

TRACING SIGNIFICANT LOSSES AND LIMITED GAINS IN FOREST COVER FOR THE KAKAMEGA-NANDI COMPLEX IN WESTERN KENYA ACROSS 90 YEARS BY USE OF SATELLITE IMAGERY, AERIAL PHOTOGRAPHY AND MAPS

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ABSTRACT:

The considerable scientific and conservation interest in Kakamega Forest, and to a lesser extent the neighbouring forests, over the last two decades has generated a multitude of apparently conflicting statistics on forest cover. Here we rationalise the figures that have already been published and by their presentation in tabular form we enable comparison of different time steps. We extend the existing knowledge of forest development back over a 90-year period with data from aerial photography and topographic mapping of 1913. The maps reveal Kakamega, North Nandi and South Nandi Forests then formed a single forest then totalling 74,718 ha, while analysis of 2001 Landsat imagery reveals that the natural forest cover has been reduced to 25,727 ha, or 34.4% of the 1913 extent. By contrast, we show that the forests of Kisere, Malava and Bunyala were separate islands at that date and have, at times, even experienced limited forest expansion. This shows that instead of considering Malava, Kisere and Bunyala as fragments of Kakamega Forest, ecologists should focus on the dateable separation of the Kakamega and Nandi Forests for fragmentation-related studies.

1. INTRODUCTION

The Kakamega-Nandi forest complex (Figure 1) is located between longitudes 34°40'00" and 35°9'30" East and latitudes 0°29'30" and 0°3'00" North in western Kenya. The Nandi escarpment provides a stark contrast in altitude between Kakamega Forest, the lowest point of which lies at 1,420 m above sea level, and North Nandi on the escarpment with the highest point of 2,140 m. These forests form an important water catchment function and the rivers of this area feed into Lake Victoria (Kamugisha et al. 1997). The area around Kakamega Forest has one of the highest levels of annual rainfall in Kenya with an annual average of 2,007 mm, as recorded at Isecheno Forest Station between 1982 and 2001 (Farwig et al. 2006). The forests are located in one of the world's most densely populated rural areas with an average population density of 600 people/km² (Blackett, 1994). A rapidly growing population places pressure upon Kakamega Forest (KIFCON, 1994) as the forest becomes an ever more important resource for satisfying the daily needs of the local people. Charcoal burning, illegal pit-sawing, hunting, collection of medicinal plants, grazing, and collection of fuelwood are some of the threats to which the forest is currently exposed (Mitchell, 2004). Additionally, the forest has been commercially exploited for gold, mainly in the 1930s, and in subsequent decades it was commercially logged, involving both selective and clear-felling. These factors have contributed to the current appearance of the forest as a mosaic of dense forest, clearings, forest plantations, regenerating forest areas, and natural grasslands (Kamugisha et al., 1997).

Kakamega Forest is renowned for its biodiversity and for laying claim to the title of the easternmost relic of the Guineo-Congolian rain forest (Kokwaro, 1988). As such it has received very considerable scientific interest and consequently many conservation initiatives have focussed on this forest to the near total exclusion of its close neighbours.

The numerous reports resulting from the scientific interest in Kakamega Forest have used forest cover figures for scientific

analysis, e.g. Brooks et al. (1999), or simply to establish the background to their research. The multitude of reports, with apparently conflicting forest cover figures, has led to some difficulty for researchers in knowing which figures to use. By contrast there is a dearth of forest cover figures for the forest fragments surrounding Kakamega Forest. Here we use tables to set out the forest area statistics collated from the published reports in a chronological and coherent series. These are supplemented by area figures as derived by the BIOTA E02 subproject from Landsat satellite imagery, aerial photography and old topographic maps. This rationalisation will clarify the figures for subsequent researchers requiring forest area statistics, for instance, for analysis of deforestation, forest regrowth, or species-area studies which can inform sound forest management.

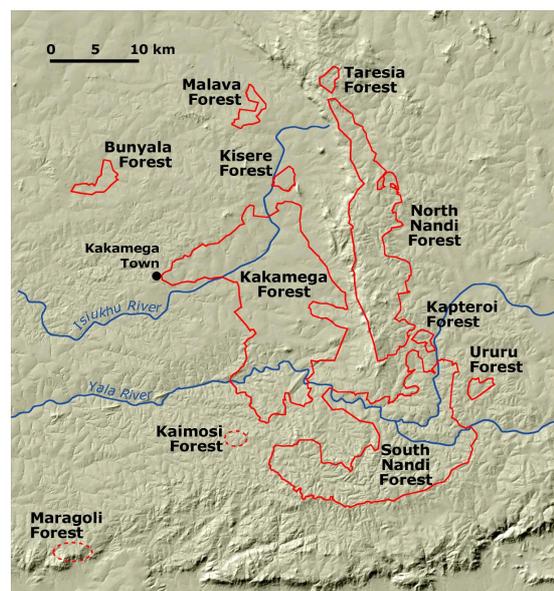


Figure 1: Map of the Kakamega-Nandi forest complex (courtesy to T. Lübker).

