Rainforest change analysis in Eastern Africa: A new multi-sourced, semi-quantitative approach to investigating more than 100 years of forest cover disturbance

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Abstract

Forest change and disturbance of the past strongly influence the state of today's forests and their biodiversity. However, knowledge of former forest landscape states can be subject to misunderstanding and the practical management of forests requires the establishment of correct narratives of forest cover change. This thesis therefore investigates the long-term forest change and anthropogenic factors at work within three tropical rain forests of high biodiversity and high use value in Kenya and Uganda.

A wide range of data sources are employed for a semi-quantitative analysis. Starting from an existing time series of satellite imagery classifications the research incorporates the visual interpretation of historical aerial photography, forestry records, maps of both topographic and thematic type, archive documents, oral histories, place name meanings, and fossil pollen evidence. GIS is used as the means to manage and focus the evidence and to analyse the wide range of data.

In combination the sources allow the building of a narrative characterised by variation across both space and time. The localised reality of forest change is reflected in the inclusion of case studies from which forest narratives of each of the three main forest areas are subsequently constructed. The forest cover time series are extended back to around 1910 for each of the forests and thus to a pre-commercial exploitation state; they reveal losses of 60% and 43% of the forests of Kakamega-Nandi and Mabira respectively. These losses have been arrested in recent years while Budongo Forest has shown negligible change across the full period with the first losses recently occurring outside the forest reserves.

The long-term approach has revealed fluctuations in forest cover, most notably in Mabira Forest across the 20th century and in parts of the Kakamega-Nandi area both across decades and across millennia. A landscape view shows these areas to have long-existed as mosaics of forest, woodland and grassland, and the loss of grassland over the last century has exceeded that of forest. The study identifies an historic role for disease and tribal conflict in the creation and protection of forest cover in East Africa but also traces a development in the underlying causes of forest cover change towards commercial and governance factors. The creation of a population time series demonstrates that population density cannot be described as the main driver of deforestation. Two spatially-explicit indices distinguish between locally and commercially-driven disturbances and are compared with an index of forest cover change. Results reveal a localised pattern and that commercial disturbance has played an especially large role in the degradation and fragmentation of the Kakamega-Nandi forests while local disturbance is shown to be most dramatic in Mabira Forest. Most of Budongo Forest has been persistently degraded by systematic commercial exploitation.

It is suggested that these forests should be managed with recognition of their mosaic heritage but also as dynamic and changing entities. The study concludes that while the heterogeneity found within forest landscapes is often due to human disturbance, ecologists should also consider natural processes, including variations in past climate, for explanations. The cumulative nature of disturbance is highlighted with the recommendation that past exploitation should be included in any assessment of forest degradation and can be usefully analysed in two parts, commercially- and locally-derived disturbance. The use of GIS and the creation of disturbance indices is recommended as a viable means of quantitatively assessing forest degradation and of distinguishing between the contributions of different types of disturbance. The most under-used resources available for researching long-term forest change are stated to be topographic maps and forestry archives. The quantitative data they provide can be usefully supported by qualitative information, most flexibly provided by forest history interviews.

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Table of contents

List of Figures

List of Tables

1. Introduction

1.1 Background

1.1.1 Background and aims of the research

In 2000/2001 the German Federal Ministry of Education and Research (BMBF) began funding the BIOTA (Biodiversity Monitoring Transect Analysis in Africa) project with programmes in East, West, South, Central, and more latterly North Africa. It has aimed to assess biodiversity (i.e. biological diversity, *cf*. Leveque & Mounolou 2003) against an understanding of the natural processes and the impact and value of human usage in order to lay the foundations for a sustainable management of biodiversity in the continent (Köhler 2004). The BIOTA-East project in Kenya and Uganda has focused on an understanding of rainforest biodiversity in the context of a gradient of degradation and anthropogenic disturbance (Köhler 2004, BMBF 2008). An initial study on forest use history was therefore commissioned and completed for Kakamega Forest (Mitchell 2004).

However, scientists and managers have still lacked the means of assessing the development of forest landscapes across meaningful time scales of a century or longer, to analyse the changing role of human interaction with forests and to spatially analyse the disturbance of forests. To this end the initial Kakamega study has therefore been further developed for the current thesis as a demonstration of the utility of a semi-quantitative, spatial approach with a long temporal perspective. It aims to demonstrate the power of integrating a diverse range of normally disparate data sources of widely varying qualities and accuracies within GIS for forest cover analysis. More specifically the study aims to achieve a comparable investigation across three separate forest areas in Eastern Africa that results in:

- the reconstruction and analysis of forest cover change across at least one hundred years, including analysis of forest quality for the last half century,
- the temporal analysis of factors contributing to forest cover change,
- the spatially-explicit analysis and quantification of accumulated anthropogenic disturbance.

The research is designed to provide the fullest understanding of the accumulated impact of human actions and the forces of degradation that have left their mark upon today's forests. This long-term analysis of forest landscape development is intended to inform the decision making for the long-term future regarding both management policy interventions and scientific research design. The scope of research encompasses Kakamega Forest, the neighbouring Nandi Forests in Kenya and two Ugandan areas of investigation, Mabira and Budongo Forests (see Figure 1.1).

1.1.2 Note on definitions

The term '**forest cover**' as used in this thesis refers to the presence of indigenous forest, whether largely undisturbed or secondary in origin. '**Forest cover change**' is used here to include both the '**conversion of forest**' to an alternative land cover or land use, such as grassland or agriculture, and '**forest modification**', i.e. the change of one forest cover class to another, e.g. from secondary forest to bushland (*cf*. Lambin & Geist 2006). '**Forest quality**' refers here to the condition of the forest regarding its intact or degraded state while the generic definition of '**forest degradation**' is adopted in which it represents the reduction of the capacity of a forest to provide goods and services (*cf*. FAO 2002). This can be present with potentially numerous gradations of quality (*cf*. Sasaki & Putz 2008). The term '**forest disturbance**' is used here to reflect human interactions with the forest ecosystem that alter the structure, composition or functioning of the forest and which often result in either forest conversion or modification. This interpretation is in line with Pickett and White's (1985) broadly accepted definition in which disturbance represents any relatively discrete event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment. Although disturbance regimes can in reality include an array of natural disturbances such as wind, insects, disease and floods etc. (Kimmins 2004), the definition here is, as far as distinction allows, restricted to those of direct human initiation.

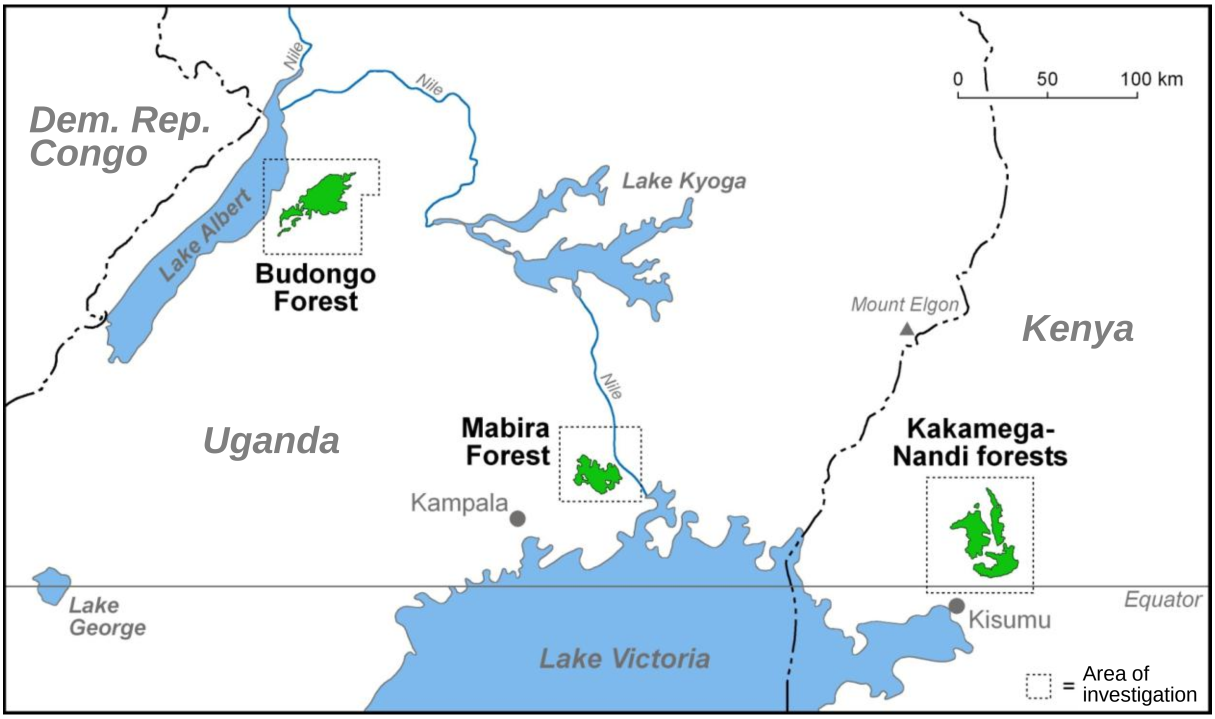


Figure 1.1: The locations of the forests researched within the BIOTA-East research project (map courtesy of Tobias Lung, slightly modified).

1.1.3 The structure of the thesis

The broad layout of the thesis is illustrated in Figure 1.2. The **introduction** (chapter 1) first establishes the context and justification for the research with a consideration of rainforest cover changes and land-use/cover change studies. This is continued with a review of the significance of forest degradation and disturbance and the reasons for pursuing a long-term approach. The main geographical, management and demographic setting of the three areas of investigation is then reviewed and compared. With a focus on the East African forests of concern to this thesis, a literature review then sets out the different methods that have previously been employed to investigate forest cover change and forest disturbance. In light of the gaps that have so far remained, the multi-sourced, spatio-temporal methodology adopted in this thesis is outlined.

The chapter on **data sources and pre-processing** (chapter 2) then reviews the data acquisition, pre-processing steps and the output in terms of data acquired and processed. The **forest cover change case studies** (chapter 3) consider in detail the forest development of twelve specific locations around the forests of Kakamega-Nandi, Mabira and Budongo. Here the utility of interlocking sources is demonstrated in building towards the reconstruction of the long-term storyline at a local scale; at the same time the main pathways of forest cover transition and the contributing causal factors are introduced. This is followed by the **forest narratives** at the broader scale of the three individual areas of investigation (chapter 4); they summarize and discuss the changes and the competing forces that were introduced in the case studies and focus mostly on the last one hundred years. Here the forest cover changes and various contributing causes are traced over time via graphs of forest cover and population against the backdrop of historical events. The **disturbance indices** (chapter 5) then show how disturbance can be analysed by its commercial or local origins and expressed in a spatially-explicit format. Comparison with a forest cover change index also allows assessment of how much of the detectable changes can be attributed to commercial and local forces.

The first part of the **discussion and synthesis** chapter (chapter 6) considers the broad results and implications regarding the forest landscape development over time and space. The degree to which they can be generalised between the three areas of investigation and the changing role of different causal factors are then discussed. The second part of the chapter allows for discussion of the advantages and disadvantages of employing multiple data sources and the benefits of using them in combination and within a GIS are also highlighted. The thesis finishes with **summarizing remarks, conclusions and outlook** (chapter 7).

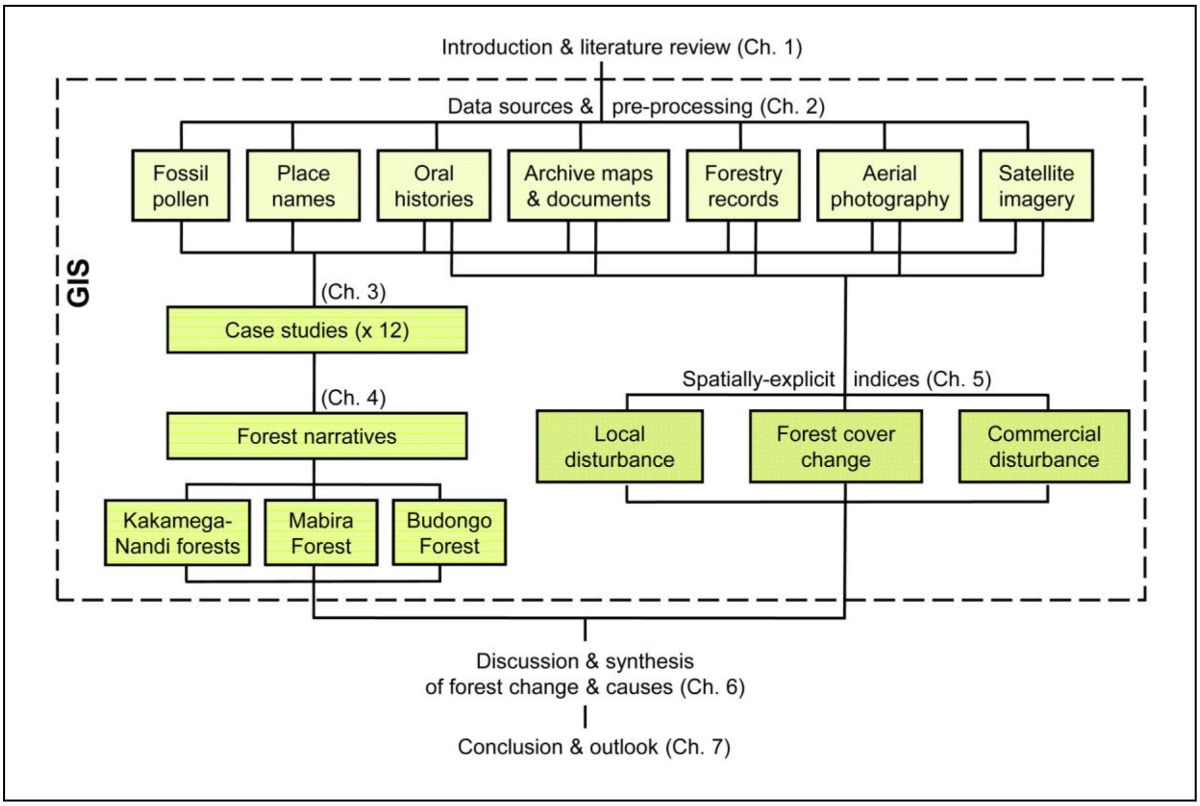


Figure 1.2: The structure of the thesis, showing the contributing data sources feeding into the case studies, the forest narratives and the spatially-explicit indices.

1.2 The context and justification for forest cover change and disturbance research

1.2.1 Rainforest cover and land-use/cover change studies

Tropical forests cover only 7% of the world's surface and yet they represent the largest terrestrial reservoir of biological diversity on earth (Myers *et al*. 2000) and the IUCN Red List of Threatened Species shows that amongst the major biomes of the world, rainforests contain by far the greatest number of threatened species (IUCN 2009). The value of African tropical rainforests as repositories for some of the planet's highest levels of biodiversity is widely accepted (e.g. Myers *et al*. 2000, Turner *et al*. 2007) and Kenya and Uganda are ranked respectively third and eighth highest amongst mainland African countries for the number of endangered or vulnerable animal species (IUCN 2009).

While an appreciation of the intrinsic, non-use value of biodiversity has been the inspiration for many conservation initiatives there is a growing understanding of its practical benefits via the interdependent relationship between species diversity and ecosystem function (Loreau *et al*. 2010). Biodiversity is now commonly referred to as effectively underpinning the resilience of ecosystem function and the provision of essential ecosystem services (e.g. Begon *et al*. 2006); however, little is known about the degree of biodiversity loss that can be tolerated before these functions are seriously compromised (Rockström *et al*. 2009). At a global level of ecosystem service, the significance of forest loss and degradation is highlighted by estimates that the forestry sector may account for 17% of global greenhouse gas emissions (UN 2008) or up to 25% of global total anthropogenic emissions (IPCC 2009). It is estimated that preventing deforestation represents the largest and most immediate means of mitigating climate change (*ibid*.) and a recent study demonstrates that the old-growth, i.e. less disturbed, rainforests of tropical Africa are of particular merit for carbon sequestration (Lewis *et al*. 2009). These forests are not merely maintaining their carbon stocks but have been absorbing increasing levels of carbon over the last four decades. Among the ecosystem services with significant local impact are the provision of fresh water, food, shelter through building materials, fuel, soil conservation, flood control, and non-timber forest products such as plant-based medicines, cultural practices, and ecotourism (Constanza *et al*. 1997). The far-reaching impact of these services makes them integral to any conservation effort that recognizes the need to develop sustainable livelihoods (e.g. Cooper 2004, Köhler 2004).

The significance of rainforest loss is therefore clear and the loss of this ecosystem more than any other carries the greatest proportional effect on total biodiversity (Foley *et al*. 2005) and their destruction should be seen as “the greatest threat to the biological diversity of the planet” (Turner & Corlett 1996, p. 330). The recent Global Forest Resources Assessment 2010 (FAO 2010) covers 233 countries and shows that the rate of conversion of tropical forest to agricultural land has decreased globally over the last decade. However, while Asia and Europe show a net gain in forest cover they highlight the continuation of alarmingly high rates of deforestation in other areas with South America and Africa showing the highest net annual loss of forests between 2000 and 2010, i.e. 4 and 3.4 million hectares, respectively. Furthermore, Wright & Muller-Landau (2006) show that Africa has the least forest remaining compared to its estimated potential forest cover. Within the continent East Africa has consistently remained amongst the regions experiencing the highest annual percentage rates of forest loss (0.94% in the 1990s and 0.97% from 2000 to 2005) with its forests predicted to shrink still further (FAO 2009). In 2002 Uganda had maintained just 4% ‘tropical high forest’ cover (Drichi 2003) while already in 1995 Kenya possessed less than 3% (Wass 1995). More localised studies are more varied in their results but most often also show declines in forest cover. For example, between the early 1970s and around 2003 forest cover in the main forest reserves of Kakamega-Nandi and Mabira have been shown to have declined by around 23% and 15%, respectively (Lung & Schaab 2010) while that of Budongo remained very stable within the forest reserve itself and declined outside it (Lung & Schaab 2008, *cf*. Plumptre 2002, *cf*. Mwavu & Witkowski 2008).

The situation therefore appears serious. The paramount importance of forest cover change is apparent due to the inevitable reduction in biodiversity from either a complete loss of forest habitat (e.g. Sayer 1992, Begon *et al*. 2006) or from the reduction of habitat as demonstrated by the relationship of species-richness to habitat area (*cf*. Brooks *et al*. 1999). Indeed, land-use and land-cover change has been recognised as one of the greatest factors in the reduction of biodiversity in tropical forest countries (Sala *et al.* 2000). The rapidly maturing area of research dedicated to tracing and analysing land-use/cover change, a major global example being the Land-Use and Land-Cover Change (LUCC) Rapid Land Cover Change Assessment, has revealed the complexities of the processes involved (Lambin & Geist

2006). Pressure from an expanding range of human activities on tropical forests increased dramatically across the 20th century (Klein Goldewijk 2001) and land-use/cover change studies have therefore debated the dynamic coupling of the human-environment system (Moran & Ostram 2005, Lambin & Geist 2006).

Many studies have sought to separate the different causal factors and the competing opinions have been summarised as representing a debate between investigators of a broadly Neo-Malthusian and those of a Boserupian persuasion (Doyle 2006). The former have stressed the idea that population growth has been too fast for sustainable use of natural resources (*e.g.* Barnes 1990) while the followers of Boserup (1965) have focused on the positive effects of a growing population with an increased social capital that enables greater agricultural activity and innovation (*cf.* Doyle 2006). Lambin and Geist (2006) have revealed reality to be more nuanced and complex than previously acknowledged and state that the richness of explanations have greatly increased although this has been at the expense of generalities.

However, their global meta-analysis of 300 tropical forest case studies indicates that although the causes of tropical deforestation are complex, they are not irreducible, i.e. there are recurrent themes allowing the identification of complex pathways of land change (Geist & Lambin 2004). Proximate causes or direct drivers of ecosystem change have been identified as those physical forces acting on the land cover generally at a local level and are typified by agriculture, forestry, infrastructure construction, and species introductions or eradications. Underlying causes, operating more remotely, diffusely and often at a more regional or national level are exemplified by demographic, economic, technological, policy or institutional, and cultural factors that are considered to impact and stimulate the operation of the proximate factors (*ibid*.). It is here at the level of cause identification that forest cover change studies are seen to be linked closely to the ultimate goal of sustainable forest conservation since it is through the identification of the causes that the design of appropriate policy intervention is facilitated (Moran & Ostram 2005).

There have been great advances in the study of land-use/cover change in the last two decades but Mayaux *et al*. (2005) note that despite the great importance of humid tropical forests and the seriousness of the deforestation situation, our knowledge of their rates of change remains limited, especially within Africa. Lambin and Geist (2006) agree stating that although deforestation is one of the best studied processes of land change, both the precise location and the changes are barely understood. Furthermore, while research has revealed that landscape change is normally not uni-directional over time or permanent (Lambin & Geist 2006), the temporal dimension has often been limited by a reliance upon remote sensing; this has consequently led to a focus on the recent past (*cf*. Mayaux *et al*. 2005, Mollicone *et al*. 2003). The HYDE database project is here acknowledged for its innovative hindcast modelling of historical land cover across the previous 300 years (Klein Goldewijk 2001) although the coarse scale results should be appreciated as estimates. The need to trace the historical state of the forest landscape appears to have been comparatively neglected due to the requirement of a more complex and multi-sourced methodology than that needed for studies of recent decades.

1.2.2 The importance of the historical perspective on land-use/cover change

Several decades ago Harper (1977) was stressing the importance of looking backwards in time for an explanation of the present vegetative state, and in the ensuing decades the emerging discipline of environmental history has gained increasing attention (e.g. Fairhead & Leach 1995, Egan & Howell 2001, Brown 2003, Dovers 2002). Lambin & Geist (2003) have noted that environmental and land-use history is critical in that it defines the initial conditions for each successive round of land-use changes. Thompson *et al*. (2002) state their belief that much of an ecosystem's present state can be understood through a combination of knowledge of its history alongside an understanding of environmental factors such as the influence of soil and topography. Other authors, for example, Foster (2006) concur when stating that virtually all ecological populations, habitats and landscapes are strongly conditioned by their history, and Herben *et al*. (2005) writing that an understanding of an ecosystem is impossible without reference to its past. Furthermore, it is on the basis that the significance of current levels of degradation are most realistically interpreted within the context of historic degradation levels, that FAO has been investigating methodologies for historical forest degradation research (Heymell 2009).

However, several researchers focusing on past landscapes have shown that false historical narratives regarding degradation rates and its causes have become enshrined in the general scientific consciousness and are perpetuated within conservation organisations without a basis in sound research (Gillson *et al*. 2003). European travellers in 19th-century Africa were quick to reach conclusive narratives of deforestation and erosion that were easily attributed to destructive African practices and such perceptions have persisted within popular understanding to the modern day (Brown 2003). The last two decades have seen numerous authors correcting established but false historical narratives regarding forest cover change and which have misled conservation efforts in Africa; examples include Leach & Mearns (1996), Maddox (2002), and more specifically in Eastern Africa, McCann (1997) and Brockington (2002). Without soundly-researched forest histories conservation strategies are liable to be based upon false premises that, as demonstrated in the above examples, commonly suppose the formerly ubiquitous existence of a now-destroyed forest or woodland landscape.

With the careful reconstruction of historical narratives the effect of human disturbance on rainforest structure has been demonstrated as persisting for many decades and even centuries (e.g. Struhsaker 1997, van Gemerden *et al*. 2003). With this long recovery period, the composition and structure of today’s forests can be seen as a legacy of an accumulated disturbance history (Egan & Howell 2001). An expanding literature demonstrates that substantial areas of the thick rainforests of equatorial Africa retain evidence of previous human settlement and activity long after the activity has ceased (e.g. White & Oates 1999, van Gemerden *et al.* 2003). Referring to the lowland Congo basin, Willis *et al*. (2004, p.403) state that this evidence has “led to the conclusion that much of this region underwent extensive habitation, clearance and cultivation” between about 3,000 and 1,600 years ago before a population crash lead to the regrowth of the rainforest. Lewis *et al*. (2009) even postulate that long-passed anthropogenic disturbance may still be causing the increase in the rate of carbon sequestration of the intact old-growth forests.

With the recognition that moderate levels of disturbance are often necessary to maintain ecosystem function and biodiversity, foresters with an ecosystem management style have increasingly been attempting to emulate natural or historic levels of disturbance (Kimmins 2004, Foster 2006). This concept of restoration ecology poses the problem of identifying a particular historic state to which to aspire (Diamond 1990), especially since modern ecological theory gives little credence to the idea of an idyllic phase in history in which ecosystems were maintained in equilibrium (Gillson *et al*. 2003). Ecologists now more commonly embrace the concept of a dynamic ecosystem continually altering the balance of its constituent parts as it adjusts to a changing suite of disturbance conditions (e.g. Gillson *et al*. 2003, Taylor *et al*. 1998, Beinart 2000). This systemic flux suggests that any attempt to identify a single idealised historic state to which managers should aim to restore ecosystems will be unsuccessful. It has therefore been suggested that a more realistic approach lies in the recreation of historic disturbance regimes (e.g. moderate levels of tree felling, cattle grazing, fire setting) to achieve a more ‘naturally’ fluctuating ecosystem (Kimmins 2004). The required identification and understanding of the levels and forms of historical disturbance regimes has, however, so far lacked adequate research (*ibid*.).

1.2.3 The significance of forest disturbance and degradation to biodiversity

The research of the last two decades has brought great advances in the understanding of the trends and processes involved in land-use/cover change (Lambin & Geist 2006). However, it is recognised both by scientists (*ibid*.) and conservation organisations (FAO 2009) that regarding forest cover such research has been focused on forest conversion to the detriment of our understanding of the degradation of forest quality which has been under-represented. Increasingly recognised for its significant role in maintaining ecosystem services, forest degradation is only rarely gauged or quantified by dedicated research (Heymell 2009); see chapter 1.4.1 for a review of the means that have previously been used to research disturbance. Unlike the well-established effects of forest cover loss therefore, there is little consensus on the complex relationships between the disturbance of tropical forest and biodiversity, ecosystem function or service provision (e.g. Hamer & Hill 2000, Groom & Vynne 2006). The significance of forest degradation is though, considered by FAO (2009) to be of similar importance to that of complete forest habitat loss.

It is clear that it is too simplistic to state that biodiversity decreases with increased disturbance, and empirical studies suggest that disturbances do not have consistent effects on species richness (Orians & Groom 2006). There is considerable evidence for human disturbance being the agent of rainforest degradation and Petraitis *et al*. (1989) have recorded that when disturbances are too frequent or too intense they can prevent habitats recovering beyond, for example, the early successional stage in which species-richness remains low. The forests studied in the current thesis also provide examples of research demonstrating negative impacts on populations of different tree species (e.g. Kirika *et al.* 2008, Farwig *et al*. 2008), foliicolous lichens (Yeshitela 2008), and bird and ant populations (e.g. Owiunji & Plumptre 1998, Schulz & Wagner 2002, Lung *et al*. in press).

However, at the other end of the disturbance scale, an ecosystem notionally free of disturbance is interpreted as progressing through a succession of vegetative stages to a stable and climax state in which the climax species exclude others resulting in an impoverishment of species richness (Eggeling 1947, Sheil 1996). Indeed, the forests considered in the current thesis also provide examples of the positive effects of disturbance and forest fragmentation; studies of certain monkey, bird, and tree species, for instance, show populations benefiting from disturbance (e.g. Fairgrieve & Muhumuza 2003, Dale & Slembe 2005, Farwig *et al*. 2006). At the broader level of vascular plants, Althof (2005) has revealed three of the four most disturbed sites in the studied forest to have the greatest diversity, while Freund (2005) has also found canopy-dwelling arthropod species to be richer in more disturbed forest. The *intermediate disturbance hypothesis* (Connell 1978) proposes that the greatest species diversity occurs therefore, not in an idealized disturbance-free regime, but with a moderate degree of disturbance. Furthermore, Pickett and White (1985) have highlighted the critical role of disturbance as the mechanism for resetting the vegetative successional process by avoiding the less diverse climax state. This successional disturbance-recovery cycle is at work within most tropical forest ecosystems and although its crucial role in maintaining productivity, biodiversity and other ecosystem conditions has long been recognized, it remains only broadly defined (Kimmins 2004).

As one of the most dramatic dimensions of forest disturbance, forest fragmentation has received considerable attention in the spheres of landscape ecology and conservation biology (e.g. Laurance & Vasconcelos 2004, Farwig *et al*. 2006). Fragmentation of habitat has been demonstrated to seriously disrupt species survival since fragmentation brings not only the reduction of habitat area but also, for example, deleterious edge-, distance- and matrix-effects (Laurance & Vasconcelos 2004). East African examples showing a reduction in rainforest wildlife populations due to fragmentation range from primates (e.g. Wahungu *et al*. 2005) to invertebrates (e.g. Lung *et al*. in press).

However, the work of Hill & Curran (2005) on fragmentation shows complex results, many of which do not support the established hypotheses regarding fragmentation and species composition. Other authors have also revealed unexpected positive correlations between fragmentation and particular species productivity (e.g. Farwig *et al*. 2006) and the long-term effects of fragmentation are proving to be complex and are not yet fully understood (Laurance & Vasconcelos 2004). It is clear that the biological reaction to fragmentation depends on the scale and on the species as to whether it is effectively interpreted as fragmentation of habitat or as an increase in habitat heterogeneity that is likely to bring positive effects for some species (Tews *et al*. 2004, *cf*. Farwig *et al*. 2006). The multiple effects of fragmentation are difficult to separate, especially since it requires a time span sufficient to discern the *relaxation* of species richness levels expected to occur only after a time-lag of several decades duration (Brooks *et al*. 1999). The occurrence of inconsistent results indicates that it is imperative to first establish the correct forest fragmentation narrative and to avoid possible misinterpretation of results due to incorrect histories (*cf*. Tilman *et al*. 1994).

In the light of the dependence of biodiversity upon disturbance in many forest ecosystems, Kimmins (2004) has called for a much better understanding of the role of disturbance in the functioning of forests. Fimbel *et al*. (2001) also conclude that changes in ecological processes and forest productivity due to, for instance proximate causes such as logging, are poorly understood. The shift of the focus of modern management away from efforts to exclude human activity, towards the sustainable utilization of forests (Kimmins 2004) highlights the increasing need for investigation into the relationship between forest use (i.e. disturbance) and forest degradation.

The forests studied within this thesis have previously been assessed for their disturbance (see chapter 1.4.1 for methods used) resulting in judgements of moderate to high levels often varying with different sample plots and transects and on the different variables included (Bleher *et al*. 2006, Boetcher *et al*. 2008 for Kakamega Forest; Baranga 2007 for Mabira Forest; Plumptre 1996 and 2002 for Budongo Forest). However, such studies commonly consider only the recent past so that the long-term and cumulative effect of disturbance is rarely taken into account.

1.3 The study sites

In the section below, the basic geographical, management and demographic backgrounds of the three separate forest areas are summarized and compared, setting the context for the consideration of the methodological approach in chapter 1.4.

1.3.1 General characterisation

The three areas of investigation, i.e. the Kakamega-Nandi forest complex in western Kenya, and Mabira and Budongo Forests in Uganda, are semi-evergreen forests (Langdale-Brown *et al*. 1964, Althof 2005) classified by White (1983) as forests of ‘Guineo-Congolian drier type’. They also share an inland East African location between the Equator and two degrees north, each being located close to one of East Africa’s major lakes (see Table 1.1 and Figure 1.1 for locations). While there are many similarities between the sites, there are also notable contrasts. There is an east to west gradient featuring a decrease in altitude and increases in rainfall, temperature and species diversity, that are also accompanied at the level of the three areas of investigation, by a decrease in human population densities.

Each of the areas includes at least one main forest reserve that lends its name to the area, although in the Kenyan example it comprises three larger forests, Kakamega, South Nandi

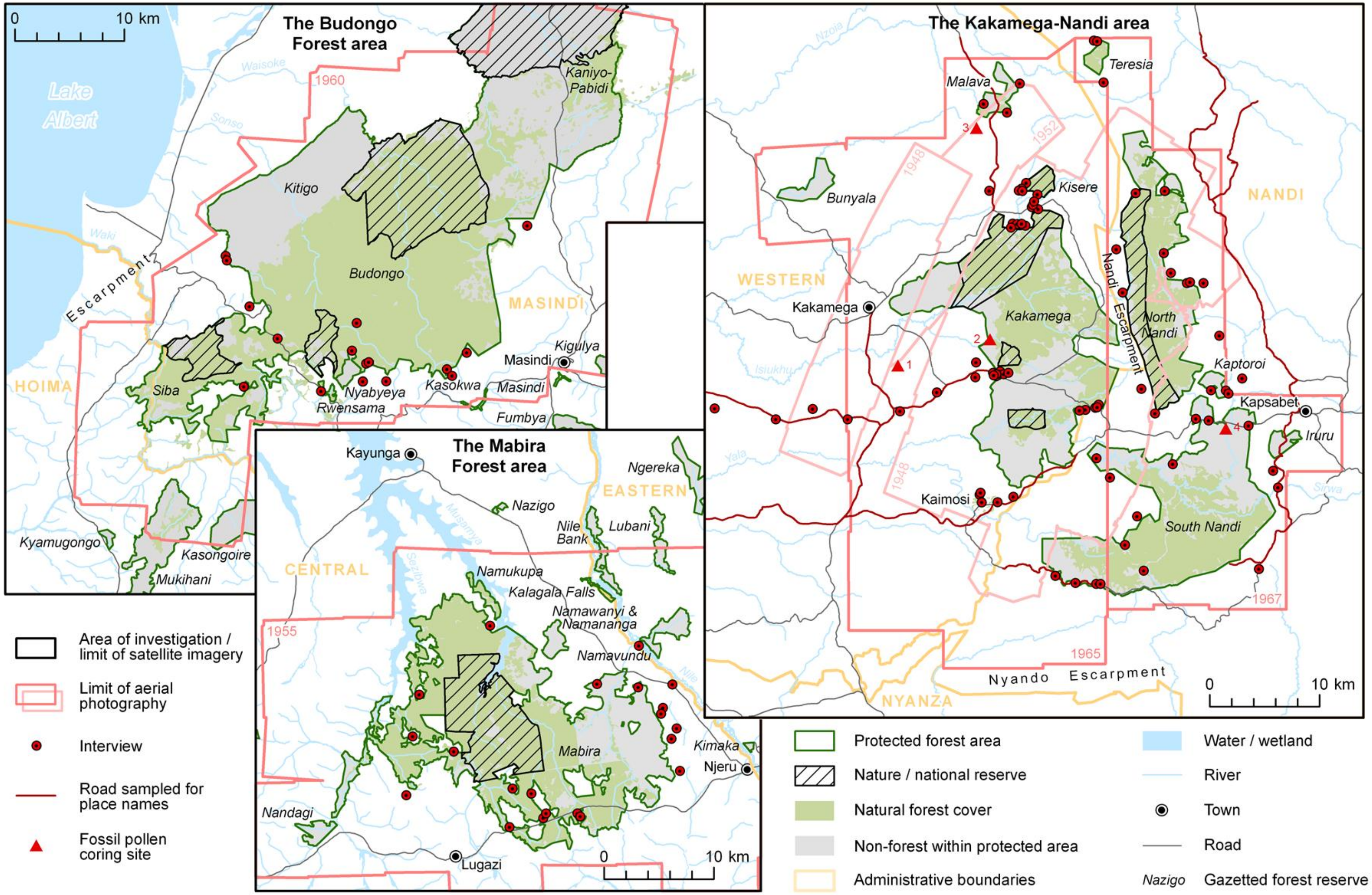


Figure 1.3: The three areas of investigation showing the extent of natural forest cover within the protected forest areas; the locations and extent of data used in the thesis are also marked.

Table 1.1: Figures and dates regarding the geographic and demographic setting.

	Kakamega-Nandi forest area	Mabira Forest area	Budongo Forest area
Location	34°37'5" to 35°9'25"E and 0°2'52"S to 0°32'24"N	2°46'34" to 33°11'22"E and 0°20'28" to 0°43'16"N	31°15'23" to 31°50'27"E and 1°29'56" to 1°59'14"N
Forest reserve area within area of investigation	55,446 ha (from boundaries provided by UNEP)	35,027 ha (from boundaries provided by NFA)	84,472 ha (from boundaries provided by NFA)
First gazettement of forest reserves referred to in text	1933: Kakamega, Kisere & Malava (Mitchell *et al*. 2009); 1936: S. & N. Nandi, Iruru, Kaptoroi, Teresia (Blackett 1994b,c); 1956: Bunyala (Mitchell *et al*. 2009)	1932: Mabira, (Karani *et al*. 1997a)	1932: Budongo, 1937: Siba, 1939: Kitigo, 1968: Kaniyo-Pabidi (Karani *et al*. 1997b)
Elevation within forest reserves (above sea level)	Reserves of Kakamega & Vihiga Districts: 1,420 m to 1,765 m; S. Nandi: 1,695 to 2,065 m; N. Nandi: 1,760 to 2,145 m	1,045 m (Nile Bank) to 1,335 m (southernmost Mabira)	695 m (north Kitigo) to 1,440 m (Mukihani)
Annual mean precipitation	Kakamega Forest: 2,007 mm at Isecheno (Farwig *et al*. 2006); S. Nandi: 1,600 to 1,900 mm; N. Nandi: 1,8000 to 2,000 mm (Blackett 1994b & c)	1,250 to 1,400 mm (Howard 1991)	1,200 to 1,800 mm (Sheil 1997)
Annual mean temperature	Kakamega Forest: min. ~15°C, max. ~ 27°C; Nandi Forests: min. ~10°C, max. ~25°C (Blackett 1994a-c)	min. 16 to 17°C, max. 28 to 29°C (Howard 1991)	min. 17 to 20°C, max. 28 to 29°C (Howard 1991)
Population density within 2 km of forest reserves	Kakamega Forest in 1999: 643 inh./km^2 Nandi forests in 1999: 371 inh./km^2 (Lung & Schaab 2010)	Mabira Forest in 2002: 302 inh./km^2 (Lung & Schaab 2010)	Budongo Forest in 2002: 158 inh./km^2 (Lung & Schaab 2010)

and North Nandi Forests. Each area also contains between six and thirteen smaller forest islands that have been gazetted as forest reserves and which range in size between 40 and 3,080 ha. However, many of these small reserve islands, especially the Ugandan examples, no longer contain forest cover of any kind.

1.3.2 Topography

The full altitudinal range of the areas of investigation reaches from a maximum of 2,180 m above sea level (a.s.l.) found north-east of North Nandi Forest, to the lowest point on the shores of Lake Albert at 620 m a.s.l.. Table 1.1 specifies the altitudinal range within the forest reserves and it can be seen that the Mabira area shows the least altitudinal variation with less than 300 m difference while those of the other two areas both have a range of 700 to 750 m. The terrain of each area is generally undulating with small but steeply rising and historically grass-covered hills punctuating each of the main forest reserves except those of the Nandi. The Kakamega-Nandi and Budongo areas are marked by sharply-defined escarpments, both representing part of the Great Rift Valley landscape formations (*cf*. Karani *et al*. 1997b, Blackett 1994c).

The rivers of the Kakamega-Nandi area drain predominantly east to west, and eventually into Lake Victoria. The two most significant rivers are the Yala running through both South Nandi and Kakamega Forests, and the Isiukhu passing Kisere Forest and through Kakamega Forest to join the major Nzoia River to the west. Mabira Forest is meanwhile the area most dominated by rivers and, with the Victoria Nile originating just east of the Mabira Forest area of investigation, it passes through the north-eastern part of the study area. The north-western part of the main forest reserve is located between the broad, reed-choked Sezibwa and Musamya Rivers that flow north to Lake Kyoga. The Nile similarly flows north, eventually curving around the Budongo area although remaining 25 km distant from it. Budongo Forest is itself drained by the relatively small rivers of Waisoke, Waki and Sonso, flowing north-west to Lake Albert.

1.3.3 Climate

The Kakamega-Nandi and Mabira areas are both influenced by the proximity of Lake Victoria which brings day-time winds and frequent thunderstorms (Blackett 1994a, Karani *et al*. 1997a), the latter also being common in Budongo Forest (Karani *et al*. 1997b). All the sites experience their driest period between December and March with their wettest period following that until May (Sheil 1997, Blackett 1994a-c, Karani *et al*. 1997a, b, Mitchell *et al*. 2009). Both the Ugandan sites have a further peak in rainfall between October and November while this distinction between the two wettest periods is only weakly detected or absent in the Kakamega-Nandi area (*cf*. Blackett 1994a, Mitchell *et al*. 2009). The ranges of rainfall are recorded in Table 1.1 but it should be highlighted that the least rain falls in the eastern forests, i.e. the Nandi Forests, and the highest rainfall is recorded in the west in the Budongo area. Variation is noted within each area of investigation, increasing east to west in the Kakamega-Nandi area (Blackett 1994a-c), north to south in Mabira Forest (Karani *et al*. 1997a), and from the north and north-west to the east and south-east of Budongo Forest (Karani *et al*. 1997b). Temperature follows the same gradient and coincides closely with altitude. In each area the warmest time of year coincides with the driest season, between December and March (*cf*. Blackett 1994a & b, Karani *et al*. 1997a & b, Mitchell *et al*. 2009).

1.3.4 Geology and soils

Most of the southern part of Kakamega Forest is located on Kavirondian rock formations of Precambrian origin, the remainder being of the underlying Nyanzian formation (Blackett 1994a). They are overlain by soils characterised as deep, well-drained weathered ferralo-chromic/orthic acrisols clay-loams and clays although Musila (2007) also distinguished between Ferralsols dominant in the north of the forest and Cambisols dominant in the south. Both North and South Nandi Forest are underlain by granitic Basement System rocks covered by very deep, well drained soils (Blackett 1994b & c). In South Nandi these are classed as humic Nitosols, friable clay soils with a thick acid humic topsoil, and in North Nandi as friable sandy clays of ferralo-chromic Acrisols.

Most of Mabira Forest is characterised by micaceous schists and shales of the Buganda-Toro system with ridges of quartzite and amphibolite (Howard 1991) while the western margin of the forest is characterised by undifferentiated gneiss rock (Karani *et al*. 1997a). The soils are weathered ferralitic types not characterised by a parent rock but instead by the topography with soils of incipient laterisation on the slopes and clays and peat in the valley bottoms (Howard 1991). The greater part of Budongo Forest is located on very old rocks of Precambrian origin: gneiss, schists and granulites of the Basement Complex, except for a small part of the south-west where it is overlain by Bunyoro Series sediments (Howard 1991). The soils are deep, weathered ferralitic type sandy loams and sandy clay loams (Karani *et al*. 1997b).

1.3.5 Flora and fauna

All of the forests featured here have grown up in the relatively warm and wet period following the end of the last glacial period c. 10-12,000 years ago (*cf*. Hamilton 1982). Forest expansion is considered to have spread to these areas from isolated refugia in, for instance, the eastern part of the Democratic Republic of Congo (DRC) (*ibid*.) and these forests are consequently characterised by species of Guineo-Congolian type (White 1983, Kokwaro 1988, Howard 1991, Sheil 1996). Figure 1.4 shows characteristic forest views today.

Budongo Forest includes all stages of forest succession from grassland and moist-*Combretum* savanna woodland though to the climax forest dominated by *Cynometra alexandri* (Plumptre 1996). However, it is the intermediate mixed forest stage (*cf*. Eggeling 1947, Sheil 1996) that makes this forest the most biodiverse of the BIOTA-East forest sites.

Figure 1.4: Characteristic views of the three study sites. Top left: Kakamega Forest, famously punctuated by numerous grassy glades, with Nandi Escarpment in the background. Right: Budongo Forest, renowned for its high biodiversity and large buttressed trees, here lining the famed bird-watching site, the 'Royal Mile'. Bottom left: Mabira Forest from the east, looking across sugar plantations to the exotic Paper Mulberry tree cover and to the natural forest in the background.

The presence of several Mahogany species (*Khaya anthotheca*, *Entandrophragma angolense*, *E. cylindricum*, *E. utile*) renders it the largest and most valuable timber forest in Uganda. Mabira Forest is meanwhile, recorded as a secondary stage forest of sub-climax communities and moderate to high biodiversity (Howard 1991). The majority of the forest is comprised of *Celtis-Holoptelea* community while poorer forest is recorded in the valleys, and in drier parts some *E. utile*, i.e. Mahogany, are found (*ibid*.).

Further east, Kakamega Forest is renowned as the easternmost limit of many lowland West African species and represents a unique mix of such species with those of a more montane character (Althof 2005). Most of the forest is classed as middle-aged and secondary forest and the largest portion is identified by Althof as comprising a *Celtis mildbraedii - Craibia brownii* alliance while the northern part is classed as *Deinbollia kilimandscharica - Markhamia lutea* alliance. Being higher in altitude the Nandi Forests are dominated by montane species (Beentje 1990), e.g. *Tabernaemontana stapfiana* in South Nandi and *Diospyros abyssinica* in North Nandi, and by a lower biodiversity (Blackett 1994b & c). There is consequently, a decrease in species diversity from west to east across the sites considered here (*cf*. Hamilton 1982, Althof 2005).

All of the main forest reserves, except South Nandi, are characterised as mosaics of forest and non-forest cover which is normally represented by grass or wooded grassland although in the case of Mabira these areas are occupied by human settlement (Tsingalia & Kassilly 2009, Karani *et al*. 1997a, b, Langdale-Brown *et al*. 1964). Invasive trees are present in the forests of Kakamega (*Psidium guajava*, the Guava) and Mabira (*Broussonetia papyrifera*, the Paper Mulberry), and along with South Nandi, these forests have also been partly planted with timber species of both indigenous and exotic species (Lung & Schaab 2010).

The faunal species diversity mirrors the vegetational diversity gradient, i.e. it increases from the Nandi Forests in the east to Budongo Forest in the west, the latter being considered exceptionally rich in biodiversity (*cf*. Blackett 1994a-c, Howard 1991). The same forest is famed for its well-studied chimpanzee (*Pan troglodytes*) population (Reynolds 2005), a species now extinct in Mabira Forest (Kingdon 1997). While Kakamega, South Nandi, Mabira and Budongo Forests are all renowned for their rich birdlife, many of the mammals, especially the larger examples, have become locally extinct (Blackett 1994a-c, Howard 1991). The most significant of these regarding its radical alteration of the forest structure, is the elephant (*Loxodonta africana*) which was eradicated first from the Kakamega-Nandi area, around 1920, then from Mabira in the 1950s, and finally from the Budongo area in the 1960s (Mitchell 2004, Howard 1991, Sheil 1996).

1.3.6 Forest management and threats

Almost all of the forest reserves considered here were gazetted in the 1930s (see Table 1.1). In Kenya they are managed mostly under Kenya Forest Service (KFS), although the two national reserves fall under Kenya Wildlife Service (KWS). The Nandi Forests are managed under KFS in Nandi District while the management of Kakamega Forest is split between Vihiga and Kakamega Districts along the Yala River. The Ugandan sites are managed under the National Forest Authority (NFA) although within the northern Budongo Forest most of the Kaniyo-Pabidi area is jointly managed with the Ugandan Wildlife Authority (UWA) (Karani *et al*. 1997b). Participatory forest management has been introduced in all of the main forest reserves (except North Nandi): first in the Ugandan sites under the name of collaborative forest management (*cf*. Karani *et al*. 1997a), and subsequently in Kakamega (Mitchell *et al*. 2008) and South Nandi Forests (RSPB 2010). Kaimosi forest, located to the south-west of Kakamega Forest, is the only remaining ungazetted and privately managed forest patch large enough to be specifically referenced within the current thesis.

Each of the main forests, except South Nandi, has at least one area of higher protection status, either nature or national reserves, as marked on Figure 1.3. The gazetted status of the reserves in the Kakamega-Nandi area is clear with Yala River and Isecheno officially thus protected since 1967, and national reserves of Kakamega and Kisere since 1985 (Mitchell *et al*. 2009); North Nandi Nature Reserve was gazetted in 1978 (Blackett 1994c). However, while the nature reserves of both Ugandan sites may still not have been officially gazetted (*cf*. Karani *et al*. 1997a & b), the N15 nature reserve of Budongo Forest has been effectively protected since the 1940s (Eggeling 1947). Those of Siba and the more northern Budongo Forest area, and that of Mabira Forest have been in effective operation since the 1997-2007 management plans (Karani *et al*. 1997a & b).

All of the main forest reserves have been commercially exploited, mostly for timber, throughout much of the 20th century and, in contrast to the Kakamega-Nandi forests, Mabira and Budongo Forests were sub-divided into compartments for a systematic plan of felling (Mitchell *et al*. 2009, Karani *et al*. 1997a, Plumptre 1996). Amongst the other most serious threats to their integrity are agricultural encroachment that was most significant in Mabira Forest in the 1970s and 1980s (Baranga 2007). Charcoal burning is prevalent in the Kakamega-Nandi forests and in Mabira (Mitchell & Schaab 2008) but is almost absent from the main forest of Budongo which suffers mostly from pitsawing and hunting (Plumptre 2002, *cf*. Reynolds 2005). The Kakamega-Nandi forests also suffer from heavy cattle grazing and trampling (*cf*. Mitchell & Schaab 2008, Blackett 1994a-c).

1.3.7 The demographic and agrarian context

There is a general decrease in population densities westwards between the sites although the Nandi area in the easternmost position is less densely populated than the Kakamega and Vihiga area to its west (Lung & Schaab 2010) (*cf*. Figure 5.4). The highest population densities are found in the farmland west of Kakamega Forest and most notably near Kakamega Town and in the Tiriki area at the southern edge of the forest where population densities are in the region of 1,000 inhabitants per km^2 (*cf*. *ibid*., Mitchell *et al*. 2009). With more moderate densities, Mabira Forest is most heavily populated on its eastern side between the forest and the River Nile (see Figure 5.5). Meanwhile Budongo Forest is characterised by low and very low population (*cf*. Figure 5.6), most settlement occurring around its southern half since it is bordered in the north by Murchison Falls National Park and Bugungu and Karuma Wildlife Reserves.

The Kakamega-Nandi area differs from the Ugandan sites in including a provincial boundary (see Figure 1.3) coinciding with the division between two distinct tribes, the Nandi (Huntingford 1950) and the Abaluhya (Wagner 1949 & 1956, Were 1967). The Mabira and Budongo Forest areas, traditionally areas of the Baganda (Reid 2003 & 2007) and Banyoro (Doyle 2006) tribes respectively, are today characterised by a very diverse ethnic mix following high immigration levels since the 1950s (*cf*. the 1:1,000,000 scale Afrika-Kartenwerk map: refmap7, Appendix A4, for contrasting the number of languages and dialects of the Kakamega-Nandi and Mabira areas, *cf*. Robertson 1971, Doyle 2006).

The Kakamega-Nandi area is characterised by small-scale cultivation interspersed with some commercial tea in the south and sugar in the north (Jätzold *et al*. 2007). The Ugandan sites also feature small-scale subsistence cultivation but the land bordering the southern halves of the main forest reserves, especially that of Mabira, is dominated by large-scale sugar plantations (*cf*. Welch Devine 2004, Mwavu & Witkowski 2008).

1.4 The multi-source and interdisciplinary approach

Bearing in mind the aim of the current thesis to investigate the long-term trends and spatial distribution of changes in forest cover as well as the impact of the impact of human activities, it is clear that no single data source is able to serve the purpose. There are many ways to capture different parts of these research aims and the following section reviews some of the options available; it is then followed by a statement of the approach adopted here which employs many of the reviewed options.

1.4.1 Literature review of the available means of investigation

Focusing on East Africa and in particular the forests of concern to this thesis, this section reviews the sources and means available to investigators of forest cover change and forest disturbance. Despite considerable overlap, the order of listing below broadly progresses from those data sources that consider forest cover (starting with those reflecting more recent times) to those that reflect forest disturbance and its causes (moving generally from the more direct methods to the more indirect).

Satellite imagery provides the cheapest and most time-effective means of monitoring changes in tropical forest cover and has formed the back-bone and the standard means of land-use/cover change studies (Mayaux *et al*. 2005). The satellite imagery-based studies focused on the forests of concern to this thesis typically use just two imagery dates and span an approximately fifteen year period (Westman *et al.* 1989, Plumptre 2002, Nangendo 2005, Awiti 2006, Mwavu & Witkowski 2008). Lung and Schaab (2006 & 2009) are alone in East Africa in making use of the full timespan of the fully-functioning Landsat programme with multiple timesteps (1972 to 2003) and a high degree of class distinction within the forest vegetation itself.

Early **aerial photography** has often been used for providing a comparison with recent satellite imagery; notable examples in Kenya include Imbernon (1999), Brooks *et al*. (1999) and Mitchell *et al*. (2006), and from further afield Petit and Lambin (2001) in Zambia, Goetze *et al*. (2006) in Ivory Coast, and Wigley (2009) in South Africa. In Nigeria, Salami *et al*.

(1999) have shown the utility of integrating aerial photography and satellite imagery for forest cover change analysis. Typically these studies extend the time-frame back to the middle of the 20th century and have been used for quantifying a generalised forest class so that examples of forest classifications within the forest cover are therefore generally lacking. Brooks *et al*. (1999) have shown the potential of historic aerial photography to recreate fragmentation histories from which to calculate the rates of future bird extinctions in Kakamega Forest and its associated forest islands.

Repeat-photography at ground level, i.e. retaking the photographs taken by early European travellers for comparative purposes, has been used by Ritler (2003) in Ethiopia in combination with written diary accounts to assess land cover change. Foden *et al*. 2007 have also employed the technique in southern Africa, combining it with a tree population census for studying the impacts of climate change. It is difficult to derive spatially-explicit outputs from such research although attempts are being made to project the vegetation identified in historical photographs into the horizontal plane (*cf*. von Hellerman 2009).

The ability of **maps** to further extend the time-frame of forest cover studies back several centuries has been amply demonstrated by researchers in Europe (e.g. Verheyen *et al*. 1999, Petit & Lambin 2002) The potential for extending the time-frame of investigations into East African forest cover with the use of maps is necessarily more modest since the first map makers of the non-coastal regions were the Germans and British of the later 19th century (Perham 1942). In Kenya, Mitchell *et al*. (2006) have extended a remote sensing time series with an early 20th century topographic map for a comparison of forest cover area figures for Kakamega Forest. Meanwhile in Tanzania, the annotations of an early 20th century topographic map have been used for a visual comparison of vegetation cover with a modern land cover dataset (Börjeson 2009) but the author notes that the potential of early maps for forest cover change studies in Africa remains very little utilized.

Place names evidence, the study of which is known as **toponymy**, has long been part of historians' means of interpreting the history of individual localities but has had little systematic application for land cover research in Africa (Bühnen 1992, Batoma 2006). The early second half of the 20th century was the period of greatest interest in East African place names with studies conducted in parts of Kenya and Uganda (e.g. Mill Hill Fathers 1952, Huntingford 1961, Roden 1974). Typically these studies devote considerable efforts to tracing linguistic technicalities and focus mainly on the implications of the names for tracing tribal migration patterns. As far as is known to the present author, place names have not until now been systematically applied to an environmental research agenda in Africa.

Historical population estimates have been utilized in modelling former forest cover states for the HYDE database in order to spatially hindcast global land-use change of the last 300 years (Klein Goldewijk 2001, Lambin & Geist 2006). These must, however, be considered as estimates and relate to analysis of a significantly coarser scale than is considered in the current thesis.

Fossil palaeoenvironmental evidence has provided the main means of interpreting the vegetation cover of pre-20th century East Africa and is most commonly represented by fossil pollen analysis (e.g. Marchant *et al*. 1997, Gillson 2006). Such data has also been interpreted in the light of the broader archaeological excavation record (e.g. Lejju *et al*. 2005, Taylor *et al*. 2005), and with charcoal and phytolith analyses (e.g. Hart *et al*. 1996, Maitima 1997) to illustrate the significant role of fire and human activity in forest clearance in East African prehistory. Due to the restricted geographical scope of the evidence, the results of these studies highlight the localised reality of prehistoric forest cover and no studies have been able to infer forest cover for the areas of interest in this thesis.

The means and sources listed above are most commonly used to detect the changes in tracing forest cover extent. The more insidious degradation of forests is more difficult to monitor and often remains unidentified and unquantified (Kimmins 2004). Previous researchers have used a variety of methods to assess levels of anthropogenic forest disturbance and, in part this reflects the range of possible disturbance forms. As seen below, this includes both direct and indirect means.

Sight-surveys have been most notably used in Kakamega Forest to record direct disturbance indicators such as the human traffic witnessed within a specified area (e.g. Gibbon 1991) or the number of tree-stumps and charcoal kilns recorded along a transect (e.g. Mutangah 1996, Bleher *et al*. 2006, Boetcher *et al*. 2008). Mabira and Budongo Forests have been subject to fewer such surveys with notable exceptions being those of Baranga (2007) and Plumptre (2002), the latter combined this approach with satellite imagery classification. These methods provide quantified results for specific locations and can be useful in defining gradients of current disturbance levels between separate observatories. However, the experience within the BIOTA project shows comparison between forests was difficult since tree-stump counts in Mabira Forest were unable to detect logging disturbance that had occurred more than thirty years prior to the survey (J. Kirika pers. comm.). This technique does not readily provide a spatially-explicit output.

In providing a quantitative description of the landscape and the arrangement of its component parts **landscape metrics** can be interpreted as expressions of forest disturbance, particularly forest fragmentation (McGarigal 2001, Gergel 2007). In the forests of concern to this thesis, metrics have been used by Hlavka & Strong (1992) to calculate the edge to forest ratio for Mabira Forest while Lung & Schaab (2006) have employed a small-scale moving-window approach to derive a spatially-explicit fragmentation index for the Kakamega-Nandi forest complex.

The use of **disturbance indicator species** represents an indirect approach for inferring anthropogenic disturbance from the presence or absence of certain species considered to be sensitive to such interference. Both Budongo and Kakamega Forests include examples of studies identifying disturbance indicators (Yeshitela 2008, Althof 2005) but there remains considerable debate over the validity of the concept within rainforest ecosystems (e.g. Watt 1998, Nummelin & Kaitala 2004).

Forestry records provide a separate source of disturbance data but require the time-consuming synthesis of logging records as has been shown for Kakamega Forest by Tsingalia (1988), Mutangah (1996) and a preliminary study by Mitchell (2004). This has not been previously attempted for Mabira Forest but Plumptre (1996) has made a thorough study of the records for Budongo Forest that represents the only spatial expression of logging data relating to any of the forests in this thesis. Plumptre's research and also that of Struhsaker in Kibale Forest in Uganda (Struhsaker 1997) have proved invaluable to subsequent ecological research (e.g. Owiunji & Plumptre 1998).

Archived documentary records (e.g. Brown 2003) and **oral history interviews** (e.g. Vansina 1995, *cf*. White *et al*. 2005) together represent the standard source material of environmental historians in Africa (Beinart 2000) and have been widely used in combination with each other (e.g. Brockington 2002). Notably they have combined in research into the history of the East African kingdoms and tribal cultures within which the forests of this thesis are located, e.g. Huntingford 1926 (Nandi), Wagner 1949 (Luhya), Reid 2007 (Buganda) and Doyle 2006 (Bunyoro). However, they generally give little attention to forest cover *per se* and instead provide a social and cultural context, interspersed with incidental information on general land cover. The use of archival sources for the forests of this thesis have been limited to their minimal inclusion by Kokwaro (1988) and Brooks *et al*. (1999) for Kakamega Forest. Tsingalia (1988) and Paterson (1991) have carried out limited interviews on forest history of Kakamega and Budongo Forests, respectively. Oral histories are gained either via interviewing individuals on a semi-structured basis (e.g. Doyle 2006) or via a structured group discussion, the results of which are used to good effect by Were (1967). Neither oral histories nor archival texts are generally able to readily provide spatially-explicit outputs.

Spatially-explicit analyses of forest disturbance are generally lacking in East Africa and in the forests of concern to this thesis. The Australian Wilderness Index employs GIS for a graded buffering of features according to proximity to human influence such as access and settlement (Lesslie & Maslen 1995) but has so far not been applied specifically to forest habitats (*cf*. Heymell 2009). Such a spatially-explicit approach would be of particular relevance directly to forest managers and conservationists concerned with forest and land-use policy.

Few of the studies reviewed above have been interdisciplinary and multi-sourced although Thompson *et al*. (2002) are highlighted here for using historical documents, oral histories and aerial photographs in combination to build a rounded analysis of the impacts of historical land use in a tropical forest in Puerto Rico. The review of available methodologies reflects the fact that, by comparison to the more standard studies of forest cover conversion across one to three decades, long-term forest cover change studies, especially those considering forest degradation, are few.

1.4.2 The approach adopted in this thesis

The data sources chosen for inclusion within the current thesis were selected for their ability to shed light on forest cover change and its causes, for their spatial properties and their potential for temporal coverage in relation to the other data sources, see Figure 1.5 (and 2.1). The source types comprise satellite imagery, aerial photography, forestry maps and documents, non-forestry archive documents, topographic and thematic maps, oral histories, place names, and fossil pollen. They are supported by ground observation that can sometimes reveal clues as to former land use and land cover.

This combination of sources is devised to provide the longest and most continuous coverage back in time from the present day. As stated above, existing studies on land-use/cover change have typically focused on a period of one to three decades. It is argued here that temporal analysis across a **longer time-frame** that includes **multiple timesteps**, should

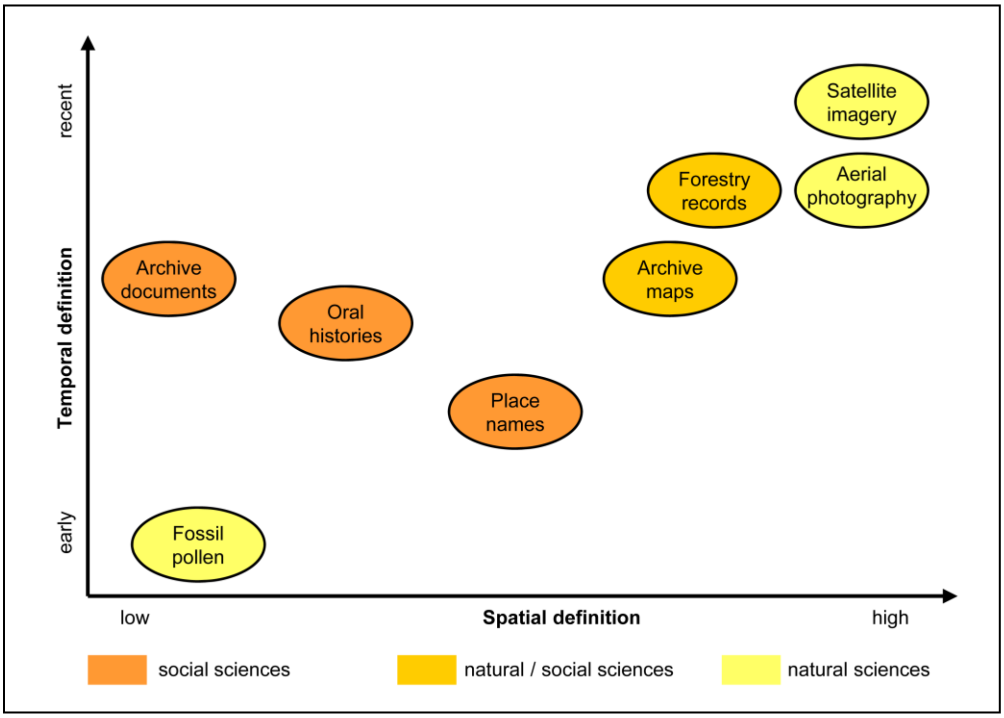


Figure 1.5: The spatio-temporal nature of the various data sources.

enable the detection of **fluctuations** in the development of the forest landscape that might otherwise skew shorter-term interpretations. The longer time-scale of the current thesis requires a **multi-sourced** approach to confidently extend back further than the most recent decades. The literature review above included some cases in which data sources have been used in combination but typically studies of forest cover change and disturbance have consulted single data sources. A combination of sources is here intended to provide support and **cross-reference** between sources and is of particular concern for the earlier periods for which the evidence is less reliable.

The time-frame of the spatially-explicit analysis included here is partly dictated by the availability of data, most notably by the limited time-frame of remote sensing and map-based data, but particular effort was made to crucially reach back to an era **before the commercial exploitation** of East African forests. Most of the focus is therefore on the period between the start of the colonial period in the late 19th century and the present and covers the period that has witnessed the greatest rise in demand for forest resources from competing forces both locally and at the commercial level (*cf*. Lambin & Geist 2006). Coverage of this full period required the addition of forestry records, archival documents and oral histories, the latter also assisting the evidence of place names to extend the research to earlier centuries. To view the detected forest changes of recent centuries within the longer-term context of previous millennia, fossil pollen evidence provides a ‘key-hole’ view across the vegetation history in the Kakamega Forest area of investigation.
The vital back-bone to forest landscape investigation is here taken to be the establishment of a **forest cover change time series** to track the trends in forest extent (see chapter 4). However, as shown above in chapter 1.2.4, **forest degradation** is increasingly understood to have been neglected in comparison to forest conversion, and due to the complex and varied reactions of vegetation to disturbances, degradation cannot be easily or uncontroversially investigated via the vegetation alone. It is therefore here considered that, in addition to change analysis of multiple forest classes derived from remote sensing (see chapter 5.1), the most practical and realistic way to reflect degradation is to **map the disturbance** that causes it (*cf*. Watt 1998). The study of disturbance requires attention to a broad range of factors and other authors have identified that the type, intensity and frequency are the features of disturbance critical to biodiversity (e.g. Petraitis *et al*. 1989, Watt 1998). This thesis therefore aims to serve the need for a broad characterisation and a graded, spatially-explicit distinction of **disturbance severity**. The inclusion of past disturbances also acknowledges, as highlighted in chapter 1.2.2 above, that disturbance accumulates and has long-term effects that have shaped today’s forest quality.

This study therefore employs **quantitative** methods to track forest cover extents over time but also demonstrates that **qualitative** data is vital for the creation of the historical narrative. Such qualitative data can shed light on, for example, the true occurrence of fragmentation, and can identify the factors and forces impacting the forests over time (see chapters 3 and 4). The integration of both types of information is exemplified in the analysis of proximate causes via their **reconciliation within GIS** and the creation of **spatially-explicit** disturbance indices that effectively summarize and quantify the knowledge gained from both quantitative and qualitative data (see chapter 4).

The use of **multiple sources** and methods for the long-term study of forests should be the predominant strategy of the environmental historian who must also maintain a basis in theories of several branches of ecology (Dovers 2002). The multi-source concept is designed not only to enable long-term coverage but also to bring the benefits of cross-referencing the evidence between source types. Furthermore it would bring **multiple perspectives** reflecting the different parent disciplines that range from forestry to various forms of ecology, conservation biology and environmental history that are employed here within the overarching concept of forest conservation, the ultimate objective (see Figure 1.6). The combination of approaches from the natural and social sciences provides the best potential for deep insight into the African environment (Viles & Gillson 2003) since land cover/change studies are increasingly understood to be a reflection of a **coupled human-environment system** (Geist & Lambin 2004). This requires an **interdisciplinary** research able to integrate sources and methods adopted from different disciplines; they are here channelled towards a cohesive spatio-temporal analysis of forest landscape change by their adoption into the **case studies**, the **forest narratives** and the **disturbance indices**.

- **Long-term:** to capture short-term fluctuations and the true extent of long-term changes; to reflect accumulation of disturbance
- **Multi-sourced / multi-disciplinary:** to ensure continuous temporal coverage, cross-referencing of evidence and breadth of perspective
- **Spatial:** to link diverse data via spatial location; to analyse disturbance spatially-explicitly to show local variation
- **Qualitative and quantitative:** to quantify forest cover change and disturbance alongside a qualitative investigation of the true forest narrative and causes of change

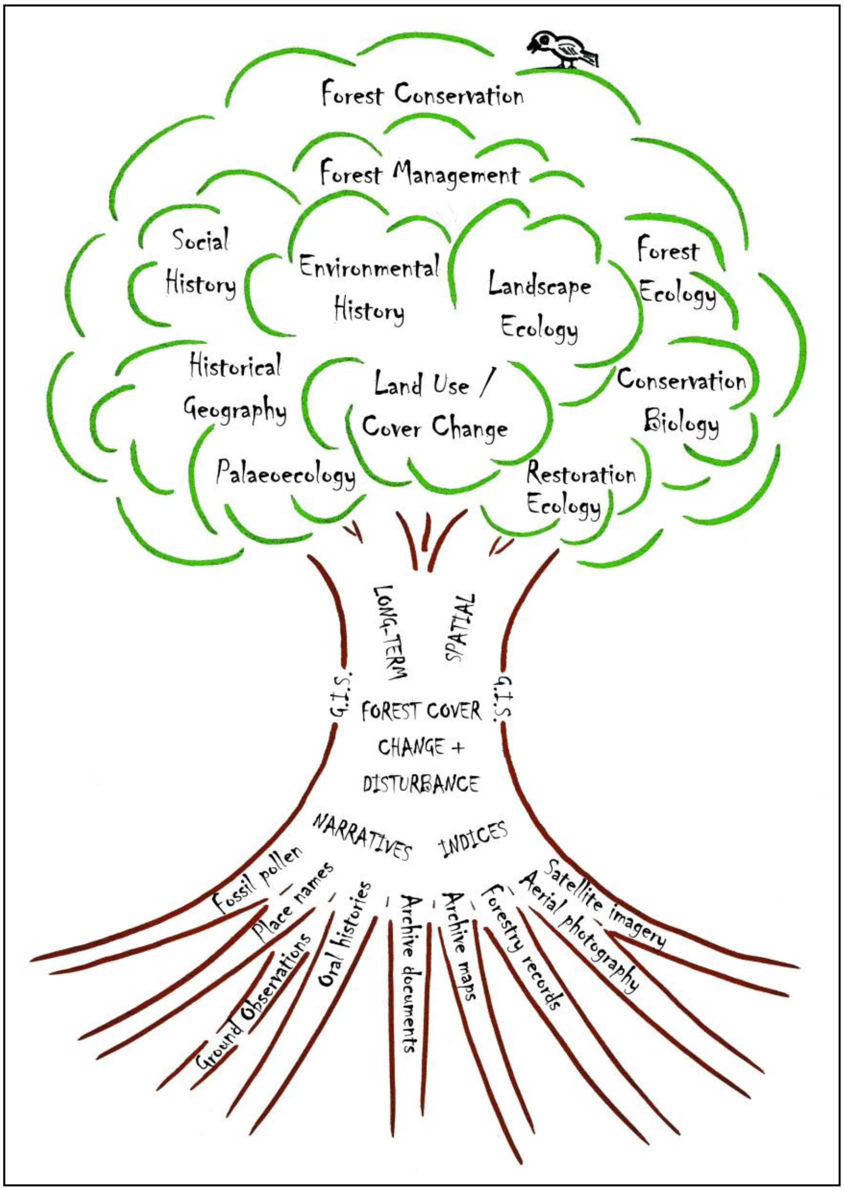


Figure 1.6: Visualisation of the main disciplines to which the thesis relates.

2. The data sources and pre-processing

This chapter reviews the acquisition of data of the main source types, the pre-processing and the creation of the numerous geodatasets from which the thesis derives its evidence. This section therefore sets the background to the case studies (chapter 3), and in turn the forest cover narratives (chapter 4) and the spatially-explicit indices (chapter 5), which draw heavily on this pool of datasets. The geodatasets are listed in Appendices A1 to A3 and are referenced in the text by individual dataset numbers, e.g. kn-d34, or in the case of maps that were not georeferenced, as e.g. refmap3 (Appendix A4). A similar system is adopted for referencing the interviews in the text, e.g. kn-i34 which provides a link to geodatasets kn-d135, mf-d91 and bf-d64).

2.1 Data acquisition criteria

The criteria underpinning the search for relevant data were set out in response to the objectives of the research, namely to explore the extent and causes of forest change and disturbance over the long-term in each of the three forest research areas. The criteria are listed below.

The content of the data should relate to:

- forest cover extent,
- forest quality, or
- forest disturbance and its causes, either commercially or locally driven.

The data should also:

- have spatial reference, i.e. able to be georeferenced or at least to be located in space,
- be temporally defined, i.e. able to be dated, and
- in combination reflect a range of different perspectives, e.g. government versus non-government, farmer versus scientist, East African versus European.

The acquisition and pre-processing of data are described in the following sections, 2.2 to 2.7, and are concluded and summarized in chapter 2.8 and in Table 2.1; however, the analysis within the GIS for the disturbance indices is dealt with separately in chapter 5.1. Figure 2.1 illustrates the contributing data sources and shows their temporal overlap designed to provide an understanding of the continuous development of the forest landscape. It was understood at the start, as is reflected in the figure, that the older data would be open to more interpretation and could be considered less reliable. Figure 1.3 shows the extent of the remote sensing data and location of the field-based data collection.

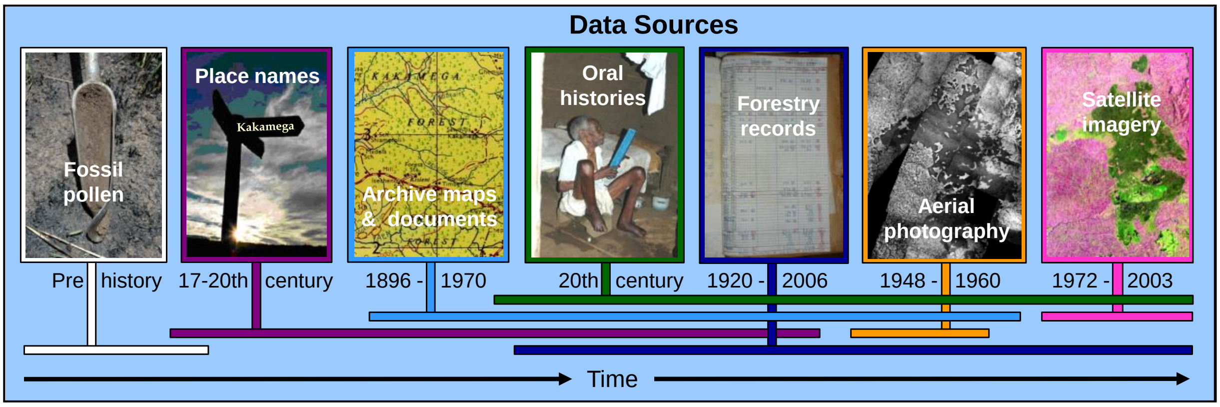


Figure 2.1: Time-line showing the temporal overlap of the data sources used within the thesis.

Table 2.1: Summary of the acquired and derived geodatasets; they are listed in detail in Appendices A1 to A3.

Geodata Types	**Kakamega Forest**	**Nandi Forests**	**Mabira Forest**	**Budongo Forest**	**Scale/ Resolution**	**Pre-processing**	**Output**
Satellite imagery of pre-existing time series of Lung (2004), Lung & Schaab (2010) (no. of images in brackets) (Ch. 2.2.1)	2003 (ETM+) (2) 2001 (ETM+) (2) 1994/95 (TM) (2) 1989 (TM) (1) 1984 (TM) (1)		2002/03 (ETM+) (2) 2001 (ETM+) (2) 1995 (TM) (2) 1989 (TM) (1) 1986 (TM) (2)	2003 (ETM+) (1) 2000 (ETM+) (2) 1995 (TM) (2) 1990 (TM) (1) 1986 (TM) (2)	30 m	(georeferencing, atmospheric correction, supervised multispectral classification)	(multi-step, dense time series of land cover classes including classes within forest)
	1979/80 (MSS) (2) 1975 (MSS) (2) 1972/73 (MSS) (2)		1976 (MSS) (1) 1973 (MSS) (2)	1975 (MSS) (1) 1972/73 (MSS) (2)	60 m		
ground truthing / photos from aeroplane	2005 & 2006 / 2001		2005 & 2006	2005 & 2006	-		
Aerial photography (Ch. 2.2.2 to 2.2.4)	(1991, Kakamega only, not interpreted for classes) 1965/67 (complete) 1948/(52) (62% complete)		1955	1960	1:30,000	(orthorectification, mosaicking) & on-screen interpretation & digitizing of vegetation classes	long-term land cover classes & thus extensions of remote sensing time series
Forestry maps (Ch. 2.3)	46 1933-2005		36 1929-2006	19 1932-1991	1:10,000 to 1:150,000	scanning/digital photo'ing, georeferencing & digitizing	spatial understanding of logging & geodatsets to create commercial disturbance index
logging records (Appendix E3)	1933-85 (near complete)	1942-47, 1966-82 (incomplete)	1929-2004 (summaries, incomplete)	1935-2003 (summaries, near complete)		incorporated into GIS as attributes of forestry geodatasets	
Topographic, sketch & thematic maps (Ch. 2.4)	62 1896-2007		39 1911-2008	27 1911-2008	1:25,000 to 1:2.5 million	scanning/digital photo'ing, georeferencing & digitizing	extension of forest cover time series to early 20th century; population & contextual geodatasets for constructing local disturbance indices
population statistics	1999 1989 1979 1948 1918 1900		2002 1991 1980 1969 1959 1921 1900	2002 1991 1980 1969 1959 1921 1900		scanning/digital photo'ing, georeferencing, digitizing; attributing with census statistics	
Oral histories (Ch. 2.5)	42 (relating to c.1910-2006)	33 (relating to c.1920-2006)	21 (relating to c.1950-2006)	20 (relating to c.1940-2006)	-	located & attributed with forest histories	understanding of causes of forest cover change; contributions to commercial & local disturbance indices
Place names relating to plants / animals / land cover (Ch. 2.6)	242 (late 17th to early 20th century)		7 (unknown date)	18 (unknown date)	1:50,000	digitized & attributed with meanings & land cover inferences	Spatially-defined inferences of former land cover

2.2 Remote sensing

Historical aerial photography was sought to extend back in time the existing land cover classification time series based on Landsat satellite imagery (Lung & Schaab 2010). Lung and Schaab's satellite imagery processing methodology is briefly summarised here first.

