Managing the Mount Kenya environment for people and elephants

by

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ABSTRACT

Forests contain much global biodiversity, and over 90% of the worlds' poorest people depend on them. Few forests remain in East Africa, and these are vulnerable to further fragmentation from expanding settlement, and to over-exploitation by people and wildlife that become prone to over-crowding through isolation. Kenya contains 26 natural habitat fragments and only 3% of forest cover across five main forest blocks. These blocks form the main water towers in semi-arid Kenya on which people and wildlife, far beyond the protected boundaries, depend. Mount Kenya (MK) is the largest forest block, and the protection of its water catchment function is of national importance (Chapter 2).

The five forest blocks in Kenya hold almost one third of the total of 28,806 elephants in Kenya, of which MK was estimated as having the largest highland elephant population with 2,911 (±640) individuals in 2001 (Chapter 3). Elephant estimates in forest are usually derived from dung count surveys, which are prone to bias and accordingly most often classed as C or D, in the range from A (best) to E (worst), in the African Elephant Database (AED). The MK elephant estimate described in this thesis was one of only two dung count estimates that were classed as quality B in the AED of 2002 (Chapter 3). Explanatory models based on the dung count data were integrated with a geographic information system (GIS) to develop the most advanced predictive seasonal distribution maps currently available for elephants in a forested environment (Chapter 4). Furthermore, least-cost elephant travel routes and foraging paths were digitally traced over cost surface images, developed from data on preferred elephant habitats in different seasons, physical barriers such as extreme slopes, and land use barriers such as farmland (Chapter 5). This enabled the location of elephant movements in relation to plantations inside the MK forest, and investigation of the relationship between measured tree damage in plantations and elephant movements (Chapter 5). Two areas where subsequently identified where elephant routes strayed from the forest into adjacent farmland, which was where most elephant crop damage was reported by farmers to Kenya Wildlife Service stations and outposts (Chapter 6). Elephants and people trespassing on each other's habitats is pronounced because MK is surrounded by a ring of small-scale farmers, totalling over 500,000 people living within 5,000m of the MK forest boundary on farms of 1.6ha on average (Chapter 6).

Time-series analysis of satellite imagery of 1987, 1995, and 2000 illustrated a gradual deterioration of MK land and resources, and results of an aerial survey conducted in 1999 showed high levels of illegal exploitation of land and resources (Chapter 7). However, management responsibility of the MK forest transferred from the Forestry Department to the Kenya Wildlife Service in July 2000, and time-series analysis of satellite images of 2000 and 2002 show regeneration of degraded MK land by 2002 (Chapter 8). Comparison of two aerial surveys conducted in 1999 and 2002, showed a significant reduction of illegal exploitation of forest resources on MK by 2002 (Chapter 8). Sound land use management plans are needed for MK to avoid deterioration of the forest by an over-crowded and confined elephant population, and by surrounding people. These plans need to address problems with longer term solutions, regardless of the short term disadvantages that they may entail (Chapter 9).

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Chapter 1

GENERAL INTRODUCTION

In this thesis, I explore all aspects of the triangular relationship between the Mount Kenya (MK) environment, its elephants and its people. I use archive data and field data in combination with geographic information system (GIS) generated data and satellite imagery to investigate the following: characteristics of the MK natural environment; seasonal elephant densities; seasonal elephant distribution; seasonal elephant movements and elephant impact to tree plantations; seasonal elephant impact to farms adjacent to the forest, and characteristics of households in the most affected areas; changes of MK land and resources from human exploitation over time; and, the effect of different managing institutions on the status of the MK environment. The thesis takes a multi-disciplinary perspective to HEC around MK, and makes recommendations for improved management of HEC.

1.1. Global systems of biodiversity conservation

1.1.1. Global threats to biodiversity

Biodiversity is defined at different levels comprising genes, species and ecosystems (Wilson, 1992; Schlapfer et al., 1999; Kapos et al., 2000). Internal and external factors determine the state of ecosystems. Internal factors such as inter- and intra-species relationships regulate ecosystems and their functions, including the protection of water basins against erosion and floods, the micro-evolution of species and habitats, carbon sequestration and photosynthesis (Nosberger et al., 1998; Young, 2000; Silori and Mishra, 2001; Downing and Leibold, 2002; Ostroumov, 2002; Hawkins et al., 2003). External factors such as geography, climate, and water availability, determine the composition of habitats, and accordingly, the type of species that they include, and the distribution and movement patterns of wildlife and people (Kapos et al., 2000; Harcourt et al., 2001; Augustine and McNaughton, 2004). Of all terrestrial environments, forests are home to the largest proportion of global terrestrial biodiversity. Of all species, people most strongly influence the state of forests and biodiversity (Scherr et al., 2004; WWF, 2004).

People can convert biodiversity through habitat fragmentation as a result of human population expansion (Groombridge and Jenkins, 2000; Kapos et al., 2000; McNeely and Scherr, 2002), and through poor land tenure, pollution and unsustainable exploitation of natural habitats to address their immediate needs (Bell and McShane-Caluzi, 1985; Campbell et al., 1999; Isely and Scherr, 2003). The level of human influence on biodiversity depends on various factors such as: human densities (Parker and Graham, 1989; Hoare and du Toit, 1999); the availability of resources for people (Emerton, 1997; Williams et al., 2003); levels of competition for resources (Kapos et al., 2000; Wiesmann et al., 2000); socio-economic status of people (Hoare, 1999; Ekbom et al., 2001; du Toit, 2002); community tolerance towards institutions in charge of resource protection (Hagiwara, 2002; Hutton and Leader-Williams, 2003; Olowu, 2003); financial capacity and levels of corruption of managing institutions (Jachmann and Billiouw, 1997; Bruner et al., 2001; Smith et al., 2003); and, legislation and institutional co-ordination (Klooster, 1999; McAlpine, 2003; Williams et al., 2003).

1.1.2. Biodiversity protection

One of the oldest forms of protecting biodiversity is through the establishment of protected areas (PAs). Some of the first PAs were established to conserve scenic beauty or hunting grounds for the rich and royal (Reiger, 1986; Runte, 1987). Today, areas can be protected, *inter alia*, for the revenues they generate, for the natural resources and biodiversity they encompass, for their function as water catchments, flood zones, grazing areas, migration corridors, archaeological sites, or research sites (Isely and Scherr, 2003; IUCN, 2003). By 2003 about 11.5 % of the earth's surface had been gazetted into over 100,000 PAs with varied legal status, ranging from strict protection to licensed offtake and tenure of all or part of its resources (IUCN, 2003).

International, national and regional laws on the protection of species, public lands, agriculture, water, and the environment, define legal status of biodiversity protection and the responsibility for it. Important global conventions that identify responsibilities of states to conserve their biodiversity and to use their resources in a sustainable manner, include the 1972 Convention of International Trade in Endangered Species (CITES), and the 1992 Convention on Biological Diversity (CBD). However, despite these laws and conventions, the vast majority of PAs suffer illegal abstraction of land and resources (Scherr et al., 2004).

1.1.3. Different approaches to biodiversity protection

The top-down approach of PA management was found to severely limit conservation efforts because it entails high management costs, and excludes community benefits from conservation, which affects community tolerance towards wildlife (Hackel, 1999; Balmford and Whitten, 2003; Isely and Scherr, 2003). This led to community-based conservation, which encouraged the involvement of communities in conservation to reduce illegal exploitation (Leader-Williams et al., 1996; Agrawal, 1997; du Toit, 2002; McNeely and Scherr, 2002), and to projects of sanctioned resource use, promoting controlled use of PA resources by the adjacent communities (Child, 2000; Kokko, 2001; Hutton and Leader-Williams, 2003). This also led to principles of ecological economics, which promote economic development of ecosystems to address economic shortfalls (Armsworth and Roughgarden, 2001; Bruner et al., 2001; Balmford and Whitten, 2003). Although well intended, these approaches are often unsustainable and can lead to serious deterioration of habitats, because rapid economic development is usually favoured over sustainable development, even in areas where funds are plenty and human densities are low (Abbot and Mace, 1999; Anderson, 2001; Huber, 2002; Lambrechts et al., 2003). Therefore, it has been recognised that strategies to improve biodiversity protection is important, and more emphasis should be placed on systematic monitoring of habitats and species, in order to identify changes in habitat structure and composition, and fluctuations in species abundance, in turn to allow rapid and appropriate intervention (Barnes, 2002; Balmford et al., 2003; Osborn and Parker, 2003).

1.1.4. Systematic monitoring of biodiversity

Systematic monitoring of habitats and species allows the cause of changes to be established and to understand factors that underlie changes, and to develop protection policies and land use management plans (Clevenger et al., 2002; Lehmann et al., 2002; Williams et al., 2003). Improved land use management is possibly one of the best ways to tackle problems of a spatio-temporal character (Kapos et al., 2000; Sanderson et al., 2002; Balmford et al., 2003; Moore et al., 2003), such as changes in land cover and resources as a result of interactions between wildlife and people (Eeley et al., 1999; Kinnaird et al., 2003; Lufafa et al., 2003; Williams et al., 2003).

Monitoring the status of habitats, and abundance and distribution of species, is often achieved with aerial surveys in open environments (McDaniel et al., 2000; Bowman et al., 2001; Chen et al., 2002; Evans et al., 2003). In forested environments, where poor visibility excludes the possibility of aerial surveys, indirect survey methods are used, such as dung counts along line transects (Barnes et al., 1997; Thomas et al., 2001; Laing et al., 2003). The inclusion of satellite images within a GIS enables a time-series analysis of habitat change and can be used to map and monitor deforestation (Willard et al., 2000; Miller and Franklin, 2002; Lambrechts et al., 2003). Predictive modelling with a GIS has been recognised as a powerful tool for conservation management within landscapes undergoing spatio-temporal changes, such as patterns of human-wildlife conflict (Linkie, 2003; Sitati et al., 2003), and in species abundance, distribution and habitat preference (Lenton et al., 2000; Hiers et al., 2003). Changes in habitat and species composition strongly affect ecosystem functions, which is the main reason why over-grazing, deforestation, misuse of land and erosion are perceived as among the biggest environmental problems in Africa (Nosberger et al, 1998; Schlapfer et al., 1999; Downing and Leibold, 2002; Kinnaird et al., 2003).

1.2. Conservation in Africa

1.2.1. The African environment

Ecosystems in Africa are mainly structured by certain flagship species, like elephants, and by people (Laws et al., 1975; Chapman et al., 1997; Barnes, 2001; Fritz et al., 2002). People play the most influential role as managers, governors and decision makers, and are heavily influenced by levels of economic stability and political corruption (Bruner et al., 2001; Balmford et al., 2003; Hutton and Leader-Williams, 2003; Smith et al., 2003). Elephants, being the largest terrestrial species, play a key role in structuring the habitats that they occupy. The number and distribution of elephants is fundamental to whether they positively structure, or are destructive towards, their habitat (Pamo and Tchamba, 2001; Nchanji and Plumptre, 2003; Augustine and McNaughton, 2004).

1.2.2. Elephant numbers in Africa

Elephant survival is increasingly determined by fragmentation of their natural habitats and habitat loss within the remaining fragments (Kapos et al., 2000; Jenkins, 2003). Therefore, many contemporary studies focus on the interrelationship between environment, elephant numbers and distribution (Hawthorne and Parren, 2000; Styles and Skinner, 2000; Holdo, 2003). Elephant numbers on the African continent were reduced from some 1.2 million animals to less then 500,000 between 1979 and 1989, as a result of poaching (Cumming et al., 1990; Milner-Gulland and Beddington, 1993). However, these continent-wide estimates of elephant numbers were very crude and based on counts of varying quality. Consequently, regular surveys are now conducted and information on elephant numbers and distributions are compiled in the regularly updated African Elephant Databases (AEDs).

Elephant numbers in the AEDs are derived from aerial counts, foot surveys, questionnaires and informed guesses. They are classed accordingly as 'definite', 'probable', 'possible' or 'speculative' (Michelmore, 1991; Said et al., 1995; Barnes et al., 1998; Blanc et al., 2003; Table 1.1).

Table 1.1. Estimated number of elephants on the continent from AEDs

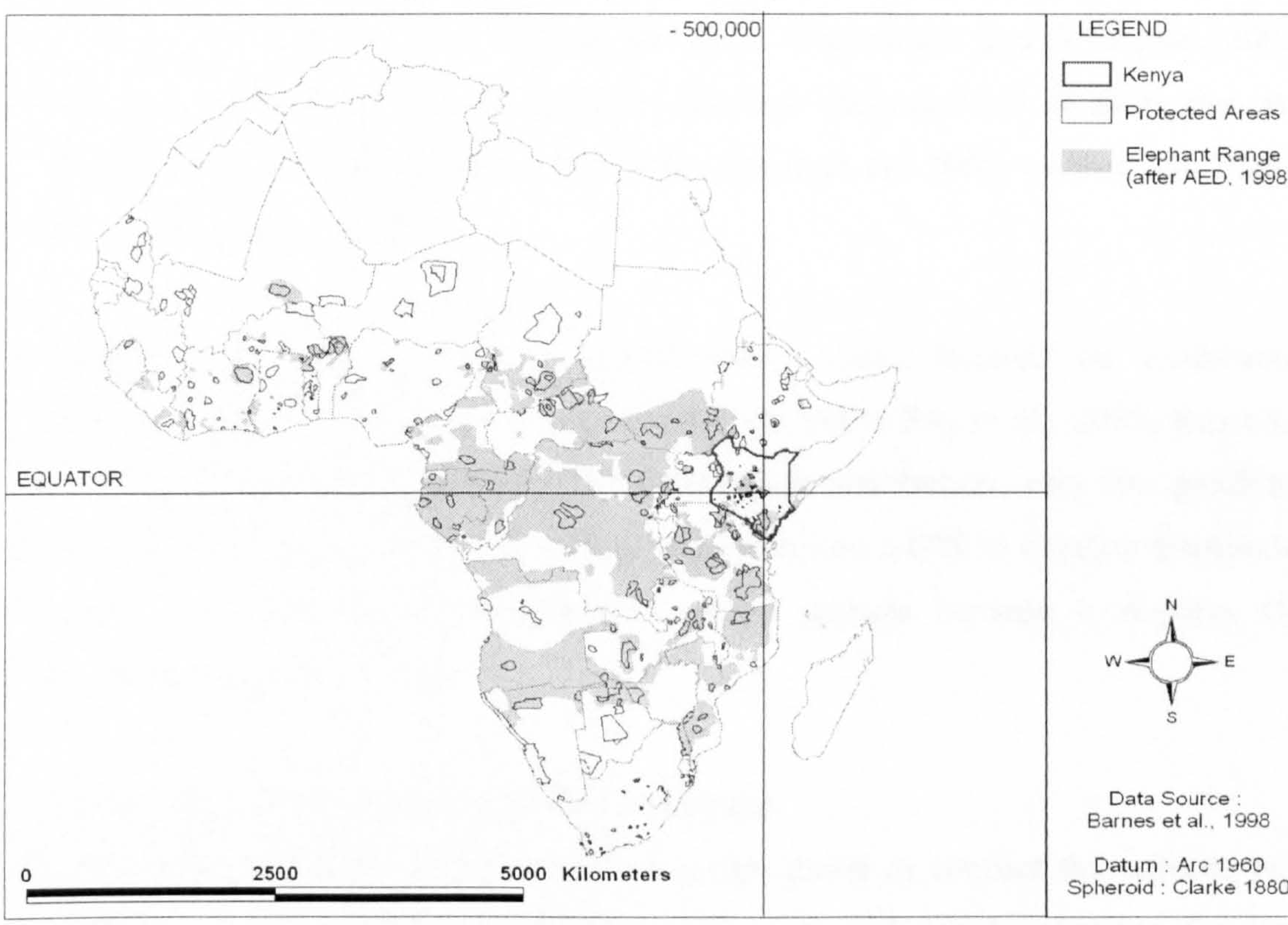
Region	*Total Area In Km2*	*Elephant Range98*	*Elephant Range02*	*AED 1989*	*AED 1991*	*AED 1995*	*AED 1998*	*AED 2002*
Central Africa	5,365,550	51.7%	38.4%	277,000	268,155	225,219	125,508	195,753
Southern Africa	5,973,020	28.9%	28.1%	204,000	194,000	228,047	236,715	303,920
West Africa	5,096,660	4.2%	4.3%	19,000	13,500	14,725	12,803	13,183
Eastern Africa	6,182,037	17.2%	15.7%	110,000	112,000	128,272	125,179	163,667
Continental	22,617,267	25.5%	21.8%	609,000	600,500	579,532	487,345	660,211

At least 30% of the continent's African elephant numbers are classified as 'uncertain'. These mainly comprise the elephants found in forested Central Africa, where 33% are listed as 'possible' and a further 42% are listed as 'speculative', with Gabon and Equatorial Guinea not listing any elephants as 'definite' (Blanc et al., 2003). This is due to lack of monitoring in general and to reduced visibility in forest environments that restricts surveys to indirect observation methods. Dung counts are often considered of low quality because minor errors in practice can lead to substantial biases (Thomas et al., 2001; Laing et al., 2003). However, several studies have shown that dung counts can produce more accurate results than aerial counts when theory is applied rigorously (Buckland et al., 2001; Whitehouse et al., 2001; Barnes, 2002). Additionally, dung count data can also be used to investigate elephant distribution (e.g. Nahonyo, 2001; Sitati, 2003).

1.2.3. Elephant distribution in Africa

Although elephants once roamed across Africa, they disappeared from North Africa during the Roman era (Scullard, 1974; Cumming et al., 1990; Delort, 1992; Blanc et al., 2003). Today, elephants only occur in increasingly isolated habitat fragments because of human expansion, which limits elephant distribution and movements (Figure 1.1).

Figure 1.1. Elephant range in Africa



Elephant home ranges can be as small as $42km^2$ (Douglas-Hamilton, 1971) and as large as $8,700km^2$ (Lindeque and Lindeque, 1991), depending on habitat quality versus elephant density, distribution and movements (Harcourt et al., 2001; Osborne et al., 2001; Kinnaird et al., 2003; Williams et al., 2003). Mobility helps elephants overcome vulnerabilities, such as the need for water, food and mates (Kapos et al., 2000).

When not over-crowded, the impact of elephants on their habitats is quite limited, and includes the suppression of tree growth and non-serious damage to mature trees (Styles and Skinner, 2000; Barnes, 2001). Additionally, elephants play a key role in structuring environments and biodiversity, through seed dispersal and creating openings in the forest canopy, helping seedling germination (Gadd 2002; Cochrane, 2003; Nchanji and Plumptre, 2003), through suppressing shrub encroachment (Augustine and McNaughton, 2004), through redistribution of nutrients in barren areas and facilitating access to water, food, and salts for other mammals (Cumming, 1982; Viljoen, 1989), or through hosting parasites that are food for other animals (Ruggiero and Eves, 1998). However, if restricted in movement, elephants become locally over-crowded and over-exploit resources. In their search for ways to address their year-round needs, they can become an increasing threat to people (Laws, 1970; Chapman and Chapman, 1997; Harcourt et al., 2001; Pamo and Tchamba, 2001; Whitehouse and Schoeman, 2003). Therefore, identifying areas and corridors between areas in need of protection is a conservation priority (Sanderson et al., 2002; Moore et al., 2003; Osborn and Parker, 2003; Williams et al., 2003).

To identify movement corridors, several studies have focused on establishing explanatory factors to least-cost travel (Bunn et al., 2000; Ray et al., 2002; Russell et al., 2003). Despite the spatial character of elephant distribution, very few predictive models of elephant distribution have been integrated into a GIS to develop distribution maps or to investigate human-elephant conflict, perhaps because it requires GIS expertise that is a field in itself.