2. METHODOLOGY

As described in Lung (2004) and Lung & Schaab (2004) Landsat satellite imagery has been used to derive information on forest cover change for the period 1972 to 2001 in seven, approximately 5-year time steps. Performing a supervised multispectral classification 12 land cover classes have been distinguished, of which six are forest formations. Aerial photography for 1965 / 67 and 1948 / 52 have been obtained to extend the series back beyond the satellite imagery. The photographs have been scanned, orthorectified and joined to form a mosaic (see Herz, 2004) to enable on-screen interpretation and digitising of the forest vegetation. This includes interpretation of both forest extent and the limits of the forest vegetation types discernible within the forests. On-screen visual interpretation of the vegetation classes was made after comparison of 1991 aerial photos to the vegetation classes already derived from 1989 and 1994/95 Landsat data (Lung, 2004). 'Natural Forest cover' is represented here by the two classes of 'near natural and old secondary forest' and 'secondary forest' as defined by Lung (2004). 'Natural Forest

cover' as seen in the aerial photography constitutes both rough-textured heterogeneous canopy forest and relatively homogenous vegetation with individual trees discernible. 'Bushland' is considered separate and belongs to neither 'forest' nor 'non-forest' vegetation. It is defined as a homogenous area of mostly closed cover vegetation with either very small or absent individual canopies being visible. Lower classes of vegetation such as 'grass with scattered trees' and 'grass' were identified but are not considered here.

All forest area figures derived from the aerial photography relate to the area within the officially gazetted forest boundary and have been executed with a clip function to be consistent with Lung (2004). Despite orthorectification of the aerial photographs, there are some discrepancies where the forest edge does not perfectly align with the gazetted boundary and must be accepted. Where these are obvious the vegetation of the area in question has not been included in the analysis as it will normally lead to the misleading inclusion of farmland within the forest estate. It should be further noted, that the forest area figures derived from the aerial photography are sometimes derived from an incomplete photo-mosaic. The 1948/52 mosaic