2.2.1 Landsat satellite processing

The images were georeferenced using the most recently published topographic maps (1:50,000 scale) with atmospheric and terrain corrections carried out based on a 30-metre digital terrain model using the ATCOR 3 module of ERDAS Imagine 8.5 (*cf.* Lung & Schaab 2004). A supervised multispectral classification was made on the basis of the maximum-likelihood decision rule considering bands 3, 4, 5, 7 plus a further artificial channel of ratio 7/2 for TM / ETM+ and bands 1 to 4 for MSS imagery. Where possible, several training areas were created for each land cover class with ground truth information for the most recent time steps provided by terrain references and amateur photographs taken from an aeroplane in 2001 and 2006. Ground truthing for the most recent time-steps was done by the present author during field visits in April-May 2005 and February-March 2006. Vegetation and forestry maps were useful for interpreting the earlier time steps. Where available, both wet and dry season images were used in combination thus taking account of seasonal variation and also allowing areas that are cloud-covered in one image to be represented by the second image alone (Lung & Schaab 2004).

2.2.2 Aerial photography pre-processing

Aerial photographs for the creation of mosaics were acquired from five separate data suppliers. The criteria dictating the search, in order of importance, were:

- date relevance with regard to usefully extending the satellite series,
- quality of photography sufficient for identification of the main land cover classes within the actual forest cover itself, and
- completeness of coverage of any of the three studied forest areas.

The Kakamega-Nandi aerial photographs for 1965/67 and most of 1948/(52) had already been pre-processed and mosaicked by Herz (2004) and had necessitated the combined use of 1965 and 1967 photographs into a single mosaic to allow complete coverage for the later time step. The adoption of 1952 photography into the earliest of the remote sensing time steps, 1948/(52), was beneficial for maximizing the forest coverage for this time step. For this research further 1948 photography was purchased to fill some of the gaps in the mosaic, bringing the mosaic to its full potential as delimited by cloud cover.

The process followed by Herz (2004) was repeated by research assistants for this research project to extend the 1948/(52) mosaic itself and to create both the Mabira and Budongo Forest mosaics (1955 and 1960 respectively). This involved the scanning of images followed by their orthorectification using Orthobase software (ERDAS) and a 30-metre digital elevation model derived from the contour lines of the most recent 1:50 000 topographic maps. The ortho-images were then mosaicked using Leica Photogrammetry Suite (LPS) software (Erdas). Colour balancing and grey-tone adjustment were carried out using the area offset method to create a more even gradation of contrast across the mosaic.

2.2.3 Classifying vegetation classes via visual interpretation

Kätsch and Kunneke (2006) have shown that while automated techniques for digitising from aerial photography are valid for the detection of forest conversion, they are normally insufficient for interpretation of different classes within the forest vegetation. For the current thesis, therefore, land cover classes were visually interpreted from the aerial photography mosaics (*cf*. Salami *et al*. 1999) and digitised on-screen with the aim of creating vegetation classes compatible to Lung & Schaab's (e.g. 2010) satellite classification. In the absence of detailed ground truth data for these time steps, close visual comparison of an existing mosaic of 1991 aerial photography (Herz 2004) was made to the temporally closest of Lung's Landsat classifications, 1989 and 1995. The manifestation of Lung's classes in aerial photography could thus be determined and this knowledge used in the initial stages of visually interpreting comparable classes in the historical aerial photography.

In the great majority of cases drawing the distinction between land cover classes was easily and unambiguously achieved. The distinction between 'Near natural and old secondary forest' (class1) and 'Secondary forest' (class 2), and also that between class 2 and 'Bushland / shrubs' (class 3) have the greatest margins of personal interpretation. It was noted that the heterogeneity of the forest canopy's aerial appearance increased with the maturity of the vegetation class, assumed to result from the increasing number of different constituent tree species increasing with age (*cf*. Beentje 1990). Detection of the other classes was easily done on account of their starkly contrasting appearances. Figure 2.2 illustrates the interpretation of forest cover classes digitised for Kisere Forest, north of Kakamega Forest.

Digitising was done while visualizing the photography on-screen, generally at a scale of 1:20,000 in order to best facilitate a correct interpretation of the vegetation. The scale of the resultant datasets is though, stated to be 1:30,000, a figure that relates to the level of detail digitised and the scale at which it is intended for viewing.

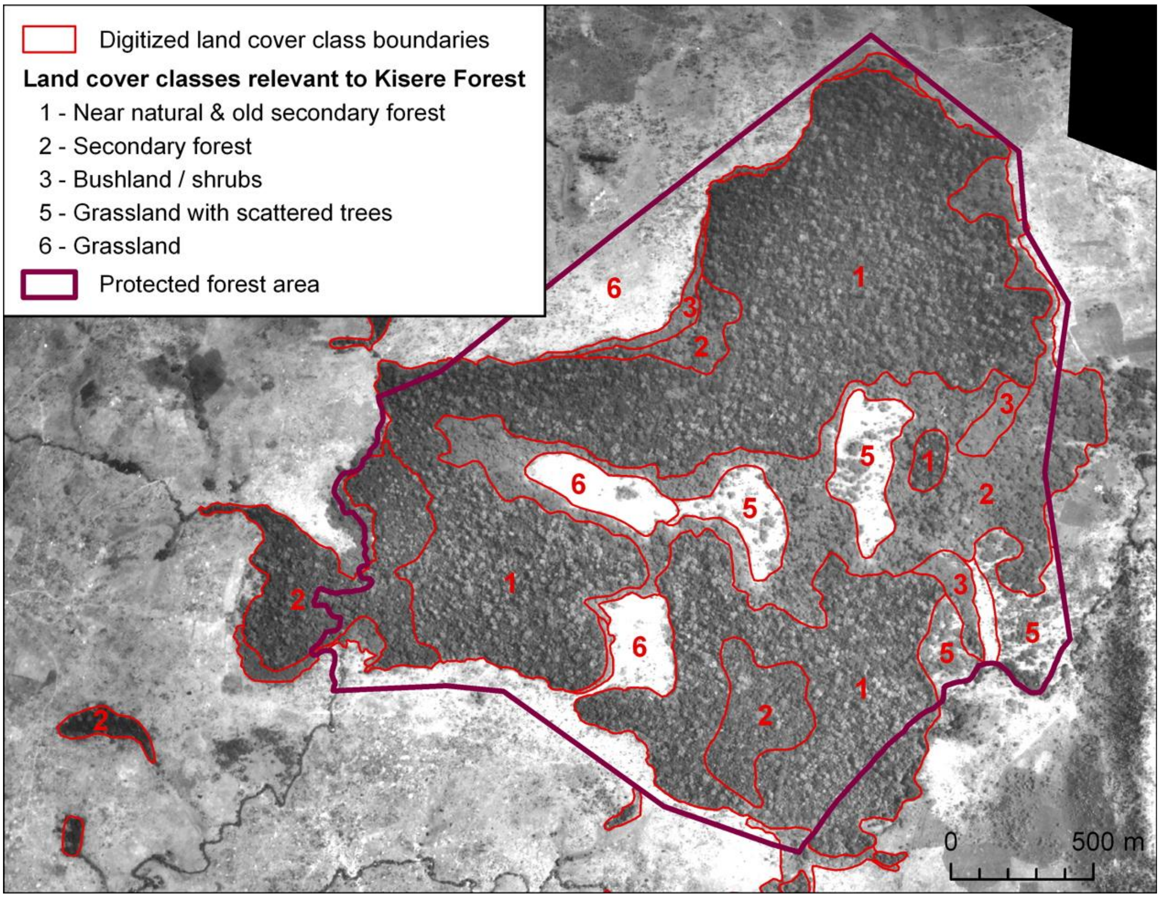


Figure 2.2: Kisere Forest as a subset of the Kakamega-Nandi aerial photography mosaic of 1948/(52), demonstrating the visual interpretation of forest cover classes.

2.2.4 Remote sensing data outcomes

Foremost amongst the concerns in the adoption of aerial photography for the extension of the satellite time series were the availability of sufficient data and the ability to discern compatible land cover classes. The following results reflect the degree to which this has been successful:

- Aerial photography was obtained and processed extending the existing remote sensing time series back in time for the forest areas of Kakamega-Nandi (to 1965/67 and 1948/(52)), Mabira (1955) and Budongo (1960), i.e. a further 24, 18 and 12 years, respectively; this results in remote sensing times series lengths of 55, 50 and 44 years.
- Mabira and Budongo Forests have one complete aerial photography time step each, while two steps were realized for the Kakamega-Nandi forests (the 1948/(52) Kakamega-Nandi mosaic has 62% coverage of the gazetted forest reserves; it lacks part of the Nandi forests and some outlying forest patches.
- 12 land cover classes of Lung's 15 satellite imagery classifications were interpreted from the aerial photography with a further two plantation classes (1:30,000 scale) (see Table 2.2).

All of the basic stages of natural forest succession as identified by the supervised satellite classification were detected by the interpretation of the aerial photography: the five most important classes for the observation of the development and disturbance of forest: 'Near natural and old secondary forest' (class 1), 'Secondary forest' (2), 'Bushland / shrubs' (3), 'Grassland with scattered trees' (5) and 'Grassland' (6) were all distinguished. However, two naturally occurring forest classes specific to Budongo Forest, 'Mature natural forest including *Cynometra'* (class 0), and 'Mesic forest / deciduous (woodland)' (class 4 in the Budongo Forest classification) were not detected in the aerial photography interpretation due to their similarities to class 1 and class 4, respectively. The class of 'secondary bushland - *Broussonetia papyrifera'* (class 4 in Mabira Forest) is not present in the photography of 1955

Table 2.2: Comparison of land cover classes detected within the visual interpretation of aerial photography and the classes derived from the supervised multispectral classification of Landsat satellite imagery by Lung & Schaab, e.g. 2010.

Class number	Class description	Kakamega-Nandi forests		Mabira Forest		Budongo Forest	
		Satellite imagery	Aerial photo	Satellite imagery	Aerial photo	Satellite imagery	Aerial photo
0	Mature natural forest incl. *Cynometra*	-	-	-	-	x	-
1	Near natural and old secondary forest	x	x	x	x	x	x
2	Secondary forest	x	x	x	x	x	x
3	Bushland / shrubs	x	x	x	x	x	x
4	Secondary bushland	x	-	x	-	x	-
5	Grassland with scattered trees	x	x	-	x	-	x
6	Grassland	x	x	x	x	x	x
7	Plantation forest - *Pinus patula*	x	x	-	-	x	-
8	Plantation forest - *Bischofia javanica*	x	x	-	-	-	-
18	Plantation forest - *Funtumia* spp.	-	-	-	x	-	-
19	Plantation forest - other	-	x	-	-	-	x
9	Tea plantation	x	-	x	x	-	x
10	Agricultural land	x	x	x	x	x	x
11	Water	x	-	x	x	x	-
12	Others	x	x	x	x	x	-
13	Wetland	-	-	x	x	x	-
14	Burnt area	-	-	-	-	x	-

as it was only artificially introduced in the early 1990s. 'Secondary bushland - *Psidium guajava*', the Guava tree, (class 4 in the Kakamega-Nandi area), is absent from the aerial photography interpretations but is also absent from the early satellite classifications (Lung 2004). Interviews (kn-i5 & 23) revealed that this tree was first noted in the district in the early 1940s but took decades to become common ground cover and was first noticed in the forest in the 1970s, establishing itself almost exclusively in areas of former forest that had been subject to agriculture.

The identification from the aerial photography of so many of the classes identified from satellite imagery is here considered to represent a success, especially in the light of the difficulty experienced by others, e.g. Harvey & Hill (2001), in deriving comparable vegetation classes from Landsat imagery and from the visual interpretation of aerial photography. However, by comparison to the satellite classifications, the visual interpretation is likely to under-estimate the proportion of 'Secondary forest' (class 2). This is because the pixel-based nature of the former is able to facilitate the classification of individual pixels of secondary forest within a matrix of class 1 forest resulting in a characteristic 'salt and pepper' appearance of the main forests (Lung 2004); meanwhile vector digitising unavoidably results in a more generalised, discrete coverage (*cf*. Congalton & Green 1999). The execution of a 'majority filter' function upon the satellite classification has the effect of reducing this discrepancy (*ibid*.). However, as this does not reflect reality more accurately it is only adopted in this research for the forest cover change index (see chapter 5) in which the satellite classification is overlaid on the aerial photography interpretation for the purposes of change analysis (*cf*. Fuller *et al*. 2003). The issue is otherwise ameliorated within this thesis by combining classes 1 and 2 when quantifying forest cover, for example, within the forest narratives of chapter 4.

2.3 Forestry records

The forests researched for this study are all gazetted as central government forest reserves and have been managed by government Forest Departments of Kenya and of Uganda since their original gazettement in the early decades of the 20th century (Brasnett 1951, Brasnett & Dale 1955, Logie & Dyson 1962). As such these institutions (and their successors the Kenya Forest Service and the National Forest Authority of Uganda) are the default repositories for much of the data on forestry operations for most of the last century. The offices and some forest guard outposts of these institutions were therefore searched for each forest area aiming to build a coherent and spatially-explicit account of the forest disturbance attributable to commercial exploitation.

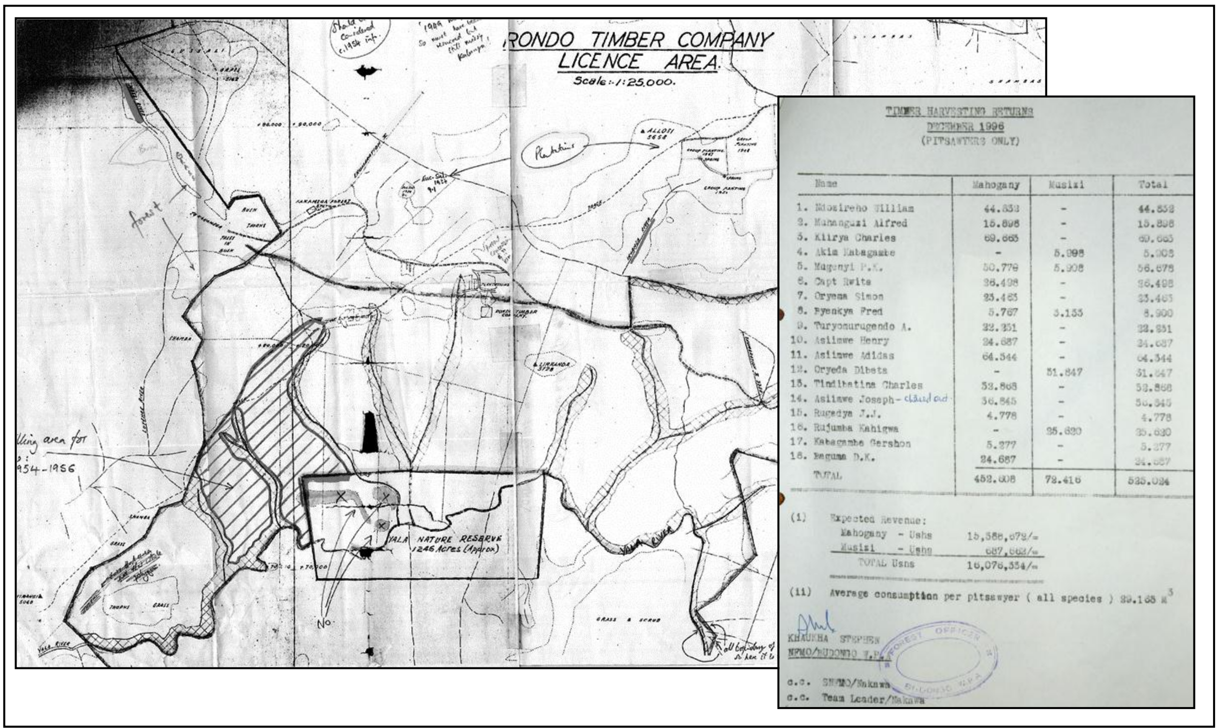
2.3.1 Acquisition of forestry data

With spatial, dating and species criteria foremost in mind, eleven forestry offices in the vicinity of the Kakamega-Nandi, Mabira and Budongo forests (and the Plant Sciences Library of Oxford University, UK) were explored in 2005 and 2006 for documents and maps relating to forestry activities. The greatest efforts were made in gathering information, both textual and cartographic, on the geographical limits of the timber extraction to later enable a spatial analysis. Maps ranging from printed examples to tracings and rough sketches were all photocopied or photographed if they indicated logging concessions or represented other silvicultural operations such as enrichment planting or arboricidal treatment. Timber volume statistics were copied from timber statements and summaries of yields within the foresters' monthly and annual reports were recorded and are reflected in reduced and summarized data provided in Appendices E3.1 to E3.4). The text sources ranged from official logging contracts, to official reports to the Chief Conservators of Forests, and letters between foresters and saw millers. While the Kakamega-Nandi and Mabira data comes from forestry archive searches, much of the Budongo Forest logging data comes from the work of

Plumptre (1996) and is here supplemented with further data taken direct from the forestry archives local to Budongo.

2.3.2 Creating GIS datasets from forestry data

The map photocopies were scanned, georeferenced and digitised to become part of the GIS. Forestry maps rarely have grid lines but normally show at least part of the official forest boundary and in most cases this was used for georeferencing. Details relevant to logging or generally to forest cover change were digitised and the dataset was attributed with the details present on the map. If maps were not available, logging concessions were digitised from written descriptions in foresters' letters or sawmiller's contracts. Working with surveys carried out by foresters required allowance to be made for some cartographic imperfections (also reflected in the data quality assessments of Appendices A1 to A3) and following georeferencing it was sometimes apparent that the original maps had erratic geometry. Rubbersheeting was sometimes employed to adjust datasets that were useful for analysis; for example, the 1976 forest inventory map of South Nandi Forest (kn-d95) had been distorted during photocopying and the digitised shapefile of forest cover types (kn-d96) was therefore rubbersheeted to the similar but less distorted version of 1966 (kn-d69).



TIMBER HARVESTING RETURNS
DECEMBER 1996
(PITSAWYERS ONLY)

Name	Mahogany	Musizi	Total
1. Ndozireho William	44.833	-	44.833
2. Muhanguzi Alfred	15.898	-	15.898
3. Kiirya Charles	69.665	-	69.665
4. Akim Kabagambe	-	5.998	5.908
5. Mugenyi P.K.	50.779	5.908	56.678
6. Capt Rwita	36.498	-	36.498
7. Oryema Simon	25.465	-	25.465
8. Byenkya Fred	5.767	3.133	8.900
9. Turyomurugendo A.	22.351	-	22.351
10. Asiimwe Henry	24.687	-	24.687
11. Asiimwe Adidas	64.544	-	64.344
12. Oryeda Dibeta	-	51.847	51.847
13. Tindibatina Charles	53.868	-	53.868
14. Asiimwe Joseph	36.845	-	36.845
15. Rugedya J.J.	4.778	-	4.778
16. Rujumba Kahigwa	-	25.630	25.630
17. Kabagambe Gershon	5.277	-	5.277
18. Bagume D.K.	24.687	-	24.687
TOTAL	452.608	72.416	525.024

(i) Expected Revenue:
Mahogany - Ushs 15,388,672/=
Musizi - Ushs 687,662/=
TOTAL Ushs 16,076,334/=

(ii) Average consumption per pitsawyer (all species) 29.168 M^3

KHAUKHA STEPHEN
NFMO/BUDONGO F.R.

c.c. SNFMO/Nakawa
c.c. Team Leader/Nakawa

Figure 2.3: Examples of forestry records: (left) a map of Rondo sawmill's concession area showing plans to fell forest adjacent to Yala River Nature Reserve, Kakamega Forest in 1954-56 (dataset kn-d52, cf. *case study 8; (right) an example of the systematic and well-kept forestry records of Budongo Forest.*

The non-harmonized manner in which the statistics were originally recorded (e.g. whether it was 'roundwood over bark', or expressed in tons, or in cubic metres, etc.) necessitated adjustment of the timber statistics to account for the differences. The figures given in this thesis (in Appendices E3.1 to E3.4) are cubic metres of sawn timber. The species names also required considerable standardisation since the *Zanthoxylum gillettii* tree, for example, is variously referred to in the records as 'Satinwood' (standard name), 'Shikuma' (Luhya name), 'Sagawoita' (Nandi word), 'Simbari' (trade name), and '*Fagara macrophylla*' (old scientific name). Foresters' knowledge, local knowledge, archive reports and published literature including the standard reference book by Beentje (1994) were used to decipher these names.

2.3.3 The forestry data generated

The search for data brought to light a wealth of maps and textual references available for reconstructing the forestry operations but there is significant variation in the level of detail, as seen in Table 2.3. Differences in the data available are, in large part, a reflection of the styles of forestry practice that differed between Kenya and Uganda. While Kakamega-Nandi forests in Kenya produced only six datasets on forest cover types, Mabira and Budongo produced 14 and 13 respectively and reflects the more systematic exploitation for timber in the Ugandan sites (*cf*. Figure 2.3) which was based on the consistent use of forest inventories in planning the felling process (*cf*. Eggeling 1947, Osmaston 2005). This is further reflected in the division of the Ugandan sites into permanent compartments for the consistent execution of silvicultural activities that virtually eliminated the need for mapping areas of logging or other silvicultural operation (see the low values, especially for Budongo, in Table 2.3). By contrast the Kakamega-Nandi forests were logged via a system of repeatedly specifying individual logging concessions to multiple companies, resulting here in 29 such geodatasets.

Table 2.3: Geodatasets derived from forestry archive information, shown per topic.

Geodataset Topic	Kakamega-Nandi forests	Mabira Forest	Budongo Forest
Logging concessions	29	9	1
Forest cover types & inventories	6	14	13
Admin. compartments, boundaries & excisions	7	7	5
Silvicultural operations	4	6	0
Totals	*46*	*36*	*19*

Table 2.4: The availability of analysed forestry records for each of the main forest reserves.

Forestry data	Kakakmega Forest	North Nandi Forest	South Nandi Forest	Mabira Forest	Budongo Forest
Total logging volumes	**good** per annum for 50 years, i.e. near complete	**good** per annum for 31 years, i.e. complete	**unavailable** fragmentary records only	**moderate** per logging phase for 33-year period, i.e. near complete	**good** per logging phase for 69-year period, i.e. near complete
Logging volumes per species	**good** 45 years	**good** 31 years, i.e. complete	**available** but very few records	**moderate-poor** representative sample available	**moderate** all Mahogany volumes specified
No. & intensity of exploitation episodes	**good** via logging figures, doc.s, oral	**good** via logging figures, documents & oral	**poor-moderate** oral	**moderate** via forestry documents & oral	**good** via Plumptre 1996, log records, oral
Spatial definition of data	**good** via sawmill concessions	**poor-moderate** via oral, due to *ad hoc* exploitation	**poor** via oral, due to *ad hoc* exploitation	**Moderate (patchy)** via forestry compartments	**good** via forestry compartments
Proportion of the forest covered	100%	100%	approx. 10%	100%	100%

The Ugandan system was not uniform, however, and as seen in Table 2.4, the Mabira Forest records exist as generalised volumes per sawmill per logging phase and timber volumes cannot therefore be attributed per compartment as with Budongo Forest. The more *ad hoc* practice in Kenya (*cf*. Logie & Dyson 1962) led to the logging of Kakamega Forest by 15 different sawmills with often overlapping concession areas. However, via numerous concession maps and descriptions this has allowed for the painstaking and detailed attribution of the logging figures to their relevant parts of the forest. The annual basis of the Kakamega and North Nandi felling records mean that unlike the other forests the temporal pattern of the timber harvest can be plotted chronologically, as is shown in the narrative graph (see Figure 4.1). The exploitation of the Nandi forests was the least systematic, no geographical restrictions having been placed on the operation of the sawmills and results in a lack of spatial definition to the logging records within the boundaries of the forest reserves. The logging figures for North Nandi Forest are complete and detailed with volumes per species but they can be only approximately allocated to location within the forest via interviews with local people and forest guards. The records of South Nandi Forest are very limited presumably due to the highly sensitive and controversial political context in which large-scale illegal selective felling occurred under government protection.

2.4 Archive maps and documents

To trace the pattern of forest cover further back than the mid-20th century, cartographic material was sought in the government archives and libraries of Kenya, Uganda, the United Kingdom and Germany. Written archive documents were also desired to provide valuable background material on the social context and the issues facing the decision makers, thus shedding light on the causes of forest cover change. Maps and written documents are included here together since they often share a common library or archive origin.

2.4.1 Acquisition and pre-processing of maps and documents

Maps and textual evidence was sought in numerous non-forestry archives; some of the most significant are the national archives of both Kenya (NAK) and the United Kingdom (NAUK), the Kakamega District archives, the Ugandan Lands and Survey Department, the libraries of the Ugandan Society in Kampala, the Bodleian and Rhodes House libraries at Oxford University in England, and the Universitäts- und Forschungsbibliothek Erfurt/Gotha, Sammlung Perthes in Gotha, Germany (see Appendices A1 to A3). Most of these archives are in good order and the national archives are now mostly computer catalogued. Textual references regarding historic events or social and cultural information held within internal government letters and reports were copied and now constitute part of the archive for this thesis. The maps were photocopied, scanned or photographed, and then georeferenced and subsequently depictions of forest cover and exploitation and disturbance were digitised.

Population census data was obtained from, for example, the Kenya National Bureau of Statistics, the Uganda Bureau of Statistics, and the Lands and Survey Department of Uganda; some of the later datasets were in digital form, some as original maps with statistics available in paper form. The latter were digitised, attributed with the statistics, and population densities calculated before being clipped to the bounding boxes of the BIOTA E02 research areas (for the later censuses of the Kakamega-Nandi area, i.e. 1979, 1989 and 1999, this had already been carried out by Tobias Lung of BIOTA E02). The results are plotted temporally in the narrative diagrams Figures 4.1 to 4.3 in chapter 4, and the 1999 and 2002 figures are displayed spatially in chapter 5, Figures 5.4 to 5.6.

2.4.2 Archival outputs

Sixty-two Kakamega-Nandi geodatasets were derived from maps classed here as topographic maps, topographic drafts, thematic or sketch maps, most of which were originally produced within government offices. There are 39 such examples for Mabira Forest and a further 27 for Budongo Forest (see Table 2.1).

These datatsets are able to extend the forest cover time series back to 1912/13 for the Kakamega-Nandi forests, to 1911/12 for Mabira Forest, and to 1911 for Budongo Forest (kn-d7, mf-d5, bf-d2). These three 1:250,000 scale topographic maps are significant for belonging to a single series, thus implying some consistency between the data of the different forests. This early time step is also significant for representing the state of the forests at the start of the effective colonial administration of forests in East Africa (Troup 1922), and soon after the start of commercial exploitation of rubber from Nandi, Mabira and

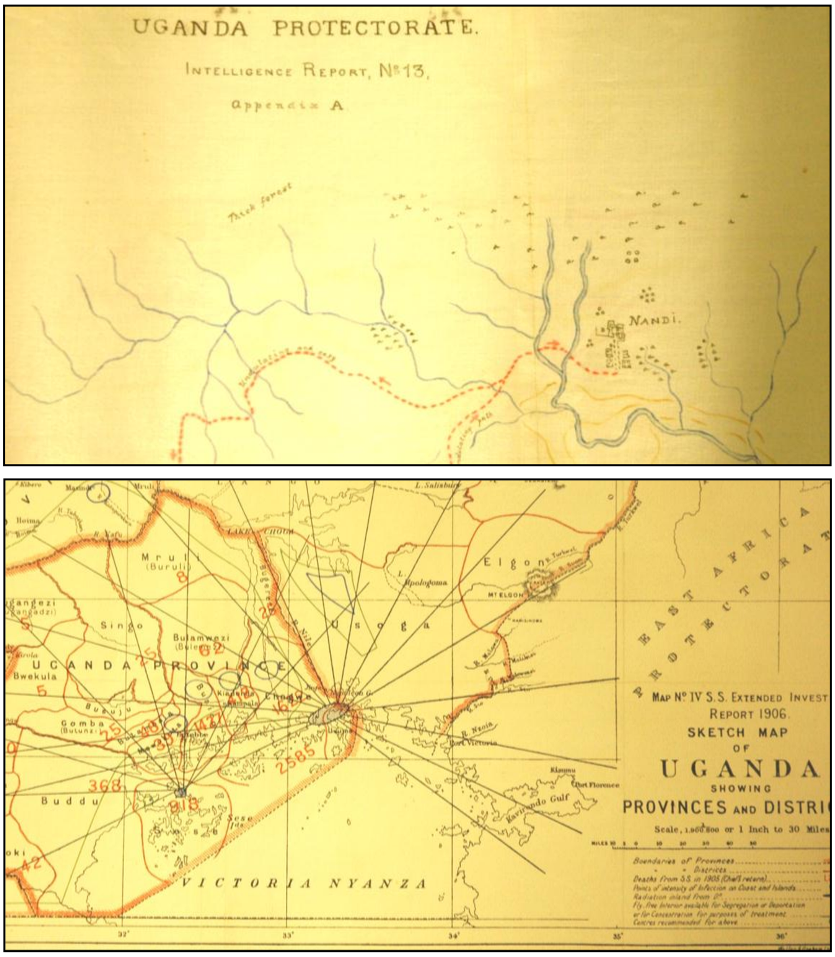


Figure 2.4: Colonial archive maps: (top) a military map of 1900 showing patches of forest along the rivers near Nandi Fort (i.e. Kaptumo, 1.8 km south-east of South Nandi Forest); (bottom) a map of 1906 showing the spread of sleeping sickness outwards across Uganda from an island in Lake Victoria.

Budongo Forests and before any of the forests were harvested for timber (Brasnett 1951, Logie & Dyson 1962).

Many other maps, such as the 1896 military map of the Nandi forests (kn-d1), provide invaluable information on the development of the forest landscape (see case studies CS 3, 8) but few are able to contribute full forest cover time steps for a complete area of investigation (see the forest cover narrative diagrams, Figures 4.1 to 4.3). Thematic maps are in several cases able to assist interpretation of the forest landscape development and examples are shown in Figure 2.4; one of the more significant is the 1:250,000 scale map of the natural vegetation cover of the wider Kakamega-Nandi area of investigation (kn-d74, see CS 1, 2, 9).

The social and political background is well represented by ample archival texts. For instance, the correspondence of Sir Harry Johnston of 1900 sheds light on the political machinations through which the colonial agreement took control of the forests from the King, or Kabaka, of Buganda. Commentary on the location and methods of the subsequent British exploitation of those forests for rubber in Mabira and Budongo Forests (CS 3, 5, 6) is traced only through non-forestry internal government (IG) reports and correspondence (corresp.) (e.g. IG Report 1903, IG Corresp. 1900, as listed in the reference list). The following notable examples concerning the main focus area of Kakamega-Nandi are listed to demonstrate the range of subject matter addressed in these primary sources and the range of the source archives:

- Blackburn family 1902-10: photograph album of the first missionaries at Kaimosi → forest vegetation and early exploitation (see case study CS 9) (Earlham College Library, Richmond, Indiana, USA)

- IG Report 1904: military report → reasoning for pattern of settlement & tribal patterns → interpretation of forest landscape development (CS 2, 3) (National Archives, London, UK)
- Heller 1912: diary & photographs of botanist Edmund Heller → forest vegetation & human interaction (CS 9) (Smithsonian Institution Archives, Washington, DC, USA)
- IG Report 1918/19: Annual report for North Kavirondo District → population estimates (see chapter 4.1) (Kenya National Archives, Nairobi, Kenya)
- Kitson 1932: report & map on goldfields → the impact on forest (CS 7) (National Archives, London, UK)
- IG Report 1960 → traditional usage of grasslands (CS 4) (Provincial Government Archives, Kakamega, Kenya)
- Ng'eny 1970: unattributed typescript → alienation of forest land for 1918 British coffee (CS 9) (British Institute in Eastern Africa, Nairobi, Kenya)
- IG Report 1981: annual report of the Land Adjudication Department → encroachment into forest (CS 3) (Kenya National Archives, Nairobi, Kenya)
- IG Report 2004: state of environment report, Nandi North District → migration & population pressure (CS 3) (District Commissioner's Office, Kapsabet, Kenya)

The population data acquired for each of the forest areas is summarized in Table 2.5 and shows that long-term data is available although the reliability of this data increases dramatically from the mid 20th century with the introduction of systematic census methods (*cf*. Brass & Jolly 1993). Although the figures for 1900 are considered here to be little more than estimates, they are included in this thesis as they represent the best available information (see Appendices A1 to A3 for data quality assessment values).

Table 2.5: Population data available for the three areas of investigation.

Year	**Kakamega-Nandi forest area**	**Mabira Forest area**	**Budongo Forest area**	**Resolution** (i.e. spatial admin. units)	**Reliability of data**	**Statistics type**
2002	-	Parish	Parish	highly resolved	good	exact figures (census)
1999	Sub-Location	-	-	highly resolved	good	exact figures (census)
1991	-	Parish	Parish	highly resolved	good	exact figures (census)
1989	Sub-Location	-	-	highly resolved	good	exact figures (census)
1980	-	Sub-County	Sub-County	medium resolution	good	exact figures (census)
1979	Location	-	-	medium resolution	good	exact figures (census)
1969	-	Sub-County	Sub-County	medium resolution	good	density ranges (census)
1959	-	Sub-County	Sub-County	medium resolution	good	density ranges (census)
1948	District	-	-	moderate resolution	moderate	density ranges (census)
1918	District	-	-	poor resolution	poor	estimates (house counts)
1921	-	County	County	low resolution	poor	estimates (house counts)
1900	District	District	District	very low resolution	very poor	estimates (unknown method)

2.5 Oral histories

2.5.1 Interviewing forest-adjacent inhabitants

A total of 42 semi-structured interviews were conducted around Kakamega Forest between October 2002 and March 2003, and a further 33 around the Nandi forests, 21 around Mabira and 20 around Budongo Forest between March and May 2005 and between January and March of 2006. The interviews were designed to provide oral histories relating to both legal and illegal forest use and to provide insight into the causes behind the forest cover changes revealed by remote sensing data and maps. It was also intended to provide a local perspective, capable of testing or challenging the statements found within forestry archives and also able to cross-reference the documentary evidence of non-forestry archives (*cf*. Vansina 1995) regarding the causes of forest cover change.

The interviews for Kakamega Forest were conducted in close proximity to the 1 km^2 BIOTA biodiversity observatories (Mitchell 2004) in order to provide the disturbance context as background to the data collected at these sites by other BIOTA researchers. With less focus of the BIOTA scientists on the Ugandan forests and with no such observatories within the Nandi forests, interviews for these forests were targeted to areas and issues of interest that required clarification. The distributions of interview locations (see Figure 1.3) broadly enclose the studied forests although Budongo Forest, bordered along its north-western side by unpopulated reserves, was investigated along only its southern edge.

With considerations of data quality foremost in mind (*cf*. Vansina 1995), the interviews were:

- conducted with the oldest people available and those that had lived in the area longest in order to recollect the earliest possible time without recourse to hearsay or tradition;
- clustered in each area of interest to enable cross-referencing and mutual testing;
- conducted through translation by locally selected field assistants who were often known to the interviewee since this brought trust and avoided suspicion of foreigners. This local connection furthermore enabled local land-mark references to be readily recognised and clearly explained in translation;
- conducted in areas of special interest in which evidence from other sources required testing or clarification, e.g. the land between Mabira Forest and the River Nile (see CS 11), and the Kitigo area of Budongo Forest (see CS 12).

A semi-structured format was preferred to a more formal, questionnaire-based approach (*cf*. White *et al*. 2005) since it was soon apparent that more information was gained when natural conversation was allowed to develop. Moreover, the advanced age of most of the interviewees often precluded long and formulaic questioning which soon initiated their disinterest. The interviews were conducted with local field assistants translating between English and the local language. Questions were posed in as simple, open-ended and value-free manner as possible, carefully avoiding leading questions (*cf*. White *et al*. 2005). To quell concerns over government connections, questions were also directed away from issues of on-going personal involvement in forest exploitation. Questioning was instead aimed at the interviewee's memory of former vegetation cover and their perception of general trends and to the changes witnessed.

Interviews first recorded the age, tribe and the period in which the interviewee had lived in that location. The dates of historical incidents that were related within an interview was established as far as possible with calendar years, sometimes estimated from a coincident event such as a famous event or a tribal conflict. The questioning varied according to the situation of each area and the knowledge of the interviewee but was typically based around the following questions:

- Has the limit of the forest changed since you first remember it? How?
- Has the forest quality changed since you first remember it? How?
- What vegetation types existed outside today's forest boundary when you first remember it?
- Were there any forest fragments or islands that no longer exist?
- Has the forest here been logged, by whom, when, which species?
- What were the main disturbances to the forest in the past, and what are the disturbances today?

- How has the management of the forest changed over time?
- What animals are now rarer, or more common, or locally extinct today?
- What plants are now rarer, or more common, or locally extinct today?
- Are there / were there any traditional spiritual beliefs associated with the forest or with vegetation?
- Were there / are there any indigenous practices or beliefs that would encourage protection of the forest?
- Did people live in the forest in the past?
- What is the tribal history of the area?
- What are the main traditional / current local uses of the forest?

Names of plant and animal species were recorded in the local language with basic descriptions to assist later translation to their scientific names. The physical limits to which statements applied were, where possible, established via reference to local landmarks, often rivers or glades and the edge of the forest. The interview locations were recorded in the field with either a GPS or by reference to 1:50,000 topographic map sheets. These locations were entered as point data in the GIS and were attributed with the summarized information of each interview (*cf*. geodatasets kn-d135, mf-d91 and bf-d64).

2.5.2 The oral histories

The number of interviews able to provide information on some of the main topics of relevance and the years of forest-adjacent experience of the interviewees are shown in Table 2.6. Against expectations many of the old Kenyan interviewees were fore-armed with an exact date of birth which the interviewees themselves (e.g. kn-i32) attributed to the introduction of identity cards in East Africa around 1920. Of the 75 interviews conducted in the Kakamega-Nandi area, 27 of the interviewees were considered to have been born in or before 1920 and thus old enough to recall the forests before the start of the commercial extraction and the official gazettement of the forests in the 1930s. The periodic evacuation of people from the Mabira Forest area (see CS 5) and the comparative lack of population around Budongo Forest in the first half of the 20th century (Doyle 2006) resulted in much greater difficulty in locating people who had known the forests for more than 50 years. In the Mabira Forest area, 11 interviewees were able to recall the area in the 1950s but nobody could be located who had been present before the area was largely evacuated due to the *Simulium neavei* fly (see forest cover narrative chapter 4.2). Four people of Budongo Forest were able to recall the forest in the 1940s and the remainder were able to recount the area in the 1960s.

Table 2.6: Summary of some main information types resulting from forest-adjacent interviews (number of interviews / percentage of total interviews for that forest).

Topic	Kakamega Forest	Nandi Forests	Mabira Forest	Budongo Forest
Total number of interviews	42	33	21	20
Interviewees's years at the forest edge	c. 40-100 yrs	c. 40-90 yrs	c. 30-55 yrs	c. 40-60 yrs
Information on logging	14 / 33%	11 / 33%	9 / 40%	8 / 40%
Information on local forest use	27 / 64%	23 / 70%	10 / 48%	8 / 40%
Information on species changes	31 / 74%	17 / 52%	9 / 43%	6 / 30%
Information on traditional beliefs	15 / 36%	10 / 30%	12 / 57%	0 / 0%
Information on tribal relations	13 / 31%	13 / 39%	8 / 38%	5 / 25%

The search for interviewees of advanced age normally brought forward men (104 cases) rather than women (12 cases) and is interpreted as reflecting the culture of the male being the head of the family and the repository of traditional information (e.g. Figure 2.5). The interviewing of women met with mixed success as they were more likely to fear strangers although when interviewed with family members translating the resulting data proved useful. Only two men were openly fearful of divulging their full information on Kakamega Forest (kn-i4, 14) while in the Nandi and Mabira forests interviewees were often muted in their willingness to discuss issues regarding controversial land settlement.

Figure 2.5: Oral history interviews showing their potential to engage both the forest managers and the local communities via discussion of forest cover change (top: interview kn-i61, South Nandi Forest, cf. case study 10, bottom: interview kn-i51, North Nandi Forest).

Between a third and a half of interviewees of each forest (see Table 2.6) were able to provide valuable information towards the analysis of commercial exploitation via the identification of logging companies, dates, locations and species exploited. Insight into local uses of each of the forests is abundant but traditional uses, often relating to religious practices, were more frequently cited in the Nandi forests, followed by Kakamega, and are very likely to relate to the comparatively long term stability of forest-adjacent settlement. The likely impacts of disturbance caused by logging (legal and illegal) and hunting on the plant and animal communities are reflected in the number of occasions that species were identified by the interviewees as having noticeably reduced in number. Kakamega Forest has an especially high rate of affirmative answers possibly reflecting a high rate of disturbance.

Questions relating to local spiritual beliefs revealed several such associations to places or individual trees within the Kakamega and Nandi Forests and some traditionally protected areas. However, Budongo Forest is notably poor in this regard and may relate to the people's lack of long-term association with the forest. Mabira Forest would follow a similar pattern here but instead has relatively high figures for spiritual associations, 12 interviewees of the total 21. This is due almost solely to the repeated mention of the *Nakalanga*, a somewhat mythical group of people, sometimes described in bestial terms but presumably stemming from the former presence of pygmies (*cf*. Johnston 1902, Pitman 1934) and after whom several places within the forest are named. As such the *Nakalanga* do not strictly relate to spirituality but are included here as part of the beliefs of the local people relating to the forest and because they also give rise to at least two 'no-go' areas for the local people. Other inter-tribal relations were willingly discussed in each forest, whether stable in their tribal locations (Kakamega and Nandi) or having experienced great influx and exchange (Mabira and Budongo). They are able to shed light on the background issues and some motivations behind trends in local use (e.g. see the Budongo Forest narrative, chapter 4.3).

2.6 Place name evidence

In the course of conducting the oral history interviews it was noticed that several village names around Kakamega Forest could be translated into scientific species names of trees and sometimes animals. Interpretation of these names was considered to represent a good means of shedding light on the land cover outside today's forest boundaries in the period prior to the evidence of the earliest maps and oral testimonies. Pilot testing of place name meanings within the forest-use history interviews for the two Ugandan forests brought very meagre results and did not warrant further investigation. Place name research was therefore focused on the Kakamega-Nandi area with the aim of investigating the likely extent of forest cover at the time of settlement by the currently inhabiting tribes.

2.6.1 Place name data collection

Initial attempts to identify village names with environment-related meanings were done through the assistance of botanically-knowledgeable local people interpreting the names on a 1:50,000 topographic map (kn-d79). However, this produced limited results and it was realized that possible misspellings on the maps could lead to false inferences: for instance, the very similar Luhya words Matundu (a swamp-reed for drinking alcohol), Mutundu (*Trimeria grandifolia*, a dry-forest tree) and Mutondo (*Funtumia Africana*, a moist-forest tree) could be easily confused. This demonstrated the necessity for field-survey in which the oldest people living in the immediate vicinity of the name itself could be questioned.

Interviewees younger than around 50 years of age were often unaware of the derivation of their local place names and deferred to the oldest generation, although occasionally the meaning of the village name is proudly displayed for all to see, see Figure 2.6. Old people were therefore sought at every settlement along selected roads and asked to identify, locate and translate the meaning of places with names of environmental significance. Other place names with meanings of no direct environmental relevance were often provided voluntarily by the interviewees and were also recorded to aid interpretation of the different cultural practices of place naming per forest area.

Questioning was carried out along roads (see Figure 1.3) selected to provide a sample of place names across the areas of greatest research interest regarding former forest cover. For example, the areas to the west and to the north of Kakamega Forest have been the subject of some debate in published literature (Tsingalia 1988, Brooks *et al*. 1999) and were therefore targeted for sampling. Interpretations of place names were also generated from the forest-use interviews conducted for this thesis and from the surveys of other BIOTA projects (E13 and E14) working in the farmland in the north and west of Kakamega Forest.

If the village names could be found on the most recent (i.e. 1970) 1:50,000 scale topographic map, this location was accepted and digitised from the georeferenced map sheets. In other cases the location of the village was recorded from the interviewee's estimation of the distance and indication of the direction (a compass-bearing was taken) from the location of the interview and was later digitised.

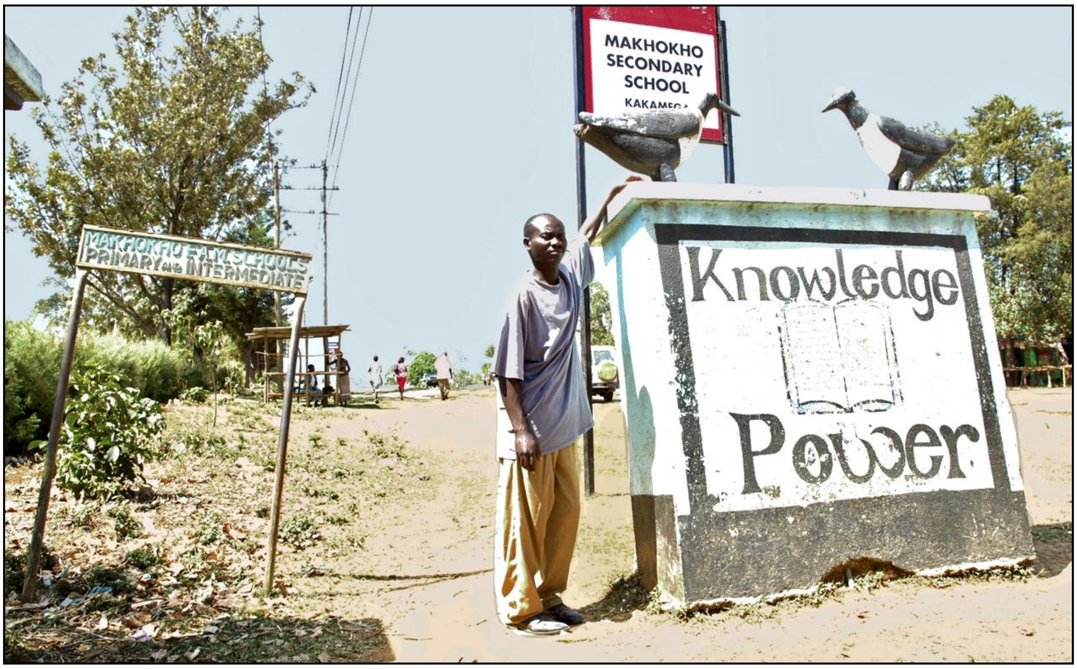


*Figure 2.6: Multiple signs for Makhokho; the sculptures depict the meaning of the village's name that is translated as Pied Crow (*Corvus albus*), the habitat of which is recorded by Zimmermann et al. (1999) as 'open country up to 3,000 m' (see Appendix B1).*

2.6.2 Analysing the place names

Translations of species names from local languages to scientific names was, where possible, initially done by field assistants and confirmed with reference books, Beentje (1994) for plants, Zimmerman *et al*. (1999) for birds, and Kingdon (2004) for mammals. The search for place names with known meanings of any kind in the Kakamega-Nandi area produced 304 securely located names. Of these, 268 names directly reflect the physical environment or landscape (see Table 2.7) and can be classed into 12 types according to the form of environment that they denote; the remaining 36 are related to specific people, battles, activities or traditional beliefs. The Kakamega-Nandi sample is easily the best represented and is dominated by place names directly specifying trees (151 examples), only distantly followed by grass-related place names (26), mammals (16) and the root/shrub/climber class (14). They reveal 59 different plant species within the historic landscape and in 71 cases in the Kakamega-Nandi area the specific reason for species-named places being so named was still known: 60 being attributed to the dominance of the stated species, and 11 reflecting an especially large or interesting individual of that type.

As seen in Table 2.7, very few place names could be translated for the Ugandan forests and of those that were translated, two-thirds (Mabira) and approximately a third (Budongo) do not relate directly to environmental matters. This may be a reflection of the lack of a long-term connection between the local people of Mabira and Budongo and their forest environment (see forest narrative chapters 4.2 and 4.3). Of Budongo Forest's 32 translated place names, 11, i.e. approximately a third, represent mammals and notably contrast with both the Kakamega-Nandi (16 of 304) and Mabira areas (2 of 21). The higher proportion of mammal place names in the small Budongo sample parallels the oral histories that recall the dangers of wild animals for settlers in the mid 20th century (bf-i6, 11, 12, see chapter 4.3).

To facilitate further analysis the 228 names that could be interpreted (using the reference books cited above) as holding an inference for a habitat or land cover were further attributed to one of eight broad land cover classes (see Table 2.8). Some overlap exists between these

Table 2.7: The place names of the three areas of investigation classified thematically according to their direct meanings, i.e. without further interpretation.

Place name type	Kakamega-Nandi forest area	Mabira Forest area	Budongo Forest area
tree	151	2	4
mammal	16	2	11
grass	26		
root / shrub / climber	14	2	
rock	13		
open area	12		
bird	9		
water	8		2
forest	5	1	1
insect	5		2
soil	5		1
hill	4		
sub-totals	*268*	*7*	*21*
other	36	14	11
totals	***304***	***21***	***32***

classes; for instance, a village name, e.g. Shivanga, stemming from the Luhya word *Muvanga*, is translated as the tree *Harungana madagascariensis* and implies ‘secondary forest’, whereas a village name, e.g. Imukavakava, stemming from the Luhya *Mukavakava*, is translated as the *Ficus lutea* tree, and cannot be attributed to a more specific land cover than ‘forest’. In 48 instances the names could only be interpreted as ‘tree cover (unclassified)’, due either to the lack of confident identification of the individual tree species or to being typical of a broad range of tree-covered habitats. A further 76 names defied land cover summary and were classed as ‘no inference’. Some place names, e.g. Musala and Amusala, meaning ‘tree’, are surprisingly ambiguous regarding land cover as, instead of simply inferring tree cover they may reflect a largely treeless landscape in which the presence of a single tree was notable; to avoid over-interpretation, these cases were classed as ‘no inference’. A full list of the place names, translations and forest cover inferences is listed alphabetically in Appendix B1. The spatial distribution of these classes and the date to which the place names relate, as suggested by the tribal histories published by Huntingford (1926), Wagner (1949) and Osogo (1966), are interpreted as part of case studies 1 and 2.

Table 2.8: Land cover classes of the Kakamega-Nandi area derived from translations of the place names and inferred from the descriptions in the published literature, i.e. Beentje 1990, Zimmermann et al. 1997, Kingdon 1999.

Inferred land cover	Typical habitat descriptions in literature	Number of place names
forest	‘forest’, ‘moist forest & relicts’, ‘(riverine) forest (remnants)’, ‘wet forest (edge)’	61
secondary forest	‘forest edge, riverine’, ‘riverine forest & remnants’	8
riverine / watery vegetation	‘wooded streams & ravines’, ‘riverine, lake shores’, ‘watery forest & bush’	12
woodland	‘woodland’, ‘*Combretum* / *Acacia* woodland’, ‘dry forest, bushland, thickets, wooded grassland’	22
bushland	‘forest margin, secondary bushland or thicket’, ‘bushy glades (& secondary forest)’	2
wooded grassland	‘open & wooded grassland’, ‘grassland or woodland’	22
open / grassland	‘grassland’, ‘without trees’, ‘open’	53
tree cover (unclassified)	‘wooded grassland & forest’,	48
sub-total		*228*
no inference	‘rocks’, ‘many birds’, ‘salty water’, ‘tree’, etc.	76
total		*304*

2.7 Fossil pollen

2.7.1 Pollen sampling

Soil samples were taken for the recovery of fossil pollen in order to investigate the pre-20th century land cover of the Kakamega-Nandi area. The sampling was restricted to the Kakamega-Nandi forest area (see Figure 1.3) where particular questions of former land cover could be addressed. In particular sampling was carried out in order to investigate the evidence emerging from the place names, oral histories and map evidence, that forest cover formerly extended west of today's Kakamega Forest, an area now under intensive cultivation. Three other samples were taken in other parts of the Kakamega-Nandi area that had contrasting evidence of historic forest cover although, for reasons of time and money, they have only been partially analysed.

Sites with waterlogged soils were sought since anaerobic conditions are required for pollen preservation. No lakes or ponds could be found without rivers or streams flowing through them and the samples were all taken in the swampy or waterlogged sediments beside rivers to streams. The samples were taken with a Russian corer (Figure 2.7) in 50 cm sections to the maximum depth that could be physically extracted. This resulted in total core-lengths of 2.6 m (sample 1), 0.65 m (2), 0.7 m (3) and 1.4 m (4).

Figure 2.7: Soil core taken with a Russian corer for fossil pollen, near Shidodo, Kakamega.

2.7.2 Processing and analysis of pollen samples

Processing of the four soil samples was carried out in Nairobi by the Department of Palynology and Palaeobotany at the National Museums of Kenya and by Rob Marchant at York University, UK. The standard palynological procedure for processing and concentrating pollen grains was carried out in accordance with the methods outlined by Faegri and Iversen (1975). The sediments were treated in the sequence of 10% HCL (Hydrochloric acid) to remove the carbonates, 5% KOH (potassium hydroxide) to remove organic matter, HF (undiluted), (Hydrofloric acid) to remove all the silica content, and finally acetolysis (Acetic anhydride plus Sulfuric acid, at a ratio of 9:1) to wash the outer cover of the pollen for clear identification. More than 200 pollen grains were then counted for each sample.

Laboratory analysis has shown that sample 1 is the most pollen-rich and also shows the most distinct changes in vegetation phases. Although the top of the sample is poorly preserved the core shows distinct phases of differing forest type and quality dating from around 6,000 years ago and also reveals a substantial grass-dominated phase occurring before a probable forest recovery. Since this sample holds the greatest potential for distinguishing a temporal sequence funds were prioritised to dating this core and four sub-samples were radiocarbon dated. The broad interpretation of sample 1 is considered within the context of the evidence of other data sources in case studies 1, and the pollen diagram is illustrated in Appendix C1. The other three samples cannot be meaningfully interpreted without dating but results from preliminary processing show that samples 2 and 3 are both dominated by Poaceae, i.e. grass pollen, sample 3 also including some trees of highland character. Preliminary results for sample 4 also indicate the dominance of grass with highland tree species appearing only late in the sequence. However, as highlighted by Bush (2002), caution should be exercised in interpreting the high Poaceae contribution as a direct indicator of dry climate or savanna vegetation; further analysis is required for more complete interpretation.

The cores, especially sample 1, have indicated their great potential for revealing the otherwise undetectable character of former forest cover. The dating and fluctuations within the pollen record of the only dated core, sample 1, are consistent with known phases of climatic changes in East Africa (e.g. Olago 2001) and indicate the internal coherence and validity of the sample.

2.8 Summary of processed data

Data fitting the criteria listed in chapter 2.1 was acquired for each of the forests in each of the different source groups of remote sensing, forestry records, cartographic and archival evidence, oral histories, place name evidence and fossil pollen. The employment of the different data types within the reconstruction of the local forest cover stories, i.e. the case studies, is summarized in Table 3.2 at the end of chapter 3. The pre-processing of the data achieved the following:

Remote sensing: The acquisition and processing of aerial photography has been successful in extending the pre-existing remotely-sensed (satellite-based) classification time series for the forest areas of Kakamega-Nandi (to 1965/67 and 1948/(52)), Mabira (1955), and Budongo (1960) (see Figures 4.1 to 4.3 for the forest narrative diagrams). Four aerial photography mosaics were visually interpreted resulting in a total of 11 land cover classes being distinguished. This identification of multiple forest cover classes consistent with the satellite imagery-based classifications enables not only the longer-term tracing of major disturbances such as forest fragmentation, but also the more subtle changes in forest quality. It therefore facilitates the development of the forest cover change index (see chapter 5.1).

Forestry records: a great wealth of data was collated from forestry archives including 101 forestry maps and has produced a relatively wide difference in the levels of detail between the separate forest reserves; most detail is available for Kakamega and North Nandi Forests, and least for South Nandi. To differing levels of detail, therefore, the records allow for the degree of accumulated disturbance caused by silvicultural operations to be reconstructed for the duration of the commercial timber exploitation period (see the commercial disturbance index, chapter 5.1 and Appendices E3.1 to E3.4).

Archive maps and documents: a large quantity of archival material, both textual and cartographic (128 either georeferenced maps or derived geodatasets) was collated from non-forestry archives. Where relevant this was entered into the GIS and extends the forest cover time series back to between 1911 and 1912/13 for each of the forests (see Figures 4.1 to 4.3). Population geodatasets were created for a total of either 6 or 7 dates for each research area, in each case back to 1900. They contribute to the forest cover narratives (chapter 4) and the local disturbance index (see chapter 5); however, reliability strongly decreases with the earlier dates. Invaluable background information on historical events and social and political issues was collated from thematic maps and archive texts for interpretation of the causal factors behind forest cover change (chapter 4).

Oral histories: A combined total of 116 semi-structured interviews with old people, mostly men, at the edges of the forest contribute substantially to an understanding of both local forest-use history and the commercial exploitation. Valuable insights were gained into the cultural, social and demographic issues that provide the context of the environmental changes. Invaluable understanding was gained in all the forests, particularly in the Kakamega-Nandi forests while interviews at both the Ugandan sites revealed a disconnection between the people and their longer-term, i.e. pre-1950, local history.

Place names: a total of 242 place names relating directly to vegetation types, animals or land cover of the Kakamega-Nandi area and provides insight into the limits and nature of forest and other land cover from the 17th century and later. This surpassed expectations regarding the sample number and the level to which they could be interpreted (i.e. 8 cover classes). However, place name studies were not successful for the Ugandan sites and this is attributed here largely to the relative instability of settlement in the study areas, but it is also clear that the Kakamega-Nandi practice of naming the majority of places after plants is not shared by the Mabira and Budongo areas.

Fossil pollen: the 4 pollen core samples have indicated their great potential for revealing otherwise undetectable changes in the character of former vegetation states. The preliminary analysis and the dating of sample 1 show an internally coherent chronological development of land cover.

The varied data types together provide a strong base with a broad base of perspectives and opinions from which to build a thorough understanding of the forest cover changes and the causes behind them. The dates range from 6,000 years ago to the present day and, as seen in Figure 2.1, provide substantial temporal overlap between the sources although with data quality reducing with earlier date (see also chapter 6). Centring this body of data within a GIS facilitates the reconstruction of local forest landscape histories (the case studies, chapter 3), the subsequent analysis of the forest cover narratives for each of the three forest areas (chapter 4), and the deriving of the spatially-explicit disturbance indices (chapter 5). The use of different data types in combination is discussed within chapter 6.

3. The forest cover change case studies

The following chapter presents twelve forest cover narrative case studies that represent some of the major forest cover changes to have occurred at different localities within the Kakamega-Nandi, Mabira and Budongo Forest areas (see Figure 3.1). The use of case studies here is a reflection of the localized nature of much of the forest cover change and the contributing factors; in order for the forest narratives to be analysed per forest area later, in chapter 4, it is necessary to first appreciate the composite parts that contribute to the creation of a full forest narrative. Some cases illustrate a set of specific, often localized historical events that have lead to changes in forest cover while others reflect widespread and perennial factors of more obvious direct relevance to land-use planning today. The range of pathways of change is therefore established and will enable later discussion of the degree to which the patterns of land cover change can be generalised as being common across the different forest areas and across different time periods.

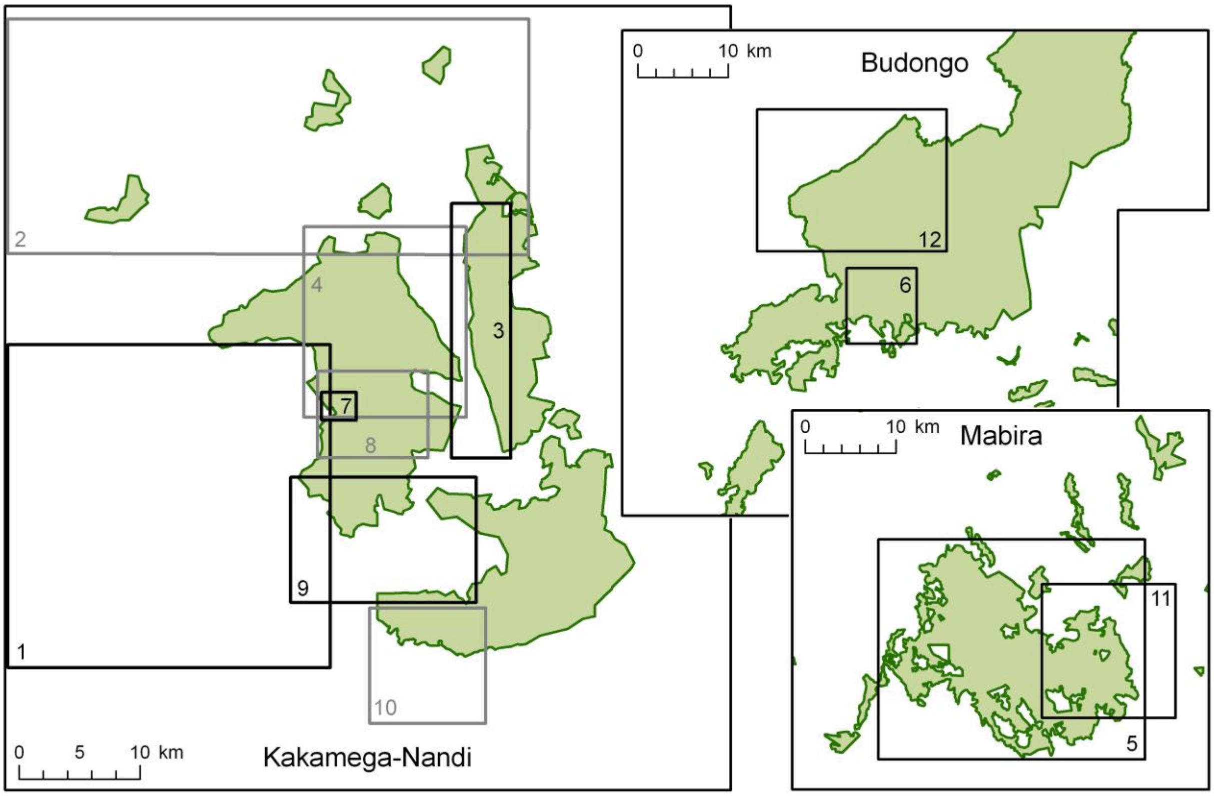


Figure 3.1: The location of the twelve case studies. Green depicts the protected forest areas; black and grey shades are employed to assist visualisation.

As indicated in Table 3.1, the case studies are chosen to illustrate some of the key developments of the forest landscape and factors that are at work behind the changes. Six cases are focused on or around the main BIOTA-East focus-site, Kakamega Forest, and serve to demonstrate the wide range of experience possible within a single forest and as such are able to provide the forest narratives of chapter 4 with a relatively comprehensive coverage. The other cases are chosen as representative experiences of the comparative forests, those of North and South Nandi, Mabira and Budongo. Aiming to reflect the complexity of forest cover change, the studies are not restricted to stories of forest loss but purposefully include a sample of the range of transition possibilities such as the more subtle degradation in forest quality, and the change from grassland towards forest (see Table 3.1).

The case studies presented here aim to:

- trace the development of the forest landscape for specified local areas, in most cases across the 20th century and occasionally back to earlier centuries, thus laying the ground for the forest narratives of chapter 4,
- identify or indicate the proximate causes of the changes, divided broadly in Table 3.1 into case studies dominated by local factors (1-6) and those that include commercial factors (7-12). They therefore pre-empt the division between local and commercial disturbance factors for the spatially explicit disturbance indices (chapter 5), and
- demonstrate how the evidence of the widely differing datasets are reconciled with each other, i.e. cross-referencing each other, often facilitated by overlay or comparison in GIS.

Many of the case studies (i.e. studies 1-2 and 4-7) consider specific locations that previous scientific research has already identified as relevant to forest ecology or forest management; other examples focus on areas of little previous scientific concern but which are here considered to be of significant scope or scale (3 and 8-12). The size of the areas of interest ranges widely with each case study defined as representing an area of broadly common land-use history. Each story is firstly set within the context of the scientific significance of the land cover change of the area under investigation and the current state of knowledge in the published literature. The case studies trace the forest cover change on a local scale and therefore allow for consideration of the proximate causes after the changes have been identified. Otherwise, the format of the studies varies according to individual circumstance, sometimes being recounted backwards in time and other times vice versa.

Table 3.1: The scope of the case studies showing the different forest cover change possibilities and summaries of the causal factors. Also shown are the parallels to the types of forest cover change experience that are characteristic of the other forest research sites.

Key: '●' strongly characteristic, '○' moderately characteristic, '-' negligible parallel.

Cause type	Case study	Name	Land cover change summary	Main causes of change	Case forest	Forest change characteristic of which forests: Kakamega	N. Nandi	S. Nandi	Mabira	Budongo	Main date range
Local factors	1	South-west Kakamega	forest → agric.	climate, migration	Kakamega	●	●	●	●	-	c. 6,000 yrs. ago-present
	2	Kabras	grass & wood → agric. & forest	climate, conflict, fire, migration	Kakamega	●	●	○	○	○	19th century - present
	3	North Nandi Nature Reserve	grass → forest & agric.	migration, politics	North Nandi	●	●	○	○	○	1896 - present
	4	Kakamega glades	grass → bush & forest	over-grazing, cultivation	Kakamega	●	○	-	-	●	c. 1900 - present
	5	Mabira enclaves	grass & agric. → forest & agric.	disease/migration	Mabira	●	○	-	●	-	1720/50 - present
	6	Budongo N15	stability	access, protection	Budongo	○	○	-	○	●	1906 - present
Commercial factors included	7	Isecheno	forest degradation	multiple exploitation	Kakamega	●	○	●	●	●	1932 - present
	8	Kakamega clear fell area	forest → plantation & bush	access, clear fell	Kakamega	●	○	●	●	-	1898 - present
	9	Kaimosi	forest → agric. & plantation	pop. expansion & cash-crop	Kakamega-Nandi	●	○	●	●	-	1896 - present
	10	South Nandi	forest → agric. & degraded forest	logging, cash-crop & politics	South Nandi	●	○	●	●	○	1896 - present
	11	Mabira & the Nile	forest & agric. → agric./monoculture	disease/migration, politics, cash crop	Mabira	●	-	●	●	-	c. 1900 - present
	12	Kitigo	wood-grass flux	disease/evacuation elephants, fire	Budongo	○	○	-	-	●	c. 1900 - present

3.1 Case Study 1

Case Study 1: South-west Kakamega: loss of a forest mosaic
Date range of main evidence: c. 6,000 years ago to the present
Forest cover change: forest ➔ agriculture

The area subject to investigation here is currently characterized by intensive cultivation and very high population density. The 1999 census for these sub-locations shows that the density of human occupation here ranges from 440 to 1,663 inhabitants per km^2 with a mean of 872 inhabitants per km^2. It is therefore remarkable that this area has been identified by other researchers (e.g. Tsingalia 1988 and Kokwaro 1988) as representing the area of Kakamega Forest's greatest forest loss in the 20th century. Tsingalia (1988) concluded from the evidence of 'senior informants' that Kakamega Forest indicates the forest extending 15 km further west up to 1932 and a total of 30 km west in 1911 or 1912. Kokwaro (1988), with a similar inference of great forest loss since about 1940, also drew attention to forest tree species growing wild 30 km west of today's forest. Such a narrative would represent the loss of forest many times the size of the current Kakamega Forest.

The nature and dating of this forest cover change is here addressed starting in the mid 20th century with aerial photography and working backwards via maps and oral histories to the late 19th century. With increasing conjecture the picture of former land cover is broadly extended to previous centuries via place name evidence in combination with the knowledge and dating of tribal movements largely extracted from the published findings of historians and anthropologists. Finally, fossil pollen sampling is considered for a 'key-hole' view of the prehistoric vegetation.

The following paragraphs trace the story of the area's land cover backwards from the most recent data sources back into prehistory and can be followed in approximately the south-western quarter of Figure 3.2.

Remote sensing and the 20th century map evidence

Satellite imagery and ground observation show the area today is under intensive cultivation and the 1948/(52) aerial photography mosaic (kn-d42), covering parts of Isukha, Idakho, North Maragoli and Tiriki locations, shows this was also the case in the mid 20th century. A 1:62,500 topographic map sheet of 1933 (kn-d30) also shows the only forest cover existing outside the boundary was two small 'tongues' extending beyond the forest boundary near Isecheno. A 1:150,000 scale map of Kakamega goldfield in 1932 (kn-d26) labels the market-centres of Sigalagala and Khayega, in the heart of our area, as 'Piccadilly Circus' and 'Oxford Circus', two synonyms for the very busiest of places. Twenty years earlier, a 1:250,000 survey of 1912/13 plots the western Kakamega Forest edge in a very similar position to that of today (see Figure 3.2). However, a 1:250,000 scale map of natural vegetation (kn-d74) allocates the whole case study 1 area as bearing natural vegetation derived from clearings from lower moist intermediate forest. The map's approximate border between this vegetation zone and the more savanna vegetation to the north is broadly coincident with the soil change depicted in the figure (see also CS 2).

Oral histories

Interviews with eight of the old people interviewed in the area (Figure 3.2) are able to reach back to the 1920s-1940s and all were consistent in stating that the area had been forest in the past. However, their testimony was mixed in that some (kn-i1, 72, 74) stated that it had simply been forest within their own lifetime while others (kn-i70, 73) stated it to have been a mix of agriculture, forest patches and grassland. Upon close questioning it became clear that there was in general a tendency to initially talk of an impressively thick former forest that they

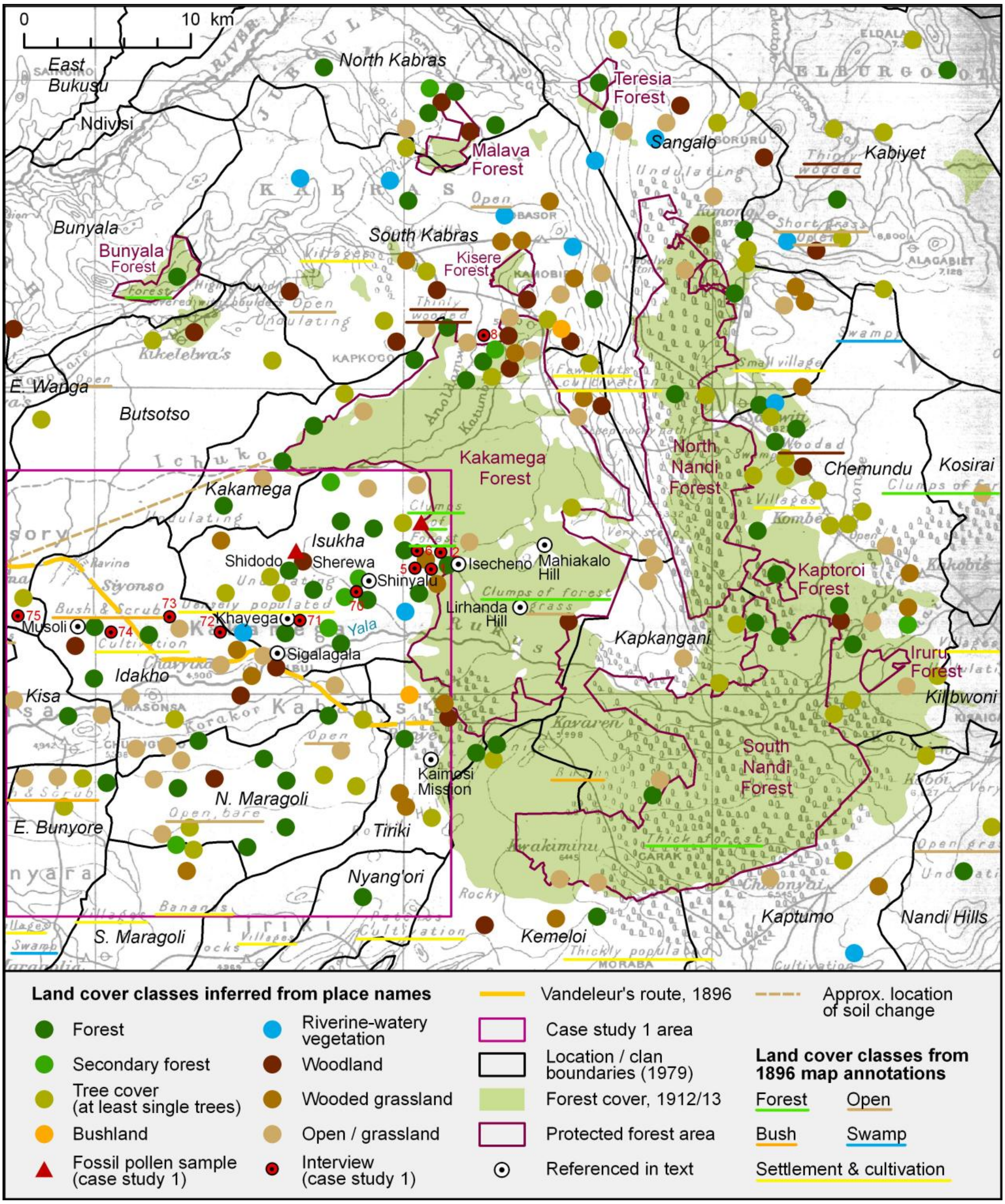


Figure 3.2: Map showing the combination of land cover inferences from place name evidence with map-based evidence, oral histories and soil samples used in case study 1. The underlying topographic map is taken from Vandeleur 1897 (kn-d1, scale 1:292,176), while the 1912/13 forest cover is digitised from a second topographic map (kn-d7, 1:250,000).

had had to clear and that this was often followed by descriptions of a cultivated landscape that included patches of remnant forest and grassy areas. This parallels the observation by Were (1972) that an exaggeration of the clearance narrative can occur due to the pride taken by the Abaluhya in having cleared large areas of wild forest or bush and in its conversion to safe, productive agricultural land. However, it cannot be doubted that patches of forest persisted into the 1930s. Amongst these interviews the most common species stated as present in these in the former landscape were *Markhamia lutea* (diagnostic of forest, Beentje 1994) (kn-i5, 73, 75) and *Bridellia micrantha* (characteristic of forest margins and wooded grassland, Beentje 1994) (kn-i70, 72). There is a slight indication of more true forest species in the east of the case study 1 area but they are generally consistent with a landscape of fragmented forest remnants. The discrepancy between their testimony of a partially-forested landscape and the maps that mark no forest in this area is likely to be explained by scale and it is noted here that the 1912/13 survey (kn-d7) marks forest patches down to 80 ha at a scale of 1:250,000.

Several interviews (e.g. kn-i1, 75) indicate that the forest clearance occurred from west to east. One interviewee (kn-i1), claiming to be born in 1907, stated that the ambition of his father's generation had been to clear all the forest up to an imaginary line between Lirhanda Hill and Mahiakalo Hill. Two interviewees west of Isecheno (kn-i2, 6) reported that it was only the colonial government ban on further forest conversion, in this area, that had stopped the eastward advance of forest clearance at the location of the current boundary. KFS records and one interview (kn-i8) show that the first forest boundary was established around 1908/10 (IG Report 1960) and therefore dates the halting of the eastward progress of the deforestation process.

