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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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).

---

**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 (Gilson 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 (Gilson 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. Owuonji & Plumtre 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.

<table>
<thead>
<tr>
<th></th>
<th>Kakamega-Nandi forest area</th>
<th>Mabira Forest area</th>
<th>Budongo Forest area</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Location</strong></td>
<td>34°37′5″ to 35°9′25″E and 0°2′52″S to 0°32′24″N</td>
<td>2°46′34″ to 33°11′22″E and 0°20′28″ to 0°43′16″N</td>
<td>31°15′23″ to 31°50′27″E and 1°29′56″ to 1°59′14″N</td>
</tr>
<tr>
<td><strong>Forest reserve area within area of investigation</strong></td>
<td>55,446 ha (from boundaries provided by UNEP)</td>
<td>35,027 ha (from boundaries provided by NFA)</td>
<td>84,472 ha (from boundaries provided by NFA)</td>
</tr>
<tr>
<td><strong>Elevation within forest reserves (above sea level)</strong></td>
<td>Reserves of Kakamega &amp; 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</td>
<td>1,045 m (Nile Bank) to 1,335 m (southernmost Mabira)</td>
<td>695 m (north Kitigo) to 1,440 m (Mukihani)</td>
</tr>
<tr>
<td><strong>Annual mean precipitation</strong></td>
<td>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 &amp; c)</td>
<td>1,250 to 1,400 mm (Howard 1991)</td>
<td>1,200 to 1,800 mm (Sheil 1997)</td>
</tr>
<tr>
<td><strong>Annual mean temperature</strong></td>
<td>Kakamega Forest: min. ~15°C, max. ~27°C; Nandi Forests: min. ~10°C, max. ~25°C (Blackett 1994a-c)</td>
<td>min. 16 to 17°C, max. 28 to 29°C (Howard 1991)</td>
<td>min. 17 to 20°C, max. 28 to 29°C (Howard 1991)</td>
</tr>
</tbody>
</table>

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 ferralochromic/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.
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 - Markhemia 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 & Kassily 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.

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.
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$^2$ \textit{(cf. ibid., Mitchell \textit{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 \textit{(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 \textit{(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 \textit{(Jätzold \textit{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 \textit{(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 \textit{(Mayaux \textit{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 \textit{(Westman \textit{et al.} 1989, Plumptre 2002, Nangendo 2005, Awiti 2006, Mwavu & Witkowski 2008)}. Lung and Schaab \textit{(2006 & 2009)} are alone in East Africa in making use of the full timespan of the fully-functioning Landsat programme with multiple timesteps \textit{(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 \textit{(1999)}, Brooks \textit{et al. (1999)} and Mitchell \textit{et al. (2006)}, and from further afield Petit and Lambin \textit{(2001)} in Zambia, Goetze \textit{et al. (2006)} in Ivory Coast, and Wigley \textit{(2009)} in South Africa. In Nigeria, Salami \textit{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. Owiunjji & 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

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**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-l34 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.](image-url)
Table 2.1: Summary of the acquired and derived geodatasets; they are listed in detail in Appendices A1 to A3.

<table>
<thead>
<tr>
<th>Geodata Types</th>
<th>Kakamega Forest</th>
<th>Nandi Forests</th>
<th>Mabira Forest</th>
<th>Budongo Forest</th>
<th>Scale/Resolution</th>
<th>Pre-processing</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Satellite imagery of pre-existing time series of Lung (2004), Lung &amp; Schaab (2010) (no. of images in brackets) (Ch. 2.2.1)</td>
<td>2003 (ETM+) (2)</td>
<td>2001 (ETM+) (2)</td>
<td>1994/95 (TM) (2)</td>
<td>1984 (TM) (1)</td>
<td>2002/03 (ETM+) (2)</td>
<td>2001 (ETM+) (2)</td>
<td>30 m (georeferencing, atmospheric correction, supervised multispectral classification)</td>
</tr>
<tr>
<td>Ground truthing / photos from aeroplane</td>
<td>1978/80 (MSS) (2)</td>
<td>1975 (MSS) (2)</td>
<td>1972/73 (MSS) (2)</td>
<td>1976 (MSS) (1)</td>
<td>1973 (MSS) (1)</td>
<td>1972/73 (MSS) (2)</td>
<td>60 m</td>
</tr>
<tr>
<td>Aerial photography (Ch. 2.2.2 to 2.2.4)</td>
<td>(1991, Kakamega only, not interpreted for classes) 1965/67 (complete) 1948/52 (62% complete)</td>
<td>1955</td>
<td>1960</td>
<td>1:30,000</td>
<td>scanning/digital photo'ing, georeferencing &amp; digitizing</td>
<td>spatial understanding of logging &amp; geodatasets to create commercial disturbance index</td>
<td></td>
</tr>
<tr>
<td>Forestry maps (Ch. 2.3)</td>
<td>46 1933-2005</td>
<td>36 1929-2006</td>
<td>19 1932-1991</td>
<td>1:10,000 to 1:150,000</td>
<td>incorporated into GIS as attributes of forestry geodatasets</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Topographic, sketch &amp; thematic maps (Ch. 2.4)</td>
<td>62 1896-2007</td>
<td>39 1911-2008</td>
<td>27 1911-2008</td>
<td>1:25,000 to 1:2.5 million</td>
<td>scanning/digital photo'ing, georeferencing &amp; digitizing</td>
<td>extension of forest cover time series to early 20th century; population &amp; contextual geodatasets for constructing local disturbance indices</td>
<td></td>
</tr>
<tr>
<td>Oral histories (Ch. 2.5)</td>
<td>42 (relating to c.1910-2006)</td>
<td>33 (relating to c.1920-2006)</td>
<td>21 (relating to c.1950-2006)</td>
<td>20 (relating to c.1940-2006)</td>
<td></td>
<td>located &amp; attributed with forest histories</td>
<td>understanding of causes of forest cover change; contributions to commercial &amp; local disturbance indices</td>
</tr>
<tr>
<td>Place names relating to plants / animals / land cover (Ch. 2.6)</td>
<td>242 (late 17th to early 20th century)</td>
<td>7 (unknown date)</td>
<td>18 (unknown date)</td>
<td>1:50,000</td>
<td>digitized &amp; attributed with meanings &amp; land cover inferences</td>
<td>Spatially-defined inferences of former land cover</td>
<td></td>
</tr>
</tbody>
</table>
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
The data sources and pre-processing

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’ (class 1) 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.

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

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.

<table>
<thead>
<tr>
<th>Geodataset Topic</th>
<th>Kakamega-Nandi forests</th>
<th>Mabira Forest</th>
<th>Budongo Forest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Logging concessions</td>
<td>29</td>
<td>9</td>
<td>1</td>
</tr>
<tr>
<td>Forest cover types &amp; inventories</td>
<td>6</td>
<td>14</td>
<td>13</td>
</tr>
<tr>
<td>Admin. compartments, boundaries &amp; excisions</td>
<td>7</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>Silvicultural operations</td>
<td>4</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>46</strong></td>
<td><strong>36</strong></td>
<td><strong>19</strong></td>
</tr>
</tbody>
</table>

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

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

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...
The data sources and pre-processing

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 datasets 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 (knd7, 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
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.

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

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 km² 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?
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- 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).

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

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.

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 Kakamaga 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.
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
The data sources and pre-processing

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

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

classes; for instance, a village name, e.g. Shivanga, stemming from the Luhya word Muvanga, is translated as the tree Harununga 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.

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

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), (Hydrofluoric 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). Centering 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.