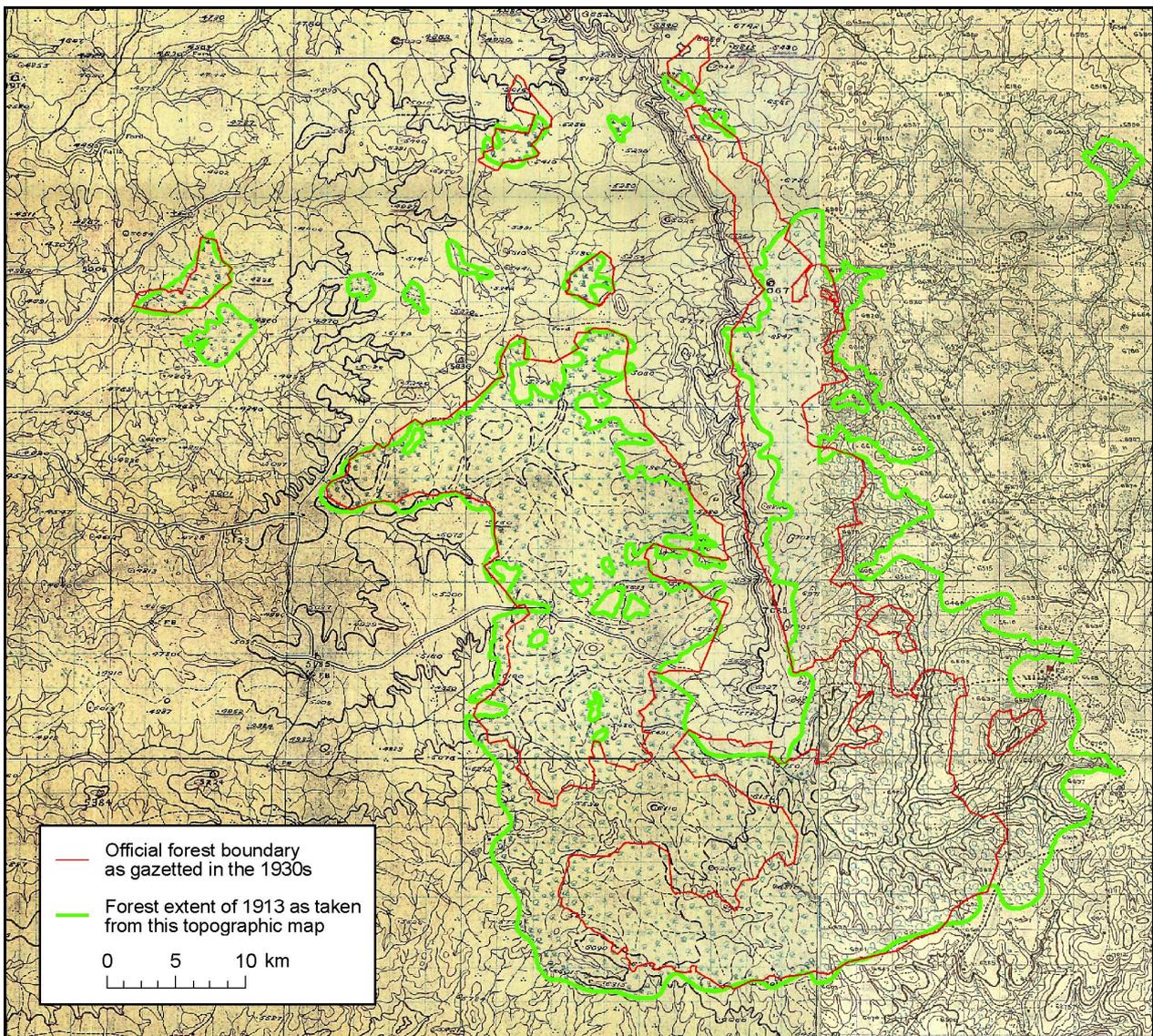


Figure 2: Original drawings of the 1913 survey for the 1:250,000 East Africa map series (sheets North A-36 W Mumias, North A-36 X Uasin Gishu; published by War Office, 1916), forest extent highlighted and additionally overlaid by official forest boundaries as gazetted in the 1930s.

covers the entire Kisere Forest and 95% and 81% of the gazetted areas of Kakamega and North Nandi Forests respectively, while Malava and South Nandi Forests are represented by just 31% and 7% photo coverage. The 1965/67 mosaic represents a complete coverage of Kakamega, Kisere, and North and South Nandi Forests although Malava is represented by 83% of the gazetted area.

The marked forest limits on the original drawings of the 1913 survey for the 1:250,000 East Africa map series (sheets North A-36 W Mumias, North A-36 X Uasin Gishu; published by War Office, 1916) have also been digitised on-screen after georeferencing of the two old topographic map sheets (see Figure 2). Forest cover figures have been derived from this although the map does not provide for distinction between vegetation classes. Their inclusion in the tables enables comparison with previously published forest cover figures and those derived within the BIOTA East Africa project, thus covering an 88-year period.

3. RESULTS AND DISCUSSION

We present the newly derived forest area figures in the context of figures extracted from publications by other authors published since 1988. These reports have described and discussed the extent of Kakamega Forest and, in a few cases, also the extent of its associated forest areas. It should be straight forward to trace forest cover change in the Kakamega area from these figures. However, statistics derived from data sources of such different types cannot in combination represent a consistent, homogenous time series and different methods of data analysis and different ways of presenting results (either as area figures or as maps) also make it hard to compile the data and appreciate the pattern of change. Some publications simply note the size of the forest area at a certain date, while others analyse the change in land cover for two or more time steps. Uncertainty is added to these numbers by the fact that they are based on different classification schemes and their use of different labels for parts of the forest estate. At first glance these publications appear to show area numbers that differ considerably from each other. Thus, an attempt has been made to tabulate the available published forest area figures to allow for comparison with results from BIOTA-E02 analyses.

Table 1 lists forest area figures (in ha) for Kakamega Forest taken from nine chronologically ordered papers and reports published between 1988 and 2004. The table further includes numbers derived by performing area calculations in GIS on vectorised map information or on results of on-screen visual interpretation of satellite imagery. In some cases the published figures have considered only 'forest cover', but in most instances a distinction has been made between what we call 'natural forest', 'plantation forest', and 'bushland or shrubs'. Numbers are also given for the gazetted forest area, for the nominal forest area (i.e. subtracting the excised areas), and the National and Nature Reserves. Table 2 is similar to Table 1 but lists forest area figures for Kisere Forest, Malava Forest, Bunyala Forest and the two Nandi Forests. Here, only six of the nine publications referred to in Table 1 list values for these forests. Figures for divisions by vegetation class within these forests are not given as they are not available except in Lung (2004). By cross-checking between reports it has been possible to clearly relate the published area figures to forest cover classes and most figures are shown to agree relatively well.