A late 19th century map and documentary evidence
The impression of a mainly unforested landscape here is supported and extended back into late 19th century by a military survey in 1896 (kn-d1) (see underlying map of Figure 3.2). The accuracy of the survey is relatively poor (see Appendix A1 for data quality assessment values) but contributes several annotations relating to the land cover and land uses of that date. It notes, for instance, 'clumps of forest' at the western edge of today's forest and appears to summarize the land north of the Yala River as 'densely populated' and the area to the south as 'open' / 'open bare'. The surveyor himself wrote an account of the expedition (Vandeleur 1897) and commented on their passage through our area. As his troops emerged from the forest, i.e. just north of today's isolated Kaimosi forest, he notes that "on all sides there extended fields of mtama [sorghum], telebone [?], potatoes and banana plantations" (pp. 386-7), and reflects on this stretch of the journey writing that "the whole country between Nandi and Mumia's [i.e. 14 km west of this case study area] is densely populated, and very fertile […], the most food-producing centre of this part of Africa".

The evidence suggests that the area was already densely occupied and without major forest patches before 1900. However, the oral history evidence recounted above indicates that ever-diminishing fragments of forest persisted for the ensuing three or four decades.

The village place name evidence regarding land cover
The names of villages translated from the local Luhya language to a plant, animal or land cover type are here taken to be a reflection of formerly dominant species or land cover (see chapter 2.6, and Appendix B1, kn-d137). Colour coded symbols in Figure 3.2 represent the village names according to the land cover class either specified or inferred by the place name. A high proportion of the settlements in this case study area, i.e. 49 of the 82 names that were assigned to a land cover class, are translated as plant species. Of this total, 31 are indicative of forest, 18 of other forms of tree or bush cover, 27 of grassland or wooded grassland, and 6 of woodland. The place name evidence for this case study area therefore represents a former mosaic landscape of forest, grassland and woodland. However, there is a tendency towards more grassland names in the west (e.g. Idakho location) and for more forest names in the north-east (i.e. Isukha location) and the south (i.e. North Maragoli). The highest density of forest-related names occurring in Isukha suggests the former presence of a more solid forest block with fewer grassy glades here.

Dating the place name evidence
Local informants on the place name meanings reported that generally the names were given by the Abaluhya at the time of clearing a site and settling. In order to date this it is necessary to refer to the work of other researchers who have reconstructed the tribal and clan ancestry of the Abaluhya people in detail (Wagner 1949, Wagner 1956, Osogo 1966, Were 1967, Were 1972). They have revealed a rich oral history still alive in the mid 20th century through which every sub-tribe has been shown to have its own oral histories recounting the lineage of leaders and in almost every case, their movements from other locations. The final distribution of the major clans is here considered to be broadly reflected in the 1979 location names and boundaries as shown in Figure 3.2 (kn-d99, *cf*. Were 1967).

In giving evidence to the committee on land tenure in North Kavirondo in 1945 the Isukha and Idakho elders gave an account of their origins and, surprisingly, in contrast to the other clans, insisted that they were indigenous to their location stating that “our clan has never been anywhere else” (Were 1967, p.77). They also acknowledged that Mwisukha and Abetakho, the founders of the two clans, had been brothers and that their separation into the locations of Idakho and Isukha “occurred only recently” (p.77) due to population pressures. Were draws on other clans’ histories to surmise that the Idakho arrived in their current location, already occupied by a Bantu population, c. 1598-1625. According to Verschuren’s (2001) chronology of the changing East African climate, this start of the immigration process therefore occurred in a period of significantly drier climate in which forest clearance would presumably have been more easily facilitated. By c. 1706-1760 population growth had lead some members of the clan to move into Bunyore, Kisa and Tiriki locations (Were 1967). In this thesis it is here suggested that the same dates are very likely to have brought the separation and creation of the Isukha clan, which presumably broke away eastwards into mostly forested land. Their unique lack of a clearly defined migration narrative would fit a pattern of gradual expansion resulting from a gradual population increase. The date of the loss of most of the Isukha forest is therefore here suggested to be after 1706-1760 but before the late 19th century when, in 1896, Vandeleur labelled at least the western part, as ‘densely populated’.

Further south, the Tiriki people are believed to have moved into the Tiriki location c. 1652-1706 (Were 1967) where Osogo (1966) notes that the Kaimosi area in particular was one of the early pockets of denser settlement, westwards from which other parts of the district were occupied. The Abalogoli are believed to have moved into Maragoli, and the Bunyole to Bunyore c. 1679-1706 (Were 1967).

The place name evidence should therefore not be considered to be a snap-shot of a single moment in history but should, instead, be seen as an impression of the landscape at the time of the most recent settlement, that of the various Abaluhya clans. As we have seen, the occupation of the land west of Kakamega Forest was an on-going process with clans arriving and emerging at different periods, presumably also continuing to clear land within their territory as their populations expanded.

The fossil pollen evidence
A pollen core (core 1 in Appendix C1) was taken from a river flood plain near the village of Shidodo, 10 km west of Isecheno, to investigate the land cover of earlier periods and which, because of the evidence of the oral histories and place names, was presumed to have been forest. Analysis shows that the pollen in the highest part of the core, i.e. the latest phase (zone I in Appendix C1), is not well preserved but the sample provides tentative evidence for a moderate level of forest cover. This may represent the same broad stage of forest-grassland-woodland mosaic indicated by the place name evidence outlined above. Two place names occur within 1 km of the soil sample: Sherewa, a name that reflects the Bushelelwa shrub that translates as *Rhus natalensis* and is known from dry forest margins and wooded grassland (*cf*. Beentje 1994); and Shidodo reflecting the Shidodo tree,

translated as *Pavetta ternifolia*, here taken to be indicative of forest and forest remnants (*cf*. Beentje 1994).

The previous phase of vegetation cover revealed within the pollen core (zone II) has been radiocarbon dated to around 2,200 years ago and shows a high count for Poaceae, i.e. grass pollen, in combination with *Polyscias* (a secondary forest tree) and vegetation types associated with human activity (e.g. Brassicaceae). However, it should also be noted that this coincides with a known period of dry climate in East Africa (Olago 2001). This followed a phase (zone III) of relatively open secondary forest (as indicated by Asteraceae and Umbelliferea) around 4,000 years ago and which also coincides with a dry climatic phase (Olago 2001, *cf*. Maitima 1991). The earliest phase of the core (zone IV), probably dating to around 6,000 years ago, shows the greatest proportion of mature forest taxa (*Olea*, *Schefflera* and *Syzygium*).

Another pollen core was taken from a site at the western boundary of Kakamega Forest Reserve. Preliminary results indicate that grassland and dry tree cover has been a significant component in the long-term history at the western edge of Kakamega Forest but appears to reflect a surprising lack of mature forest trees. However, further interpretation of this sample is not possible without detailed analysis and radiocarbon dating.

In conclusion: using the first fossil pollen analysis relating to the Kakamega-Nandi area this case study has indicated that the fullest forest cover in this area occurred around 6,000 years ago. This was succeded by more a mosaic landscape varying in forest type and in the proportions of forest and grass cover. Place name, oral history and map evidence in particular have dispelled the notion of a broad forest cover extending 15 or 30 km west until the 1930s or 1940s in favour of the area's main clearance before around 1900. The first Abaluhya clans, arrived around 1600 into an area already of largely mosaic forest-woodland-grassland. While the immigration and expansion of the human population have been key in the clearance of forest, climatic variation is also identified as a factor.

Chronological summary of case study 1

- **up to 6,000 years ago:** mature forest (*fossil pollen*)
- **4,000 years ago:** more open type of forest (*fossil pollen*)
- **2,200 years ago:** large increase in grassland with probable human impact (*fossil pollen*)
- **c. 1,000 years ago to early 17th century:** probable forest-recovery; mosaic of forest, grassland & woodland at first arrival of the Abaluhya; most continuous forest cover is in Isukha location (*fossil pollen & place names*)
- **early 17th century to pre 1890s:** population expansion & forest clearance (*place names, oral hist.*)
- **1890s to 1930s:** small forest patches persist amidst cultivation (*oral hist., archive docs, topo maps*)
- **1930s to present:** intensively cultivated (*oral hist., aerial photos*)

Forest cover change: flux: forest ➔ grassland ➔ forest recovery ➔ agriculture
Causal progression: settlement & agric. ➔ immigration & agric. ➔ pop./agric. expansion

3.2 Case Study 2

Case Study 2: Kabras: fragmentation versus forest islands
Date range of main evidence: 19th century to present
Forest cover change: grassland & woodland ➔ agriculture & forest

The forests of northern Kakamega District occur in a characteristically fragmented or islandised state and this has lead to debate especially regarding the impact of fragmentation on biodiversity within these forests (e.g. Kokwaro 1988, Tsingalia 1988, Wahome *et al*. 1993, Brooks *et al*. 1999, Farwig *et al*. 2006, Wagner *et al*. 2008). The published literature has considered the separate nature of these forests to be the result of fragmentation of a single large forest block. Brooks *et al*. (1999) have estimated that Malava Forest was probably isolated from the main Kakamega Forest around 1912 and that Kisere Forest had been isolated around 1933. This case study seeks to demonstrate an alternative time-frame and an alternative means by which these forests could have become today's islands of forest within an agricultural landscape.

Forest cover change of the northern forest patches, 1912/13 to 2003
All steps of the Landsat imagery time series show a densely populated and cultivated landscape punctuated by several forest reserves. The 1948/(52) aerial photography (kn-d42) shows a patch of secondary forest (Mahira forest, 73 ha) south-west of Malava and some small patches of riverine forest between Kakamega and Kisere Forest. However, interviewees (kn-i9, 10, 16) were firm in stating that there had been no historical forest link between the two. The topographic map of 1912/13 (kn-d7) depicts six other small patches amounting to 1,134 ha. However, oral histories revealed that these patches were lighter forests and woodland patches (kn-i7, 11, 35) and significantly the map does not honour them with boundary outlines.

Some expansion of forest is seen with Malava Forest extending northwards between the 1912/13 map and the 1958-62 topographic map (kn-d61). Several forest history interviews (kn-i9, 10, 16) also concluded that Kisere Forest had been expanding and maturing over the 20th century and 2003 satellite imagery confirms a slight increase in forest cover to 413 ha from the 347 ha of the 1912/13 map. Furthermore, Teresia Forest appears to have matured from the fragmentary entity in 1912/13 to become a forest island of 309 ha by the time of the 2003 Landsat satellite imagery. In the same period, the small patches of light forest and woodland outside the gazetted forest reserve boundaries, lacking in official protection, were cleared for agriculture (kn-i42). The reduction of Malava and the eradication of Bunyala Forest in the second half of the century were due to commercial forestry, as seen in chapter 5.2.1.

The matrix between the forests at the turn of the 20th century
The remote sensing, maps and oral histories seen above combine to indicate a landscape of patchy and ephemeral woodland and forest that were not permanent. The intervening matrix between the patches of tree cover is consistently reported by interviewees (kn-i7-10, 15, 16, 35, 36) to have been grassland in the first half of the 20th century and is also seen in the 1948/(52) aerial photography to be at that time largely uncultivated and to be dominated by grassland. This picture is borne out and extended back in history by several archive documents as seen below.

The written account of the journey by the surveyor of the 1896 map (kn-d1, see Figure 3.3) describes the landscape to the south-west of their camp at 'Kamobir Hill' (Kambiri Hill) as "undulating and covered with short grass. Here and there were large clumps of forest" (Vandeleur 1897, p. 380). The map of that expedition (at a scale of 1:292,176) also records the area between Kisere and Malava and Bunyala Forests as 'open'. An area just north of

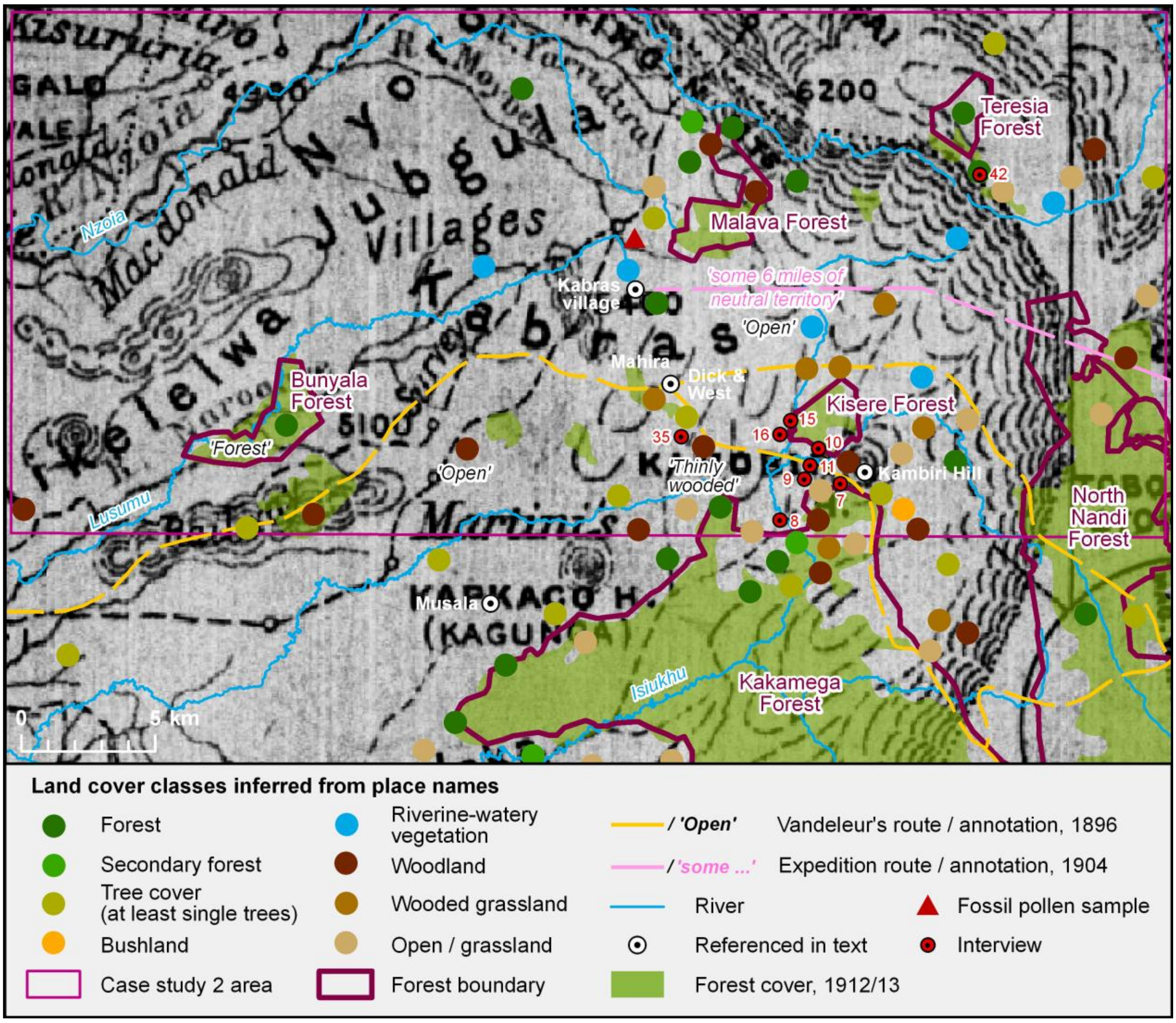


Figure 3.3: Map of the Kabras area showing evidence for the state of former forest cover of the case study 2 area. The underlying topographic map dates from 1900 (kn-d5, scale 1:633,600).

Kakamega Forest is labelled as 'thinly wooded' and corresponds well with the evidence of one very old man (kn-i35) nearby who recalled it to have been mostly grass with some trees of dryland character, the most common being *Combretum molle*, a small tree of woodland or wooded grassland habitat (Beentje 1994).

In an 1899 account of his 'sporting adventures' passing from Nandi through our case study area of Kabras to Mumias in the west, Ansorge (1899, p. 61) writes of the 'tropical' vegetation of the villages but recalls the "treeless grass-plains outside the village". Vandeleur (1897, p. 388) also notes that "with the exception of Kikelelwa's forest [Bunyala Forest], hardly a tree is visible, and great difficulty is experienced in getting wood". The first European to travel through this area was Thomson in 1883 and he notes (Thomson 1885, p. 276) that as they descended the Nandi escarpment the journey was "chiefly remarkable for the length of grass, which made walking a serious labour". He describes and illustrates the village of Kabras as "surrounded by smiling fields" (p. 278) (see Figure 3.4), and the fact that he also includes an illustration of the village of 'Massala' (Musala meaning 'tree') as utterly treeless suggests that this place name may reflect the presence of a single tree in an otherwise grass landscape. Thomson writes "the whole country was remarkable for its poverty in trees, a few small ones alone being seen in the villages" (p. 288). The land further west from Kabras to Kwa-Sundu (Mumias) was notable for the "surprising number of villages […] almost every foot of ground seemed to be under cultivation" (p. 284).

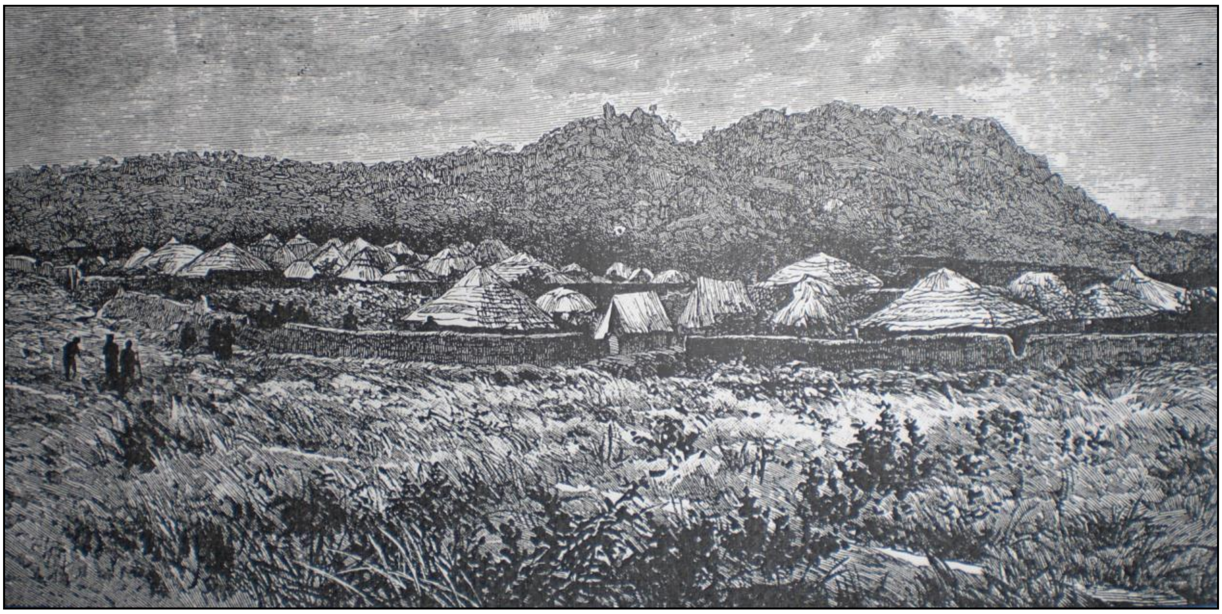


Figure 3.4: The village of Kabras in 1883: "On the 28th of November, 1883, I entered the village of Kabaras … surrounded by smiling fields" (Thomson 1885, p. 278).

The place names evidence

The place names of this case study area are consistent with this picture of grassland interspersed with woodland and forest patches. Of the 51 place names occurring within the defined area of the case study names reflecting grassland / wooded grassland are the most numerous with 15 and are followed by woodland and bushland with 13 examples. There are 11 names that can be assigned to forest and these tend to be located near the established and gazetted forests such as Malava. A further six names reflect watery or riverine vegetation, e.g. three villages named Mukhuyu and one called Kamogoiywa, both words meaning *Ficus sur* which Beentje (1994) records as inhabiting 'riverine forest and bush' (see Appendix B1). There are six other tree names that cannot be classified (i.e. they could reflect forest or simply wooded grassland) (see Figure 3.3, and Appendix B1). The names therefore suggest a mixed landscape but one with more grassland and woodland than true forest. The place names are not easily dated but the Kabras people are said to have arrived into this case study area as refugees in the early 1800s (Osogo 1966). The earliest Luhya place names translated and used in this case study are therefore likely to date from the 19th century. The dominance of grass in this 19th-century landscape is also echoed in the results of preliminary analysis of fossil pollen from an undated soil core taken from a river-edge 1 km south-west of Malava Forest.

Settlement distribution

However, at the end of the 19th century the area east of Malava Forest and south to Kakamega Forest appears to have been curiously coincident with a total lack of human population. The traveller Elliot (1896) travelled from east to west through the area in 1893/94 and recalls that it is only "on reaching the Kabrassie [Kabras people] that one finds oneself amongst human beings" (p. 34) while, similarly, Vandeleur (1897) travelling in the opposite direction, indicates a total absence of habitation between the villages of Kabras and the 'few huts' of the Nandi at the base of the escarpment. The 1900 map (kn-d5) underlying Figure 3.3 notably marks 'villages' only west of Malava Forest.

A clue as to a military reason for the lack of habitation here is found in a government report of 1904 (IG Report 1904) which recounts a reconnaissance trip for a future Nandi Native Reserve and recalls their having passed "over some six miles [9.7 km] of neutral territory lying between Nandi and Kabras". A reconstruction of the route from a written description is seen in Figure 3.3 and places Malava Forest at the cusp of this unpopulated no-man's-land and at the start of the inhabited area. Indeed, all four of the 19th century travellers cited here noted the defended nature of the settlements here which are consistently described as circular with by a high wall of earth, a deep ditch around the outside. Furthermore, Vandeleur (1897) notes that two nights before they arrived in Kabras, the Nandi had killed nine people within one village. He also recounts passing the spot at which the traders Dick and West had been killed by the Nandi, "a gruesome spot with several skulls lying about" (p. 380), and laments that none of the Kabras would accompany them further than this into the "dreaded Nandi country". This area was therefore, at least in the late 19th century, a demilitarised no-man's-land. With the gradual stabilizing of inter-tribal relations across the 20th century, the area has become increasingly settled in the second half of the century, the contrast being most notable between the two aerial photography mosaics (kn-d42, 70).

The nature of the forest islands and their possible origins

These northern forest islands could be the remnants of a forest formerly joined to Kakamega Forest in a landscape cleared by fire during drier climatic conditions sometime before the 1880s. However, as noted by the interviewee above (kn-i35), woodland patches were able to spring up within the grassland matrix and it is possible that Malava Forest, for instance, could also have grown up within its significant position of a military buffer zone. In connection with this it is notable that KFS archives show repeatedly (e.g. IG Corresp. 1946a, IG Report 1961) that the main part of Malava Forest was dominated by *Olea capensis*, a species known to regenerate mostly in grassland (pers. comm. P. Karani) and stated by Tsingalia (1988) as not regenerating within Kakamega Forest except within the glades. It is therefore possible that Malava Forest is little more than one or two centuries old. The same species is also common in Kisere Forest (Tsingalia 1988) and in Teresia Forest (labelled as '*Diospyros-Olea'* forest type by the 1:250,000 scale map of natural vegetation (kn-d74). The same map also distinguishes Kisere, Malava, and Bunyala forest types as from that of the main Kakamega Forest. In a 1951 letter to the District Forest Officer (IG Corresp. 1951) the Forester justified the selection of Kisere Forest as a nature reserve on the grounds that it was 'similar' to Malava Forest, instead of the much closer main forest block of Kakamega Forest. These forest islands therefore appear to hold more in common with each other than with the main forests of Kakamega and the Nandi Forests and their likely origins as islands of forest maturing within a grassland matrix may be dictating their floristic structure.

The long-term lack of widespread forest cover here, in contrast to the adjacent Kakamega Forest, is likely to stem from a change in the underlying geology. A 1:250,000 scale 'Reconnaissance Soil Map' (kn-d104) also indicates the underlying geology and marks a change from the mudstones and claystones of Kakamega Forest (and the area to its west), to the granites and granodiorites of the current case study area; the change coincides closely with the whole northern edge of Kakamega Forest and may account for the presence of forest to the south and savanna to the north. The 1:250,000 scale map of natural vegetation also indicates that the vegetation of this area ('*Combretum* and allied broad-leaved savanna types') is markedly drier than all other parts of the Kakamega-Nandi area of investigation. One of the several drier climatic phases of the last millennium (*cf*. Alin & Cohen 2003, see also earlier climate phases in CS 1) are likely to have seen conditions sufficiently dry to allow any woodland and dry forest cover to have been burnt off. Verschuren (2001) reveals significant periods of very wet East African climate but also confirms prolonged arid spells such as c. 1800 to 1890 and c. 1540 to 1630 and c. 1000 to 1300 that were more severe than any 20th century drought. Meanwhile, the more clay soils of Kakamega Forest are likely to have maintained more moist conditions, sufficient to resist destruction by fire.

The role of fire

Oral testimony in the Kisere-Kambiri region (kn-i7) shows that until about 1950 the Nandi were still in the habit of regularly descending from the escarpment to burn and graze the open pastures thus keeping the forest in abeyance. One interviewee (kn-i35) reported that some patches of woodland would grow up afresh while in the drier years some patches could be burnt by the annual grass fires. Indeed the name of one of these patches, Mahira, meaning ‘burning’, was so named due to the fire said to have burned within it for two weeks. In 1899 Ansorge was unquestioning in his attributing the lack of trees here to “the destruction caused by annually recurring grass-fires for generations past” (p. 62). A further reflection of fire is also seen in the 1:250,000 scale ‘Vegetation’ map which assigns our area to ‘undifferentiated moist *Combretum-Terminalia* types’, of which several species are used as fire indicators by Nangendo (2005) in Budongo Forest. Five place names here also translate as these tree types, *Combretum molle* or *Terminalia mollis*, both of which are here interpreted as reflecting the significant role of fire in this area.

In conclusion: the combination of place names, oral histories, archive documents, early topographic maps and aerial photography in particular has been able to reveal that the Kabras area has for long been dominated by grass (and woodland). It therefore dispels the myth of the northern forest patches representing 20th century fragmentation from the main Kakamega Forest; instead it indicates a process of forest patches growing up in an uninhabited, demilitarised no-man’s-land between the Luhya and Nandi tribes. Geology and former dry climates are shown to be the most compelling factors in the determination of the non-forest landscape.

Chronological summary of case study 2

- **Prehistory:** grassland domination due to dry climatic phase & geology / soils (*undated fossil pollen, soil map*)
- **19th century:** grassland with woodland & forest islands, maintained in oft-burnt Abaluhya / Nandi no-man’s-land (*place names, archive docs*)
- **c. 1900 to c. 1950:** expansion of forest islands in largely uninhabited tribal conflict zone (*archive & forestry docs, oral hists, topo maps, aerial photos*)
- **c. 1950 to present:** from grassland to agriculture due to immigration (*aerial photos, oral hists*)

Forest cover change: grass & woodland ➔ forest islands ➔ forest islands amidst agriculture
Causal progression: geology & climate ➔ geology, conflict & fire ➔ immigration

3.3 Case Study 3

Case Study 3: North Nandi: encroachment of a nature reserve
Date range of main evidence: 1896 to the present
Forest cover change: grassland ➔ forest & agriculture

Agricultural encroachment has often been cited as a cause of deforestation in the Kakamega-Nandi forest region (Blackett 1994b & c, Kokwaro 1988, Kamugisha *et al*.1997). Although little attention has been given to the Nandi forests in the published literature, agricultural encroachment has, in various degrees of legality, been one of the largest threats to their integrity in recent decades. The current case study focuses on the Nature Reserve that occupies the western half of North Nandi Forest (see Figure 3.6) located along the top of the Nandi escarpment that forms the boundary to the neighbouring Luhya tribe. This area represents the largest example of encroachment in North Nandi Forest and is here set in the context of the longer term forest cover change to best gauge its true significance.

Agricultural encroachment, c. 1950 to the present
Ground observation in the Tobolwa village area in 2006 revealed large tree stumps still burning following recent forest clearance within the official forest boundary (see Figure 3.5).

Figure 3.5: Tobolwa: the western edge of North Nandi Forest, looking south with the Nandi Escarpment to the right. Following the encroachment of agriculture into the forest the tree stumps are burnt off.

Comparison of the eight satellite imagery classification time steps shows that the forest edge has been retreating and expanding since 1972/73 and is also reflected in the forest cover figures of Figure 3.7. They show a decrease in forest extent from the 1948/(52) levels to 1965/67 with a subsequent broadly decadal fluctuation of forest in which the 1970s was a period of loss, the 1980s one of growth, the 1990s of loss, with a rise to the 2003 state in which the deforested area within this western boundary totalled 543 ha.

Forest expansion, early 20th century to c. 1950
Visual interpretation of aerial photography 1948/(52) shows a limited forest cover extending beyond the boundary in the form of several small spits of primary and secondary forest protruding up to 1 km. The next earliest quantification of the forest cover here is taken from the official forest boundary gazetted in 1936 and mapped in 1938 (kn-d34) since the partial coverage provided by a 1:62,500 scale topographic map of 1931 (kn-d24) shows that the western limit of the forest vegetation coincides closely with the official forest boundary. Overlay of this reserve boundary with the visual interpretation of the 1948/(52) aerial photography (kn-d43) suggests a slight increase of forest in the intervening decade. Such a trend of expansion would be consistent with the 1:250,000 scale topographic map of 1912/13 A 1904 account of a reconnaissance journey through Nandi territory (IG Report 1904) can be traced across North Nandi Forest to the escarpment on the western side of the forest (see Figure 3.6). The author comments on the absence of settlement until several kilometres after descending the escarpment (see also CS 2). A decade earlier, the written account (Vandeleur 1897) of an expedition in 1896 describes the camp near the top of the escarpment which they found to be ‘open and grass-covered’. Four kilometres further north they passed through the forest but without sign of settlement until they emerged from the forest on its eastern side. Together these sources indicate that the top of the escarpment was unoccupied between 1896 and the first decades of the 20th century. With the assumption that the occupation of the area to began in the 1940s or 1950s, the forest’s dramatic advance of 1-2 km westward in the 35 years between the 1912/13 map and the 1948/(52) aerial photography is notably seen to have occurred when it lacked human occupation. This period of forest expansion might be extended back to 1896 via the knowledge of the area’s non-occupancy.

Furthermore, it is possible that this area had never been intensively occupied before the later 20th century settlement. Huntingford’s 1926 map (kn-d16) of his ancient monuments survey locates many ‘Nandi-Masai’ sites on the eastern side of the forest but none in our area of interest except for the ritual site of Tobolwa Stone. He states that the very numerous hut

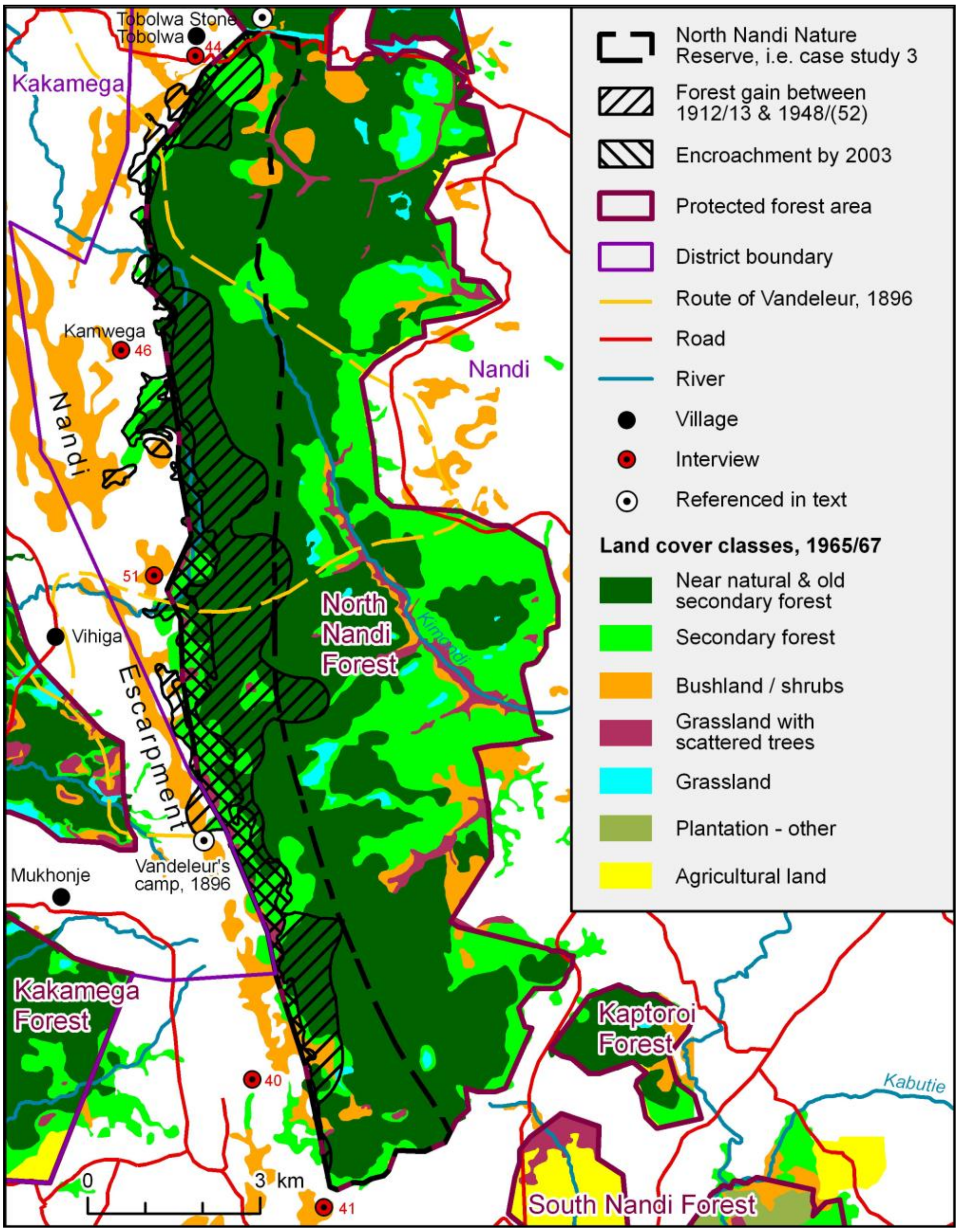


Figure 3.6: Map of North Nandi Forest showing evidence for forest cover change since 1912/13 within the nature reserve, i.e. the case study 3 area.

circles of the Pre-Nandi phase “seem to be entirely absent” from Chesume, the ‘Emet’ (i.e. district) of our case study (Huntingford 1926 p. vii).

Causes of the encroachment

One interviewee (kn-i51) stated that the area had been settled mostly since the 1950s and reflected on the in-migration having lead to the loss of tree cover on the Nandi escarpment itself by the 1960s and 1970s. Annual reports of the Land Adjudication Department (e.g. IG Report 1977) show that the authorities were fully aware of the pressures building due to population expansion and to the first demarcation of private land in the Nandi District, but seemed powerless to prevent small repeated encroachments into the forest. Discussions with Nandi people in this area (kn-i44) reveal the firm belief that the Luhya people, having moved up the escarpment since the 1970s due to a lack of available land in Kakamega District, are to blame for much of the encroachment within the boundary. Indeed the stresses placed upon various government services are repeatedly and specifically attributed to this factor in annual reports of different government departments, e.g. Social Services (IG Report 1976a), and the Kenya Forest Service (KFS) (e.g. IG Report 1976b). This led to a dispute in 1982 in which the Abaluhya were allegedly forced back westwards before the government

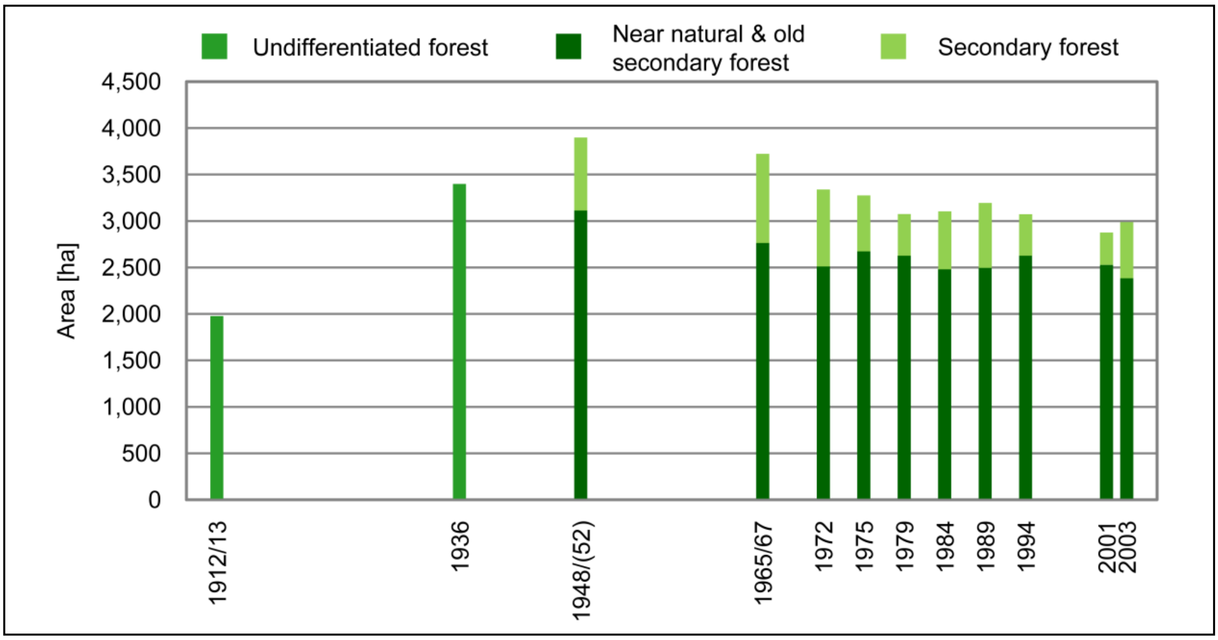


Figure 3.7: Forest cover change of the North Nandi Forest Nature Reserve as detected from a topographic map of 1912/13 (kn-d8, scale 1:250,000), the reserve boundary survey of 1936/38 (1:250,000, kn-d34), the visual interpretation of aerial photography (1948/(52): kn-d43, and 1965/67: kn-d71), and Landsat satellite imagery classification (kn-d88, 94, 102, 109, 111, 116, 122, 124, 128).

intervened (kn-i40). KFS officials also verbally confirm the pressure for land on the Kakamega side as a major factor in the loss of forest. The 1981 annual report of the Land Adjudication Department (IG Report 1981, p. 8) puts this into the context of an on-going issue with the words "again toward the end of the year there was misunderstanding of Nandi and Abaluhya tribes. This also interfered tremendously on our operation, especially along the border of Nandi/Kakamega Districts". Discrepancies between the survey records of this department and those of the KFS surveyors are locally reported to be the main obstacle to straight forward legal action (kn-i44, 46). The Land Adjudication Department annual reports (e.g. IG Report 1981) and other internal government reports (e.g. IG Report 2004) confirm that the almost complete lack of boundary-marking cairns along the western North Nandi Forest edge has bedevilled the KFS's attempts to control the boundary for decades.

Government actions are seen to be key when we note that the first encroachment beyond the forest boundary occurred in the 1970s when it is known that the KFS had lost some control and local respect (e.g. Tsingalia 1988). The pause of the ingress into the forest in the 1980s, as noted above, coincides with a change in government policy when tangible measures for conservation were seen to be taken (e.g. for Kakamega Forest: Tsingalia 1988, KIFCON 1992, Mitchell 2004), (see also CS 7 and 9). The renewed encroachment seen since the 1994 satellite imagery has been coincident with the deterioration of forest law enforcement that accompanied the advent of party politics and political favouritism, especially in the Nandi District (Klopp 2002). One example of this is the 100 ha of forest allocated to the people of Kamwega in 2001 and which is the subject of an on-going court case (IG Corresp. 2009). Continued migration into the area has also contributed to the pressures (IG Report 2004) and a land slide leaving a large scar on the escarpment visible to the present author in 2007 is likely to reflect this over-population of steep and marginal land.

In conclusion: topographic maps, archive documents, oral histories and remote sensing have been able to place the recent encroachment into the North Nandi Forest Nature Reserve within a century-long perspective thus revealing the contrary notion that over this period the area represents a net gain in forest cover. Factors are seen to be the long-term lack of human habitation in this isolated area, enclosed as it is by forest and a steep escarpment; while politics is strongly implied behind the more recent encroachments.

Chronological summary of case study 3

- **1890s to c. 1950:** forest expanding 1-2 km into grassland while uninhabited (*archive docs, topo maps*)
- **1950s:** 1st habitation of top of Nandi escarpment (*oral hist.*)
- **1960s to 1970s:** 1st encroachment into forest due to immigration, especially Luhya (*oral hist., archive docs, aerial photos, satellite*)
- **1980s to present:** fluctuating forest edge varies with political climate (*oral hist., forestry records, satellite*)

Forest cover change: flux: grassland ➔ forest ➔ forest & some agriculture
Causal progression: non-habitation ➔ immigration ➔ national politics

3.4 Case Study 4

Case Study 4: Kakamega glades: a shrinking historic ecosystem
Date range of main evidence: c. 1900 to the present
Forest cover change: grassland ➔ bush & forest

The glades of Kakamega Forest have often been briefly discussed in the published literature (Kokwaro 1988, Emerton 1992, Mutangah 1996, Kamugisha *et al*. 1997, Althof 2005, Musila 2007) and their existence has been considered a defining characteristic of the forest. They have become the focus of research by Tsingalia and Kassilly (2009) in which the authors propose the origins of the glades to lie in forest destruction by elephants, and the subsequent mode of glade colonisation by forest to be facilitated by termite mounds (Tsingalia 1988, Tsingalia & Kassilly 2010). However, issues of their origin and their colonisation cannot yet be considered resolved and notable changes in their extent identified by Mitchell *et al*. (2006) and Lung and Schaab (2010) demonstrate that they represent a rapidly shrinking entity.

Since the glades are found mostly in the northern half of Kakamega Forest and because the southern part of the forest has been decimated by clear felling, this case study focuses on the glades of the northern half (Figure 3.8). It first seeks to address the antiquity of the glades since their history has sometimes been considered a short and recent one (e.g. Mutangah 1996). Next, the change in the glades' land cover is traced and quantified and possible reasons for the change identified before a brief consideration of the likely origins.

The heritage / antiquity of the glades

The glades antique heritage is shown by several sources, one being an incomplete topographic draft map of 1931 (1:62,500 scale, kn-d24). A reflection of large proportion of grass at that time is provided by a line drawn onto the map by hand in 1931 (kn-d23) indicating the early-proposed extent of the soon-to be gazetted forest reserve. If it had been accepted the boundary proposal would have excluded 1,526 ha of today's forest reserve in the north-east due to its consisting mostly of grass. Two decades earlier the existence of multiple glades is confirmed by Edmund Heller's unpublished diary of the first science-based expedition to the forest in which he writes: that Kakamega Forest "looks very solid but in reality it is everywhere broken by openings with shambas [small farms]" (Heller 1912, p. 98). A report by the African District Council names 56 glades that it records as being originally possessed by Isukha people between 1905 and the declaration of the forest as a Central Forest Reserve in 1926 (IG Report 1960). This picture of forest and grass co-existing here is extended back to the 19th century by a map surveyed in 1896 (scale 1:292,176, kn-d1) that describes Kakamega Forest with the annotations 'Clumps of forest grass' and 'Clumps of forest' (see the underlying map of Figure 3.2).

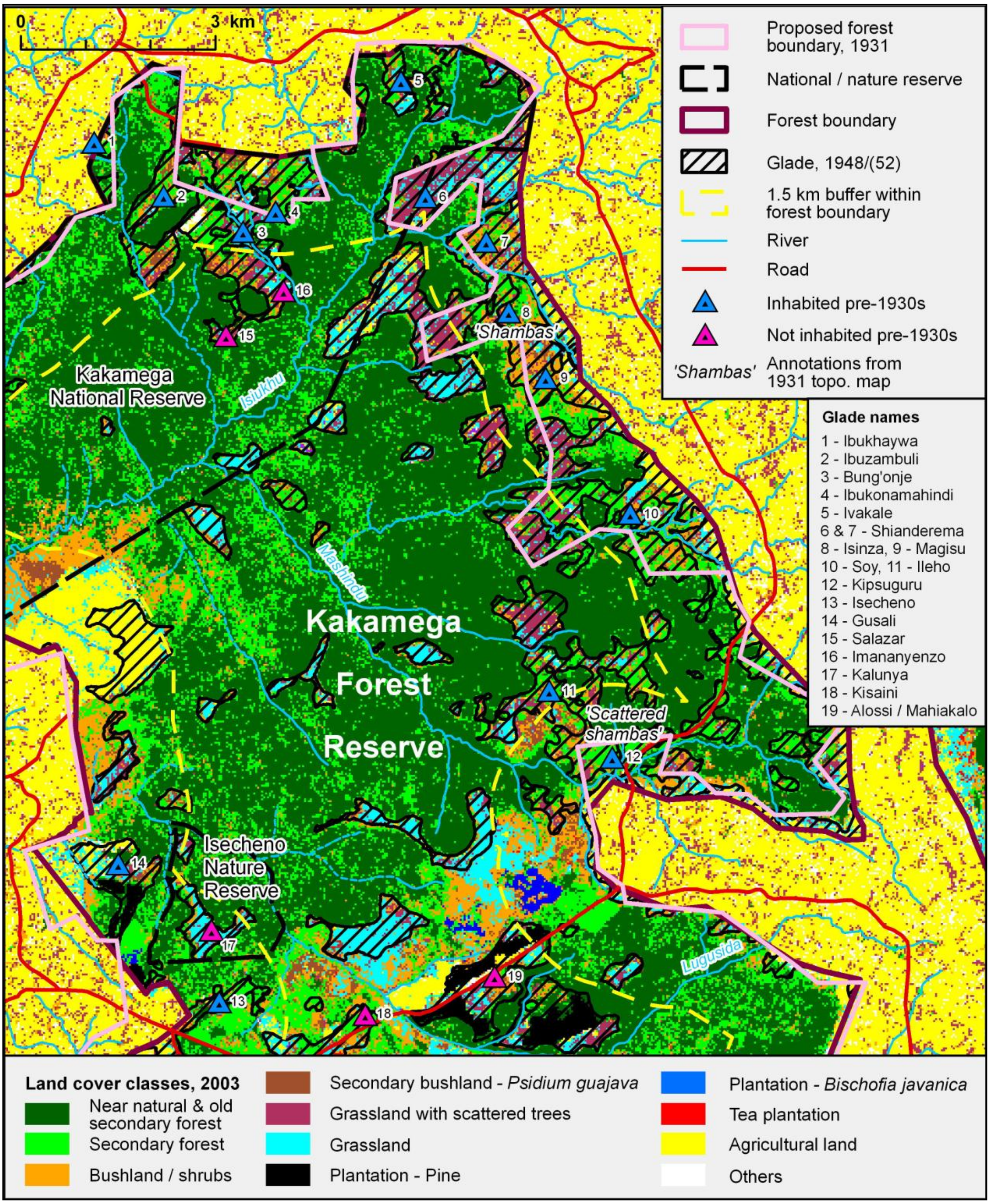


Figure 3.8: Part of Kakamega Forest, showing changes in the extent of the glades between their extent digitised from aerial photography of 1948/(52) and the satellite imagery classification of 2003 (kn-d43, 128); other map evidence, e.g. the 1931 proposed boundary (kn-d23) is overlaid.

The changes in the glades

The physical extent of the glades before commercial forest exploitation started in 1933 can be quantified by supplementing the missing parts of the 1931 topographic map (1:62,500 scale) with the visual interpretation of the 1948/(52) aerial photography (kn-d43). This reveals 4,205 ha of glades for the whole of Kakamega Forest, i.e. 17.6% of the full gazetted reserve and accords well with early FD (Forest Department) annual reports (e.g. IG Report 1949) that refer to a round-figure of 11,000 acres, i.e. 4,452 ha, being grassland. Forest-adjacent

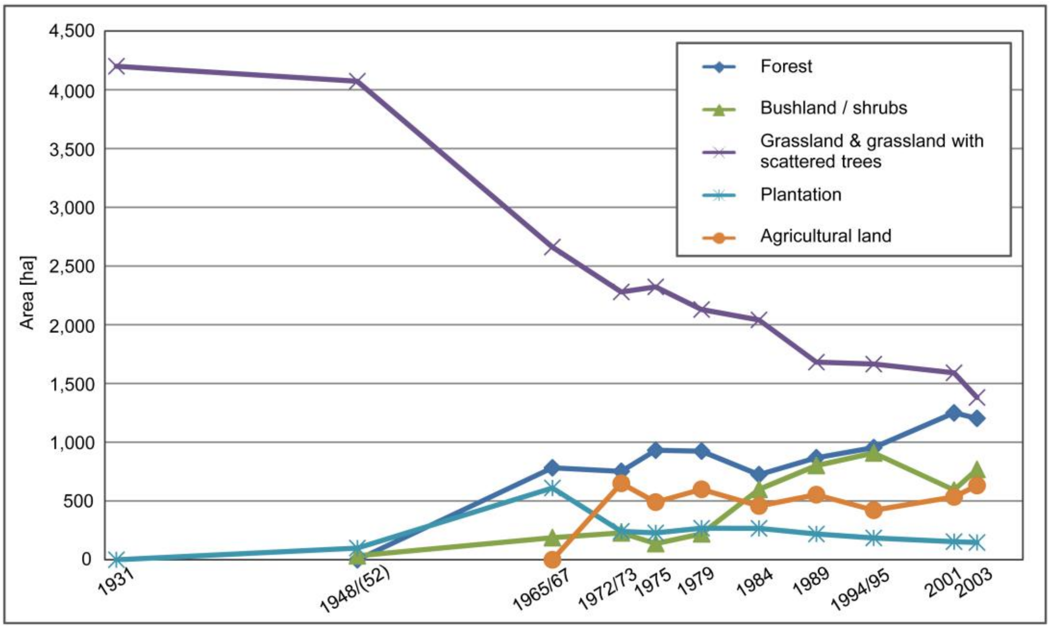


Figure 3.9: Graph showing the change in land cover of the glades of Kakamega Forest Reserve since 1931. The values are derived from a topographic map of 1931 (kn-d21, 1:62,500), the visual interpretation of aerial photography for 1948/(52) (kn-d43) and 1965/67 (kn-d71), and Landsat satellite imagery classification (kn-d88, 94, 102, 109, 111, 116, 122, 124, 128). The extent of the glades is taken from the 1948/(52) timestep.

interviews (e.g. kn-i6) testify to the shrinking size of the glades since the early 20th century and this is borne out by the remote sensing time series back to 1948/(52). Figure 3.9 shows that by 2003 the glades (‘Grassland’ and ‘Grassland with scattered trees’) of the complete Kakamega Forest had been reduced to 1,381 ha, i.e. a loss of two-thirds (67.2%) since the gazettement of the forest 70 years earlier.

In the northern half of Kakamega Forest the earliest aerial photography time step demonstrates a landscape of forest sharply defined against clear grasslands and the landscape was nearly devoid of scattered trees and bush. As seen in the graph the ten timesteps of the remote sensing time series show a blurring of this distinction in which the proportion of grassland has typically been reduced in favour of forest, bushland including Guava (*Psidium guajava*), and agricultural land since 1948/(52). This is particularly true for the glades in the northern and eastern part of the forest, also highlighted by Lung & Schaab (2010), while the central glades have remained much more stable. Most of the western glades have been altered either by plantations (e.g. Gusali) or by agricultural encroachment.

Factors at work in the glade changes in the 20th century

The successional development from grass towards forest cover as described above occurs both inside the KWS-managed Kakamega National Reserve in the north and outside it in the main KFS-managed part of the forest. The strong contrast between the neighbouring management regimes that have coexisted for the last two decades should not therefore be considered in the search for causes of forest cover change. Indeed, the areas that have remained as ‘Grassland’ in the 2003 satellite imagery classification show a high coincidence with the areas of the very purest, shrub-free grass in the 1948/(52) aerial photography mosaic and indicates that the start of the process of succession was already underway. Two possible factors are here presented as being likely contributors to the spatial pattern of vegetation succession occurring in the outer glades and less in the inner examples.

Fire in combination with grazing: The role of fire in the encroachment of bush into grasslands is complex and has absorbed the dryland ecology scientific community for decades (e.g. Trollope 1984, Huenneke & Ward 2003, Ayana & Gufu 2008). Fire often allows grassland to regenerate while burning off any developing bushland, and therefore seasonally-sensitive grass-burning regimes are often practiced in rangeland management for the maintenance of grasslands (e.g. Nangendo 2005). However, it has also been established elsewhere, for example in South Africa, that in combination with grazing, fire is sometimes unable to prevent the encroachment of bush into grasslands (e.g. Balfour & Midgley 2008). In these cases the intensity of grazing reduces the biomass or available fuel so that the fire burns at a relatively low temperature, leaving any nascent shrubs relatively unscathed (see Figure 3.10).

Figure 3.10: An intensively-grazed glade at Shiamiloli: the resulting low biomass / fuel-load has prevented high-temperature fire and the last burning episode was unable to spread across to the right-hand side of the path or to burn off more than the lightest of the Guava shrub growth on the left-hand side.

This mode of bush and forest encroachment is here proposed as a likely major factor in the reduction of the glades of Kakamega Forest since a District Forest Officer's report comments on the heavy overgrazing and erosion already apparent to him within the outer glades of the north and north-east of Kakamega Forest in 1949 (IG Report 1949). This is in spite of the relatively low human population density of these areas in the 1940s (see population graph in Figure 4.1, kn-d41). Interviews (kn-i20, 31) reveal that the Buyangu glades were still being seriously overgrazed in the 1970s and early/mid 1980s with reports that this often prevented the glades from being burnt at all. Such a pattern of high grazing intensity and low temperature fires or an absence of fires, could therefore lead to the rapid succession of forest cover classes as seen in the north and east of the forest. It is to be expected that the outer glades would have been the most heavily grazed before the growth of bushland and this is borne out by KIFCON research that mapped only the glades deepest in the forest (approximately 20 examples) as lacking any traditional cattle grazing claim by the surrounding communities (Opole 1991). Consistent with this is the fact that, in general, the development of higher vegetation, i.e. bushland or forest, has occurred within, the outer part of the forest reserve, a dashed line marking a 1.5 km distance from the inside of the forest reserve boundary is marked in Figure 3.8 to assist interpretation. Reduced fire due to overgrazing is therefore here put forward for the first time as a likely cause of bush and forest encroachment in the northern and easternmost glades.

Human habitation of the glades: It is probable that the hardness of the glade soils, as testified by Musila's morphological characterisation (2007), provides one significant obstacle to the establishment of indigenous trees. This obstacle is though clearly not insurmountable given certain conditions as is demonstrated by the rapid colonization of the glades of the north and north-eastern parts of the forest. A second reason suggested here is that this could have been facilitated by the breaking of the ground for cultivation, either before the initial eviction of human settlement in 1926 and 1932 (IG Report 1960 suggests 1,500 people were evicted).

The evidence available to the present author regarding the occupation of identified glades is limited to those with an opening to the forest edge. The evidence for this is derived not only from interviews (e.g. kn-i6, 31, 35) but also from, for example, correspondence held within the KFS archives from the District Forest Officer (DFO) who wrote that signs of occupation were still visible to him in 1949 in the outer glades (IG Report 1949). The Ileho arm of forest in the east has been quickest in its succession process and it may be significant that this area was picked out for comment in 1912 in a report of the District Commissioner's Office with the words 'occupation is fairly dense' (IG Report 1912, p. 1). The 1:62,500 scale topographic map of 1931 also annotates the southern part of this area with 'scattered shambas'. In contrast, the only glades that can now be established as having been unoccupied were fully surrounded by forest. Alossi / Mahiakalo, the largest of the interior glades, is one such example and is identified in the 1912 report (IG Report 1912, p.2) as one of "a number of unoccupied glades". Tsingalia (1988) reports that traditional rulings did not permit the occupation of Kalunya and Shisaina (i.e. Kiseini) Glades (both are enclosed by forest) so that Chief Keba lost his position when he briefly allowed settlement there in 1911.

The combined evidence indicates that the outer glades were populated and suggests that the inner glades may not have been occupied at all. If the reasons for the persistence of pure grass cover in the interior glades lie in the hard soils that prevent tree-root penetration, the lack of ground-breaking cultivation in the interior glades may represent a significant factor.

No conclusion can be drawn regarding the cause of the pattern of the glade vegetation succession without further research but the two factors discussed above are here put forward as likely major contributing factors: (a) the over-grazing leading to low-temperature burning or a lack of burning, and (b) the former settlement and cultivation leading to the breaking up of the hard soils of the outer glades but not those at the core of the forest. Both are here proposed as representing anthropogenic disturbance reflecting increased impact with closer proximity to human settlement and greater access to the forest/glade resources. It is also possible that both factors are contributing simultaneously and perhaps in combination with other factors such as the old termite mounds espoused by Tsingalia and Kassilly (2010).

Glade Origins

The question of the glades' origins has lead many to enquire as to how they originated (e.g. Mutangah 1996) with one recently proposed theory suggesting that they result from the actions of large herbivores (Tsingalia & Kassilly 2009). However, as demonstrated above, the forest has been spreading out into the glades over the last hundred years and it is here suggested that the question of 'how did the glades originate within the forest?' should be replaced with the statement that the forest has instead been developing into the historic grasslands in recent centuries. The 1948/(52) aerial photography mosaic (kn-d42) clearly shows the glades at the northern and north-eastern edges of Kakamega Forest were at that date 'one and the same' with the grasslands outside the forest. As such the glades should be seen as historic remnants of a probably largely open plain that extended up to Malava Forest during an earlier phase of drier climate (see CS 2). This would also be consistent with the pattern of landscape development broadly implied by preliminary analysis of the undated fossil pollen samples 2-4, all of which indicate the former major role of grassland (briefly outlined in chapter 2.7.2). The probable mode of forest expansion is here suggested as the spreading outwards from riverine gallery forests and such a process is most clearly demonstrated in CS 10, Figure 3.20. The present glades probably represent the areas of thinnest, most compact soils that therefore have longest resisted the forest's advances; significantly here Musila (2007) has demonstrated that the glade soils are more 'penetration resistant' and less nutrient-rich than those of the forest. Large herbivores such as elephants and buffalo, both of which persisted into the 20th century (e.g. kn-i1, 35, 55), alongside traditional burning to regenerate grass for grazing cattle, will all have helped to maintain and prolong the existence of the glades (overgrazing notwithstanding).

In conclusion: aerial photography, satellite imagery and oral histories have especially been crucial in tracing the encroachment by the forest vegetation into the glades of Kakamega Forest. This is strongest in the outer glades and is here suggested as resulting from historic over-grazing that prevented high-temperature burning that could trim the encroaching bush (possibly assisted by the hard soils also being broken up here by former cultivation). The notion that the glades were created as forest clearings is here rejected in favour of forest growing outwards from rivers into historic grassland, the hardest, thinnest soils resisting colonisation the longest.

Chronological summary of case study 4

- **Recent centuries:** expansion of forest outwards from rivers into grassland that resulted from a former drier climatic phase (implied from: *fossil pollen, topo maps*)
- **1905 to 1932:** glades large & open; 1,500 people inhabiting outer glades evicted (*archive docs, forestry records, oral hist., topo maps*)
- **1940s to 1960s:** slight vegetation succession in outer glades (*aerial photos*)
- **1970s to present:** inner glades relatively stable; outer glades grow over likely due to overgrazing that prevents burning, and perhaps also due to earlier cultivation that broke up hard soils (*aerial photos, satellite, oral hist., forestry records*)

Forest cover change: grassland ➔ bushland ➔ secondary forest
Causal progression: dry climate ➔ habitation & cultivation ➔ over-grazing

3.5 Case Study 5

Case Study 5: Mabira enclaves: periodic habitation
Date range of main evidence: c. 1720/50 to the present
Forest cover change: grass & agriculture ➔ forest & agriculture

Most published reports on Mabira Forest include discussion of the numerous occupied enclaves within Mabira Forest (e.g. Aluma 1989, Westman et al. 1989, Howard 1991, Hlavka & Strong 1992, Welch Divine 2004, Baranga 2007, Lung & Schaab 2008). The NFA states the existence of at least 27 such enclaves which are either wholly or partially (e.g. Lugala, Figure 3.11) enclosed by the forest (Karani *et al*. 1997a) although a definitive list is not available. There are an estimated 50,000 inhabitants of the enclaves (*ibid*.) and several studies have indicated the high level to which the forest is affected by these occupants (e.g. Welch Divine 2004, Baranga 2007). The pattern of development of these enclaves is therefore key to understanding the land cover change and conservation of Mabira Forest.

The NFA and the official management plan state that the enclaves were created when the original forest cover was cleared in the early 20th century for the commercial cultivation of, coffee and exotic rubber (Karani *et al*. 1997a). The evidence for this, the only published version of the origin of the enclaves, is here examined first before establishing the physical changes in the extent and number of enclaves over the 20th century. This is followed by discussion of the role of insects and disease in relation to the development of the enclaves.

The heritage of the enclaves
The assertion that the enclave openings were created through the clearance of forest land for commercial agriculture and plantation in the early 20th century (Karani *et al*. 1997a) is directly contradicted by the 1903 report of the first reconnaissance visit to the forest carried out with a view to future commercial exploitation (IG Report 1903). This report, by the

Figure 3.11: Lugala enclave at the southern edge of Mabira Forest.

foresters Messrs. Dawe and Ormsby, noted that the "more central part of the forest is frequently intercepted by grassy plains and small hills, which are studded with useless small trees" (*ibid*., p. 46). They also record that the "hill sides are for the most part covered with an Andropogon grass" and also refer to "old deserted and overgrown gardens" (*ibid*., p. 46) in the forest. Specifically near Dangala (one of the mid southern enclaves of Mabira) they recall that "large gardens are deserted and the odour of decaying bananas fills the air" (*ibid*., p. 47).

In internal government correspondence relating to the landmark Buganda Agreement of 1900, Sir Harry Johnston refers to his successful negotiations for the adoption of all forest land as Crown property, i.e. British government property (IG Corresp. 1900). The Kabaka or King of Buganda meanwhile legally retained authority for the appropriation of non-forest lands, termed *mailo* land and this land division established was subsequently enshrined in the 1904 cadastral survey at a scale of 1:50,000 (mf-d2). A single sheet of this map showing only the north-west part of Mabira Forest, was located in a forest guards' outpost, and was still in practical use as a current map more than a hundred years later in 2006. The map shows all three of the fully enclosed enclaves in this area, Kulunku, Nadagi and Bulango, already plainly in existence. It is therefore clear that even before the first commercial developments, Mabira forest was peppered with openings. Some of these were occupied, some showed signs of abandoned settlement, while others were grassy with occasional small trees.

In 1876 the explorer Sir Henry Morton Stanley arrived in the Kingdom of Buganda and was invited for an audience at King Mudete's residence. Stanley recorded the stories of the Buganda kings that were recounted to him (Stanley 1878, Gray 1935, Kiwanuka 1965). These included tales of King Mawanda, the twenty-second king of Buganda believed to have reigned in the c. 1720 to 1750 (Wrigley 2002) and who governed what now represents Kyaggwe County in which Mabira Forest is located. One of these oral histories tells of how one night the King set out westwards into the forest (Stanley 1878) from Lulumbu Hill (possibly Lugalambo Hill, see Figure 3.12) to meet his dead ancestor, Kintu, and at the village of Mubango "reached the border of the forest" (Kiwanuka 1965, p. 258). This is here identified with a village of the same name located at the edge of the main forest body of Mabira and classed as one of Mabira's southern enclaves. A further but more disturbing feature rings a note of familiarity for an identification with the Mabira Forest area with the words "the cause for the founding of many capitals and their frequent abandonment, was the plague which used to kill very many people wherever the king settled" (Kiwanuka 1965, p. 296); see below for the plague of the *mbwa* fly. These stories of King Muwanda reveal that at least some of Mabira's enclaves were already occupied by the early-mid 18th century.

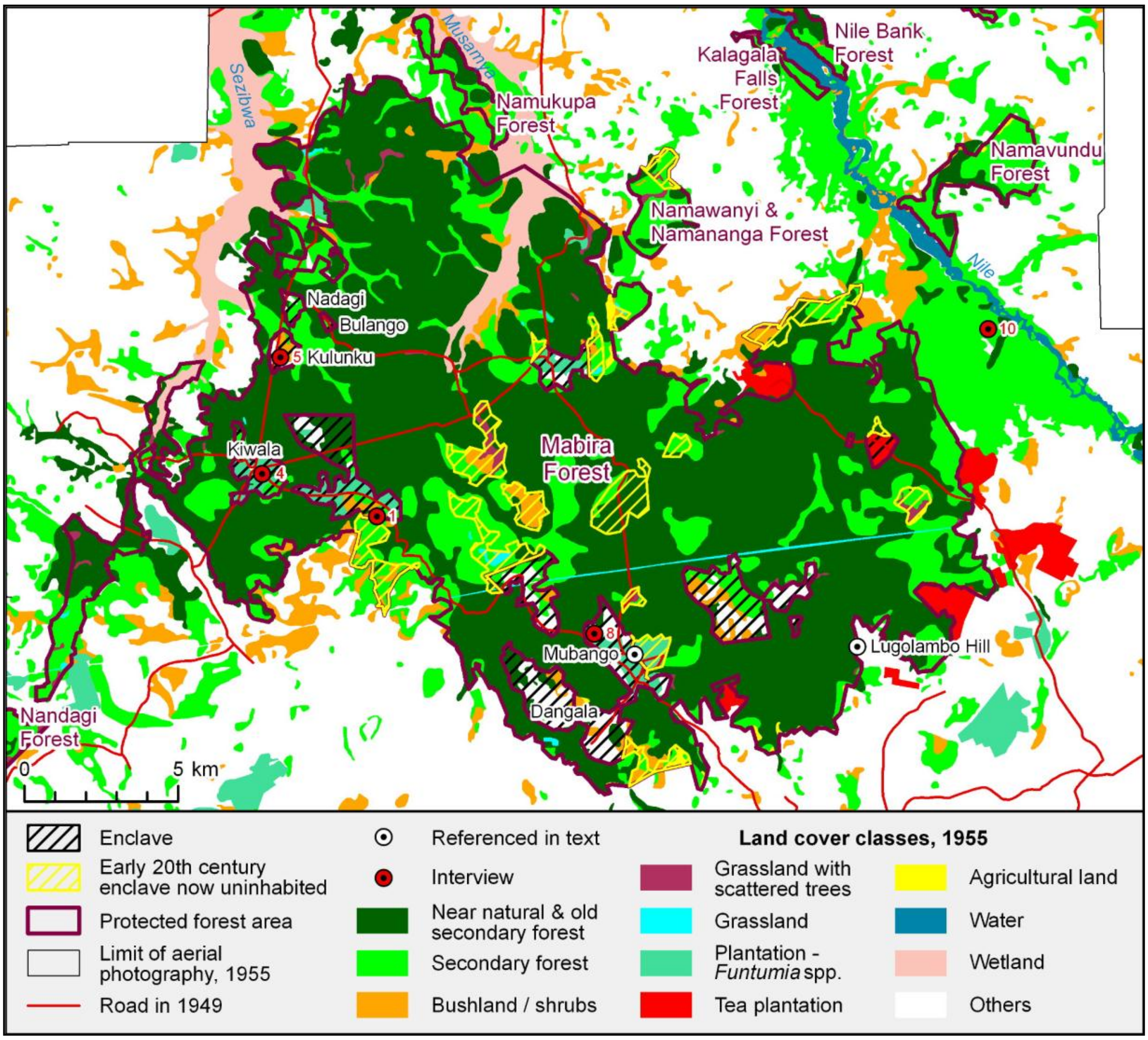


Figure 3.12: Map of Mabira Forest showing the change in the extent of the enclaves between 1904 (from a 1949 dataset mf-d27, 1:50,000) and the modern gazetted forest reserve (mf-d98, 1:50,000).

Quantifying the changes in enclave extent over the 20th century

A memorandum from the Land Officer to the Deputy Commissioner in February of 1907 refers to a Dr. Christy's application to extract rubber, and comments that "less than 100 square miles [25,900 ha] appears to be forest, the remainder being open patches of which about half are the property of natives" (IG Corresp. 1907b, *cf*. Figure 4.2 for GIS-derived forest cover figures). This informs us not only that areas of non-forest, i.e. enclaves, existed without commercial development, but also implies the large scale of the phenomenon.

The 1904 map depicts only the north-western part of the forest and although it shows remarkable stability in the extent of the enclaves of this area, it cannot show changes across the wider forest. However, the extent of the 1904 enclaves is here considered to be reflected in a forestry map dated 1949 and which does cover the full forest extent (mf-d24). This interpretation is made since the aerial photography mosaic of 1955 (mf-d30) clearly demonstrates that the size and shape of the enclaves indicated in the 1949 map are wholly incompatible with the map's date. Overlaying the single sheet of the 1904 cadastral map with the '1949' map in GIS reveals the close similarity of their geometry and suggests that the former had been derived from the latter. It is most likely to have been traced from the 1917 edition of the survey (mf-d9), also only available here for the north-west part of the forest) which was clearly used by foresters in the late 1940s when they hand-painted it with colours according to a recent forest inventory. The '1949' map is therefore interpreted as showing the

1904 enclaves that represent *mailo* land, i.e. non-forest land belonging to the king following the 1900 Uganda Agreement when the colonial government took control all forested land in the Kingdom of Buganda (*cf*. Johnston 1902).

Contrary to reports of enclaves expanding in number (e.g. Hlavka & Strong 1992), the ‘1949’ map reveals the enclaves to have been more numerous and extensive in 1904 than those of today. The 2002/03 satellite image (mf-d89) shows the limits of today’s enclaves are in close agreement with the modern gazetted boundaries of the official NFA geodataset (mf-d92). Comparison of this modern dataset with that digitised from the ‘1949’ map (see Figure 3.12) shows that the total number of fully enclosed enclaves has reduced by six, that some of today’s enclaves were formerly larger, and that the total area of the enclosed enclaves has reduced from 4,280 ha in 1904 to 2,956 ha in 2003.

Insects and disease as an explanation for the enclave changes
In their report of 1903 (IG Report 1903), Dawe & Ormsby state that many of the enclave inhabitants had died of sleeping sickness although they also note, with surprise, the apparent lack of the disease vector, the tsetse fly, within the forest. This last point is mirrored by a 1:1,900,800 scale sketch map of 1906 (refmap3) showing the spread of the sleeping sickness outbreak and which appears to locate most of the Mabira area as ‘fly-free interior’. It also specifically marks an area that would include the western part of Mabira Forest as a centre recommended for “segregation or deportation or for concentration for purposes of treatment”. Another sketch map of 1915 (scale 1: 633 600, *ibid*. refmap5) reveals the outbreaks up to that time had been east of the River Nile and further north than Mabira Forest. Therefore, it appears that Dawe and Ormsby may have been mistaken in attributing the deserted enclaves of Mabira Forest to sleeping sickness and that another reason could be considered.

In Kiwala enclave one man recounted in detail (mf-i4) that his father and grandfather had told him about parts of the central forest area being deserted in 1914 and through the 1920s due to a plague of the *mbwa* fly, *Simulium neavei*. The fly is known to spread Onchocerciasis, also called river blindness (Davies 1994, Fischer *et al*. 1997). The disease is generally noted to cause chronic suffering and severe disability, thus constituting a serious obstacle to socio-economic development (Opperdoes 2002). More locally, though, it is considered to cause various ailments including shortness (mf-i4, doubtless a link to the *Nakalanga* pygmies now consigned to history, see chapter 2.4.1, Johnston 1902, Pitman 1934).

Writing in 1935 Gibbins (1935) noted that as a result huge tracts of invaluable land in the area were rendered worthless despite being located in one of the most fertile cotton-growing areas of Uganda. A year earlier Pitman had recorded finding only “scanty settlements … here and there in the heart of forest” (Pitman 1934 p. 14). Close inspection of the aerial photography mosaic of 1955 supports this account of events showing that several of the central enclaves had grown over leaving only very slight signs of their former open status and clearly they had been abandoned for decades. Indeed, the same pest had been noted as far back as 1862 by the first European to visit this area, John Speke, on his famous journey in which he ‘discovered’ the source of the Nile, less than 10 km to the south-east of Mabira Forest (Gibbins 1935). He noted that the *mbwa* fly “infests the place and torments the naked arms and legs of people with its sharp stings to an extent that must render life there miserable to them” (*ibid*., p. 272). An official evacuation of parts of the forest in the 1930s was clearly the result of only the latest outbreak in a recurring series that had presumably lead to the abandonment of many enclaves before Dawe and Ormsby (see above) made their visit in 1903.

The *mbwa* fly was discovered to breed in the fast-flowing waters of the River Nile and was virtually eradicated in the Mabira area in the early 1950s by the addition of poison to one of the sluice gates of the newly erected Owen Falls dam at the source of the River Nile

(Robertson 1971). Immediately following this, the repopulation of the Mabira area began in earnest (mf-i8, 10) (see also CS 11 and the population graph line of Figure 4.2) although some of the enclaves were never resettled (mf-i1, 4, 5).

In conclusion: oral histories, forestry maps, archive documents and aerial photography have all been instrumental in revealing the long but fluctuating heritage of the enclaves and repealing the myth that they result from 20th century commercial exploitation. Similarly the notion that they have increased in number is replaced with a quantification showing that the area and number of the enclaves has been much reduced over the last century. Disease and the consequent fluctuation in human habitation are the attributed causal factors.

Chronological summary of case study 5

- **c. 1720-50:** enclave(s) inhabited; King of Buganda's capital on hilltops in/near Mabira Forest; *mbwa* fly causes shifting of settlement (*archive docs, oral hist.*)
- **c. 1750-1900:** probable periodic habitation & abandonment due to *mbwa* fly (implied from: *archive docs, oral hist.*)
- **1900:** numerous inhabited enclaves (45% greater area than current enclaves) placed under king via Buganda Agreement (*archive docs, cadastral/forestry maps, oral hist.*)
- **1903-1950s:** most enclaves deserted & growing over due to *mbwa* fly causing evacuation (*archive docs, topo maps, aerial photos*)
- **1950s to present:** some enclaves inhabited afresh due to *mbwa* fly eradication; six enclaves fully closed up by forest (*aerial photos, satellite*, *oral hist.*)

Forest cover change: grass & cultivation ➔ forest ➔ forest & cultivation
Causal progression: disease ➔ emigration ➔ immigration ➔ disease ➔ (repeat)

3.6 Case Study 6

Case Study 6: Budongo N15: A highly valued nature reserve
Date range of main evidence: 1904 to the present
Forest cover change: stability, primary rainforest

The nature reserve of Nyakafunjo Block compartment 15 (normally referred to as N15) in the south of Budongo Forest is characterized as '*Khaya*-dominant, mixed' (Howard 1991) reflecting the significant quantities of several Mahogany species. The compartment is famed for representing virgin forest and as such it has been the focus of many research projects covering many decades (e.g. Eggeling 1947, Plumptre & Reynolds 1994, Sheil 1996, Schulz & Wagner 2002, Bahati 2005, Yeshitela 2008). The work of Plumptre, in particular, has helped to identify this compartment as a credible control site against which the forest ecology of other, disturbed parts of the forest can be compared. The case study considers the evidence for the continued use of the 'undisturbed' status label.

c. 1904 to 1910: exploitation for rubber
A very distorted sketch map (scale c. 1:250,000 and too distorted for inclusion within the GIS, refmap4) was drawn for the East Africa Trading Company in 1906 and shows that a large part of the core of Budongo Forest had already been 'cut over', i.e. harvested for rubber. Despite the distortions in the map, it is clear that the area they had exploited along the southern part of the forest included the area that is now the N15 nature reserve. The colonial government archives contain repeated reports of poor standards in the Budongo rubber harvest. One 1907 letter to the Colonial Office states that the East Africa Trading Company was using 800 old 'V' knives, referred to as being "deadly to the rubber trees of Uganda" and 'ruin' was predicted for the Budongo rubber trees, *Funtumia elastica* (IG Corresp. 1907b). The second contract, due to run between 1907 and 1915, prescribed that the harvesters should plant within the forest fifty trees or seventy vines per square mile (i.e. 259 ha) every

year, although by 1910 Mr. Dawe had observed that the planting had a very poor rate of success (Harris 1935).