1.2.4. Human-elephant conflict in Africa

Human-elephant conflict (HEC) is defined in this thesis as conflict that affects, or is effected by, either elephants or people. Elephants and people compete for land, resources and freedom of movement, and so any conflict can affect both species (Coughenour, 1991; McCarty et al., 2002; Fritz et al., 2003). The numbers of studies that focus on HEC indicate a growing interest in this topic. In the main conservation literature of the 1960's, 1970's and 1980's, a total of less than 20 papers were published on HEC (e.g. Vesey-Fitzgerald, 1968; Caughley, 1976; Bell, 1984). From 1990 to

2003, however, over 40 HEC papers and reports were published for Kenya alone (e.g. Thouless, 1994; Kasiki, 1998; Earnshaw and Emerton, 2000). Studies have focused on improving methods to locate, quantify and analyse, levels of elephant damage to human resources (e.g. Hoare, 2000; Sitati et al., 2003), and on improving methods to locate, quantify and analyse, changes arising from human damage to elephant habitats (e.g. Crawley, 1993; Legendre et al., 2002; Vanleeuwe et al., 2003).

Elephant and human densities are negatively correlated, and co-existence is only possible in areas where there is little human disturbance (Barnes et al., 1991; Happold, 1995; Hoare, 2000). Human population growth in Africa causes a shift from pastoralism to agriculture, the degazetting of protected areas for agriculture and fragmentation of inherently poor agricultural land (Thouless and Sakwa, 1995; UNEP/WMO, 1996; Jacquemin et al., 2003). Ultimately, it brings poaching (Jenkins, 2003), deforestation and erosion (Groombridge, 2000; Mati and Veihe, 2001; Kinnaird et al., 2003), and introduction of diseases (Prins et al., 2000). Increasing conflict between people and elephants is linked with human population expansion and the subsequent overlap in habitats occupied by people and elephants (Hoare, 1999; Harcourt et al., 2001; Jenkins, 2003). In dry areas of Zimbabwe, it was estimated that elephants were unable to exist at human densities over 18.9 people/ km^2 (Hoare and du Toit, 1999). In contrast, in highly fertile areas of Kenya, it was estimated that human densities over 82.5 people/ km^2 would exclude elephants (Parker and Graham 1989).

1.3. Conservation in Kenya

1.3.1. The Kenyan environment

Kenya is a very biodiversity-rich country, with a variety of habitats and unique fauna and flora (Wass, 1995). In 1995, it was estimated that arid and semi-arid lands (ASALs) occupied 81% of Kenya, where annual rainfall is less than 500mm, including woodlands, bushland, grasslands, and deserts. A further 16% of Kenya comprised farmland and urban development and about 3% was indigenous forests, plantation forests and mangroves combined (Wass, 1995; Matiru, 2000). Forest land in Kenya is threatened because it continues to be excised for settlements, despite the important role this forest has in water catchment (Liniger, 1992; Wiesmann et al., 2000).

The five main forest blocks in Kenya are fertile biodiversity-rich islands in a sea of ASALs, and they are also the main water towers. These main forest blocks include MK, Mount Elgon, the Aberdares, the Cherenganis and the Mau escarpment (Liniger 1992; Wiessmann et al., 2000; Lambrechts et al., 2003). Climate and geography in Kenya, define the distribution, quantity, type and productivity of primary herbivorous consumers or non-selective grazers, and the highest natural densities of herbivores occur in areas of Kenya with 500-1,000mm rainfall (Coughenour, 1991; Ogara and Awuor, 1997; McCarty et al., 2002). However, these also include the most people, at densities over 82.5 people/ km^2 (Republic of Kenya, 2000), which was estimated to exclude co-existence with elephants (Parker and Gragham, 1989). As human populations continue to expand, the elephant range in Kenya is shrinking, and elephants living in isolated protected fragments are becoming over-crowded (Leuthold, 1996; Ottichilo et al., 2000; Jenkins; 2003).

1.3.2. Elephants numbers in Kenya

During an era of heavy poaching, elephant numbers in Kenya were estimated to have declined from 130,570 animals in 1979 to some 16,000 in 1989 (Ngure, 1992). Thereafter, elephant numbers have gradually increased and were estimated at 30,694 by 1998, of which 47% were considered 'definite' (Barnes et al., 1998). Most elephant surveys in Kenya have been conducted by air because less than 3% of the total land surface is forested. However, around one third of the total elephant population in Kenya lives in these forests. Elephant estimates in forests in Kenya were derived from dung counts and were considered 'speculative' in the AED of 1998. Dung counts estimates were typically allocated a survey quality 'C' or 'D' within the range from the best quality, 'A', to the worst, 'E' (Barnes et al., 1998). By 2002, the elephant population in Kenya was estimated at 28,806 elephants (Blanc et al., 2003). A potentially worrying reduction of 1,888 elephants between 1998 and 2002 was explained by improved accuracy in forest surveys. Some 47% of the elephants in Kenya were classified as 'definite' in 1998, and this increased to 76% classified as 'definite' by 2002. Of these, 26% were counted in forests, compared with 38% in 1998. For the first time, two dung-count results in Kenya were assigned the quality 'B' in the AED, one of which was completed as part of this thesis (Chapter 3).

1.3.3. Elephant distribution in Kenya

Kenya is estimated to have lost over 44% of its wildlife between 1977 and 1994 due to land fragmentation, and the total elephant range has shrunk from 24% of the total land surface in 1998 to 19% in 2002, of which 79% occurs outside PAs (Barnes et al., 1998; Norton-Griffiths, 1998; Blanc et al., 2003). In Kenya, elephants are presently distributed in 26 fragments, the largest being the 44,732km^2 MK-Northern Grazing Area (MK-NGA) fragment (Sitati, 2003). Habitat fragmentation due to human expansion often leads to blocking of migration routes, and to increasing pressure on, and over-exploitation of, remaining fragments by over-crowded and confined animals and by surrounding people (Lamprey, 1985; Gachago and Waithaka, 1995; Vanleeuwe and Lambrechts, 1999; Wittemyer, 2001; Sitati et al., 2003).

In countries such as Kenya, aerial counts of elephants are also used to assess elephant distribution in non forested areas, but information on elephant distribution in forests is limited to what is known for the small areas sampled by line transects. However, the application of predictive GIS modelling allows the extrapolation of information from line transects to large areas that have not been sampled (Chapter 4).

1.3.4. Human use of the Kenyan environment

The human population in Kenya has grown by 2.7% per annum and totalled 30 million people in 1999. Of these, 10%, or 530,000 households, were settled within a 5,000m buffer around fertile forests, while 4,000 households were forest dwellers (Emerton, 1995; Wass, 1995; Republic of Kenya, 2000). As the population has grown, the subsequent pressure has also increased on the finite fertile land and resources. Land use in Kenya is influenced by rainfall, with very intensive small-scale farming and cash crops occurring around the fertile forest areas in the highlands, and pastoralism and ranching occurring in the dryer lowlands (Winiger, 1986; Liniger, 1992; Wiesmann et al., 2000). Areas that sustain rain-fed crops lie within fragile ecosystems constrained by the climate and soil structure, making them highly susceptible to soil erosion (Mati, 1999). Soil erosion has been reported as a threat to land productivity since the 1930s, and it was reported as the greatest threat to land productivity in Kenya by 1999 (Maher, 1937; Speck, 1983; JIKA/GOK, 1999). The cause of erosion in dry areas is from over-grazing, and in fertile areas it is from poor land tenure and deforestation to address daily needs (Abira, 1997; Ogola and Omulo, 1997; Mwaura and Mutonga, 2003).

In 1997, firewood accounted for as much as 79% of Kenya's energy consumption (Republic of Kenya, 1998). Only 10% of fuelwood was purchased, while 30% came from indigenous and plantation forests, and 30% came from the lowlands, with the demand for fuelwood increasing at a rate of almost 5% per annum in 1997 (Ogola and Omulo, 1997; Omenda, 1997; Onyango et al., 1997). Sustainable fuelwood production only met about one quarter of the national requirements and deforestation led to a 40-60% loss of standing wood between 1970 and 2000 (MENR, 1994; Gathaara, 1999; Matiru, 2000). Despite the enormity of this problem, 932.08 km^2 of land was excised for settlements between 1963 to 1999 and resulted in decreased forest protection (Onyango et al., 1997; Matiru, 2000). Deforestation threatens agriculturalists through the deterioration of soil quality; public health through affected downstream water supply; hydro-electricity schemes through sediment loss and silting of dams; the tourist industry through altered wildlife habitats; and, future generations through loss of gene pools (Omenda, 1997; Nkako, 1999). When the water supply is affected through deforestation, this also causes increasingly violent conflicts over water between highland and lowland communities, and between people and elephants in low human density areas (Kapos et al., 2000; Wiesmann et al., 2000).

1.3.5. Human-elephant conflict and mitigation in Kenya

By 2002, Kenya held about 28,800 elephants and around 30 million people (Republic of Kenya, 2000; Blanc et al., 2003). The interface between the highest densities of people and elephants, and therefore the highest levels of HEC, occurred around Kenya's fertile forest complexes. HEC translates into elephant impact to human resources (e.g. Sitati et al., 2003), and human impact on elephant-inhabiting environments (e.g. Vanleeuwe and Lambrechts, 1999).

The Kenyan government has acknowledged that poverty and environmental concerns are intertwined, and almost all ongoing conservation projects now include components of community involvement, or principles of sanctioned resource use, or both (Gichuki

1999; COMPACT, 2001; KWS, 2001; Mbora and Simons, 2002). Although the success of community-based conservation projects and human-elephant co-existence is more likely in areas where human densities are low (e.g. Kuriyan, 2002), tolerance towards wildlife by low density patoralist communities in Kenya has declined in recent years due to growing competition for water and forage (Wiessmann et al., 2000; Mwaura and Mutunga, 2003). Over-use of water and trees close to the water sources occurs because the first concerns of subsistence farmers is to gain access to water sources (Decurtis, 1992; Ekbom et al., 2003). Many subsistence farmers around the five forested water towers of Kenya have never been to the ASALs, and they do not understand why the apparent abundance of water and trees cannot be used to promote their own economic development (Decurtis, 1992; Wiesmann et al., 2000).

The impact of elephants on human resources and land has generally been addressed with plans that focus on direct solutions (Thouless and Sakwa, 1995; Gichohi, 2000; Smith and Kasiki, 2000; Sitati et al., 2003), with an increasing amount of community involvement (European Commission, 1994; Mwathe et al., 1998; KWS, 2001; Mathuva, 2002). These plans have included financial compensation for crop loss, translocating and driving out of elephants, control shooting, and protective fencing (European Commission, 1992; Kangwana, 1995; Kasiki, 1998; Campbell et al., 2000). Financial compensation schemes created unsustainable expectations, did not reduce elephant crop raiding, and were abolished due to abuses of the system (KWS, 1995a, 1995b, 1995c). Translocation and driving out of elephants, control shooting, and protective fencing, have rarely addressed the underlying causes of human-elephant conflict.

Considering the demographic growth of both species, HEC in Kenya will most probably worsen. With the exception of some pastoralist areas where densities and life-style might allow co-existence, elephants in Kenya will most likely become increasingly confined to PAs (Jenkins, 2003). It is therefore essential to identify and protect elephant routes to secure important remaining natural ecosystems and their functions, so that they are not jeopardised through destruction by over-stocked and confined elephants, or by people (Harcourt et al., 2001; Osborn and Parker, 2003). Legislation can be enacted to secure resources from total destruction. However, this has very little meaning without effective law enforcement and land use management plans that focus on long-term benefits for people and elephants, regardless of the short-term disadvantages that this may bring for either species.

1.3.6. Biodiversity protection and institutions in Kenya

Kenya is a signatory to the CBD, CITES and the Global Forest Principles (GFP). To protect its biodiversity, Kenya has established over 100 PAs of different protection status. These PAs are variously under the management of the Forestry Department (FD) and the Kenya Wildlife Service (KWS) when located on government land, or managed by County Councils when located on trust land, and under private management when located on private land (Matiru, 2000).

Due to budgetary constraints and a flourishing black market for ivory and rhino horn, corruption within the former Wildlife and Conservation Management Department (WCMD) was rife. During its 15 years of administration, before it was recognised as a parastatal in 1991, the elephant and rhino populations dropped by 85% and 97%, respectively (Wass, 1995). Like the WCMD in the past, the FD still remains a government institution that relies on limited and insufficient funds from the central government treasury. The treasury gains the financial revenue generated from reserves and forests, and reallocates it to government departments according to development priorities, resulting in very little being returned to conservation. In contrast, the KWS is a parastatal, and funds that it generates remain within the KWS, which has improved salaries and equipment substantially. Most importantly, it has greatly improved the effectiveness of law enforcement and stopped large-scale poaching in Kenya.

1.4. The conservation interest of Mount Kenya

MK was chosen as the research location for this study because it combines all aspects of the triangular relationship between a PA, its elephant population and the surrounding human population. The environment is unique and represents the largest forest complex and water catchment in semi-arid Kenya. MK's extreme topographic features result in extreme gradations in altitude, climate and vegetation. The logistical difficulties of working on MK have meant that information available on the elephants before this study were limited to some educated guesses, and to two dung counts that estimated MK to 'possibly' house the largest highland population in Kenya (Said et al., 1995; Barnes et al., 1998). MK is surrounded by one of the most densely populated rural human communities in Kenya (Republic of Kenya, 2000). Accordingly, levels of human impact on natural resources, and levels of elephant impact on human resources, or HEC, are very pronounced.

Being almost isolated by a ring of agriculture, the relationship on MK between its environment, its elephants and its people, could be studied without being confounded by external factors. Therefore, MK offers the opportunity to study factors that explain elephant distribution and movement, and the spatio-temporal distribution of elephant damage to farms adjacent to the MK forest, in isolation. Finally, the change in the management of the MK forests changed from FD to KWS during this study, allowed an investigation into the effect of a key institutional change to a more effective management regime on HEC.

The ecological functions of MK are of great importance for the Kenyan economy and the well-being of its people and wildlife, and these functions cannot be jeopardised either by people or a confined elephant population. However, the threat that habitat loss may lead to irreversible and detrimental consequences is very real on MK. Research to help improve land use management for elephants and people on MK is therefore also needed.

1.5. Aims of the Study

The study aimed to explore the relationship between the MK environment, elephants and people, by the following steps:

- To identify the problems and define the goals and aims of this thesis for management of the MK environment for the benefit of elephants and people (Chapter 1);

- To create a complete picture of the MK environment, in terms of its climate, geology, topography and biodiversity by exploring archive data and GIS-generated data (Chapter 2);

- To investigate the problems and sources of error encountered with estimating elephants in forested environments like MK (Chapter 3);

- To develop strong explanatory models of elephant seasonal distribution from transect data, using adapted methods, tests of model strength and robustness, and to integrate explanatory models and GIS to create distribution maps (Chapter 4);

- To predict the location of elephant travel routes and foraging paths based on least-cost travel assumptions, and to investigate their relationship to measured elephant destruction in tree plantations (Chapter 5);

- To model spatio-temporal patterns of elephant impact on farms adjacent to the MK forest from conflict reports, and to investigate its mitigation in more detail for the two most affected areas around MK (Chapter 6);

- To quantify and illustrate the use of land and resources under FD management of MK until July 2000, and to identify the success and failure of strategies that aimed to address the demands for land and resources (Chapter 7);

- To identify and explain the effect of different governing institutions through comparing the state of the MK environment before and after July 2000, when MK management changed from the FD to the KWS (Chapter 8);

- To combine all conclusions and accordingly provide recommendations for future management for the benefit of people and elephants in and around MK (Chapter 9).

1.6. Thesis structure

Chapter 1 has introduced the main themes of the thesis. Chapter 2 sets MK within the context of Kenya and explores all aspects of its environment. Chapter 2 also describes methods and technical jargon that re-occurs throughout the thesis. The six chapters that follow explore the relationship between elephants and the environment, between elephants and people, and between people and the environment. Chapter 3 estimates elephant densities on MK and explores sources of error associated with estimating elephants from dung counts in mountain forests. Chapter 4 establishes the explanatory factors for elephant seasonal distribution through multivariate analysis of line transect data, and uses predictive modelling within a GIS to develop seasonal distribution maps. Chapter 5 predicts how elephants move within their confined habitat and identifies explanatory factors for elephant damage to human resources inside the MK Forest Reserve, namely tree plantations. Chapter 6 identifies the explanatory parameters of elephant crop damage, and the reporting of damage, and explores site-specific HEC and mitigation strategies for the two most affected areas around MK. Chapter 7 identifies and quantifies the spatio-temporal patterns of human use of MK's land and natural resources, the success and failure of projects that aim to address peoples' demands for land and resources. Chapter 8 explores the effect of different managing institutions on the protection of MK land and resources, and investigates the underlying causes. Chapter 9 concludes by discussing the combined results of previous chapters, and provides applied recommendations to improve the situation through land use management for the benefit of people and elephants.

Chapter 2

STUDY AREA AND GENERAL METHODS

This chapter introduces the study area in Section 2.1 and describes the general methods in Section 2.2. In Section 2.1, I set Mount Kenya (MK) in its geographical context, before describing its geology, hydrometeorology, biodiversity and protection, and economic potential. Section 2.2 introduces the general methods used throughout this study and describes the technical terminology tools used for the analyses, namely: geographic information system (GIS); satellite image; and, satellite image classification.

2.1. The Mount Kenya study area

MK is the second highest mountain in Africa, reaching 5,200m asl, and has a variety of climatic and ecological zones that supports a rich biodiversity. MK has been a site of international importance for palaeogeography, palaeoclimatology, and palaeoecology since its formal discovery by JW Gregory in 1893, and by H Mackinder in 1899 (Mahaney et al., 1997; Ficken et al., 2002; Wooller and Agnew, 2002). MK has also been the site of important research in glaciology (Grab, 1996; Shanahan and Zreda, 2000; Kaser, 2001), climatology (Rietti-Shati et al., 1998; Olago, 2001; Molg et al., 2003) and geology (Speck, 1986; StreetPerrott et al., 1997; Huang et al., 1999).

MK is of national importance as a water catchment, which feeds the two largest rivers in Kenya, the Tana and the Ewaso Ngiro (Speck, 1983; Liniger, 1992; Emerton, 1997; Mwaura and Mutunga, 2003). MK is important in attracting tourists, providing fertile grounds for agriculture and tree plantations, which provides employment in the forestry, agricultural and tourism sectors, the last two being the most important overall economic earners of foreign exchange for Kenya (Emerton, 1997; Republic of Kenya, 1998). MK, however, also faces considerable pressures. The fertile lands around MK are heavily settled by poorly tenured small-scale farms, and the resulting soil erosion and sediment leaching has silted up the main dams in Kenya. Shortage of water has created increasingly violent disputes between highland communities over-using water around the sources, and lowland communities such as pastoralists depending on water for their cattle away from the sources (Wiesmann et al., 2000). Poor land management practices are rife around MK, and with one of the densest human and elephant populations living adjacent to one another and regularly trespassing on one another's habitat, human-elephant conflict is very common (Hagiwara, 2002; Mathuva, 2002).

