opening the forest cover by numerous small gaps. At the same time for some areas, especially for those under strict conservation managment, regeneration via successional stages can be observed in the time series. So far the classification quality has been only assessed by a visual interpretation. Colour aerial photography from 2000 will be hopefully available soon for the demanded accuracy assessment via error matrices (Congalton & Green, 1998) for the most actual classification result. Further, it is planed to elongerate the time series by means of historical aerial photography (1948, 1952, 1965, 1967) as well as by old topographic maps (ca. 1910).

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