The forest boundary of Kakamega Forest was gazetted in 1933 with an area of 23,777 ha. The nominal forest area with 20,750 ha, only specified in Blackett (1994) and valid for 1991, should be a more precise official figure because it takes the excision areas (e.g. Shikusa prison land) into account. However, in both cases the area actually covered by forest should be considered smaller because of the inclusion of the grassy glades, for which Kakamega Forest is renowned (see e.g. Kokwaro, 1988). In some cases confusion is still possible due to reports referencing other works without citing the exact wording or term originally used. For example, Kokwaro (1988) and KIFCON (1992) both refer to figures derived by the 1966 Reconnaissance Inventory of Indigenous Forest Areas and give an unspecified 'area' of 25,600 ha and 25,569 ha respectively. Out of these figures, Kokwaro refers to 16,700 ha of 'merchantable strata' (not included in Table 1), while KIFCON reports that 16,685 ha represents 'indigenous forest'. The values of forest cover derived by ICRAF (1996), based on a digitising of topographic map sheets of 1967 and a threshold analysis of Spot imagery for 1991, seem too low when compared to the neighbouring figures in Table 1. However, they match relatively well with the results derived by Lung (2004) when the numbers for natural forest cover, forest plantation cover and bushland / shrubs are added together. As expected, the 1967 figure broadly agrees with our area figure derived from digitising the same topographic map. The values for natural forest as specified by Brooks et al. (1999) also match reasonably well (see Table 1), although we question the manner in which they have been derived from Landsat imagery and aerial photography. The figures for natural forest from Doe 1979 (11,645 ha) and Beentje 1990 (8,000 ha) as cited in KIFCON (1992) appear to be too low. Kamugisha et al. (1997) state that Kakamega Forest "covers about 23,000 ha" (p. 32), but also that the forest complex has been 'reduced to a little over 10,000 ha' (p. 42). Thus, the 23,000 ha should be the size of the gazetted forest area with a more exact area of 23,777 ha, as also specified in the same paper, while the 10,000 ha probably refer to the physical forest extent at that time. Likewise, area numbers provided for Kisere, Malava, Bunyala and South Nandi forests, (see Table 2), probably refer to the gazetted forest areas.

Further confusion arises over the reserves, e.g. in Kamugisha et al. (1997) where contrary area figures (9,698 ha and 3,985 ha) are provided within the same document for the Kakamega National Reserve. This reserve, (in some papers referred to as 'Buyangu National Reserve', e.g. Gibbon 1991, Kamugisha et al. 1997 Fig. 3.1b), is located in the northern part of Kakamega Forest but also includes Kisere Forest. Kamugisha et al's area figure of 3,985 ha for the reserve appears to be the more accurate. In addition, two Nature Reserves, 'Isecheno Nature Reserve' and 'Yala Nature Reserve', are located within the main body of Kakamega Forest but are not commonly or accurately located on maps.

The area of bushland given by Tsingalia (1988) for 1974 seems to be too low. Area numbers for plantation forest cover taken from the different publications vary greatly. Due to the fact that plantations of *Maesopsis eminii* could not be separated by the multispectral classification of Landsat time series data and are therefore included in the classes 'Secondary forest' and 'Bushland / shrubs' (see Lung 2004 or Lung & Schaab 2004), the values of Lung (2004) for natural forest should be lower and the values for plantation forest cover slightly higher. Established mixed indigenous plantations are included in 'Near natural + old secondary forest'. As there has been repeated logging and reforestation in Kakamega Forest (Mitchell 2004, Scully 2001, KIFCON 1994, Tsingalia 1988), further inform-

Table 1: Comparison of forest area figures (in ha) for Kakamega Forest, as derived within the BIOTA East Africa project, with figures from published literature.