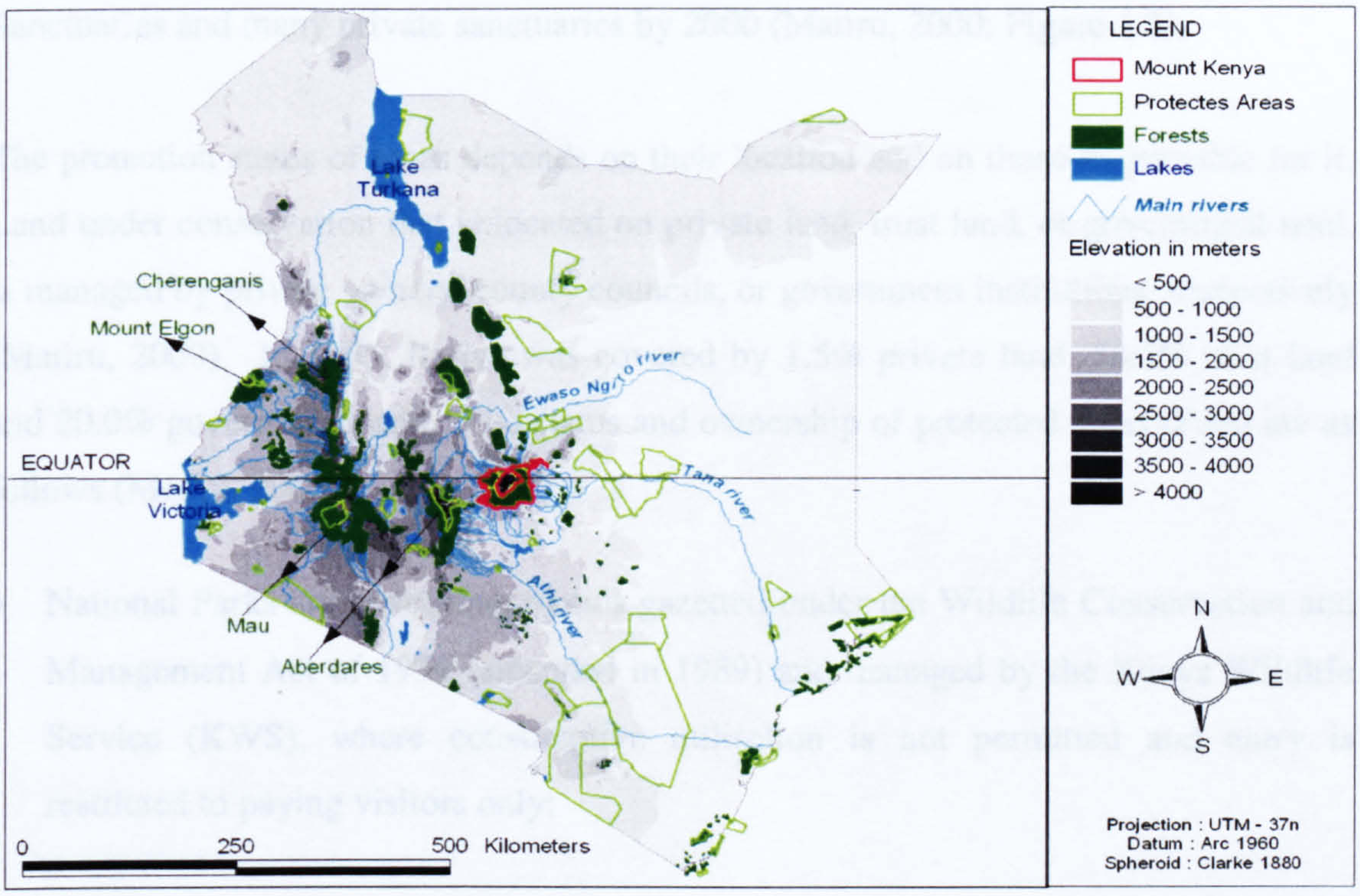
2.1.1. Setting Mount Kenya in context

To set MK in its wider Kenyan context, I first explored Kenya through the following sub-sections: geology and hydro-climatology; biodiversity and its protection; human distribution and land use; and, economic potential.

2.1.1.1. Geology and hydro-climatology of Kenya

The land area of Kenya covers 582,644km^2 and has an altitude that ranges from sea level to the peak of MK at 5,200m asl (Winiger, 1986; UNEP/WMO, 1996). The five main catchment basins are the Rift Valley, the Ewaso Ngiro River, Lake Victoria, the Tana River, and the Athi River, of which the latter three basins contribute to over 90% of the total annual water discharge in Kenya (Abira, 1997; Figure 2.1).

Figure 2.1. Main forests, lakes, and rivers in Kenya



With the exception of Lake Victoria, most lakes lie in the ASALs, where evaporation greatly exceeds precipitation (JICA/GOK, 1999). Most of Kenya receives less than 500mm of rain per annum (Wass, 1995), and only eight rivers in Kenya flow permanently throughout the year. The mean annual volume of rainwater in Kenya is about 3.6 x 10^{10} m^3, comprising surface and ground water (Speck, 1983; Winiger, 1986;

Abira, 1997). Water within those basins mainly originates from five water towers, which are MK, Mount Elgon, and the Aberdares, Cherengani, and Mau escarpments, of which MK is the largest (Leibundgut, 1986; Wiesmann et al., 2000). Kenya's large range of geological and hydro-climatological conditions gives rise to a large variety of habitats with unique fauna and flora.

2.1.1.2. Biodiversity and its protection in Kenya

Onyango et al. (1997) reported that 24,375 animal species, 6,817 plant species, excluding algae, fungi, and lichens, and 1,841 microbial species occur in Kenya. In 1992, the Government of Kenya also reported 683 species of fish of which 67 were endangered, 101 species of amphibians of which two were endangered and 24 species of reptiles of which 11 were endangered. To conserve its biodiversity, Kenya had established 28 National Parks, 33 National Reserves, 34 Forest Reserves, 8 National Sanctuaries and many private sanctuaries by 2000 (Matiru, 2000; Figure 2.2).

The protection status of areas depends on their location and on those responsible for it. Land under conservation that is located on private land, trust land, or government land, is managed by private owners, county councils, or government institutions, respectively (Matiru, 2000). In 1995, Kenya was covered by 1.5% private land, 78.5% trust land and 20.0% government land. The status and ownership of protected areas (PAs) are as follows (Matiru, 2000):

- National Parks are government lands gazetted under the Wildlife Conservation and Management Act of 1976 (amended in 1989) and managed by the Kenya Wildlife Service (KWS), where consumptive utilisation is not permitted and entry is restricted to paying visitors only;

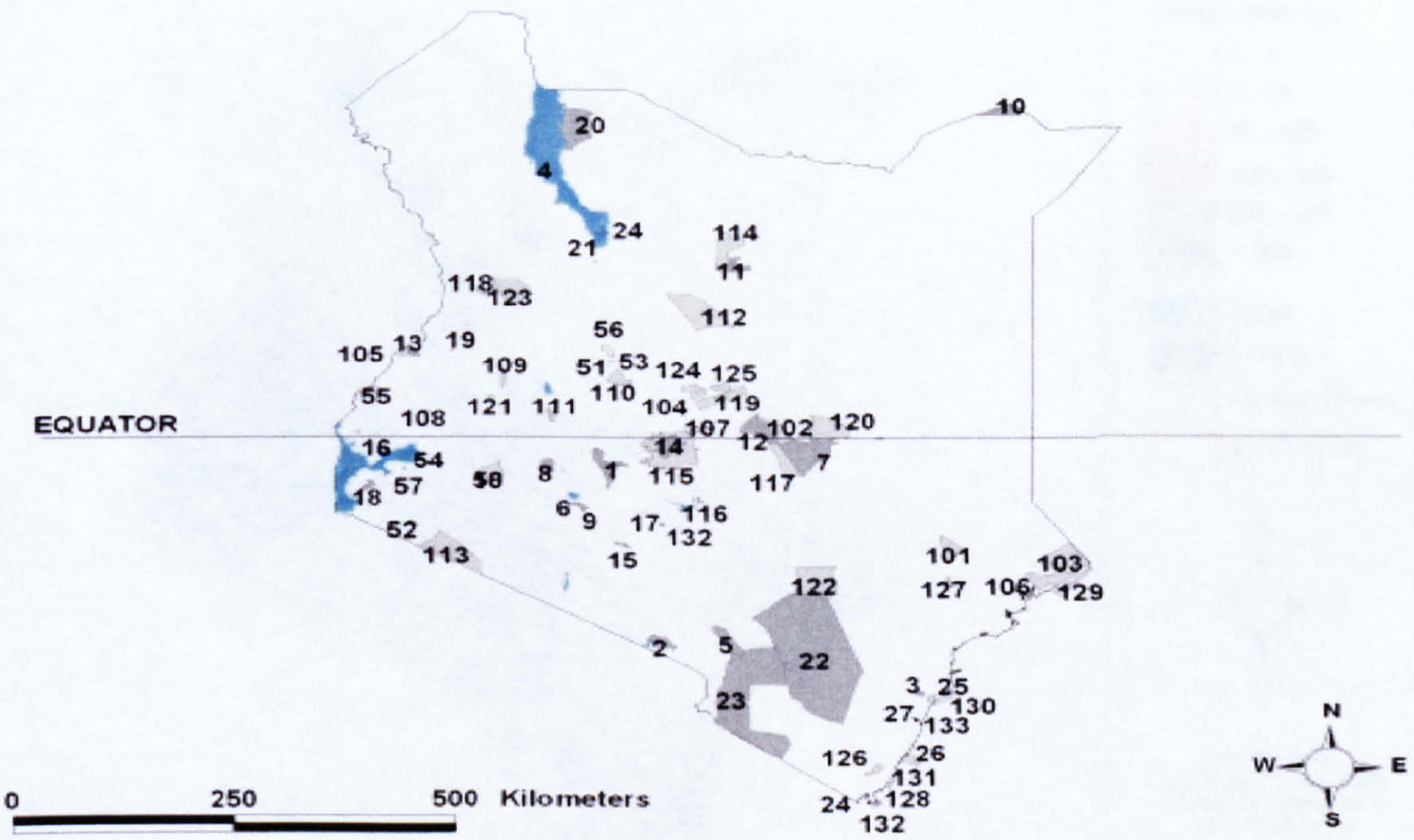
- National Reserves are trust lands gazetted under the Wildlife Conservation and Management Act of 1976 (amended in 1989) on agreement between county councils and the Minister for Wildlife, that are managed either by the KWS or by district councils and that allow a certain level of licensed access and resource use;

- Forest Reserves are lands gazetted under the Forest Act of 1962 (revised in 1982 and 1992) or/ and the Forest Policy of 1968 (amended in 1994), that are either trust lands or government lands, including both indigenous and plantation forests, and that allow both licensed consumptive and non-consumptive resource use. Forest Reserves on trust land are managed by county councils, whereas Forest Reserves on government land are managed by the Forestry Department (FD);

- National Sanctuaries are all lands that are gazetted under the Wildlife Conservation and Management Act of 1976 (amended in 1989) to protect specified species, and that have a maximum size of $26km^2$.

Conservation of PAs is strongly influenced by human distribution and land use patterns.

Figure 2.2. National Parks, Reserves, and Sanctuaries in Kenya, 2000



National Parks
1 Aberdares
2 Amboseli
3 Arabuko-sokoke
4 Central Island
5 Chyulu Range
6 Hells Gate
7 Kora
8 Lake Nakuru
9 Longonot
10 Malka Mari
11 Marsabit
12 Meru
13 Mount Elgon
14 Mount Kenya
15 Nairobi
16 Ndere Island
17 Ol donyo Sabuk
18 Ruma
19 Saiwa Swamp
20 Sibiloi
21 South Island
22 Tsavo East
23 Tsavo West

Marine Parks
24 Kisiti
25 Malindi
26 Mombasa
27 Watamu

National Reserves
101 Arawale
102 Bisanadi
103 Boni
104 Buffaloe Springs
105 C. Kitale
106 Dodori
107 Imenti forest
108 Kakamega
109 Kamnarok
110 Laikipia
111 Lake Bogoria
112 Losai
113 Maasai Mara
114 Marsabit
115 Mount Kenya
116 Mwea
117 N. Kitui
118 Nasolot
119 Nyambeni hills
120 Rahole
121 Rimoi
122 S. Kitui
123 S. Turkana
124 Samburu
125 Shaba
126 Shimba hills
127 Tana River Primate
129 Kiunga
130 Malindi
131 Mombasa
132 Mpunguti
133 Watamu

Marine Reserves
128 Diani Chale

National Sanctuaries
51 Enkara Narok
52 Kihancha
53 Kisima
54 Kisumu Impala
55 Malaba
56 Maralel
57 Ondago Swamp
58 S.W. Mau

2.1.1.3. Human distribution and land use in Kenya

According to the 1999 national census, 15.6% of 30 million Kenyans live in urban areas and 84.4% in rural areas, of which 9.7% or 2.9 million people live within 5,000m of forested mountains (Republic of Kenya, 2000; Figure 2.3). This is because the combination of trade winds from the Indian Ocean and high local precipitation produce favourable agricultural conditions on the rainy sides of the mountains (Speck, 1983; KNEAP, 1994; Figure 2.4). In contrast, the ASALs where evaporation highly exceeds precipitation, including their woodlands, bushlands, grasslands and deserts, are only viable for pastoralists with nomadic or semi-nomadic lifestyles (Winiger, 1981; Odok, 1991; Wiesmann et al., 2000; Table 2.1).

Figure 2.3. The distribution of water, forests and human density in Kenya in 1998

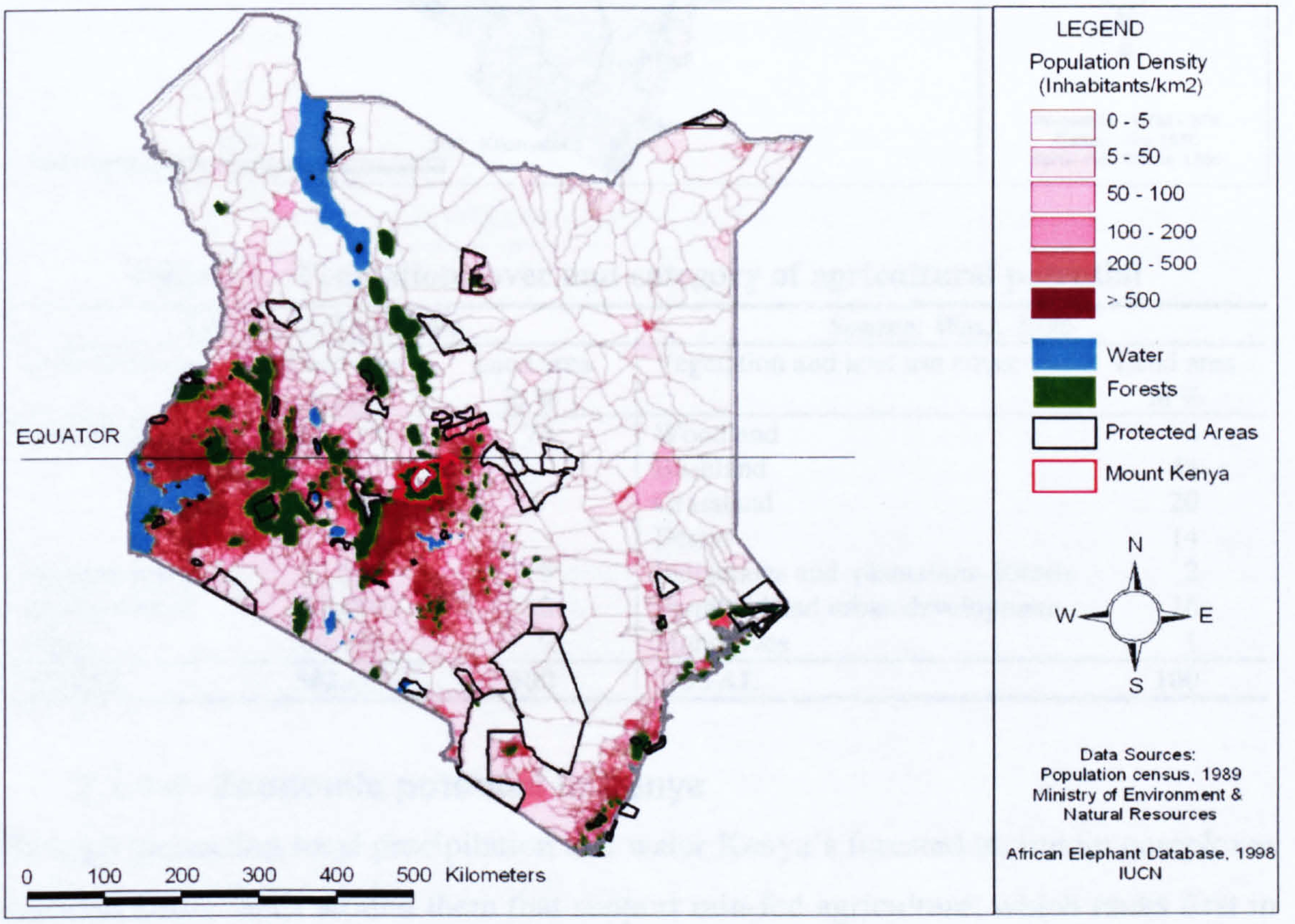


Figure 2.4. Land cover in Kenya in 1998

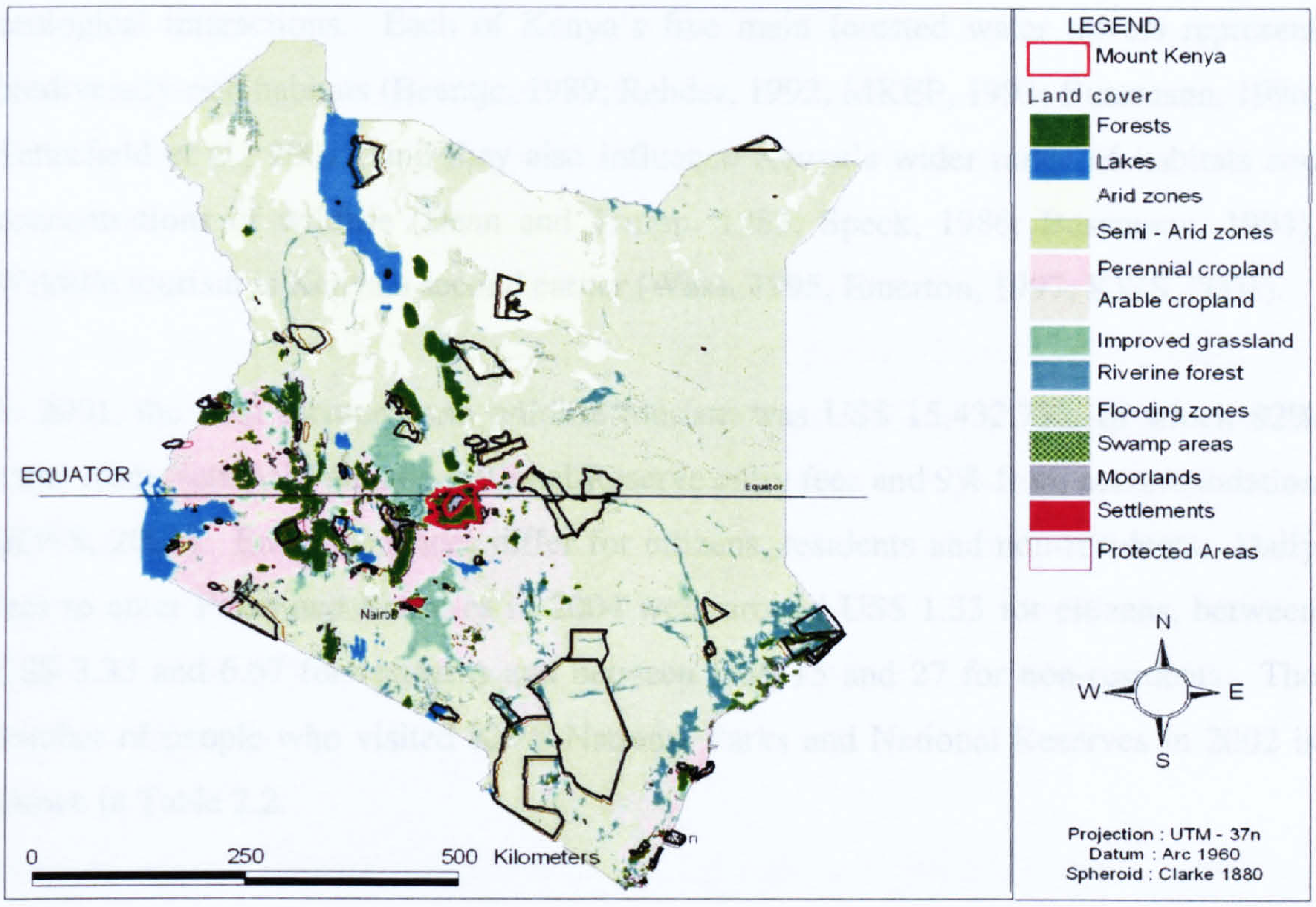


Table 2.1. Vegetation cover and category of agricultural potential

Source: KNEAP, 1994			*Source: Wass, 1995*	
Land category	Land area in km^2	Land area in %	Vegetation and land use cover	Land area in %
Low potential	451,050	74	Woodland	4
			Bushland	43
			Grassland	20
			Desert	14
Medium potential	31,570	5	Indigenous and plantations forests	2
High potential	67,850	12	Farmland and urban development	16
Other	62,174	9	Mangroves	1
TOTAL	**582,644**	**100**	**TOTAL**	**100**

2.1.1.4. Economic potential in Kenya

Through generating local precipitation and water Kenya's forested mountain complexes maintain fertile lands around them that support rain-fed agriculture, which ranks first in the Kenyan economy, contributing 30% of the Gross Domestic Product (GDP), 60% of the foreign exchange, and 80% of the national employment (Republic of Kenya, 1998). The cash crops produced included coffee, tea, sisal, wheat, maize, tuber crops and fruits (Government of Kenya, 1994; Awuor and Ogala, 1997). Forested PAs also bring important direct economic benefits through their resources such as timber, fuelwood and medicinal plants, and important indirect benefits through their regulation of ecological interactions. Each of Kenya's five main forested water towers represent biodiversity-rich habitats (Beentje, 1989; Rehder, 1992; MKEP, 1993; Bussmann, 1996; Tatterfield et al., 2001), and they also influence Kenya's wider range of habitats and concentrations of wildlife (Dean and Trump, 1983; Speck, 1986; Bussmann, 1994). Wildlife tourism is Kenya's second earner (Wass, 1995; Emerton, 1997; KWS, 2001).