1920s to the 1960s: stability

The first sawmill of Budongo Forest, Eccleshall's mill was located at Mururongo Estate at the edge of N15 in 1925 but its reported inefficiency restricted its impact to compartment B1(Harris 1935). Writing in 1947, Eggeling referred to "the preservation of a small piece of virgin forest, an area of some 100 ha […] as a permanent Nature Reserve" (Eggeling 1947) although this is considerably smaller than the 1,062 ha of the N15 compartment, about three-quarters of which is forest. Just three years later a forestry map of 1950 (bf-d15) shows most of the forested portion of N15 to have fallen within Nyakafunjo Block felling coupes 1 and 4 (see Figure 3.13). The forestry working plan of 1955-1964 also describes the progress of felling through these blocks in the late 1940s and early 1950s in some detail with no mention of a nature reserve (Trenaman *et al*. 1956). However, the area figures relating to the logged forest given by Trenaman *et al*. imply that, contrary to the map, the N15 area was spared. Overlay of the rivers dataset (bf-d26) on, for instance, the satellite imagery classification of 2000 (bf-d58), indicates that it was probably the rivers of Kamirambwa, Nyabisabo and Sonso that provided a barrier to the logging companies that had planned to exploit the full extent of coupes 1 and 4.

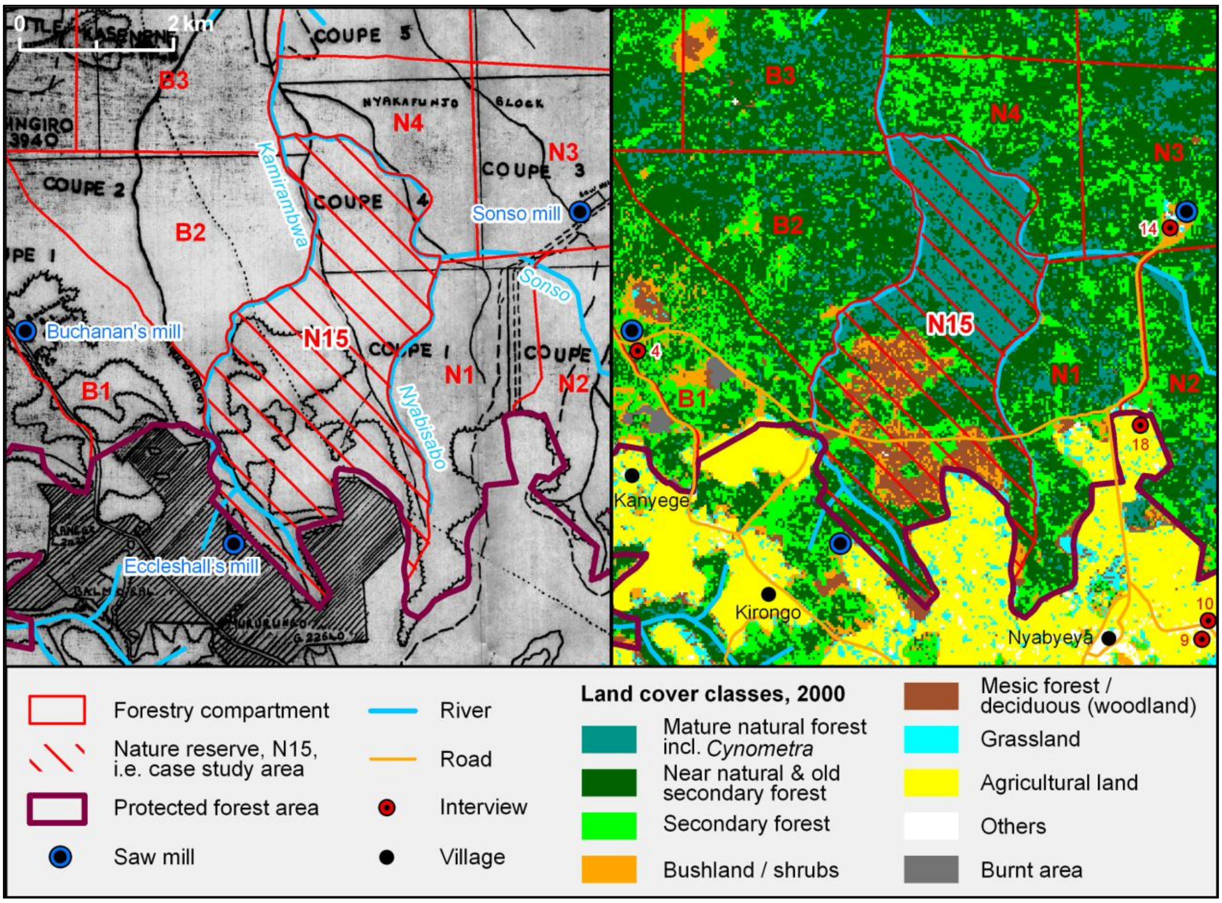


Figure 3.13: The N15 nature reserve of Budongo Forest: (left) surrounded by sawmills and the underlying forestry map of 1950 reveals plans to fell N15 as part of coupes 1 and 4 (bf-d15, scale 1:50,000), and (right) the 2000 satellite imagery classification (bf-d58) indicating N15 as intact forest.

The evidence of the forestry records is therefore unclear and other sources are required to clarify the facts. Local inteviewees (bf-i5, 18), and a further interview carried out in 1970 by Paterson (1991), claim the area to have been free of logging. This is also consistent with ground truthing which conspicuously reveals N15 to be in sharp contrast to its logged neighbours in retaining a large number of mature Mahoganies. Furthermore, the visual interpretation of aerial photography of 1960 (bf-d22) classifies N15 to be mostly 'Near natural and old secondary forest' in contrast to the 'Secondary forest' of the neighbouring N1 and N4 compartments.

1970s to 2000: stability in the dominance of *Cynometra alexandri*

The satellite imagery classification time series published by Lung and Schaab (2009) shows that N15 has become increasingly isolated amongst its neighbouring compartments in retaining a canopy mature natural forest characterised by the inclusion of *Cynometra alexandri* (i.e. class 0). The distribution of this class agrees well with the pattern shown by NFA records of the arboricide poisoning of 'weed species' across Budongo Forest (*ibid*.) and it can therefore be confidently stated that N15 has escaped the widespread programme of poisoning in the 1950s and 1960s (see chapter 5.2.3 for the commercial disturbance index)

2000 to the present: degradation of primary forest

Conversations with NFA forest managers and forest guards and interviews within the nearby communities (e.g. bf-i5) revealed that N15 has experienced a great increase in the number of pitsawing incidents since around 2000. Partly on the grounds of safety (official NFA records show that patrolmen had been seriously attacked in the villages in May 2005) the conducting of interviews regarding N15 was actively discouraged by NFA in the vicinity of the nature reserve. Ground truthing confirmed the reality of numerous pitsawing incidents with *Khaya*

Figure 3.14: Victim of its own success as a protected area: the largely intact forest of the N15 nature reserve has retained its large mahoganies and has therefore attracted the attentions of pitsawyers in recent years.

and *Entandrophragma* Mahogany species being virtually the sole targets of the sawyers (see Figure 3.14). Interviewees (bf-i5 & 18) report that the pitsawing problem did not exist before about 2000 and this is consistent with the NFA records that begin to show a high concentration of forest offences in N15 from 1999. Records of forest guard patrols between September 2005 and March 2006 show that of the 23 instances in which arrests were successfully made during this period, 13 occurred within N15 where a total of 36 people were arrested. In one of these cases 6 arrests were made, 6 saws and 140 pieces of timber were confiscated and 3 charcoal kilns dismantled. This is the only case in N15 in which charcoal featured while all other instances were solely for timber sawing.

Local informants consistently suggested that most of the illegal sawyers live in the forest-adjacent villages of Kanyege and Kirongo and the NFA records of forest guard patrols between September 2005 and March 2006 show that these villages feature most prominently as the homes of the people arrested. However, the inclusion of addresses as far away as Hoima (31 km) contrasts with the offences carried out in other compartments and reflects the extent to which pitsawing of this N15 compartment has developed as a lucrative enterprise. Many of the sawyers in this compartment are said to have migrated from outside the area and to lack respect for either the local natural resources or the local traditional community leadership (bf-i11).

In conclusion: archive documents and maps reveal for the first time that Budongo's N15 Nature Reserve has been exploited for rubber. However, forestry records, oral histories and ground observations combine to confirm that the area has been protected from legal logging as initial plans to log the area were thwarted by difficult access across rivers while later protection was provided by its nature reserve status. Such protection has focused the attention of illegal pitsawyers on felling N15's intact Mahoganies in the last decade and requires strongly enforced protection to retain its value as the most valuable reference site.

Chronological summary of case study 6

- **c. 1906:** virgin forest exploited for rubber (*thematic maps, archive docs*)
- **1910 to the present:** untouched by loggers due initially to difficult river access & later nature reserve status (*forestry records & maps, oral hists, aerial photos, satellite*)
- **2000 to the present:** targeted by illegal pitsawyers due to Mahoganies being untouched by loggers, & due to immigration (*oral hist., forestry records, ground observ.*)

Forest cover change: stability: primary rainforest ➔ slightly degraded forest
Causal progression: commercial rubber ➔ river & legal protection ➔ immigration

3.7 Case Study 7

Case Study 7: Isecheno: an early commercial target **Date range of main evidence:** 1932 to the present **Forest cover change:** intact forest ➔ degraded forest

This case study considers an area of approximately 100 hectares of forest between the forest office at Isecheno and the Isecheno Nature Reserve that encloses Kalunya Glade to the north. It holds a key location, adjacent not only to the forest office but also to the Kakamega Environmental Education Programme (KEEP) and to tourist facilities. The area is small but is chosen here for its rich history that incorporates multiple forms of commercially driven forest change and for being one of the two main focal sites for forest research in Kakamega Forest (e.g. Zimmerman 1972, Diamond 1979, Cords 1984, Fashing *et al*. 2004, Pazol & Cords 2005), and as such it also contains one of the BIOTA-East biodiversity observatories (Bleher *et al*. 2006, Farwig *et al*. 2008, Kirika *et al*. 2008). The site therefore has broad relevance and an understanding of its heritage is key to any interpretation of its present ecology.

The 1980s to the present: clear felling for tea zone, local village usage of the forest
Personal observations show the site to suffer most commonly from firewood collection but also the cutting of small diameter poles for construction in the adjacent village. Except for the removal of 50 m of forest along the western forest boundary for the Nyayo Tea Zone around 1986, the satellite imagery classifications of the 1980s to 2003 (Appendix A1) generally show a forest in the process of maturing.

The 1960s and 1970s: arboricidal treatment and its after-effects
The interpretation of aerial photography of 1965/67 (kn-d71) shows most of the area to be class 1, 'Near natural and secondary forest' and is in stark contrast to the almost total

dominance of secondary forest in the satellite imagery classifications of the 1970s. The results of Fashing *et al*.'s (2004) comparison of their own 1999 survey of the vegetation structure here, with that of an earlier 1981 survey (Cords 1984) suggested to the authors that the forest was still recovering either from the logging of many decades earlier or from another more recent but unknown disturbance. The answer appears to lie in a forestry report that refers to a programme of arboricidal treatment (i.e. poisoning of trees) underway in the 1960s in this specific area, experimenting in the removal of 'weed' tree species that were not useful for timber production (IG Report 1961). It is suggested here that the impact upon the forest structure was significant and Budongo Forest provides a useful comparison for the effect of poisons continuing decades after the initial application (*cf*. Osmaston 2005, Lung & Schaab 2008).

1940s and 1950s: timber transport and enrichment planting
Ground observation reveals numerous deep tracks showing that the western part of the case study area was heavily disturbed by further heavy wheeled transport. One interviewee reported that these are the result of the 1940s and early 1950s transporting of timber from the north of the forest to the Isecheno Glade where Mr. Kelly's Kakamega Sawmill was then located.

The interpretation of the aerial photography of 1948/(52) (kn-d43) and of 1965/67 (kn-d71) classifies most of the area as 'Near natural and old secondary forest'. However, there is a higher proportion of 'Secondary forest' and 'Bushland / shrubs' in the earlier of these time steps and this can be directly attributed to the commercial timber extraction and enrichment planting of the area in the late 1930s and 1940s. These patches of degraded forest often accompany the network of trackways visible in the 1948/(52) aerial photography mosaic (kn-d42) through the broken forest canopy. These tracks were cut to facilitate the planting and cultivation of groups of tree seedlings designed as an experiment in the regeneration of logged forests and the development of a sustainable cycle of timber harvesting. Annual reports show that each year between 1941 and 1945 and in 1947 (IG Reports 1941-45, 1947) areas approximately nine metres apart were cleared of scrub, undergrowth and 'trees of no value' and 'enriched' by the planting of seedlings of valuable timber species. Thus, many thousands of each of *Olea capensis*, *Zanthoxylum gillettii*, *Milicia excelsia*, *Trichilia emetica*, *Maesopsis eminii*, *Khaya anthotheca*, *Acrocarpus fraxinofolius* and *Bischofia javanica* were added to this 100 ha area.

The 1930s: gold prospecting & logging
Forestry records show that selective logging had preceded the planting and had in part facilitated that process via the creation of forest gaps within which seedlings were planted. Local oral history (kn-i6) maintains that a man called 'Geary' was the sawmiller responsible for the timber extraction of this area and he is prominent in the KFS records as 'Mr Kelly' of Kakamega sawmill that was based at the east end of Isecheno Glade from the 1930s to the mid 1950s. With no explicit statement of the date of the logging of this area in the archives, it can be deduced that this area was mainly logged between 1938 and 1940. This is taken from various oblique archive references and from one interviewee (kn-i13) who reported that the logging occurred just before World War II. The forester's annual report of 1943 (IG Report 1943) refers to the need for a further effort to complete the exploitation of the area via platform sawing, and this is also recalled by the same interviewee. The felling of 1938 to 1940 is partially captured in the extant timber statements filled out by Mr Kelly's sawmill and shows that *Olea capensis* and *Zanthoxylum gillettii* had been cut.

Kakamega District experienced a gold rush in the early 1930s (Kitson 1932, Kamugisha *et al*. 1997) and the first commercial exploitation of Isecheno area is still physically apparent to the observant ground truther in the form of numerous pits concentrated in the western half of the area (Mitchell 2004). One of the old people interviewed for this study had been one of the initial gold diggers in the nearby rivers and testified that the pits, each approximately 1 m

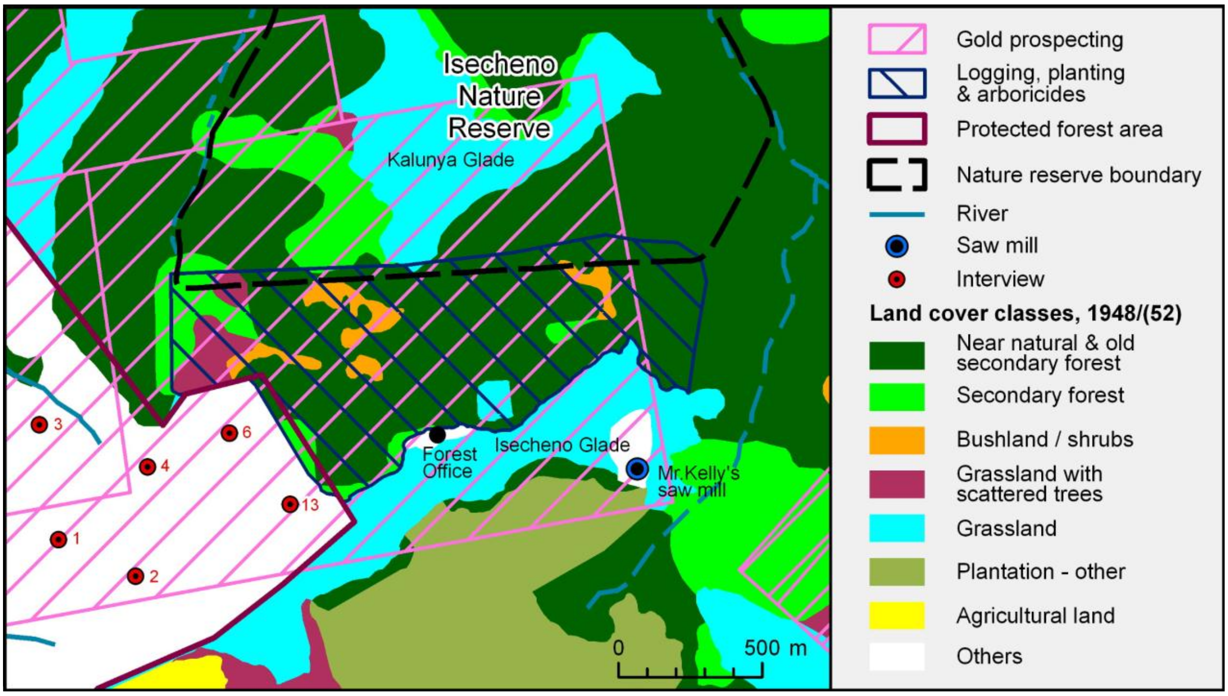


Figure 3.15: Map of the commercial exploitation of the Isecheno area of Kakamega Forest, showing the extent of gold prospecting (from 1932 topographic map, kn-d27, 1:150,000), selective logging, planting and arboricide (tree-poison) application (location taken from forestry map kn-d39, 1:62,500). The underlying forest cover is an interpretation of aerial photography of 1948/(52).

deep and 10-15 m across, were the result of gold prospecting. A map drawn as part of an internal colonial government report of 1932 (Figure 3.15) (kn-d26) shows that this case study area fell within the gold concession or a Mr. Button.

In conclusion: forestry records, oral histories, remote sensing, maps and ground observations have all here demonstrated that this area, one of the primary scientific research sites of Kakamega Forest, has experienced an unusually wide range of commercial disturbances. As a research site it should not therefore be considered in any way representative of the natural forest. Its exploitation has stemmed from its location near the forest office, i.e. the place of first consideration for exploitation and experimentation; the same location now brings the protective benefits of KFS, community conservation, and the scientific and tourist community.

Chronological summary of case study 7

- **1932 to mid 1930s:** forest degraded by gold prospecting (*ground observ., oral hist., archive maps*)
- **1938 to 1943:** degraded by selective logging (*forestry records, oral hist., aerial photos*)
- **c. 1943/44**: degraded by legal pitsawing (*forestry records, oral histories*)
- **1941 to 1947:** group planting of indigenous (& exotic) species (*forestry records*)
- **1940s to 1960s:** forest recovery with cessation of logging / planting (*aerial photos*)
- **1972/73 to 1979/80:** degraded back to secondary forest due to 1960s tree poisoning (*forestry records, satellite*)
- **1980s to the present:** recovering forest due partly to scientific interest (*satellite)*

Forest cover change: intact forest ➔ heavily degraded ➔ recovering forest
Causal progression: mining ➔ logging ➔ planting ➔ arboricide ➔ conservation

3.8 Case Study 8

Case Study 8: Kakamega clear felling: fragmentation of a reserve
Date range of main evidence: 1898 to the present
Forest cover change: forest ➔ clear felled

The fragmentation of forests is well known to create a barrier to the communication of species and can lead to a range of ecological declines including the reduction of gene pool quality and eventual population relaxation (e.g. Turner & Corlett 1996, Laurance *et al*. 1997, Benitez-Malvido 1998, Brooks *et al*. 1999, Farwig *et al.* 2006, Peters *et al*. 2008). The central part of Kakamega Forest is here chosen as an example of forest clearance that has not only resulted in the fragmentation of the main forest block. It represents a swathe, almost 3.5 km wide, devoid of natural forest between the only two parts of Kakamega Forest unexploited by commercial timber extraction, the Nature Reserves of Yala River and Isecheno.

Pre-commercial extraction, around 1930
The first cartographic survey of the area sufficiently detailed to convincingly show the interior of the forest was carried out around 1931 (1:62,500, kn-d24) before any commercial extraction had been begun and shows the forest here to have been punctuated by several large glades (as reflected in Figure 3.16a). The northern branch of a road through the forest follows the easiest route by passing from glade to glade. The southern branch was formally ‘constructed’ in 1898 as the Sclater Road, the main trade route from the coast to Uganda until the Uganda railway was completed in 1902 (Perham 1942) and is marked as a sealed road on the 1912/13 topographic map (1:250,000 scale, kn-d7).

Commercial extraction, 1932 to c. 1980
A 1932 map of the ‘Kakamega Goldfield’ (kn-d26) shows that the four gold prospecting concessions in the interior of the forest were located within this case study area and were facilitated by the forking road thorough this part of the forest. One of these was developed as a dynamited gold mine on Lirhanda Hill. The gold mining directly stimulated the decision to open the forest to commercial logging in 1933 when the first official concessions were given out in the centre of this case study area to Risks Sawmill, Kelly’s Sawmill, and Kenya Consolidated Goldfields’ mill (kn-d28). The latter mill later became Kavirondo Gold Mines (KGM) in 1936 and subsequently Rondo Sawmill which came to dominate the exploitation of this case study area (*cf*. kn-d38, 52). Multiple concession maps allow the tracing of every alteration to the felling scheme and an example of the digitised concession areas is shown in Figure 3.16a. KGM’s area of operation expanded to establish their dominance of the southern part of the area while Kakamega Sawmill was given the northern part. The progress of the felling can also be traced in the aerial photography of 1948/(52) (kn-d42) and 1965/67 (kn-d70) and shows that most of the clear felling was done in close proximity to the road network. The satellite imagery time series reveals the progression of felling and which eventually resulted in the separation of the northern and southern parts of Kakamega Forest between 1972/73 and 1979/80 (kn-d88 & 101) (see Figure 3.16b).

The shamba system, and its abandonment in 1986
For most of the years of logging operations here, the felled land was settled and tended by shamba-system cultivators between the 1940s and 1986 (e.g. kn-i36, 43, 54). The system encouraged people to live within the forest and to farm an allocated clear-felled forest patch, normally 0.4-0.8 hectares (Logie & Dyson 1962), alongside newly planted tree-seedlings until they were established, normally 3 to 4 years later. However, it lead to widespread abuse of the forest and was discontinued in 1986 effectively evicting hundreds of people from the centre of Kakamega Forest, the current case study area. Analysis of the satellite imagery classification time series shows that the 218 ha of agriculture within our case study area in 1984 (kn-d109) was virtually halved to 116 ha three years after the eviction in 1989 (kn-

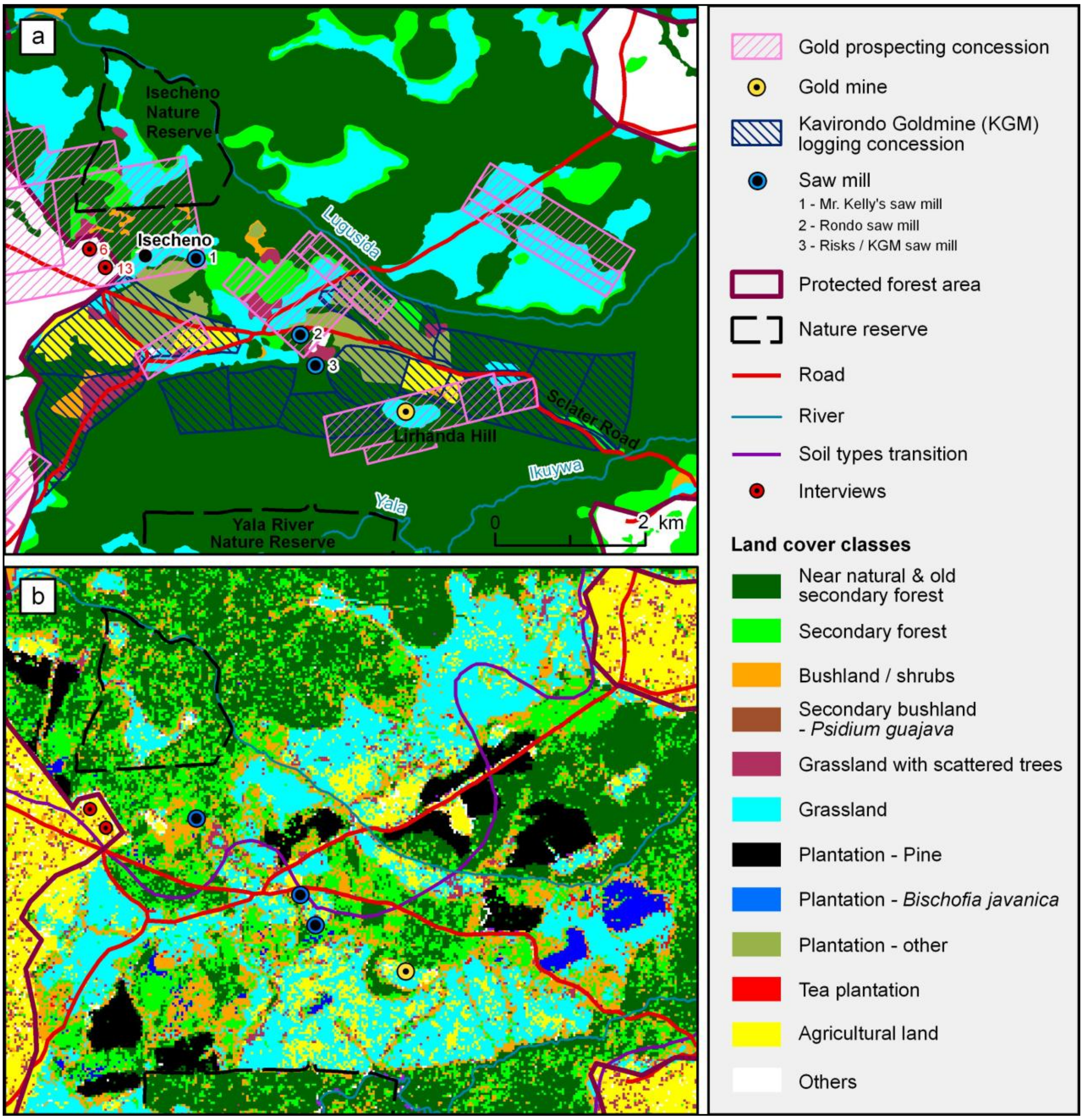


Figure 3.16: Map of central Kakamega Forest showing identified factors leading to forest clearance: from soil differences to glades to roads to gold prospecting to logging; it shows a) the roads / tracks of 1931, the gold concessions of 1932, the logging concessions of 1947, overlaid on the visual interpretation of aerial photography of 1948/(52) (kn-d25, 27, 38, 43), b) the satellite imagery classification of 1989, and the main soil transition within the forest (kn-d112, 104).

d112). The farmland or shambas of the forest had quickly become grassland after the eviction and the people turned to grazing the area from their homes at the forest edges. Although the distinction between grassland and agricultural land in the satellite imagery classification is not considered reliable (Lung 2004) the reconstruction of the story from local interviewees (e.g. kn-i13) is entirely consistent with such a transition to grassland.

The abandonment of the shamba system lead to an inability of the FD to plant large areas of clear felled forest since they were now deprived of their cost-effective means of seedling protection. The satellite imagery time series is able to show the consequences within the case study area, i.e. a slowing of the rate of new plantations but also a marked increase in natural vegetation succession. Thus, the grassland of 1989 (kn-d112) has in large part turned to ‘Bushland/shrubs’, ‘Secondary bushland – *Psidium guajava* (Guava), and ‘Secondary forest’. Ground truthing confirms the abundance of Guava trees that has developed following the end of the shamba system.

The area as a zone of transition

The forestry records referred to below appear to show that this case study area represents a natural transitional zone within Kakamega Forest. The foresters of the 1950s recorded their observation that the trees *Funtumia africana* and *Olea capensis* grew predominantly in the north of the forest and that *Celtis mildbraedii* grew predominantly in the south (IG Reports 1957, 1959). Forest inventories of 1958 also show little overlap between trees in the south (*Manilkara butugi* being most prevalent) and those in the north (with most *Croton megalocarpus*) and demonstrate the heterogeneity of the forest before commercial exploitation. Analysis of logging records for the current case study area situated in the middle of the forest shows that four of the species mentioned above (*C. megalocarpus, M. butugi, C. mildbraedii* and *O. capensis*) were the four most common of the 29 tree species clear-felled between 1939 and 1963 (9,120 cu’m, i.e. 68% of the harvest). This overlap here of species from the north and the south enables the tentative suggestion that instead of a random heterogeneity, the variation may represent a fundamental ecological difference between the north and the south of the forest. Biologists recording a variation between the north and the south of the forest today should not therefore interpret the findings as simply reflecting disturbance (Mutangah 1996, *cf*. Althof 2005) but instead as the combination of long-term, largely natural variation, and the subsequent disturbance by commercial felling.

Overlaying a 1:250,000 scale soil map (kn-d104) in the GIS provides an indication that soil may be a likely main reason for that difference; Figure 3.16b shows a line marking the soil change from nitro-rhodic ferrasols with ferralo-orthic acrisols soil in the north of Kakamega Forest to ferralo-orthic acrisols in the southern half. Furthermore, the soil change appears to also broadly coincide with the transition from the commonly occurring glades of the north to a general paucity of natural glades in the south, best shown in the aerial photography mosaic of 1948/52. The soil change in this case study area may be a reason for this transition between north and south of the forest regarding both species and glade occurrence (see also CS 4).

In conclusion: forestry records and maps alongside remote sensing in particular have allowed the tracing of the clearance of forest cover in this case study area and thus the major fragmentation of Kakamega Forest. Facilitated by the ease of access via an early trade route and the natural presence of glades here, the area was exploited for gold and subsequently for timber. Since the cessation of the shamba system the area natural vegetation succession has occurred between plantations. The area is suggested as occupying an area of natural transition between the north and south of the forest and is likely to stem from a change in geology / soils.

Chronological summary of case study 8

- **1898:** East African trade route created through the forest (*archive docs & topo maps)*
- **Up to 1932:** intact forest but with large glades facilitating fork in the road (*topo maps*)
- **1932 to c. 1940:** gold mining via the 2 roads (*archive docs & maps, oral hist.*)
- **1933 to c. 1980:** full fragmentation by c. 1980 due to clear-felling following the 2 roads (*forestry maps & records, satellite, aerial photos, oral hist.*)
- **1940s to 1986:** plantation & agric. via shamba system (*forestry rec., satellite, oral hist.*)
- **1986 to present:** succession to bush due to lack of shamba system (*forestry records, satellite, oral hist.*)

Forest cover change: forest ➔ clear fell & fragmentation ➔ indigenous & exotic forest/bush
Causal progression: geology/soils ➔ road access ➔ mining ➔ logging ➔ ‘conservation’

3.9 Case Study 9

Case Study 9: Kaimosi: a major fragmentation
Date range of main evidence: 1896 to the present
Forest cover change: forest ➔ agriculture & tea

The former existence of a physical connection between the Kakamega and Nandi Forests was demonstrated by Mitchell *et al*. (2006) where it was stated that the two should in some respects be considered as a single natural and historical entity. The two forests are today very separate and the 2003 Landsat satellite imagery classification shows a nearly 7 km gap between them. The forest fragment of Kaimosi Mission lies more than 5 km adrift from both and the area between the three forests represents the largest fragmentation of the Kakamega-Nandi forest complex. Published literature has not so far investigated the nature of the original forest link or the process and reasons for its break-up. (Note: The names of Kaimosi and Kabwaren / Kapwaren both refer to the whole area of this case study area.)

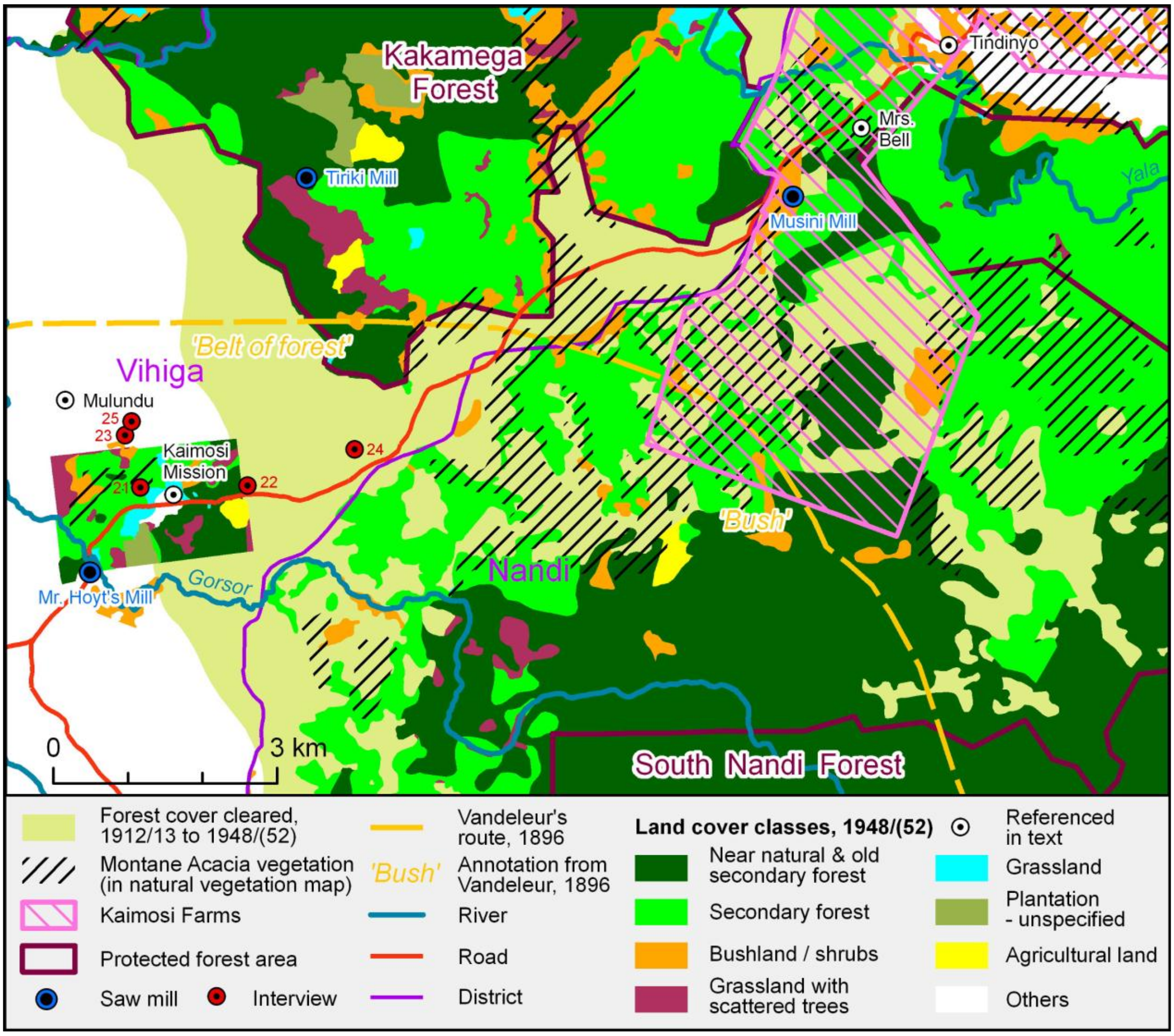


Figure 3.17: Map of the Kaimosi / Kapwaren area showing Kakamega and South Nandi Forests as a single forest in 1912/13 (kn-d8, 1:250,000) and the reduced, fragmentary link by 1948/(52) (kn-d43).

The link between Kakamega and South Nandi Forests
Vandeleur (1897) recorded that his 1896 expedition (see Figure 3.17 for route, kn-d1) encountered a belt of forest about 5 miles (c. 8 km) wide here separating the Kavirondo (Abaluhya) from the Nandi people. This is consistent with Willis Hotchkiss, one of the three members of the Friends' Africa Industrial Mission to establish the mission at Kaimosi in 1902, when he wrote "we are on the edge of the fine Nandi Forest" (Hotchkiss 1902, p. 982). However, the diary of Reverend Chilson implies a less than continuous forest cover when recounting the first discovery of the site on which they would establish their mission at Kaimosi; they approached from the east through our case study area and Chilson commented on "forcing our way through jungle in places […] through a wild country" (Chilson 1943, p. 28). This impression is confirmed by the 1905 report of a British army officer regarding their tracking of the Nandi people through 'Kabwaren Forest' stating about this area that "there is a certain amount of cultivation in the forest and some inhabited clearings of considerable extent" (IG Report 1905, p. 143).

Seven years later the first biologist to visit the area, Edmund Heller, stayed at the mission and wrote that "it is well situated on a forested hill in the edge of Kakumega forest" (Heller 1912, p. 94) thus indicating that it was still connected to the main forest to the north. Heller walked north-east from Kaimosi Mission to Tindinyo (see Figure 3.17) and recorded that he had "passed through weed grown shambas [farms] nearly all the way, passed very many creeks with bordering forest" but the natural vegetation he notes indicates a predominantly bushland area: "most of the vegetation along the way Acanthus, purple compositae and solanum" (p. 98). He refers to "clusters of the nude Tiriki working" there (p. 103) (see Figure 3.18) and it is probable that this clan, that was already significantly located on both the east

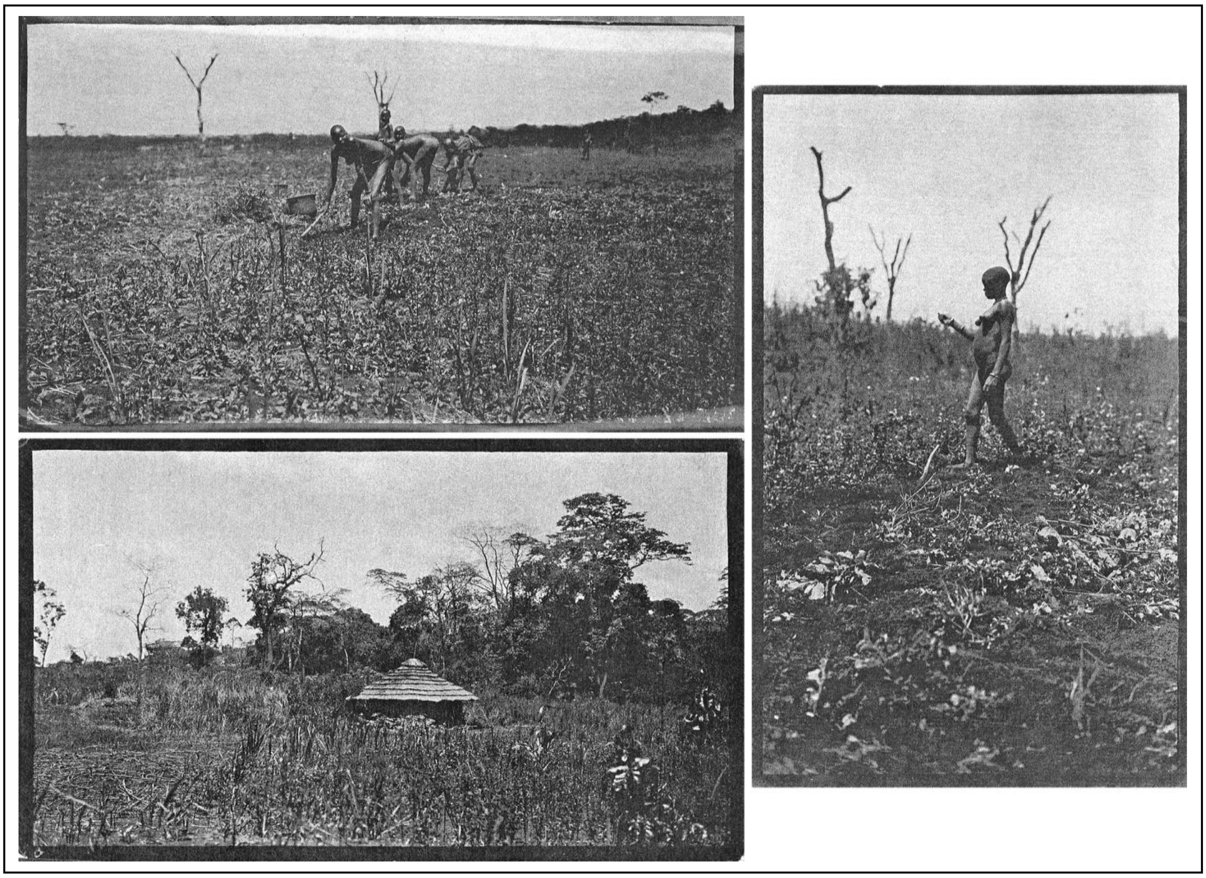


Figure 3.18: Photographs of the Kaimosi area in 1912. Clockwise from the top left: a and b) "the nude Tiriki working" in the open landscape dotted with dead acacia trees, c) a house beside a degraded forest remnant (source: unpublished records of Edmund Heller's expedition, record unit 7179, Smithsonian Institution Archives, Washington, DC, USA).

and west sides of the forest, had cleared the vegetation almost all the way along Heller's route, the forerunner of today's road running approximately east-west. This interpretation is supported by a statement written in 1924 by the Agricultural Officer of Nyanza complaining that the Tiriki, having already denuded their own area of trees were doing the same to the Nandi areas (IG Report 1924).

These first-hand written accounts therefore suggest an incomplete forest cover here by 1912, evidence that is at odds with the 1:250,000 scale topographic map of 1912/13 (kn-d7) that depicts a full 10 km-broad forest connection here. The same map is known to have omitted internal details of Kakamega Forest such as several glades in other parts of the forest that are known from interviews to have existed at that date and many such omissions may reflect the relatively coarse scale of the map while it is also likely that they had not surveyed all of the forest interior. The evidence of the written documents and the correct locating of their area of relevance, need not therefore be called into question and reveal that the break-up of the connection between Kakamega and South Nandi Forest was already underway within the first decade of the 20th century.

European and commercial interests

From the earliest years of the 20th century the Tiriki were not alone within the area of this case study which has been one of the main focii for a range of European commercial interests. The Kaimosi Mission was entirely a religious endeavour but photographic evidence testifies to their early ventures into timber milling with a saw mill and shingle machine already established by 1903, and a felled tree trunk ready for milling (see Figure 3.19b & c). Photograph 'd' shows the 'Forest Road Kaimosi' at some date between 1903 and 1910 revealing it to have been flanked by low and irregular forest that appears to have been already degraded. One of Heller's 1912 photographs (Figure 3.18c) also shows forest of a somewhat broken and secondary appearance behind a house. Another suggestion of a highly disturbed forest is also taken from the single tall tree in the distance on the right of photograph 'a' (Figure 3.18) that is suggestive of a forest-grown tree now isolated by felling.

Commercial gain was the motivation for much of the subsequent European involvement in this area. In 1918, having identified the area of the 'Kaimosi Farms' (see Figure 3.17) as the best location for growing coffee, the colonial government allocated the land for demobilized British soldiers specifically for this purpose (Ng'eny 1970). It represents the conclusion of a search lasting many years for the best land for the commercial production of coffee (*cf*. Elliot 1896, Hutchins 1911, IG Report 1912). One resident of this area, a Mr. Pentreath, wrote to the Kakamega forester in 1933 to beg him to fell the forest on his land so that he could expand his coffee plantations (IG Corresp. 1933). He also revealed another commercial incentive stating that the gold mines, then at their peak in the Kakamega gold rush, could provide a good market for his timber. Two internal government letters also reveal commercial logging infrastructure in this area with a sawmill in Mr Hoyt's ownership within the Kaimosi Mission [see Figure 3.17] from which he "has been cutting considerable numbers of trees from the Native Reserve […] in small patches of forest" (IG Corresp. 1938), and the Musini Sawmill cutting timber on "private land in the Kaimosi area" (IG Corresp. 1946b).

It is interesting to note that the visual interpretation of the 1948/(52) aerial photography (kn-d43) shows that the limit of the deforestation closely followed the district boundary that marks the division between the Abaluhya and the Nandi (see Figure 3.17). This is likely to reflect both the more populous nature of the Abaluhya, and, as shown in Figure 5.4, especially in the Tiriki area, of Kakamega and Vihiga Districts, and their more agriculturally-based, land-hungry culture, as compared to the Nandi (*cf*. Were 1967, Huntingford 1950). The local inhabitants' role in the clearance is therefore again implied and it is perhaps significant that an early name of our case study area, 'Kapwaren' is a Nandi word meaning 'unoccupied' (IG Report 1905) and appears to have been superseded by the word 'Kaimosi', also a Nandi word, meaning 'you [neighbour] are coming close' (kn-i25).

Figure 3.19: Photographs of the Kaimosi Mission area, 1903-10: clockwise from the top left: a) the first camp amidst grass and bush surroundings, 1903, b) Doris Blackburn, aged 5 atop a felled tree trunk, c. 1907, c) the sawmill and shingle machine, 1903-10, d) disturbed forest, 1903-10 (source: the Blackburn family album, Earlham College Library, Richmond, Indiana, USA).

The last link between Kakamega and South Nandi Forests

In 1955 a Mrs. Bell wrote to the forester based at Isecheno (IG Corresp. 1955) from her home within the Kaimosi Farms (see Figure 3.17) complaining of the forest loss continuing between Kakamega and South Nandi Forests. Her property is marked on the 1:50,000 topographic map of 1958-62 (kn-d61) and the visual interpretation of the 1948 aerial photography (kn-d43) confirms that she was maintaining the last remaining forest link. She lamented that this was the only point at which the Colobus monkeys could pass over the road from one forest to the other. The 1965/67 aerial photography (kn-d71) confirms that she was correct in her fears and the forest connection had by then been lost, a mere sliver of bushland remaining. This loss of forest cover is seen to have been fully completed with the loss of the last forest fragments outside the official forest boundaries by the time of the 1979/80 Landsat satellite imagery (kn-d100-101). The commercial factor has continued to the present day and ever since the 1950s (*cf*. topographic map kn-d61) the central parts of the Kaimosi Farms have been tea estates (*cf*. satellite imagery classifications, e.g. kn-d128).

Why the break-through occurred here

Oral histories reported that this area was in some parts true forest and in others much lighter in character and in some parts grassland (kn-i22 & 23). Overlay of the visual interpretations of the 1948/(52) and 1965/67 aerial photography with the natural vegetation map (kn-d74) shows that much of the early deforestation coincides with the areas of drier and more woodland character, mostly ‘Montane Acacia vegetation’, that would have been easier to clear than the fuller forest. Supporting this are several photographs taken by Heller as he passed from Kaimosi Mission to Tindinyo in 1912 and which depict Tiriki women digging, with apparently dead acacia trees in the background, see Figure 3.18a and b. While forest vegetation features in several of Heller’s photographs the openness of much of the landscape is also notable and is mirrored by the photograph dated 1903 (Figure 3.19a) taken at the first camp at Kaimosi (Blackburn 1903-1910).

The montane character noted in the natural vegetation map reflects the gradual rise up from the Guineo-Congolian forest type of Kakamega Forest (Blackett 1994a) to the more montane forest type of South Nandi Forest (Blackett 1994b). In addition to the altitude, the vegetation change is perhaps also influenced by the change in geology from the mudstones / claystones of Kakamega Forest and Kaimosi Mission, to the granites / granodiorites of South Nandi Forest seen on a reconnaissance soil map (kn-d104). These factors and the resulting vegetation (*cf*. IG Report 1912) are likely to have been critical in the identification by the British of part of this area as highly desirable for coffee growing and which was key in opening up the land to European commercial development.

Regarding the initial breaking of the forest link in this area, it is interesting to note that if the Kakamega-Nandi forests represented a barrier keeping the warring Luhya and Nandi tribes apart, it was the Tiriki, with their combined Nandi/Luhya heritage (Were 1967) that appear to have first made the break-through across the forest. It is relevant here too that Osogo (1966) identifies the western edge of this case study area, as one of the early centres of population from which other parts of Kakamega District were settled; the expansion of the Tiriki into the forest here is therefore not surprising. This narrative is inconsistent with the famed reputation long enjoyed by this clan for the conservation of sacred forest groves in this area (e.g. Opole 1991, Kassilly & Tsingalia 2009), and the reality of which was confirmed by interviews in the area (kn-i21 & 24) and ground observations, e.g. at Mulundu just north of Kaimosi Mission. However, the evidence of this case study shows that this historic role of the Tiriki in conserving patches of forest for traditional rites should not be over-stressed beyond the scope of these often very small fragments of sacred forest.

In conclusion: archive documents, maps and photographs, forestry records and remote sensing have all been crucial in tracing the fragmentation of the Kakamega-Nandi forest that was previously a single entity, and in identifying both locally-based and commercial factors. The cross-cultural Tiriki clan appear to have been the first to break through the forest that would have formed a physical barrier between two traditionally warring tribes; the Tiriki’s modern reputation as conservationists should therefore not be exaggerated. The British confirmed the non-forest future for this area by sequestering a large part for their own commercial cash-crop interests.

Chronological summary of case study 9

- **1896:** 8 km-wide forest cover (*military map, archive docs*)
- **1902/03:** Kaimosi Mission established, 1st sawmill starts (*archive docs & photos*)
- **1905 to 1920s:** clearance of lighter forest by Tiriki (*archive docs & photos, oral hist.*)
- **1918:** start of European settlement & clearance for coffee plantations (*archive docs*)
- **1930s:** gold rush stimulates timber cutting (*forestry records*)
- **1950s to present:** tea estates replace coffee (*topo maps, satellite*)
- **by 1965/67:** final fragmentation of Kakamega and South Nandi Forests from each other (*aerial photos, archive docs*)
- **by 1979/80** (& maintained to present): last fragments of forest cleared (*satellite*)

Forest cover change: forest ➔ agriculture & plantation
Causal progression: population expansion ➔ continued expansion & commercial exploit.

3.10 Case Study 10

Case Study 10: South Nandi Forest: flux, tea and politics
Date range of main evidence: 1896 to the present
Forest cover change: forest ➔ bushland and tea

The southern edge of South Nandi Forest is the focus area for this case study that considers the changes in forest cover since the late 19th century and the introduction of the Nyayo Tea Zone almost a century later. The tea zone scheme was begun in 1985-87 and was designed to protect the forest boundary with a buffer zone while simultaneously creating goodwill and an economic opportunity for the forest-adjacent communities (Sayer 1992, Blackett 1994b, Wass 1995). The chosen area includes the most continuous length of forest boundary enclosed by successfully cultivated tea bushes in the Kakamega-Nandi forest complex.

Fluctuating forest cover, the late 19th century to the 1980s

The 1:292,176 scale military survey of 1896 (kn-d1) appears to only mark the forest cover along the expeditionary route in the east of the case study area, but indicates that at that date at least part of the southern edge of South Nandi Forest had extended 3 km further south than today (see Figure 3.20). A very rough annotation of forest depicted on a military sketch map of 1901 (kn-d6) indicates a similar limit. The relatively dense settlement of the area reflected in the 'Thickly populated' annotation of the 1896 map probably contributed to the northward retreat of the forest edge to the position located in the 1:250,000 scale topographic survey of 1912/13 (kn-d7).

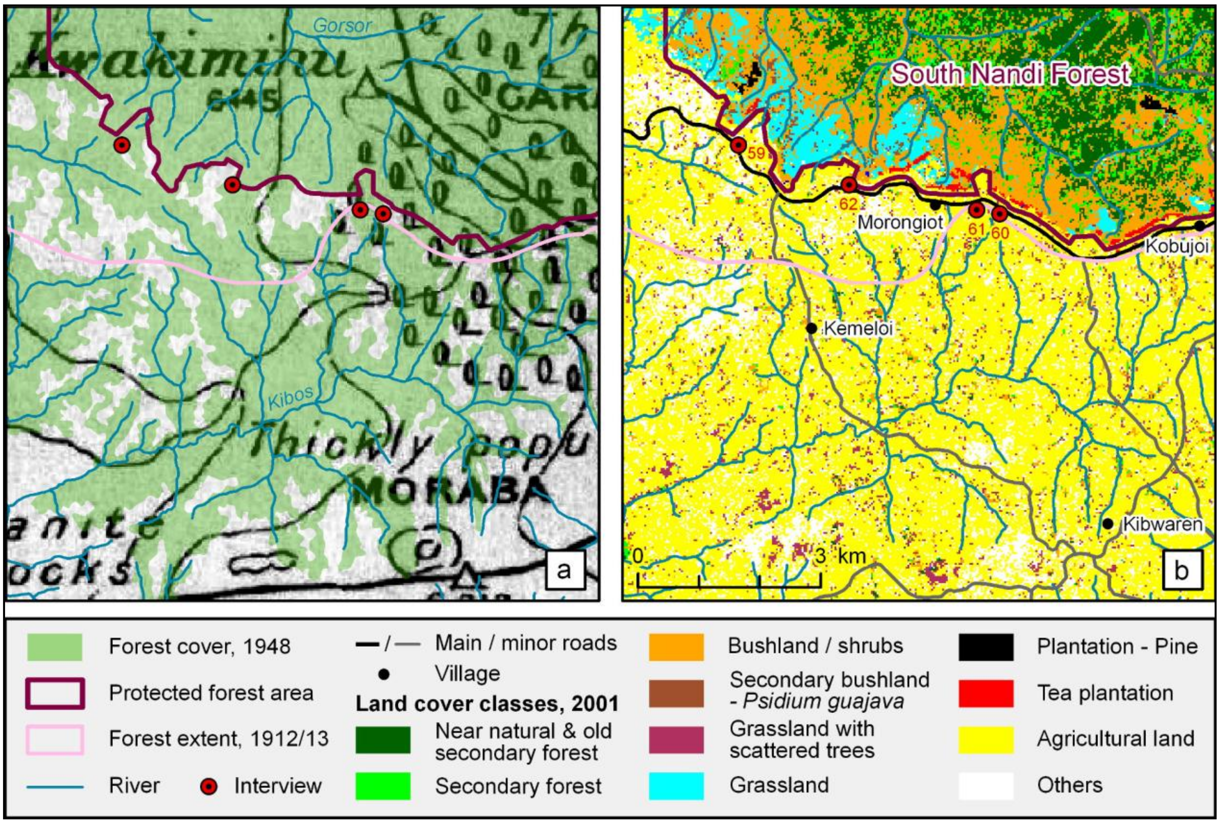


Figure 3.20: Map of the south-western edge of South Nandi Forest, showing fluctuation in forest cover across approximately one century: a) the 1896 map survey represented by the black and grey (kn-d1, 1:292,176), the 1912/13 forest limit (kn-d8, 1:250,000), and the 1948 forest cover (kn-d62, 1:50,000), b) satellite imagery classification of 2001 (kn-d124).

A period of dramatic expansion of forest then occurred, the 1948 extent of which is seen in Figure 3.20a via the 1:50,000 scale topographic map of 1958-60 (kn-d61) which is based on aerial photography of 1948. This expansion follows a period of low fortunes of the Nandi after heavy military defeat to the British in the early part of the century (Ng'eny 1970) and to famine and rinderpest around 1918 (IG Report 1935, Ng'eny 1970). A 1:633,300 scale map of 1915 (refmap5) marks the area south of the Yala River and including this area as a 'New endemic plague area' and it seems likely that population would have been minimal. The earliest oral histories from this area date to the 1950s and refer to the clearance of riverine forest. Indeed, as seen in the figure, the overlay of datasets in the GIS shows clearly that the forest expansion had occurred via the network of rivers. The visual interpretation of the partial coverage of the 1948/(52) aerial photography mosaic (kn-d42, 43) confirms this forest growth as mostly secondary vegetation and it was quickly cleared back to the current forest boundary by the time of the 1965/67 aerial photography (kn-d70). The last vestiges of riverine forest can be traced as gradually vanishing across the satellite imagery classification time series before 1984 (kn-110).

Encroachment into the forest reserve and the Nyayo Tea Zone, 1980s to the present
In the wake of the first major logging of South Nandi Forest in the 1970s (see Appendix E3.2, *cf*. Blackett 1994c), a 700 m-wide band within the forest boundary can be seen in the satellite imagery time series (e.g. kn-d109) to have been virtually clear felled. Local interviewees (kn-i60, 61) refer to the uncontrolled logging that was allowed and which ignited the local practice of encroaching upon the forest for cultivation in the 1980s and 1990s. This encroachment followed on directly from the officially authorized clearance of forest for commercial cultivation of tea within the Nyayo Tea Zone. The Forest Department was unable or unwilling to halt forest clearance at the limits of the tea zone and the archived correspondence of the forester in 1995 notes that the tea zone had been a catalyst for the re-opening of the forest to illegal squatters (IG Corresp 1995). He wrote that the intended 100 m zone width had in places been allowed to expand to more than 500 m and had therefore had the opposite effect to the original, stated intention. It is also locally claimed that during the partisan politics of the 1990s, many people were told by government authorities that they could enter the forest to burn charcoal and to cultivate the forest (kn-i59).

The political circumstances of the 1990s undoubtedly facilitated the unchecked encroachment of the forest in this period as paralleled by the logging of the whole forest under government protection despite a nationwide ban on logging (kn-i63). The Nyayo Tea Zone is interpreted by some as being simply part of the corruption designed to fill the coffers of the then-KANU government. Of the 1,564 ha of Nandi forests felled for planting tea, only 401 ha had been planted in the ensuing 10 years (Wass 1995). Interviewees reported that many people around the forest had learned charcoaling skills during the clearance of bushland for the tea zone and that they had at that time also grown accustomed to using cheap and readily available charcoal (kn-i59). By the destructive nature of its origin, the Nyayo Tea Zone had fostered charcoaling skills and the local expectation of cheap fuel consumption. Together with a political climate prepared to tolerate such abuses, these factors have led to the severe degradation of South Nandi Forest witnessed in the figure by the very high proportion of bushland in 2001.

It is clear from Figure 3.20b and ground truthing and interviews in 2006 (e.g. kn-i62) that the grasslands (displayed in blue) represent areas of former cultivation and grazing in 2001. However, it is also noticeable that there has been a comparative lack of encroachment in the areas more fully enclosed by a line of tea. There is therefore an indication that if the scheme had been fully implemented with full backing from the government authorities, the original intention of the tea zone may have met with some success, at least in preventing encroachment. Although the cultivators have now been evicted, the tea zone must be considered to represent a failure for forest protection, and as a victory of party-political machinations over a supposed conservation measure.

In conclusion: topographic maps, oral histories and remote sensing in particular have shown this area to have lost substantial forest cover and the remaining forest to have been severely degraded. The roles of the initial logging, the subsequent Nyayo Tea Zone, and political interests are all implicated in the stimulation of the ensuing disturbance via rampant charcoaling and cultivation.

Chronological summary of case study 10

- **c. 1900:** forest cover 3 km south of today's limit (*military maps*)
- **1900 to c. 1915:** forest cleared to north by 'dense' population (*military & topo maps*)
- **c. 1915 to c. 1948:** forest expanded along rivers likely due to plague & emigration (*topo maps & derived geodatasets*)
- **c. 1948 to mid 1980s:** forest clearance northwards due to population expansion (*topo maps, aerial photos, oral hist.*)
- **mid 1980s to 2003:** Nyayo Tea Zone and politics bring major charcoaling and forest cultivation (*archive docs, oral hist., satellite*)
- **2003 (to present):** cultivators evicted (*oral hist.*)

Forest cover change: forest ➔ agriculture ➔ forest ➔ agriculture & degraded forest
Causal progression: cultivation ➔ disease ➔ cultivation ➔ politics & cultivation & charcoal

3.11 Case Study 11

Case Study 11: Mabira and the Nile: flux, flies and politics
Date range of main evidence: c. 1900 to the present
Forest cover change: forest & agriculture ➔ agriculture & cash-crop

Mabira Forest recently faced the very real threat of a political decision to fell a large portion (7,100 ha) for the growth of commercial sugar (New Vision 2007, The Monitor 2007a & b, Reuters 2006). This case study highlights the fact that this echoes something of Mabira's recent past and that a longer term view is needed for the correct perspective. The area under investigation here is well known from the literature to include by far the largest area of forest encroachment within Mabira Forest (Howard 1991, Westman *et al*. 1989, Aluma 1989, Baranga 2007, Lung & Schaab 2008). In addition, this case study includes an area of outside the official forest reserve but immediately adjacent and which stretches as far east as the Nile River; both areas disappeared within an approximately 20-year period. These two parts of the case study area are now covered by an exotic monoculture inside the boundary (see Figure 3.21) and by private cultivation on the outside.

Figure 3.21: The abrupt transition between the natural forest (left) and the encroached area, now covered by Paper Mulbery trees (photograph by Nina Farwig).

The current state, c. 1990 to present

The north-eastern part of the case study area, outside the forest boundary, is now simply agriculture. Ground observations in the eastern part of the forest reserve reveal that the vegetation of large parts of this area is almost entirely *Broussonetia papyrifera*, an exotic tree known commonly as Paper Mulberry. As seen in the 2002/03 time step in Figure 3.22, this is clearly distinguished as a separate land cover class in the classifications of the satellite imagery of 1995 to 2002/03 (mf-d81, 84, 89).

Interviewees (mf-i10, 11) reported that Mulberry seeds were sprayed from aeroplanes in the late 1980s in the hope of recovering this area for useful economic gain through the development of a planned paper manufacturing industry. The industry has never materialised

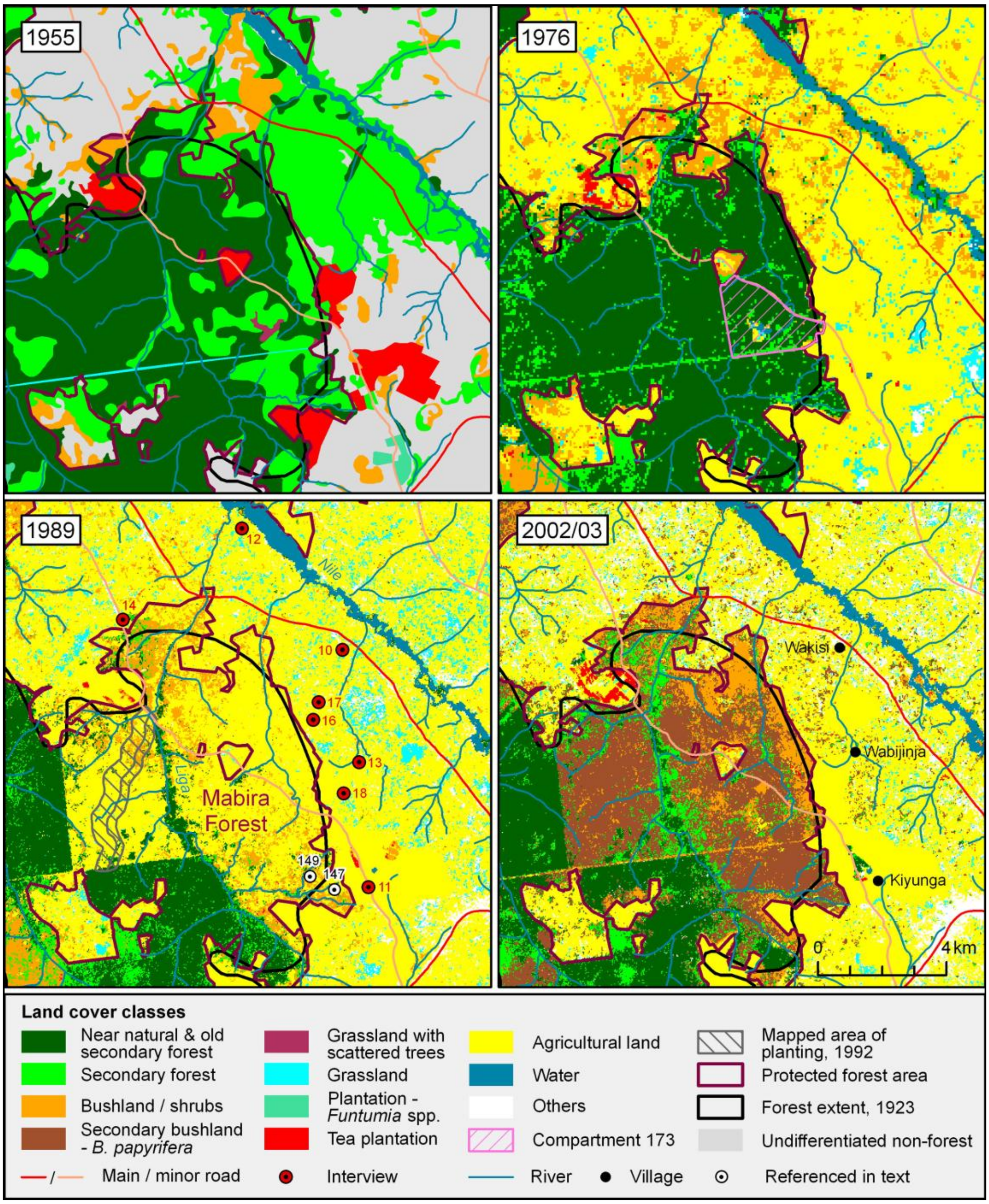


Figure 3.22: The fluctuating forest of eastern Mabira Forest and the River Nile: a) the 1923 forest limit (mf-d14) and the expansion of forest to the Nile by 1955 (aerial photography visual interpretation, mf-d31), b) and c) the reductions in forest cover by 1976 and 1989, and d) the dominance of Paper Mulberry, 2002/03 (satellite imagery classification, mf-d58, 69, 89).

although the Mulberry establishment has been very effective. The only gaps in cover are the frequent clearings made by charcoalers and a 750 m transect walk in 2006 (between GPS way-points 147 and 149 in Figure 3.22) brought to light 29 different charcoaling sites.

A forestry map of 1992 (mf-d74, see Figure 3.22) marks an area of planting which appears, when compared to the satellite imagery classification time series (e.g. mf-d81, 84), to have been drawn in the wrong place. Its correct path is here interpreted to be along the Liga River which is the only area to have experienced a healthy expansion of the forest classes. The north-west edge of the reserve is largely bushland and the remains of recent shambas are clearly visible here in ground observations in 2006; encroachments for cultivation since c. 2000 appear to explain much of the bushland in this area (*cf*. mf-i14).

Forest loss within the forest boundary, 1976 to 1989

The dramatic forest loss that preceded the Mulberry establishment is illustrated by the starkly contrasting satellite image classifications of 1989 and 1976 (mf-d69, 58) in Figure 3.22. This forest loss in eastern Mabira is often straight forwardly referred to as an ‘encroachment’ (Westman *et al*.1989, Howard 1991, Baranga 2007). However, the military government of Idi Amin had declared all land in Uganda in 1974 available for settlement of Ugandans and was chastising the people of the cities for not being productive in the countryside (mf-i10). It is

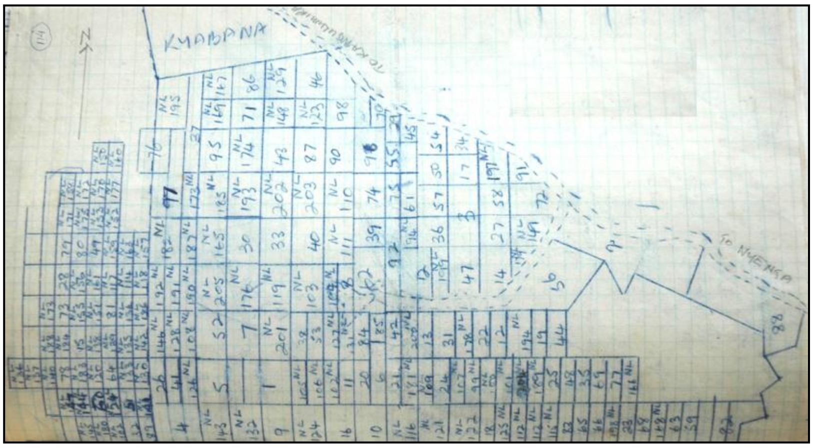


Figure 3.23: A forest guard’s sketch map of compartment 173 of Mabira Forest in 1977 (refmap6), showing a degree of order and control to the encroachment process with licence numbers being issued to settlers (located on Figure 3.22).

directly from this that the Kanani Co-operative Farmers Society, claiming they had run out of land, took their cue for entering and felling the forest (mf-i18 and Aluma 1989, Karani *et al.* 1997a). Their clearance began in compartment 173, within one of the once inhabited but overgrown enclaves considered in case study 5 (*cf*. Figures 3.12 and 3.22). Against the wishes of the FD, the action was supported by the District administration which interpreted this act as a self-help project rather than an encroachment (Aluma 1995, Karani *et al.* 1997a). However, the FD gave out licenses and, in the process, effectively legitimised the process of farming within the forest (mf-i10 and Karani *et al.* 1997a).

The ensuing encroachment was to a large extent controlled by the FD and a forest guard’s 1977 rough sketch map of compartment 173 (Figure 3.23, refmap6) shows that they had sub-divided the compartment into 200 private plots. Evidence that the FD was still able to exercise some authority over the encroachment process is also witnessed in the long and very straight division, visible in the satellite images of the 1980s (e.g. mf-d63), between the encroaching shambas and the natural forest (e.g. Figure 3.22). The stimulus underlying the encroachment had been the fresh influx of immigrants arriving to work in the Metah Company sugar and tea plantations that had been expanding since the 1950s (mf-i13, 15). FD records, supported by local opinion (e.g. mf-i13, 17), show that the settlers originated from most parts of Uganda and East Africa; Aluma (1989) provides FD census records from which it is can be calculated that, of the 3,296 families within the whole of Mabira Forest, 40% came from Mabira’s home District of Mukono, 54% from 22 other Ugandan Districts and

6% from other countries. This influx of migrants is said to have contributed significantly to the disregard for the sanctity of the forest that enabled the encroachment (mf-i10). Their successful eviction occurred in 1988 & 1989 (Karani *et al*. 1997a, Baranga 2007) leaving those within the legal enclaves as the only inhabitants enclosed within the forest (see CS 5).

Maximum forest cover, c. 1955
Topographic maps of 1958/60 and 1962 (mf-d36, 42) show the area with even greater forest cover, stretching, unbroken, as far east as the River Nile and suggest a far greater loss has occurred. The aerial photography mosaic of 1955 (mf-d30) also shows the forest extending to the Nile but crucially differs in revealing the large area of forest outside the official forest boundary was secondary forest (see Figure 3.22d). Provisional interpretation might suggest that this reflects the process of degradation from primary forest and targeting of interviews to this area revealed that the area had been thick forest when the first settlers arrived in the 1950s (mf-i10, 12, 16, 17). However, when asked about the meaning of village place names it was explained that the village of Wabijinja translates as 'of the stones', a reflection of the grinding-stone found in the forest soils during clearance (mf-i13). Further enquiry amongst the oldest generation revealed that they had also found pottery and a smoking pipe while converting the forest to shamba (mf-i10). These artefacts are clear evidence that the area had hosted human settlement before the forest had grown up and that the secondary forest seen in the aerial photography was a reflection of fresh growth rather than degradation.

Forest expansion, c. 1900 to 1955
Several early maps depict this area: a topographic map of 1923 (mf-d14), although at a coarse scale of 1:500,000, shows the forest edge to be in much the same position as today's boundary; and is mirrored by a 1:250,000 topographic map of 1911/12 (mf-d5). Other maps that are not included in the GIS also support the case: an extremely coarse sketch map drawn by a forester, Mr Dawe, in 1905; the first known map to roughly show the forest extent in 1900; and an 1898 sketch map of military operations marking the 'Waganda' people as occupying this specific area, are all in agreement in revealing a substantial non-forested strip between Mabira Forest and the Nile. The evidence of these maps indicates that today's boundary, rather than the inflated forest extent of the topographic maps of the 1950s and 1960s, represents the long-established position of the forest edge.

Interviews in other parts of the forest (mf-i1, 3) explained that large parts of the Mabira area, had been evacuated in the early decades of the 20th century due to an infestation of the *mbwa* fly, *Simulium neavei* (see CS 5). This fly, known to cause the disease Onchocerciasis, was breading in the River Nile (Robertson 1971) and it appears that this case study area, located adjacent to the Nile was one of the worst affected. This area was entirely abandoned for decades until the fly was eradicated; in the absence of a human population in the decades up to the 1950s (*ibid.*), the forest here had increased by 3,995 ha outside the forest boundary (see also Figure 4.2 and 5.5 for population densities for the Mabira area).

In conclusion: oral histories, topographic maps and remote sensing have been central to uncovering the full extent of Mabira Forest west of the Nile but also in showing this to be part of a fluctuating forest cover that should not be viewed simply as a loss of forest. Mabira Forest expanded to reach the Nile while the mbwa fly rendered the area uninhabitable. The massive agricultural encroachment of the forest occurred under government sanction and resulted in an unusable exotic monoculture. In some respects, it provides a forerunning example to the recent sugar-based crisis in which a political decision has threatened the forest with alternative commercial production.

Chronological summary of case study 11

- **c. 1900 to 1955:** forest expanding east to the Nile due to evacuation for the *mbwa* fly (*oral hist., aerial photos, topo maps*)

- **1955 to 1976:** forest clearance due to rapid immigration after eradication of the *mbwa* fly (*oral hist., satellite*)
- **1976 to 1989:** massive encroachment of forest reserve following a presidential declaration of its legality (*satellite, oral hist., forestry records*)
- **1990 to the present:** exotic monoculture (& bush) domination due to commercial incentive (*satellite, oral hist., ground observ.)*

Forest cover change: flux - forest/agric. ➔ forest ➔ forest/agric. ➔ monoculture/agric.
Causal progression: disease ➔ rapid migration ➔ governance ➔ commercial

3.12 Case Study 12

Case Study 12: Kitigo grassland / woodland: fire and elephants
Date range of main evidence: c. 1900 to the present
Forest cover change: flux between woodland & grassland

The Kitigo part of Budongo Forest Reserve (see Figure 3.24) lies adjacent to the forested part of the reserve and stretches as far as the top of the escarpment above Lake Albert. Despite its large size, Kitigo has not been the subject of published research as far known to the present author, and is in large part due its lack of full forest that is often considered to be less species rich than rainforest (Nangendo *et al*. 2002). The interest that has been shown in this area has centred on its potential for conversion to timber-producing forest, either by means of assisted natural regeneration or by large-scale plantation (Trenaman *et al*. 1956, pers. com. P. Karani). Other areas of grassland around Budongo Forest, such as Kaniyo-Pabidi and Siba, have received some attention from a limited number of researchers, most notable amongst whom are Nangendo (2005) and Mwavu & Witkowski (2008) who report a reduction in woodland cover towards grassland. Although specific mention of Kitigo is generally omitted, the savanna and woodland vegetation in the north of Budongo is considered in several publications that discuss the issue of elephants that have impacted the silviculture and forest economics of Budongo (Eggeling 1947, Trenaman *et al*. 1956, Buechner & Dawkins 1961, Paterson 1991, Sheil 1996, Hill 2002).

The opportunity is taken here to observe long term changes in land cover alongside the changing management policies which, being largely uncomplicated by the factor of human settlement, can be more directly interpreted as the ‘causes’ of change. The land cover changes are traced here first before considering the various contributing changes in management.

Early occupation and woodland, late 19th and early 20th century
Ground observation visits in 2006 showed fragments of pottery half-buried beneath the surface of the soil (see Figure 3.25) despite the Kitigo area having been unoccupied as far as human memory stretches (Harris 1935, Trenaman *et al*. 1956, bf-i1, 13). The earliest spatial representation of the area, a military sketch map by Captain Hicks of the Uganda Rifles Brigade of 1899 (refmap1) marks two villages within Kitigo, and the topographic map of 1911 (bf-d2) also locates Bisu within its limits (see Figure 3.24). Both maps mark patches of yellow to reflect the presence of agriculture while the 1911 map marks the entire remainder of the Kitigo area as ‘thick bush’.