Forest areas considered	Year	Tsingalia 1988 ⁸	Kokwaro 1988	Gibbon 1991 (KIFCON)	KIFCON 1992	Blackett 1994 (KIFCON)	ICRAF 1996	Kamugisha et al. 1997	Brooks et al. 1999	Lung 2004 ²⁵ (BIOTA-E02)	BIOTA-E02 results
Gazetted forest area	as of 1933		23,777			23,777		23,777			23,632 ²⁹
Nominal forest area ¹	1991					20,750					
Kakamega National Reserve	1986			3,997 ¹²		3,985 ¹⁷		3,985 ²²			3,812 ³⁰
Isechono Nature Reserve	1967										295 ³⁰
Yala Nature Reserve	1967										460 ³⁰
	Source	not specified	not specified	not specified	not specified	aerial photos	Spot imagery + topo maps	not specified	aerial photos + Landsat	Landsat imagery	Landsat, aerial photos + topo maps
Forest cover	1913										74,718 ³¹
	1966		25,600 ⁹								
	1967				25,569 ¹⁴		17,058 ²¹				
	1979										
	1991			18,497 ¹³			16,826 ²¹				
	1997						a little over 10,000				
Natural forest cover	1948/52										(17,529) ³²
	1965/67							ca. 15,000 ²³			16,811 ³³
	1967		14,268 ^{10,11}		16,685 ¹⁴						16,875 ²⁹
	1972 ²		14,268 ¹⁰						15,207 ²⁶		
	1974	13,504 ⁶									
	1975								14,553 ²⁸		
	1976		13,088 ¹⁰								
	1979				11,645 ¹⁵						
	1980 ³		12,308 ¹⁰							14,277 ²⁶	
	1984									12,523 ²⁶	
	1989							11,550 ²⁴		13,103 ²⁶	
	1990				8,000 ¹⁶						
1991					10,100 ¹⁸						
1995 ⁴									12,922 ²⁶		
2001									12,288 ²⁶	11,106 ³⁴	
Forest plantation cover	1948/52										(397) ³²
	1965/67										1,577 ²³
	1967										1,672 ²³
	1972 ²								880 ²⁷		
	1974	2,411 ⁷									
	1975								925 ²⁷		
	1979				2,655 ¹⁵						
	1980 ³		1,690 ¹⁰							732 ²⁷	
	1984									1082 ²⁷	
	1989									894 ²⁷	
	1991					1,700 ¹⁹					
1995 ⁴									620 ²⁷		
2001									1,047 ²⁷		
Bushland / shrubs	1948/52										(352) ³²
	1965/67										505 ³³
	1972 ²								1,437 ²⁶		
	1974	238 ⁵									
	1975								851 ²⁸		
	1980 ³								1,227 ²⁸		
	1984								2,934 ²⁶		
	1989								3,252 ²⁶		
	1991					3,500 ²⁰					
	1995 ⁴								4,541 ²⁶		
2001								4,113 ²⁶			

1 managed by Forest Department (FD) or Kenya Wildlife Service (KWS), gazetted forest area minus excision areas (in parts estimated values)
2 in Lung (2004) refers to time step 1972/73
3 in Lung (2004) refers to time step 1979/80
4 in Lung (2004) refers to time step 1994/95
5 adopted from F.A.O. World Forestry Inventory Specifications, Forest Inventory Section
6 sum of 12,212 ha "indigenous forest", 452 ha "erosion protection", 535 ha Yala Nature Reserve and 305 ha Forest Station Nature Reserve
7 sum of 2,375 ha "plantations" and 36 ha "under planting"
8 sum of 129 ha "bush and scattered trees" and 109 ha "bush"
9 named "indigenous forest", taken from the Inventory Section of Kenya Forest Department
10 figures estimated by KREMU, taken from Doute et al. 1981 and Ochanda et al. 1981
11 refers to the years 1959-67
12 named "Buyangu National Reserve"
13 sum of 14,500 ha "Kakamega main block" and 3,997 ha "Buyangu National Reserve"; no further information on how Kakamega main block is exactly defined
14 reconnaissance inventory of indigenous forest, refers to 1963-67
15 taken from Doe 1979 (reference year not specified); value of 11,645 ha for natural forest cover calculated by subtracting 2,655 ha of plantation forest from 14,300 ha
16 taken from Beenlje 1990 (reference year not specified)
17 named "National Reserve"
18 named "heterogeneous, high and continuous canopy", the same figure can be found in Wass (1995)
19 named "homogeneous, high level canopy or symmetrical planting lines"
20 sum of 2,000 ha "forest / scrub" and 1,500 ha "scrub", named "homogeneous, low and fragmented canopy"
21 based on a threshold analysis distinguishing "forest" and "non-forest"; named "tree cover", including plantation forest
22 Kakamega National Reserve also specified with 9,698 ha; in a map called "Buyangu National Reserve" (Kamugisha et al. 1997, Fig. 3.1b)
23 refers to 1965 only
24 sum of 8,600 ha Kakamega main forest, 1,450 ha Ikuywa forest and 1,500 ha Yala forest
25 based on a supervised multispectral classification of Landsat imagery; 60 m resolution for time steps 1972/73, 1975 and 1979/80, 30 m resolution for time steps 1984, 1989, 1994/95 and 2001
26 sum of classes "Near natural + old secondary forest" and "Secondary forest"
27 sum of classes "Plantation forest - *Pinus patula*" and "Plantation forest - *Bischofia javanica*"
28 sum of classes "Bushland / Shrubs" and "Secondary Bushland - *Psidium guajava*"
29 digitised from topographic maps East Africa 1:50'000 (Kenya), Sheets 102/2 and 102/4, Series Y731 (D.O.S. 423), Edition 6 (1970), which are based on aerial photogr. from 1967
30 derived from Forest Department maps or extrapolated from sketch maps
31 derived from East Africa map series 1:250,000 surveyed in 1913 (sheets North A-36 W Mumias, North A-36 X Uasin Gishu; published by War Office, 1916); Kakamega Forest, South and North Nandi Forests formed one unit by that time
32 derived by visual interpretation of aerial photography from 1948/52 with 95% coverage of the gazetted area only
33 derived by visual interpretation of aerial photography from 1965/67
34 sum of 8,537 ha Kakamega main forest, 1,370 ha Ikuywa forest and 1,200 ha Yala forest, derived by a visual interpretation and on-screen digitising of a Landsat scene from 05 Feb 2001 displayed as band combination 5/4/3 and contrast-enhanced