In 2001, the total income from wildlife tourism was US$ 15,432,733, of which 82% came from National Park and National Reserve entry fees and 9% from accommodation (KWS, 2001). Entry fee prices differ for citizens, residents and non-residents. Daily fees to enter Parks and Reserves in 2004 were around US$ 1.33 for citizens, between US$ 3.33 and 6.67 for residents and between US$ 15 and 27 for non-residents. The number of people who visited KWS National Parks and National Reserves in 2002 is shown in Table 2.2.

Table 2.2. Visitors at KWS-managed National Parks and Reserves, 2002

Protected Area	*Citizens*	*Residents*	*Non-Residents*	*All visitors*
Lake Nakuru National Park	123,990	14,180	91,638	229,808
Tsavo East National Park	41,153	3,890	107,733	152,776
Nairobi National Park	44,605	22,311	23,531	90,447
Amboseli National Park	20,675	4,623	63,466	88,764
Tsavo West National Park	24,286	4,334	47,426	76,046
Kisite Marine National Park	9,389	2,817	34,871	47,077
Aberdare National Park and National Reserve	8,350	4,155	28,658	41,163
Hells Gate National Park	23,992	9,365	4,243	37,600
Mombasa Marine National Park and National Reserve	8,362	1,110	21,042	30,514
Watamu Marine National Park and National Reserve	2,799	6,167	20,382	29,348
Malindi Marine National Park and National Reserve	8,934	2,634	17,732	29,300
Mount Kenya National Park and National Reserve	12,033	3,078	13,205	28,316
Shimba Hills National Reserve	6,979	1,787	5,668	14,434
Longonot National Park	7,120	4,495	1,201	12,816
Meru National Park	4,609	734	1,220	6,563
Arabuko-Sokoke National Park	1,253	720	2,276	4,249
Kakamega National Reserve	2,195	675	2,774	5,644
Mount Elgon National Park and National Reserve	1,225	1,081	589	2,895
Nasolot National Reserve	54	2,011	128	2,193
Ol Doinyo Sabuk National Park	1,905	186	13	2,104
Marsabit National Park and National Reserve	274	881	444	1,599
Saiwa Swamp National Park	411	309	321	1,041
Ruma National Park	296	309	272	877
Central Island National Park	84	117	633	834
Sibiloi National Park	104	181	241	526
South Island National Park	91	246	94	431
Mwea National Reserve	251	10	40	301
TOTAL	355,419	92,406	489,841	937,666

Source: KWS Head Quarters – 2003

2.1.2. Mount Kenya's characteristics

The characteristics of MK and the threats it faces are explored through the sub-sections: geology; hydro-climatology; altitudinal zonation; biodiversity and its protection; human distribution; human land use; economic potential; and, problem identification..

2.1.2.1. Geological conditions around Mount Kenya

MK is an extinct volcano, and the majority of eruptions occurred in the lower and middle Pleistocene around 1.2 to 0.2 million years ago. One million years ago, MK rose to 7,000m asl, but through weathering and sediment transport by wind and water, the crater wall wore down to its present shape and height (Pratt and Gwynne, 1977; Mahaney et al., 1991b; Mbuvi and Kironchi, 1994; Kaser, 2001). Below the peaks, the valleys on MK are U-shaped, but around the lower part below 3,600m asl they are fluvial V-shaped.

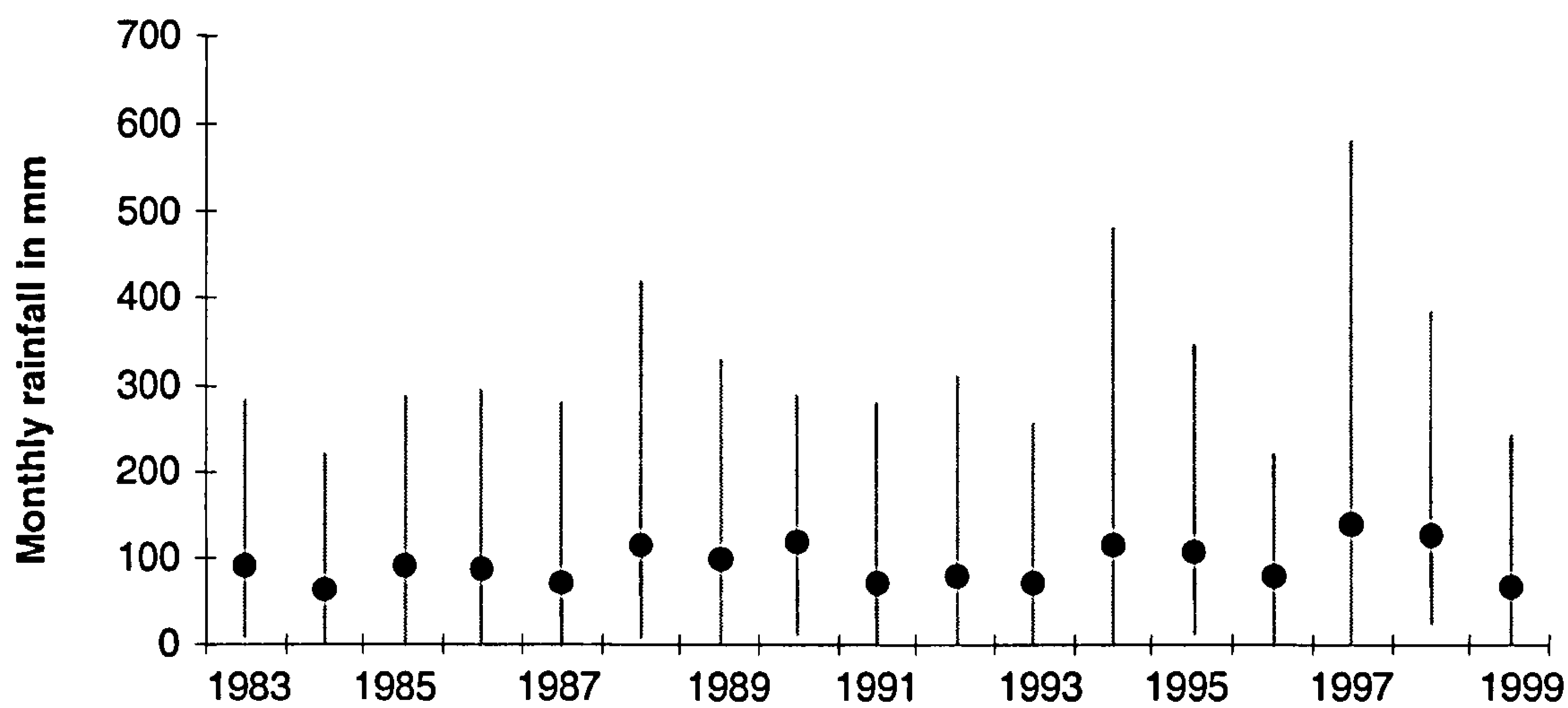
Some residual soils have developed *in situ* but most are transported soils, which are defined according to the way they arrived, whether: aeolian, by wind; alluvial, by stream flow; colluvial, by surface flow; lacustrine, by lake deposition; or, pyroclastic, by volcanic activity. Much of the mountain is covered by pyroclastic rocks and volcanic ash originating from various secondary eruptions (Pratt and Gwynne, 1977; Speck, 1986; Kironchi et al., 1992; Molg et al., 2003).

The higher altitudes above 2,000m asl are dominated by deep clay loam soils on volcanic rocks that have thick humic topsoils with a high organic matter content. In contrast, deep dark red to red-brown clays occur at lower altitudes and have strong angular topsoil with a moderate angular blocky soil underneath. These soils are very fertile, but also highly erodible (Olago et al., 2000; Gatari et al., 2001; Gatebe et al., 2001).

2.1.2.2. Hydro-meteorological conditions around Mount Kenya

Water runoff has been measured at 200 gauging stations by the Ministry of Land Reclamation, Regional and Water Development since 1940, and many hydro-meteorological studies have been conducted since that date (Tetley, 1940; Government of Kenya, 1962; Ondieki, 1987; Liniger, 1992; Wiesmann et al., 2000). MK is the largest mountain massif in Kenya and receives an equatorial bimodal pattern of rainfall that in turn generates the local rainfall. The south-eastern slopes or the rainy side, are exposed to humid winds from the Indian Ocean and receive almost twice as much rainfall as the north-western slopes or the dry side (Leibundgut, 1986; Figures 2.6 and 2.7). Between 1983 and 1999 there have been some particularly dry years, with average monthly rainfall below 70mm in 1984 and 1999, and some very wet years with monthly average rainfall above 120mm in 1988, 1997 and 1998 (Figure 2.5). Up to 579mm of rain was recorded during October 1997.

Figure 2.5. Mean, minimum, and maximum monthly rain per year, 1983-1999



The rivers usually contain least water flow in February and September, while they flow most strongly in May and November, and monthly discharges depend on the monthly rainfall (Sanyu Consultants, 1999). March to May are months of heavy rainfall (Figure 2.6). When the aquifer is refilled during these heavy rains, discharge is able to fill the rivers throughout the subsequent dry period of the year in June to August (Figure 2.7). The rains during the wet months of September to November are not as pronounced as those in March to May. Thus, less water is discharged during the subsequent dry months of December to February (Leibundgut, 1986).

Figure 2.6. Monthly wet season rainfall: March to May 1991 to 1999

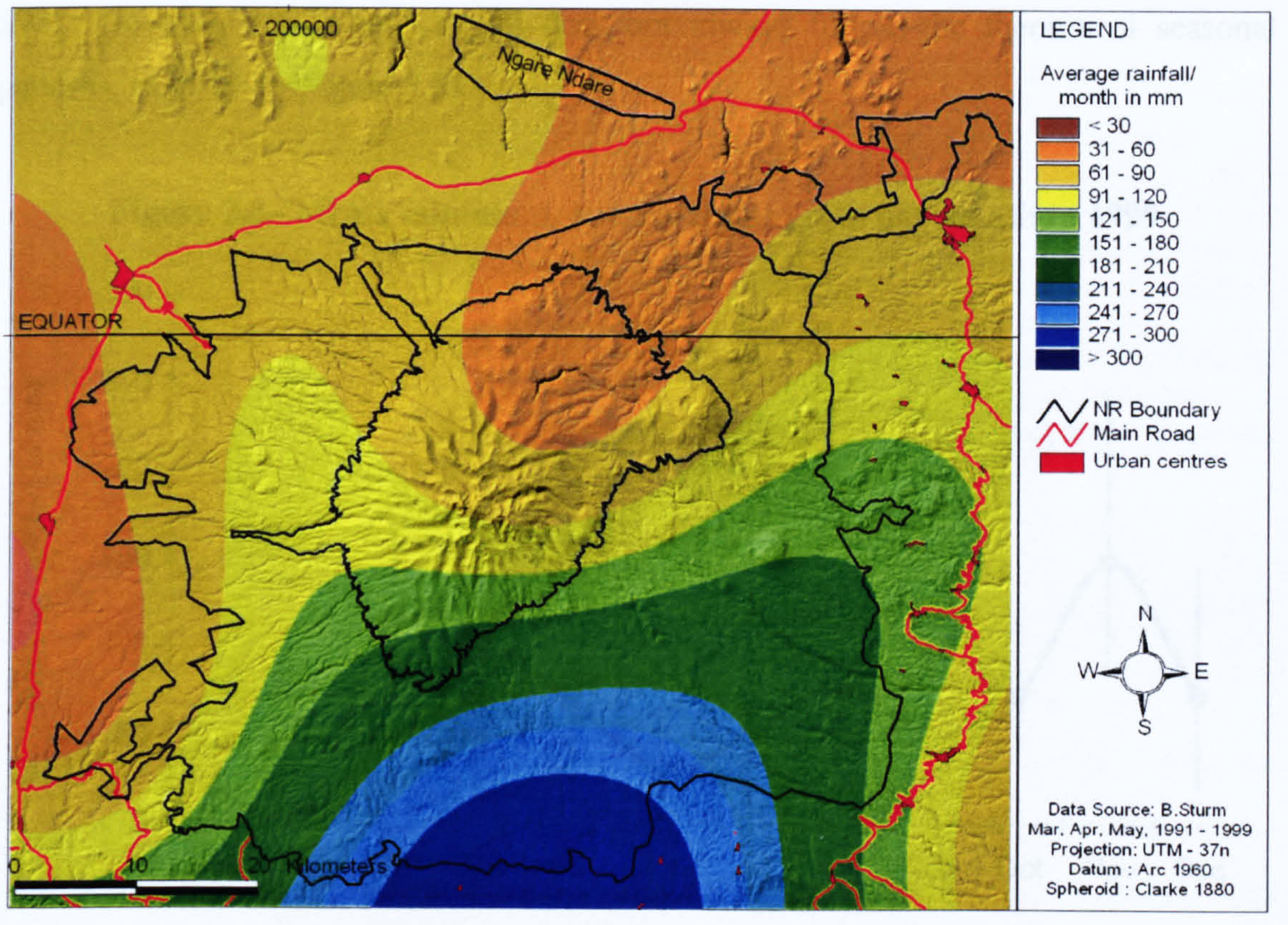
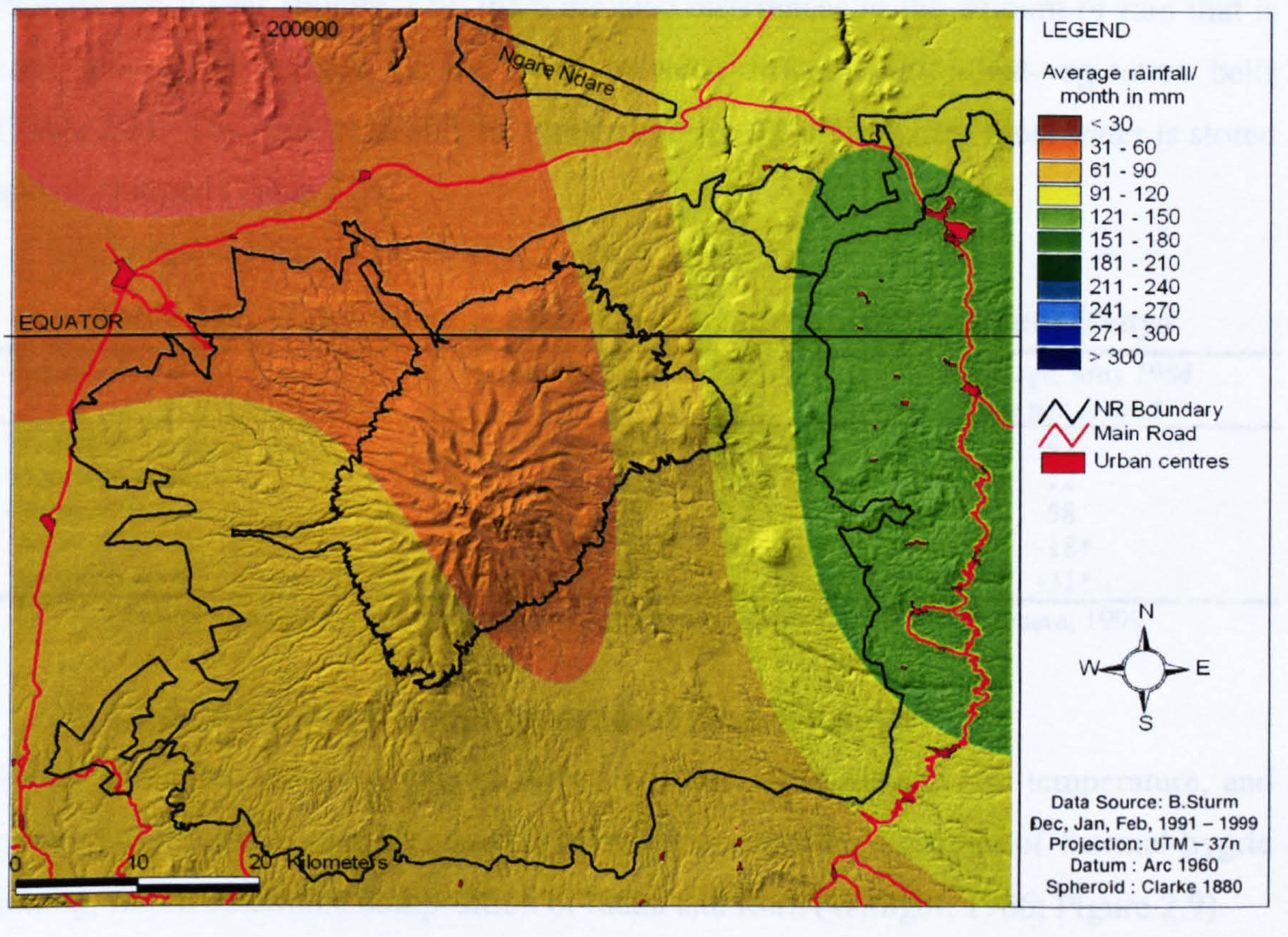
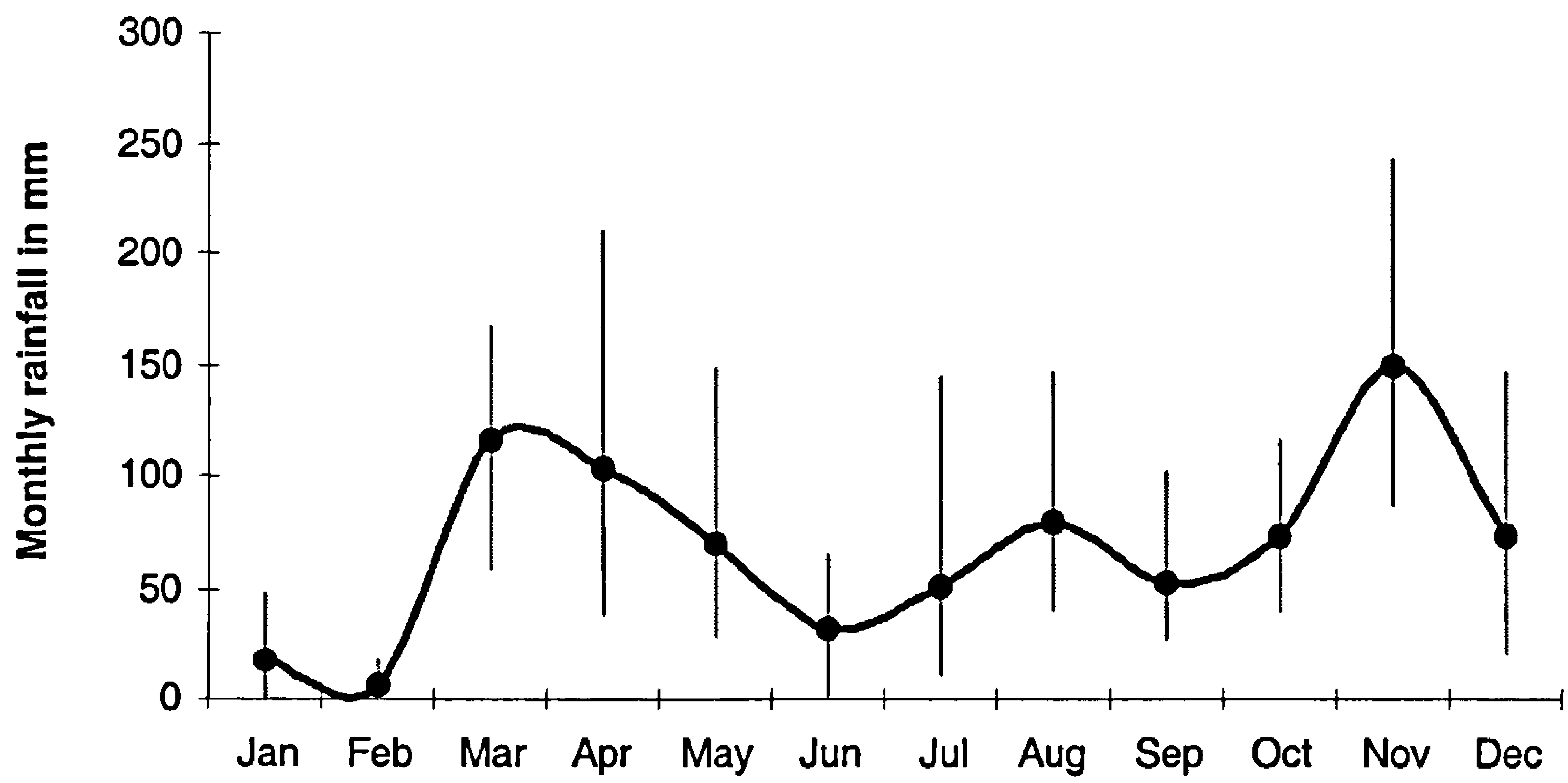