Forest expansion and from woodland to grassland, 1911 to 1960
The expansion of the main forest of Budongo into the Kitigo area after 1911 can be seen by overlay of the topographic map with the forest extent digitised from a 1:12,150 scale forestry map of 1932 (bf-d11) (see Figure 3.24). Caution must be exercised in the use of this latter map since the Budongo management plan of 1935 (Harris 1935) comments on the inaccuracies of the aerial photography mosaic on which the map was based. However,

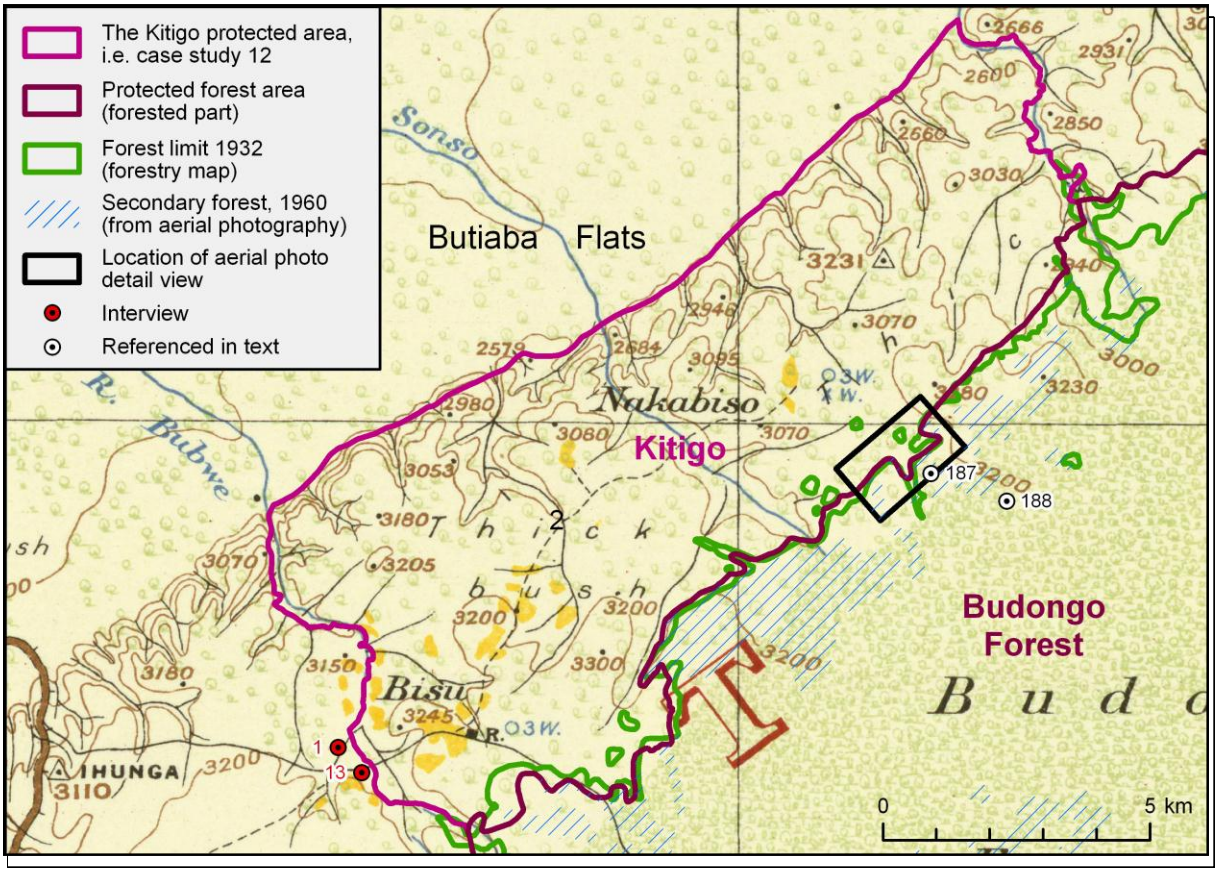


Figure 3.24: Map of the Kitigo area, Budongo Forest, showing forest expansion between the date of the underlying map of 1911 (bf-d2, 1:250,000) and that of the forestry map of 1932 (bf-d12, 1:12,150), with support from part of the 1960 aerial photography visual interpretation (bf-d22).

taking the maps of 1911 and 1932 at face value, the forest is seen to have advanced approximately 1 km into the Kitigo area in just over 20 years. The evidence of the 1911 survey might be questioned in the light of the difference with later time steps and the remarkable stability of this forest edge since 1932, but support is provided by ground observations carried out within the adjacent forest. This revealed termite mounds deep within the forest, one example is illustrated in Figure 3.25b, although they decrease in prominence and definition with increasing distance from the forest edge. They are here taken to indicate the former presence of grassland within a time scale short enough to have precluded their total erosion. Termite mounds, with their distinctive soil properties differing from the grassland in which they originate, have been noted to play a crucial role in the colonization of grasslands by forest trees (Eggeling 1947, Tsingalia 1988, Tsingalia & Kassilly 2010). Numerous examples were found during a walk between GPS way-point 187 and 188 (see Figure 3.24), the latter being the mound found deepest in the forest, 1.7 km from the current forest edge. Further indications that the forest had expanded are also provided by the observation of low-branching trees, i.e. a sign of their growth within an open rather than forest environment. The visual interpretation of 1960 aerial photography (bf-d22) also identifies secondary forest along much of this western edge of the main forest (shown in Figure 3.24).

The mid-20th century land cover change of one part of the Kitigo area can be traced in aerial photography of three different decades. An aerial photograph of 1931 shows a small subset of the Kitigo area to be thinly wooded (see Figure 3.26) but the tree cover is clearly thinned by the next aerial photography in 1951 by which time the area had become scrubby grassland with a scattering of small trees or bushes. By the 1960 aerial photography (bf-d21), the vegetation appears to have become slightly thinner and the grass element more

Figure 3.25: Ground observations showing, clockwise from the top left: a) the woodland canopy, b) a tree apparently damaged by elephants, c) a Terminalia tree resprouting after being burnt, d) an old termite mound within the forest (between GPS points 187 and 188 in Figure 3.24), e) half-buried pottery.

firmly defined. It is to this date that the earliest memory of the area reaches, that of the forester in charge of patrolling the area at that time and who independently reports that Kitigo was then simply grassland (pers. comm. P. Karani).

A return from grassland to woodland, 1960 to 2003

The classification of the first satellite imagery time step, 1972/73 (bf-d31), identifies the area to have been almost entirely 'Woodland' and 'Bushland / shrubs' and implies a process of vegetation succession from the grassland of 1960. The seven satellite imagery classifications between 1972/73 and 2003 show the area maintaining a predominantly woodland profile with 'Grassland' showing periodic and temporary increases, e.g. 1975, 1995 and 2003 (bf-d33, 55, 62).

Seeking the causes of the Kitigo land cover change

The reason for the human depopulation of Kitigo for the last century is reflected in an ungeoreferenced map of 1906 that serves as reference material (refmap2) and specifically singles out the area of our case study alone as being infested with the tsetse fly, *Glossina fulca*. The Budongo Forest management plan of 1935 recalls that the whole of the northern side of Budongo Forest had been forcibly evacuated, a process completed by 1909 (Harris 1935). In the light of the sudden removal of the entire human population the spectacular 1911 to 1932 advance of the forest into the Kitigo area, in parts up to one kilometre (see Figure 3.24), seems credible. Also facilitating the forest advance was the virtual absence of savanna burning in the years between 1916 and 1932. This absence of fire is remarked upon

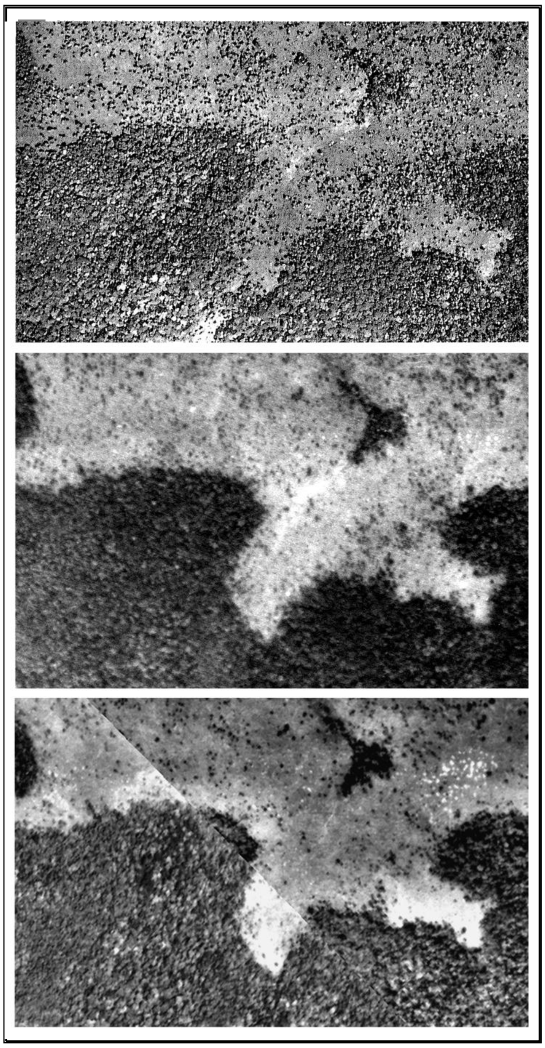


Figure 3.26: Three early aerial photographs of 1931 (top), 1951 (middle), and 1960 (bottom, bf-d21) illustrating the change from thin tree cover to a purer grassland during the period characterised by elephants and late-season burning. (Located on Figure 3.24; 1931 image from Eggeling 1947; 1951 image courtesy of Budongo Conservation Field Station).

in the 1935 management plan when referring to the successful suppression of hunting since 1916 which had, by coincidence, discouraged burning that had previously been done annually by hunters (Harris 1935).

The changes are here attributed, in part, to the introduction in 1932 of a deliberate policy by the FD to burn savanna vegetation late in the dry season, i.e. 'late burning' (Harris 1935) in which the dried bushy vegetation is burnt off at a high temperatures (*cf*. Nangendo 2005). The change in burning regime should though, be seen in parallel with the explosion of the elephant population of Budongo Forest that followed the removal of humans and, more importantly, their cattle against which the elephants had previously competed for forage (Buechner & Dawkins 1961). Ever since Dawe's first visit to Budongo in 1906 (Dawe 1906) foresters had been wary of the damage wreaked by elephants on the forest's timber trees, and another early forester, Swynnerton, believed there to be more than 5,000 elephants in Budongo Forest in 1924 (Eggeling 1947). Trenaman *et al*. (1956) reports that the vegetation of Kitigo had been much influenced by 'game', and ground observations provide evidence of former elephant activity in the Kitigo area; Figure 3.25b shows one of the most mature trees in Kitigo still apparently bearing the scars of 'tusking' damage by elephants.

To combat such wanton vandalism the game wardens of the adjoining Murchison Falls National Park embarked upon a concerted cull between 1926 and 1958, shooting more than 40,000 elephants in the southern part of the park to the north of Budongo Forest (Paterson 1991). In 1955 the Budongo management plan continues to refer to them as a "major pest in regeneration areas" (Trenaman *et al*. 1956, p. 7) and advocates shooting as the only option for their 'control' while in 1959 herds up to a thousand strong were still reported from the adjacent Butiaba Flats (Paterson 1991). One forester active around 1960 recalled patrolling the Kitigo area in particular in order to shoot elephants upon sight (pers. comm. P. Karani). This later phase of culling in the 1960s specifically by the FD of Budongo Forest proved to be remarkably successful in removing the elephant from their concerns, one interviewee (bf-i16) recalling that the last Budongo elephant was shot in 1969. The transformational impact of elephants on the Kitigo area cannot be in doubt and their removal should be considered equally significant in the subsequent growth of woodland.

A further factor in this transformation from the grass-domination of the 1960s to woodland was the introduction of a deliberate policy of 'early burning' in the mid 1950s. This was designed to remove much of the mass of fuel without burning fiercely in order to prevent the more destructive 'late burning' that would otherwise be carried out by hunters (Trenaman *et al*. 1956). The same writer expressed the hope that this would result in the likely "spread of the rich colonising forest type" (p. 13). Indeed, an extensive study of burning policy in Uganda in 1967 concluded that changing from 'late' to 'early burning' was likely to result in a marked growth of dense bush cover (Langlands 1967 as cited in Paterson 1991). This policy has been continued ever since and the interviewees living adjacent to the south-west end of Kitigo (bf-i1, 13) confirm that the area is annually burnt by the NFA and the Uganda Wildlife Authority. Landsat satellite images show that Kitigo and the neighbouring areas to the north are normally burnt in late December and / or January, i.e. early burning (bf-d32, 36, 37, 53).

Ground observations highlight the extent to which fire has dictated the vegetation of Kitigo by revealing that the dominant trees are *Terminalia* and *Combretum*, both of which are largely resistant to low and medium intensity fires (see Figure 3.25c) (Nangendo 2005). Nangendo (2002) has shown how fire can maintain grassland of other parts of Budongo Forest if the burning regime is varied. The maintenance of a regular 'early burning' regime in Kitigo, in the continued absence of elephants, has held the woodland composition of fire-resistant tree species and prevents the domination of grassland. However, ground observation also suggests that the foresters' wish for succession to full rain forest vegetation is also occurring along the forest-woodland juncture where fire penetrates least often.

In conclusion: forestry records and maps, topographic maps and remote sensing have been foremost in uncovering the fluctuation between woodland and grassland in the Kitigo area and an expansion of the forest. Disease has led indirectly to the emergence of a commercially-oriented forestry policy; it necessitated the evacuation of settlements here, resulting in a boom in elephant numbers and in the loss of tree cover. This, in turn, stimulated the eradication of elephants, the change to early-season burning and the return of woodland. If these conditions are maintained the woodland is expected to very gradually become forest.

Chronological summary of case study 12

- **c. 1900:** woodland, in part settled & cultivated (*topo maps*)
- **1906 to c. 1911:** sleeping-sickness leads to human evacuation (*archive docs, thematic maps, forestry records*)
- **1911 to 1932:** expansion of forest in absence of humans (*forestry maps & records, topo maps, ground observ.*)
- **1932 to 1960:** from woodland to grassland due to late-season burning & elephant population explosion (*aerial photos, forestry records, oral hist., ground observ.*)
- **1960 to present:** A return from grass to woodland enabled by commercial forestry, i.e. early-burning & eradication of elephants (*aerial photos, satellite, oral hist.*)

Forest cover change: flux: woodland ➔ grassland ➔ woodland
Causal progression: disease ➔ evacuation ➔ elephant pop. explosion; with late burning ➔ early burning & elephant culling

3.13 A brief review of the contribution of the case studies

The case studies have shown a variety of forest cover changes at the local scale that are not restricted to forest loss but which also include examples of forest degradation and of the succession from grassland towards forest. Moreover, they have also provided several examples (CS 1, 3, 5, 10, 11, 12) in which forest cover change is not uni-directional but fluctuating, thereby demonstrating the relevance of the longer term view in which the significance of short-term losses can be better understood. The localised nature of these processes of change is best appreciated when considering the divergent fortunes of different parts of the same forest ecosystem in which one area experiences a loss of forest cover at the same time that forest cover of another expands. Examples of two such areas simultaneously responding to different stimuli are provided by cases studies 1 and 2 in the

Table 3.2: The contributions of the different data sources to the case studies. Black ticks indicate a strong contribution while grey ticks reflect a supporting role.

Case study	Name	Contributing data sources: Fossil pollen	Place names	Oral histories	Archive documents	Archive maps	Forestry records & maps	Aerial photography	Satellite imagery	Ground observations	Main date range
1	South-west Kakamega	✓	✓	✓	✓	✓		(✓)			c. 6,000 yrs. ago - present
2	Kabras	(✓)	✓	✓	✓	✓	(✓)	✓			19th century - present
3	North Nandi Nature Reserve			✓	✓	✓	(✓)	✓	✓		1896 - present
4	Kakamega glades			✓	(✓)	(✓)	(✓)	✓	✓		c. 1900 - present
5	Mabira enclaves			✓	✓	✓	✓	✓	(✓)		1720/50 - present
6	Budongo N15			(✓)	✓	✓	✓	(✓)	(✓)	✓	1906 - present
7	Isecheno			✓		(✓)	✓	✓	✓	✓	1932 - present
8	Kakamega clear fell area			(✓)	(✓)	(✓)	✓	✓	✓		1898 - present
9	Kaimosi			(✓)	✓	✓	✓	✓	✓		1896 - present
10	South Nandi			✓	(✓)	✓		✓	✓		1896 - present
11	Mabira & the Nile			✓		✓	(✓)	✓	✓	(✓)	c. 1900 - present
12	Kitigo			(✓)	(✓)	✓	✓	✓	✓	✓	c. 1900 - present

19th and early 20th centuries, and by studies 4 and 10 in the later 20th century. An understanding of the divergent processes involved could not therefore be easily appreciated by tracing forest cover change at the forest-wide scale alone.

The proximate causes of forest change have, as far as possible, been identified for each individual situation with local causes present in almost all cases and commercial forces present in half of the examples (CS 7 to 12). The locally-driven forces that have been highlighted include the expansion of settlement and cultivation both in forest reserves and outside them, charcoaling, pitsawing and cattle-grazing. Meanwhile the range of commercial factors featured includes the harvest of rubber, mining, selective logging, clear felling, tree planting, arboricidal treatment and cash-cropping. The variation and localisation of the alternative proximate causes have therefore been highlighted but there are also some commonalities of experience, especially at the level of underlying causes and other biophysical drivers (*sensu* Lambin & Geist 2006). The *en masse* movement of people in the face of disease or conflict (CS 2, 5, 10, 12), and the potential for the negative impact of national politics and governance (CS 3, 10, 11) are examples of themes that feature in both the Kenyan and Ugandan forests. In several cases the pre-disposing environmental factors contributing to the type of vegetation present, e.g. geology, soils (CS 2, 4, 8, 9), as well as climate (CS 1, 2), have been identified where they are relevant to gaining a deeper insight into the forest landscape.

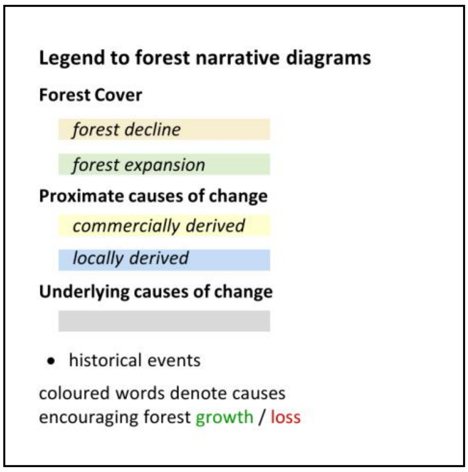
The case studies also reveal that the evidence of one data source is not always consistent with the evidence of others (e.g. CS 5, 6, 9) sometimes due to issues of differing scale, the level of detail or a discrepancy between the date of the source and the date of its content. It has been shown how this can usually be resolved by seeking the support of other independent sources. Table 3.2 shows the contributions of the different source types and reveals that there are six core data types that contribute on a very regular basis to the investigation of forest cover change with oral histories, non-forestry maps and aerial photography each playing especially ubiquitous roles. They are supplemented on an occasional basis by place names, fossil pollen and ground observations.

It is only with this multiplicity of sources that in several instances the case studies have been able to make interpretations that challenge the previously accepted understanding of an area's landscape development (e.g. CS 1, 2, 5). The case studies have repeatedly demonstrated how such interpretations made from so diverse a range of datasets have been facilitated by the overlay and viewing of geodatasets in GIS. It is the spatial definition inherent within GIS that has also enabled the detection of the processes that can only be traced at the local scale. These local experiences of forest cover change and the accompanying causes have been highlighted in the forerunning pages of the case studies and are next brought together with a wider perspective in the forest cover narratives of chapter 4.

4. The forest narratives

The forest narratives chronologically trace the forest cover stories of each of the three forest areas across the 20th century but also seek to place them within their longer context of the preceding centuries. They are intended to be read in combination with the narrative diagrams (Figures 4.1 to 4.3) and together they chart the forest cover change against the factors interpreted as having influenced their development, both the underlying drivers and the proximate causes (*sensu* Lambin & Geist 2006). The narratives draw heavily from the case studies (CS) and as such they serve to summarize the main findings therein, presenting the stories of forest development both chronologically and graphically within single-view diagrams. At the end of the narrative chapter the paths of the graph lines reflecting forest cover and population, and the temporal development of causal factors are discussed briefly in section 4.4.

The reader can navigate chronologically through the diagrams by reading broadly from left to right observing the different phases as summarized at the top of each diagram. The paths of forest cover development and population density are indicated by the green and red graph lines, respectively (see Appendix D1 for notes on the method of deriving the figures and for further detail references); to aid interpretation the contributing factors are colour-coded according to their type (underlying or proximate causes, the latter being sub-divided into local and commercial type). The Kakamega-Nandi area is given greater consideration due largely to its being the main focus area of investigation, but also to the complexity of its narrative stemming from its inclusion of three main forest reserves that have never shared a unified management. Greater recourse to published literature is made for the Ugandan forest narratives, especially for the Budongo area which has been the focus of considerable research by other investigators, and since they are represented by fewer case studies.



4.1 The Kakamega-Nandi forest narrative (see Figure 4.1)

Research into the **early forest landscape development** (not represented in Figure 4.1 due to issues of time-scale) indicates that forest cover has been incomplete in the Kakamega-Nandi region since the forest of around 6,000 years ago gave way to the more open forests of the drier climate of around 4,000 years ago (CS 1). Another dry phase coincides with the first detectable human impact on the land cover around 2,200 years ago when grassland constitutes a major share of the vegetation before a later but undated forest recovery. In the northern part of the Kakamega-Nandi area the grassland either persisted or recurred via later dry periods, encouraged by the differences in geology and soils and further assisted by herbivore grazing and fire (CS 2, 4). Forest appears to have expanded into the grasslands often along the rivers leaving grassy glades in northern Kakamega and North Nandi Forests in areas where the hardest, thinnest soils resisted forest growth the longest (CS 2 & 4).

The phase heading of **clearance and growth** reflects the contrasting fortunes of two areas of change that overlap temporally. At the time of the Abaluhya migration into the western part of the Kakamega-Nandi area, starting around 1598-1625, the forest in the south-west appears to have extended in patches up to 20 km from the current forest edge (CS 1). Perhaps significantly, the start of this immigration process therefore began towards the end of a prolonged spell of dry climate (Verschuren 2001) that would have brought favourable conditions for forest clearance. A progression of different clans migrated into this area and

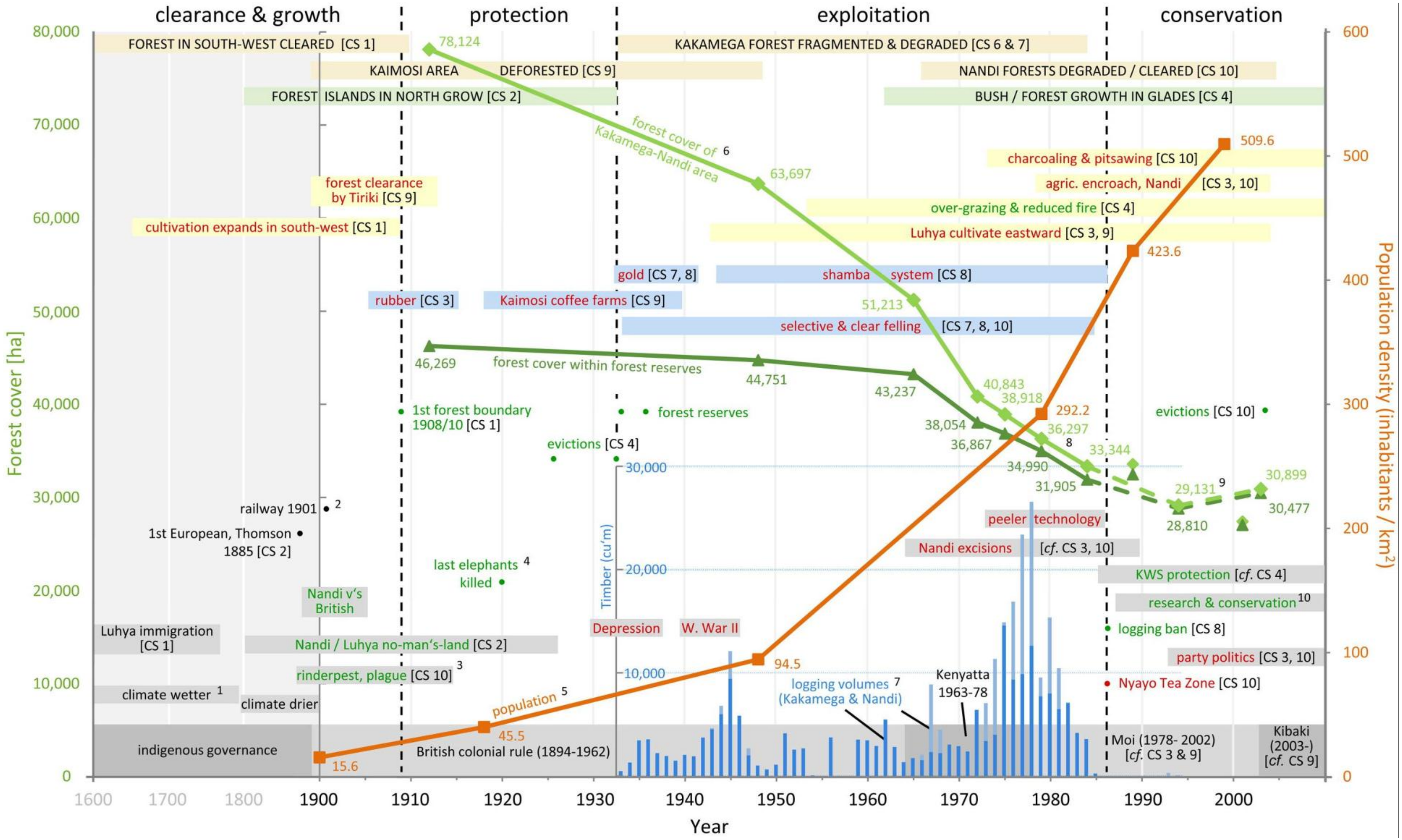


Figure 4.1: The Kakamega-Nandi forest narrative diagram, see p. 91 for colour legend and Appendix D1 for numbered end-notes, 'CS' refers to case studies.

with their hunger for fresh, fertile agricultural land, brought the gradual clearance of most of these forest patches (CS 1).

The great majority of the population were concentrated in the south-western, Luhya part of the Kakamega-Nandi area of investigation and it is only here that significant forest cover was cleared (*cf*. Hobley 1898). By contrast, the probable emergence and expansion of forest islands in the north was occurring at the same time. There, the reign of terror maintained by the increasingly dominant Nandi certainly contributed to forest growth by depopulating the area in the 19th century. Emptied of its human settlement, the forest and woodland patches of this no-man's-land north of Kakamega Forest stretching to Malava and Bunyala Forests, continued to expand in the early decades of the 20th century (CS 2) when rinderpest, plague and famine also reduced human ability to impact their environment (*cf*. Doyle 2006).

The maintenance of much of the Kakamega and Nandi forests might also be interpreted in this context of existing within and of even representing a natural buffer zone or barrier between the opposing tribes of the Abaluhya and the war-like Nandi. Notably, it was the Tiriki clan, with their ancestry and culture stemming from a combination of Luhya and Nandi long before they migrated into this area (CS 1 & 9), who first cultivated a strip through the forest, thus connecting the two opposing tribes at the start of the 20th century (CS 9).

The **protection** phase follows the quashing of the Nandi resistance to colonial rule between 1893 and 1906 and which was focused by the British desire to protect the new Uganda railway from sabotage (e.g. IG Report 1904, Huntingford 1950, Ng'eny 1970). The end of open hostilities opened opportunities for the first, if short-lived, commercial exploitation of the Nandi forests for rubber, timber, wild coffee & banana fibre (CS 3). Consequently the colonial government recognised the need to protect their newly identified sources of natural wealth and the first surveys and forest boundary demarcations were carried out around 1908/10, thus halting the eastward progress of the Abaluhya's forest conversion (CS 1). Total forest cover in the area is calculated to then have been 78,124 ha. However, with the loss of markets for wild rubber the exploitation ended and European interests shifted to coffee plantations for which forested land (the 'Kaimosi Farms') was given out to British subjects in 1918 (CS 9). This contributed to the eventual full physical separation of Kakamega and South Nandi Forests (CS 9). The local people were further alienated from the forest with the 1926 and 1932 eviction of hundreds of families from their homes within the glades (CS 4).

The main **exploitation** phase inside the forest reserves opens with gold prospecting in Kakamega Forest in 1932 (CS7 & 8) spurred on by the world economic depression (*cf*. Kitson 1932). The following years brought the gazettement of the main forest boundaries in 1933 and 1936 thus ensuring the means of colonial control and the commercial harvest of timber and fuelwood to supply the goldmines (CS 7 & 8). Timber output increased temporarily to meet military needs during World War II (*cf*. Logie & Dyson 1962) and over the following decades felling resulted in the fragmentation of Kakamega Forest and the clearance of most of its centre and south. The northern half was, meanwhile, selectively felled for good timber species (CS 8 and chapter 5.2.1). Together this felling accounts for the gradual drop in the dark green graph line of Figure 4.1 up to 1965/67 and reflects a slight decrease in the forest cover within the area of the forest reserves. As indicated by the diagram, the subsequent sharp drop in forest cover of the reserves is attributable to the first of the major Nandi forest excisions and the start of the main logging phase there. This steep decline is continued in the 1970s by the dramatic increase in the timber volumes largely due to improvements in logging (i.e. peeler) technology; this enabled the harvest of a much increased range of species and thus facilitated the felling of the Nandi tree species in commercially viable numbers for the first time (*cf*. chapter 5.2.1).

The shamba system had meanwhile come into full effect and soon hundreds of cultivators were living within the forest assisting in establishing plantations, both indigenous and exotic, and effectively preventing the natural regeneration of clear felled areas (CS 8). However, at the same time, four nature reserves (Yala River, Isecheno, Kisere and North Nandi) had secured legal protection in the 1960s and 1970s (Blackett 1994a & c, Mitchell *et al*. 2009).

Until the 1960s, the pattern of deforestation between Kakamega and South Nandi Forests was sharply reflective of the district / provincial boundary that divides the Nandi and the Abaluhya and is here attributed to differences both in population density and in tribal land-use culture (CS 9). The very high densities of population in Kakamega and Vihiga Districts (see Figure 5.4 for the spatial distribution) have, since the 1970s, led to the expansion of Luhya settlement through the Kaimosi area and also up the Nandi escarpment, bringing both agricultural encroachment and tribal tensions (CS 3 & 9). It also accounts for the continued narrowing of the gap between the pale and the dark green lines of the diagram. The response to the land shortage has seen many parts of the Nandi Forests being officially and unofficially excised since the 1950s, most obviously politically motivated during the last years of the Moi government (*cf*. CS 3, 10). High population densities (see population graph line in Figure 4.1) with few alternatives to agriculturally-based subsistence have lead to acute land pressures and have encouraged the rise in local forest resource use (CS 4) and forest resource extraction such as charcoal burning (CS 10 and chapter 5.2.1) and pitsawing.

The **conservation** phase was initiated by the presidential bans on logging in the mid/late 1980s although this took several years to come into effect, as reflected in the continued drop in forest cover levels of the graph lines (CS 8). Also contributing to the drop was the Nyayo Tea Zone scheme that led directly to deforestation and which, despite passing under the guise of conservation, is open to accusations of serving party-political interests (CS 10).

The first increase in forest cover witnessed by the rise in green graph lines followed soon after and can be in large part attributed to the shamba system's abandonment which enabled the start of natural forest regeneration (CS 8). The establishment of two national reserves under the strict protectionist management of KWS also heralded a new seriousness within government regarding conservation. Their alteration of the grazing and burning practices has accelerated the encroachment of bush and forest into the historic glades and further contributed to the recent forest expansion (CS 4). Over-grazing that prevented high-temperature burning is a likely major contributor to the marked expansion of bush and forest in the outer glades of Kakamega Forest (CS 4).

Since the early 1990s the establishment of community-based conservation groups, conservation programmes and the increase in scientific research interest have increased the local, national and international awareness of the significance and threats faced by Kakamega Forest (Mitchell *et al*. 2009). The Nandi forests have, by comparison, received little attention and in a move of undisguised political favouritism, South Nandi Forest was exempted from the logging ban (CS 10, *cf*. Klopp 2002). However, with the eviction of all forest squatters the Kibaki presidency made a start in reversing the losses of the Nandi Forests although numerous controversial court cases have followed in its wake (*cf*. CS 10). Considering the Kakamega-Nandi area as a whole, there are positive signs for forest conservation and the indications of the graph lines of Figure 4.1 appear to bear this out.

4.2 The Mabira forest narrative (Figure 4.2)

The Kingdom of Buganda, in which Mabira is located was regionally pre-eminent after around 1800 (Reid 2003, Wrigley 2002) and became renowned by early European travellers and colonialists as a model of sophistication and stability (Speke 1863, Stanley 1878). However, specifically regarding the Mabira Forest area a less perfect picture is presented here with the phase of disease and low population and reflects a human-environment system more in flux than stability.

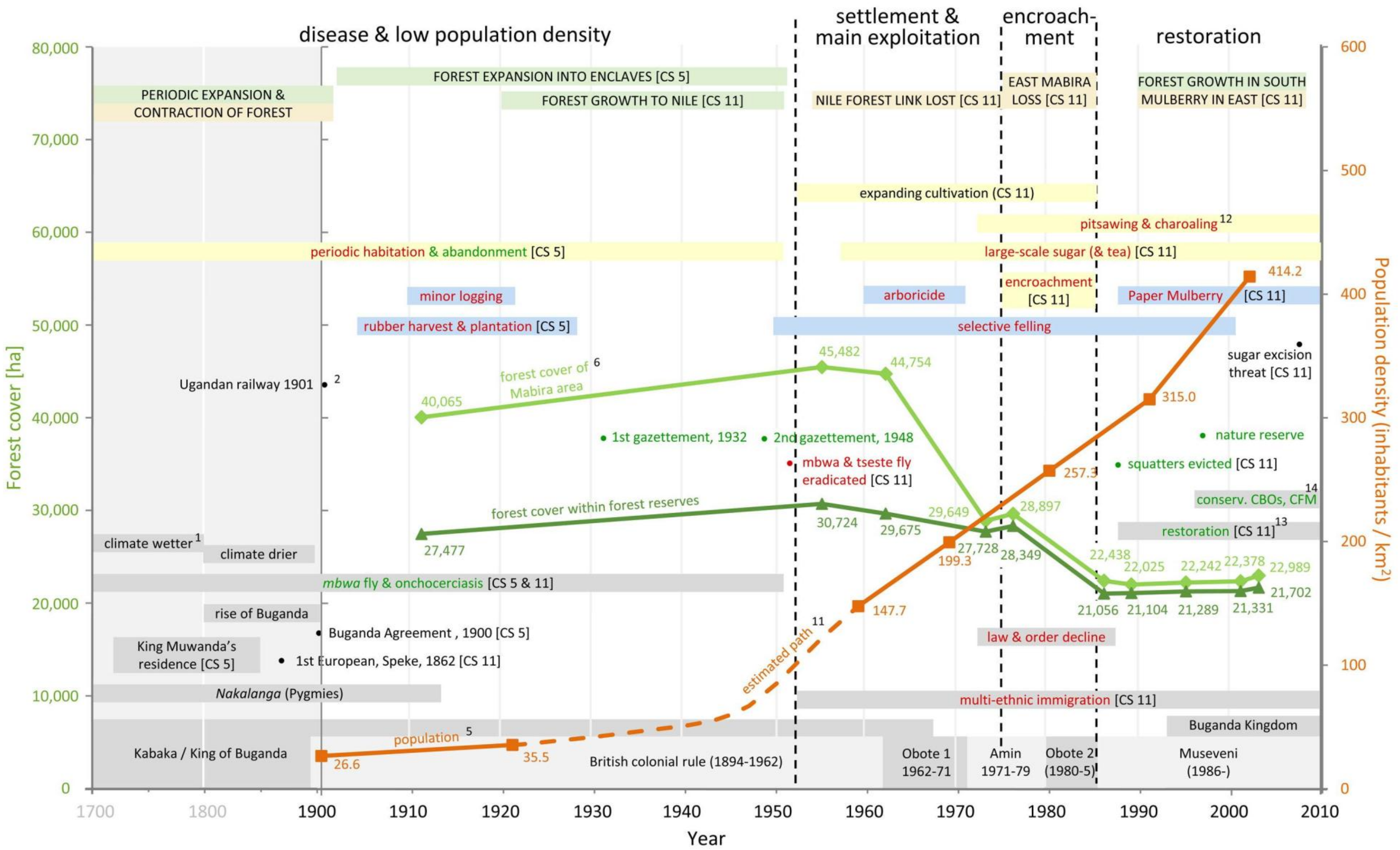


Figure 4.2: The Mabira forest narrative diagram, see p. 91 for colour legend and Appendix D1 for numbered end-notes, 'CS' refers to case studies.

The habitational history of the Mabira area since at least the early 18th century appears to have been cyclical, i.e. settlement followed by abandonment due to disease followed by resettlement (CS 5). Intermittent bouts of the disease, Onchocerciasis, transmitted by the *mbwa* fly (*Simulium neavei*) that bred in the River Nile, periodically left many of the enclaves abandoned. Evidence shows that in the early-mid 18th century, King Muwanda, who appears to have established palaces on grassy openings on the hilltops within and at the edge of today's Mabira Forest, was repeatedly forced to relocate due to the spread of the disease. The existence and habitation of these multiple forest openings, now referred to as enclaves, are therefore indicated to have long historical roots (CS 5). Perhaps resistant to the disease, the Nakalanga who have now passed into the realm of mythology but are here interpreted as pygmies, continued to exist in Mabira Forest into the 20th century (chapter 2.5.2, CS 5).

The historic Buganda Agreement of 1900 had set out the basic division and sharing of land rights between the British and the king of Buganda. This effectively secured control and rights over the commercial exploitation of Uganda's forests for the British around the date that secure rail route to the export market was established; within a few years the first harvest was made of latex from Mabira's wild *Funtumia elastica* rubber trees. However, the wild rubber industry here was thwarted by competition from plantation rubber and consequently attention switched to planting at the forest edges and within the enclaves (IG Corresp. 1907b). These trees continued to be tapped for their rubber in the following decades (mf-i1, *cf*. mf-d31). The start of the rubber industry was followed quickly by the first short-lived exploitation for timber around 1910 although only very limited timber harvest was made further in this phase and did not affect forest cover levels (see also chapter 5.2.2).

The habitational history of the Mabira area appears to have been cyclical, i.e. settlement followed by abandonment due to disease, followed by resettlement. Intermittent bouts of the disease periodically left many of the enclaves abandoned, and some areas such as the area between Mabira Forest and the River Nile, were officially evacuated for reasons of human health (CS 5). Consequently many of these areas became entirely covered with forest in the decades before the 1950s (CS 11). As reflected in the rise of the light green graph line of Figure 4.2, total forest cover of the Mabira area rose 14% between 1911/12 and its maximum extent of more than 45,000 ha in 1955.

The abrupt transition to the **settlement and main exploitation** phase brought the sharp reduction in forest cover following the peak of 1955 and was triggered by the eradication of the *mbwa* fly in the early 1950s (CS 5, 11). This enabled the return of human habitation to many of the enclaves and to the area between the forest reserve and the River Nile, thus bringing the clearance of the Nile-adjacent forest. The Bugandan population of the Mabira area that had managed only to maintain itself at a low density during the years of fly infestation, were now joined by an unprecedented multi-ethnic influx attracted to the freshly available land and the new economic opportunity of large-scale sugar (and tea) plantations (CS 5, 11). However, some of the enclaves were never resettled (CS 5) and have remained the subject of land disputes ever since (mf-i1, 4).

The more favourable conditions also brought renewed commercial selective logging (chapter 5.2.2). The ensuing decades saw every part of Mabira Forest legally selectively felled at least once as no concept of a nature reserve was enforced until the 1997-2007 management plan (Karani *et al*. 1997a). The two green graph lines show that by 1973/74 forest cover outside the forest boundaries had been almost entirely cleared (mf-d56, *cf*. Figure 4.2) and the gazetted forest reserves became the sole focus of both legal and illegal logging operations for the first time (mf-i20). As general law and order and the economy declined catastrophically in the 1970s, local pitsawing and charcoaling skills developed accordingly (mf-i7).

The **encroachment** phase is marked by the loss of approximately a quarter of the gazetted reserves' forest cover starting with the first encroachers in 1975 (CS 11). The population at the east of Mabira, newly emerged since the 1950s, had quickly become accustomed to accommodating its own expansion via the clearance of forest. In great numbers they therefore began the rapid clearance and cultivation of Mabira Forest reserve itself. Even though it was resisted by the FD the encroachment was sanctioned by the government of Idi Amin and was to some extent an ordered, licensed and controlled process, mostly concentrated on the east and south of the forest (CS 11). As seen in the graph, total forest cover dropped to just 22,025 ha in 1989.

The **restoration** phase begins with the advent of Museveni to the Ugandan presidency in 1986 and was followed by the successful eviction of the squatters (CS 11). The encroached areas of the southern part of Mabira Forest were quickly and effectively restored with the planting of largely indigenous species and the assistance of a European Union funded programme (mf-i15). However, the north-eastern quarter was seeded with the exotic Paper Mulberry trees intended for a paper industry that, in reality, never developed. The area shows very few signs of reverting to natural forest cover without considerable effort and expense (CS 11) and now acts as a reservoir of seed-trees from which this highly invasive species has spread across the forest-adjacent farmland (mf-d81, mf-i16).

Notable successes of recent decades include the emergence of conservation-orientated community-based organisations, the careful introduction of collaborative forest management apparently resulting in the reduction of illegal chain-saw felling (CFM) (e.g. mf-i9), and the apparent victory over the sugar company threatening to expand into the forest (CS 11). As indicated in the graph lines of Figure 4.2, this combination appears to have achieved the stabilizing of forest cover from 1986, even displaying a slight forest increase in spite of an acceleration in the rate of population growth.

4.3 The Budongo forest narrative (Figure 4.3)

Following a period in which the Bunyoro Kingdom was the regionally dominant power, a period of political and social decline, **Bunyoro's decline**, characterizes the 18th and 19th centuries (Doyle 2006). A political resurgence in the 1870s and 1880s was effectively washed away in a crushing defeat to the British between 1894 and 1899 (Beattie 1960). This compounded the effects of decades of slave trading, outbreaks of famine, diseases including sexually-transmitted diseases that left the population 'diminished enormously' between the first visit by a European, Baker in 1863, and 1900 (IG Corresp. 1900 p. 69). Although climate was drier than today in the 19th century (Verschuren 2001) Bunyoro's political and social decline left the very low population density unable to manage their environment, i.e. to hold the bush, forest and disease in check (Doyle 2006).

The **untamed bush** phase, starting in 1900, saw the continued decline of the already low population density thus encouraging the growth of bushland that further facilitated tsetse fly reproduction (CS 12). This lead to the rapid spread of sleeping sickness and, in turn, necessitated the evacuation of almost the entire north-west side of Budongo Forest by 1909/1912 (CS 12). Meanwhile, around 1904 the first commercial extraction of wild rubber had begun (CS 6) and was followed by the first pitsawing in 1919 and a small-scale timber mill operating in the south of the forest in 1925 (CS 6; *cf*. Brasnett 1951). However, the Bunyoro region continued to suffer economic and social stagnation for the first half of the 20th century (Doyle 2006).

In the absence of human habitation the forest along the north-west edge expanded around 1 km by the 1930s (CS 12). The vacuum created by the low density of human population all around the forest was filled by an explosion in wild animal populations, most notable amongst which was that of elephants. In combination with the practice of annual late burning

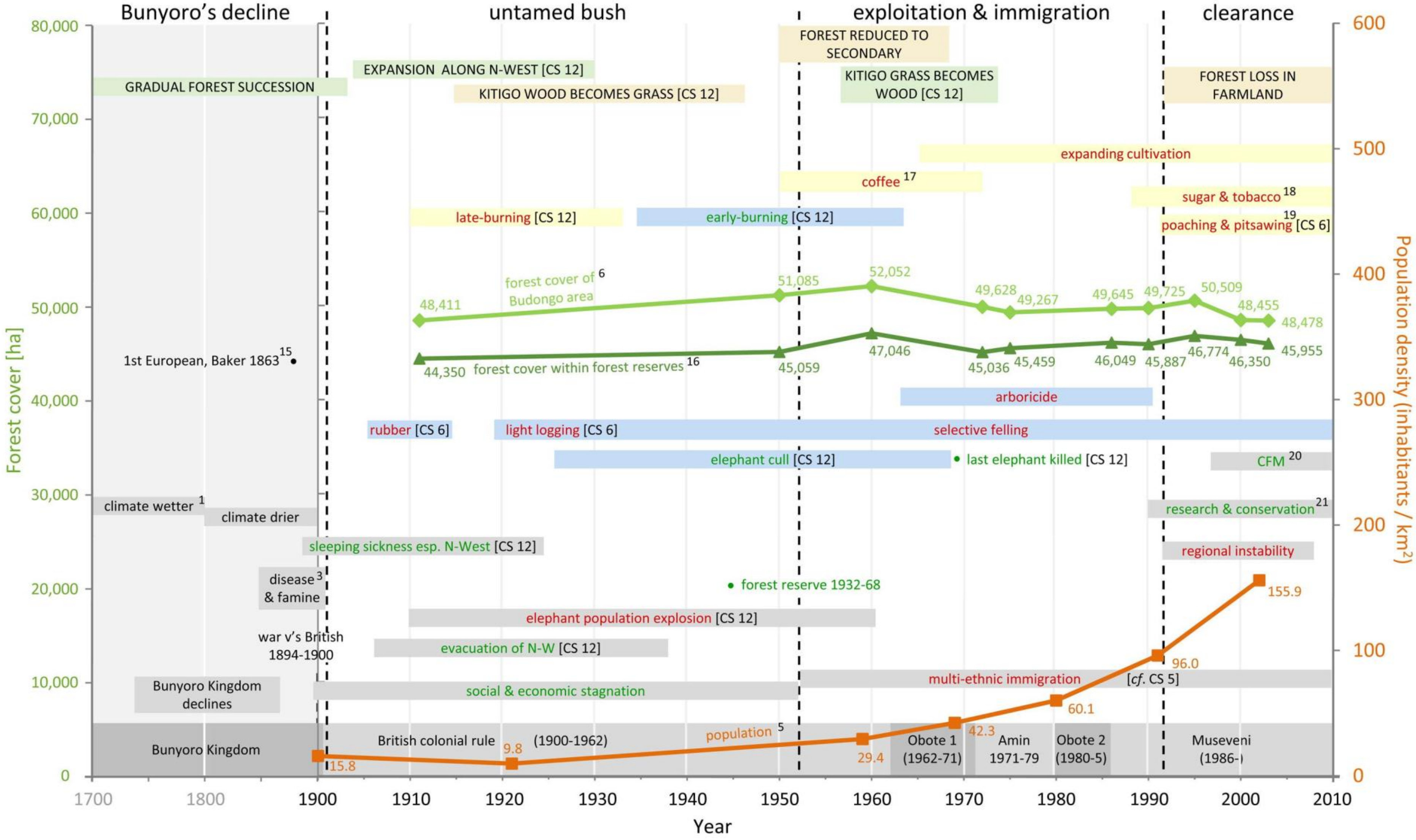


Figure 4.3: The Budongo forest narrative diagram, see page 91 for colour legend and Appendix D1 for numbered end-notes, 'CS' refers to case studies.

of grass, the actions of elephants appear to have caused the conversion of the Kitigo woodland to grassland by 1950 (CS 12). The southern forest edge meanwhile remained stable (CS 6) but the green graph lines in Figure 4.3 show that forest cover had gradually swelled over the decades of low human activity.

The **exploitation and re-population** phase brought larger-scale timber extraction and the diversification of harvested species, expanding from a reliance on the four mahogany species and *Milicia excelsa* (pers. comm. B. Plumptre). These classic timber species though remained the focus of on-going felling but also of the accompanying enrichment planting. In the 1950s and 1960s this was carried out alongside by the widespread application of arboricide, i.e. the poisoning of ‘weed tree’ species, especially *Cynometra alexandri* (chapter 5.2.3). The arboricide programme markedly altered the forest structure with the poison continuing to take effect decades after its application (Karani *et al*. 1997b, Plumptre 1996). This is clearly reflected in the reduction in mature forest classes apparent between the 1960 aerial photography interpretation and the satellite imagery classifications (chapter 5.2.3). The resultant spaces, intended for Mahogany regeneration, have in reality been filled by a larger range of species and, arguably, greater biodiversity (Karani *et al*. 1997b).

The swelling numbers of elephants and their tree-felling propensity alarmed colonial foresters sufficiently to initiate a cull as early as 1926 but was most effective in the 1960s when elephants were eradicated from the Budongo Forest environs. In combination with the systematic policy of early-season burning, this facilitated the transition of the north-western side of the forest from grassland back to woodland by the 1970s (CS 12). The lack of elephants also aided conditions for human settlement and cultivation while European owned coffee plantations and Budongo Sawmill provided paid employment opportunities for the first time (Paterson 1991). Alongside pest control and improved health care these factors have stimulated the settlement of the southern and south-eastern side of the forest since the 1950s (*cf*. Doyle 2006) although the areas along the north-western and northern side of Budongo Forest remain unpopulated gazetted reserves (CS 12).

The **clearance** phase is marked by deforestation outside the forest reserves since the early 1990s and brings with it the first dip in the light green forest cover graph line of Figure 4.3. This has resulted from clearance for cultivation by the steadily rising population, i.e. the rising red graph line, coupled with the development of the tobacco industry (e.g. bf-i7) and major sugar plantations and is reflected in the narrowing of the gap between the two green graph lines. While Budongo Forest Reserve itself has remained remarkably constant in its forest extent since 1911, it is increasingly exposed as the only potential supply of wood products (*cf*. CS 6). Indeed, Budongo’s most highly valued nature reserve, compartment N15 which is unexploited except for rubber, has been under high pressure for the first time by the birth of a sophisticated illegal pitsawing network around 2000 (CS 6). Regional instability impacts the Budongo area due to its location between several East African trouble spots and has lead to a high rate of immigration from Eastern Congo, Rwanda, and the Gulu area of northern Uganda; this has resulted in a high proportion of the population that lack connectivity with local traditions and traditional authority (*cf*. CS 6, bf-i9, 12). This has been accompanied by greatly increased levels of poaching that poses a serious threat to forest wildlife (Plumptre 2002, Reynolds 2005). However, the activities of locally established research and conservation organisations (Reynolds 2005) and the gradual expansion of collaborative forest management appears to be bringing favourable conditions to parts of this forest environs (e.g. bf-i5, 17, ground observations).

4.4 The development of forest cover and causal factors over time

The green graph lines of the graphs of Figures 4.1 to 4.3 illustrate and to some extent summarize the three contrasting experiences regarding forest cover over the 20th century. Considering the pale green lines that represent the full areas of investigation, the Kakamega-

Nandi forest cover is seen to have been decreasing steadily until 1994, before a reversal of the trend in the last few years of the sequence; meanwhile the Mabira area forest expanded until the 1950s before a sudden drop followed by a stabilizing of cover since the later 1980s; and the Budongo area forest cover has remained remarkably stable. The latter has a measured variance of only 67 ha between the topographic survey of 1911 and the classification of 2003 satellite imagery varying only with a slight gain in the intervening years that has been eroded since 1995. In combination with the darker green line, these figures are able to reveal the proportion of change inside and outside the forest reserve areas. The majority of the losses have occurred outside the reserves and serve to highlight the value of those protected areas which therefore show a degree of success in preventing agricultural encroachment despite the legal logging that has reduced their forest coverage.

The population curves are more similar in that all three cases show an almost continual upward trajectory, although the Mabira and Budongo sites both include periods of nearly static population density. The generally downward trends in forest cover therefore generally accompany the rise in population densities and suggests some degree of link between these two most easily quantified aspects of the human-environment system (*sensu* Lambin & Geist 2006). It is interesting to note that shortly after population density reaches around 100 inhabitants per km^2, forest cover either drops slightly more sharply (Kakamega-Nandi), or drops sharply (Mabira), or drops for the first time (Budongo). However, the forest cover figures of the recent decades for the Mabira and Kakamega-Nandi areas show a stabilizing and an increase in forest cover, respectively, even though population density continues to rise very sharply. Any suggestion of a strictly causal link between population density and forest cover is therefore disproved.

The narrative diagrams reveal a temporal development in the causal factors in that the underlying factors (i.e. the grey boxes in the diagrams) are dominated in the early stages by conflict, i.e. disease / war, and migration and are intimately linked. After 1950 disease is no longer a major factor but immigration continues to be relevant in Mabira and Budongo areas from the 1950s onwards when it is driven by economic opportunity in the form of commercial-scale cash-crop plantations such as sugar. The Kakamega-Nandi area population expands steeply but less from immigration.

The proximate causes of local (yellow boxes) and commercial factors (blue boxes) differ in that the local factors represent a more constant presence. Commercial exploitation becomes a characteristic feature of all sites for most of the middle part of the century and although continuous in Budongo Forest, declines sharply in relevance in the Kakamega-Nandi forests and also decreases in Mabira Forest around the turn of the millennium. Following the relative stability of the colonial phase, the underlying factors of politics and governance have featured more significantly in the latter part of the period in both Kenya and Uganda. This is present both as political favouritism allowing increased forest use, and as positive conservation measures since the late 1980s. Local community conservation groups have become increasingly empowered within forest management in all of the forest reserves in recent years and collaborative / participatory forest management is slowly becoming adopted in each case. Considering the combined forces at work and the trajectory of the forest cover graph lines, the general outlook therefore looks good for the Kakamega-Nandi and Mabira forests. The prospects for Budongo Forest appear less positive since the recent dip in the total forest cover is also matched by an upsurge in degradation of forest due in part to pitsawing.

The temporal analysis is now followed by a spatially-explicit perspective to show the distribution of disturbance across the individual forest areas.

5. The spatially-explicit indices of forest cover change and disturbance

Forest cover changes and the causes of change were examined in detail at the local scale in the case studies (chapter 3), and were brought together into a continuous chronological perspective by the forest narratives (chapter 4); they are now analysed to provide a spatially-explicit expression of change and disturbance. With a view to rationalising the numerous proximate causes highlighted in chapters 3 and 4 for spatial analysis, the current chapter summarizes these factors as representing two distinct types, local and commercial. The division is here considered useful since the two types differ fundamentally in the source of their decision-making and the solutions by which the problem of forest conservation can be addressed.

The two spatially-explicit indices, one of local disturbance (LD) and one of commercial disturbance (CD), are accompanied by a third index, forest cover change (FCC) which allows comparison of the disturbance with the actual change over approximately the last half century. This therefore enables an interpretation of the differing contributions of the two distinct disturbance types. The use of a single valuation scheme of 0 to 10 in each case, also enables comparisons between the different forests. In creating spatially-explicit expressions of forest cover change and disturbance across the complete forest reserves, the indices are designed to be of greatest value to forest managers seeking to identify the areas of greatest and least human impact and to target appropriate conservation measures. The renowned difficulties of measuring forest degradation (e.g. Nummelin & Kaitala 2004, UN 2008, Heymell 2009) are also thus addressed by mapping and quantifying the disturbances that directly cause degradation.

5.1 Methodology for the spatially-explicit indices

The methodology used in the creation of the disturbance indices is summarized in Figure 5.1 and shows how the data are brought into the GIS via georeferencing, orthorectifying and digitising, with GIS functions subsequently carried out (including buffering and overlay, *cf*. Chrisman 2002) to derive intermediate datasets. Following the overlay of these datasets the resulting index is reclassified, 0 to 10. It is, however, only the commercial disturbance index that achieves a zero value that represents no disturbance. The diagram is supported by Appendices E1 to E4 which provide details and allow the calculation and valuation of disturbance levels to be traced.

The **local disturbance (LD) index** of each forest reserve is constructed from four component sets of values, the criteria for which are set out in Appendix E2 and which represent separate intermediate geodatasets. One such set of values mimics the effect of proximity to population density (see Appendix E2.1), a second shows the influence of accessibility via the distance to roads (E2.2), a third expresses the weight of actual detected forest utilization (E2.3 to E2.5), and a fourth dataset reflects the protection status of different parts of the forest reserves (E2.6). The use of the several such datasets in overlaid combination is designed to moderate the effect of any gaps or biases contained within the component data and to provide the most comprehensive and realistic coverage of the full forest.

Population was ring-buffered up to 5 km inside the boundary since research suggests that forest resource-users in Kenya live within 5 km of the boundary and also penetrate the same distance into the forest (Wass 1995). The wide-ranging sight-surveys by KIFCON in Kakamega Forest (Gibbon 1991, also in agreement with Boetcher *et al*. 2008) highlight that almost twice as many incidents occur in the forest as in the glades and population derived values were therefore reduced accordingly for the grassland areas (Appendix E2.1). The

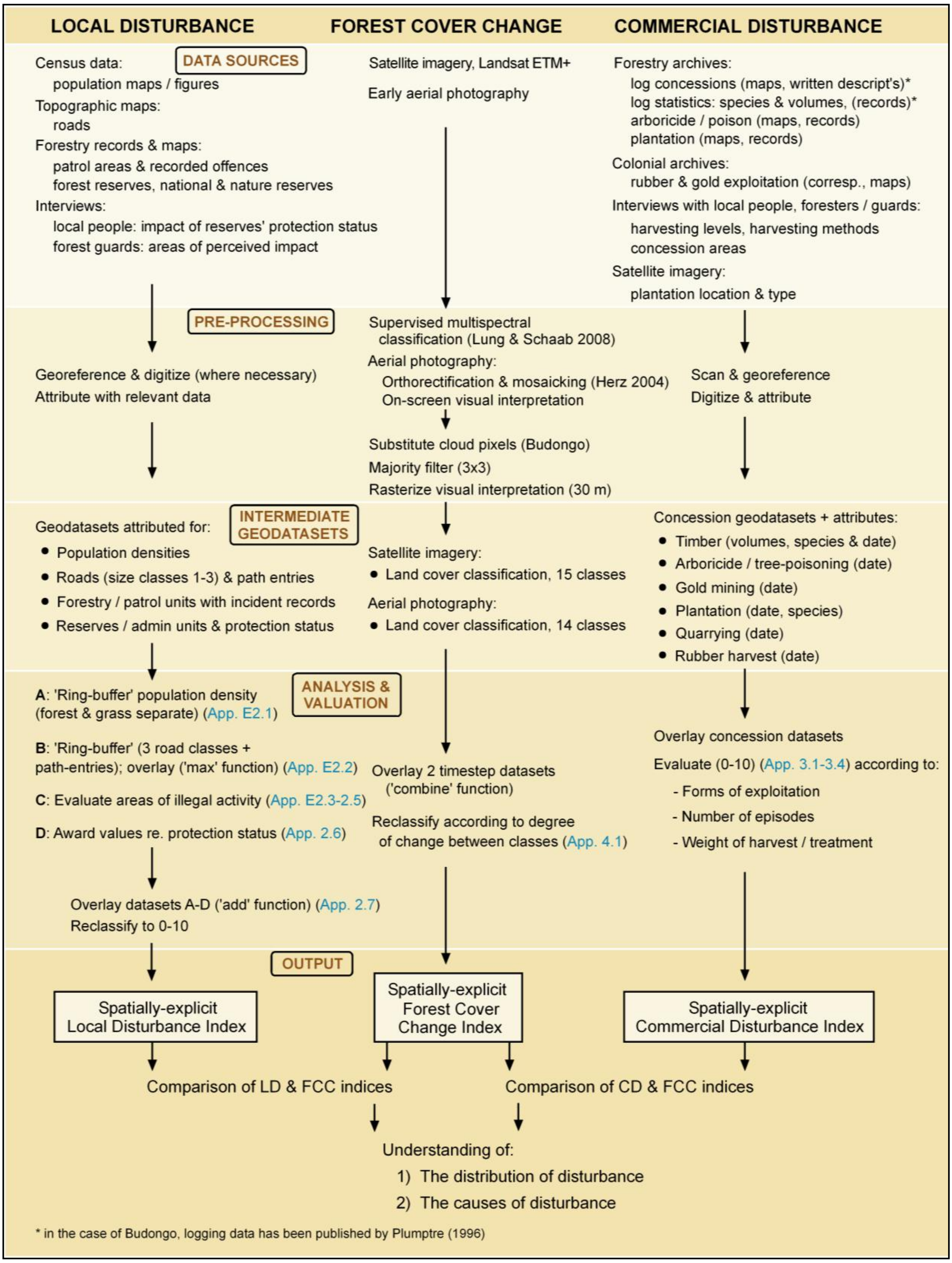


Figure 5.1: The methodological steps followed in the creation of the spatially-explicit indices. Appendices E1 to E4 provide the detail upon which they are based.

road values (E2.2) were consistent in reflecting three classes of road size for each forest but in the case of the Kakamega-Nandi forests, it has also been possible to create a dataset of path-entry points which was overlaid (with a ‘max’ function) to provide a finer level of detail.

The third dataset (E2.3 to E2.5) expresses the known level of local forest utilization, the basis of which is captured in the records of regular forest guard patrols (although only fragmentary for Budongo Forest) which provide a ready quantification of disturbance. However, these records do not always provide data for every forest compartment and may also contain biases according to the patrol patterns; they are therefore supplemented by other written reports, both forestry- and non-forestry-based, and by oral reports, thus providing a wider basis for evaluation. Judgement and discretion are therefore required in making the final valuation and heavy reliance is placed on such records for the Budongo and Nandi reserves where the patrol records are poor and unavailable, respectively. The overlay of the fourth dataset (E2.6) which reflects the strictness of the different protection regimes within each forest (as interpreted from oral sources and ground observations) aims to redress the expected bias towards areas such as nature reserves that are more frequently patrolled.

The weighting given to the four different datasets that constitute the LD index has been usefully informed by the earlier creation of preliminary disturbance indices at the more localised level of biodiversity observatories (BDOs) (Mitchell & Schaab 2008). The differing impacts of proximity to population, roads etc. were thus observed for multiple 1 km^2 areas of the forest that were well known to BIOTA scientists. In particular, the significant influence of the differing protection levels of the different management zones was notable and

Figure 5.2: Examples of local disturbance varying in prevalence from forest to forest and locally within each forest: clockwise from the top left: pitsawing, preparation for charcoal-burning, agricultural encroachment, firewood collection, cattle grazing.

consequently, they were here given prominence in the LD index. The resulting four intermediate datasets were overlaid (with an ‘add’ function) and were reclassified 1 to 10 according to the values shown in Appendix E2.7.

The scope of the contributing four elements partly overlap, a feature necessary for the production of the most complete and representative coverage for each forest. The combination of both the values awarded according to population and roads, and the values awarded according to real forest activity as monitored by forest guard patrols (with input from other oral and written sources) is designed to provide a balanced valuation that avoids gaps and bias in the patrol records. The resulting values of local disturbance should be considered relative rather than absolute but are consistent between the study sites, therefore enabling comparison of the index across different forests. They provide the best available impression of local disturbance across complete forest reserves.

The **commercial disturbance (CD) index** has been created by collating and summarizing data that reflect a broad knowledge of several different forms of commercial extraction and by subsequently attributing this to geodatasets of concession boundaries. The combined impact is then valued in accordance with criteria based upon the accumulation of the types of commercial disturbance over many decades. Amongst the different forms of commercial activity, logging is the most consistent contributor but is considered alongside the use of arboricide poisons, tree planting, rubber extraction, gold prospecting, and quarrying which have all impacted on the forests in question. The index reflects only the gazetted forest reserves although, in the case of Kakamega-Nandi, the boundaries of the 1930s have been used since they include forest areas impacted by commerce that were later excised.

Appendix E3.1 shows that the basis on which the disturbance values were generally awarded lies in the number of episodes and the forms of exploitation that an area has experienced. Where known, the extracted timber volume levels (e.g. not available per compartment for Mabira Forest), the strength of arboricidal application, and the nature of enrichment planting (e.g. exotic or indigenous) were all used to refine the final disturbance levels (see Appendices E3.2 to E3.4).

Colonial archives, forestry records, maps and correspondence, and orally provided information all contribute to the identification and location of each of these forms of extraction within the forest. This required varying degrees of work reflecting the state of the previously known and published records per forest. Most research was concentrated on the focus study forest of Kakamega for which no previous study has attempted a spatial understanding of commercial disturbance (*cf.* Tsingalia 1988 and Mutangah 1996). The lack of forest administration units in consistent use in the Kakamega-Nandi forests necessitated the reconstruction of the concession areas of the licensed sawmills from a combination of sketch maps, written boundary descriptions and oral recollections which were then overlaid to form a single dataset (see Appendix E1). Timber records were collated and the volume of cut timber was summarized and linked to the concession dataset (see Appendix E3.2). Due to the often convoluted management of harvesting operations in Kakamega Forest, the sawmills often operated in more than one area at a time and partially overlapped with previous logging concessions. This has sometimes required the proportional distribution of a sawmill’s annual timber volume to more than one concession area based upon the area sizes of the respective areas harvested. Significantly, it has been generally possible to separate the statistics for the substantial clear felled areas of Kakamega Forest from those relating to selectively logged areas and thus avoids a misrepresentation of the volume removed from today’s surviving indigenous forest.

Of all the forest areas the logging figures of North Nandi Forest are considered the most complete and include reliable species figures but, due to the total absence of administrative sub-divisions within the forest, only the crudest of spatial patterns can be discerned. The

Figure 5.3: The final product of the timber trade served by the sawmills (Kapsabet, Nandi District).

statistics for South Nandi and most of the small forest islands are extremely meagre and can at best only provide an estimation of the relative proportions of species harvested.

The same base criteria set out in Appendix E3.1 are used for the calculation of the disturbance values for each of the three forest areas although much more of the silvicultural activities of Budongo Forest, and to a lesser extent Mabira Forest, have been catalogued in management plans (e.g. Trenaman *et al*. 1956, Karani *et al.* 1997a & b) and by Plumptre (1996). These have been supplemented here by more recent NFA records and by oral testament (see summary expressions of this in Appendices E3.3 and E3.4). The adherence of forestry practices to defined and numbered compartments within the forests of Mabira and Budongo has rendered the task of identifying the location and levels of commercial harvest or treatment much easier than for the Kakamega-Nandi forests.

The **forest cover change (FCC) index** results from the overlay of the most recent of the detailed land cover classification timesteps for each area of investigation (the last step of the multispectral classification of Landsat TM satellite imagery time series) with the earliest (a visual on-screen interpretation of historical aerial photography). The use of detailed land cover classifications (see chapter 2.2.3) enables more subtle developments in forest cover change to be detected (e.g. between 'Near natural and old secondary forest' and 'Secondary forest') than a simple overlay of forest extents would allow.

The resulting FCC index area reflects the limits of the aerial photography mosaics. The earliest remote sensing available for the Kakamega-Nandi area is the 1948/(52) aerial photography (kn-d42) but since this is incomplete for the Nandi forests, 22% of this time step is represented by the digitisation of the forest fill from a 1:50,000 scale topographic map of 1958-62 (kn-d61) that was originally created using aerial photography of 1948. The remaining 14% was taken from the visual interpretation of aerial photography of 1965/67 (kn-d71). The part that was derived from the map therefore lacks the subtlety of the changes seen elsewhere in the FCC index.

The later timestep for Budongo Forest required the replacement of the cloud-obscured pixels of 2003 to be replaced by the equivalent pixels of the nearest timestep, that of 2000, but was not required for the forests of the Kakamega-Nandi or Mabira areas. The satellite imagery classifications attain a finer level of detail in comparison to the more generalising vector digitisation of the visual interpretation of the aerial photography (see chapter 2.2.4); to ensure a more compatible overlay a majority filter (3x3 window) was therefore applied in each case to the later timestep to effectively reduce the 'salt and pepper' effect. The visual interpretations of the aerial photography were converted to raster format and the two timesteps were subsequently overlaid (‘combine’ function) and reclassified to become the FCC index.

This reclassification of overlaid land cover classes as new values of forest cover change is tabulated in Appendix E4.1 and results in values reflecting the degree to which the land cover of each pixel has changed over the intervening decades. Thus, pixels experiencing no change in land cover class are classed as value 5, while those experiencing a change towards higher levels of vegetation cover are classed with values below 5, and those experiencing a degradation are valued between 6 and 10. At one end of the scale the value 10 represents total loss of forest cover and is commonly attained in the FCC index; at the other end, zero remains only a theoretical possibility since the growth to virgin forest is impossible, at least within the time-frame under consideration. Less dramatic alterations in the land cover, for instance a change from ‘Grassland’ to ‘Bushland/shrubs’, are represented by the mid-range values.

The valuation of the changes between land cover classes is informed by some of the classic texts on natural vegetation in Kenya and Uganda, i.e. Eggeling (1947), Langdale-Brown *et al*. (1964) and Beentje (1994). The first two references listed here demonstrate that the processes of succession towards mature forest and of forest degradation are continuous gradients that pass through many different classes. In respect of this, all the classes of the land cover classifications (except ‘Water’ and ‘Wetland’) have been included in the FCC index. Small and subtle changes seen across any part of the full spectrum of the forest cover development are therefore captured and weighted accordingly to provide the most comprehensive spatial illustration of the trends towards and away from forest cover. However, it should be noted that it was impractical during the visual interpretation of the aerial photography to distinguish small parcels of ‘Agriculture’ from patches of ‘Grassland’ and ‘Grass with scattered trees’ and the very occasional settlements within the highly heterogeneous and mainly agricultural matrix that lies outside the forest reserve boundaries. These areas were therefore classed as ‘Agriculture’ for the purposes of overlay with the satellite imagery time step and reflecting this less subtle level of classification, such pixels were given a value in the FCC index only when they demonstrate clear change, i.e. change to or from the forest classes 1 to 4.

In the text below the salient points of the LD and CD indices are highlighted separately before the FCC index for each forest is assessed in the context of the two disturbance types. The indices are then concluded with a comparative view across the three forest areas.

5.2 The spatially-explicit indices results

5.2.1 Kakamega-Nandi forests (see Figure 5.4)

The **local disturbance (LD) index** shows that amongst the forests of the Kakamega-Nandi area, Kakamega Forest has the greatest range of local disturbance values. The smaller forest islands do not conform to a single generalised pattern and instead show marked variation between them. The highest local disturbance levels are seen at Ikuywa and in Kaimosi forest where the combined pressures of a high population density adjacent to the forest and the passage of roads through the forest itself contribute to the high scores. Road access within or nearby the forest reserves also contributes significantly to the high values of Teresia and Malava Forests, the eastern side of Kakamega Forest, Kaptoroi Forest, and to the northernmost part of South Nandi Forest. As see in Figure 5.4, population around the Nandi Forests is generally less dense than that surrounding Kakamega Forest and their local disturbance levels are consequently more moderate. Although there has been agricultural encroachment of both Nandi Forests this has generally occurred in the wake of commercial

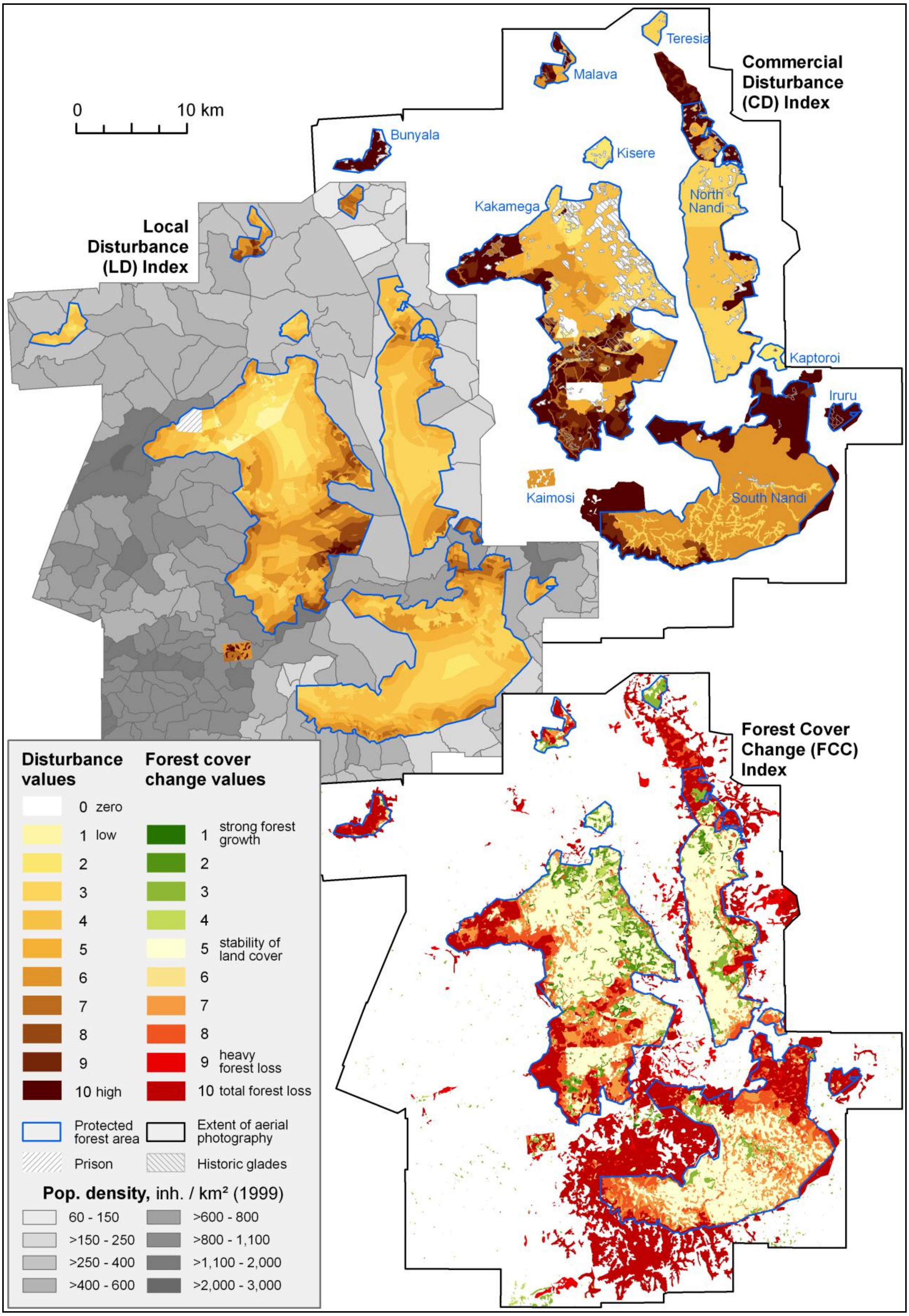


Figure 5.4: The spatially-explicit indices for the Kakamega-Nandi area.

felling (e.g. CS 10) or where natural physical circumstances dictate peculiarly restrictive conditions regarding space (e.g. CS 3).

Adjacent to human settlement, the forest margins naturally experience higher levels of human interference. The Yala River Nature Reserve (*cf*. Figure 3.16 and 1.3) though has a relatively high disturbance value despite its seclusion due to the high level of pitsawing. This is the unwelcome result of remaining untouched by legal sawmillers and thus retaining the valuable timber species. By contrast, the other unlogged Nature Reserve, at Isecheno, holds fewer mature trees of great attraction to pitsawyers (Mitchell 2004).

The Kakamega National Reserve in the north of the forest is managed by KWS under strict forest-use regulations that forbid local inhabitants to enter the reserve. This combines with the lack of roads penetrating deep into the forest and with the more moderate density of surrounding population, to indicate that the national reserve includes the parts least disturbed by local activities.

There have been no published disturbance studies of the Nandi Forests but surveys of Kakamega Forest (Gibbon 1991, Bleher et al. 2006, Boetcher et al. 2008) are in broad agreement with the LD index. There is general consensus that the KWS-managed area experiences low levels of human usage while Boetcher et al. (2008) are alone in agreeing with the LD index in highlighting the eastern part as suffering the greatest disturbance. However, these cited surveys and others, e.g. Mutangah (1996) and Fashing et al. (2004), are restricted to specific locations or routes and do not attempt to scale up to the full forest in the manner of the current index.

The extremely high **commercial disturbance (CD) index** values for most of Bunyala and Malava Forests, the south and west of Kakamega Forest and the northern parts of both Nandis, all reflect their experience of clear felling. Following clearance, only the southern half of Kakamega Forest has experienced any substantial regeneration and is mostly the result of KFS plantations (see CS 8). The CD index values of 10 represent clear-felled areas that have remained clear of vegetation while, in most cases values of 7 to 9 reflect clear-felled areas that have experienced some regeneration back towards forest. Regeneration for commercial plantation was, with varying degrees of success, facilitated by the shamba system of tenant-farmers; however, the same system is also to blame for maintaining clear-felled areas as agriculture, thus preventing natural succession to forest (CS 8).

There has been no previous research into the logging history of the Nandi Forests, but Tsingalia (1988) and Mutangah (1996) carried out research of logging in Kakamega Forest, both considering the forest as a whole and making no spatial differentiation. In the current thesis, the processing of the timber records per species and per logging concession necessary to produce the CD index (figures are here only summarized as total volumes per forest location in Appendix E3.2) has brought to light the contrast in species harvest between the Kakamega-Nandi forest reserves but also within Kakamega Forest. This revealed that the difference between the naturally-occurring range of tree species growing in the north and the south of Kakamega Forest have dictated their contrasting experiences at the hands of the sawmillers. With its higher stocking of the valuable *Olea capensis*, the north was selectively logged (*cf*. CS 7) with that species constituting a third of the timber harvested; meanwhile the more mixed forest of the south was most productively harvested by clear-felling (CS 8). Even the indigenous forest in the south that was only selectively felled was more heavily harvested than in the north and for a greater number of species, *Antiaris toxicaria* and *Croton megalocarpus* being foremost. These three species also feature most prominently in Tsingalia's figures (1988) although the latter only cover the period of 1974 to 1981, but there is little agreement with Mutangah (1996). The part of the northern Kakamega Forest that bears the highest CD index values reflects the higher timber volume identified there ahead of logging in the 1970s (kn-d90).