ation from silvicultural records would be needed for assessing the reliability of these numbers. Further numbers on the size of Kakamega Forest have been published, but due to missing reference years or confusing specifications they have not been included in Table 1. For example, Fashing (1999, p. 21) claims the “remaining forested” area to be only 4,000 ha without giving any reference year. As this figure does not match at all, we assume that it must refer to a protected forest area, most probably the Kakamega National Reserve. Mutangah (year unknown) specifies an area of 13,888 ha of ‘natural forest’ and 1,592 ha “occupied by plantation forests” referring to personal communication with a forester from the Kakamega Forest Station Headquarters, but does not give a reference year. These values would be of a plausible magnitude for the guessed time of publication (ca. 1996/97), but has not been included in the table for the above reason.

For area numbers on the forests associated with Kakamega Forest (see Table 2), especially for Malava and Bunyala Forests, statements regarding the reliability of the given values for the different years are made difficult by the exposure of these forests to rapid changes in logging and reforestation activities. Bunyala has experienced a dramatic loss in forest cover in the late 1960s and early 1970s, as our time series figures reveal. Malava Forest is remarkable for having been surveyed at a smaller size in 1913 (485 ha) than at the time of its gazettal in the 1930s (703 ha) and suggests that the forest had expanded in the intervening years. In the decades subsequent to the 1930s Malava suffered major reductions in forest cover due to forestry operations (Mitchell 2004), and figures derived here from aerial photography for 1965/67 show the total forest cover at 375 ha although only 83% of the gazetted forest is represented by the aerial photograph coverage. The 600 ha given by Brooks et al. (1999) for Malava for the same time step seems to be an overestimation. Landsat-derived figures indicate a further decrease of forest cover to less than 200 ha in the year 2001. The forest cover of Kisere Forest has expanded within its official boundary from 347 ha in 1913 to 371 ha by 1965/67 and to 410 ha by 2001 as shown by Landsat data. This is due to the protection provided after its boundary was generously set to include some grassland in the 1930s (Mitchell 2004). The numbers for Kisere Forest specified by Kokwaro (1988) and Brooks et al. (1999) have to be handled with care since they imply that there has not been any change between 1967 and 1980 and 1948 and 1999, respectively.

We provide no figures for North and South Nandi Forests in Table 2 for 1913 although these areas are represented on the map of that date. Instead a forest cover figure of 74,718 ha is placed in Table 1 for Kakamega Forest since at that time the forests of Kakamega, North Nandi and South Nandi formed a single, U-shaped forest which left a stretch of bare land between what are now North Nandi and Kakamega Forests. Thus, the forest cover figure of 74,718 ha should be compared with the total of the values for Kakamega and North and South Nandi Forests at later dates. The surveyors’ criteria for interpreting exactly which vegetation constituted ‘forest’ in 1913 is unknown. However, it is clear from oral histories (unpublished data) and historic aerial photography that bushland in the earlier half of the twentieth century was of limited extent and resulted in a distinct forest / non-forest boundary that would have reduced the difficulties in plotting the forest edge. The map (Figure 2) marks some blank areas within the forest which represent a few of the larger grassy glades that are still a prominent feature of Kakamega Forest today. Both oral and written histories, e.g. Mitchell (2004) and Brooks et al. (1999), reveal that many glades existed at that date. The forest cover

figure of 74,718 ha derived from these maps is therefore likely to be a slight over-estimate of forest cover.