Figure 2.7. Monthly dry season rainfall: December to February 1991 to 1999



Because of its equatorial position, there is almost daily precipitation on MK (Winiger, 1981; Decurtis, 1992) and rainfall does not always follow the theoretical seasonal patterns, as in 1999 (Figure 2.8).

Figure 2.8. Mean, minimum, and maximum rain per month in 1999



Besides the differences in rainfall between years (Figure 2.5) and between the same months every year (Figure 2.8), there are also differences in the amount of rain that is absorbed and discharged via the rivers between different altitudinal-vegetation belts (Table 2.3). The peak zone and the forest zone are the areas where most water is stored and discharged (Table 2.3).

Table 2.3. Water discharge per sub-catchment area for Mount Kenya

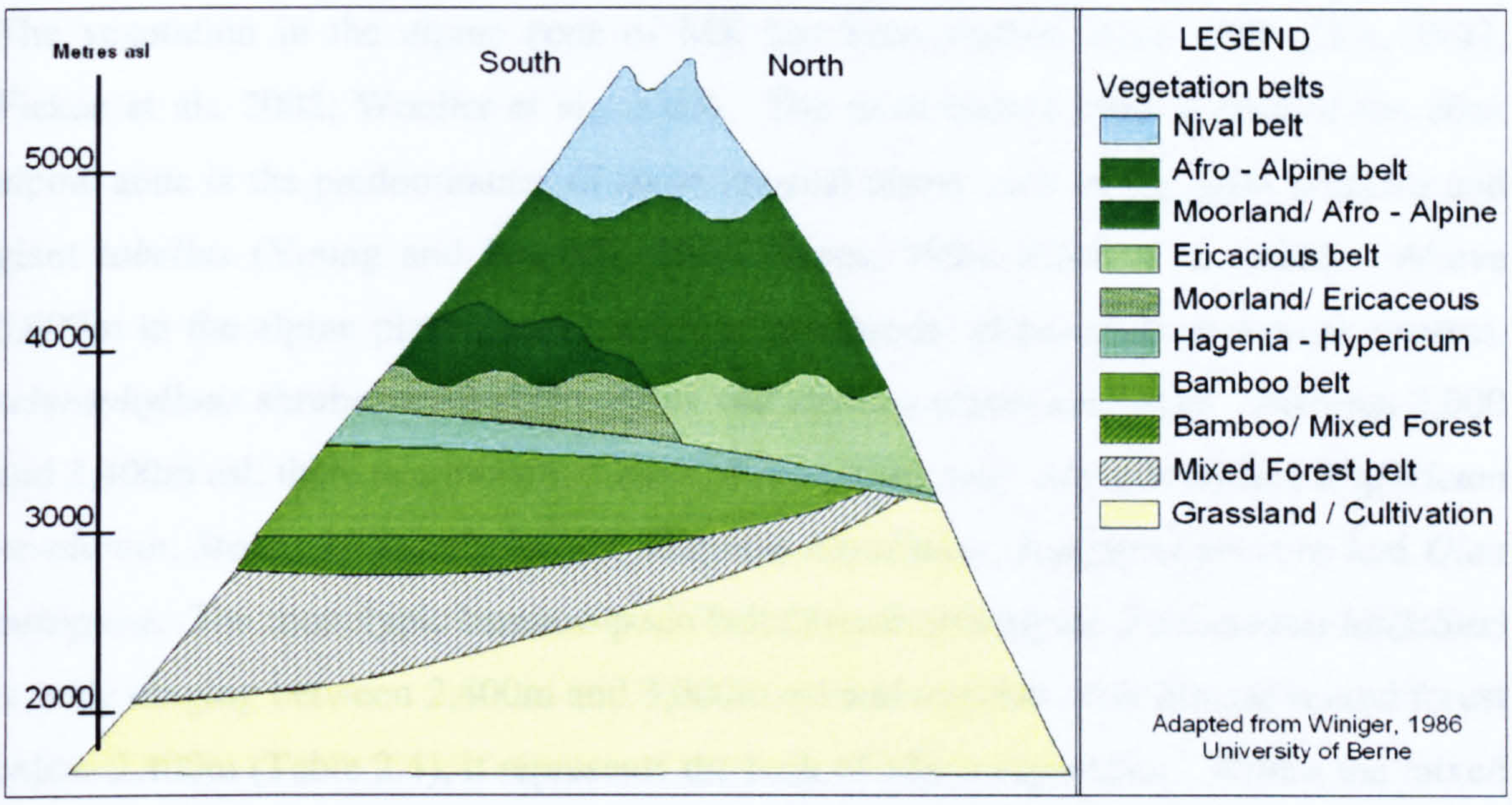
Sub-catchment	*Discharge, Feb 1984* *Litre per second*	*Discharge, May 1984* *Litre per second*
Peak zone	78	43
Moorland zone	6	12
Forest zone	42	58
Slope zone	-38*	-18*
Savannah zone	-67*	-31*

*water absorption. Source: Adapted from Decurtis, 1985 - in Gathaara, 1999

2.1.2.3. Altitudinal zonation around Mount Kenya

Altitude, rainfall and frost, exert a direct influence upon air and soil temperature, and evapotranspiration. Rainfall and soil temperatures are the elements of thermal-hygric zoning, which determine composition of fauna and flora (Winiger, 1986; Figure 2.9).

Figure 2.9. Altitudinal zonation of Mount Kenya



At shady sites, constant soil temperatures can be reached at a depth of 30cm with soil temperature equalling the air temperature. At sunny sites, constant soil temperatures can be reached at 60cm with soil temperature being 3°C higher than the air temperature. The lower slopes of the mountain, between 1,000m and 2,700m asl, shows a rapid decreases in soil temperatures of 1.25°C per 100m, the zone between 2,700m and 4,500m a decrease of 0.5°C per 100m and the area above 4,500m a decrease of 1°C per 100m (Winiger, 1986). The characteristics of the hygric belts on MK are:

- The nival belt with soil temperatures < 1°C and permafrost above 4,800m asl;
- The periglacial/moorlands belt with less than 50% vegetation cover below 3,600m asl, soil temperatures between 1°C and 5.5°C and up to 300 days of frost per year;
- The afro-alpine/moorlands belt with soil temperatures between 5.5°C and 8.5°C and with more than 1,500mm of rain per year;
- The afro-montane/ *Hagenia-Hypericum* belt with soil temperatures between 8.5°C and 18°C and with more than 900mm of rain per year;
- The bamboo zone with soil temperatures between 12°C and 14°C and with more than 1,200mm of rain per year; and,
- The mixed forest with *Ocotea* and *Podocarpus* in the south-east with more than 1,800mm of rain per year.

2.1.2.4. Biodiversity on Mount Kenya, and its protection

The vegetation in the alpine zone of MK has been studied since 1885 (Coe, 1967; Ficken et al., 2002; Wooller et al., 2003). The most conspicuous feature of the afro-alpine zone is the predominance of some unusual plants such as the giant *senecios* and giant *lobelias* (Young and Peacock, 1992; Evans, 1996; Silva et al., 2000). Above 3,400m in the alpine plains, also known as moorlands, plants such as tussock grasses, *sclerophyllous* shrubs, acaulescent plants and cushion plants are found. Between 3,000 and 3,400m asl, there is a transition zone of moorlands with tree species like *Hypericum revolutum, Stoebe kilimandscharica, Hagenia abyssinica, Juniperus procera* and *Olea europaea.* The monotypic bamboo-podo belt *(Arudinaria alpina-Podocarpus latifolius)* is wide ranging between 2,400m and 3,000m asl and together with diverse mixed forest below 2,400m (Table 2.4), it represents the bulk of MK's vegetation. Within the mixed forests, some 210km^2 of tree plantations are found, mainly composed of *Cupressus, Eucalyptus* and *Pinus* (Gathaara, 1999).

Table 2.4. Mount Kenya's major mixed forest and bamboo forest types

Major forest types	*Location*	*Altitude (m)*	*Area (km^2)*
Newtonia	East	1,200 – 1,800	35
Croton-Brachylaena-Calodendrum	North-east / south-west	1,450 – 1,850	30
Croton-Sylvaticus-Premna	North (Upper Imenti)	1,500 – 1,800	16
Juniperus-Olea	West / north-west	1,800 – 2,300	73
Ocotea	East / south	1,900 – 2,400	275
Mixed *Podocarpus latifolius*	West / east	1,900 – 2,800	680
Juniperus-Nuxia-Podocarpus falcatus	West	1,950 – 2,250	35
Bamboo zone (*Arudinaria alpina*)	South-west	2,400 – 3,000	800

Source: Gathaara, 1999 after Beentje, 1991

The most common species of large trees on MK are camphor (*O. usambarensis*), cedar (*J. procera*), wild olive (*O. europaea*), Meru oak (*Vitex keniensis*), podo (*P. latifolius*), East African Rosewood (*H. abyssinica*), Croton (*C. macrostachyus*) and Mugumo (*Ficus thonningii*). The latest studies on vegetation below 3,200m asl identified 882 plant species, subspecies and varieties belonging to 479 genera and 146 families (Bussmann, 1994; Appendix I).

MK houses five threatened large mammals of international conservation importance: elephants (*Loxodonta africana africana*), black rhinoceros (*Diceros bicornis*), leopards, giant forest hogs (*Hylochoerus meinertzhageni*), bongos (*Tragelaphus eurycerus*), and black-fronted duikers (*Cephalophus nigrifrons hooki*) and several endemic species. Present in large numbers are the elephant, Cape buffalo (*Syncerus caffer caffer*), defassa waterbuck (*Kobus ellipsiprymnus*), bushbuck (*Tragelaphus scriptus*), spotted hyena (*Crocuta crocuta*), black and white Colobus (*Colobus guereza*), Sykes monkey (*Cercopithecus mitis*), olive baboon (*Papio anubis*), and hyrax (*Dendrohyrax arboreus* and *Procavia johnstoni mackinderi*). A list of mammals is found in Appendix II (Litoroh, 1993).

Common avian species include eagles, francolins, hornbills, flycatchers, mouse birds, owls, starlings, cuckoo-shikes and weavers, among others. The MK bird list is found in Appendix III (UNESCO, 1996).

Individual species among plants that have been studied on MK include: *senecios* (Young and Peacock, 1992); *lobelias* (Young, 1990; Young and Augspurger, 1991; Embuscado et al., 1996); and, giant caulescent rosettes (Silva et al., 2000). Among lower animal orders: molluscs (Warui et al., 2001); insects and other invertebrate animals (Somme and Zachariassen, 1981; Salt, 1987); and, land-snail faunas in the afro-montane forests (Tatterfield et al., 2001) have been studied. Among the birds: eagle owls (Rodel et al., 2002); and, scarlet-tufted malachite sunbirds (Evans and Hatchwell, 1992; Evans and Barnard, 1995; Evans, 1996; Evans, 2003) have been studied. Among the mammals: the naked mole rat (Brett, 1991); Sykes, and black and white Colobus monkeys (Holdo, 2000); buffalo (Mahaney, 1987; Mahaney and Hancock, 1990); and, elephants have been studied. Prior to the elephant research that was conducted as part of this thesis; elephant research was limited to a study on elephant predation on senacios in the alpine zone (Mulkey and Young, 1984) and two elephant dung counts (Reuling et al., 1992; Omondi, 1998).

To protect forest resources on MK from over-exploitation and its unique biodiversity-rich habitats and important ecological functions, the ~2,000km^2 forest belt below 3,200m asl was declared a Forest Reserve in 1932 under the administration of the Forestry Department (FD). To protect the 715 km^2 alpine area and snow-caps above

3,200m asl, they were declared a National Park in 1948, under the administration of the Kenya Wildlife Service (KWS). The National Park became a Biosphere Reserve under the UNESCO Man and Biosphere Programme in 1978, and the MK National Park and a large part of the Forest Reserve were also declared a World Heritage Site in 1997 (UNESCO, 1997). The protection status of the MK forests changed in July 2000 through upgrading the MK Forest Reserve to a National Reserve and transferring its administration from the FD to the KWS. The conservation of MK is influenced by its protection status and efforts of institutions responsible for it, as well as by demands for land and resources by surrounding human populations.

2.1.2.5. Human distribution around Mount Kenya

Before 1650, Gumba, Athi and Ndorobo hunter-gatherers inhabited the north-east and south-east slopes of MK (Dundas, 1908; Huntingford, 1929; Muriuki, 1974; Blackburn, 1982; Bussmann, 1994). The Gikuyu settled in the south-west foothills around 1730, following conflicts with the Gumba and Athi tribes. The waMeru and Gikuyu settled on the north-east slopes and the Embu on the south-west slopes, and then began clearing large areas of forest for small-scale cultivation (Reader, 1989; Bussmann, 1994). Ilaikipiak and Ilpurko Maasai already inhabited the south-west, and they remained separated from the Gikuyu by a forest corridor called *Dondole* or 'everybody's land' (Hoft, 2002). The corridor was declared as the 'Maasai African Reserve' and the south was declared as the 'Bantu (Kikuyu) African Reserve' in 1902, the same year that the FD was created and that many forests were declared as Forest Reserves.

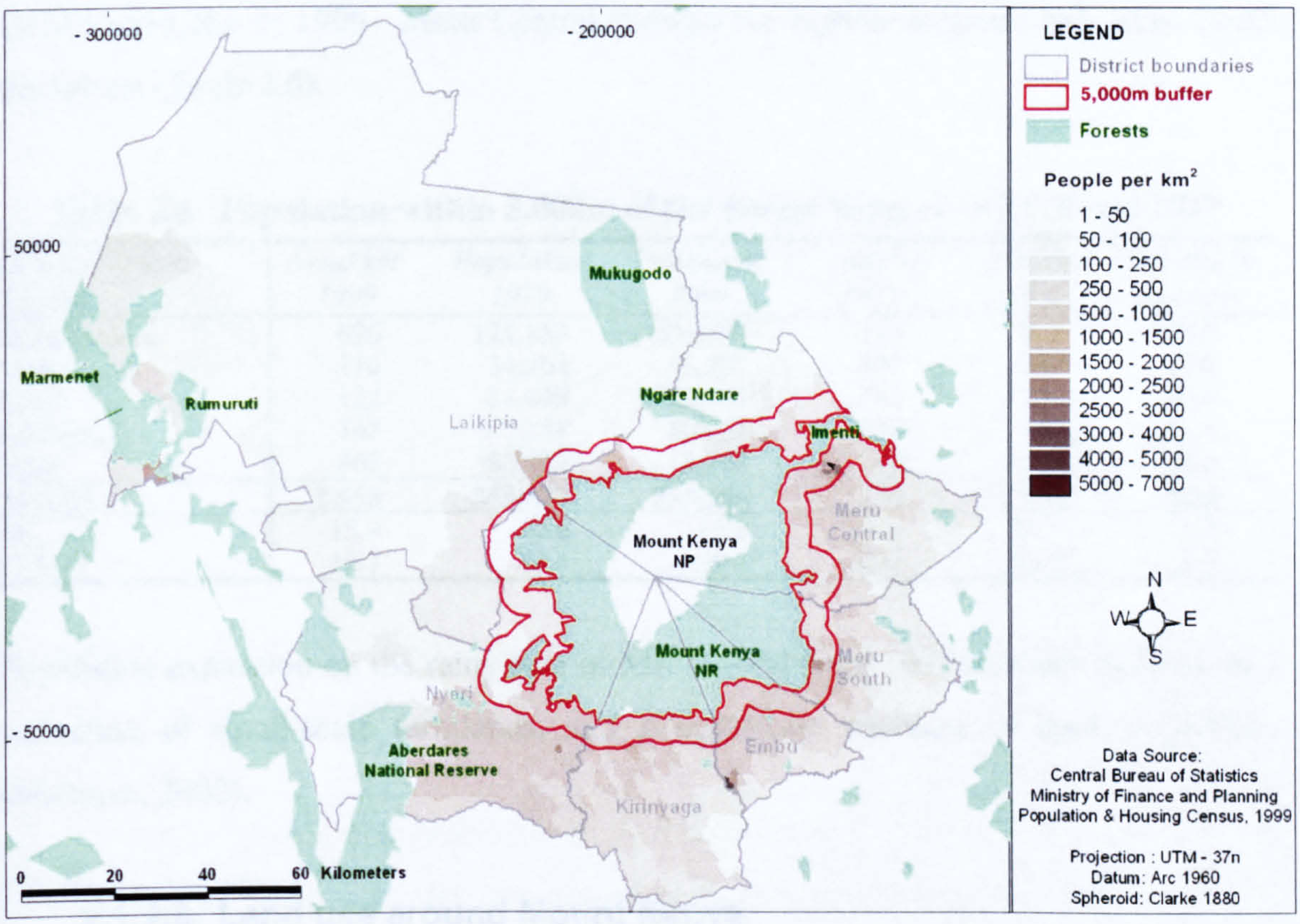
The rapid expansion of agriculture was eventually limited by the creation of the MK Forest Reserve in 1932 (Hoft, 2002). The MK Forest Reserve was one of the first protected areas in Kenya to be commercially logged, supplying sleepers for the Ugandan railways and timber for the settlers (Emerton, 1997). Between 1902 and 1963, around 210km^2 of commercial plantations were established on the mountain. The people from the forest stations alone totalled about 6,300 people. By 1930, the forest had been cleared to nearly their present extent, with plantations occurring up to 1,800m asl in the south, 2,400m asl in the east and west and 2,900m asl in the north (Bussmann, 1994). The most northern area is devoid of forest due to either or both low annual precipitation (<750mm/year) and detrimental damage by Maasai fires for grazing (Kohler, 1986; Bussmann, 1994).