Selective felling has continued longest in South Nandi Forest and the heavy harvest of the late 1990s results in the high commercial disturbance values. However, as noted in chapter 5.1, the South Nandi Forest CD index relies heavily on oral reports due to the poor preservation of logging records. Analysis of logging records suggests that the comparatively light exploitation of its neighbour, North Nandi Forest, is largely due to its poorer timber species availability. The harvest there was dominated by the softwood *Polyscias kikuyuensis* while South Nandi has been able to supply relatively good timber from C*roton megalocarpus* and *Prunus africana*. The altitudinal gradient almost certainly accounts for the differing species stocks (*cf*. Blackett 1994b, Mitchell *et al*. 2006).

Some glades have been impacted by sawmilling operations or plantations, gold prospecting and quarrying but the majority are free of commercial interference. Of the forested areas, the Yala River and Isecheno Nature Reserves are the only areas free of any legal commercial activity.

The **forest cover change (FCC) index** shows that extensive forest has been lost from almost all parts of the Kakamega-Nandi forest complex both inside and outside the forest reserves. Showing that most of the loss has occurred in the southern half of the forest complex, the index is in agreement with the results of Lung's cluster analysis (2004) that considers the period 1972/73 to 2001, but is in disagreement with other researchers (e.g. Brooks *et al.* 1999). Most of the changes outside the reserve boundaries are directly attributable to locally-made household-level decisions for the conversion of forest to agricultural land. However, the largest single area of forest loss, i.e. that representing the fragmentation of the original forest block into the separate South Nandi and Kakamega Forests, results both from local settlement with cultivation and from commercial coffee and tea plantations (see CS 9).

Perhaps the most significant example of the LD index highlighting local causes for forest degradation within the gazetted reserves is the thinning of the forest at Ikuywa, located at the south-east edge of the square block extending from the east side of Kakamega Forest. This narrow forest strip is considered ecologically significant due to its strategic location and role as the bridge between the two remaining blocks of forest in the southern half of the forest (Lung & Schaab 2006, Mitchell *et al*. 2009) and will require specific measures to prevent its complete destruction. The small Quaker-controlled Kaimosi forest is now much reduced due in large part to the expansion of settlements and farms. Kaptoroi Forest also scores highly in the LD index and has suffered chronic charcoaling that has lead to the serious impoverishment of forest seen in the FCC index.

However, comparison of the FCC index with both the LD and CD indices clearly indicates that the overwhelming bulk of the forest loss inside the full extent of the forest reserves as they were originally gazetted in the 1930s is due to commercial pressures. Most significantly, clear felling is responsible for the loss of forest islands and the major fragmentation of Kakamega Forest via a substantial swathe cut east to west across its middle (see CS 8). Aside from clear felling, the loss of forest quality due to the commercial logging in the late 1990s (CS 10) is also detectable as the orange flecks in the FCC index within the heart of South Nandi Forest where the LD index values are not high. In several cases in the Nandi Forests the commercial felling of trees has been followed by the illegal cultivation of the land by local people (CS 10) but in these cases the initial commercial disturbance is considered to be the dominant cause.

Ileho, the more northerly of the two eastward-jutting arms of Kakamega Forest, registers relatively high LD index values but has experienced forest growth rather than loss. This is explained by the dominance of grassland in the 1948/(52) timestep and which, like most of the outer glades of Kakamega Forest, has since developed into 'Bushland / shrubs' and

‘Secondary forest’. Although the exact cause of the growth of forest cover in the outer historic glades is not yet fully understood, the change is here attributed to natural vegetation succession in the context of local disturbance via cattle grazing and burning (see CS 4). Forest gains are almost entirely restricted to the forest reserves and are mostly confined to the northern half of the area of investigation where the forest glades were historically predominant.

In conclusion, the forest cover of the farmland surrounding the Kakamega-Nandi forest reserves was eliminated mostly by local factors but commercial disturbance has been the strongly dominant factor in forest loss inside the gazetted forest reserves. While there are several identifiable areas within the gazetted reserves that are attributed to local disturbance and which have high values in the LD index, these are smaller and more localised. Specifically regarding Kakamega Forest, statements of agricultural expansion being responsible for most of the loss of forest within the gazetted reserves since approximately 1970 (e.g. Kokwaro 1988, Kamugisha *et al.* 1997) should therefore be revised. Such statements have arisen from confusion over the role of the shamba system which led to many abuses of the forest but was responsible for a lack of forest regeneration rather than for forest clearance. The agricultural encroachments that have occurred have been mostly in the Nandi forests although population is less dense than around Kakamega Forest, and have followed commercial exploitation and political incitement.

5.2.2 Mabira Forest (see Figure 5.5)

The **local disturbance (LD) index** shows that Mabira Forest has experienced very high local disturbance within a substantial proportion of the gazetted reserve. After the renewed settlement of the west bank of the River Nile the incoming population flooded over into the eastern part of the forest reserve (see CS 11) and settlement spread to parts of the south and north of the forest. The outlying forest island reserves to the north and north-east were also surrendered to the land-hungry and largely immigrant population and the map of population density (Figure 5.4) shows that the north-east is still the most densely populated today (*cf.* Robertson 1971, Aluma 1989). Many of the small forest patches around the southern half of the forest reserve, most notable in the west, have been cleared for the extensive sugar plantations.

The LD index shows that the greatest local interference in the remaining indigenous part of the forest lies in the south; the only other measurement of local disturbance (Baranga 2007) known to the current author is non-spatial in its results. The most recent census figures reveal the area north-east of the forest as the most populous and the western side as the least populated. However, much of the human habitation in the south and west is significantly interspersed with the forest itself and combines with road access that repeatedly penetrates the forest reserve and contributes to high local disturbance values. The southern areas, particularly along the main road, have, over several decades seen the highest levels of charcoal burning and other detected forest offences (Appendix E2.4). The LD index shows that only the north-western part and the central forest interior have been sufficiently secluded to register low levels of local disturbance.

The **commercial disturbance (CD) index** shows the highest values occur in the south and west of Mabira Forest. This reflects not only the area of the most logging, also mapped in generalised form by Howard (1991) but, coincidently, the entire programme of arboricidal poisoning and the brunt of the rubber extraction as discerned from forestry and colonial archives (*cf*. Appendix E3.3). Oral testimony (mf-i4) suggests that this is partly the result of the location of the main forestry offices but also due to the direction of the main national timber market located in Kampala. The northern half has, meanwhile, experienced less logging and no arboricide treatment. The full records of species logged are not available for Mabira Forest but the available timber statements indicate that *Holoptolea grandis* (34%),

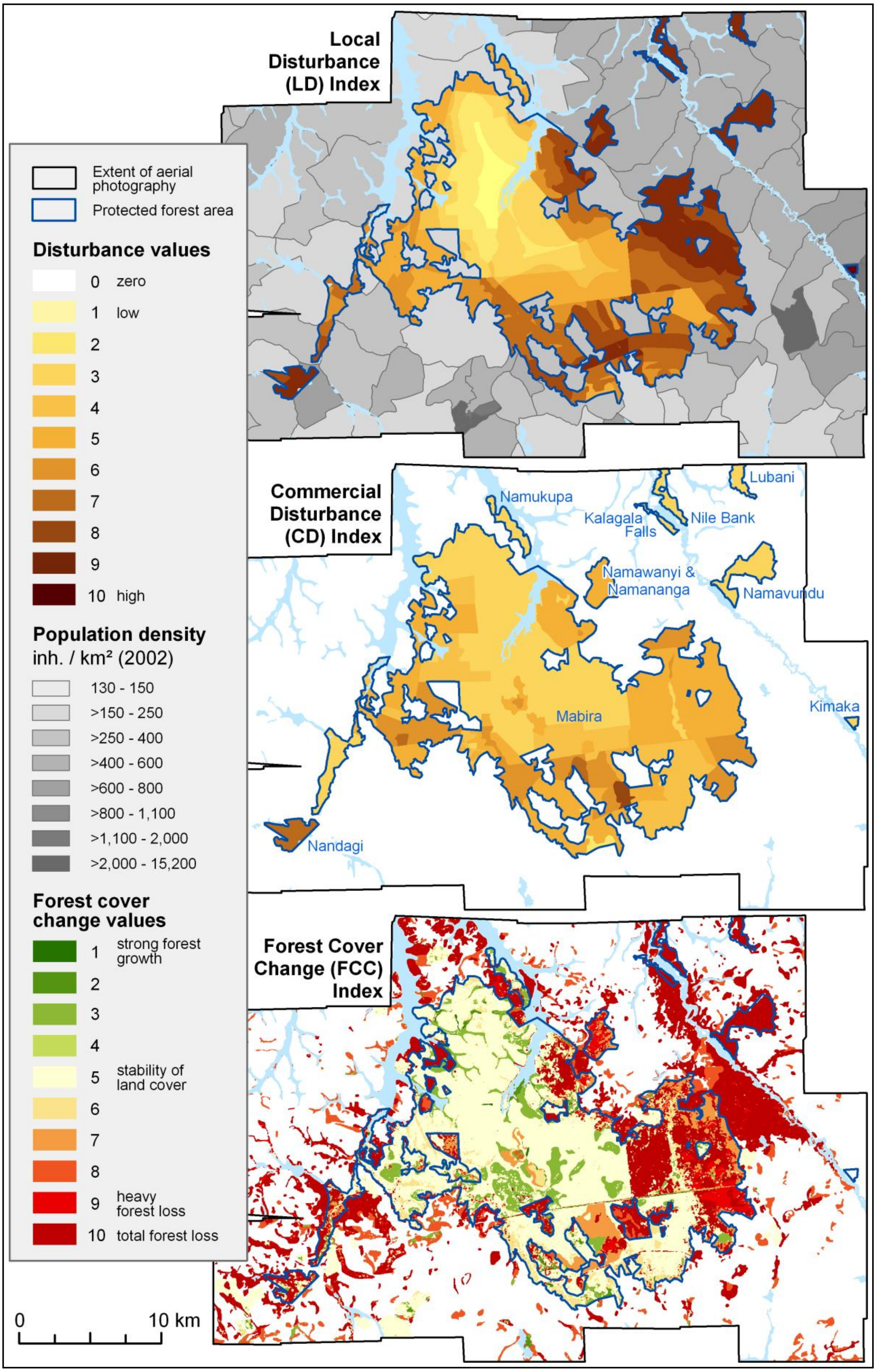


Figure 5.5: The spatially-explicit indices for the Mabira Forest area.

Albizia spp. (21%) and *Antiaris toxicaria* (15%) have dominated the timber harvest (from a sample of 9,490 cu'm timber). Disturbance values of the east and mid-north are boosted to moderate levels by the deliberate establishment of the exotic Paper Mulberry trees originally intended to serve a proposed paper industry. This invasive tree has proved to be extremely tenacious and slow to accede to the processes of natural succession (see CS 11) but by contrast, the southern encroached areas have been regenerated by the successful planting of largely indigenous tree species. Considering the rubber and timber harvest, the arboricides and the planting together, it is the centre and most of the north-west of the forest that have suffered the least commercial disturbance.

The **forest cover change (FCC) index** illustrates the disappearance of numerous small forest islands in the areas to the east, north and west of the reserve and from the river valleys of the north. The largest single block of lost forest is revealed as having formerly joined Mabira Forest to the River Nile (CS 11). Neither of these facts are reported in the literature that has so far been published on forest change regarding Mabira Forest due to their considering a shorter time period; Lung and Schaab's (2008) change analysis reaches back to 1973/74 while most authors (e.g. Westman *et al*. 1989, Howard 1991, Hlavka & Strong 1992) focus on the changes of the 1970s and 80s.

The losses outside the boundary all broadly stem from the dramatic influx of people and the accompanying cultivation after the early 1950s (CS 11) and which together also account for the significant loss of forest within especially the eastern part of the reserve. The published accounts cited above have been able to assign the internal loss of the eastern area to local forces although Bahati (2005) highlight the crucial role of governance in Mabira's local disturbance. This latter point is echoed by the major dispute of recent years over government attempts to excise part of the forest for sugar (*cf*. CS 11).

In the shadow of the well-publicized local disturbance, the commercial interference of Mabira Forest has gone largely unreported, except by Howard (1991). It is indeed responsible for only few examples of actual forest loss, the clearest example being the triangular area of high CD index values in the south-west that reflects a lease for sugar plantations. Commercial concerns are though the reason for the introduction of the exotic Paper Mulberry that has almost totally stifled the recovery of the encroached area (CS 11). Conversely, indigenous tree planting has assisted the natural vegetation succession in some other parts of the forest interior following the evacuation of settlements in the first half of the 20th century (CS 5) and also after the 1970's encroachment.

In conclusion, the FCC index shows great loss of forest in the east and the occurrence of the losses both inside and outside the forest reserve are highly correlated to the LD index with a relatively minor role suggested by the CD index. Of the remaining indigenous forest, the disturbance indices show that it is the south and west of the reserve that are most impacted by both local and commercial factors. However, the FCC index shows little sign of change in forest cover in these areas although the forest composition and structure there must have been heavily altered. Both the LD and CD indices indicate that Mabira's most natural forest is to be found in the north-west, and to a lesser degree in the centre.

5.2.3 Budongo Forest (see Figure 5.6)

The **local disturbance (LD) index** for Budongo Forest shows a general increase in disturbance from north to south with the relatively high values midway along its southern edge reflecting its adjacency to the main area of human population. These findings are broadly consistent with Plumptre's (2002) survey of illegal disturbance. There is little impact from roads and the only access to the forest centre is via a single forestry track. With little access and low human population there are no areas of Budongo Forest that register very

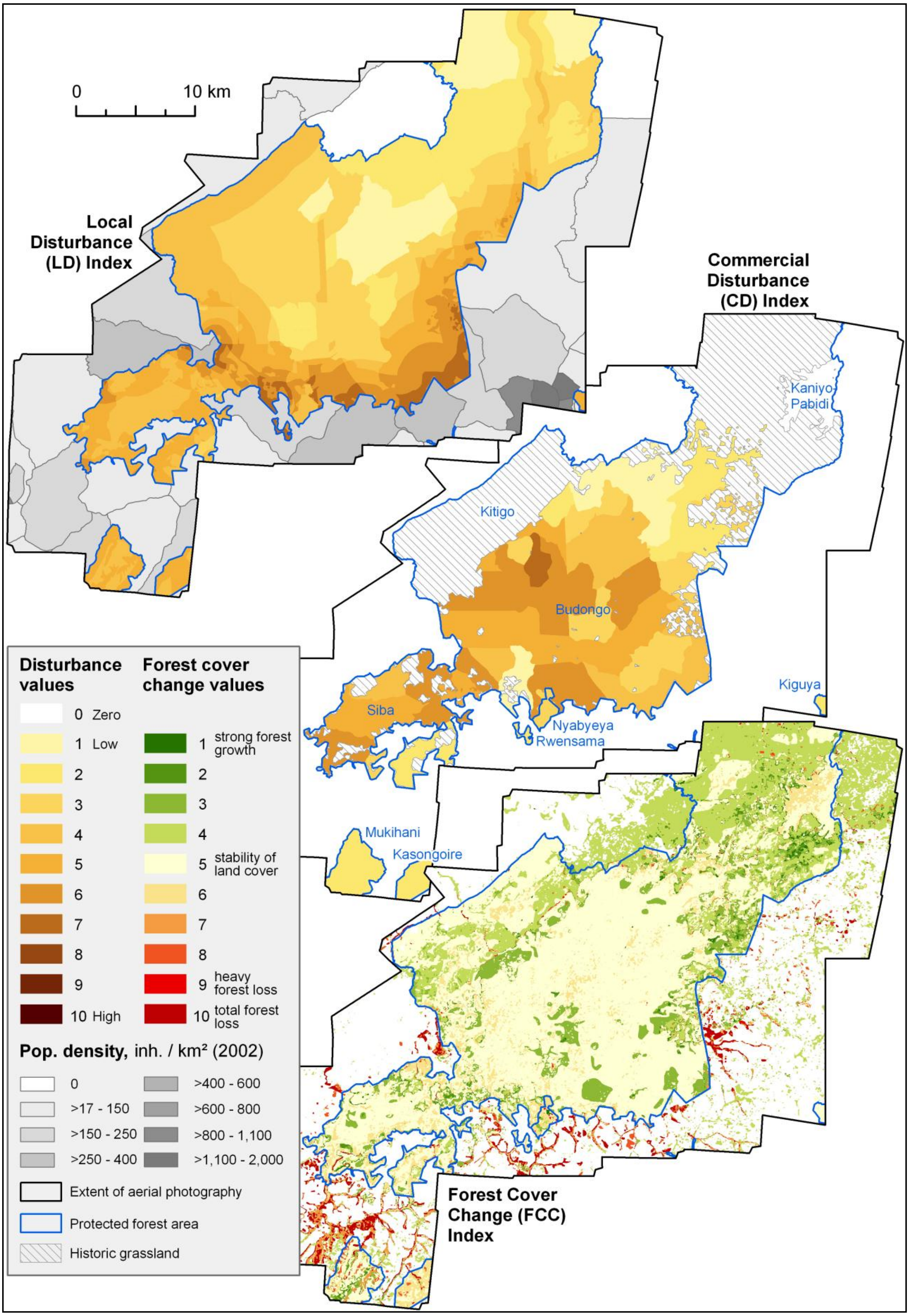


Figure 5.6: The spatially-explicit indices for the Budongo Forest area.

high levels of local impact. The south-east is closest to the market of Masindi and the route to wider markets and accordingly suffers the greatest illegal exploitation. The N15 Nature Reserve (*cf*. Figure 3.13), highly valued amongst scientists and pitsawyers alike, also records high disturbance levels due to rampant pitsawing of Mahoganies (CS 6). While illegal timber cutting is currently focused on the compartments that escaped heavy legalized logging (*cf*. Appendices E2.5 and E3.4), charcoal production is conversely found in those areas without Mahoganies and which therefore enjoy less NFA protection. The area of low disturbance north of the centre of Budongo is protected not only by its status as a nature reserve and by distance from settlement but also by the continued dominance of the *Cynometra alexandri* tree (*cf*. 'class 0' in Lung & Schaab 2008) that normally proves too tough for pitsawyers (Sheil 1996).

The woodland and remaining grassland areas of Kitigo and much of the north of the reserve experience a virtually annual burning regime that is partially regulated by UWA and NFA (CS 12) with the woodland also suffering regular charcoal burning near human habitation. The northern compartments are subject to the least local disturbance since they are in part bordered by other game or nature reserves (Bugungu and Karuma Wildlife Reserves and Murchison Falls National Park) that have long been depopulated.

The **commercial disturbance (CD) index** for Budongo Forest shows a generally heavier legal exploitation in the western half and results from both multiple logging episodes and arboricidal poisoning of commercially undesirable tree species (Appendix E3.4). The exploitation of Budongo has been dominated by the harvest of the three Mahogany species which have contributed 70% of the total timber removed from Budongo Forest. It is interesting to note from the early forestry maps (e.g. bf-d11) that the irregular natural distribution of Mahoganies and the often-poisoned *Cynometra alexandri*, is broadly reflected in the map of commercial disturbance, i.e. with less Mahogany and more *Cynometra* in the north-east. This natural variation therefore appears to some extent to have indirectly led to the localised pattern of the commercial exploitation of Budongo Forest.

Although the arboricide programme was halted in the late 1960s its poison has continued to take active effect on the forest trees several decades later (Osmaston 2005). It is also indicated by the strong correlation between the pattern of Lung & Schaab's (2008) class '0' (i.e. 'Mature natural forest including *Cynometra*') in 2000 (bf-d58) with forestry records that identify the poisoned compartments. The abusive rubber harvest of parts of the forest in the early 20th century means that even the unlogged nature reserves cannot be considered

Figure 5.7: The derelict Sonso sawmill within Budongo Forest (located in Figure 3.13).

totally free of commercial disturbance (CS 6). There are no records of the Kaniyo-Pabidi forest having been exploited despite its classification as a ‘mixed forest’ (bf-d46) that is characteristic of most of the Mahogany areas. It therefore appears to be alone with the historic grasslands as the only parts of Budongo Forest to have escaped commercial exploitation.

The **forest cover change (FCC) index** for Budongo Forest demonstrates that the dominant change has been one of low-level growth rather than loss. Most of this change occurs in the northern half of the forest and represents the transition from ‘Grassland’ to ‘Mesic forest / deciduous (woodland)’ (CS 12) and is considered to represent the initial stage of a very gradual transition to full forest (*cf*. Eggeling 1947, Sheil 1996). At first sight the index appears to contradict Mwavu & Witkowski (2008), Moreau and Cleemput (2004) and Plumptre (2002) who report a loss of forest / woodland to agriculture since the mid 1990s. However, this is seen in the index as the red linear areas south of Budongo that represent the loss of riverine forest for small-holder cultivation and sugar plantation outside the forest reserves (bf-i2, 17 and ground observations). The forest cover graph lines of the forest narrative (see Figure 4.3) shows this coincides with Budongo’s only phase of loss, i.e. in the 1990s.

The growth of woodland here might be expected to be an exaggeration since the somewhat ethereal existence of woodland in 1960 is not easily detected by a visual interpretation of aerial photography in which it appears as scattered trees (see chapter 2.2.4). However, the transition from grassland to woodland as indicated by the FCC index is strongly confirmed by oral histories from the 1950s and 1960s (bf-i1, 6). Nangendo (2005) records a 1% net ‘vegetation cover’ growth between 1984 and 2002 for the northern third of our area but also shows the woodland cover to be in flux in accordance with the fire regime. With a longer term perspective the FCC index demonstrates the area of growth towards forest to be 20.5% of the area classified for the FCC index and is reflected in Figure 5.8.

Within the main body of the forest the several areas of darker green in the FCC index represent a natural maturing to ‘near natural and old secondary forest’ nearer the forest edges and a recovery following selective logging in the forest interior. Many of the changes seen in the FCC index had already occurred prior to the 1970s and therefore do not feature in the land cover development analysis of Lung and Schaab (2010) which shows notable stability between 1972 and 2003. The edges of the main Budongo Forest have otherwise remained very static and published statements of the southern edge having steadily expanded over the preceding half century accompanied by the erosion of forest in the north (Sheil 1996) are not borne out by the evidence of the FCC index.

In conclusion, the FCC index shows that Budongo Forest area has lost very little forest cover except the riverine forest in the southern half, and is contrasted by the development from grassland to woodland in the northern half. Lower levels of local disturbance seen in the LD index in the northern areas have partly enabled this transition although the eradication of elephants and the change in fire policy for commercial forestry reasons are also key factors (see CS 12). The CD index shows that commercial logging and arboricide application have certainly severely impacted the Mahogany composition of Budongo Forest, especially in the western half, but they have not reduced the forest cover.

5.2.4 Comparing the indices across the three forest sites

The indices provide the means to compare the disturbance fate of the different forests in compatible terms and to assess the differing contributions of local and commercial disturbance. However, it should here be noted that the three FCC indices cannot be strictly compared since they do not all reflect the same length of time: a 55, 48 and 43 year period for the Kakamega-Nandi, Mabira and Budongo areas, respectively. They show that the forests of Kakamega-Nandi and Mabira have similar patterns of forest change, as summarized in Figure 5.8. They are characterized by high loss both inside and outside the official forest boundaries, a moderate proportion of stable forest, and limited gains; however, Kakamega-Nandi shows the most extreme change in having maintained only 31% of its classified vegetation cover without change. Budongo Forest provides a stark contrast in having lost very little forest, all of which is outside the gazetted boundary, and witnessed much woodland growth inside the reserve boundaries. The FCC index therefore provides an alternative and more subtle reading of the landscape change than that of the forest cover narrative graphs (Figure 4.3) which showed a stability of cover by considering just the two classes of fullest forest (i.e. classes 0, 1 and 2 of the classes set out in Table 2.2).

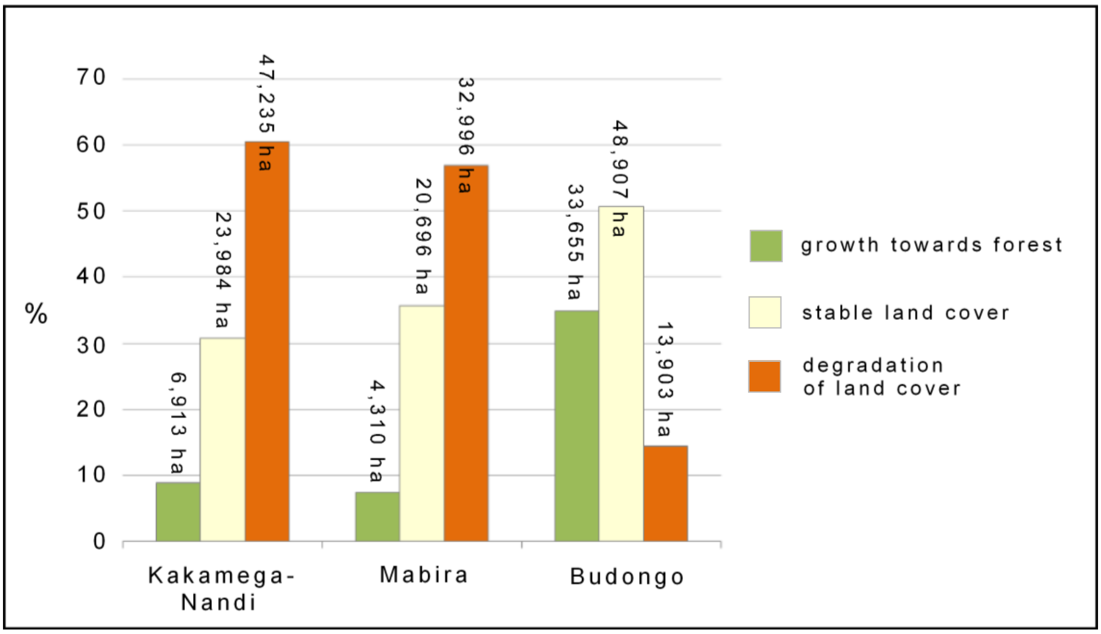


Figure 5.8: Summary quantification of the forest cover change (FCC) index for each forest, showing the percentages of the total area classified that is represented by a growth towards forest (green), the stability of land cover (yellow), and land cover degradation (orange). The figures reflect the changes in the Kakamega-Nandi forest area between 1948/(52) and 2003, in the Mabira Forest area between 1955 and 2002/03, and in the Budongo Forest area between 1960 and 2003. It is inclusive of subtle changes in land cover class so that, for instance, the green column reflects growth of vegetation towards forest and not growth of full forest.

While Mabira Forest has experienced the clearance of a significant block of forest, the Kakamega-Nandi forest complex is alone in having suffered two major fragmentations of the full forest block forest and a third, in Kakamega Forest, is still threatened. Both Mabira and Kakamega-Nandi show a failure to restore large cleared areas with the former bearing witness to a large-scale policy error in the attempt to reforest the encroached area with an exotic monoculture. Degradation of forest quality, rather than forest loss is demonstrated as most widespread in the South Nandi FCC index.

In the great majority of cases in which the FCC index illustrates growth towards forest cover it occurs within the reserves. In most cases this has been at the expense of historic grasslands, particularly in the case of Budongo and Kakamega Forests where grassland has been reduced by about two-thirds, while in Mabira Forest the growth represents a maturing from secondary forest. The mosaic nature that has defined the Mabira and Kakamega Forest ecosystems (Eggeling 1947, Nangendo 2005, Kokwaro 1988, Mitchell *et al*. 2006, Tsingalia & Kassilly 2009) is therefore under threat. Since this mosaic aspect has been demonstrated to increase biodiversity (e.g. Nangendo *et al*. 2002, *cf*. Kamugisha *et al*. 1997) its loss would undoubtedly represent an impoverishment of the ecosystem. The diminution of the grasslands within Kakamega and North Nandi Forests appears most significant since the grass outside the reserves has mostly disappeared under cultivation over the last half century; the glades therefore represent some of the last grassland ecosystems protected from cultivation in the area of investigation.

The LD indices have shown that both Kakamega and Mabira Forests demonstrate a wide range of local interference levels across their reserves, ranging from low to very high while Budongo Forest has a generally lower set of values. Mabira Forest has suffered the highest levels of local disturbance although its surrounding population is significantly less dense than that of Kakamega Forest. The CD indices show that commercial disturbance has been most dramatic in the Kakamega-Nandi forests with many areas of having been clear felled and only partially replanted. The presence of highly valuable timber species, especially in Budongo Forest, has lent itself to heavy and highly profitable selective felling (CS 6, chapters 4.3 and 5.2.3) but which has conversely protected it from clear felling.

With the lack of protection status the forest cover outside the reserves has been lost largely due to local private decisions to clear land for agriculture; however, in the areas adjacent to the Mabira and Budongo Forest reserves, commercial sugar plantations have contributed significantly to forest clearance. The losses shown in the FCC index inside the Mabira reserve have coincided with the highest levels of the LD index; meanwhile the largest areas of gain within the Budongo reserve show a correspondence with low LD index values, and together they are suggestive of some degree of a link between population density and forest cover. However, the Kakamega-Nandi area shows the least correlation to the LD index and by far the greatest correlation to the CD index, this being in spite of this area having the highest adjacent population densities. The reality behind statements on the dominant role in East African forest reserves of local pressures such as agricultural encroachment stemming from high population densities (*cf*. Wass 1995, Kamugisha *et al*. 1997) should therefore be understood to be subject to variation from reserve to reserve.

The indices display a visible spatial relationship between forest cover change (FCC) and local (LD) and commercial disturbance (CD) indices. However, they also highlight the considerable disturbance experienced that does not result in detectable changes in forest cover class as derived from aerial photography and satellite imagery. In this way, persistent and insidious interferences such as pitsawing or slow-acting arboricide poisons, gradually but radically change the forest structure without registering a detectable change in forest classes. The LD and CD indices are therefore here considered to be of key significance in providing the means to readily appreciate the accumulation and spatial distribution of forest disturbance. As such they are able to reveal the highly localised nature of disturbance that renders a single valuation figure of disturbance for any single forest (e.g. Adhola *et al*. 2008) to be of limited applicability. The indices highlight the need to consider both locally and commercially-driven disturbances since both forms are commonly present as factors that have accumulated over decades and together result in the current, inherited forest structure.

6. Discussion and synthesis

This chapter aims to discuss and synthesize some of the main findings of the investigation in the context of other research. In the first half (section 6.1) the significance of maintaining both an historical and spatial approach is highlighted as essential to a full understanding of the forest landscape, its natural changes, its anthropogenic disturbance and its causes. In the second half (section 6.2), the role played by the adopted methodology, characterized by the integration of multiple data sources, is shown to be central to this approach.

6.1 Interpreting the forest landscape

6.1.1 Making temporal and regional generalisations

The summary statistics for the three forest areas for the period since around 1911/1913 show a lack of consistency between them since the forests of the Kakamega-Nandi complex and Mabira Forest have shrunk by 60% and 43%, respectively, while Budongo Forest has expanded by 0.1% (chapter 4.4). Furthermore, recent trends do not conform to the figures given in the introduction (chapter 1.2.1), namely a rate of nearly 1% annual loss across East African since 1990; over the same period two of the forests show growth and the other a very minor loss (Figures 4.1 to 4.3). The figures relating to the forest cover change of the 1990s show, in each case, a reversal of the forest cover trend for the near-century time span. These simple summary statements of forest cover change serve as initial pointers to the variation of experience between the three sites and to the difficulty of drawing generalised statements on forest cover in East Africa.

Although the losses of the Kakamega-Nandi forests since the 1970s (e.g. Lung & Schaab 2006) are here shown to be correctly representative of the previous decades, the paragraph above shows the possibility of major discrepancies between the results of short-term and long-term analyses of forest cover change. While the short-term, approximately 15-year coverage of Mwavu & Witkowski (2008) and Moreau and Cleemput (2004) suggest a worrying loss and degradation of woodland at Budongo, the longer-term forest cover change index (chapter 4.3 and 4.4, *cf*. CS 12) reveals the reverse, i.e. a growth in woodland and a reduction in grassland. Likewise, the focus on the dramatic forest loss of the 1970s and 1980s in Mabira Forest (e.g. Westman *et al*. 1989, Hlavka & Strong 1992) is placed within this thesis within the context of an expanding forest in the decades prior to the 1950s. The short-term perspective is therefore shown to be sometimes misleading as to the true seriousness of the conservation condition of a forest. As shown by Gillson *et al*. (2003), this commonly errs towards ‘narratives of degradation’, i.e. dramatic storylines that feed the agenda of conservation organisations.

As shown by the Mabira example above, it is therefore not only the long-term but also the multiple-step time series approach adopted here that is required to reveal the paths of forest cover development, whether they are generally downward (Kakamega-Nandi) or fluctuating (Mabira) or stable (Budongo). Without this the general summary statement of forest cover at the start of this chapter could misleadingly suggest that the Kakamega-Nandi and Mabira forest areas have had broadly similar forest cover change experiences. Significantly, the long-term and multiple-step approach has been able to show a fluctuation of forest cover in six of the twelve case studies and in each of the three forest areas (CS 1, 3, 5, 10-12). Such fluctuation is visible at different time-scales, ranging from decadal (CS 3), to periods of approximately 40 years (chapter 4.2), to centuries or millennia (CS 1). The Mabira forest narrative in particular is here interpreted as a forest historically in flux, having swelled in extent when bouts of the *mbwa* fly had driven out or reduced human habitation, and being partly cleared again when settlement returned. Taking the longer view, Taylor *et al*. (1998) have suggested that in reality the forests of western Uganda have never been stable and in the current thesis their suggestion is echoed in western Kenya indicating a generally unstable experience of the forest ecosystem in this region. Such patterns of fluctuation are consistent with current ecological theory regarding ecosystems existing in a state of flux across various temporal scales rather than in equilibrium (e.g. Gillson *et al*. 2003, Beinart 2000).

The history of forest cover change is not therefore easily summarized either across the three forest areas of investigation, or as a simple trend across time for any one forest. It is localised and fluctuating. These narratives of flux hold significant implications for conservation in that many observers would argue that having survived cycles of loss and growth, the biological populations contained within them should be relatively disturbance-resilient (*cf*. Willis *et al*. 2004, Brncic *et al*. 2007). Wright & Muller-Landau (2006) have controversially asserted, opposed by Laurance (2007), that it is only the historically unprecedented losses that are likely to result in species losses. It is in this context that the current thesis demonstrates that these East African rainforests have long been subject to anthropogenic disturbance and the natural forces of change, and have consequently fluctuated with periods of loss and re-growth. Therefore, references to recent losses of forest cover in terms of the loss of the single sheet of rainforest stretching across the continent (*cf*. Kokwaro 1988) should be read with the knowledge that this state of forest cover appears to have occurred only several thousand years ago (chapter 4.1).

The localised and fluctuating reality of forest cover change in East Africa requires a local-scale approach to research and in this thesis has therefore necessitated the employment of the case-studies (chapter 3) from which the full forest-wide narratives (chapter 4) could be constructed. This echoes Dovers' (2002) obsevation that it is the fine-scale variability of interactions between people and nature that must represent the bedrock of environmental history. This variation and localisation, i.e. the dynamic nature of the human-environment system witnessed across the longer term perspective, has profound implications for those making predictions for future forest development.

6.1.2 The mosaic landscape: the long-term and landscape-scale perspectives

The long perspective of forest cover change for both the Budongo and Kakamega-Nandi areas has revealed the historic existence of considerable grassland alongside rainforest in a mosaic landscape. Kotze and Samways (2001) have shown that the maintenance of both forest and grassland contributes significantly to overall biodiversity levels, largely due to the heterogeneity of habitats inherent to a mosaic landscape. Nangendo *et al.* (2002) have meanwhile demonstrated the biodiversity of the grasslands themselves, which remain largely under-studied. Simply due to the unavailablilty of satellite imagery prior to the 1970s, purely satellite image-based research (e.g. Nangendo 2005, Lung & Schaab 2008) have not been able to detect the major changes in Budongo Forest and this thesis has shown for the first time that the historic grasslands of both Budongo and Kakamega-Nandi forests have been dramatically reduced since the mid 20th century (e.g. see CS 4, 12, *cf*. chapter 5.2.4).

The long heritage of the grasslands and the spread of forest into historic grasslands has been shown repeatedly within this thesis (CS 1-5, 12). Reflecting this experience and drawing from case study 2, the historical forest narrative for the Kakamega-Nandi forest area (chapter 4.1) challenges the identity of Malava, Bunyala, Kisere and Teresia Forests as 20th-century fragmentations of the main forest block as had previously been concluded in the published literature (e.g. Brooks *et al*. 1999). The very real likelihood that some of these forests have naturally established themselves as forest islands within a wider grassland landscape is crucial to an understanding of their role within the landscape today and their value as forest islands. With regard to the forest complex, the differences between the forest structure of the main forest blocks and the small northern Kakamega-Nandi forest patches noted by Tsingalia (1988), Mitchell (2004) and Farwig *et al*. (2006) may therefore stem from their identity as separate forest islands rather than fragments.

The potential for forest islands to be misconstrued as remnants of a former complete forest cover has been demonstrated in West Africa by Fairhead and Leach (1996). The significance of this distinction is illustrated by an example of naturally occurring forest patches in Gabon (Ukizintambara 2007) in which the author demonstrates that they retain a significant number of species absent from the main forest block and which would not occur if the advancement of continuous forest was allowed (*cf*. Wright & Muller-Landau 2006). The maintenance of the forests as islands is therefore seen as beneficial to maintenance of biodiversity levels. In South Africa Kotze and Samways (2001) found an absence of the expected edge-effects characteristic of fragmented forests in researching Afromontane forest patches that had developed 'naturally' rather than by fragmentation. Indeed, in some respects the effects of fragments and islands are likely to be entirely opposite, the former reacting with declining species numbers as patch-size shrinks, while the latter would be expected to gain species over time (*cf*. theories of island biogeography, e.g. MacArthur & Wilson 1967). It is, therefore, possible that in some cases historical investigation of the origins of such forest patches could explain some of the unexpected and apparently contrary results of ecological investigations that have been noted by Hill & Curran (2005) and which are often conducted against a fragmentation storyline.

6.1.3 The causes of forest heterogeneity: natural variation and forest disturbance

Further significance of the mosaic landscape of former centuries is appreciated when we recognise its presence not only in the remnant forest glades but also in the structure and composition of today's standing forests. Some of the forest heterogeneity is a reflection of a development from woodland and grassland in earlier and drier centuries (note the prevalence of grass amongst the three undated pollen samples, chapter 2.7.2, *cf*. Verschuren 2001). As demonstrated by Eggeling (1947) and Pickett & White (1985), it is through vegetative succession that the resultant wider forest comes to comprise a patchwork of multiple different seral stages of vegetative maturity. This heterogeneity of the forest structure and composition is often testified by transect biological studies by BIOTA and other scientists, for instance in Kakamega Forest (e.g. Fashing *et al*. 2004, Althof 2005, Farwig *et al*. 2006). The variance within the forest is commonly attributed to a degradation of forest and anthropogenic disturbance is the factor commonly chosen against which to compare results and by which explanation is routinely sought. The variation of Kakamega Forest tree communities as outlined by Althof (2005) is here interpreted as more likely to represent the echoes of the formation processes referred to above than the impact of human disturbance after the forest was established. The case studies 7, 4, 2 are, for instance, listed here in reflection of the likely order of a south to north progression of forest development that has left its mark upon the maturing forest structure today. These case studies indicate a causal role for natural vegetation succession dictated by background abiotic factors such as historic climate, geology and soils, alongside biotic factors such as herbivory and human activities, for instance, burning. These indications of long-past formation processes are in line with the findings of Buechner & Dawkins (1961) and Chapman *et al*. (1997) regarding the spatial and temporal variability of tree communities in two reserves in Uganda, Murchison Falls and Kibale. The causes of forest heterogeneity therefore should not by default be attributed to anthropogenic disturbance enacted upon a supposedly mature forest, without consideration for other historic processes within the landscape.

This highlights the need to identify the degradation of forest created by the disturbance laid upon forests, as per the disturbance indices of this thesis (chapter 5) which effectively enable investigators to separate it from the original forest heterogeneity. The spatially-explicit indices show strong local variation in the human impact within the individual forests and mapping the variation can therefore inform interpretations of the causes of ecological variation. Researchers using only recent disturbance indicators unable to, for instance, find a correlation between disturbance and the occurrence of adult trees (Farwig *et al*. 2008, *cf*. Bleher *et al*. 2006) may be assisted by the commercial disturbance (CD) index which, by contrast, is able to show the strongly contrasting disturbance levels of the two Isecheno sites. The value of extending disturbance analysis to include former events is therefore highlighted and contrasts with studies of sight-surveys of human traffic (e.g. Gibbon 1991) or tree-stump etc. counts (e.g. Bleher *et al*. 2006, Baranga 2007, Boetcher *et al*. 2008) that are able to capture current or recent past events.

Comparison of the disturbance indices with the forest cover change index highlights the major contribution of commercial activity to forest degradation of especially the Kakamega-Nandi forests and Budongo Forest (chapter 5). The role of local disturbance is also significant in each case, the most serious part of which is agricultural encroachment since this equates to a destruction of forest and is characteristic of Mabira, and to a lesser extent, the Nandi Forests (CS 3, 5, 10).

These results regarding the respective contributions of local and commercial disturbance in the two Ugandan sites are broadly consistent with other writers (Plumptre 1996 & 2002, Westman *et al*. 1989, Hlavka & Strong 1992). The Nandi Forests though have attracted very little published science in this regard and these results represent the first analysis of either disturbance type known to the current author. However, the much-studied Kakamega Forest has been the subject of wide-ranging publication regarding the locally-driven disturbance (e.g. Gibbon 1991, Emerton 1992, Bleher *et al*. 2006, Boetcher *et al*. 2008) and very little concerning the commercial disturbance (Tsingalia 1988, Mutangah 1996). The emphasis regarding these two proximate cause types is therefore here shifted towards commercial activities which have been shown in this thesis to have reduced the forest cover, fragmented it and, as with the other forests, degraded the remainder (chapters 4.1, 5.2.1). Based on the findings of this thesis, previously published summary statements on agricultural encroachment being the main cause of loss in Kakamega Forest (Kokwaro 1988, Kamugisha *et al*.1997) should only be read as reflecting the shamba system (CS 8), i.e. part of government policy to reforest the clear-felled areas, rather than encroachment. The extremely high density of population in the farmland surrounding Kakamega Forest (Figure 5.4) understandably encourages an expectation that most of the forest degradation is attributable to this, but, as considered in the next section, it should not be considered in isolation.

6.1.4 Population, conflict and governance as factors in East African forest cover change

Lambin and Geist (2006) conclude that simplifications regarding the underlying causes of forest cover change are difficult to achieve due to the interacting complexities of the dynamic human-environment system. In similar acknowledgement of the complexity and localised nature of such factors, the United Nations REDD programme (UN 2008) also assert that the causes of forest degradation do not lend themselves easily to generalisation. However, while the preceding sections of this chapter highlighted that both forest cover change and its causes are localised, it is possible to identify some commonalities and some changes that have occurred in the dominant causal factors over time, as reflected in Figure 6.1.

The most obvious relationship seen across the three forest narratives of chapter 4 is that for much of the 20th century forest cover decreased as population density increased. However, instead of supporting Neo-Malthusian notions of an inexorable ecological decline resulting from rising population (e.g. Ehrlich 1968, *cf*. Barnes 1990), it is clear that this initial indication is a misleading over-simplification. The absence of such a direct causal relationship is indisputably demonstrated by the halt and apparent reversal of the Kakamega-Nandi and Mabira deforestation trends in the last two decades despite the continuing steep rise in population (Figures 4.1 to 4.2). Such a rise in population and a concomitant growth in vegetation cover is not commonly reported but is also seen in Machakos in Kenya for a different period, starting in the 1930s (Tiffen *et al*. 1994). The indications provided by the

Kakamega-Nandi and Mabira forests are in line with Mather and Needle's (2000) finding that while there is good evidence for a relationship between population density and environmental degradation this link may have been weakened over recent decades. Lambin and Geist (2006) have also reported that globally two-thirds of cases indicate a link between population and forest cover but have also concluded the absence of a deterministic relationship with any single factor. Instead, they have revealed a dynamic combination of forces, a finding that is also reflected by the forest narratives of the current thesis and shown in Figure 6.1.

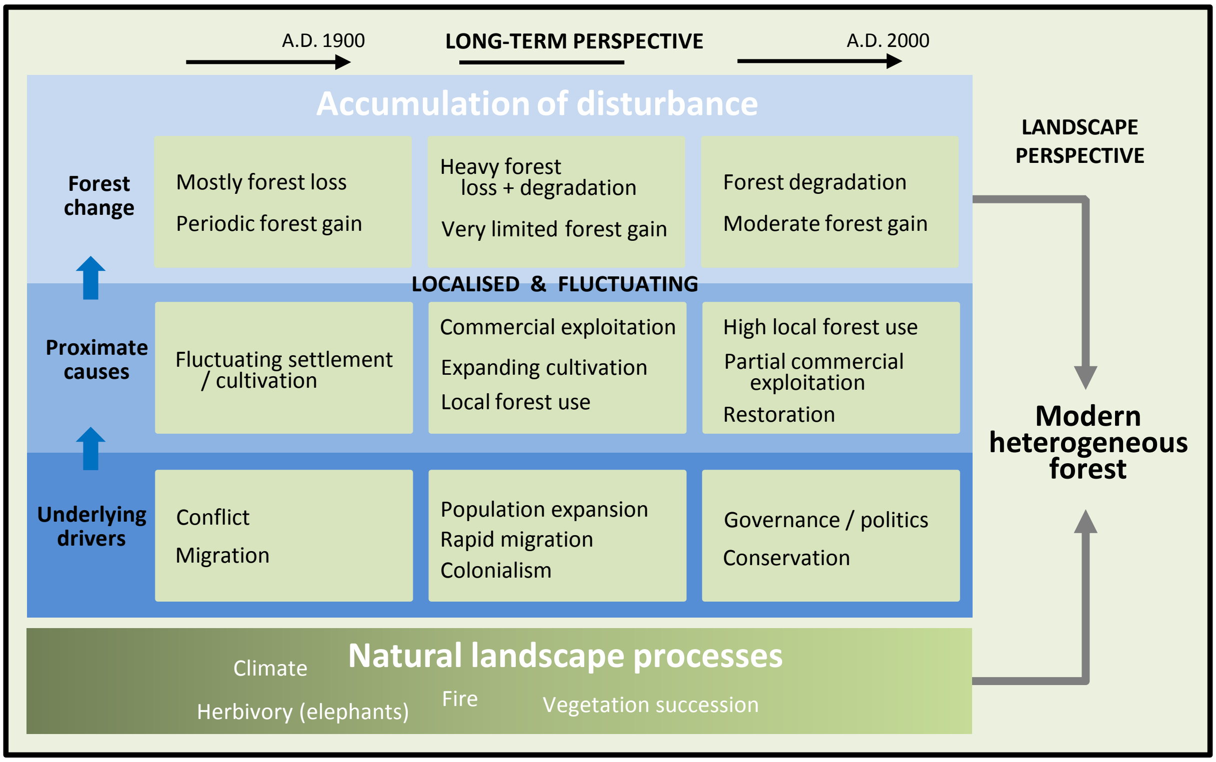


Figure 6.1: Summary of the dynamic anthropogenic factors causing forest change in East Africa, seen alongside the natural landscape processes: both should be recognised for contributions to the modern heterogeneous forest landscape shaped by an accumulation of factors over time.

The coupling of demographic factors with conflict, stemming either from disease or from warfare, is featured in each of the forest narratives of chapter 4. Both the conflict between the Abaluhya and the Nandi (CS 2), and the war between the Bunyoro and the British (chapter 4.3) had serious demographic impacts that contributed to forest growth in the context of low density or absent human populations. The phases of forest growth in both of the Ugandan areas of investigation were also characterised by prolonged bouts of fly-borne disease (see CS 5, 11, 12). The narrative diagrams (Figures 4.1 to 4.3) of both Mabira and Budongo show forest cover as increasing while population density remained below approximately 100 inhabitants per km^2. In this regard it supports the views of Doyle (2006) who has pointed out that the Bunyoro population, weakened by disease, was deprived of sufficient numbers (plus resources and freedom of action) to maintain its environment, i.e. to keep in check the bushland or forest habitat in which disease-bearing pests thrive.

Other authors (e.g. Kjekshus 1977) have demonstrated the role of the colonialism in the spread of the tsetse fly and sleeping sickness and paint a picture of a resulting ecological catastrophe. However, it is the connection between disease, population density and forest cover that leads to the suggestion here (*cf*. chapter 4.1) that it is the forest-protecting powers of the disease-bearing pests that have allowed Mabira Forest to exist as late as the mid 20th century in an otherwise largely cultivated landscape. Its location astride the swampy heads of two large rivers and neighbouring the *mbwa* fly breeding-grounds of the River Nile (CS 11), is key to its historical relationship with pest-borne disease. Elsewhere in East Africa Reid *et al*.

(2000) have shown disease, spread by the tsetse fly, to have a role in ecosystem conservation and the forest case of Mabira and fly-borne disease here appears compelling. The Budongo Forest area, historically beset with tsetse fly has also been protected by pests and disease, factors that were magnified by severe and prolonged military struggles in the 19th and early 20th centuries (chapter 4.3, *cf*. Doyle 2006).

Alongside the oft-reported negative impacts of military conflict on biodiversity, the benefits of a deserted no-man's-land to forest development have been recorded by, for example, Draulans and Van Krunkelsven (2002) in the Democratic Republic of Congo. This thesis has indicated that at least the northern Kakamega-Nandi forest islands such as Malava, are likely to have grown up under such deserted conditions due to military conflict between the Abaluhya and the Nandi (CS 2). It is also conceivable that such a theory could also be extended to the main part of the Kakamega-Nandi forest which is shown in case study 9 to have been broken through only by the Tiriki clan who are unique in the region in having a cross-tribal heritage.

Colonial governance dominated much of the 20th century as the main driver of changes within the three forests areas considered here and gradually brought political stability, the eventual reduction in disease, and the protection of forest reserves (chapter 4). As recorded by Logie and Dyson (1962) and Brasnet and Dale (1955), the gazettement of forest reserves was largely intended to enable the sustainable economic exploitation of forests but, as reflected in the commercial disturbance index, has led to their systematic degradation (chapter 5.2). The management of such reserves has negative associations such as the exclusion of local people from their own forests (e.g. CS 4) and which are highlighted on a continent-wide basis by Adams and McShane (1992). However, the conservation significance of such areas has been championed by Oates (1999) in an African regional context, and their value is highlighted in this thesis by the contrasting experience outside the reserve boundaries (*cf*. the two green graph lines of Figures 4.1 to 4.3, also the forest cover change index of chapter 5). The forest cover in these areas has been virtually eradicated as local settlement and cultivation expanded with rising population.

The economic opportunities initiated outside the forest reserves during the colonial regime also played a large part in this deforestation especially via the commercial sugar plantations of the two Ugandan sites that attracted large numbers of immigrants (*cf*. Welch Divine 2004, Reynolds 2005). The rapid immigration stimulated by economic opportunity has been followed by forest clearance both inside and outside the forest reserves (e.g. CS 11, chapter 4.3). In this regard it therefore conforms to the pattern indicated by both Rudel & Roper (1996) in East Africa, and Cohen (1997) globally, who have shown the key role of immigration into agriculturally-based areas, rather than population density *per se*, as being a common feature of tropical deforestation.

However, immigration cannot here be separated from the role of the quality of governance that is often complicit in allowing agricultural encroachment. Sayer and Maginnis (2005) conclude that the effectiveness of formal governing institutions is essential to the sustainable management and control of forest abuse. For example, the unprecedented scale of immigration in the Mabira area (CS 11) only gave rise to forest loss inside the reserve crucially within the political context set by Idi Amin and the consequent flexible attitude to the rule of law. Likewise in Kenya, the migration of Abaluhya eastwards into Nandi District combined with the party politics of the Moi regime as highlighted by Klopp (2002) to result in settlement schemes via excisions and pseudo-excisions from the Nandi forests (CS 3, 10).

Positive governance stories are also testified by, for instance, the positive response of the forest authorities to the world-wide conservation movement that has impacted all of the three forest areas of this thesis (chapter 4). These efforts are characterised by the fostering of emerging community-based conservation groups, restoration programmes (e.g. chapter 4.2, *cf*. Mitchell *et al*. 2008), and the establishment of additional reserves with higher protection levels, i.e. Kakamega National Reserve, and the first nature reserve in Mabira Forest and additional examples in Budongo Forest. The emergence of civil society as an active force for conservation, sometimes running contrary to government wishes, has also been a significant in recent forest management, most notably in Mabira Forest (Childs 2009, see CS 11). The nature of governance and the interaction of the people with the forest ecosystem may be forever altered by the advent of participatory and collaborative forest management (chapter 1.3.6, *cf*. Wily 2003). Such an alteration potentially represents a fundamental change to the coupling of the human-environment system (*sensu* Lambin & Geist 2006), i.e. the relationship between forests and the forest users.

In light of the above discussion, and as reflected in Figure 6.1, it can be concluded that there is no single dominating cause of forest change but a series of changing combinations affecting and filtering each other. This therefore supports Mather and Needle's (2000) observation of changes in causal relationships over time, while they also point out that due to the difficulties in assembling time-series data, there have been few studies of temporal changes in the relationship between forest cover and its causes. With its long-term approach, the current thesis is able to indicate such changes so that while migration continues as a factor, the dominant forces triggering it shift from those of conflict to that of economic opportunity under colonial governance, continuing under national governance; and while party politics sometimes overrides other drivers, the backdrop of the world-wide conservation movement of the last decades has been increasingly significant. Immigration, with its disruption of the traditional norms, is here stressed as a factor more than simple population density *per se*. At the level of the immediate, proximate causes it is not only the patterns of settlement and cultivation but also commercial forestry policies that are relevant and which have often been overlooked in analyses of disturbance.

As reflected in Figure 6.1, the findings of this thesis draw attention to the original heterogeneity within forests (e.g. CS 4, 8, 9, chapters 5.2.1 and 5.2.3) and also emphasise that further spatial variation is subsequently laid upon it by the anthropogenic disturbances of both local and commercial exploitation (CS 6, 7, 10). The mapping and quantification of disturbance can therefore be seen as a proxy for mapping forest degradation; the latter is increasingly recognised by conservation organisations such as FAO as a difficult but significant goal, for instance in the context of quantifying the carbon emissions (UN 2008). The shaping role of accumulated disturbance is therefore here highlighted as crucial for interpreting the current forest structure but it should also be paired with an understanding of other historic landscape processes which, to a lesser or greater degree, will include human interaction.

6.2 Methodological matters

The introduction (chapter 1) highlighted the occurrence of false historical narratives that can be easily established within the general public and scientific consciousness and which often profoundly impact conservation policy (*cf*. Gillson *et al*. 2003). The methodology employed within the current thesis has therefore been tailored to avoid either following or creating such misleading storylines. The written accounts of early European travellers, for instance, have been incorporated only where the evidence is considered to represent fact rather than interpretation coloured by 19th-century European bias (*cf*. Dobson & Ziemann 2009). Thus, statements of Hobley (1898) and Ansorge (1899) (CS 1 & 2) regarding the openness of the western Kakamega landscape are useful but the accompanying sweeping attribution of the treeless state to the reckless clearance of trees by 'natives' is here ignored since no evidence is given and appears to be an assumption. It is regarding such accounts that Reid (2007) advises modern investigators to be cautious, warning them not to be drawn into the myths of 19th-century African life. It is the same ingrained narrative of deforestation that has lead to the common interpretation of the northern Kakamega landscape as a fragmented one resulting from 20th century human expansion and exploitation. Similar patterns of firmly established belief in narratives of inexorable degradation have been exposed by other researchers such as McCann (1997) in Ethiopia and Leach and Mearns (1996) in West Africa. Common to each of these re-interpretations is the avoidance of relying on single sources.

6.2.1 The use of multiple sources

The broad-ranging historical and spatial approach employed in this research has, due to the limited scope of any single data type, necessitated the use of multiple data sources to provide the necessary length and breadth of coverage (*cf*. Figure 2.1) and have required GIS for their integration (e.g. chapter 5.1). Fuller *et al*. (2003) warn of the incompatibility of the data sources that are commonly combined for land cover change detection, and the several sources employed here within the forest cover time series should similarly be accompanied by concerns for data quality and compatibility. The change from raster-based satellite data to a vectorised interpretation of aerial photography represents one such point of departure from data homogeneity that has been highlighted by Harvey and Hill (2001) and is here acknowledged; as described in the initial data sources chapter, chapter 2.2.3, attention was given to maintaining the compatibility of the land cover classifications. Petit and Lambin (2001) identified the generalising of one or more spatial datasets as a useful means of ensuring compatibility for land cover change detection and this approach is followed here for the overlay of satellite imagery- and aerial photography-derived datasets for the forest cover change index (chapter 5.1). The comparison of later aerial photography broadly contemporary with the satellite imagery also brought confidence in the compatibility of the classification. Börjeson (2009) recognizes the difficulty in comparing vegetation cover data derived from remote sensing and that derived from cartographic sources. In the current thesis this is represented by the step from aerial photography-derived datasets to maps and since both can be classed as visual interpretations of land cover without pixel-based automation, the data quality is here considered to be less significant than from satellite imagery direct to maps. However, the ability to distinguish multiple land cover classes within the aerial photography but not from most maps represents a major difference in the potential of these source types to contribute to nuanced analyses of forest cover trends, i.e. the forest cover change indices (see chapter 5).

The use of comparable data sources in order to make valid comparisons is a highlighted feature of most assessments of data collection (e.g. Congalton & Green 1999). The use of comparable sources across the three forests for the approximately equivalent timesteps of each time series has facilitated generalising statements across both space and time and across all three sites. In each case, therefore, coverage is provided by Landsat satellite data back to 1972/73, and is extended by aerial photography to the mid 20th century, and back to pre-commercial logging era, around 1910, by selected topographic maps, 1:250,000 scale in each case. Importantly, therefore, the lack of similarities found in the forest cover change paths of the three sites cannot be attributed to data incompatibility between the three time series.

Outside the forest cover time series the availability of most data types required for constructing the forest cover narratives and the spatial indices, such as forestry records, archive maps and documents including population records, has also proved to be broadly similar between the three sites. However, first-hand local forest histories were not so evenly available and while they reached back to the early 20th century for the Kakamega-Nandi area, they could only be extended back to around 1950 for the Ugandan sites (chapter 2.5.2). This contrasts with the work of other authors who have successfully reconstructed a detailed history of much of Uganda from an extremely rich oral history regarding the tribal and military lineage (Kiwanuka 1965, Wrigley 2002, Reid 1997). The difficulty here can be traced to the specific forest areas of Mabira and Budongo being coincident with areas of pest-borne disease that necessitated periods of evacuation and emigration (chapters 4.2 and 4.3); there is a resultant disconnection between today's forest-adjacent inhabitants and their long-term local history. This in turn impacted the efficacy of the place names evidence which requires a continuous oral tradition for the credible translation of village name meanings. Despite being numerous and enlightening in the Kakamega-Nandi area (CS 1, 2), place names have proved to be the least transferable source type employed here. Pollen cores were restricted only by time and money to the Kakamega-Nandi area where they were designed to address issues of particular concern to the area.

Therefore, although coverage of most of the source types used here has been broadly comparable between the three forest sites, investigators should remain flexible in their approach to inclusion of data types; different contexts may require different approaches and each research project will require a different focus and treatment of sources.

6.2.2 Source criticism

The need to remain flexible echoes Coops *et al*.'s (2007) statement that researchers should be selective in their choice of source combinations according to the information needs and to the potential of the data types. In addition to the land cover change scientists, also historians such as Vansina (1995), encourage us to be discerning in our use of different sources and to be fully aware of their capabilities and drawbacks. It is in this light that Table 6.2 acknowledges the positives and negatives of each of the data types as they have been employed within the current thesis.

As stated by Tosh & Lang (2006) information recorded by other people should be considered to have been already filtered and provides only an interpretation of the facts, i.e. it represents a secondary rather than primary source (Tosh & Lang 2006). Oral history has been amply demonstrated by other authors to be often open to both interpretation and selectivity and Reid (2007), for example, advises maintaining appropriate levels of scepticism. The clustering of interviews in this thesis is here considered helpful in ameliorating the inconsistencies of individual human memory but the bias of collective memory at the community or tribal level is not so easily mitigated. This collective bias has also been especially noted with specific regard to forest and bush clearance since narratives of taming vast tracts of wilderness can effectively aggrandise the community (Were 1972). This appears to be a factor in the case of Kakamega Forest (CS 1) and only with the employment of a suite of alternative sources (i.e. multiple maps and the written accounts of early European travellers in CS 1) has a change of emphasis and date from the established oral tradition regarding forest clearance been possible.

Forestry records, in particular, highlight the need to appreciate biases or simple differences of perspective. Thus, the Yala River Nature Reserve is classified as full and mature forest in the satellite imagery classifications of the 1970s while contemporary forestry maps summarize a large part of it as 'poor forest', simply reflecting the predominance of trees of little commercial use. It is easier to be misled by records that neatly ignore issues or events as demonstrated here by the absence of South Nandi logging records (CS 10), and by the absence of forestry records regarding the evacuation of Mabira Forest enclaves and the subsequent use of this land by the FD/NFA (CS 5). In these cases oral histories have a crucial role and could be interpreted in the words of Vansina (1995, p.191) as 'exploding the silence of written documents'.

Tosh and Lang (2006) show how historical researchers aim to deal mostly with primary sources, i.e. first-hand accounts. While remote sensing data and topographic maps can be considered to be based on primary data although it should be acknowledged that their final outputs are the products of effective filtering by our own, secondary interpretations (*cf*. Coops *et al*. 2007, *cf*. chapter 2.2.3). The documentary sources employed here, both forestry and

Table 6.2: Summary of the main characteristics and contributions of the data source types according to their use within this thesis. (FCC – forest cover change, LD – local disturbance, CD – commercial disturbance, CS – case study).

Satellite imagery	Pros	spatially-explicit, multiple timesteps, high level of detail / no. of classes within-forest, already in digital format. CONTRIBUTES to: forest cover time series (narratives), FCC & CD indices, & INTERPRETATIONS of: forest quality (CS 6, 7, 8, 10), evolution of grasslands (CS 4, 12), etc.
	Cons	date restricted to 1972+, 'noise' & misclassifications possible
Aerial photography	Pros	spatially-explicit, high level of detail / no. of classes within-forest, compatible with satellite-derived classes. CONTRIBUTES to: forest cover time series (narratives), FCC & CD indices, & INTERPRETATIONS of: forest quality (CS 6, 7, 8, 10), evolution of grasslands (CS 4, 12), etc.
	Cons	date restricted to 1 or 2 timesteps, labour-intensive, subjective interpretation, vector digitizing brings generalised result *cf.* raster
Forestry records	Pros	often spatially-explicit, high level of detail, CONTRIBUTE to: CD indices, & INTERPRETATIONS of: forest quality, disturbance (CS 6, 7, 8)
	Cons	map quality very variable, not compatible with forest cover time series, logging data often incomplete & labour-intensive, forestry bias, archives widely spread & often in poor state
Archive maps	Pros	spatially-explicit, reaching to late 19th century. CONTRIBUTE to: forest cover & population time series (narratives), LD indices, & INTERPRETATIONS of: forest fragmentation (CS 2, 9)
	Cons	map quality very variable, lack of within-forest classification, more generalised results *cf.* raster data
Archive documents	Pros	wide ranging in theme, CONTRIBUTE to: narratives, & INTERPRETATIONS of: causes of change - historical events, disease, warfare, governance (CS 5, 11, 12)
	Cons	labour-intensive extraction, often poorly defined spatially, government bias
Oral histories	Pros	can be targeted to location, theme & period, cross-references spatially-explicit data, CONTRIBUTE to: narratives, LD & CD indices, & INTERPRETATIONS of: forest-use histories, causes of change - historical events, disease, warfare, governance, tribal practice, etc. (e.g. CS 1, 2, 5, 9, 10)
	Cons	lack of spatially-explicit output, prone to community bias & faulty memory recall, normally requires translator, less informative in areas of unstable demographic history
Ground observation	Pros	ground-truthing recent Landsat, can suggest otherwise-hidden historical factors or processes (CS 6, 7, 12), CONTRIBUTES to: narratives, & INTERPRETATIONS of: disturbance & succession
	Cons	sporadically useful, i.e. cannot be planned, no spatially-explicit output
Place names	Pros	spatially-specific, high level of detail (often giving species names), CONTRIBUTE to: narrative, INTERPRETATIONS of: pre-20th century landscape, fragmentation, mosaic landscape (CS 1, 2)
	Cons	distribution useful with numerous samples, difficult to date, open to false interpretation, interpretation only possible with stable & continuous demographic history
Fossil pollen	Pros	long time-span, high level of detail regarding species, CONTRIBUTES to: narrative, INTERPRETATIONS of: fragmentation, mosaic landscape, climate change (CS 1, (2))
	Cons	catchment is only vaguely defined, not spatially-explicit, sampling restricted to swamps, dating expensive & can only be dated at intervals

non-forestry, are considered to be largely primary as they are written by people actively involved in the chosen area and were writing during, or shortly after, the period of relevance (e.g. CS 2, 9). Forest use history interviews within the current research have generated both primary histories, i.e. those recalled first-hand by the interviewee (e.g. CS 1), and secondary histories, i.e. stories passed down from previous generations (e.g. CS 5). Greater use has here been made of the directly-recalled accounts as they can be more easily directed geographically and thematically and can be dated more closely.

Source criticism has been an essential part of historiographical debate for centuries (Dobson & Ziemann 2009) and can be interpreted as being akin to the more quantitative approach now adopted by remote sensing and GIScience under the guise of data quality assessment (Congalton and Green 1999). In this thesis data quality has been assessed for each of the geodatasets according to lineage, positional accuracy, number and accuracy of attributes, date reliability, logical consistency and completeness (data quality results are shown within Appendices A1 to A3 and those for Kakamega-Nandi datasets are published in Huth *et al.* 2007). Satellite imagery was revealed to be the highest scoring source type across most data quality categories and is followed by aerial photography. The topographic and especially forestry maps, many of which are classed as sketch maps, are highly variable in their scores and such quality issues were borne foremost in mind when constructing the time series. When creating the commercial disturbance (CD) index (chapter 5.1) such concerns were more commonly over-ridden in the quest to fill data gaps and to achieve the most complete and representative coverage.

Data quality is generally observed here to decrease with earlier date. The extension of investigations back in history is inevitably accompanied by a varied reliability often related, for instance, to scale but also to the reduced ability to 'ground truth' older datasets. The cross-referencing of data, i.e. seeking thematic and temporal overlap between datasets is therefore required. This has the added benefit of linking the past to the modern day thus establishing its relevance to current forest cover changes. This is in line with Vansina's (1995) advice for those reconstructing past environments to first establish the most recent past before working backwards into the past.

6.2.3 Breadth of data and cross-referencing

It is not only the older data types that require supplementing and a breadth of data is widely acknowledged as a positive goal for researchers of environmental history (e.g. Dovers 2002) to provide confirmation and support of the less reliable datasets. Historians have long highlighted the need for the use of cross-referencing sources to avoid reliance upon a single subjective perspective with Robertshaw (1999), for instance, highlighting the benefits of supplementing historical data with archaeological evidence and vice versa. Amongst the land-use/cover change scientists, Fuller *et al*. (2003) have suggested the inclusion of a broader set of knowledge as part of a flexible, intelligent approach to land cover change detection when comparing remote sensing and other sources; this rationale has formed a central theme of this thesis. Vansina (1995) has suggested that independent confirmation of events and situations from different sources is not easily achieved due to the differences in the aims and content; overlap between sources he suggests, is the exception rather than the norm. This thesis demonstrates that with the deliberate targeting of sources to a common location and a specific period (see case studies, i.e. chapter 3), overlap is often possible and is highly beneficial, as illustrated in Figure 6.2.

The diagram shows that all sources have at times both contributed to the interpretation of other sources and, in return, been supported by others. The relationships in the diagram reflect, for instance, the fact that satellite imagery requires not only ground observation and vegetation maps for ground-truthing for the classification process, but also information from forestry records etc., for subsequent interpretation of the changes identified (e.g. CS 7, 8). The forestry records are likewise supported by all the remote sensing steps for the synthesis that results in the commercial disturbance indices (chapter 5.1, Appendix E3). Aside from such examples of mutual support, cross-referencing can also pose serious challenges to the evidence of different sources. The Mabira Forest aerial photography of 1955, for instance, is able to demonstrate that the forest extent depicted on a forestry map dated 1949 must reflect a date several decades distant from the ascribed date (CS 5).

Despite the disadvantages of subjectivity and of not providing an independent spatially-explicit output, it is oral histories, with their capacity to be targeted thematically, geographically and temporally, that have been at the core of the cross-referencing process. To some extent this targeting of oral history interviews substitutes for the inability to ground-truth older datasets such as topographic maps that appear to contradict either published statements (CS 2), or the expected path of forest cover change (CS 11). Interviews have also been crucial, for instance, in confirming that the dry-season timing of the aerial photography was not obscuring seasonally-grown woodland of Kitigo in Budongo Forest (CS 12). However, in the case of the Kitigo area of Budongo Forest, oral histories cannot reach back to the early 20th century to confirm or deny the evidence of a single forestry map showing a forest limit unexpected from the evidence of later maps; ground observations from a targeted transect walk were instead able to support the map by revealing numerous termite mounds and low-branching trees deep within the forest (CS 12). Such an approach has been

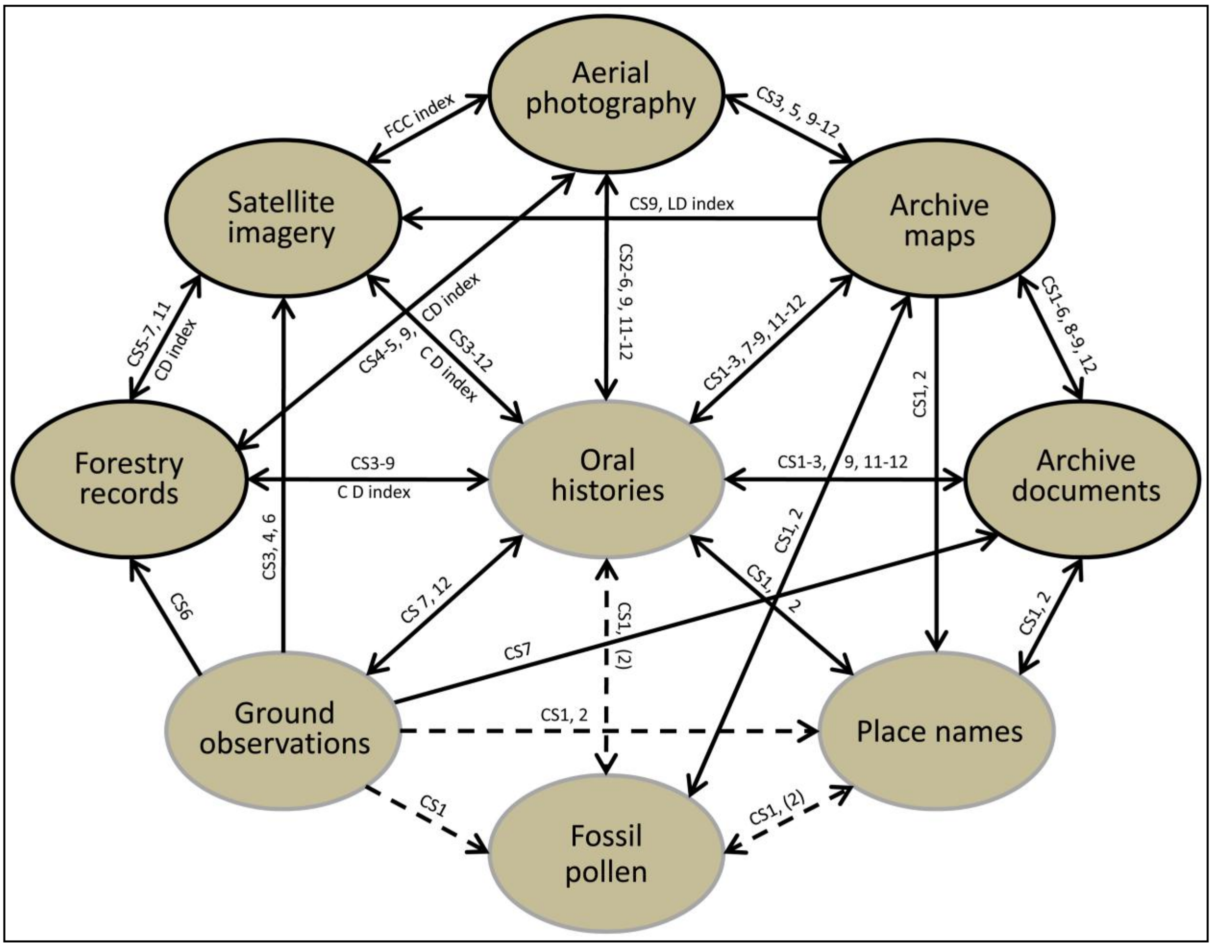


Figure 6.2: The main relationships of support and cross-reference between the sources. The direction of the arrows indicates the main direction of the support, i.e. a supporting role to the main evidence. Black outlines denote spatially-explicit source types.

used to good effect in, for example, North America by Marks & Gardescu (2001) but remains much underused as a supporting technique.

Contemporary cross-reference material for place name evidence is difficult to establish but a broader reassurance is found through generalised oral histories and by later 19th-century accounts of European travellers (CS 1 and 2). Pollen is the source with the least claim to direct support from other sources; it commonly stands alone or alongside archaeological research in investigations of East African landscapes although Taylor *et al*. (2005) and Lejju (2009) have made use of historical data for the interpretation of former landscapes. The opportunity for establishing an overlap of the Kakamega pollen evidence with that of place names remains open with the possibility of purchasing further radio-carbon dates.

The discussion above has highlighted the breadth of sources, the wide range of the data quality and the use of a long-term and spatial approach that are required for a rounded analysis of forest cover change and disturbance. It is the spatial component and the use of GIS that has usefully focused these disparate datasets upon identified locations and which has enabled the coherent management of datasets for overlay, interpretation and analysis. The use of GIS therefore allows a motley collection of data that would otherwise remain disparate to be rationalised and focused; furthermore, the resulting ability to compare the old with the recent returns a relevance to old datasets otherwise viewed as simply of historic interest.

7. Summarizing remarks, conclusions and outlook

As noted in the introduction (chapters 1.2.1 and 1.2.3), the degradation caused by forest loss and anthropogenic disturbance is acknowledged to be intimately linked to levels of biodiversity that are believed to underpin the ecosystem services so vital to human existence. The relationship of biodiversity to disturbance is complex and therefore requires attention to be focused firstly on a rounded understanding of the disturbance and degradation history that has cumulatively shaped an individual forest's biology. Understanding of the disturbance in its various guises (loss, fragmentation, degradation) will allow us recognise the conservation state of a forest, the possibilities for its future conservation and sustainable use. By such attention to quantifying the extent and pathways of forest disturbance across three forest areas in East Africa, this study has demonstrated the points listed below.

7.1 Historical forest cover and disturbance / degradation

Generalised statements on forest cover change in East Africa are difficult and the **pattern is localised**. The Kakamega-Nandi forest complex has experienced a dramatic, almost two-thirds' reduction in forest cover over the 20th century while Mabira Forest has witnessed both phases of expansion and of contraction, and Budongo Forest has remained exceptionally stable.

An **historical perspective** has demonstrated that we should not expect forests to be stable entities: their history either over the last century or across the last few millennia shows **pulses and fluctuations** according to human activity and climate. The forests that have shown loss are also seen to have endured fluctuations; the biological populations surviving today and the functioning of those forest ecosystems can, therefore, be inferred to have already displayed a large degree of **resilience**.

A **long-term view of the forest landscape** has revealed **mosaics of forest and grassland** in past centuries and millennia: the mosaic has probably been continually shifting and fluctuating according to changing local conditions and human activity but grassland has been a major loss within the landscape. The dramatic loss of grassland, largely to agriculture and woodland, has therefore reduced the heterogeneity of the landscape that is beneficial to biodiversity.

A **landscape viewpoint** has indicated that some forest patches previously presumed to be fragmented remnants of an earlier intact forest, have probably grown up as **independent forest islands**. Such a fundamental change in our interpretation of the identity and role of these forest patches within the landscape should significantly alter (i.e. raise) our expectations of the sustainability of their biological processes and the viability of these patches as 'isolated' ecosystems.

Spatially-explicit analysis of forest cover classes shows a **highly localised pattern of forest degradation** and a more limited growth towards forest cover.

A spatially-explicit analysis of the impacts of **locally- and commercially-driven disturbance** reveals a high degree of variation within single forests. Commercial exploitation is shown to represent a very significant factor in the degradation of these forests but is often under-considered.