The aerial photographs of 1948/52 show the connection to Kakamega Forest still in evidence but sharply reducing and the 1965/67 photographic mosaic shows the link to be almost entirely eroded. The link to North Nandi is not shown in the 1948 / 52 photographs but it is already clearly broken by 1965/67. Adding together the figures derived from the 2001 Landsat imagery for North Nandi, South Nandi and Kakamega Forest (in total 28,038 ha) and comparing it with the forest cover from 1913 (74,718 ha) reveals that the forest block has been reduced to 37.5% of its former size. In more recent decades the greatest loss in forest cover has occurred in South Nandi Forest which, in 2001, stood at 44% of the forest cover of 35 years earlier (17,869 ha in 1965/67 as compared to 7,845 ha in 2001). In the same period North Nandi Forest was reduced to 68% of its former cover (10,122 ha in 1965/67, reduced to 6,858 ha in 2001) and Kakamega Forest to 73% (18,388 ha in 1965/67, reduced to 13,335 ha in 2001). There have been further losses from these forests outside the official gazetted boundaries. It should be noted that values given by BIOTA for South Nandi Forest here are lower than those of ICRAF (1996) for 1991 and result from treating ‘Bushland / shrubs’ as a separate class while the ICRAF threshold analysis assigns bushland to forest. To conclude, the most dramatic forest loss is apparent if we exclude plantation from the 2001 figure in which case natural forest cover is seen to have reduced to 25,727 ha, i.e. to 34.4% of its 1913 extent.

4. CONCLUSION

For the first time the extent, manner and dates of forest cover change for Kakamega Forest and its associated forest areas are revealed for a period of almost 90 years. This demonstrates the value of combining satellite imagery, aerial photography and old topographic maps in order to derive figures on forest losses and gains from the early 20th century up to the start of the 21st. Old topographic maps and aerial photography enable us to chart the considerable decline of forest cover and the process of separation into the three fragments known today as Kakamega, South Nandi and North Nandi Forests. The multispectral classification of the Landsat imagery reveals that forest cover has continued to reduce since breaking into separate fragments while bushland increases up to 2001.

The existence of the forest as a single unit joined with the Nandi Forests within living memory has not been acknowledged by the scientific community which has consistently considered the biodiversity-renowned Kakamega Forest in isolation, as an island without neighbours. It is our belief that the Nandi Forests should receive more attention from scientists and conservationists as having been part of the Kakamega Forest block. These facts should be of importance to those managing these forests and to ecologists, especially those considering population dynamics in any of these fragments.

It is of interest to note that, by contrast to the Nandi Forests, the Kisere, Malava and Bunyala blocks to the north were separate from Kakamega Forest in 1913, although some other forest fragments were present that are now lost to agriculture. The clearly arranged compilation of area numbers via tables presented here enables us to place our derived numbers in the context of area figures from other sources and should reduce confusion in the use of area numbers relating to Kakamega

Table 2: Forest area figures (in ha) for some of the forests associated with Kakamega Forest, comparing those derived within the BIOTA East Africa project with others from published literature.