During the years of the British protectorate, Maasai land in the north-west was claimed for European settlement and was turned into the so-called white highlands by the Kenya Land Commission in 1933. Today the 'White Highlands' refer to Laikipia District, where wheat, barley and pyrethrum are grown on a large scale on the mountainside in the district. However, most of Laikipia is too dry for agriculture and so ranching dominated land use (Kohler, 1986). Life was difficult for the early settlers due to unfamiliar threats like cattle raids, the MauMau rebellion, carnivores preying upon cattle, diseases introduced by wild herbivores, flies, ticks and bacteria killing both people and livestock. Though the railway line between Nairobi and Laikipia District was under construction in the 1920's, it took several more decades before goods could be transported between Nairobi and Laikipia by rail or by road. Without a labour market, infrastructure and economic structure, most European settlers left before independence in 1962. Those who remained gained exclusive rights over the land (Winiger, 1981). Abandoned white farms were reclaimed by the government or were purchased by private companies who divided the land into small plots for sale (Winiger, 1981; Brunner, 1986; Kohler, 1986).

Clockwise from the north, the six districts that border the current MK National Reserve (Figure 2.11) are: Meru Central and Meru South, both named after the waMeru people whom settled in this area; Embu named after the waEmbu people; Kirinyaga and Nyeri that are mainly inhabited by Kikuyu; and Laikipia, with its very large white-owned ranches combined with large pieces of land inhabited by native Maasai pastoralists. The fertile rainy side of MK formed part of a trust land before independence and comprised only farming communities such as the Kikuyu (70%), the waEmbu and waMeru (Kohler, 1986). By 1962 the rural population density of 5-30 people/km^2 on the dry side starkly contrasted to the density of up to 400/km^2 on the rainy side. The population multiplied 4-6 fold between 1962 and 1976, though densities remained low with only 10-20 people/km^2 on the white farms (Government of Kenya, 1962; Republic of Kenya, 1980; 1991; 2000).

Laikipia covers 9,229km^2 and is larger than the five other districts combined, and with 322,187 people (Republic of Kenya, 2000), it is nine times less populated than the five other districts combined. Laikipia borders the current MK Forest Reserve boundary by only a tiny stretch of land between Meru Central and Nyeri districts (Figure 2.10), and does not rely on MK's forest resources like the other five districts. Laikipia differs in so many ways from the other five districts around MK and hence, will only be mentioned where appropriate but is omitted from subsequent analyses in this thesis.

Figure 2.10. Human population density and distribution around MK in 1999



For the other five districts around MK combined, the population density increased by 37.4% between 1979 and 1999 (Table 2.5). Meru Central has experienced the highest population increase (63.1%), while Nyeri experienced the lowest increase (9.1%). Population growth slowed from 3.4% per annum in 1969 to 2.8% by 1999 (Table 2.5). The demographic situation within 5,000m of the MK Forest Reserve boundary (Figure 2.10) is important as these people most directly use the MK resources and land.

Table 2.5. Population per district in 1979 and 1999 around Mount Kenya

Districts	**Area/ km² 1979*	**Area/ km² 1999*	*Population 1979*	*Population 1999*	*Density 1979*	*Density 1999*	*Density % increase*
Meru Central	2,076	1,952	325,912	498,880	157	256	63.1
Meru South	685	712	153,953	202,723	225	285	28.6
Embu	490	519	174,432	277,864	356	535	50.3
Kirinyaga	1,045	1,127	281,724	457,105	270	405	50.4
Nyeri	1,722	2,322	448,551	660,170	260	284	9.1
TOTAL	**6,018**	**6,632**	**1,384,572**	**2,096,742**	**230**	**316**	**37.4**
SE	12	13	152	179	14	16	5.6
CL95%	54	61	8,130	11,307	73	85	10.9

*area changed due to sub-location boundary re-allocations; Source: CBS, 1999

The estimated number of people within the 5,000m buffer increased from 355,627 in 1979 to 513,166 in 1999. Meru Central showed the highest increase and Meru South the lowest (Table 2.6).

Table 2.6. Population within 5,000m of the Forest Reserve in 1979 and 1999

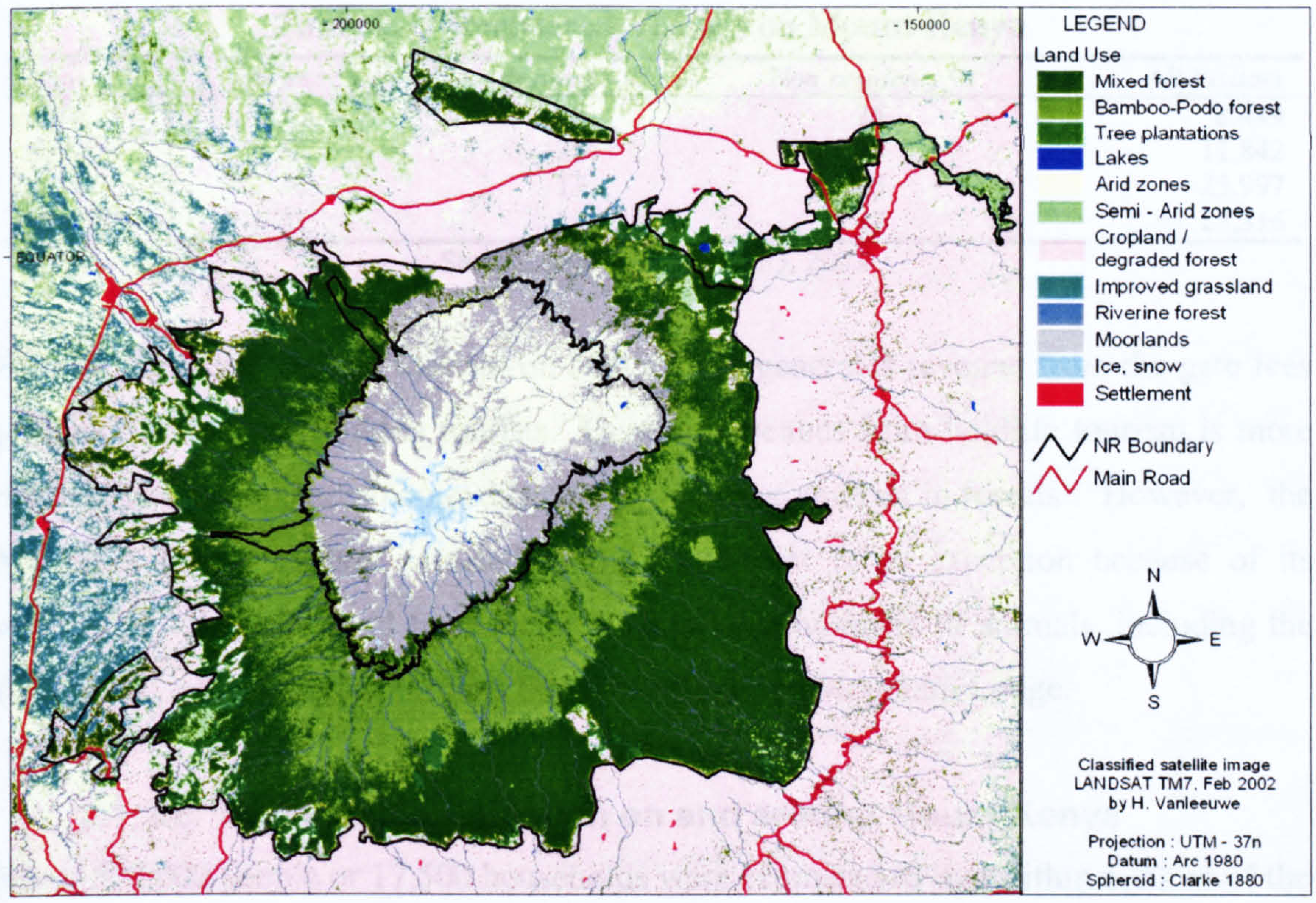
Districts within 5,000m	*Area/ km² 1999*	*Population 1979*	*Population 1999*	*Density 1979*	*Density 1999*	*Density % increase*
Meru Central	696	121,857	204,749	175	294	68.0
Meru South	116	34,961	42,967	302	371	23.9
Embu	132	51,449	72,865	391	554	42.6
Kirinyaga	147	63,388	80,264	432	546	27.6
Nyeri	467	83,972	112,321	180	240	34.8
TOTAL	**1,558**	**355,627**	**513,166**	**228**	**329**	**44.3**
SE	15.9	10.6	12.8	12.4	14.1	4.8
CL95%	12.7	27.4	39.7	10.0	11.3	3.8

Population expansion on the rainy side of MK slowed from 1995 onwards because of a saturation of small-scale farmlands, and a significant decrease in land availability (Mathuva, 2002).

2.1.2.6. Land use around Mount Kenya

As small-scale family farms continue to be divided between children, many farms around MK have become less than 1 acre in area and are poorly tenured because they are continuously under crop (Mathuva, 2002). The soils on the lower slopes have excellent physical features, including good water permeability, water retention capacity and rooting characteristics (Olago et al., 2000; Gatari et al., 2001; Gatebe et al., 2001). However, the soils also erode easily and appropriate methods of cultivation are required to prevent significant losses of sediments (Speck, 1983; Mwaura and Mutunga, 2003). Little is being done about soil erosion and the surrounding ring of poorly tenured small-scale cropland that marks the lower Forest Reserve boundary of MK (Figure 2.11) continues to expand (Tengberg et al., 1999).

Figure 2.11. Land cover and land use around Mount Kenya in 2002



Human distribution and land-use around MK influence the conservation status of MK and thus also its economic potential.

2.1.2.7. Economic potential of Mount Kenya

MK has considerable economic importance through supporting agriculture and forestry. Therefore, MK was given several legal status of protection. The economic benefits gained from the combined goods and services provided by the MK forest ecosystem continues to be debated. Emerton (1997) assigned a value of around US$ 40 million per year, excluding ecological, option and existence values, but including the value from watershed catchment protection and domestic use benefits. Although a somewhat under-developed tourist destination, the mountain attracts both domestic and international visitors, including climbers, walkers, bird-watchers and fishermen. The number of registered visitors between 1999 and 2002 on MK tripled after 2000, although it is not certain if this reflects a real increase in visitors or better registration of visitors (Table 2.7). If MK was better developed for tourism, it is estimated that it could earn US$ 1 million per year, which would go a long way to supporting economic development (Gathaara, 1999).

Table 2.7. Registered Visitors on Mount Kenya

Date	*Citizens %*	*Residents %*	*Non residents %*	*All Visitors*
1999	58	16	26	8,449
2000	52	20	28	11,842
2001	38	17	45	25,997
2002	42	11	47	28,316

Source: data from KWS HQ, 2003

Besides a handful lodges, tourism on MK mainly generates revenue from the gate fees paid by climbing and hiking tourists. Gaining revenues from wildlife tourism is more difficult because of the obvious difficulties of seeing animals in forests . However, the Mountain Lodge saltlick, situated in the south-west is an exception because of its artificially added salts and fresh water attracts large numbers of animals, including the five closely protected black rhinos that live around the Mountain Lodge.

2.1.2.8. Problem identification on and around Mount Kenya

Some 500,000 people or 17,500 households were estimated to live within 5,000m of the MK Forest Reserve boundary in 1999 (Republic of Kenya, 2000). The vast majority are small-scale farmers, using farming techniques and water abstraction methods that spill a lot of water. Poor land-tenure has led to pronounced levels of erosion. Consequently, the Tana River now transports several hundred cubic meters of sediment per hour, which has already silted up dams that are responsible for generating 70% of the hydro-electricity in Kenya (Kohler, 1986). The function of MK as an essential water catchment area cannot be jeopardised by people or wildlife destroying its resources.

The rural population around MK is one of the densest in Kenya (Republic of Kenya, 2000), and the MK elephant population is estimated to be the largest highland population in Kenya (Blanc et al., 2003). With the exception of two narrow migration corridors that connect MK with the northern grazing areas, a rapidly expanding ring of agriculture and settlements have isolated the current MK National Reserve. Extreme geographical features present natural elephant movement barriers in many places within the largely confined habitat (Vanleeuwe and Lambrechts, 1999). If the MK elephants become entirely confined, the MK protected areas will not be able to sustain their year-round needs, and elephants will cause substantial damage to the natural environment and to the human resources adjacent to the protected area (e.g. Harcourt et al., 2001; Whitehouse and Schoeman, 2003).

Currently, elephants on MK are not yet over-crowded and their impact on the natural environment is not marked, compared to the human impact on the MK natural environment (Vanleeuwe and Lambrechts, 1999; Vanleeuwe et al., 2003). Elephant impact on human lands around MK mainly consists of damage to crops (Gachago and Waithaka, 1995; Mathuva, 2002). Crop damage varies between areas and between seasons, and ranges from extreme and repetitive damage in certain areas and seasons, to negligible and sporadic damage in other areas. Elephant pressures are addressed with direct solutions, such as control shooting and fencing (Mwathe et al., 1998; COMPACT, 2001), which does not address the underlying cause of elephant pressures.

Under FD management, human over-utilisation of the natural forests was reaching catastrophic dimensions (Gathaara, 1999). MK resources (mainly water and forest products) were over-utilised, both legally and illegally, by the surrounding communities and others (Emerton, 1997; Hoft, 2002). Coupled with land-loss through clear-felling, encroachment and de-gazettement of large pieces of forest for settlement, poor land tenure, cultivation on steep hillsides near rivers, and arson in the moorlands by poachers, largely affect the mountain ecosystem and its functions (Vanleeuwe et al., 2003).

2.2. GENERAL METHODS

I now provide a general introduction to the methods used throughout this thesis, while more detailed descriptions are found in the relevant chapters, and stepwise procedures and additional information are to be found in Appendices. Ground and aerial surveys were combined with archive data, GIS generated data and satellite image data, to explore all aspects of the relationships between the environment, elephants and people on MK.

2.2.1. Archival data

Archival data on the natural environment of Kenya were mainly assembled from the Laikipia Research Program (LRP), an institution established in Nanyuki town, north-east of MK, by the Geology Department of the Swiss University of Berne at the end of the 1970's. LRP is managed by a Kenyan director and is run by Kenyan staff, but most projects are generated by, and most finances still come from, the University of Berne. Next to their independent national and regional function as a data resource unit, LRP also functions as the base for many Swiss and Kenyan Masters and PhD geology students.

Reports on the human environment of Kenya including population distribution, numbers and socio-economic status mainly came from the Central Bureau of Statistics (CBS) in the Ministry of Planning and National Development, Government of Kenya (GOV), and from reports of the World Bank, from the United Nations Environmental Programme (UNEP) and the United Nations Development Programme (UNDP).

Archive data on elephant numbers were derived from the African Elephant Databases (AED) of the IUCN-SSC African Elephant Specialist Group (AfESG) and from reports of the KWS. Archival data on the use of natural resources and forests came from the FD, UNEP and consultant reports (Emerton, 1997; Hoft, 2002). Raw data on the destruction of trees in the indigenous forests of MK were obtained from a complete aerial survey conducted in 1999 by the KWS Senior Warden of MK, B Woodley, and C Lambrechts of UNEP.

2.2.2. Ground and aerial surveys

All the field research was conducted between February 1999 and 2003. Fieldwork comprised: running line transect surveys at the end of seasons in 1999 and 2001; undertaking six months of dung decay monitoring from March to August in 2000; monitoring of tree destruction in forest plantations throughout 2002; collecting occurrence book (OB) records on HEC from KWS stations and outposts at the end of December 2002; aerial surveying between February and June 2002; a socio-economic survey in February 2003; and, a ground controlling mission in July 2003.

- Dung decay surveys were conducted from March to August 1999 (Chapter 3) by myself.

- Sets of line transects were walked at the end of seasons in 1999 and 2001 (Chapter 3 and Chapter 4) and completing one set took between 21 and 28 days continuous walking, depending on the terrain. The teams usually comprised five members, which included: a KWS field assistant under training; two armed rangers for security and under fieldwork training such as reading maps, using GPS and compass, and locating elephant dung; one local casual assistant with knowledge of plants as an extra member in case of emergencies; and, myself. The KWS assistant in 1999 was B Elfes, and in 2001 was J Muriuki. Only the casual assistant, PM Kamau, participated on all censuses. Rangers were regularly replaced along the way, both because the KWS Senior Warden of MK, B Woodley, assumed that fieldwork was good training for new recruits, and because rangers dropped out along the way due to exhaustion and small injuries, with the exception of corporals W Thanui and D Mwangi, and ranger J Muriuki.

- Elephant tree damage was surveyed at six forest stations throughout 2002 in collaboration with FD foresters, forest assistants and especially FD field staff, who were trained to fill out station-specific data-sheets. Attempts to monitor elephant tree damage in plantations in the north-east failed because no access was allowed (Chapter 5).

- Reports of HEC from 1999, 2000, 2001 and 2002 were collated in December 2002, from OBs that were filled in by KWS staff at all KWS stations and outposts around MK (Chapter 6).

- Socio-economic surveys of forest-adjacent farming households were conducted in the two regions that were most affected by HEC around MK. One socio-economic survey was designed and conducted by J Mathuva of LRP in which he interviewed 75 households in the north-east region of MK in 2001, and these data were made available for this study. I undertook a comparative survey in February 2003 in which 74 households were interviewed in the south-west region of MK (Chapter 6).

- Two aerial line transect surveys were conducted between February and June 1999, and between February and July 2002, to monitor destruction in the indigenous forest (Chapter 7), and to look at change of the status of the forest under FD management before July 2000 and under KWS management after July 2000 (Chapter 8). The 1999 survey was conducted by KWS Senior Warden of MK, B Woodley, and C Lambrechts of UNEP (Gathaara, 1999). Due to budgetary constraints, a sample survey of 270km^2 was conducted in 2002. As for the 1999 survey, the pilot in 2002 was the KWS Senior Warden of MK, B Woodley, flying a KWS Aviat Husky equipped with a Trimble GPS unit to trace flight lines. The observers were C Lambrechts from UNEP and myself, each equipped with a Garmin GPS unit to log in waypoints of each observed tree destruction site and a data sheet to fill in the extent and type of damage observed at each waypoint. The results were published in Vanleeuwe et al. (2003).

- The GPS data of a collared elephant was obtained from the NGO Save the Elephants, and predicted locations of elephant routes and areas used intensely by elephants were ground-controlled in July 2003. Given the vast size of MK and its difficult access only accessible hiking routes running from the moorlands to the slopes in NaruMoru, in Sirimon, in Chogoria and in Kamweti, and some tracks running along the Forest boundary where predicted routes crossed the boundary into farmland, were scanned for dung (per 100m).

2.2.3. Re-occurring concepts

I use a GIS and satellite imagery extensively in this study. Maps were generated from field data, from satellite image analysis and from cross-tabulation of existing archive and self-generated GIS layers. Most GIS generated data were analysed at the LRP GIS lab in Nanyuki. The GIS work mainly consisted of on-screen digitising of scanned and geo-referenced 1:50,000 topographic sheets of the mountain, correcting existing layers such as district boundaries and developing vegetation maps through classification of satellite imagery. The main GIS packages used were ArcGIS version 7.2.1, ArcView version 3.2, Idrisi version 32, and Erdas version 8.7. Given the extensive use of digital data and to avoid repeating technical jargon in each chapter, the concepts of GIS, of satellite imagery and of satellite image classification are outlined next.