Temporal analysis has demonstrated that the **forest cover narratives are comprised of multiple pathways** (reflected in the individual case studies) comprised of different combinations of forces varying with local situations. Conflict (disease and war) has played a significant role in the origins and preservation of these forests until the mid 20th century. There is evidence for a shift in the contribution of the roles of different causal factors over time towards commercial and governance factors. For most of the 20th century forest cover has decreased when population density has risen but population density is also revealed as not dictating forest cover levels and should not be stated as the main cause of deforestation in these forests.

7.2 The methodological approach

Temporal and spatial combination requires multiple sources to cover the period and to cross-reference each other but which also require us to be discerning in our inclusion and usage since they are not all of equal data quality or reliability. Fitting with its status as the most commonly used data source throughout land-use/change studies, Landsat satellite imagery is also found in this thesis at the forefront of the data types regarding the detection of forest cover conversion and forest quality change. It is highly valued here as the data source from which most time steps can be derived and for allowing the detection of multiple classes within the forest vegetation. All other data types used in this thesis have proved insightful in different ways and are here considered to be under-used within land-use/cover change research:

1. the detailed visual interpretations of **early aerial photography** can extend the forest cover time series and, by their overlay with the satellite imagery classifications, reveal subtle quality changes; they could be much more widely used for this purpose with particular attention to the identification of multiple vegetation classes for the detection of forest degradation;
2. **early topographic maps** represent the simplest and most obviously under-used means of extending the time-frame of a forest cover time series to a period predating commercial exploitation;
3. **interviews with old people** can target oral histories to chosen themes and locations and are here revealed as the most broadly adaptable form of ground truthing for historic datasets, also able to provide reasoned explanations for the changes; they have normally remained the preserve of historians and socio-economists but could be regularly used in long-term land-use/cover change studies;
4. **forestry records**, often believed to be inadequately preserved, are time-consuming but have proved to be essential in the interpretation of forest degradation; at least some spatially-distinguishing assessment of logging records should be attempted if ecologists wish to interpret their results against disturbance levels;
5. **non-forestry archive documents** including early European travellers' reports can shed light on the state of the broader landscape surrounding the forests and include social and political conditions of the area; although used by many historians their potential remains largely under-used by land-use/cover change scientists;
6. **place names** have illuminated an otherwise unknown phase of Kakamega-Nandi forest history; however, they rely upon continuous oral histories for their interpretation and are, therefore, not appropriate for all locations; they represent an undeveloped means of interpreting former forest cover in East Africa and a pilot study can quickly establish the local validity of the process;
7. **ground observations** are a standard means of ground truthing satellite imagery but in several cases here are also able to fill information gaps; they cannot deliver results upon demand but on occasion can fill important information gaps if the investigator is alert to the possibility;
8. **fossil pollen** here provides the long-term context for human/forest interaction and climate change in the Kakamega-Nandi area; the opportunity for the pollen analysis to be linked to the forest cover time series of more recent history holds potential for bringing further conservation relevance to their evidence.

The two sources of greatest potential (relative to their previous use) are topographic maps for extending time series, and forestry records for assessment of commercial exploitation. The use of other sources should be tailored to the information needs and the data availability but the addition of interview data to almost any suite of historical sources will facilitate greater security and depth of interpretation. Multiple data sources ensure a fuller coverage and greater confidence in the resulting interpretations and also bring multiple biases of different disciplines but which should be appreciated for bringing a balance of perspective. This approach should help to avoid the fresh establishment of false narratives that pervade the literature regarding both forest cover change and the causes of forest disturbance and degradation.

7.3 Implications for scientists

Scientists wishing to interpret biological results against a disturbance gradient should be aware that:

- that disturbance is in large part cumulative and cannot be measured by recording on-going disturbances alone; it requires a characterization and probably a quantification of past interference, most notably commercial exploitation;
- basic consideration of the wider landscape history can reveal factors allowing meaningful interpretation of the patterns of ecology and are relevant even for scientists such as BIOTA ecologists monitoring at the scale of 1 km^2 plots;
- disturbance is localised and therefore assessments need to be spatially-differentiating. With the use of GIS and the creation of a spatially-explicit index a mass of data can be rationalised by reduction to simple numerical values. This is most reliably performed for commercial disturbance due to the more easily quantifiable forestry evidence;
- there is a need to dedicate time and resources to the study of disturbance since it can be highly complex and is too often assessed by summary statements from casually gathered local opinion. However, such a study need not be as in-depth as the current thesis. Such research should be the initial study either before or at the start of any large research project. It has the potential to critically inform and shape many of the ensuing investigations either ecological or socio-economic: both the formulation of the research questions and the location of transects or study sites.

7.4 Implications for conservationists and forest managers

Decision makers aiming for the effective conservation of the forest should bear in mind that:

- only with a long-term view of forest cover change can the true seriousness of a forest loss or degradation situation be appreciated; histories of forest fluctuation are able to demonstrate the likely resilience and sustainability of remaining forest cover;
- the localised nature of forest disturbance and degradation requires localised and targeted solutions / interventions to individual circumstance;
- the mixed and changeable pathways to forest cover change and degradation seen here show that predicting future states of forest cover in East Africa is fraught with difficulty and models of prediction should be interpreted with caution;
- the degradation of forest, as opposed to forest conversion, is often ignored due to the relative difficulty in its quantification, but can be usefully quantified via the proxy of anthropogenic disturbance levels. Within a GIS disturbance can be analysed and simplified via spatially-explicit indices; notably an index of local disturbance will provide only a best-impression of the localised occurrence but will assist decision-makers in the effective targeting of protection or restoration efforts;

- managing a forest for biodiversity in East Africa is likely to be best addressed by a management for a mosaic landscape of forest and grassland that retains high landscape heterogeneity. Forest policy should therefore resist the instinct of both the traditional forester and forest conservationist to maximize forest cover and instead remain open to the active maintenance or restoration of the fast diminishing, historic grasslands ecosystems;
- decision makers should be wary of false narratives of forest cover loss and its causes that can develop within the scientific and conservation worlds from an over-enthusiastic application of established concepts of degradation.

A combined temporal and spatial quantification and characterization of forest cover change is both possible and necessary; only then can a rounded understanding of the patterns of ecology be gained and forest policy can be meaningfully shaped. Until now studies of environmental history and land-use/cover change have been largely practiced by different scientists via different means and with different perspectives. The benefits of moulding both approaches together should be realized for greater impact and resonance. Starting the process by reconstructing the recent past and working back in time ensures a connectivity to the today's forests that enables the case to be more easily made for a direct relevance to the conservation of biodiversity and ecosystem services.

7.5 Outlook

Building on the work of the current thesis, the following points represent potential avenues for further investigation:

- The mapping and monitoring of forest degradation remains a difficult task currently desired and debated by major conservation organisations; the development of practical guidelines for the rapid assessment of forest disturbance as a proxy for forest degradation would be highly beneficial. The incorporation of several data sources and perspectives via GIS and spatially-explicit indices as the means to quantify degradation are likely to find success. Their application would be beneficial in the devising of participatory / collaborative forest management zonation schemes.

- Forest history has not yet successfully made a case for its relevance to, and its regular inclusion within forest management and conservation. It is here suggested that local oral histories could stimulate active dialogue between, e.g. local elders, school children, forest managers and scientists. By this means, forest histories could form the centre-piece of environmental education projects aiming to promote awareness and local pride in natural forest resources.

- The processes at work in the transition between grasslands and forest (relevant to both Kakamega and Budongo Forests) are relatively poorly understood; the development of effective management policies is required if the eventual eradication of historic grasslands by forest expansion is to be prevented. The combination of targeted interviews regarding the intensity of land use history with limited experimentation regarding varying degrees of grazing and burning are here recommended and could usefully accompany soil sampling to compare, e.g. soil compaction.

- The three comparable, near century-long forest cover time series, plus the spatially-explicit indices of disturbance could be valuable for other scientific studies, such as ecological studies wishing to compare results against a disturbance gradient, or as the basis for modelling.

- The pollen samples, all of which are so far analysed to only a preliminary level, show good potential for a greater understanding of the long-term development of the Kakamega-Nandi forest complex and its likely modern resilience to degradation. Detailed analysis, e.g. for charcoal remains, could help to indicate human involvement in the observed vegetation changes; further radiocarbon dates for the uppermost horizons would be especially useful if an overlap with the narratives generated from the other sources could be established.

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Appendices

Appendix A The geodatasets and their data quality assessments.

The geodatasets are listed in Appendices A1 to A3 to allow reference from the text via their number, e.g. kn-d34. Following the list of abbreviations used in the dataset lists, the data quality assessment columns are explained.

Abbreviations of source archives and institutions in the dataset lists

Bod. – New Bodleian Map Library, Oxford, UK
BIEA – The British Institute in Eastern Africa, Nairobi, Kenya
Egg. 1947 – Eggeling 1947 (see literature reference list)
Eurimage – Eurimage, Rome, Italy
EVC/ILH – East View Cartographic / Internationales Landkartenhaus, Stuttgart, Germany
FAO – The Food and Agriculture Organization of the United Nations, Rome, Italy
How. 1991 – Howard 1991 (see literature reference list)
HSC – Hunting Survey and Consultants Ltd., London, UK (courtsey of Thomas Brooks & Ordnance Survey)
ILH – Internationales Landkartenhaus, Stuttgart, Germany
ILRI – International Livestock Research Institute, Nairobi, Kenya
Isecheno – Isecheno Forest Office, Kakamega, Kenya
KCBS – Kenya Central Bureau of Statistics, Nairobi, Kenya
Kimondi – Kimondi Forest Office, South Nandi Forest, Kenya
LSD Ug. – Lands and Survey Department, Entebbe, Uganda
MC – Marina Cords, Columbia University, New York, USA
NA K – Kenya National Archives, Nairobi, Kenya
NA UK – National Archives, London, UK
NFA HQ – National Forest Authority, Kampala, Uganda
NFA Lwan. – National Forest Authority, Lwankima, Mabira Forest, Uganda
NFA, Muk. – National Forest Authority, Mukono, Uganda
NFA Nag. – National Forest Authority, Nagojje, Mabira Forest, Uganda
PII – Photomap International Inc., Nairobi, Kenya
Plum. 1996 – Plumptre 1996 (see literature reference list)
PSLib. – Plant Sciences Library, Oxford University, UK
RAF, UK – Royal Air Force, UK (courtsey of Thomas Brooks & Rhodes House, Oxford University, UK)
SPerthes – Universitäts- und Forschungsbibliothek Erfurt/Gotha, Sammlung Perthes, Gotha, Germany
SBib. – Staatsbibliothek in Berlin, Germany
SurKen – Survey of Kenya, Nairobi, Kenya
UBOS – Uganda Bureau of Statistics, Kampala, Uganda
Ug. Soc. – The Uganda Society, Kampala, Uganda
UNEP – United Nations Environment Programme, Nairobi, Kenya
WAC/ICRAF – World Agroforesty Centre / International Centre for Research in Agroforestry, Nairobi, Kenya, (amended by BIOTA E02)
Wag. 1949 – Wagner 1949 (see literature reference list)
West. 1989 – Westman *et al*. 1989 (see literature reference list)

Geodata Quality

The geodata quality assessments were carried out by the current author and a review of their use for a visualisation tool has been published by Huth *et al*. (2007); the following text is taken from the tool developed by Kerstin Huth (Huth 2007), reproduced here with amendments.

Parameter	**What is judged**	**Additional information**
temporal information (TI)	difference between year on map / geodataset and year of content, plus knowledge of dates (Ti1)	year on map/geodataset; reliability of the knowledge regarding dating (Ti2)
lineage (Li)	reliability of original (parent) dataset	data type of original (parent) dataset
positional accuracy (PA)	the georeference of the objects	scale or resolution
attribute accuracy (AA)	quality of attributes (AA2)	number of attribute classes (AA1)
completeness (Co)	value reflecting percentage of completeness (Co3)	referring to full area of investigation (Co1) or to forest boundaries (Co2)
logical consistency (LC)	mainly geometric contradictions in dataset	(none)

Temporal information
Date reliability is measured in relation to the number of years between the date as specified on the map and the date of its actual content. Five classes are created wherein class 5 represents no difference between the two dates. Since some of the maps hold historical information the scale has been set to include those cases of large time spans and thus class 1 represents a discrepancy of at least 100 years. However, for about two thirds of the geodatasets the 'date of the map/geodataset' is consistent with the date of its content. In particular the satellite

imagery is, as would be expected, very high scoring. While forestry sketches also score highly since they represent snap-shots in time, the forestry maps are poorly rated here since they attempt to locate multiple data of differing phases of forestry on the same map. A further scale 'a' to 'c' is used to reflect the state of our knowledge of these dates wiuth 'a' representing good and 'c' being poor or vague knowledge.

Lineage
The lineage scale is related to the purpose of the product used to derive the described dataset for inclusion in the GIS and thus it is an impression of its process of emergence or heritage. The products used are related to 8 categories:

- Satellite imagery
- Aerial photography
- Topographic maps
- Topographic drafts
- Forestry maps
- Forestry sketch maps
- Thematic maps
- Field work

The grading is a nominal scale of 1-5 with 5 being the best. In general, satellite imagery as the source is ranked high, while forestry maps gain a higher grading than forestry sketches.

Positional accuracy
The positional accuracy was also ranked by ‘factors’ on a scale of 1-5. Here, the scale or resolution of the graphic enabled a rough ranking as a starting point. For example, datasets of a scale larger or equal to 1:10,000 received a score of 5, while those of 1:1 million or less scored a value of 1. This grading has been further refined by also taking into account knowledge of the georeferencing process or the fitting of features in a visual overlay by means of GIS. In the case of forest logging geodatasets, the ratings for positional accuracy are typically adjusted downwards by a value of 1 in order to compensate for the inaccuracy of the actual logging which is known to often stray beyond the boundaries of marked logging concessions. In general the older the stage represented by the geodataset the lower it has been judged for its positional accuracy.

Attribute accuracy
Attribute accuracy was assessed again on the basis of a purely nominal scale of 1 (inaccurate) to 5 (accurate). This judgement is independent of the number of attributes and is solely related to a judgement on the accuracy with which the attributes were assigned. As additional information the number of attributes or datafields are shown and this excludes the default datafields. In the case of imagery, scans of maps or vector datasets showing a single class, for example forest cover only, no attributes or datafields are present. Scanned maps and such vector datasets can nevertheless be judged regarding their attribute accuracy.

Completeness
The judgement of completeness (1-7 with 7 representing full coverage) is derived from a percentage coverage of either the official forest boundaries or by the percentage represented of the full area of investigation. It is the only quality measure that is derived directly from factual numbers without an element of judgement although at present in most cases these are only estimated visually.

Logical consistency
This quality parameter is predominantely judged on the basis of the correct positioning of the landscape objects in relation to each other. Here a scale of 1 to 3 is used, representing low, medium and high consistency levels. The judgement has generated a very limited range with most datasets scoring the highest class. Only few datasets appear to be inconsistent in terms of positioning of objects in the landscape in relation to each other and are therefore judged with a '2'.

Appendix A1 Geodatasets with data quality assessments for the area of the Kakamega-Nandi forests. Datasets without dates in their abbreviated title represent the most up-to-date datasets available to BIOTA-E02 regarding the subject matter. (See legend at start of Appendix A for explanation of abbreviations and of the data quality assessment).

Number	Date	File name	Scale/ Resolution	Abbreviated title	Source	Lineage	Data quality assessment									
							Li	PA	AA1	AA2	LC	Co1	Co2	Co3	Ti1	Ti2
kn-d1	1896	kn_vandmap1896_nm.tif	1:292,176	Topographic map of the Nandi country, Vandeleur, 1896	NA UK	topo draft	4	3	.	3	3	100%	.	7	4	a
kn-d2	1899	ea_macdonmap1899_nm.tif	1:1,900,800	Map of Uganda Protectorate, Macdonald, 1897-98	NA UK	thematic map	2	1	.	3	3	100%	.	7	4	a
kn-d3	1900	ea_popmap1900_nm.tif	1:2,500,000	Map of Uganda Protectorate population, 1900	NA UK	thematic map	2	1	.	2	3	100%	.	7	5	a
kn-d4	1900	kn_pop1900_nm.shp	1:2,500,000	Uganda Protectorate population, 1900	.	thematic map	2	1	1	2	3	100%	.	7	5	a
kn-d5	1900	kn_ugmap1900_nm.tif	1:633,600	Topographic map of Uganda, Sheet 4, 1900	NA UK	topo map	1	1	.	1	3	100%	.	7	3	b
kn-d6	1901	nf_nyandomap1901_nm.tif	1:125,000	Topographic map of southern Nandi, 1901	NA UK	topo draft	3	2	.	4	3	8%	.	1	5	a
kn-d7	1912/13	kn_topmaps1912-13_nm.tif	1:250,000	Topographic map draft, Kakamega-Nandi, 1912/13	Bod.	topo map	3	3	.	4	3	92%	.	6	5	a
kn-d8	1912/13	kn_forcov1912-13_nm.shp	1:250,000	Forest cover, Kakamega-Nandi, 1912/13	.	topo map	3	3	0	4	3	.	100%	7	5	a
kn-d9	1919	kn_topmap1919_nm.tif	1:1,000,000	Topographic map of Uganda, 1919	PSLib.	topo map	4	1	.	3	3	100%	.	7	5	a
kn-d10	1921	kn_pop1918_nm.shp	1:3,000,000	Kakamega-Nandi population, 1918	.	thematic map	2	2	4	2	3	100%	.	7	5	a
kn-d11	1921	kn_forestrymap1921_nm.tif	1:1,500,000	Map of forests of Kenya, 1921	PSLib.	topo draft	3	1	.	5	3	100%	.	7	5	a
kn-d12	1922	kn_distrmap1922_nm.tif	1:1,000,000	Map of Kenya, 1922	PSLib.	topo draft	3	1	.	5	3	80%	.	5	4	a
kn-d13	1924	kf_goldmap1924_nm.tif	1:250,000	Scan of a map of Kakamega goldfield, 1924	NA UK	sketch map	2	2	.	4	3	100%	.	7	5	a
kn-d14	1924	kf_goldprop1924_nm.shp	1:250,000	Promising properties for gold, 1924	.	sketch map	2	2	0	4	3	100%	.	7	5	a
kn-d15	1924	kf_gold1924_nm.shp	1:250,000	Kakamega goldfield, 1924	.	sketch map	2	2	1	4	3	100%	.	7	5	a
kn-d16	1926	nf_ancmonmap1926_nm.tif	1:300,000	Map of Nandi ancient monuments, 1926	BIEA	sketch map	2	2	.	2	3	50%	.	4	1	b
kn-d17	1926	nf_oldemotinuek1926_nm.shp	1:300,000	The Nandi limit and Emotinuets, 1926	.	sketch map	2	3	1	5	3	100%	.	7	2	b
kn-d18	1926	nf_nandires1926_nm.shp	1:300,000	The Nandi Native Reserve, 1926	.	sketch map	2	3	0	5	3	100%	.	7	5	a
kn-d19	1926	nf_ancmon1926_nm.shp	1:300,000	The ancient monuments of Nandi, 1926	.	sketch map	2	2	1	1	3	20%	.	2	2	c
kn-d20	1926	nf_masai1800-50_nm.shp	1:300,000	Masai limit in 1850, 1926	.	sketch map	2	2	0	4	3	100%	.	7	1	b
kn-d21	1931	kf_vegecov1931_nm.shp	1:62,500	Vegetation cover, Kakamega Forest, 1931	.	topo draft	3	4	2	4	3	.	40%	3	4	b
kn-d22	1931	kf_vegannot1931_nm.shp	1:62,500	Vegetation annotations, Kakamega Forest, 1931	.	topo draft	3	4	1	2	3	.	5%	1	4	b
kn-d23	1931	kf_propbound1931_nm.shp	1:62,500	Proposed forest boundaries, Kakamega, 1931	.	sketch map	5	4	1	5	3	.	40%	3	5	a
kn-d24	1931	kf_topdraft1931_nm.tif	1:62,500	Topographic map draft, Kakamega Forest, 1931	Isecheno	topo draft	3	4	.	5	3	.	40%	3	4	b
kn-d25	1931/32	kf_tracks1931-32_nm.shp	1:62,500	Tracks of Kakamega Forest, 1931-32	.	topo draft	2	2	0	3	3	30%	.	3	5	b
kn-d26	1932	kf_goldmap1932_nm.tif	1:150,000	Map of Kakamega Goldfields, 1932	NA UK	topo draft	2	3	.	4	3	50%	.	4	5	a
kn-d27	1932	kf_gold1932_nm.shp	1:150,000	Gold concessions, Kakamega Forest, 1932	.	topo draft	2	3	1	5	3	40%	.	3	5	a
kn-d28	1933	kf_firstconmap1933_nm.tif	1:15,625	Map of first logging, Kakamega Forest, 1933	Isecheno	forestry sketch	2	3	.	4	3	.	100%	7	5	a
kn-d29	1933	kf_firstcon1933_nm.shp	1:15,625	First logging, Kakamega Forest, 1933	.	forestry sketch	2	3	3	4	3	.	100%	7	5	a
kn-d30	1933	kf_topmap1933_nm.tif	1:62,500	Topographic map, west of Kakamega Forest, 1933	NA UK	topo map	4	4	.	4	3	.	15%	2	5	a
kn-d31	1937	kf_risksmap1937_nm.tif	1:16,000	Map of Risks Sawmill concession, 1937	Isecheno	forestry sketch	3	3	.	4	3	.	100%	7	5	a
kn-d32	1937	kf_risks1937_nm.shp	1:16,000	Risks Sawmill concession, 1937	.	forestry sketch	3	3	0	4	3	.	100%	7	5	a
kn-d33	1938	kn_forboundmap1938_nm.tif	1:250,000	Map of forest boundaries, Kakamega-Nandi, 1938	SurKen	topo draft	4	3	.	5	3	100%	.	7	5	a
kn-d34	1938	kn_forbound1938_nm.shp	1:250,000	Forest boundaries Kakamega-Nandi, 1938	.	topo draft	4	3	2	5	3	100%	.	7	5	a
kn-d35	late 1930s	kf_kfamap1930s_nm.tif	1:10,000	Map of Kakamega Fuel Area, 1930s	Isecheno	forestry sketch	2	3	.	4	3	.	100%	7	0	b
kn-d36	late 1930s	kf_kfa1930s_nm.shp	1:10,000	Kakamega Fuel Area concession, 1930s	.	forestry sketch	2	3	1	4	3	.	100%	7	0	b
kn-d37	1947	kf_kellykgmmap1947_nm.tif	1:62,500	Map of Kelly, Kavirondo Goldmine concessions, 1947	Isecheno	forestry sketch	3	3	.	4	3	.	100%	7	5	a
kn-d38	1947	kf_kgm1947_nm.shp	1:62,500	Kavirondo Goldmine concession, 1947	.	forestry sketch	3	3	1	4	3	.	100%	7	5	a
kn-d39	1947	kf_kelly1947_nm.shp	1:62,500	Kelly Sawmill concession, 1947	.	forestry sketch	3	3	1	4	3	.	100%	7	5	a
kn-d40	1948	kn_popmap1948_nm.tif	1:3,000,000	Kakamega-Nandi population, 1948	NA K	thematic map	2	2	.	2	3	100%	.	7	5	a
kn-d41	1948	kn_pop1948_nm.shp	1:3,000,000	Kakamega-Nandi population, 1948	.	thematic map	2	2	3	2	3	100%	.	7	2	b

Number	Date	File name	Scale/ Resolution	Abbreviated title	Source	Lineage	Data quality assessment									
							Li	PA	AA1	AA2	LC	Co1	Co2	Co3	Ti1	Ti2
kn-d42	1948/(52)	kn_airmos1948-52_kh.img	1:30,000	Aerial photo mosaic, Kakamega-Nandi, 1948/(52)	RAF, UK	aerial photo	4	4	.	.	3	.	60%	4	5	a
kn-d43	1948/(52)	kn_airmosint1948-52_nm.shp	1:30,000	Land cover classes, Kakamega-Nandi, 1948/(52)	.	aerial photo	4	3	2	3	3	.	60%	4	5	a
kn-d44	1948/(52/6	kn_forcov1948-52-67_nm.shp	1:50,000	Forest cover, Kakamega-Nandi, 1948-52-67		aerial photo	3	3	3	3	3	.	100%	7	3	a
kn-d45	1949	kf_topdraft1931-49_nm.tif	1:62,500	Map of Kavirondo Goldmine concession, 1949	Isecheno	topo draft	3	3	.	4	3	.	100%	7	5	a
kn-d46	1949	kf_kgm1949_nm.shp	1:62,500	Kavirondo Goldmine concession, 1949	.	forestry sketch	3	3	1	4	3	.	100%	7	5	a
kn-d47	1949	kf_propexcismap1949_nm.tif	1:70,000	Map of proposed excisions, Kakamega, 1949	Isecheno	sketch map	2	3	.	3	3	.	100%	7	5	a
kn-d48	1949	kf_propexcis1949a_nm.shp	1:70,000	Proposed excisions, Kakamega, 1949	.	sketch map	2	3	2	5	3	.	100%	7	5	a
kn-d49	1949	kf_propexcis1949b_nm.shp	1:70,000	Two proposed excisions, Kakamega, 1949	.	sketch map	2	3	1	5	3	.	100%	7	5	a
kn-d50	1949	kn_chiefmap1949_nm.tif	1:700,000	Map of Chieftaincies, North Kavirondo, 1949	Wag. 1949	thematic map	1	1	.	4	3	65%	.	4	5	a
kn-d51	1949	kn_chief1949_nm.shp	1:700,000	The Chieftaincies, North Kavirondo, 1949	.	thematic map	1	1	1	4	3	65%	.	4	5	a
kn-d52	1954	kf_rondomap1954_nm.tif	1:25,000	Map of Rondo Sawmill concession, 1954	Isecheno	forestry sketch	3	3	.	3	3	.	100%	7	5	b
kn-d53	1954	kf_rondo1954-56_nm.shp	1:25,000	Rondo Sawmill felling, Kakamega, 1954-56	.	forestry sketch	3	3	0	5	3	.	100%	7	5	a
kn-d54	1954	kf_rondosel1954_nm.shp	1:25,000	Rondo Sawmill selective felling, Kakamega, 1954	.	forestry sketch	3	3	0	3	3	.	100%	7	5	a
kn-d55	1954	kf_enum1931-54_nm.shp	1:62,500	Enumerations, Kakamega, 1931-1954	.	forestry map	3	4	1	5	3	.	20%	2	3	c
kn-d56	1957	kf_blocksmaps1957_nm.tif	1:25,000	Map of forest blocks, Kakamega Forest, 1957	Isecheno	forestry map	5	4	.	5	3	.	35%	3	5	a
kn-d57	1957	kf_blocks1957_nm.shp	1:25,000	Forest blocks, Kakamega Forest, 1957	.	forestry map	5	4	2	5	3	.	35%	3	5	b
kn-d58	1959	kn_distrmap1959_nm.tif	1:1,000,000	Map of Nyanza Province districts, 1959	NA K	thematic map	4	2	.	4	3	100%	.	7	3	a
kn-d59	1959	kf_rondoenum1959_nm.shp	1:50,000	Rondo Sawmill enumeration, 1959	.	forestry sketch	3	3	1	5	3	.	100%	7	5	a
kn-d60	1961	nf_excismap1961_nm.tif	1:100,000	Map of excisions, South Nandi Forest, 1961	Kimondi	topo draft	2	3	.	2	3	.	35%	3	3	b
kn-d61	1958-62	kn_topmaps1958-62_nm.tif	1:50,000	Topographic map of Kakamega-Nandi, 1958-62	Kimondi	topo map	4	4	.	5	3	80%	.	5	3	a
kn-d62	1958-62	kn_forcov1958-62_nm.shp	1:50,000	Forest cover, Kakamega-Nandi, 1958-62	.	topo map	4	4	2	5	3	.	80%	5	3	a
kn-d63	1962	kf_rondoext1962_nm.shp	1:50,000	Rondo Sawmill concession extension, 1962	.	forestry sketch	3	3	0	4	3	.	100%	7	5	a
kn-d64	1962	kn_kaimosi1918_nm.shp	1:50,000	The Kaimosi Farms, 1918	.	topo map	5	4	1	5	3	100%	.	7	5	a
kn-d65	1962	kf_rondomap1962_nm.tif	1:50,000	Map of Rondo Sawmill concession, 1962	Isecheno	forestry sketch	3	3	.	4	3	.	100%	7	3	b
kn-d66	1962	kf_rondo1950s_nm.shp	1:50,000	Rondo Sawmill concession, 1950s	.	forestry sketch	3	3	0	4	3	.	100%	7	3	b
kn-d67	1964	kn_topmaps250_gs.tif	1:250,000	Topographic map of Kakamega-Nandi, 1962/64	ILH	topo map	4	3	.	4	3	100%	.	7	4	a
kn-d68	1966	kn_inventmaps1966_nm.tif.	1:25,000	Map of inventory, part of Kakamega-Nandi, 1966	Kimondi	forestry map	4	4	.	4	3	.	50%	4	4	a
kn-d69	1966	kn_covertype1966_nm.shp	1:25,000	Forest covertypes, part of Kakamega-Nandi, 1966	.	forestry map	4	4	7	4	3	.	50%	4	5	a
kn-d70	1965/67	kn_airmos1965-67_oh.img	1:30,000	Aerial photo mosaic, Kakamega-Nandi, 1965/67	HSC	aerial photo	4	3	.	.	3	.	100%	7	5	a
kn-d71	1965/67	kn_airmosint1965-67_nm.shp	1:30,000	Land cover classes, Kakamega-Nandi, 1965/67	.	aerial photo	3	3	2	3	3	.	100%	7	5	a
kn-d72	1967	nf_excismap1967_nm.tif	1:10,000	Map of excisions, North Nandi Forest, 1967	Kimondi	forestry map	3	3	.	3	3	.	100%	7	12	b
kn-d73	1968	nf_excismap1968_nm.tif	1:10,000	Map of excision, South Nandi Forest, 1968	Kimondi	forestry map	4	5	.	5	3	.	5%	1	3	c
kn-d74	1966/69	kn_veg250_gs.shp	1:250,000	Vegetation types, Kakamega-Nandi, 1966/69	ILH	thematic map	4	3	1	4	3	100%	.	7	5	b
kn-d75	1970	kn_settlem_tl.shp	1:50,000	Settlements, Kakamega-Nandi	ILRI	topo map	4	4	3	4	3	100%	.	7	5	b
kn-d76	1970	kn_forest_gs.shp	1:50,000	Forest cover, Kakamega-Nandi, 1970	.	topo map	4	4	1	4	3	.	100%	7	3	b
kn-d77	1970	kn_river_aa.shp	1:50,000	Rivers, Kakamega-Nandi	WAC/ICRAF	topo map	3	2	0	3	3	100%	.	7	3	b
kn-d78	1970	kn_riversm_tl.shp	1:50,000	Major rivers, Kakamega-Nandi		topo map	4	4	1	4	3	100%	.	7	3	b
kn-d79	1970	kn_topmaps50_gs.tif	1:50,000	Topographic map of Kakamega-Nandi, 1970	EVC/ILH	topo map	4	4	.	5	3	100%	.	7	4	b
kn-d80	1970	kn_road_tl.shp	1:50,000	Roads, Kakamega-Nandi	.	topo map	5	5	0	5	3	100%	.	7	3	b
kn-d81	1970	kf_ksmmap1943-70s_nm.tif	1:50,000	Map of Kakamega Sawmill concessions, 1970s	Isecheno	forestry sketch	3	3	.	5	3	.	100%	7	2	b
kn-d82	1970	kf_ksmext1962_nm.shp	1:50,000	Kakamega Sawmill concession extension 1962	.	forestry sketch	3	3	0	5	3	.	100%	7	3	a
kn-d83	1970	kf_ksm1970s_nm.shp	1:50,000	Kakamega Sawmill concession after 1970	.	forestry sketch	3	3	0	5	3	.	100%	7	5	a
kn-d84	1970	kf_ksm1943-62_nm.shp	1:50,000	Kakamega Sawmill concession, 1943-62	.	forestry sketch	3	3	0	5	3	.	100%	7	3	a
kn-d85	1970	kf_ksmenum1962_nm.shp	1:50,000	Enumeration, Kakamega Sawmill's 1962 concession	.	forestry sketch	3	3	1	5	3	.	100%	7	3	a
kn-d86	1972	kn_satimg1972Sep28_gs.img	60 m	Landsat image, Kakamega-Nandi, Sept 1972	Eurimage	satellite image	4	3	.	.	3	100%	.	7	5	a

Number	Date	File name	Scale/ Resolution	Abbreviated title	Source	Lineage	Data quality assessment									
							Li	PA	AA1	AA2	LC	Co1	Co2	Co3	Ti1	Ti2
kn-d87	1973	kn_satimg1973Feb1_gs.img	60 m	Landsat image, Kakamega-Nandi, Feb 1973	Eurimage	satellite image	4	3	.	.	3	100%	.	7	5	a
kn-d88	1972/73	kn_satclass1972-73_tl.img	60 m	Land cover classes, Kakamega-Nandi, 1972/73	.	satellite image	3	3	2	4	3	100%	.	7	5	a
kn-d89	1974	kf_inventmaps1974_nm.tif	1:25,000	Map of inventory, Kakamega and Kisere, 1974	Isecheno	forestry map	4	4	.	4	3	.	40%	3	5	b
kn-d90	1974	kf_covertype1974_nm.shp	1:25,000	Forest covertypes, Kakamega and Kisere, 1974	.	forestry map	4	4	7	4	3	.	60%	4	5	a
kn-d91	1974	kf_road1974_nm.shp	1:25,000	Roads, Kakamega Forest, 1974	.	forestry map	4	4	2	4	3	.	100%	7	5	a
kn-d92	1975	kn_satimg1975Sep22_gs.img	60 m	Landsat image, Kakamega-Nandi, Sept 1975	Eurimage	satellite image	4	3	.	.	3	100%	.	7	5	a
kn-d93	1975	kn_satimg1975Dec21_gs.img	60 m	Landsat image, Kakamega-Nandi, Dec 1975	Eurimage	satellite image	4	3	.	.	3	100%	.	7	5	a
kn-d94	1975	kn_satclass1975_tl.img	60 m	Land cover classes, Kakamega-Nandi, 1975	.	satellite image	3	3	2	4	3	100%	.	7	5	a
kn-d95	1976	nf_inventmap1976_nm.tif	1:25,000	Map of inventory, part of South Nandi Forest, 1976	Kimondi	forestry map	4	4	.	4	3	.	20%	2	3	a
kn-d96	1976	nf_covertype1976_nm.shp	1:25,000	Forest covertypes, South Nandi Forest, 1976	.	forestry map	4	4	7	4	3	.	60%	4	5	a
kn-d97	1977	nf_bhangramap1977_nm.tif	1:50,000	Map of Bhangra concession, South Nandi, 1977	Kimondi	forestry sketch	3	4	.	5	3	.	100%	7	5	a
kn-d98	1977	nf_bhangra1977_nm.shp	1:50,000	Bhangra concession, South Nandi, 1977	.	forestry sketch	3	4	1	5	3	.	100%	7	5	a
kn-d99	1979	kn_pop1979_tl.shp	1:50,000	Kakamega-Nandi population, 1979	KCBS	thematic map	3	3	15	4	2	100%	.	7	5	a
kn-d100	1979	kn_satimg1979May16_gs.img	60 m	Landsat image, Kakamega-Nandi, May 1979	Eurimage	satellite image	4	3	.	.	3	100%	.	7	5	a
kn-d101	1980	kn_satimg1980Dec3_gs.img	60 m	Landsat image, Kakamega-Nandi, Dec 1980	Eurimage	satellite image	4	3	.	.	3	100%	.	7	5	a
kn-d102	1979/80	kn_satclass1979-80_tl.img	60 m	Land cover classes, Kakamega-Nandi, 1979/80	.	satellite image	3	3	2	4	3	97%	.	7	5	a
kn-d103	1981	nf_excismap1981_nm.tif	1:10,000	Map of an excision, Iruru Forest, 1981	Kimondi	forestry map	4	5	.	5	3	.	5%	1	3	a
kn-d104	1983	kn_soil250_gs.shp	1:250,000	Reconnaissance soil map, Kakamega-Nandi	EVC/ILH	thematic map	4	3	19	3	3	100%	.	7	5	a
kn-d105	1983	kn_aez_ilri.shp	1:250,000	Agro-ecological zones, Kakamega-Nandi, 1983	ILRI	thematic map	4	3	1	4	3	100%	.	7	5	b
kn-d106	1984	nf_excis1951-68_nm.shp	1:100,000	Excisions and proposed excisions, Nandi, 1951-68	.	topo draft	2	3	4	4	3	.	50%	4	3	b
kn-d107	1984	nf_excismap1984_nm.tif	1:10,000	Map of an excision, South Nandi Forest, 1984	Kimondi	forestry map	4	5	.	5	3	.	5%	1	2	a
kn-d108	1984	kn_satimg1984Dec31_gs.img	30 m	Landsat image, Kakamega-Nandi, Dec 1984	Eurimage	satellite image	5	5	.	.	3	100%	.	7	5	a
kn-d109	1984	kn_satclass1984_tl.img	30 m	Land cover classes, Kakamega-Nandi, 1984	.	satellite image	4	5	2	4	3	100%	.	7	5	a
kn-d110	1989	kn_pop1989_tl.shp	1:50,000	Kakamega-Nandi population, 1989	KCBS	thematic map	3	3	20	4	2	100%	.	7	5	a
kn-d111	1989	kn_satimg1989Nov19_gs.img	30 m	Landsat image, Kakamega-Nandi, Nov 1989	Eurimage	satellite image	5	4	.	.	3	100%	.	7	5	a
kn-d112	1989	kn_satclass1989_tl.img	30 m	Land cover classes, Kakamega-Nandi, 1989	.	satellite image	4	4	2	4	3	97%	.	7	5	a
kn-d113	1991	kf_airmos1991_oh.img	1:25,000	Aerial photo mosaic, Kakamega Forest, 1991	PII	aerial photo	4	4	.	.	3	.	40%	3	5	a
kn-d114	1991	kn_lukifcon_sk.shp	1:250,000	Land use cover, Kakamega-Nandi, KIFCON, 1991	BIOTA E12	thematic map	4	5	1	4	3	.	90%	6	5	b
kn-d115	1994	kn_satimg1994nov25_gs.img	30 m	Landsat image, Kakamega-Nandi, Nov 1994	Eurimage	satellite image	5	4	.	.	3	100%	.	7	5	a
kn-d116	1995	kn_satimg1995apr2_gs.img	30 m	Landsat image, Kakamega-Nandi, Apr 1995	Eurimage	satellite image	5	4	.	.	3	100%	.	7	5	a
kn-d117	1994/95	kn_satclass1994-95_tl.img	30 m	Land cover classes, Kakamega-Nandi, 1994/95	.	satellite image	4	4	2	4	3	100%	.	7	5	a
kn-d118	1972-1995	kf_forFD_gs.shp	1:10,000	Land use/cover, Kakamega, Forest Department	MC	forestry map	4	5	5	4	3	.	35%	3	5	b
kn-d119	1933-1985	kn_sawmill_nm.shp	1:50,000	Sawmills, Kakamega-Nandi	.	forestry map	4	4	3	4	3	.	60%	4	5	a
kn-d120	1995	kn_lucafricover_nm.shp	1:200,000	Africover landcover, Kakamega-Nandi	FAO	thematic map	4	5	2	3	3	100%	.	7	5	b
kn-d121	1999	kn_pop1999_tl.shp	1:50,000	Kakamega-Nandi population, 1999	KCBS	thematic map	3	4	17	4	2	100%	.	7	5	a
kn-d122	2001	kn_satimg2001feb5_gs.img	30 m	Landsat image, Kakamega-Nandi, Feb 2001	Eurimage	satellite image	5	4	.	.	3	100%	.	7	5	a
kn-d123	2001	kn_satimg2001apr10_gs.img	30 m	Landsat image, Kakamega-Nandi, Apr 2001	Eurimage	satellite image	5	4	.	.	3	100%	.	7	5	a
kn-d124	2001	kn_satclass2001_tl.img	30 m	Land cover classes, Kakamega-Nandi, 2001	.	satellite image	4	4	2	4	3	97%	.	7	5	a
kn-d125	2003	kf_quarry_nm.shp	1:50,000	Some murram quarries of Kakamega Forest	.	forestry map	4	4	1	5	3	.	60%	4	5	b
kn-d126	2003	kn_satimg2003jan10_tl.img	30 m	Landsat image, Kakamega-Nandi, Jan 2003	Eurimage	satellite image	5	4	.	.	3	100%	.	7	5	a
kn-d127	2003	kn_satimg2003may18_tl.img	30 m	Landsat image, Kakamega-Nandi, May 2003	Eurimage	satellite image	5	4	.	.	3	100%	.	7	5	a
kn-d128	2003	kn_satclass2003_tl.img	30 m	Land cover classes, Kakamega-Nandi, 2003	.	satellite image	4	4	2	4	3	100%	.	7	5	a
kn-d129	1962	kf_goldmine_nm.shp	1:50,000	Some goldmines of Kakamega District	.	topo map	4	4	1	5	3	60%	.	4	5	b
kn-d130	2003	ok_East_bdo_gs.shp	1 m	BIOTA-East Biodiversity Observatories, Kakamega	.	field work	3	3	2	5	3	.	100%	7	5	a
kn-d131	2003	kn_forcov2003_tl.shp	1:50,000	Forest cover, Kakamega-Nandi, 2003	.	satellite image	4	4	1	3	3	100%	.	7	5	a

Number	Date	File name	Scale/ Resolution	Abbreviated title	Source	Lineage	Data quality assessment									
							Li	PA	AA1	AA2	LC	Co1	Co2	Co3	Ti1	Ti2
kn-d132	2005	kf_opsmap2005_nm.tif	1:50,000	Map of Kenya Forest Service operations, 2005	Isecheno	forestry map	3	3	.	2	3	.	35%	3	2	a
kn-d133	2005	kf_ops2005_nm.shp	1:50,000	Kenya Forest Service operations, 2005	.	forestry map	3	3	1	3	3	.	35%	3	5	a
kn-d134	2005	kf_fgposts2005_nm.shp	1:50,000	Forest guard posts, Kakamega	.	forestry map	3	3	1	4	3	.	35%	3	5	a
kn-d135	2002-06	kn_intview2002-06_nm.shp	1:50,000	Forest-adjacent interviews, Kakamega-Nandi	.	field work	3	3	7	3	2	100%	.	7	2	b
kn-d136	2006	kn_pollen2006_nm.shp	1:50,000	Fossil pollen sampling, Kakamega-Nandi, 2006	.	field work	4	5	5	5	5	100%	.	7	1	c
kn-d137	2008	kn_placename_nm.shp	1:50,000	Placename evidence, Kakamega-Nandi	.	field work	2	3	8	2	3	80%	.	5	1	c
kn-d138	2008	kn_indexfcc_nm.img	1:50,000	Forest cover change index, Kakamega-Nandi, 1948-	.	aerial photo	4	4	1	4	3	100%	.	7	2	a
kn-d139	2008	kn_indexlocaldist_nm.img	1:100,000	Local disturbance index, Kakamega-Nandi	.	thematic map	3	3	1	3	3	.	100%	7	5	a
kn-d140	2008	kn_indexcomdist_nm.shp	1:50,000	Commercial disturbance index, Kakamega-Nandi	.	forestry sketch	3	3	15	3	3	.	100%	7	2	a
kn-d141	2008	ok_E02_grtruthLC_tl.shp	1:30,000	Ground truth points, Kakamega-Nandi, 2005-06	.	field work	5	5	4	5	3	.	60%	4	4	a
kn-d142	2009	kn_reserve_tl.shp	1:50,000	The nature / national reserves, Kakamega-Nandi	.	topo map	4	4	1	5	3	.	100%	7	3	b
kn-d143	2009	kn_protforest_tl.shp	1:50,000	Protected forest areas, Kakamega-Nandi	UNEP	forestry map	5	4	1	5	3	.	100%	7	5	a

Appendix A2 Geodatasets with data quality assessments for the Mabira Forest area. Datasets without dates in their abbreviated title represent the most up-to-date datasets available to BIOTA-E02 regarding the subject matter. (See legend at start of Appendix A for explanation of abbreviations and of the data quality assessment).

Number	Date	File name	Scale/ Resolution	Abbreviated title	Source	Lineage	Data quality assessment									
							Li	PA	AA1	AA2	LC	Co1	Co2	Co3	Ti1	Ti2
mf-d1	1900	mf_pop1900_nm.shp	1:2,500,000	Population, Mabira area, 1900	.	thematic map	2	1	2	1	3	100%	.	7	4	a
mf-d2	1904	mf_nwmap1904_nm.tif	1:50,000	Topographic map of north-west Mabira, 1904	NFA Nag.	topo map	4	4	.	4	3	.	20%	2	5	b
mf-d3	1904	mf_forbound1904_nm.shp	1:50,000	Forest boundary, north-west Mabira, 1904	.	topo map	4	4	0	4	3	.	20%	2	5	b
mf-d4	1908	mf_nilemap1908_nm.tif	1:125 000	Topographic map of the River Nile area, 1908	Ug. Soc.	topo draft	3	3	.	3	3	25%	.	2	5	a
mf-d5	1911/1912	mf_topmap1911-12_nm.tif	1:250,000	Topographic map of Mabira area, 1911/12	SPerthes	topo map	3	3	.	4	3	85%	.	6	4	a
mf-d6	1911/1912	mf_forcov1911-12_nm.shp	1:250,000	Forest cover, 1911/12	.	topo map	3	3	0	4	3	85%	.	6	5	a
mf-d7	1911/1912	mf_bush1911-12_nm.shp	1:250,000	Bush cover, 1911/12	.	topo map	3	3	0	4	4	85%	.	6	5	a
mf-d8	1911/1912	mf_agric1911-12_nm.shp	1:250,000	Agricultural land, 1911/12	.	topo map	3	3	0	3	3	85%	.	5	5	a
mf-d9	1917	mf_nwmap1917_nm.tif	1:50,000	Topographic map of north-west Mabira, 1917	NFA Nag.	topo map	4	4	.	4	3	.	20%	2	5	b
mf-d10	1917	mf_covertype1917_nm.shp	1:50,000	Forest cover types, north-west Mabira, 1917	.	topo map	4	4	1	4	3	.	20%	2	5	b
mf-d11	1919	mf_topmap1919_nm.tif	1:1,000,000	Topographic map of Mabira area, 1919	PSLib.	topo map	3	1	.	3	3	100%	.	7	5	a
mf-d12	1921	mf_popmap1921_nm.tif	1:1,500,000	Map of population, Mabira area, 1921	NA UK	thematic map	3	1	.	2	3	100%	.	7	4	a
mf-d13	1921	mf_pop1921_nm.shp	1:1,500,000	Population, Mabira area, 1921	.	thematic map	3	2	3	2	3	100%	.	7	4	a
mf-d14	1923	mf_bugamap1923_nm.tif	1:500,000	Topographic map of Buganda, Mabira area, 1923	SPerthes	topo map	3	2	.	4	3	100%	.	7	5	b
mf-d15	1923	mf_forcov1923_nm.shp	1:500,000	Forest cover of Mabira area, 1923	.	topo map	3	2	0	4	3	100%	.	7	5	b
mf-d16	1929	mf_enummap1929_nm.tif	1:50,000	Map of enumeration, south-west Mabira, 1929	NFA HQ	forestry sketch	3	4	.	4	3	.	100%	7	5	a
mf-d17	1929	mf_enum1929_nm.shp	1:50,000	Enumeration lines, south-west Mabira, 1929	.	forestry sketch	3	4	4	4	3	.	100%	7	5	a
mf-d18	1946	mf_inventmap1946_nm.tif	1:10,000	Map of inventory, south-west Mabira, 1946	NFA HQ	forestry map	4	5	.	4	3	.	100%	7	5	a
mf-d19	1946	mf_covertype1946_nm.shp	1:10,000	Forest cover types, south-west Mabira, 1946	.	forestry map	4	5	1	4	3	.	100%	7	5	a
mf-d20	1947	mf_inventmap1947_nm.tif	1:10,000	Map of inventory, Bulanga, Mabira, 1947	NFA HQ	forestry map	4	5	.	4	3	.	100%	7	5	a
mf-d21	1947	mf_covertype1947_nm.shp	1:10,000	Forest cover types, Bulanga, Mabira, 1947	.	forestry map	4	5	1	4	3	.	100%	7	5	a
mf-d22	1947	mf_utile1947_nm.shp	1:10,000	*Entandrophragma utile,* Bulanga, Mabira, 1947	.	forestry map	4	5	0	4	3	.	100%	7	5	a
mf-d23	1949	mf_lwankmap1949_nm.tif	1:10,000	Lwankima Forest, Mabira, 1949	NFA HQ	forestry sketch	2	3	.	4	2	.	100%	7	5	a
mf-d24	1949	mf_inventmap1949_nm.tif	1:50,000	Map of inventory, Mabira, 1949	NFA HQ	forestry sketch	4	4	.	3	3	70%	.	5	5	a
mf-d25	1949	mf_roads1949_nm.shp	1:50,000	Roads, Mabira area, 1949	.	forestry map	4	4	1	4	3	70%	.	5	5	a
mf-d26	1949	mf_forpatch1949_nm.shp	1:50,000	Forest patches outside the Mabira boundary, 1949	.	forestry map	4	4	1	4	3	70%	.	5	5	a

Number	Date	File name	Scale/ Resolution	Abbreviated title	Source	Lineage	Data quality assessment									
							Li	PA	AA1	AA2	LC	Co1	Co2	Co3	Ti1	Ti2
mf-d27	1949	mf_forbound1949_nm.shp	1:50,000	Forest boundary, Mabira, 1949	.	forestry map	4	4	1	3	3	.	100%	7	5	a
mf-d28	1949	mf_covertype1949_nm.shp	1:50,000	Forest cover types, north-west Mabira, 1949	.	forestry map	4	4	1	4	3	.	100%	7	5	a
mf-d29	1949	mf_settl1949_nm.shp	1:50,000	Settlements, Mabira area, 1949	.	forestry map	4	4	2	4	3	50%	.	4	5	a
mf-d30	1955	mf_airmos1955_kh.img	1:30,000	Aerial photo mosaic, Mabira area, 1955	LSD Ug.	aerial photo	4	4	.	3	3	.	100%	7	5	a
mf-d31	1955	mf_airmosint1955_nm.shp	1:30,000	Land cover classes, Mabira area, 1955	.	aerial photo	4	4	2	3	3	.	100%	7	5	a
mf-d32	1958	mf_inventmap1958_nm.tif	1:50,000	Map of inventory, Mabira, 1958	NFA HQ	forestry map	4	4	.	4	3	.	100%	7	5	a
mf-d33	1958	mf_covertype1958_nm.shp	1:50,000	Forest cover types, Mabira, 1958	.	forestry map	4	4	1	3	3	.	100%	7	5	a
mf-d34	1959	mf_popmap1959_nm.tif	1:1,250,000	Map of population, Mabira area, 1959	LSD Ug.	thematic map	3	1	.	4	2	100%	.	7	4	a
mf-d35	1959	mf_pop1959_nm.shp	1:1,250,000	Population, Mabira area, 1959	.	thematic map	3	1	3	4	3	100%	.	7	4	a
mf-d36	1958/60	mf_topmap50_tk.tif	1:50,000	Topographic map of the Mabira area	SBib.	topo map	5	4	.	5	3	100%	.	7	3	b
mf-d37	1958/60	mf_forcov_kh.shp	1:50,000	Forest cover, Mabira area	.	topo map	5	4	0	5	3	100%	.	7	3	b
mf-d38	1958/60	mf_river_jn.shp	1:50,000	Rivers, Mabira area	.	topo map	5	4	6	4	3	75%	.	5	3	b
mf-d39	1958/60	mf_road_nfa.shp	1:50,000	Roads, Mabira area	NFA HQ	topo map	5	4	6	4	3	100%	.	7	3	b
mf-d40	1960	mf_swcoupemap1960_nm.tif	1:50,000	Map of logging concession, Mabira, 1960	NFA HQ	forestry map	3	4	.	5	3	.	5%	1	5	a
mf-d41	1960	mf_daplantmap1960s_nm.tif	1:10,000	Map of Dangala, Sese refined/enriched, 1960s	NFA Lwan.	forestry map	4	5	.	4	3	.	100%	7	5	b
mf-d42	1962	mf_topmaps1962_nm.tif	1:250,000	Topographic map of Mabira area, 1962	LSD Ug.	topo map	3	3	.	4	3	100%	.	7	4	b
mf-d43	1962	mf_forcov1962_nm.shp	1:250,000	Forest cover, Mabira area, 1962	.	topo map	3	3	0	4	3	100%	.	7	4	b
mf-d44	1965	mf_cmptmap1965_nm.tif	1:50,000	Map of Mabira, 1965	NFA HQ	forestry map	4	4	.	4	3	.	100%	7	5	a
mf-d45	1965	mf_ecoupemap1965_nm.tif	1:50,000	Map of eastern Mabira, 1965	NFA HQ	forestry map	4	5	.	5	3	.	100%	7	5	a
mf-d46	1965	mf_swcoupemap1965_nm.tif	1:50,000	Map of south-west Mabira, 1965	NFA HQ	forestry map	4	5	.	5	3	.	100%	7	5	a
mf-d47	1965	mf_leased1965_nm.shp	1:50,000	Leased land, Mabira, 1965	.	forestry map	3	4	1	5	3	.	100%	7	5	a
mf-d48	1965	mf_exch1955-56_nm.shp	1:50,000	Land exchanges, Mabira, 1955-56	.	forestry map	3	4	3	4	3	.	100%	7	5	a
mf-d49	1966	mf_walogplantmap1966_nm.tif	1:10,000	Map of Wagola, Mabira, 1966	NFA, Muk.	forestry map	4	5	.	5	3	.	100%	7	5	a
mf-d50	1966	mf_bulogmap1963-68_nm.tif	1:10,000	Map of felled/refined areas, Buwola, Mabira, 1966	NFA Lwan.	forestry map	4	5	.	5	3	.	100%	7	5	a
mf-d51	1967	mf_naplantmap1967_nm.tif	1:10,000	Map of Namaganda planting, Mabira, 1967	NFA Lwan.	forestry map	4	5	.	5	3	.	100%	7	5	a
mf-d52	1969	mf_popmap1969_nm.tif	1:1,500,000	Map of population, Mabira area, 1969	LSD Ug.	thematic map	3	3	.	4	3	100%	.	7	5	a
mf-d53	1969	mf_pop1969_nm.shp	1:1,500,000	Population, Mabira area, 1969	.	thematic map	3	3	2	4	3	100%	.	7	5	a
mf-d54	1973	mf_satimg1973Feb2_tl.img	60 m	Landsat image, Mabira area, Sept 1973	Eurimage	satellite image	4	3	.	.	3	100%	.	7	5	a
mf-d55	1974	mf_satimg1974Jan29_tl.img	60 m	Landsat image, Mabira area, Jan 1974	Eurimage	satellite image	4	3	.	.	3	100%	.	7	5	a
mf-d56	1973/74	mf_satclass1973-74_tl.img	60 m	Land cover classes, Mabira area, 1973-74	.	satellite image	4	3	2	4	3	100%	.	7	5	a
mf-d57	1976	mf_satimg1976Jan27_tl.img	60 m	Landsat image, Mabira area, Jan 1976	Eurimage	satellite image	4	3	.	.	3	100%	.	7	5	a
mf-d58	1976	mf_satclass1976_tl.img	60 m	Land cover classes, Mabira area, 1976	.	satellite image	4	3	2	4	3	100%	.	7	5	a
mf-d59	1980	mf_popmap1980_nm.tif	1:1,250,000	Demarcation of constituencies, 1980	LSD Ug.	thematic map	3	2	.	4	3	100%	.	7	5	a
mf-d60	1980	mf_pop1980_nm.shp	1:1,250,000	Population, Mabira area, 1980	.	thematic map	3	2	4	4	3	100%	.	7	5	a
mf-d61	1986	mf_satimg1986Nov10_tl.img	30 m	Landsat image, Mabira area, Nov 1986	Eurimage	satellite image	5	4	.	.	3	100%	.	7	5	a
mf-d62	1986	mf_satimg1986Dec28_tl.img	30 m	Landsat image, Mabira area, Dec 1986	Eurimage	satellite image	5	4	.	.	3	100%	.	7	5	a
mf-d63	1986	mf_satclass1986_tl.img	30 m	Land cover classes, Mabira area, 1986	.	satellite image	5	4	2	4	3	100%	.	7	5	a
mf-d64	1987	mf_disturbmap1987_nm.tif	1:150,000	Map of disturbance of Mabira Forest, 1987	West. 1989	thematic map	3	2	.	3	3	.	100%	7	4	a
mf-d65	1987	mf_lumap1987_nm.tif	1:150,000	Map of land use, Mabira, 1987	West. 1989	thematic map	3	2	.	3	3	.	100%	7	4	a
mf-d66	1987	mf_disturb1987_nm.shp	1:150,000	Forest disturbance, Mabira, 1987	.	thematic map	3	2	1	3	3	.	100%	7	4	a
mf-d67	1987	mf_lu1987_nm.shp	1:150,000	Land use activities, Mabira, 1987	.	thematic map	3	2	1	3	3	.	100%	7	4	a
mf-d68	1989	mf_satimg1989Feb27_tl.img	30 m	Landsat image, Mabira area, Feb 1989	Eurimage	satellite image	5	4	.	.	3	100%	.	7	5	a
mf-d69	1989	mf_satclass1989_tl.img	30 m	Land cover classes, Mabira area, 1989	.	satellite image	5	4	2	4	3	100%	.	7	5	a
mf-d70	1991	mf_disturbmap1991_nm.tif	1:150,000	Map of disturbance, Mabira, 1991	How. 1991	thematic map	3	2	.	3	3	.	100%	7	5	b
mf-d71	1991	mf_disturb1991_nm.shp	1:150,000	Forest disturbance, Mabira, 1991	.	thematic map	3	2	1	3	3	.	100%	7	5	b

Number	Date	File name	Scale/ Resolution	Abbreviated title	Source	Lineage	Data quality assessment									
							Li	PA	AA1	AA2	LC	Co1	Co2	Co3	Ti1	Ti2
mf-d72	1991	mf_admin1991_nfa.shp	1:50,000	Administrative boundaries, Mabira area, 1991	NFA HQ	thematic map	4	4	9	4	3	100%	.	7	5	a
mf-d73	1991	mf_pop1991 _nm.shp	1:50,000	Population, Mabira area, 1991	.	thematic map	4	4	6	4	3	100%	.	7	5	a
mf-d74	1992	mf_kasoplantmap1992_nm.tif	1:10,000	Map of plantations, Kasokoso, Mabira, 1992	NFA Lwan.	forestry sketch	3	5	.	5	3	.	100%	7	5	a
mf-d75	1993	mf_inventmap1993_nm.tif	1:50,000	Map of forest inventory, Mabira, 1993	NFA HQ	forestry map	4	4	.	4	3	.	100%	7	5	a
mf-d76	1993	mf_covertype1993_nm.shp	1:50,000	Forest cover types, Mabira, 1993	.	forestry map	4	4	1	4	3	.	100%	7	5	a
mf-d77	1994	mf_kasoplantmap1994_nm.tif	1:10,000	Map of plantations, Kasokoso, Mabira, 1994	NFA Lwan.	forestry sketch	4	5	.	5	3	.	100%	7	5	a
mf-d78	1994	mf_luc_nfa.shp	1:50,000	Land use/cover, Mabira area	NFA HQ	thematic map	4	4	12	4	3	100%	.	7	3	b
mf-d79	1995	mf_satimg1995Apr9_tl.img	30 m	Landsat image, Mabira area, Apr 1995	Eurimage	satellite image	5	4	.	.	3	100%	.	7	5	a
mf-d80	1995	mf_satimg1995Jan19_tl.img	30 m	Landsat image, Mabira area, Jan 1995	Eurimage	satellite image	5	4	.	.	3	100%	.	7	5	a
mf-d81	1995	mf_satclass1995_tl.img	30 m	Land cover classes, Mabira area, 1995	.	satellite image	5	4	2	4	3	100%	.	7	5	a
mf-d82	2001	mf_satimg2001Jan27_tl.img	30 m	Landsat image, Mabira area, Jan 2001	Eurimage	satellite image	5	4	.	.	3	100%	.	7	5	a
mf-d83	2001	mf_satimg2001Nov27_tl.img	30 m	Landsat image, Mabira area, Nov 2001	Eurimage	satellite image	5	4	.	.	3	100%	.	7	5	a
mf-d84	2001	mf_satclass2001_tl.img	30 m	Land cover classes, Mabira area, 2001	.	satellite image	5	4	2	4	3	100%	.	7	5	a
mf-d85	2002	mf_pop2002_nm.shp	1:50,000	Population, Mabira, 2002	UBOS	thematic map	4	4	6	4	3	100%	.	7	5	a
mf-d86	2002	mf_admin_nm.shp	1:50,000	Administrative boundaries, Mabira area, 2002	UBOS	thematic map	4	4	3	4	3	100%	.	7	5	a
mf-d87	2002	mf_satimg2002Nov30_tl.img	30 m	Landsat image, Mabira area, Nov 2002	Eurimage	satellite image	5	4	.	.	3	100%	.	7	5	a
mf-d88	2003	mf_satimg2003Feb2_tl.img	30 m	Landsat image, Mabira area, Feb 2003	Eurimage	satellite image	5	4	.	.	3	100%	.	7	5	a
mf-d89	2002-03	mf_satclass2002-03_tl.img	30 m	Land cover classes, Mabira area, 2002-03	.	satellite image	5	4	2	4	3	100%	.	7	5	a
mf-d90	2005	mf_gaz_nfa.shp	1:50,000	Gazetted forest reserves, Mabira area	NFA HQ	forestry map	4	3	12	5	3	100%	.	7	5	b
mf-d91	2005/06	mf_intview2005-06_nm.shp	1:50,000	Forest-adjacent interviews, Mabira area	.	field work	3	3	12	3	2	100%	.	7	2	b
mf-d92	2006	mf_cmpts_nfa.shp	1:50,000	Forest compartments, Mabira	NFA HQ	forestry map	4	4	6	4	3	.	100%	7	5	a
mf-d93	2008	mf_logging1949-87_nm.shp	1:50,000	Logging in Mabira	.	forestry map	4	4	5	3	3	.	40%	4	2	b
mf-d94	2008	mf_planting1963-93_nm.shp	1:10,000	Plantations of Mabira	.	forestry map	4	5	4	3	3	.	90%	6	2	b
mf-d95	2009	mf_indexfcc_nm.shp	1:50,000	Forest cover change index, Mabira area, 1955-2002/03	.	aerial photo	4	4	1	4	3	100%	.	7	2	a
mf-d96	2009	mf_indexlocaldist_nm.shp	1:100,000	Local disturbance index, Mabira	.	thematic map	3	3	1	3	3	.	100%	7	5	a
mf-d97	2009	mf_indexcomdist_nm.shp	1:50,000	Commercial disturbance index, Mabira	.	forestry sketch	3	3	12	3	3	.	100%	7	2	a
mf-d98	2009	mf_protforest_nm.shp	1:50,000	Protected forest areas, Mabira area	NFA HQ	forestry map	5	4	1	5	3	.	100%	7	5	a

Appendix A3 Geodatasets with data quality assessments for the Budongo Forest area. Datasets without dates in their abbreviated title represent the most up-to-date datasets available to BIOTA-E02 regarding the subject matter. (See legend at start of Appendix A for explanation of abbreviations and of the data quality assessment).

Number	Date	File name	Scale/ Resolution	Abbreviated title	Source	Lineage	Data quality assessment									
							Li	PA	AA1	AA2	LC	Co1	Co2	Co3	Ti1	Ti2
bf-d1	1900	bf_pop1900_nm.shp	1:2,500,000	Population density, Budongo area, 1900	.	thematic map	2	1	3	1	3	100%	.	7	5	a
bf-d2	1911	bf_topmap1911_nm.tif	1:250,000	Topographic map of Hoima, 1911	SPerthes	topo map	3	3	.	4	3	100%	.	7	4	a
bf-d3	1911	bf_forcov1911_nm.shp	1:250,000	Forest cover, Budongo area, 1911	.	topo map	3	3	0	4	3	100%	.	7	4	a
bf-d4	1911	bf_bush1911_nm.shp	1:250,000	Bushcover, Budongo area, 1911	.	topo map	3	3	0	4	4	100%	.	7	4	a
bf-d5	1911	bf_agric1911_nm.shp	1:250,000	Agriculture, Budongo area, 1911	.	topo map	3	3	0	3	3	100%	.	7	4	a
bf-d6	1919	bf_topmap1919_nm.tif	1:1,000,000	Topographic map, Uganda, 1919	PSLib.	topo map	3	1	.	3	3	100%	.	7	5	a
bf-d7	1921	bf_popmap1921_nm.tif	1:1,500,000	Map of population, Budongo area, 1921	NA UK	thematic map	3	1	.	2	3	100%	.	7	4	a
bf-d8	1921	bf_pop1921_nm.shp	1:1,500,000	Population, Budongo area, 1921	.	thematic map	3	2	3	2	3	100%	.	7	4	a
bf-d9	1925	bf_topmap1925_nm.tif	1:250,000	Topographic map of the Budongo area, 1925	Ug. Soc.	topo map	3	3	.	4	3	.	80%	5	5	b
bf-d10	1925	bf_forcov1925_nm.shp	1:250,000	Forest cover of Budongo Forest, 1925	.	topo map	3	3	0	4	3	.	80%	5	5	b

Number	Date	File name	Scale/ Resolution	Abbreviated title	Source	Lineage	Data quality assessment									
							Li	PA	AA1	AA2	LC	Co1	Co2	Co3	Ti1	Ti2
bf-d11	1932	bf_mahogmap1932_nm.tif	1:12,150	Map of Budongo Mahogany areas, 1932	NFA HQ	forestry map	2	3	.	3	3	.	60%	4	4	a
bf-d12	1932	bf_mahog1932_nm.shp	1:12,150	Budongo Mahogany areas, 1932	.	forestry map	2	3	1	3	3	.	60%	4	4	a
bf-d13	1947	bf_busingmap1947_nm.tif	1:50,000	Map of forest cover, Busingiro, 1947	Egg. 1947	forestry sketch	4	5	.	4	3	.	10%	1	5	a
bf-d14	1947	bf_busing1947_nm.shp	1:50,000	Forest cover, Busingiro, 1947	.	forestry sketch	4	5	1	4	3	.	10%	1	5	a
bf-d15	1950	bf_coupemap1950_nm.tif	1:50,000	Map of Budongo and Siba Forests, 1950	NFA HQ	forestry map	4	4	.	5	3	.	80%	5	5	a
bf-d16	1950	bf_coupes1950_nm.shp	1:50,000	Coupes of Budongo and Siba, 1950	.	forestry map	4	4	2	4	3	.	80%	5	5	b
bf-d17	1950	bf_estates1950_nm.shp	1:50,000	Plantation estates, Budongo area, 1950	.	forestry map	4	4	1	4	3	50%	.	4	5	b
bf-d18	1950	bf_forcov1950_nm.shp	1:50,000	Forest cover, Budongo, 1950	.	forestry map	4	4	0	5	3	.	80%	5	5	b
bf-d19	1959	bf_popmap1959_nm.tif	1:1,250,000	Map of population, Budongo area, 1959	.	thematic map	3	1	.	4	2	100%	.	7	4	a
bf-d20	1959	bf_pop1959_nm.shp	1:1,250,000	Population, Budongo area, 1959	.	thematic map	3	1	5	4	3	100%	.	7	4	a
bf-d21	1960	bf_airmos1960_kh.tif	1:30,000	Aerial photo mosaic, Budongo area, 1960	LSD Ug.	aerial photo	4	4	.	3	3	.	100%	7	5	a
bf-d22	1960	bf_airmosint1960_nm.shp	1:30,000	Land cover classes, Budongo, 1960	.	aerial photo	4	4	2	3	3	.	100%	7	5	a
bf-d23	1966	bf_topmap_kh.tif	1:50,000	Topographic map of the Budongo area	SBib.	topo map	5	4	.	5	3	100%	.	7	3	b
bf-d24	1966	bf_bush_kh.shp	1:50,000	Bushland, Budongo area	.	topo map	5	4	0	5	3	100%	.	7	3	b
bf-d25	1966	bf_forcov_kh.shp	1:50,000	Forest cover, Budongo area	.	topo map	5	4	0	5	3	100%	.	7	3	b
bf-d26	1966	bf_river_jn.shp	1:50,000	Rivers, Budongo area	.	topo map	5	4	0	4	3	100%	.	7	3	b
bf-d27	1969	bf_popmap1969_nm.tif	1:1,500,000	Map of population, Budongo area, 1969	LSD Ug.	thematic map	3	3	.	4	3	100%	.	7	5	a
bf-d28	1969	bf_pop1969_nm.shp	1:1,500,000	Population, Budongo area, 1969	.	thematic map	3	3	3	4	3	100%	.	7	5	a
bf-d29	1972	bf_satimg1972Sep13_tl.img	60 m	Landsat image, Budongo area, Sept. 1972	Eurimage	satellite image	4	3	.	.	3	100%	.	7	5	a
bf-d30	1973	bf_satimg1973Feb_tl.img	60 m	Landsat image, Budongo area, Feb. 1973	Eurimage	satellite image	4	3	.	.	3	100%	.	7	5	a
bf-d31	1972/73	bf_satclass1972-73_tl.img	60 m	Land cover classes, Budongo, 1972/73	.	satellite image	4	3	1	4	3	100%	.	7	5	a
bf-d32	1975	bf_satimg1975Dec_tl.img	60 m	Landsat image, Budongo area, Dec. 1975	Eurimage	satellite image	4	3	.	.	3	100%	.	7	5	a
bf-d33	1975	bf_satclass1975_tl.img	60 m	Land cover classes, Budongo, 1975	.	satellite image	4	3	1	4	3	100%	.	7	5	a
bf-d34	1980	bf_popmap1980_nm.tif	1:1,250,000	Map of constituencies, Budongo area,1980	LSD Ug.	thematic map	3	2	.	4	3	100%	.	7	5	a
bf-d35	1980	bf_pop1980_nm.shp	1:1,250,000	Population, Budongo area, 1980	.	thematic map	3	2	5	4	3	100%	.	7	5	a
bf-d36	1986	bf_satimg1986Jan_tl.img	30 m	Landsat image, Budongo area, Jan. 1986	Eurimage	satellite image	4	3	.	.	3	100%	.	7	5	a
bf-d37	1986	bf_satimg1986Dec_tl.img	30 m	Landsat image, Budongo area, Dec. 1986	Eurimage	satellite image	4	3	.	.	3	100%	.	7	5	a
bf-d38	1986	bf_satclass1986_tl.img	30 m	Land cover classes, Budongo, 1986	.	satellite image	4	3	1	4	3	100%	.	7	5	a
bf-d39	1990	bf_satimg1990Dec_tl.img	30 m	Landsat image, Budongo area, Dec. 1990	Eurimage	satellite image	4	3	.	.	3	100%	.	7	5	a
bf-d40	1990	bf_satclass1990_tl.img	30 m	Land cover classes, Budongo, 1990	.	satellite image	4	3	1	4	3	100%	.	7	5	a
bf-d41	1991	bf_pop1991_nm.shp	1:50,000	Population, Budongo area, 1991	.	thematic map	4	4	7	4	3	100%	.	7	5	a
bf-d42	1990/91	bf_inventmapa1990-91_nm.tif	1:30,000	Inventory map A, Budongo, 1990/91,	NFA HQ	forestry map	4	4	.	4	3	.	100%	7	5	a
bf-d43	1990/91	bf_inventmapb1990-91_nm.tif	1:30,000	Inventory map B, Budongo, 1990/91,	NFA HQ	forestry map	4	4	.	4	3	.	100%	7	5	a
bf-d44	1990/91	bf_inventmapc1990-91_nm.tif	1:30,000	Inventory map C, Budongo, 1990/91,	NFA HQ	forestry map	4	4	.	4	3	.	100%	7	5	a
bf-d45	1990/91	bf_inventmapd1990-91_nm.tif	1:30,000	Inventory map D, Budongo, 1990/91,	NFA HQ	forestry map	4	4	.	4	3	.	100%	7	5	a
bf-d46	1990/91	bf_covertype1990-91_nm.shp	1:30,000	Forest cover types, Budongo, 1990/91	.	forestry map	4	4	1	4	3	.	100%	7	5	a
bf-d47	1991	bf_inventmap1991_nm.tif	1:150,000	Map of forest types, Budongo, 1991	How. 1991	forestry map	3	2	.	3	3	.	80%	5	5	b
bf-d48	1991	bf_covertype1991_nm.shp	1:150,000	Forest cover types, Budongo, 1991	.	forestry map	3	2	1	3	3	.	80%	5	5	b
bf-d49	1991	bf_admin1991_nfa.shp	1:50,000	Administrative units, Budongo area, 1991	NFA HQ	topo map	4	4	4	4	3	100%	.	7	5	a
bf-d50	1994	bf_luc_nfa.shp	1:50,000	Land use/cover, Budongo area	NFA HQ	thematic map	4	4	5	4	3	100%	.	7	3	b
bf-d51	1994	bf_road_nfa.shp	1:50,000	Roads, Budongo area	NFA HQ	topo map	5	4	1	4	3	100%	.	7	3	b
bf-d52	1994	bf_gaz_nfa.shp	1:50,000	Gazetted forest reserves, Budongo area	NFA HQ	forestry map	4	3	3	5	3	100%	.	7	5	b
bf-d53	1995	bf_satimg1995Jan_tl.img	30 m	Landsat image, Budongo area, Jan 1995	Eurimage	satellite image	4	3	.	.	3	100%	.	7	5	a
bf-d54	1995	bf_satimg1995Mar_tl.img	30 m	Landsat image, Budongo area, March 1995	Eurimage	satellite image	4	3	.	.	3	100%	.	7	5	a
bf-d55	1995	bf_satclass1995_tl.img	30 m	Land cover classes, Budongo area, 1995	.	satellite image	4	3	1	4	3	100%	.	7	5	a

Number	Date	File name	Scale/ Resolution	Abbreviated title	Source	Lineage	Data quality assessment									
							Li	PA	AA1	AA2	LC	Co1	Co2	Co3	Ti1	Ti2
bf-d56	2000	bf_satimg2000Feb_tl.img	30 m	Landsat image, Budongo area, Feb 2000	Eurimage	satellite image	4	3	.	.	3	100%	.	7	5	a
bf-d57	2000	bf_satimg2000May_tl.img	30 m	Landsat image, Budongo area, May 2000	Eurimage	satellite image	4	3	.	.	3	100%	.	7	5	a
bf-d58	2000	bf_satclass2000_tl.img	30 m	Land cover classes, Budongo area, 2000	.	satellite image	4	3	1	4	3	100%	.	7	5	a
bf-d59	2002	bf_pop2002_nm.shp	1:50,000	Population, Budongo area, 2002	UBOS	thematic map	4	4	7	4	3	100%	.	7	5	a
bf-d60	2002	bf_admin_nm.shp	1:50,000	Administrative boundaries, Budongo area, 2002	UBOS	thematic map	4	4	3	4	3	100%	.	7	5	a
bf-d61	2003	bf_satimg2003Feb_tl.img	30 m	Landsat image, Budongo area, Feb 2003	Eurimage	satellite image	4	3	.	.	3	100%	.	7	5	a
bf-d62	2003	bf_satclass2003.img	30 m	Land cover classes, Budongo area, 2003	.	satellite image	4	3	1	4	3	100%	.	7	5	a
bf-d63	2005	bf_cmpts_nfa.shp	1:50,000	Forest compartments, Budongo	NFA HQ	forestry map	4	4	2	4	3	.	100%	7	5	a
bf-d64	2005/06	bf_intview2005-06_nm.shp	1:50,000	Forest-adjacent interviews, Budongo area	.	field work	3	3	12	3	2	100%	.	7	2	b
bf-d65	2009	bf_indexfcc_nm.shp	1:50,000	Forest cover change index, Budongo area, 1960-2003	.	aerial photo	4	4	1	4	3	100%	.	7	2	a
bf-d66	2009	bf_indexlocaldist_nm.shp	1:100,000	Local disturbance index, Budongo	.	thematic map	3	3	1	3	3	.	100%	7	5	a
bf-d67	2009	bf_indexcomdist_nm.shp	1:50,000	Commercial disturbance index, Budongo	.	forestry map	3	3	16	3	3	.	100%	7	2	a
bf-d68	2009	bf_protforest_nm.shp	1:50,000	Protected forest areas, Budongo area	NFA HQ	forestry map	5	4	1	5	3	.	100%	7	5	a

Appendix A4 Non-georeferenced maps referred to in the text.