Forest areas considered	Year	Kokwaro 1988	Gibbon 1991 (KIFCON)	ICRAF 1996	Kamugisha et al. 1997	Brooks et al. 1999	Lung 2004 ¹¹ (BIOTA-E02)	BIOTA-E02 results
	Source	not specified	not specified	Spot imagery + topo maps	not specified	aerial photos + Landsat	Landsat imagery	Landsat, aerial photos + topo maps
Kisere Forest, gazetted area	as of 1930s	484	471		600 ⁵		458	458 ¹²
	1913							347 ¹³
	1948/52					400 ⁹		352 ¹⁵
	1965/67							373 ¹⁶
	1967	472 ⁵						380 ¹²
	1972 ²	472					353	
	1975						363	
Kisere Forest, forest cover ¹	1976	472						
	1980 ³	472					359	
	1984						354	
	1989						392	
	1991		471 ⁵					
	1995 ⁴						393	
	1999					400		
	2001						410	420 ¹⁷
Malava Forest, gazetted area	as of 1930s	718	719		800 ⁵	718	703	703 ¹²
	1913							485 ¹³
	1948/52							(141) ¹⁵
	1965/67					600 ¹⁰		375 ¹⁶
	1967	0 ⁵						421 ¹²
	1972 ²	0					195	
	1975						158	
Malava Forest, forest cover ¹	1976	205						
	1980 ³	218					123	
	1984						162	
	1989						244	
	1991		ca. 150 ⁵					
	1995 ⁴						192	
	1999					100		
	2001						183	113 ¹⁶
Bunyala Forest, gazetted area	as of 1930s	825	825		1,000 ⁵		807	807 ¹²
	1913							845 ¹³
	1965/67							588 ¹⁶
	1967	825 ⁵						609 ¹²
	1972 ²	0					215	
	1975						36	
Bunyala Forest, forest cover ¹	1976	0						
	1980 ³	105					18	
	1984						32	
	1989						97	
	1991		<10 ⁵					
	1995 ⁴						95	
	2001						54	
North Nandi Forest, gazetted area	as of 1930s							11,437 ¹²
	1913							¹⁴
	1948/52							(7,907) ¹⁵
	1965/67							10,122 ¹⁶
	1967			10,452 ⁷				10,777 ¹²
	1972 ²						9,328	
	1975						8,800	
North Nandi Forest, forest cover ¹	1980 ³						8,099	
	1984						7,417	
	1989						7,651	
	1991			7,915 ⁷				
	1995 ⁴						7,457	
	2001						6,858	
South Nandi Forest, gazetted area	as of 1930s				19,502 ⁸			19,536 ¹²
	1913							¹⁴
	1948/52							(1,350) ¹⁵
	1965/67							17,869 ¹⁶
	1967			17,653 ⁷				18,719 ¹²
	1972 ²						14,558	
	1975						14,288	
South Nandi Forest, forest cover ¹	1980 ³						13,886	
	1984						13,276	
	1989						12,588	
	1991			15,955 ⁷				
	1995 ⁴						9,141	
	2001						7,845	

¹ including plantation forest but not bushland / shrubs

² in Lung (2004) refers to time step 1972/73

³ in Lung (2004) refers to time step 1979/80

⁴ in Lung (2004) refers to time step 1994/95

⁵ refers to the years 1959-67

⁶ only indigenous forest considered

⁷ based on a threshold analysis distinguishing "forest" and "non-forest"

⁸ reference year not specified; refer most probably to gazetted forest areas

⁹ refers to 1948 only

¹⁰ refers to 1965 only

¹¹ based on a supervised multispectral classification of Landsat imagery; 60 m resolution for time steps 1972/73, 1975 and 1979/80, 30 m resolution for time steps 1984, 1989, 1994/95 and 2001

¹² digitised from topo maps East Africa 1:50'000 (Kenya), Sheets 102/1, 102/2 and 102/4, Series Y731 (D.O.S. 423), Edition 6 (1970), which are based on aerial photos from 1967

¹³ derived from East Africa map series 1:250,000 surveyed in 1913 (sheets North A-36 W Mumias, North A-36 X Uasin Gishu; published by War Office, 1916)

¹⁴ derived from East Africa map series 1:250,000 surveyed in 1913 (sheets North A-36 W Mumias, North A-36 X Uasin Gishu; published by War Office, 1916); Kakamega Forest, South and North Nandi Forests formed one unit by that time, see table 1 for area figure

¹⁵ derived by visual interpretation of aerial photography from 1948/52 with partial coverage of the gazetted areas only (Kisere Forest: 100%, Malava Forest: 31%, Bunyala Forest: no coverage, North Nandi Forest: 81%, South Nandi Forest: 7.4%)

¹⁶ derived by visual interpretation of aerial photography from 1965/67

¹⁷ derived by visual interpretation and on-screen digitising of Landsat scene (05 Feb 2001) displayed as band combination 5/4/3 and contrast-enhanced; excluding plantation forest

Forest and its associated forest areas. Comparison of the figures shows that the results of the multispectral classification by Lung (2004) represent the first time series based on homogenous (by contrast to Brooks et al. 1999) and dense (by contrast to ICRAF 1996) data sourcing and processing. Lung's series relates to the entire period that Landsat has been in orbit since the early 1970s, and has now been extended back with three more time steps to 1913 using aerial photography and old topographic maps. As such it serves as a solid basis for assessing forest cover development for almost one century.

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