2.2.3.1. What is GIS?

A GIS is a computer-assisted system or software tool for the acquisition, storage, analysis and display of remotely sensed or user-developed, such as digitising maps and geographic data. It allows the user to fully incorporate their field knowledge by interactively guiding and analysing the information extraction procedures (Valenzuela, 1992). A GIS, especially when it is integrated with image processing capabilities, is a powerful tool for computer-assisted land use mapping, and for this reason it has been increasingly used to solve ecological problems (Walpole, 2000). Today there is access to remotely sensed images in digital form, allowing rapid integration of the results of remotely sensed data into a GIS for analysis. The procedures involved in restoration, enhancement and computer-assisted interpretation of remotely sensed images, is called 'Image Processing'. A GIS allows spectral bands of satellite images to be combined according to user needs. The resulting images are called composites. Composite images are often referred to as RGB images because they are always composed of three colour spectra, namely reds, greens and blues. The RGB images differ according to which satellite band is allocated to each red, green and blue component. True colour composite images in which bands 1, 2, and 3, represent the red, green, and blue bands, are often used in this thesis for interpretation because they best represent the true colours on the ground. Most GIS can automatically generate spectral band combinations that are commonly used for certain applications such as NDVI composites (Normalised Difference Vegetation Index), which are used for vegetation classification.

2.2.3.2. What are satellite images?

Satellite-mounted remote sensors read and store electromagnetic (EM) energy waves. Lasers or radars sometimes supply EM energy but most remote sensing systems use EM energy derived from reflection of the sun. All features on earth emit their own EM waves. The characteristics of these waves or the Spectral Response Patterns (SRP) depend on factors such as the nature of the material, the physical condition whether wet or dry, the surface roughness, the exposure to the sun and the spectral colour characteristics. The specific SRP of features are the key to interpretation of remote sensing data for land-cover and land use classification. SRP are classed within the EM spectrum that is expressed in micrometers (um). The EM spectrum is very broad and divided into portions or bands of which the visible (VIS; 0.38 – 0.72 um), the near infra-red (NIR; 0.72 – 1.30 um), the middle infra-red (MIR; 1.30 – 3.00 um) and the thermal infra-red (TIR; 7.00 – 15.00 um) are assumed to be of greatest importance for remote sensing (Table 2.8).

Table 2.8. Spectral bands in a LANDSAT 7TM image and their application

Band	Principal application in geography	Wavelength (um)	Spectral colour location
1	Land Use and Land Cover mapping (differentiates soil vas plants, deciduous vs. coniferous)	0.45 – 0.52	Blue Visible (VIS)
2	Land Use and Land Cover mapping (green reflectance and vegetation health)	0.52 – 0.60	Green Visible (VIS)
3	Land Use and Land Cover mapping (plant species and chlorophyll absorption)	0.63 – 0.69	Red Visible (VIS)
4	Geologic mapping (biomass content, water delineation)	0.76 – 0.90	Near Infra-Red (NIR)
5	Geologic mapping (soil and vegetation moisture, clouds and snow)	1.55 – 1.75	Middle Infra-Red (MIR)
6	Thermal mapping (plant heat stress and soil moisture)	10.40 – 12.50	Thermal Infra-Red (TIR)
7	Hydrothermal mapping (mineral and rock type differentiation)	2.08 – 2.35	Middle Infra-Red (MIR)

Radiation detected by remote sensors passes through the atmosphere, which may cause absorption or scattering of short wavelengths. Scattering occurs when dust particles or water droplets in the atmosphere reflect radiation. Absorption refers to loss of energy by water vapour, carbon dioxide and ozone (Lillesand and Kiefer, 1994). Scattering and absorption greatly affects short wavelengths such as ultraviolet (UV). Therefore, blue wavelengths are often left out in remotely sensed images. The green, red and near infra-red (IR) wavelengths, on the other hand, all provide good opportunities for reflecting the earth surface without significant interference by the atmosphere. They also provide important clues to the nature of many of the earth's surface materials.

There are several satellite systems presently operating and each type offers remotely sensed data (satellite images) that is appropriate for particular applications. Data differs in spatial, temporal and spectral resolutions. Remote Sensors vary according to the frequency with which they return to a location on earth (temporal resolution). The images that remote sensors provide are raster images that are composed of numerous pixels or cells that reflect a surface on the ground at a certain resolution (spatial resolution). In a 30m resolution satellite image for example, each pixel represents a 30x30m area on the ground. Satellite images also vary in the number and types of spectral bands in which data are recorded (spectral resolution). The main criteria of the satellite data choice are spatial, temporal, and spectral resolution, but also their cost, cloud cover and availability. For the MK study, I used data recorded with LANDSAT Thematic Mapper (TM) with five bands for February 1987, and TM with seven bands for October 1995 (the February 1995 image had extreme cloud cover), February 2000 and February 2002. All images came with a spatial resolution of 30m.

The World-wide Reference System (WRS) is used to catalogue recorded satellite scenes and refers to a grid of paths and rows covering the earth. The WRS is made up of 233 (east to west) path numbers and 248 row numbers (north to south) so that the location of every satellite scene can be identified by the intersection of its row and path number. The scenes comprising the MK study area, for example, are coded path 168 and row 60.

2.2.3.3. What is satellite image classification?

Land cover and land use classification of satellite images can be achieved by identifying and grouping the pixels on an image where the land cover type is known. Grouped identified pixels are referred to as AOI's (areas of interest) or training sites and they have a specific Spectral Response Pattern (SRP). Using a GIS, the remaining unidentified pixels of an image are given the value of the identified class category that its SRP most resembles. This process is called 'supervised classification'. A GIS can also automatically generate groups or clusters of pixels according their spectral resemblance. This technique produces all possible clusters. After verification of what each cluster represents in the field, clusters are then fused to represent the same land cover type. This method of classification is called 'unsupervised classification'. Both supervised and unsupervised classification of large images or images with a very diverse land cover pattern may result in clustering different land-cover types that resemble the spectral characteristics. Plantation forests, for example, occur in various stages (from saplings to very mature trees) and will therefore cover a large variety of spectral colours. Some of these colours may also be represented in other land cover types such as mixed forest. As a result, land cover may be wrongly classified. Wrongly defined clusters can be manually allocated another class value. This process is referred to as 'analytical classification' and is almost always used after supervised and unsupervised classification. To limit errors derived from computer-assisted interpretation of complex images, cutting an image into several distinct subsets prior to classification can reduce complexity. To avoid confusion during classification, the MK image was for example sub-setted into 3 separate images, namely the plantations, the area inside the reserve, and the agriculture land outside the reserve.

2.2.3.3.1. Satellite image classification for MK

The vegetation cover of MK was classified from satellite images of 1987, 1995, 2000, and 2002, using supervised, unsupervised, and analytical classification, as described above. Subsets of the images were classified separately for plantation forests, the area outside the forest boundary, and the area inside the boundary, to avoid error from spectral resemblance between grasslands and moorlands, and between all age stages of plantation forests and indigenous forests. Verification of the classification was done through checking against prior knowledge of locations and their characteristics from extensive ground and aerial surveying.

Next, I seek to establish the number of elephants that live on MK, as the basis on which to examine the relationship between MK's environment and elephants (Chapter 3).

Chapter 3

MINIMISING SOURCES OF ERROR WITH COUNTING ELEPHANTS IN MOUNTAIN FORESTS

3.1. INTRODUCTION

Correct estimates of elephant numbers are an essential piece of information for managing forested areas of Africa. Unlike in savannah areas where visibility allows aerial surveys, forest elephants can only be estimated using indirect survey methods (Okouyi et al., 2002; Sinsin et al., 2002; Eggert et al., 2003). The most used and developed indirect method is counting dung along line transects. Because many sources of potential bias can be introduced to counting dung, results are generally considered of low quality in the African Elephant Database (Said et al., 1995; Barnes et al., 1998; Blanc et al., 2003). Nevertheless, dung counts can produce more accurate results than aerial counts, when implemented correctly (Buckland et al., 2001; Whitehouse et al., 2001; Barnes, 2002).

Obtaining precise estimates demands time and expertise, which are the two factors that are usually lacking. Theory is rarely strictly converted into practice, and minor violations of theory can lead to substantial biases. For example, errors can be introduced from biased siting of transects and from errors in values of the parameters of dung decay rate, dung defecation rate, and dung density, all of which are used to extrapolate elephant numbers from dung counts (Plumptre and Harris, 1995; Thomas et al., 2001; Laing et al., 2003). Originally developed in African lowland forests (Wing and Buss, 1970; McClanahan, 1986; Barnes and Jensen, 1987; Barnes et al., 1997; Buckland, 2000; Plumptre, 2000), dung counts are now also applied in mountain forests in East Africa (Blom et al., 1990; Reuling et al., 1992; Butynski, 1999; Vanleeuwe, 2000). In such habitats, geographical features are extreme, habitat stratifies very rapidly, and natural barriers to elephant movement are many. These factors may affect the area that is actually used by elephants, as well as the probability of dung detection because of poor visibility and physical obstruction (Vanleeuwe, 2004).

An example where such problems may have arisen is on Mount Kenya (MK). Compared to elephant densities recorded in the rest of Africa's forests, some estimates of elephant densities recorded in Kenya's forested areas such as MK, Aberdare, and Imenti forests, were suspiciously high. A particularly high estimate of up to 5.61

elephants/ km^2 was recorded for MK in 1992 (Table 3.1). Therefore, I sought to explore the potential reasons behind the high estimates for MK.

Table 3.1. All elephant density estimates from dung counts, based on the African Elephant Databases of 1995 and 1998 (Said et al., 1995; Barnes et al., 1998)

Country	Site	Area	E/ km^2	Survey reliability	Source	AED year
Kenya	Aberdare NP	767	1.35	D	Mulama, 1995	1995
		1,030	4.00	C	Bitok et al., 1997	1998
	Arabuko Sokoke	372	0.20	D	Gisicho, 1991	1995
		415	0.24	D	Litoroh and Mwathe, 1996	1998
	Imenti FR	100	0.92	D	Njumbi and Litoroh, 1994	1995
		70	2.23	C	Bitok et al., 1997	1998
	Loroki forest	596	0.52	D	Mwangi et al., 1992	1995
		596	0.35	C	Bitok, 1997	1998
	Mathews Range	750	0.84	D	Reuling et al., 1992d	1995/1998
	Marmanet Forest	317	0.16	D	Litoroh et al., 1992	1995
	Mau Forest	1,065	0.23	D	Reuling et al., 1992c	1995
		1,267	0.79	D	Njumbi et al., 1995	1998
	Mount Elgon	125	0.42	D	Reuling et al., 1992a	1995
		1,083	1.03	C	Mulama et al., 1996	1998
	Mount Kenya	**1,367**	**1.95 - 5.61**	C	**Reuling et al., 1992a**	**1995**
		2,810	**1.43**	C	**Omondi et al., 1998**	**1998**
	Shimba Hills NR	217	1.38	D	Reuling et al., 1992b	1995
	Transmara forest	300	0.67	C	Wamukoya et al., 1997	1998
Cameroon	Korup NP	1,250	0.34	C	Powell, quest. reply., 1993	1995/1998
	Banyang-Mbo	426	0.86	C	Powell, quest. reply., 1993	1995/1998
	Boumba-Bek	1,322	1.06	C	Ekobo, pers. comm., 1994b	1995
		2,500	0.50	D	Ekobo, pers. comm., 1998	1998
	Nki FR	1,815	1.20	D	Ekobo, pers. comm., 1998	1998
	Lobeke	1,965	1.89	C	Ekobo, 1995	1995/1998
	Mongokele	830	0.91	C	Ekobo, pers. comm., 1994b	1995/1998
CAR	Bangassou/ Dzanga	5,500	0.48	D	Fay and Agnagna, 1991a	1995
		16,600	0.10	C	Kpanou et al., 1998	1998
Gabon	Lope	5,000	1.10	D	White, 1994	1995
	Forest elephant range	222,627	0.28	C	Barnes et al., 1995	1995/1998
DRC	Maiko NP	10,800	0.56	C	Hart and Sikubwabo, 1994	1995/1998
	Okapi NP	13,700	0.54	C	Hart, pers. comm., 1998	1998
	Kahuzi-Biega	15,570	0.24	C	Hall et al., 1997	1998
Tanzania	Kilimanjaro	418	0.53	C	TWCM, 1992a	1995/1998
Liberia	Sapo NP	1,391	0.31	E	Anstey and Dunn, 1991	1995/1998
Mali	Gouma Area	27,000	0.02	C	Jachmann, 1991b	1995
Nigeria	Omo biosphere R	870	0.03	D	Coad, 1993	1995
	Okwangwo	239	0.31	D	Obot et al., 1998	1998

*Survey reliability from A (best) to E (worst) (Annexe 3.2)

For dung counts to be implemented at large scale by local staff, the traditional transect method needs to be robustly designed to reduce the array of potential biases that can be introduced at different levels. Therefore, I sought to identify problems associated with dung surveys in mountain forests and to explore simulation data and real data collected on MK during this study. The following questions will be addressed with regard to dung counts on MK:

- Is rainfall a major determinant of dung decay rates at high altitudes on MK?
- Does transect length on terrain with physical obstacles, such as large rocks and vertical valley-walls, affect the expected dung detection curve "g(x)"?
- Do barriers to sightability, such as trees, stones, and ground cover, affect g(x)? and,
- How does the difference between map and ground area of geographically pronounced terrain affect dung density calculations?

3.2. METHODS

The four main parameters used to extrapolate elephant numbers from dung counts are:

- dung density "Y";
- dung decay rate "r";
- defecation rate "D";
- area "a".

Elephant density "E" is extrapolated from dung counts using the formula $E = (Y*r)/ D$. The correct size of different strata representing the elephant habitat or area "a" is essential to correctly extrapolate elephant density to elephant numbers.

Dung density "Y" is calculated from the number of dung piles "n" monitored along a transect divided by 2 x the effective strip width "2ESW" x transect length "L", using the formula "$Y = n / (L*2ESW)$". With the distance method, the probability of spotting an object, or the detection probability "g(x)", declines with increasing distance from the transect centre-line. The ESW or effective strip width on both sides of the transect is calculated from perpendicular distance measurements. In the early stages of developing dung counts, the average sighting distance was recognised as the effective strip width surveyed (Gates et al., 1968). More rigorous approaches included the construction of sample variance, confidence intervals, tests of assumptions, and the fitting of data to a standard distribution model that takes into account the expected decline in visibility with distance from the transect centre-line (Eberhardt, 1968; Gates et al., 1968).

During the 1970's and 1980's those principles were developed further (see Buckland et al., 1993). Various assumptions about the shape of the detection curve were proposed. Software packages such as ELEPHANT (Dekker and Dawson, 1992), LINETRAN (Gates, 1980), TRANSECT (Laake et al., 1979), DISTANCE (Thomas et al., 2001), and LOPES (Walsh, 1998), were developed to help users analyse their data. A detailed outline of the principles and history of distance sampling are found in Buckland et al. (1993).

The 95% confidence limit "CL95%" and standard error "SE" of Y and r, all contribute to the coefficient of variance of the elephant estimate. The variance can be calculated as:

$$\text{Var "E"} = \text{var "D"} * \frac{(Y*r)^2}{D^4} + \frac{\text{var}(Y*r)}{D^2}$$

3.2.1. Dung decay rate "r" and defecation rate "D"

A value for dung decay rate (r = 0.013) for MK was obtained in 1992 from 78 days of monitoring 93 dung piles located from 1,723 to 2,230m asl (Reuling et al., 1992). However, most elephant habitat on MK lies between 2,250 and 3,250m asl, and higher rainfall occurs at higher altitudes. As rainfall is known to affect dung decay rate (Barnes and Barnes, 1992; Barnes et al., 1994; Plumptre and Harris, 1995; Laing et al., 2003), it was expected that dung decay rates would vary at different altitudes. To test this, the decay rates of 30 marked dung piles were monitored for 180 days at each of 2,500m asl and 3,000m asl in March to August 1999. The 60 fresh piles were deposited on the same night of March the 3rd 1999 by elephants that browsed around the MET station at 3,000m asl and around the NaroMoru HQ at 2,500m asl. Each pile was tagged by hanging a white ribbon from nearby or overhanging twigs, and was labelled with a number from 1 to 60. Rainfall was measured daily at both stations by the KWS. The state of dung pile decay was measured weekly, following the criteria of Barnes and Jensen (1987) as follows:

- Stage A: pile intact, very fresh, moist, with odour;
- Stage B: pile intact, fresh but dry, no odour;
- Stage C1: more than 50% of the pile is distinguishable, some has disintegrated;

- Stage C2: less than 50% of the pile is distinguishable, the rest has disintegrated;
- Stage D: pile completely disintegrated, forms a flat mass;
- Stage E: decayed to the stage where it would be impossible to detect at 2 meters range in the undergrowth, and it would not be seen unless directly underfoot.

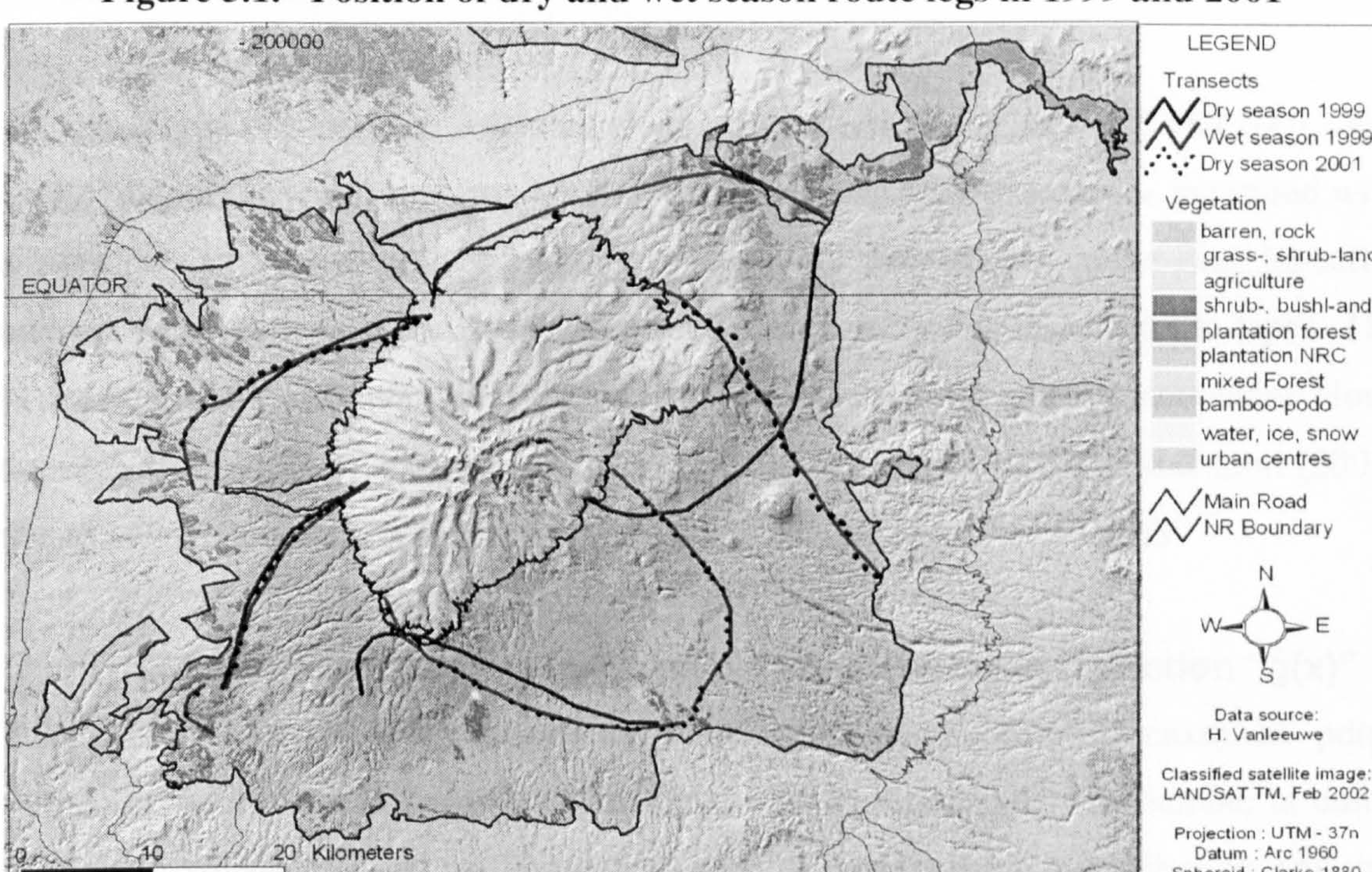
Because recordings were made weekly, the exact date when dung disappeared was unknown. A random number from 0 to 7 was therefore subtracted from the total number of days that had elapsed since the dung pile was originally deposited and the date when it was recorded as fully decomposed (Appendix IV). Because dung survival times were not normally distributed, but instead were poisson distributed, decay rates were calculated using the square root of dung survival times (White, 1995). A t-test was conducted to determine if differences in dung decay rates at different altitudes were significant, and the bootstrap mean decay rate using 1,000 iterations was calculated on my behalf by Dr RFW Barnes.