Reference	Date	Scale	Title	Source	Archive reference code
refmap1	1899	1:760,320	Military sketch map, Intelligence Report no. 8, Captain Hicks, Uganda Rifles Brigade	NA UK	MR 1/1013/14
refmap2	1906	1:633,600	Map no. 1. Sleeping sickness and *Glossina palpalis* in the Uganda Protectorate	NA UK	MR/1/1395 Map I
refmap3	1906	1:1,900,800	Map no. IV, Sleeping sickness extended investigation report	NA UK	MR 1/1395 Map IV
refmap4	1906	c. 1:250,000	Budongo Forest as harvested for rubber by the East African Trading Company	NA UK	CO 879/95
refmap5	1915	1:633,600	Map VI, Old and new plague areas	NA UK	MPG 1/1114/4
refmap6	1977	c. 1:20,000	Mabira Forest compartment 173, cultivation licence allocation	NFA Lwan.	‘Encroachments' file, p. 114
refmap7	1978	1:1,000,000	Afrika Kartenwerk Sheet E10: Linguistik / Linguistics / Linguistique	-	-

Appendix B1 Place name evidence showing translations to scientific names and the resulting land cover inferences. Places with more than one name reflect instances in which more than one version or spelling was given. See chapter 2.6 and case studies 1 and 2. ('n/a' – not applicable; 'tree cover (unclass.)' – tree cover unclassified, i.e. could relate to a broad range of land cover possibilities that include trees: from 'wooded grassland' to 'forest'.)

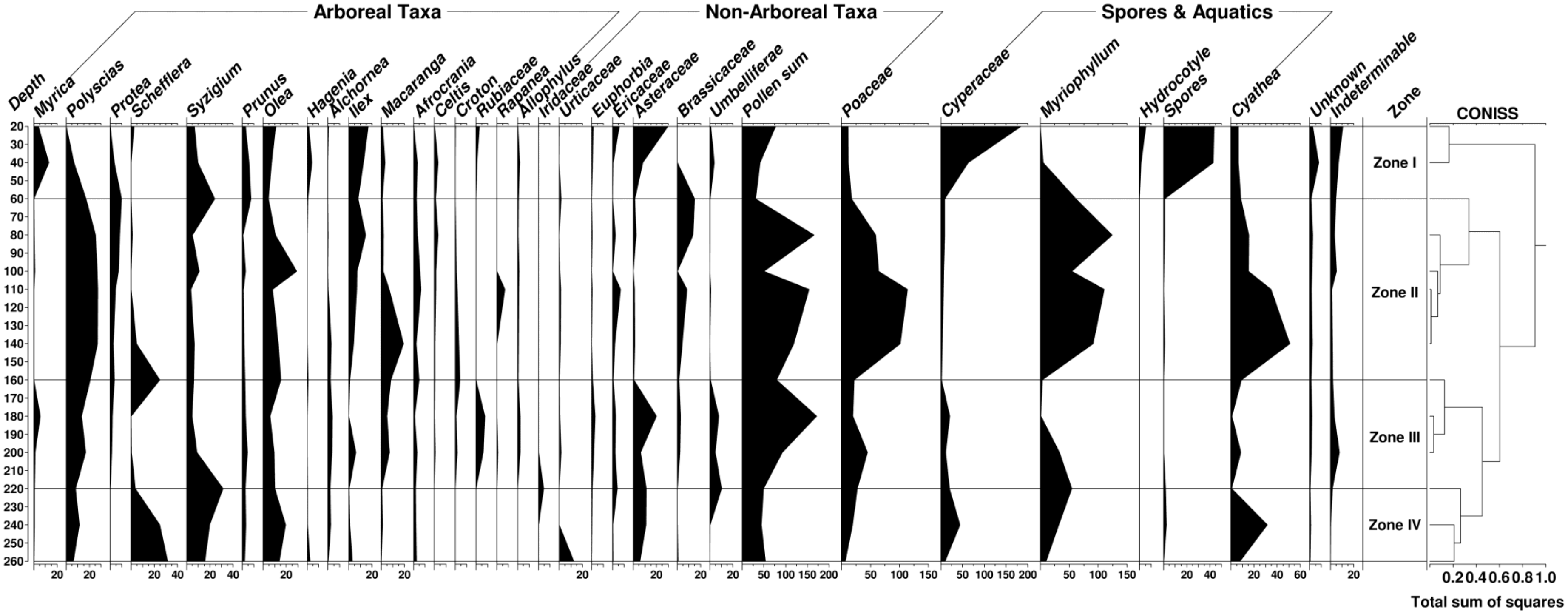
Place	Root word	Meaning	Type	Scientific name	Land cover
Alutali	lutali	lutali tree	tree	*Manilkara butugi*	forest
Amuyundi	amuyundi	Bronze Mannikin bird	bird	*Lonchura cucullata*	grassland / open
Avikeke	avikeke	termites	insect	unknown	grassland / open
Bukhaywa	mukhaywa	mukhaywa tree	tree	*Macaranga kilimandscharica*	forest
Butsotso / Mutsotso	butsotso, mutsotso	mutsotso tree	shrub	*Alchornea laxiflora*	tree cover (unclass.)
Buyangu	buyangu	open space	opening	n/a	grassland / open
Chemagas	unknown	forests	forest	n/a	forest
Chemogonja	unknown	chemogonja tree	tree	unknown	tree cover (unclass.)
Chemundu	unknown	grasshoppers, large	insect	unknown	grassland / open
Chepchur	unknown	without trees	opening	n/a	grassland / open
Chepchur	chepchur	hot, open place	opening	n/a	grassland / open
Chepkober	koberiat, koberik	koberiat tree	tree	unknown	tree cover (unclass.)
Chepkongony	kungonyot	Grey Crowned Crane	bird	*Balearica regulorum*	grassland / open
Chepnoet	unknown	unknown tree species	tree	unknown	tree cover (unclass.)
Chepsogor	sogoriet, sogorik	tsetse fly	insect	*Glossina* sp.	woodland
Chepsoton	unknown	kalabash i.e. gourd	tree	unknown	tree cover (unclass.)
Cheptilil Suswa	unknown	clear, grass	grass	unknown	grassland / open
Cheptuiyet	cheptuyet	cheptuyet tree	tree	*Diospyros abyssinica*	forest
Cheptuiyet	cheptuyet	cheptuyet tree	tree	*Diospyros abyssinica*	forest
Chepyewet	cheptuyet	cheptuyet tree	tree	*Diospyros abyssinica*	forest
Chepyewet	cheptuyet	cheptuyet tree	tree	*Diospyros abyssinica*	forest
Chimangeti / Kimanget	kimangetia	hyena	mammal	*Hyaena* sp.	wooded grassland
Chomisia	chomisiat, chomisia	chomisiat tree	tree	*Ficus exasperata*	forest
Efikoye	shikoye	shikoye tree	tree	*Psydrax schimperiana*	woodland
El'longo	el'longo	Napier-like grass for baskets	grass	unknown	grassland / open
Emakale	emakale	grass for thatching	grass	unknown	grassland / open
Emasutswi / Emasutsu	musutsu	musutsu tree	tree	*Croton macrostachyus*	tree cover (unclass.)
Emucango / Mukango	mukango	mukango tree	tree	*Aningeria altissima*	forest
Eshikhumu	shikhuma	eshikhumu tree	tree	*Zanthoxylem gillettii*	forest
Eshikunga	likunga	likunga tree	tree	*Acacia laha*	woodland
Fugoye	fugoye	rope from the forest soil	root / shrub	unknown	forest
Ibusamia / Busamia	misamia, busamia	misamia / busamia trees & fruits	tree	*Bequaertiodendron oblanceolatum*	forest
Iguhu	iguhu	tsetse fly	insect	*Glossina* sp.	woodland
Ikikondi / Kegondi	ikikondi, kegondi	grass for grazing	grass	unknown	grassland / open
Ilungu	ilungu	Napier-like grass for baskets	grass	unknown	grassland / open
Ilunyenye	lunyenye	lunyenye tree	tree	*Acacia abyssinica*	woodland
Imakholove / Bukholove	makholove, bukholove	Common Bulbul	bird	*Pycnonotus barbatus*	tree cover (unclass.)
Imakhuvu / Imakhuva	makhuvu	makhuvu shrub	shrub	*Dracaena fragrans*	forest
Imalaha	malaha	malaha tree	tree	*Combretum molle*	woodland
Imatsu / Ematsuri	matsu	stick-like grass	grass	n/a	grassland / open
Imukavakava	mukavakava, imukava	mukavakava tree	tree	*Ficus lutea*	forest
Imusuthu	musutsu	musutsu tree	tree	*Croton macrostachyus*	tree cover (unclass.)
Imutoto	mutoto	mutoto tree	tree	*(perhaps Ficus thonningii*	tree cover (unclass.)
Inderema / Shianderema	nderema	nderema vegetables near rivers	root / shrub	*Basella alba*	bushland
Ishavilaha	ishavilaha	vilaha tree	tree	*Combretum molle*	woodland
Ishiamabwoni	mabwoni	sweet potatoes 'glade potatoes'	food	unknown	secondary forest
Ishikulilu	ishikulilu	opening	opening	n/a	grassland / open
Ishivembe	ishivembe	shivembe grass for thatching	grass	unknown	grassland / open
Isiola	isiola	isiola tree	tree	*Markhamia lutea*	forest
Isulu	isulu	small forest	forest	n/a	forest
Ivakale	ivakale, makale	nothing found, nobody seen	opening	n/a	grassland / open
Ivokondi / Ivukondi	kikondi	kikondi grass, short, for grazing	grass	unknown	grassland / open
Ivona	ivona	ivona woodland	tree	*Acacia abyssinica*	woodland
Kaigat	unknown	tree species	tree	unknown	tree cover (unclass.)
Kakalelwa	kakalelwa	"squirrel forest"	forest	n/a	forest
Kakunga	mukunga	mukunga tree	tree	*Acacia laha*	woodland
Kakunga village	mukunga	mukunga tree	tree	*Acacia laha*	woodland
Kalunya	unknown	imperata grass for thatching	grass	*Imperata*	grassland / open
Kamimei	unknown	open area, where people discuss	opening	n/a	grassland / open
Kamobo	mobet	mobet tree	tree	*Markhamia lutea*	forest
Kamogo / Kamogonchoi	kamogo, mogochet	kamogo tree	tree	*Acacia abyssinica*	woodland

Place	Root word	Meaning	Type	Scientific name	Land cover
Kamogoiywa	mogoiywet, mogoinik	mogoiywet tree	tree	*Ficus sur*	riverine-watery
Kamoiywa	moiywok	moiywok tree	tree	unknown	tree cover (unclass.)
Kamoson	moset, mosonik	Olive Baboon	mammal	*Papio anubis*	woodland
Kamulembe	murembe	murembe / red-hot poker tree	tree	*Erythrina abyssinica*	wooded grassland
Kamurguiywa	murguiwet, murguonik	murguiwet tree	tree	*Olea capensis*	forest
Kamurkuywa	unknown	murguiwet tree	tree	*Olea capensis*	forest
Kanyarwate	nyarwat, nyaronik	nyawat tree	tree	unknown	tree cover (unclass.)
Kapchepkok	chepkokit	honey badger	mammal	*Mellivoraÿcapensis*	woodland
Kapchorua	choruet	choruet tree	tree	*Buddleia polystachya*	tree cover (unclass.)
Kapewai	ewat, ewek	ewat tree	tree	*Schefflera abyssinica*	tree cover (unclass.)
Kapkangani	kungonyot	Grey Crowned Crane	bird	*Balearica regulorum*	grassland / open
Kapkesenkin	unknown	tree species	tree	unknown	tree cover (unclass.)
Kapkimagetoi	unknown	hyena's place	mammal	*Hyaena* sp.	wooded grassland
Kapkoroit	unknown	colobus monkey	mammal	*Colobus guereza*	forest
Kapkures	kuresiet, kuresik	kuresiet tree	tree	*Euphorbia candellabrum*	woodland
Kapkures	kuresiet, kuresi	kuresiet tree	tree	*Euphorbia candellabrum*	woodland
Kaplamai	lamaywet	lamaiywet tree	tree	*Syzygium guineense*	tree cover (unclass.)
Kapn'getuny	ngetundo, ngetunyik	place of lion	mammal	*Panthera leo*	wooded grassland
Kapsabet	sabetiet , sabetonok	sabetiet tree	tree	*Spathodea campanulata*	secondary forest
Kapsakawat	sakawatiet	sakawatiet tree	tree	*Zanthoxylem gillettii*	forest
Kapsaos	unknown	swamp	water	n/a	riverine-watery
Kapsaos	unknown	swamp	water	n/a	riverine-watery
Kapsasur	sasurwet, sasuronik	sasurwet tree / wild banana	tree	*Ensete edule*	forest
Kapserton	unknown	tree species	tree	unknown	tree cover (unclass.)
Kapserton	unknown	tree species	tree	unknown	tree cover (unclass.)
Kaptoroi	teret, terok	wild forest pigs	mammal	unknown	forest
Kaptel	unknown	teldet tree	tree	*Ekeburgia capensis*	forest
Kaptel	teldet	teldet tree	tree	*Ekeburgia capensis*	forest
Kaptendon	unknown	tree species	tree	unknown	tree cover (unclass.)
Kaptendwan	unknown	teldet tree	tree	*Ekeburgia capensis*	forest
Kaptumo	tumoyat	tumoek / tumeyiot tree	tree	unknown	tree cover (unclass.)
Kebulonik	kebulonik, keb	kemelyet tree	tree	*Combretum molle*	wooded grassland
Kemeloi	kemelyet	tree species	tree	*Combretum molle*	wooded grassland
Kibebetiet	kiibebetiet	bird	tree	*Bersama abyssinica*	riverine-watery
Kimolwet	kimolwet	kimolwet tree	tree	*Vangueria infausta*	tree cover (unclass.)
Kipsamoite	samoitet	samutet tree	tree	*Cordia africana*	tree cover (unclass.)
Kipsirwa	unknown	tree species	tree	unknown	tree cover (unclass.)
Kipsirya	siryat	siryat tree	tree	*Rhus natalensis*	woodland
Kiritu / Kilitu	kiritu, kilitu	small forest (here mutava trees)	forest	n/a	forest
Kiropget	ropget	place alongside trees	openness	n/a	grassland / open
Koibem	koibem	grass	grass	unknown	grassland / open
Koiparak	koiparak	Nandi name for tree	tree	n/a	tree cover (unclass.)
Koisalik	koisoliat, koisolik	koisoliat, a tall grass	grass	unknown	grassland / open
Koisoliat	koisoliat, koisolik	koisoliat, a tall grass	grass	unknown	grassland / open
Koli	koli	scores: an open place for games	opening	n/a	grassland / open
Kosirai	unknown	grass	grass	unknown	grassland / open
Kyambiti	kyambiti	place of hyenas	mammal	*Hyaena* sp.	wooded grassland
Lirhembe	murembe	red-hot poker tree	tree	*Erythrina abyssinica*	wooded grassland
Lukango	mukango	mukango tree	tree	*Aningeria altissima*	forest
Lukanji	lukanji	grass, short, for grazing	grass	unknown	grassland / open
Lunyenye / Lwamanyenye	munyenye	munyenye tree	tree	*Acacia abyssinica*	woodland
Lusengeli	musingere, lusingel	musengere tree	tree	unknown	tree cover (unclass.)
Lusero	ilusero	place without grass or vegetation	opening	n/a	grassland / open
Lusiola	lusiola	lusiola tree	tree	*Markhamia lutea*	forest
Lusui	lusui	lusui tree	tree	*Diospyros abyssinica*	forest
Luvambi / Luvambo	luvambi, luvambo	luvambo tree	tree	*Nuxia congesta*	forest
Luvambo	luvambi, luvambo	luvambo tree	tree	*Nuxia congesta*	forest
Lwamakhuvu	lwamakholoven	lwamakholoven grass	grass	unknown	grassland / open
Lwamanani	lwamanani	hyena	mammal	*Hyaena* sp.	wooded grassland
Lwangare / Ilwangale	lwangare, ilwangale	no trees or grass or vegetation	opening	n/a	grassland / open
Makale	makale	makale grass for thatching	grass	unknown	grassland / open
Makhokho	likhokho, makhokho	Pied Crow	bird	*Corvus albus*	grassland / open
Makhomo	makhomo	makhomo shrub	root / shrub	*Chaetacme aris*	forest
Makhonje	makhonje	makhonje tree	tree	*Terminalia mollis*	wooded grassland
Makhwavuya	makhwavuya	makhwavuya tree	tree	unknown	tree cover (unclass.)
Makuche	inguche	place of baboons	mammal	*Papio anubis*	woodland
Makuchi / Imakuchi	makuchi, imakuchi	place of baboons	mammal	*Papio anubis*	woodland
Malaba	hulava	clear of trees, you can see far	opening	n/a	grassland / open
Masati / Emasatsi	masati, emasatsi	musatsi tree	tree	*Ensete edule*	forest

Place	Root word	Meaning	Type	Scientific name	Land cover
Masiyenze	misiyenze	misiyenze tree	tree	unknown	woodland
Matsitsi	masitsi, lisitsi	masistsi tree	tree	*Ensete edule*	forest
Matundu	matundu	matundu shrub or tall grass	root / shrub	unknown	grassland / open
Mbitondo	mutondo	mutondo tree	tree	*Funtumia africana*	forest
Meswa	meswat, mesonik	meswat shrubs	root / shrub	unknown	tree cover (unclass.)
Mihande / Mkhanda	mhanda	mhanda tree	tree	*Craibia brownii*	forest
Mokobenik	mokobenik, mokobet	mokobenik tree	tree	unknown	tree cover (unclass.)
Morogniot	morogniot	morogniot grass	grass	unknown	grassland / open
Mosombero	mosomboryet	mosomboryet tree	tree	*Faurea saligna*	wooded grassland
Mudete / Mutete	mutete	mudete tree	tree	*Maesopsis eminii*	forest
Mugomati	mukomari	mukomari tree	tree	*Cordia africana*	tree cover (unclass.)
Mugumari	mukomari	mukomari tree	tree	*Cordia africana*	tree cover (unclass.)
Muhudu	muhudu	muhudu tree	tree	*Vitex doniana*	bushland
Mukaba	mukaba	mukava tree	tree	*Ficus lutea*	tree cover (unclass.)
Mukango	mukango, mukangu	mukangu tree	tree	*Aningeria altissima*	forest
Mukangu	mukango, mukangu	mukangu tree	tree	*Aningeria altissima*	forest
Mukarama	mukarama	mukarama tree	tree	unknown	tree cover (unclass.)
Mukava	mukava	mukava tree	tree	*Ficus lutea*	tree cover (unclass.)
Mukayuni	mukayuni	mukayuni tree	tree	*Ficus* sp.	tree cover (unclass.)
Mukhonje	mukhonje, mikhonje	mukhonje tree	tree	*Terminalia mollis*	wooded grassland
Mukhonje	mukhonje, mikhonje	mukhonje tree	tree	*Terminalia mollis*	wooded grassland
Mukhonje	mukhonje, mikhonje	mukhonje tree	tree	*Terminalia mollis*	wooded grassland
Mukhonje	mukhonje / mikhonje	mukhonje tree	tree	*Terminalia mollis*	wooded grassland
Mukhonje	mukhonje, mikhonje	mukhonje tree	tree	*Terminalia mollis*	wooded grassland
Mukhuyu	mukhuyu	mukhuyu tree	tree	*Ficus sur*	riverine-watery
Mukhuyu	mukhuyu	mukhuyu tree	tree	*Ficus sur*	riverine-watery
Mukhuyu	mukhuyu	mukhuyu tree	tree	*Ficus sur*	riverine-watery
Mukingi	mukingi	mukingi tree	tree	unknown	tree cover (unclass.)
Mukomari	mukomari, mukumari	mukomari tree	tree	*Cordia africana*	tree cover (unclass.)
Mukomari / Imukomati	mukomari	mukomari tree	tree	*Cordia africana*	tree cover (unclass.)
Mukuli	mukuli	mukuli tree	tree	unknown	tree cover (unclass.)
Mukumu	mukumu	mukumu tree	tree	*Ficus thonningii*	tree cover (unclass.)
Mukuyu	mukhuyu	mukhuyu tree	tree	*Ficus sur*	riverine-watery
Mukuywa	mukuywa	open space	opening	n/a	grassland / open
Mululu	mululu	mululu tree	tree	*Chrysophyllum albidum*	forest
Mulundu	mulundu	mulundu	tree	*Antiaris toxicaria*	forest
Mulundu	mulundu	mulundu	tree	*Antiaris toxicaria*	forest
Mulundu	mulundu	mulundu	tree	*Antiaris toxicaria*	forest
Murhanda	murhanda	murhanda tree	tree	*Craibia brownii*	forest
Muriri	muriri	muriri tree	tree	*Trichilia emetica*	riverine-watery
Musasa	musasa	musasa tree	tree	*Sapium elipticum*	forest
Musasa	musasa	musasa tree	tree	*Sapium elipticum*	forest
Musavulenze	musavulenze	musavulenze tree	tree	unknown	forest
Musembe	musembe	unknown tree species	tree	*Entada abyssinica*	woodland
Musembe	musembe	unknown tree species	tree	*Entada abyssinica*	woodland
Musembe	musembe	unknown tree species	tree	*Entada abyssinica*	woodland
Museno	museno, liseno	museno tree	tree	*Ficus exasperata*	forest
Musine	musine	musine tree	tree	*Croton megalocarpus*	tree cover (unclass.)
Musingu	imusingu	musingu tree	tree	*Ficus sur*	riverine-watery
Musudzu / Musutsu	musutsu	musustu tree	tree	*Croton macrostachyus*	tree cover (unclass.)
Mutsulio	mutsulio, mutsulia	mutsulio tree	tree	*Spathodea campanulata*	secondary forest
Mutsulyu	mutsulio, mutsulia	mutsulio tree	tree	*Spathodea campanulata*	secondary forest
Mutsuria	mutsulio, mutsulia	mutsulio tree	tree	*Spathodea campanulata*	secondary forest
Mutukuyu	mutukuyu	Elgon Olive tree	tree	*Olea capensis*	forest
Mwilitsa / Mwiritsa	mwilitsa, mwiritsa	mwiritsa tree	tree	*Prunus africana*	forest
Mwilonje	mwilonje	mwilonje tree	tree	*Terminalia mollis*	wooded grassland
Mwitua	litua	tree with sap for hunting	tree	unknown	tree cover (unclass.)
Ngechebcha	ngecheberet	ngecheberet tree	tree	*Pouleria adolfi-friedereci*	tree cover (unclass.)
Nukya	nukyiat, nukyik	nukyiat tree	tree	*Dovyalis abyssinica*	tree cover (unclass.)
Oln'getuny	unknown	big lion	mammal	*Panthera leo*	wooded grassland
Sabatia	musabatia	sabatia tree	tree	*Cordia africana*	tree cover (unclass.)
Senetwet	senetwet, senetonik	senetwet tree	root / shrub	*Senna didymobotrya*	riverine-watery
Senyede	senyede	senyede bird	bird	unknown	secondary forest
Septanok	septanok	kalabash, a place to get gourds	tree	*Podocarpus latifolius*	forest
Shamakhokho	likhokho, makhokho	Pied Crow	bird	*Corvus albus*	wooded grassland
Shelelo / Sherero	shelelo, sherero	thorny tree	tree	unknown	tree cover (unclass.)
Sherewa	bushelelwa	bushelelwa shrub	root / shrub	*Rhus natalensis*	woodland
Sheywe	sheywe	grass for thatching	grass	n/a	grassland / open
Shidodo	shidodo	shidodo tree	tree	*Pavetta ternifolia*	forest
Shihingo	shihingo	creeping plant species	root / shrub	unknown	tree cover (unclass.)
Shikangania	shikangani	shikangania tree	tree	*Bridellia micrantha*	woodland

Place	Root word	Meaning	Type	Scientific name	Land cover
Shikomari	shikomari	mukomari tree	tree	*Cordia africana*	tree cover (unclass.)
Shikondi wa Milimu	shikondi	shikondi grass	grass	n/a	grassland / open
Shikulu	shikulu	a hill with forest	forest	n/a	forest
Shikulu / Shikuyu	mukhuyu	mukhuyu tree	tree	*Ficus sur*	riverine-watery
Shikusa	mukusa	mukusa climber for roofing ropes	root / shrub	*Hibiscus flaviolus*	grassland / open
Shinakos	shinakos	shinakos tree	tree	unknown	secondary forest
Shisejere / Shisekere	shisejere, shisekere	shisejere tree	tree	unknown	tree cover (unclass.)
Shiswa	shiswa, tsiswa	termites	insect	n/a	grassland / open
Shivanga	muvanga	muvanga tree	tree	*Harungana madagascarensis*	secondary forest
Siksik	siksiket	siksiket tree	tree	unknown	tree cover (unclass.)
Siksiket	siksiket	siksiket tree	tree	unknown	tree cover (unclass.)
Sisiola	lusiola	lusiola tree	tree	*Markhamia lutea*	forest
Soiyet	unknown	soiyet tree	tree	*Polyscias fulva*	forest
Soy	soy	warm grasslands, grassy plains	grass	n/a	grassland / open
Soy	soy	warm grasslands, grassy plains	grass	n/a	grassland / open
Surungai	unknown	grass	grass	unknown	grassland / open
Surungai	unknown	grass	grass	unknown	grassland / open
Tangaratwet	tangaratwet, tangaratok	tangaratwet tree	tree	unknown	tree cover (unclass.)
Tebeswet	unknown	tebeswet tree	tree	*Croton macrostachyus*	tree cover (unclass.)
Teresia	teresiat, indereresia	teresia / teresiat shrub	root / shrub	unknown	forest
Teresia	teresiat, indereresia	teresia / teressiat shrub	root / shrub	unknown	forest
Tilolwa	tilalwet, tololonik	tilalwet tree	tree	*Sclerocarya birrea*	wooded grassland
Vikoye / Ibikoye	shikoye, vikoyee	vikoyee tree	tree	*Psydrax schimperiana*	woodland
Virembe	murembe	red-hot poker tree	tree	*Erythrina abyssinica*	wooded grassland
Virembe	murembe	red-hot poker tree	tree	*Erythrina abyssinica*	wooded grassland
Imasindi	imasindi	grass for thatching & grazing	grass	n/a	grassland / open
Wumtich	unknown	cows gather	livestock	n/a	grassland / open

Appendix C1 Fossil pollen analysis.



Pollen diagram for soil core 1, near Shidodo, Kakamega District. The vertical axis marks the depth within the core from the ground surface; the horizontal axes left of the ‘Pollen sum’ show the percentages of the total pollen represented by the respective taxa; the horizontal axis of the ‘Pollen sum’ and those of the records to its right represent total counts of pollen and spores. The horizontal lines mark the divisions between zones 1 to IV as referred to in case study 1, radiocarbon dates are shown below. (With thanks to Rahab Kinyanjui of Museums of Kenya and Rob Marchant of York University, UK, for laboratory processing and interpretation).

Radiocarbon dates (AMS - Accelerator Mass Spectrometry dates from Beta Analytic Radiocarbon Dating Laboratory, Miami, Florida, USA)

Depth (cm)	Measured radiocarbon age	Conventional radiocarbon age	2-sigma calibration
80	1930 +/- 40 BP	1910 +/- 40 BP	Cal AD 10 to 210 (Cal BP 1940 to 1740)
110	2120 +/- 40 BP	2080 +/- 40 BP	Cal BC 200 to Cal AD 10 (Cal BP 2150 to 1940)
130	2530 +/- 40 BP	2480 +/- 40 BP	Cal BC 780 to 410 (Cal BP 2730 to 2360)
192	3910 +/- 40 BP	3880 +/- 40 BP	Cal BC 2470 to 2260 (Cal BP 4420 to 4220) and Cal BC 2260 to 2210 (Cal BP 4210 to 4160)

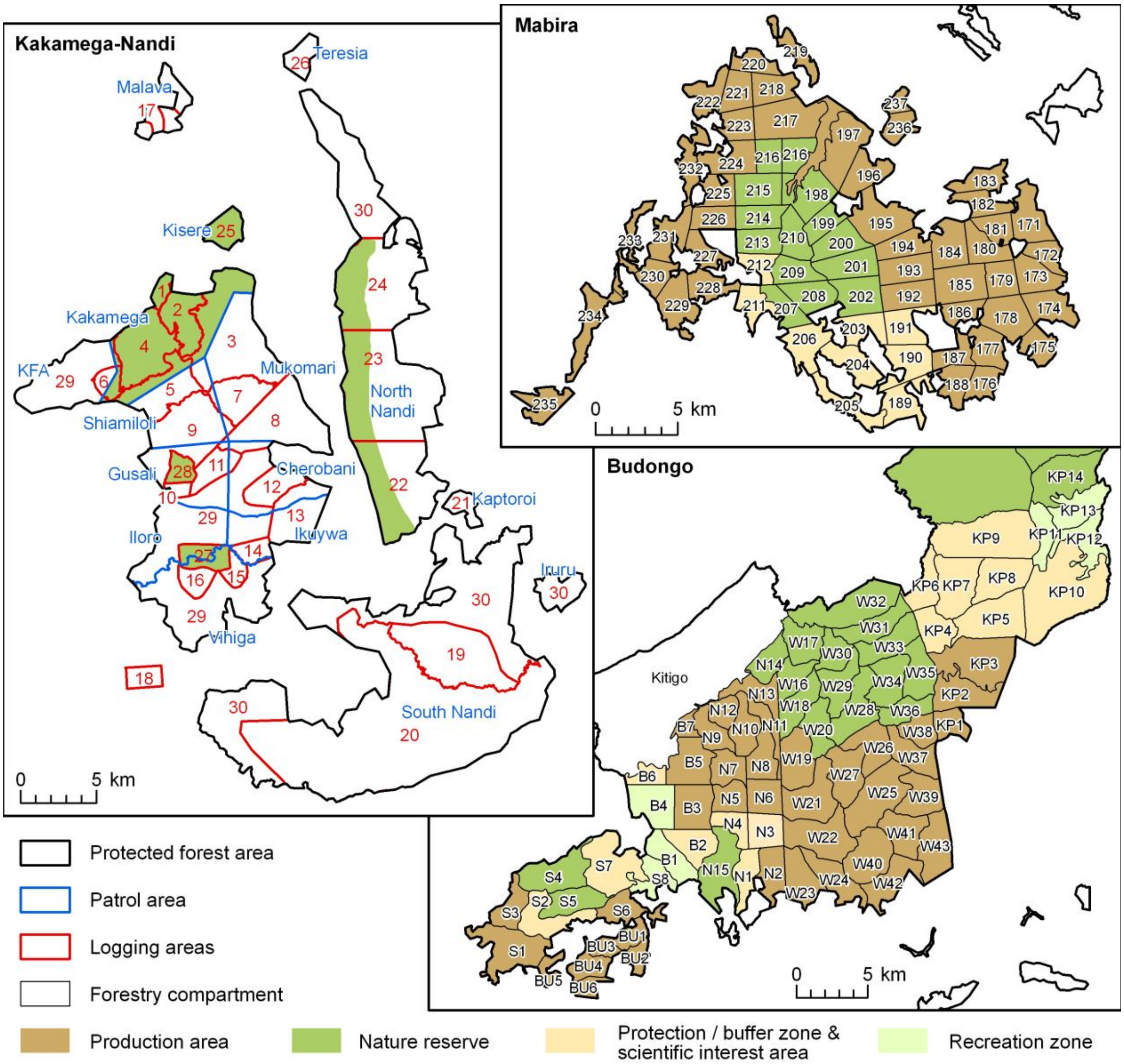
Appendix D1 End-notes for the forest narrative diagrams of chapter 4, i.e. Figures 4.1 to 4.3.

1. Verschuren (2001) reports that the 19th century in East African was much drier than any 20th century drought but followed a much wetter period.
2. The Uganda railway reached Kisumu in 1901 and Kampala in 1931; it greatly assisted in opening up western Kenya and Uganda to European development (Miller 1972).
3. Late 19th and early 20th century East Africa was beset by disease (e.g. rinderpest, sleeping sickness, influenza) and famine (Elliot 1896, Johnston 1902, IG Report 1925, IG Report 1935, Ng'eny 1970, Du Toit 1998, Doyle 2006, kn-i40, mf-i1).
4. Interviewees (kn-i1, 6) asserted that elephants caused tree clearance: the last seen in the Isecheno area was chased into a swamp where it died, around 1920; the last from Buyangu were heading north "to Mt. Elgon" before 1920 (Zimmerman 1972, *cf*. kn-i35).
5. Population figures relate to the extent of the respective aerial photography mosaics. Geodatasets were digitised from population maps and adjusted to account for the uninhabited forest areas. The 1918 density of the Kakamega-Nandi area has been generated from a total inhabitant figure from the 1918/19 annual report for North Kavirondo district (IG report 1918/19) and was attributed to administrative units digitised from 1921 and 1922 maps (kn-d11, 12); the remaining districts (16% of the area) were assigned figures as percentages of the known North Kavirondo figure based on the proportions of the 1948 districts.
6. Forest cover figures relate to the physical extent covered by the respective aerial photography mosaics. For timesteps since 1972 figures are derived from satellite imagery classifications; the 1948/52, 1955, 1960 and 1965/67 steps from aerial photography visual interpretations; the remaining steps from topographic and forestry maps. For all remote sensing steps forest cover is represented by classes 0, 1 and 2 (see Table 2.2). A majority filter was applied to the satellite imagery classifications outside the forest reserves to reduce the class 1 and 2 pixels in the farmland for compatibility with non raster-based timesteps.
7. Logging volumes have been compiled from original KFS records and annual reports (see chapters 2.3, 5.1, Appendix E3.2).
8. To account for plantations misclassified as classes 1 or 2 by the satellite imagery classifications, the forest cover figures between 1972 and 2003 have here been reduced with information derived from KFS maps. Kakamega-Nandi values were thus reduced by 3.3%; Mabira Forest figures were reduced by 5% in the post-restoration-planting timesteps (1989 and later) and by 1.5% in the pre-restoration steps (according to proportions indicated by forestry records).
9. The satellite imagery classifications of 1989 and 2001 are regarded by Lung (Lung 2004, T. Lung pers. comm.) as less reliable and forest cover figures are therefore shown here but not joined by the graph line.
10. Since the early 1990s international research and conservation programmes, e.g. KIFCON (e.g. Blackett 1994a-c), Columbia University (http://www.columbia.edu/~mc51/web-pages/Publications.html, 21/01/2010), and BIOTA (http://www.biota-africa.de, 21/01/2010), have had an on-site presence in Kakamega Forest. The most prominent conservation CBO is Kakamega Environmental Education Programme (KEEP), practicing both education and alternative income generation, it has several branches around the forest (http://www.columbia.edu/cu/e3b/conservation/KEEP/index.htm, 21/01/2010).
11. The path of the population density curve has been amended between 1921 and 1959 to reflect knowledge of low population density due to the pests and disease until the early 1950s *(cf*. Richards *et al*. 1973).
12. Interviewees report (mf-i7, 8) that pitsawing and charcoaling became serious problems under Idi Amin but agree with forest guards that CFM has reduced chain-sawing.
13. EU funding and the Natural Forest Management and Conservation Project of the Forestry Rehabilitation Programme enabled the restoration after encroachment (Karani *et al*. 1997a).
14. Conservation community-based organisations, e.g. Mabira Forest Integrated Conservation Organisation (MAFICO), and Collaborative Forest Management (CFM) have emerged as mutually beneficial (pers. comm. Leo Twinomuhangi).
15. Doyle 2006 references Baker, S. 1866.
16. To amend for cloud coverage obscuring parts of the 2003 and 1972/73 satellite imagery classifications values for these pixels have been substituted with those of the nearest timestep (i.e. 2000 and 1975, respectively) via an 'extraction by mask' function.
17. Paterson 1991 states that most of the plantations around the forest were coffee in the 1950s.

18. Following the return of law and order in the late 1980s, sugar, followed by tobacco brought employment opportunities (Reynolds 2005) although tobacco markets have since dropped dramatically (bf-i2).
19. Wire snares set to catch bush-meat animals increased dramatically with population and high poverty levels (Reynolds 2005)
20. Collaborative Forest Management (CFM) has been tried in several locations with positive results (e.g. bf-i15, 16)
21. Research and conservation has been spearheaded by Budongo Conservation Field Station BCFS (formerly Budongo Forest Project) (http://www.budongo.org, 21/01/2010) working with communities and the Kinyara sugar company.

Appendix E The creation of the spatially-explicit indices (see chapter 5.1).

Appendix E1 The forest compartments and areas used to create the disturbance indices.



Appendix E2 The creation of the values used in the local disturbance (LD) index.

Key to terms used in Appendices E2 to E4:
- PS – pitsawing
- CB – charcoal burning
- CFM – Collaborative Forest Management

Appendix E2.1 Values awarded in the distance-weighted inwards buffering of the forest boundary reflecting distance from nearest habitation and density of the adjacent population.

			Distance		
Population (inh./km^2)	**<1 km**	**1-2 km**	**2-3 km**	**3-4 km**	**4-5 km**
>1,000	10 / 5	9 / 5	7 / 4	4 / 2	2 / 1
651-1,000	9 / 5	8 / 4	6 / 3	3 / 2	2 / 1
401-650	7 / 4	6 / 3	3 / 2	2 / 1	1 / 1
251-400	5 / 3	4 / 2	3 / 2	2 / 1	1 / 1
151-250	4 / 2	3 / 2	2 / 1	1 / 1	-
0-150	3 / 2	2 / 1	1 / 1	-	-

Population densities were derived from 1999 census data for Kakamega-Nandi area (kn-d121), and from 2002 census data for the Mabira and Budongo areas (mf-d85, bf-d59). Six initial datasets, i.e. each of the population range groups, were buffered separately and then combined in the GIS with a ‘max’ function. The two values provided in each case reflect the population impact as evaluated differently for the forest / grassland.

Appendix E2.2 Values awarded in the buffering of roads reflecting decreasing accessibility to the forest with distance from roads.

	Distance (km)			
	<0.5	**0.5 - 1.0**	**1.0 - 1.5**	**1.5 - 2.0**
Main roads	4	3	2	1
Mid-sized roads	3	2	1	-
Minor roads	2	1	-	-
Path-entry points	2	1	-	-

The roads datasets (kn-d80, mf-d39, bf-d51) were originally digitised from the most recent 1:50,000 scale topographic maps (kn-d79, mf-d36, bf-d23); the classification of major, mid-sized and minor roads was made with the assistance of the topographic maps, remote sensing and knowledge of the area from observations during fieldwork. To further refine the dataset for the Kakamega-Nandi area, the point at which footpaths were marked on the topographic map as entering the forest reserves were buffered up to 0.5 km and 1 km and valued as per the table. The four contributing datasets, i.e. the different buffered road classes, were combined in the GIS with a ‘max’ function.

Appendix E2.3 Values awarded to reflect illegal activities in the Kakamega-Nandi forest area as recorded by KFS patrol records for 2005 and in combination with other disturbance notes. A map of the relevant patrol areas is provided in Appendix E1.

	Charcoal-burning (CB)				Pitsawing (PS)							
Patrol Area	**bags**	**arrests**	**bags plus arrests**	**re-scaled 1 to 10**	**logs**	**arrests**	**logs plus arrests**	**rescaled 1 to 10**	**PS plus CB**	**Rescaled 1 to 10**	**Disturbance level notes**	**Combined value**
Ikuywa	89	21 (49)	138	9	5	5 (25)	30	6	15	10	1991 & 2005/06: very high	9
Iloro	2	3 (7)	9	1	32	5 (25)	57	10	11	7	1991 & 2005/06: high	7
Shiamiloli	36	49 (114)	150	10	12	0	12	2	12	8	1970s/80s: encroach, 1991 & 2008: moderate	8
Cherobani	27	19 (44)	71	5	3	2 (10)	13	2	7	5	1991: moderate-high	6
Gusali	2	2 (5)	7	1	16	2 (10)	26	5	6	4	1991 & 2005/06: moderate	5
Mukomari	65	1 (2)	67	4	0	0	0	0	4	3	1991: moderate	4
Kakamega Fuel Area	2	5 (12)	14	1	4	1 (5)	9	2	3	2	1991: low	2
Vihiga	31	6 (15)	46	3	10	6 (29)	39	7	10	7	1991: high	7
Malava	12	3 (7)	19	1	3	2 (10)	13	3	4	3	2005/06: moderate-high	6
Bunyala	0	0	0	0	0	0	0	0	0	0	2005/06: low (grazing)	2
Kakamega, Kisere Nat. Reserves	-	-	-	-	-	-	-	-	-		1991 & 2005/06: low	2
N. Nandi, Teresia, Iruru	-	-	-	-	-	-	-	-	-		2005/06: moderate (CB)	5
S. Nandi, Kaptoroi	-	-	-	-	-	-	-	-	-		2005/06: high (CB)	7

Charcoal-burning and pitsawing statistics are taken from KFS patrol records for the full 12 months of 2005. They provide the basic measures of illegal activity but since arrests and the number of confiscated items (either bags of charcoal or sawn logs) represent widely differing figures in each individual instance, neither set of figures could be assumed to be a fair representation alone. The figures for the number of arrests were therefore normalised (in parentheses) with the number of confiscated items by scaling up proportionately before the two figures were added together and rescaled 1 to 10. The resulting figures for charcoaling and for pitsawing were then aggregated and again rescaled 1 to 10 for the final values. The column of disturbance notes is derived from KIFCON sight surveys (when denoted by the date 1991) that reflect the number of incidents of forest utilization (pitsawing, charcoal-burning, hunting, grazing, firewood collection, gold collecting, grass and fruit collection (n=1,162), from satellite imagery and interviews (as denoted by the date 1970s/80s), and from conversations with forest guards targeted to this issue and personal observations in 2005/06 and 2008 (as denoted by 2005/06, 2008). This information was used to create values for the lowest three rows of the table for which no patrol records were available. Records were present for Bunyala but there were no recorded offences due to its lack of indigenous forest cover.

Appendix E2.4 Values awarded to reflect illegal activities in the Mabira Forest as recorded by NFA patrol records for 2005, in combination with other disturbance notes. A map of the relevant forest compartments is provided in Appendix E1.

Compart-ment	Number of incidents PS	CB	PS plus CB	Rescaled 1 to 10	Disturbance level notes	Combined value
171	0	0	0	0	1970s/80s: fully encroached	10
172	0	0	0	0	1970s/80s: fully encroached; 2006: very high CB	10
173	0	0	0	0	1970s/80s: fully encroached; 1995 & 2006: high CB; 1997: moderate CB;	10
174	0	0	0	0	1970s/80s: fully encr.; 1995 & 2006: very high CB; 1997: moderate CB;	10
175 east	1	6	7	2	1970s/80s: fully encroached; 1995: very high CB; 1997: moderate CB;	10
175 west					1995: moderate PS, very high CB; 1997: moderate CB	6
176	2	4	6	2	1992: moderate CB; 1995: moderate PS, high CB; 1997: high CB	6
177	19	12	31	8	1992: high CB; 1995: moderate PS, very high CB; 1997: moderate CB	7
178 east	1	2	3	1	1970s/80s: fully encroached; 1995: moderate PS;	10
178 west					1995: moderate PS	3
179	3	0	3	1	1970s/80s: fully encroached	10
180	0	3	3	1	1970s/80s: fully encroached	10
181	6	0	6	2	1970s/80s: fully encroached; 1995: moderate PS	10
182	3	0	3	1	1970s/80s: fully encroached; 1995: moderate PS	10
183	3	15	18	5	1970s/80s: fully encroached; 1995: moderate PS	10
184	0	0	0	0	1970s/80s: fully encroached	10
185	1	0	1	0	1970s/80s: fully encroached	10
186	3	5	8	2	1995: moderate PS	4
187	34	5	39	10	1987: moderate CB; 1995: moderate PS	7
188 east	2	2	4	1	1995: moderate PS, very high CB; 1987 & 1997: moderate CB	5
188 west					1970s/80s: fully encroached; 1995: moderate PS, very high CB; 1987 & 1997: moderate CB	10
189 east	18	8	26	7	1970s/80s: fully encroached; 1995: high PS; 1987: moderate CB	10
189 west					1995: high PS; 1987: moderate CB	6
190	13	1	14	4	1970s/80s: fully encroached; 1995: moderate PS; 1987: moderate (CB & grazing)	10
191 east	6	1	7	2	1995: moderate PS	3
191 west					1970s/80s: fully encroached; 1995: moderate (PS & much grazing)	10
192	0	5	5	1	1995: moderate PS	3
193	0	0	0	0	1995: moderate PS	3
194	4	0	4	1	1995: moderate (PS & grazing)	3
195	12	25	37	9	1995: moderate PS	7
196	10	8	18	5	1970s/80s: fully encroached, 1995: moderate (grazing)	10
197 north	4	11	15	4	1970s/80s: mostly encroached	9
197 south					1970s/80s: partly encroached	6
201	0	0	0	0	1995: moderate PS	3
202	5	0	5	1	1995: moderate PS	3
203 east	12	2	14	4	1970s/80s: fully encroached; 1995: moderate (PS & grazing)	10
203 west					1995: moderate PS	4
204 east	13	16	29	7	1970s/80s: fully encroached; 1995: PS & very high (CB & very high grazing); 1997: moderate CB	10
204 west					1995: moderate PS & very high CB; 1997: moderate CB	7
205	6	9	15	4	1987: moderate CB; 1995: moderate PS, very high CB; 1997: high CB	6
206	1	16	17	4	1995: moderate PS, very high CB; 1997: high CB	6
207	32	43	75	10	1995: very high CB; 1997: moderate CB	8
208	0	0	0	0	1995: moderate PS	3
209	7	6	13	3	1997: Namaganda Hill encroachment by veterans 1945-61/62	5
210	0	0	0	0	1997: Namaganda Hill encroachment by veterans 1945-61/62	5
211	3	9	12	3	1997: prospecting for precious stones	3
213	1	0	1	0	(patrol records available only)	1
219	2	0	2	1	(patrol records available only)	1
220	4	0	4	1	(patrol records available only)	1
222	6	0	6	2	1995: one of 7 cmpts affected least by PS	2
223	0	2	2	1	(patrol records only available)	1
224	0	0	0	0	1995: one of 7 cmpts affected least by PS	1
225	0	0	0	0	1995: one of 7 cmpts affected least by PS	1
227	8	11	19	5	1995: one of 7 cmpts affected least by PS	4
228	5	7	12	3	1995: one of 7 cmpts affected least by PS	3
229	10	12	22	6	1995: one of 7 cmpts affected least by PS	5
230	0	1	1	0	1995: one of 7 cmpts affected least by PS	1
231	1	3	4	1	(patrol records available only)	1
233	1	11	12	3	(patrol records available only)	3
234	3	22	25	6	1987: moderate CB	6
235	0	0	0	0	1997: heavily encroached	8
236	8	13	21	5	1970s/80s: fully encroached	10
198-200,	0	0	0	0	*(no illegal activities are recorded by either the patrol records or the other*	1

Compart-ment	Number of incidents PS	CB	PS plus CB	Rescaled 1 to 10	Disturbance level notes	Combined value
212, 214-18, 221, 226, 232					*noted by forest guards and local people to be little disturbed)*	

Charcoal-burning and pitsawing statistics are taken from NFA patrol records for the full 12 months of 2005. They provide a basis for evaluating the level of illegal activity but since the patrols recorded no incidents in some of the compartments, the final evaluation per compartment represents a combination of patrol records and the information summarized in the disturbance notes column. The information given in the disturbance notes column is taken from satellite imagery (where denoted by the date of 1970s/80s), from foresters' annual reports (as denoted by 1987 and 1992), from an EC-funded project report, i.e. EC 1995 (denoted by 1995), from the 1997-2007 management plan, i.e. Karani *et al*. 1997a (denoted by 1997), and from personal observations and conversations with foresters and local people (as denoted by 2006).

Appendix E2.5 Values awarded to reflect illegal activites in Budongo Forest as identified from patrol records of 2005 and other NFA sources, both oral and written. A map of the relevant forest compartments is provided in Appendix E1.

Compartment	Disturbance notes	Value
B1	patrol: relatively high PS; 2006: high PS, fuelwood & pole-cutting	5
B2	2005: largest *Cordia* trees cut for boats, high PS & pole-cutting	5
B3	2005, 2006: fuelwood & pole-cutting	3
B4	patrol: relatively high PS; 2006: moderate PS, fuelwood & pole-cutting	4
B5	patrol & 2006: fuel & pole cutting	3
B6	patrol: modest PS; 2006: moderate PS, fuelwood & pole-cutting	4
B7	2006: modest CB	3
BU1	2005: modest CB	3
BU3	2005: modest CB	3
BU4	patrol & 2006: modest PS	3
BU5	2005 & 2006: modest PS	3
BU6	2006: modest CB	2
Kitigo	2006: moderate CB; annually burnt as a 'grassland'	3
KP1	2005: grazing & burnt; 2006: moderate CB	5
KP2	2005: grazing & burnt (due to boundary being undefined)	3
KP3	2005: grazing & burnt, moderate CB	3
KP5	2005: modest grazing & burning	2
KP11	2005: moderate PS & modest CB	4
KP12	2005: high PS & modest CB	4
KP13	2005: high PS & modest CB	4
N1	2005: generally disturbed; 2006: moderate PS before CFM (i.e. before 2005);	4
N2	patrol: moderate high PS; 2006: moderate CB	5
N3	2006: little illegal activity due to research station proximity	1
N4	2006: little illegal activity	1
N7	2006: boats cut from largest *Cordia* since new logging road made	3
N8	2006: boats cut from largest *Cordia* since new logging road made	2
N9	2006: boats cut from largest *Cordia* since new logging road made	3
N10	2006: moderate PS, new logging road gives access	3
N11	2006: moderate PS	2
N12	2006: moderate PS, new logging road gives access	3
N13	2006: moderate PS	2
N14	2006: no PS as immature forest	1
N15	patrol, 2006 & ground observations: very high PS	8
S1	2005: modest CB	3
S2	2005: modest CB	3
S3	2005: modest CB; 2006: fuelwood & pole-cutting	4
S4	2005: modest CB; 2006: moderate PS & fuelwood & pole-cutting;	4
S5	2005: modest CB; 2006: moderate PS	4
S6	2005: modest CB	3
S7	2005: modest CB; 2006: fuelwood & pole-cutting	3
S8	patrol: moderate PS, modest CB	3
W16	2005 & 2006: modest general disturbance	3
W17	2005: modest general disturbance	3
W19	2006: very little disturbance, very modest CB	1
W21	2006: very little disturbance, very modest CB	1
W22	2006: very little disturbance, very modest CB	1
W23	2005& 2006: high CB area (until 2006)	5
W24	patrol & 2005: moderate PS; 2006: high CB before CFM (i.e. before 2005)	3
W25	2006: moderate PS / high CB	5
W26	2006: moderate disturbance before CFM (i.e. before 2005)	3

W31	2005: modest CB	2
W32	2005: modest disturbance	2
W33	2005: modest disturbance	2
W36	2006: moderate CB & PS	4
W37	2006: moderate-high CB & PS	5
W38	2006: moderate disturbance	4
W39	2005: one of two highest for CB	6
W40	2006: moderate-high CB	5
W41	2006: moderate-high CB	5
W42	2006: encroachment & CB	6
W43	2005: highest for CB; 2006: hiugh CB before CFM (i.e. before 2005)	7
BU2, KP4, 6-10, 14, N5-6, W18, 20, 27-30, 34-35	*(no information was available and and are noted by foresters, forest guards and local people to be little disturbed)*	1

Patrol records for Budongo Forest were only partially available and consequently contribute only where denoted by the word ‘patrol’; other disturbance notes (denoted by the date 2005) are provided by multiple NFA correspondence on illegal activity in 2005, other information (denoted by the date 2006) is provided by foresters, forest guards and local people and by ground observations.

Appendix E2.6 Values awarded according to the protective status per forest reserve / forest zone.

Budongo Forest	Mabira Forest	Kakamega-Nandi forests	Value
		Kakamega National Reserve	1
Recreation Zone & N15 nature reserve	Nature reserve	Kisere National Reserve	2
Nature reserves	Recreation Zone	Nature reserves	3
Protection / Buffer Zone & Sites of Scientific Interest		Kakamega Forest Reserve (remainder)	4
Production Zone	Production Zone	Teresia, Malava, Bunyala, N. & S. Nandi, Kaptoroi, Iruru Forest Reserves	5
Nyabyeya Forestry College Reserve			6
		Kaimosi forest (privately managed)	7
Outlying forest reserves (minimally protected)			8
	Outlying forest reserves (effectively unprotected)		10

The values were awarded from an understanding gained mostly in 2005 and 2006 from numerous conversations with foresters, forest guards and field scientists, interviews with local people and, and from ground observations. See maps in Appendix E1, in the introduction and in case studies 4 and 8 for location of zones and reserves.

Appendix E2.7 Final reclassification scheme for ‘reducing’ aggregated values to final values for the LD index.

Aggregated values	Reclassified LD index value
1-2	1
3-4	2
5-6	3
7-9	4
10-12	5
13-15	6
16-18	7
19-20	8
21-22	9
23-24	10

Following the overlay (using ‘add’ function) of the four intermediate geodatasets contributing to the LD index of each forest (as derived from data shown in Appendices E2.1 to E2.6), the values were reclassified as per the values in the table above for the final LD index.

Appendix E3 The creation of the values used in the commercial disturbance (CD) index.

Key to terms:

- Log – selectively logged
- PS – pitsawing, i.e. indicative of a more selective and less intense felling
- CB – charcoal burning
- gold – gold prospecting / mining
- rubber – exploitation of wild rubber from c. 1906/07 (*Landolphia* spp. in the Nandi forests; *Funtumia elastica* in Mabira and Budongo Forests)
- peeler – felling for plywood/peeler industry, i.e. indicative heavy harvest of species other than traditional timber trees
- enrichment planted – planting various indigenous trees within a selectively logged forest (normally by group or line planting)

Maesopsis – Maesopsis eminii
A question mark (?) indicates uncertainty regarding the date or figure provided.

Appendix E3.1 Guideline criteria for the valuation of disturbance levels for the commercial disturbance (CD) index. The details of each area's exploitation are provided in Appendices E3.2 to E3.4.

Criteria	Disturbance Value
no commercial disturbance	0
exploited for gold	1
exploited for rubber	1
light & medium (10-40 L/ha) arboricide	1
heavy arboricide (40-50 L/ha)	2
logged once	2
logged twice	4
logged thrice	5
very heavy logging episode (>50 cu'm/ha)	1
known light logging episode	-1
clear felled but restored to class 1 or 2	7
clear felled, now bush	8
clear felled, now agriculture or grass	10
clear felled, exotics planted	10
glade planted with exotic monoculture	9
glade planted with indigenous trees	7 or 8

The table provides a guideline to the final evaluation of an area regarding commercial disturbance but still allowing scope for judgement if further information is available that qualifies the values indicated here. The values are added according to the cumulative experience of an area, to a maximum value of 10.

Appendix E3.2 Commercial disturbance values awarded per logging area of the Kakamega-Nandi forests with summarized details of disturbance histories.

Logging area	Disturb-ance value	Disturbance summary	Logging episode 1st	2nd	3rd	Logging (cu'm/ha)	Arbori-cide	Planting
1	3	log x 2: incl. PS x 1	1947	1961-73		6.5		
2	3	log x 2: incl. PS x 1	1961-73	c. 1974-78		5.9		
3	4	log x 2	1968-73	1975-80		9.7		
4a	4	log x 2	1969-74	1975-80		6.5		
4b	5	gold; log x 2	1969-74	1975-80				
4c	3	log x 2: erosion protection area with lighter harvest	1969-74	1975-80				
4d	5	log x 2: higher harvest	1969-74	1975-80				
5a	5	log x at least x 1: abusive felling in 1970s	1972-74	1975-80		8.3		
5b	6	log x at least x 1: very abusive felling 1970s	1972-74	1975-80				
6a	5	log x 2: intensive	1972-73	1975-80		14.2		
6b	5	log x 2: intensive	1972-73	1975-80				
7a	4	log x 2	1962-65	1975-80		14.9		
7b	5	log x 2: incl. high peeler yield in 1970s	1962-65	1975-80				
8a	3	log x 2: non-intensive in 1950s	1952-61	1975-80		10.2		
8b	3	log x 2: non-intensive in 1950s	1952-61	1975-80				
8c	3	log x 2: non-intensive in 1950s	1952-61	1975-80				
8d	4	log x 2	1952-61	1975-80				
9a	5	log x at least x 1: abusive felling in 1970s	1972-74			10.4		
9b	5	log x 2: abusive felling in 1970s	1971-74	1975-80				
9c	6	log x 2: abusive & intensive felling in 1970s	1971-74	1975-80				
9d	5	log x 3	1940-43	1952	1975-80			
9e	6	gold; log x 3	1940-43	1952	1975-80			
10	6	gold; log x 1 plus PS; enrichment planted incl. exotics; arboricide	1938-40			6.3	1960s	1941-1947
11	5	log x 2: intensive felling in 1970s	c. 1948-51	1975-80		8.3		
12a	2	log x 1: very heavy; enrichment planted	1947-56			8.0		1948-57
12b	3	gold; log x 1; enrichment planted	1947-49					1948-50
12c	4	log x 2	1947-48	1981				
12d	4	log x 2: intensive 1940s; enrichment planted	1946	1981				1947
13	6	log x 3: heavy harvest	1957-62	c. 1970-78	1982-84	14.6		
14	5	log x 2: heavy harvest	1952-53	1974-78		18.9		
15	5	log x 3	1962-63	1974-78	1980s	20.0		
16	5	log x 2	1974-78	1994/5-2001		12.6		

Logging area	Disturb-ance value	Disturbance summary	Logging episode 1st	2nd	3rd	Logging (cu'm/ha)	Arbori-cide	Planting
17a	5	log x 2: incl. PS x 1; enrichment planted	1943-1949	1969-73		14.2		c. 1950
17b	6	log x 2: incl. PS x 1, very intensive harvest	1943-49	1969-73				
18	6	gold; log x 2: sporadic & abusive logging	1940s	1965 & later		(0.1)		
19	6	rubber; log x 3: heavy harvest	1966-76	1990-95	1990-95	-		
20	6	rubber; log x 3: heavy harvest	1947	1973-76	1990-95	(0.6)		
21	2	log x 1	1940s &/or 50s			(0.1)		
22	3	rubber; log x 2: light & selective early phase	1943-47	1973-74 & 76		5.5		
23	4	rubber; log x 3: light & selective early phase	1943-47	1977-79	1980s early			
24a	3	rubber; log x 2: light & selective early phase	1943-47	1980-82				
24b	5	rubber; log x 3: heavy 3rd felling	1943-47	1956	1980-82			
25	2	log x 1: PS only	1960s & 70s			unknown		
26	3	log x 1: PS only, intensive	1990s early			unknown		
27	0	none				0.0		
28	0	none				0.0		
29	7 to 10	clear-felled after 1933; variously planted or abandoned	1933 & later			(not included)		1933 & later
30	9 to 10	clear-felled after 1950; variously planted or abandoned	1950 & later			(not included)		1950 & later

See Appendix E1 for a key to the numbered areas; the lettered sub-divisions are too small and numerous to show but are reflected in the localised variation seen in the final CD index (Figure 5.4). Areas 29 and 30 represent multiple small areas digitised within the clear felled areas to reflect e.g. erosion protection areas along the rivers, and the different degrees of forest regeneration; therefore, they are present in the table only as summaries. Logging volume figures in parentheses are derived from figures known to be very incomplete.

Appendix E3.3 Commercial disturbance values awarded per logging area of Mabira Forest with summarized details of disturbance histories.

Compart-ment	Disturb-ance value	Disturbance summary	Logging episode 1st	2nd	3rd	Arborocide	Planting
171, 180/1, 184	5	log x 1; Mulberry & enrichment planted	1960s mid-late				1989 & early 1990s
172/3, 178 east, 179, 185	5	log x 1; Mulberry planted	1960s late				1989 & early 1990s
174	6	log x 2: incl. fuel-cutting; Mulberry planted	1960s late	unknown date			1989 & early 1990s
175	6	log x 2: incl. fuel-cutting; Mulberry & cardamom planted	1960s late	unknown date			1989 & early 1990s; 1997
176-78, 186	4	prob rubber; log at least x 1: PS	1970-91				
178 mid	4	prob. rubber; log at least x 1: PS	1970-91				
179/80	3	log x 2; enrichment planted along River Liga	1960s	1976-79			1989 & early 1990s
182	5	log x 1; Mulberry planted	1960s				prob. late 1980s
182	5	log x 1; Mulberry & *Maesopsis* planted	1960s mid-late				1989 & early 1990s
183 south	6	log x 2; Mulberry planted	1964/65	unknown date			prob. late 1980s
183 s-west	5	log x 1; Mulberry planted	1964/65				prob. late 1980s
186 west	4	prob. rubber; log at least x 1: PS					
187	5	rubber; log x 1; arboricide		c. 1967			1967/68
188	4	rubber; log at least x 1	1950-80				
189	5	rubber; log x 2: incl. PS & fuel-cutting	1970 & 1973	1980-82			
190 north	8	clear felled; legal CB; *Maesopsis* planted	1970-73				1973 & 1992/93
190 mid	6	rubber; log x 1: heavy; legal CB; *Maesopsis* & Mulberry planted	1970-73				1973 & 1992
191 mid	5	rubber; log x 1: very heavy; *Maesopsis* planted	1970-76				1993
191 n-west	4	rubber; log x 2; enrichment planted	1963-64	1970-76			1993
192	3	rubber; log x 1: PS	1976/1973-80				
192 s-west	5	log x 2 prolonged	1963/64	1973-80			
193	3	prob. rubber; log x 1: PS	1980				
194	3	prob. rubber; log x 1: PS	1970-91				
195	3	prob. rubber; log x 1: PS	1970-91				
196	5	log x 1 (PS); prob. rubber; Mulberry & *Maesopsis* planted	1970-91				1989 & early 1990s
197	5	prob. rubber; log x 1: PS; Mulberry planted	1970-91				1989 & early 1990s

Compartment	Disturbance value	Disturbance summary	Logging episode 1st	2nd	3rd	Arborocide	Planting
197 south	3	prob. rubber; log x 1: PS	1970-91				
198-200	3	prob. rubber; log x 1: PS	1970-91				
201	3	prob. rubber; log x 1: PS	1969-72				
202	5	prob. rubber; log x 2: incl. PS	1971	unknown date			
203	7	rubber; log x 3: incl. PS; legal CB; *Maesopsis* planted	1964	1971	1985-88		1989 & early 1990s
203 north	6	log x 3	1964	1971	1985-88		
204 mid	5	rubber; log x 2	1971	1984-87			
204 s-east	3	rubber; log x 1	1984/87				1992
205	5	log x 2: prolonged, incl. peeler & PS; plus fuel-cutting	1965	1972-77 & 1979-82			
206	6	log x 3; arboricide; enrichment planted	1929 prob.	pre-1965	1983, 1988	1967-70	prob. early 1960s
207	5	log x 2; plus fuel-cutting	1929 prob.	1983 & 1988			
208/9	3	prob. rubber; log x 1	1929 prob.				
210	3	prob. rubber; log x 1: PS	1970-91				
211	4	log x 2	1929 prob.	early 1960s			
212 s-east	5	log x 2; arboricide; enrichment planted	1929 prob.	1965/66		1965/66	1967/70
212	3	log x 1; arboricide	1965/66			1967-70	
213	3	prob. rubber; log x 1	1969-72				
214	3	log x 1; arboricide	1960-65			1963	
215	3	prob. rubber; log x 1	late 1960s prob.				
216	3	prob. rubber; log x 1	1949-54 prob.				
217/8, 220/1	3	prob. rubber; log x 1	1949-54 prob.				
219	3	log x 1; plus fuel-cutting	1974				
222	3	prob. rubber; log x 1	1949-54 prob.				
223	4	log x 2; plus palm tree cutting	1949-54 prob.	1974			
224	5	log x 3	1949-54 prob.	1970	1987		
225	4	log x 2	1949-54 prob.	1971/72			
226 south	4	rubber; log x 1; arboricide	1960			1962	
226	4	rubber; log x 1; arboricide	1960-65			1962/63	
227	6	rubber; log x 2; arboricide	1959	1974		1963	
228	6	log x 3: incl. peeler; arboricide	1929 prob.	1954	1972/73	1960	
229 west	6	log x 3: incl. peeler; arboricide	1955	1972/73	2000-04	1961	
229 north	6	log x 3: incl. peeler; arboricide	1929 prob.	1955	1973	1961	
229 mid	5	log x 2: incl. peeler; arboricide	1956	1973		1961	
230 north	4	rubber; log x 1; arboricide	1957			1964	
230	6	log x 3; arboricide	1929 prob.	1956	2000-04 prob.	1962	
231	5	log x 2: incl. peeler; arboricide	1958	1969		1963	
232	5	log x 2: abusive harvest	1949-54 prob.	1972			
233 north	4	prob. rubber; log x 1; plus bush-cutting	1974				
233	5	log x 2; plus bush-cutting; arboricide	1958	1974		1963	
234	3	log x 1; plus bush-cutting; arboricide	1957	1970s		1964	
235	7	log x 2 prolonged; legal CB; exotics planted	1958 prob.	1970/71 & 1975/76			1973-77
236	5	log x 1; *Maesopsis* & Mulberry planted					1989 & early 1990s

See Appendix E1 for a key to the forest compartments. The volume of timber logged per compartment was not available for Mabira Forest.

Appendix E3.4 Commercial disturbance values awarded per logging area of Budongo Forest with summarized details of disturbance histories.

Compart-ment	Disturbance value	Disturbance summary	Logging episode		Logging (cu'm / ha)		Arborocide date	Arborocide (litres / ha)
			1st	2nd	total	Mahogany		
B1	6	rubber; log x 2: prolonged, 30-50 cu'm; low arboricide;	1925-35	1981-96	*41.4*	*25.2*	*1957-58*	unknown
B2	4	prob. rubber; log x 1; 30-50 cu'm; low arboricide	*1936-38*		*40.2*	*33.9*	*1958-59*	*20.4*
B3	5	log x 2: 30-50 cu'm; arboricide	*1939-43*	?2006	*34.9*	*23.7*	*1959-60*	unknown
B4	5	log x 2: incl. PS x1, 30-50 cu'm; lower arboricide	*1941-42*	*1985-92*	*34.8*	*19.8*	*1955-57*	*20.0*
B5	6	log x 2: 30-50 cu'm; arboricide	*1943-44*	?2005	*34.2*	*25.2*	*1960-61*	*42.6*
B6	6	log x 2: incl. PS x1; heavy arborocide	*1943*	mid 1980s	*14.0*	*10.4*	*1961-63*	*42.6*
B7	5	log x 2; arboricide	*1944*	?2006	*20.2*	*14.7*	c. 1960	unknown
BU1	2	log at least x 1	?2003		unknown	unknown		
BU2	2	log at least x 1	?2004		unknown	unknown		
BU3	2	log at least x 1	?2006		unknown	unknown		
BU4	2	log at least x 1	date unknown		unknown	unknown		
BU5	4	log x 2 prob.	1963-69	?2009	unknown	unknown	unknown	?medium
BU6	2	log at least x 1	date unknown		unknown	unknown		
KP1	4	log x 2	*1970-72*	?2000	*11.7*	*9.4*		
KP2	4	log x 2	*1970-72*	?2000	*?3.1*	*?2.3*	unknown	unknown
KP3	4	log x 2	1971-77	?2006	unknown	unknown		
KP4	4	log x 2	1972	*1987-92*	*20.7*	*12.6*		
KP5	2	log x 1	*1985-87*		*25.6*	*17.2*		
KP6	2	log x 1	1992-94		unknown	unknown		
KP7	2	log x 1	*1987-89*		*11.1*	*9.0*		
KP8	2	log x 1: 30-50 cu'm	*1986-89*		*31.5*	*15.1*		
KP9, 10 & 14	0	no commercial: mostly grassland / woodland			0.0	0.0		
KP11-13	0	no early rubber; no known logging			*0.0*	*0.0*		
N1	7	rubber; log x 2: over 50 cu'm; arboricide	*1945*	1996-97	*58.7*	*47.1*	*1962-63*	*?medium*
N2	6	rubber; log x 2: 30-50 cu'm; low arboricide	*1945-47*	?2000	*46.2*	*33.1*	*1955-56*	*11.1*
N3	6	log x 2: over 50 cu'm; lower arboricide	*1947-52*	?1987	*80.0*	*39.1*	*1959-61*	*22.0*
N4	6	log x 2: over 50 cu'm; arboricide	*1952-54*	1998	*94.0*	*48.0*	*1960-62*	*?medium*
N5	6	log x 2: over 50 cu'm; arboricide	1954-56	?2000	*51.5*	*41.2*	*1963-64*	*38.1*
N6	7	log x 2: over 50 cu'm; heavy arborocide	1955-64	?2000	*59.8*	*49.4*	*1956-58*	*41.6*
N7	5	log x 2: 30-50 cu'm; arboricide	*1958-59*	?2000	*31.9*	*26.1*	*1957-58*	*44.8*
N8	6	log x 2; heavy arborocide	*1957-58*	1998-2000	*25.7*	*20.8*	*1957*	*47.0*
N9	6	log x 2; heavy arborocide	1958-60	?2000	*15.2*	*10.7*	*1958*	*42.3*
N10	6	log x 2: 30-50 cu'm; heavy arboricide	1958-60	?2000	*30.2*	*23.5*	*1958-60*	*50.4*
N11	6	log x 2; heavy arboricide	1959-61	1998-2000	*26.5*	*21.7*	*1958-60*	*42.6*
N12	3	log x 1; arboricide	1959-62		*?3.0*	*?2.5*	*1959-60*	*32.9*
N13	5	log x 2 (first time lightly); heavy arborocide	1960-62	?2000	*13.0*	*8.5*	*1960*	*40.3*
N14	2	log x 1	*1961-62*		unknown	unknown		
N15	1	rubber			*0.0*	*0.0*		
S1	6	log x 2: over 50 cu'm; arboricide	1925-45	*1963-69*	62.5	*23.5*	*1972/73*	*34.4*
S2	5	log x 2; arboricide	1925-44	*1969-71*	21.6	unknown	*1971-72*	*40.0*
S3	5	log x 2; arboricide	1925-44	*1966-70*	21.6	unknown	?1971-75	unknown

Compart-ment	Disturbance value	Disturbance summary	Logging episode		Logging (cu'm / ha)		Arborocide date	Arborocide (litres / ha)
			1st	2nd	total	Mahogany		
S4	4	log x 2: over 50 cu'm	1925-44	*1972-77*	50.5	unknown	unknown	unknown
S5	5	log x 2: over 50 cu'm	1925-44	1971-75	21.6	unknown	unknown	unknown
S6	6	log x 2: over 50 cu'm; arboricide	1925-44	1971-73	21.6	unknown	*1972-75*	unknown
S7	6	log x 2: over 50 cu'm; rubber	1925-44	1990-95	21.6	unknown		
S8	6	rubber; log x 2: over 50 cu'm	1925-44	*1979-90*	69.9	*26.3*		
W16	3	log x 1; arboricide	*1961-62*		*21.7*	*14.3*	*1961-62*	unknown
W17	1	rubber			unknown	unknown		
W18	4	log x 1; heavy arborocide	1960-62		*28.8*	*19.3*	*1960-62*	*43.6*
W19	6	log x 2; heavy arborocide	1960-63	1997	*25.6*	*16.3*	*1961-63*	*41.4*
W20	4	log x 1: 30-50 cu'm; heavy arborocide	*1963-64*		*30.8*	*20.3*	*1962-63*	*41.4*
W21	3	log x 1: 30-50 cu'm volume; low-mid arboricide	1963-65		*36.1*	*23.9*	*1963-64*	*29.1*
W22	5	log x 2: 30-50 cu'm; arboricide	*1965-67*	1985-86	*35.9*	*23.0*	*1966*	unknown
W23	6	rubber; log x 2: incl. PS x1; arboricide	*1966-68*	1982-86	*26.4*	*18.5*	*1966*	unknown
W24	4	rubber; log x 1 lightly; arboricide	1965-69		*14.2*	*9.3*	*1966-67*	unknown
W25	6	log x 2: over 50 cu'm; arboricide	*1968-69*	?2007	>50.0	*5.4*	*1970-71*	unknown
W26	6	rubber; log x 2: 30-50 cu'm; arboricide	*1970-71*	?2000	*30.6*	*19.1*	*1971-72*	*36.0*
W27	6	log x 2; heavy arborocide	*1970-71*	?2004	unknown	unknown	*1970-71*	*46.5*
W28	5	rubber; log x 1: over 50 cu'm; lower arboricide	1971-73		*51.4*	*29.1*	*1972-73*	*29.5*
W29	4	rubber; log x 1: over 50 cu'm	*1972-74*		*64.0*	*40.5*		
W30	3	rubber; log x 1	1974-77		*8.1*	*7.5*		
W31	1	rubber			*0.0*	*0.0*		
W32	1	rubber			*0.0*	*0.0*		
W33	1	rubber			*0.0*	*0.0*		
W34	3	rubber; log x 1	1995-97		unknown	unknown		
W35	2	rubber; log x 1: PS	?1970s		unknown	unknown		
W36	2	rubber; log x 1: PS	?1970s		unknown	unknown		
W37	3	log x 2	1978-82	?2001-02	*22.2*	*10.7*		
W38	4	log x 2: incl. PS x 1, over 50 cu'm	1983-84	1998-2000	>50.0	unknown		
W39	5	log x 3: incl. PS x 1, 30-50 cu'm	*1974-76*	1982-86 & ?2003	43.5	25.5		
W40	4	log x 2: incl. PS x 1	1969-70	1982-86	unknown	unknown		
W41	4	log x 2: incl. PS x 1	1975-77	1982-86	unknown	unknown		
W42	4	rubber; log x 1: prolonged, over 50 cu'm	1977-86		>50.0	unknown		
W43	5	log x 2: prolonged x 1, over 50 cu'm	1977-86	?2006	>50.0	unknown		
A	3	partially planted, harvested, cultivated, never full forest	various		unknown	unknown		

See Appendix E1 for a key to the forest compartments. Figures in italics are taken from Plumptre 1996; the remainder are taken from numerous NFA archive documents and from Trenaman *et al*. 1956. Although enrichment planting of Mahoganies has taken place within Budongo Forest, the records of the locations were not available. ‘?’ means unsure data.

Appendix E4 The forest cover change (FCC) index

Appendix E4.1 Reclassification scheme for the forest cover change (FCC) index. See Table 2.2 for a key of the original land cover classifications; classes 11 (water) and 13 (wetland) do not feature since they were masked out for the analysis.

Land cover class		Reclassification (Kakamega-Nandi & Mabira / Budongo*)
Timestep 1 (aerial photo)	Timestep 2 (satellite imagery)	
1	0, 1	5
1	2	6
1	3	7
1	4*	10 / 9
1	5	9
1	6, 7, 9-10, 12, 14, 18-19	10
1	8	8
2	0, 1	3
2	2	5
2	3	7
2	4*	9 / 8
2	5	9
2	6, 7, 9-10, 12, 14, 18-19	10
2	8	9
3	0, 1	2
3	2	3
3	3	5
3	14	6
3	4*	8 / 6
3	5	6
3	6, 7, 9-10, 12, 18-19	8
3	8	7
5	0, 1	1
5	2	3
5	3	4
5	4*	8 / 5
5	5 / 14	5
5	6	6
5 or 6	7, 9, 12, 18-19	9
5 or 6	10	6
5 or 6	8	8
6, 7, 9-10, 12, 18-19	0, 1	1
6, 7, 9-10, 12, 18-19	2	2
6, 7, 9-10, 12, 18-19	3	3
6, 7, 9-10, 12, 18-19	4	6 / 4
6, 7, 9-10, 12, 18-19	5	4
6	6 / 14	5
7, 9-10, 12, 18-19	14	4
7, 9-10, 12, 18-19	7-10, 12, 18-19	5
7, 9-10, 12, 18-19	6	4
10	14	5
5/6/10/12 **	0, 1	1
5/6/10/12 **	2	2
5/6/10/12 **	3	3
5/6/10/12 **	4*	8 / 4
5/6/10/12 **	5-10, 12, 14	no value assigned

*Class 4 of the satellite imagery classification gives rise to two options in the third column here since this class represents a natural stage in the succession process in Budongo, while elsewhere it represents a monodominant exotic species.

** The combined class of 5/6/10/12 is present only outside the forest reserves and reflects the impracticality of distinguishing these classes from the dominant class 10 in the aerial photography visual interpretation.