Rates of defecation depend on several factors, such as consumed food types, food quality, and body size - with food needing a long time to pass through a large elephant body (i.e. Lambert, 2002; Milton, 2003). Physical encounters of elephants in the MK forests are too sporadic to derive the rate of defecation through direct observations. A value for defecation rate for elephants on MK was therefore chosen from the few that are found in the literature. Given the effect of food type and quality on defecation, the values for defecation was taken from studies conducted in habitat that most likely resembles the MK habitat. Wing and Buss (1970) obtained a mean value of 17.5 dung piles per day (SE 1.180; CL95% 1.114) from 400 hours of observation of elephants in Ugandan forests. Plumptre and Harris (1995) later assumed 17 dung piles per day for a study in the Parc National des Volcans in Rwanda, which is also a forested mountain. The value of D assumed for MK should therefore also fall in the range 17 to 18. To be consistent with previous studies on MK (Reuling et al., 1992; Omondi et al., 1998), the value for defecation rate was assumed at 18 per day in this study.

3.2.2. Dung density "Y"

A route with six legs was walked around the mountain at the end of the dry season in February 1999, at the end of the wet season in May 1999, and again in February 2001 (Figure 3.1). Monitoring transects along the six route legs were positioned to dissect ridges, and to cross altitude gradients and forest types approximately in proportion to their occurrence in the habitat. However, the alpine rock area was not surveyed because elephants rarely go beyond 3,500m asl (Figure 3.1). The six route legs around the mountain totalled about 150km and required 28 days continuous walking to complete, which was the reason why more transects were not conducted. A compass was used for guidance and a global positioning system or GPS was used where possible, but tree cover often obstructed GPS satellite reception. To establish elephant density in different seasons, line transects along the route legs were walked at the end of seasons because dung remains visible for 3 to 4 months on MK. Therefore, line transects monitored at the end of seasons mirror elephant presence for the previous season.

Figure 3.1. Position of dry and wet season route legs in 1999 and 2001



3.2.2.1. Long versus short transects

The routes walked in the same season, namely from February 1999 and February 2001, were used to compare the effectiveness of short (0.2km) and long (4km) line transects.

The 1999 and 2001 route legs were located in almost the same position around the mountain (Figure 3.1). Each of the six route legs were treated as one long line transect along which continuous monitoring was done in 1999. Some transect data that were collected along the route legs of February 1999 were not used for analysis. The six long transects were subdivided into sets of mainly 4km transect segments, interspersed by 5km sections that were not analysed to ensure sample independence (Vanleeuwe, 2004). Some transects were shorter than 4km because certain vegetation strata occurred in patches, for example, plantations and forest clearings, and transect lengths were reduced in length to encompass only that strata.

In contrast, only very short (0.2km) transects, intersected with 1km routes of least resistance or recces, were monitored in February 2001 (Figure 3.1). The 2001 method is also referred to as the recce-transects (RT) method, and was designed as part of the MIKE (Monitoring of Illegal Killing of Elephants) programme (Beyers et al., 2001). On the recce-transect method applied in 2001, only the short 0.2km transects were included in the analysis.

The same type of data were collected along all transects walked in 1999 and 2001. For every dung pile encountered, the running distance along the transect was measured with a hip-chain and the distance from the dung pile to the transect centre-line, hereafter referred to as perpendicular distance (pdist), was measured with a metallic tape. The two distance measurements are needed to extrapolate dung piles encountered along transects to dung density per square kilometre (km^2). The long (1999) and short (2001) transects were analysed with the programmes DISTANCE 4.0 and LOPES.

3.2.2.2. Effect of obstacles on expected dung detection "g(x)"

Twenty perfectly straight transects of 1,000m in length, with a maximum pdist sightability of 10m on either side of the transect, were simulated. The number of dung piles per simulated transect was drawn randomly from a lognormal distribution, and the mean dung density Y for the combined 20 transects was fixed at 1,500/ km^2. The position of each dung pile was determined by two random numbers: one between 0 and

1,000 to establish dung pile distance along the 1,000m transect; and one between 0 and 20 to establish dung pile location within the 20m strip (2ESW) around the transect.

In reality, not all dung piles within the 10m strip width would be observed, and detection probability g(x) would depend on the sampling methods used and sightability. Each dung pile has a g(x), expressed as a value between 0 and 1. Dung piles located near the transect centre-line are more likely to be seen than those further away from it. The g(x) was established for all dung piles along the simulation transect, assuming a Fourier detection curve. This means that the g(x) of dung lying between 0 and 10m pdist decreased from 1.0 at pdist 0m to 0.0 at pdist 10m, following a fourier detection curve. To determine which dung piles along the simulation transect would be sighted, a random number between 0 and 1 was generated. If this value was less than or equal to the dung pile g(x), then it was assumed to be sighted. If this value was larger than g(x), it was considered as not sighted. This process was repeated ten times to obtain 10 data sets of 20 transects each, to represent the zero obstacle scenarios.

To look at the effect of obstacles on dung pile detection, obstacles in groups of 2,500 were added to the 20,000m^2 area around the simulation transects (Table 3.2). Obstacle location was established as for dung piles. In reality, many small obstacles such as rocks and stones, ground vegetation, and some larger obstacles such as trees, shrubs, and small hills, obstruct sightability on forested mountains. Each of the 5 obstacle density classes tested included 90% of small obstacles with a random diameter between 0 and 0.5m and 10% of larger obstacles with a random diameter between 0.5 and 2m.

Table 3.2. Tested obstacle density classes

Obstacle density class N/ km^2	*# obstacles of diameter ≤0.5m / transect*	*# obstacles of diameter 0.5 - 2m / transect*	*# m^2 per obstacle of diameter ≤0.5m*	*# m^2 per obstacle of diameter 0.5 - 2m*
125,000	2,250	250	8.89	80
250,000	4,500	500	4.44	40
375,000	6,750	750	2.96	27
500,000	9,000	1,000	2.22	20
625,000	11,250	1,250	1.78	16

Dung piles recorded as sighted in the zero obstacle scenario became 'not sighted' if situated behind obstacles. Dung piles situated on obstacles that dissect the transect and within a radius of 0.5m of the centre-line were also considered sighted, because the straight line assumption would require the observer to walk over it. All data sets were analysed with the uniform, half-normal, hazard-rate, and negative exponential assumptions in DISTANCE4.0. The cut-off point intervals of pdist were taken at 0.5m. Analysis were done on the total data, and truncated with a maximum effective strip width of 3.5m.

3.2.2.3. Area "a"

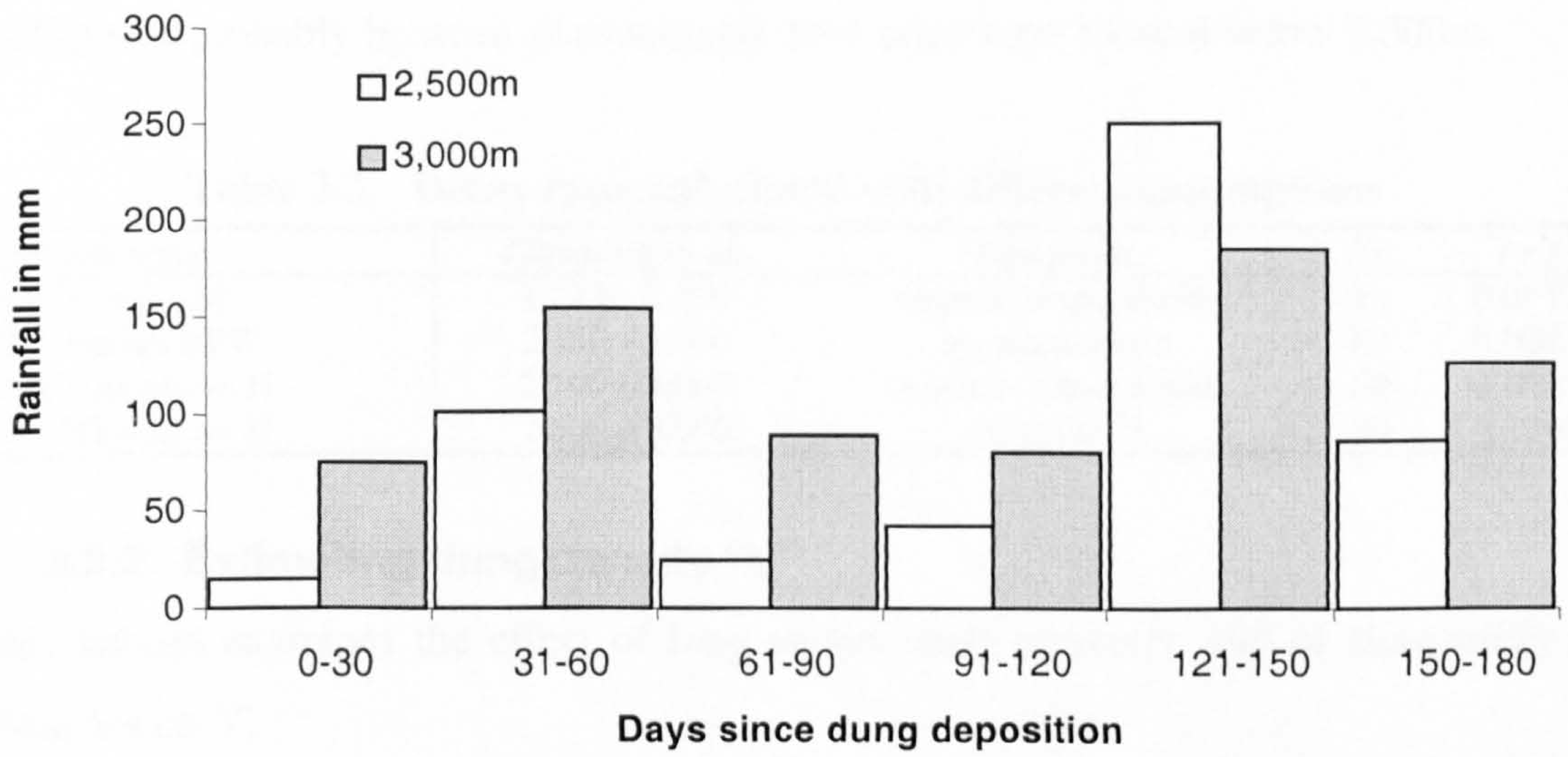
A vegetation map was developed through classification of Landsat TM satellite imagery. The module AREA in the geographical information system Idrisi32 was used to calculate the area digitally of each vegetation stratum. A digital elevation model or DEM was developed by digitising 20m contours from scanned toposheets in ArcInfo version7.2.1. Using the digital calculator in Idrisi32, the vegetation layer was superimposed onto the DEM, the mean slopes were derived per vegetation stratum, and the 2D and 3D surface areas were calculated.

3.3. RESULTS

3.3.1. Dung decay rates

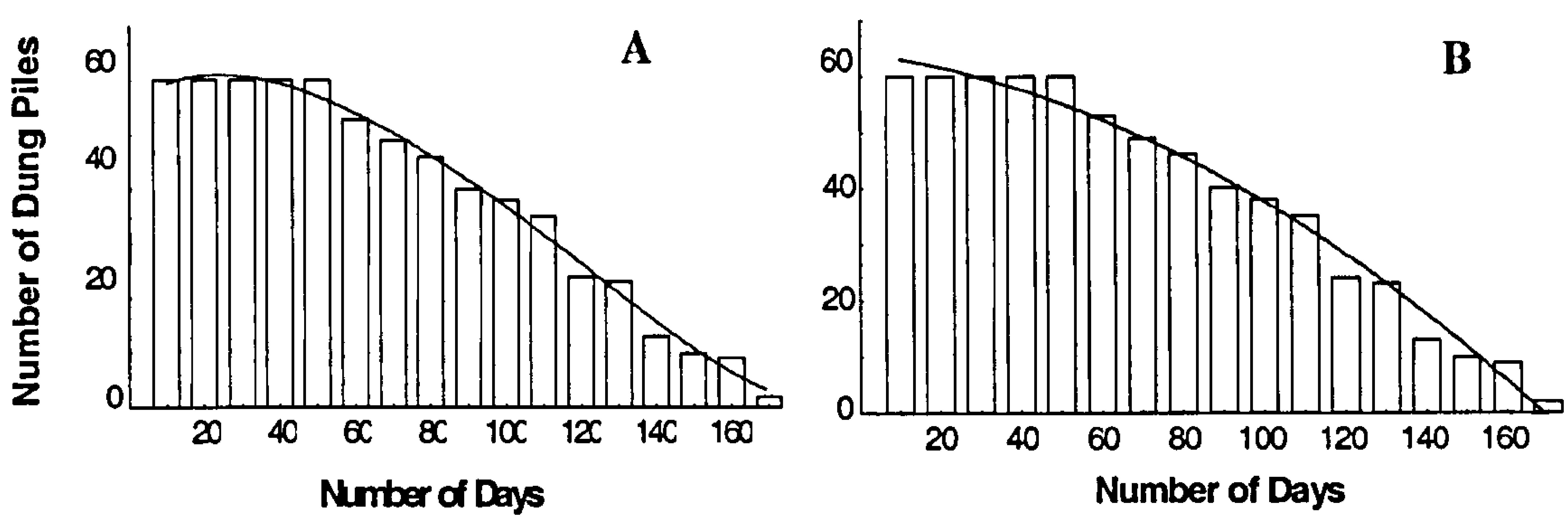
Some 712mm of rain fell over 103 out of 180 days at 3,000m, and 521mm of rain fell over 83 out of 180 days at 2,500m altitude. A paired t-test showed that patterns of daily rainfall differed at 2,500m and 3,000m ($t = -2.496$, df 179, $P = 0.013$) (Figure 3.2).

Figure 3.2. Rainfall at 2,500m and 3,000m altitude



The half-life for dung samples to decay at 2,500m was 90 days, suggesting a decay rate of 0.0092 (SE 0.00063; CL95% 0.00123) per day. In contrast, the half-life for dung samples at 3,000m was 115 days, suggesting a decay rate of 0.0088 (SE 0.00043; CL95% 0.00085) per day. A t-test on the square root of the dung lifespan showed that there was no difference in decay rate at different altitudes ($t = 0.615$, df 58, $P = 0.541$). As a result, the data from both altitudes were pooled to arrive at a dung decay rate for 60 piles. Several assumptions fitted the combined decay rates well, including the polynomial and negative exponential assumptions, plotted per 10 day interval (Figure 3.3). The polynomial suggests a rate of 0.0086 per day while the negative exponential suggests a rate of 0.0094 per day and the bootstrap mean with 1,000 iterations suggests a rate of 0.0089 (SE 0.00040; CL95% 0.00079) per day, and was used for further analysis in this chapter.

Figure 3.3. The polynomial (A) and negative exponential (B) assumptions



The similar results from applying different assumptions suggest that the dung pile decay dataset was very robust (Table 3.3). The faster decay rate estimated by Reuling et al. (1992) was probably because all monitored dung piles were located below 2,500m.

Table 3.3. Decay rates calculated with different assumptions

Date, reference	*Elevation in m.*	*Equations*	*No*	*(r)*
1992, Reuling M.	1,723 – 2,230	negative exponential	93	0.0130
1999, Barnes RFW	2,500 – 3,000	bootstrap mean	60	0.0089
1999, Vanleeuwe H	2,500 – 3,000	negative exponential	60	0.0094
1999, Vanleeuwe H	2,500 – 3,000	polynomial	60	0.0086

3.3.2. Estimating dung density "Y"

This section examines the effect of long versus short transects, and of sightability of obstacles on Y.

3.3.2.1. The effect of long versus short transects on Y

During the February 1999 census it had proved impossible to walk a dead-straight line for long because many physical obstacles and barriers were encountered. Minor deviations due to physical barriers such as rocks lead to following routes of least resistance because elephants are likely to deviate around the same obstacles. The consequence of this was that more dung was recorded on the centre-line, resulting in a skew in measuring pdist, and thus violation of important assumptions in line transects theory (e.g. Thomas et al., 2001).

Transects walked in 2001 were therefore kept very short at 0.2km to allow a dead-straight line to be maintained. As a result, dung piles were not recorded as clustered around the centre-line for the 2001 dataset. Such clustering would seriously bias estimates of density, and smoothing the clustered data around the centre-line would be necessary to ensure that assumptions over distribution of dung piles were not violated. Using the 2001 dataset, combining data between 0 and 1m pdist gave very similar estimates to those obtained from treating 0 to 1m pdist data as 2 classes of 0.5m (hazard-rate: x^2 = 0.19, df 2, P = 0.91). For the 1999 dataset, this smoothing was achieved by combining the pdist data between 0 and 1m. In addition to combining data up to 1m pdist, the 1999 data was also truncated at pdist 3.5m, to improve the pdist distribution curve and reduce the variance between transects.

Table 3.4. Dung density "Y" and elephant density "E" with various g(x) assumptions

Analysing Program	*Survey year*	*Data set*	*Fitted detection curve g(x)*	*Goodness of Fit x^2test* X^2	*df*	*p*	*Y*	*E*	*%CV*
Distance 4.0	1999	LONG	Uniform	5.28	2	0.07	2,338	1.16	24.90
Distance 4.0	1999	LONG	Half-normal	2.32	3	0.51	2,376	1.17	24.68
Distance 4.0	1999	LONG	Hazard-rate	2.18	4	0.70	2,413	1.19	24.27
Distance 4.0	1999	LONG	Negative exponential	0.89	4	0.93	2,963	1.47	24.78
LOPES	1999	LONG	Default (unknown)	?	?	?	2,105	1.04	38.24
Distance 4.0	2001	SHORT	Uniform	3.30	5	0.65	2,764	1.37	19.84
Distance 4.0	2001	SHORT	Half-normal	1.46	4	0.83	3,002	1.48	20.88
Distance 4.0	2001	SHORT	Hazard-rate	0.23	3	0.97	2,933	1.45	21.97
Distance 4.0	2001	SHORT	Negative exponential	1.10	3	0.78	3,232	1.60	25.00
LOPES	2001	SHORT	Default (unknown)	?	?	?	2,980	1.47	29.00

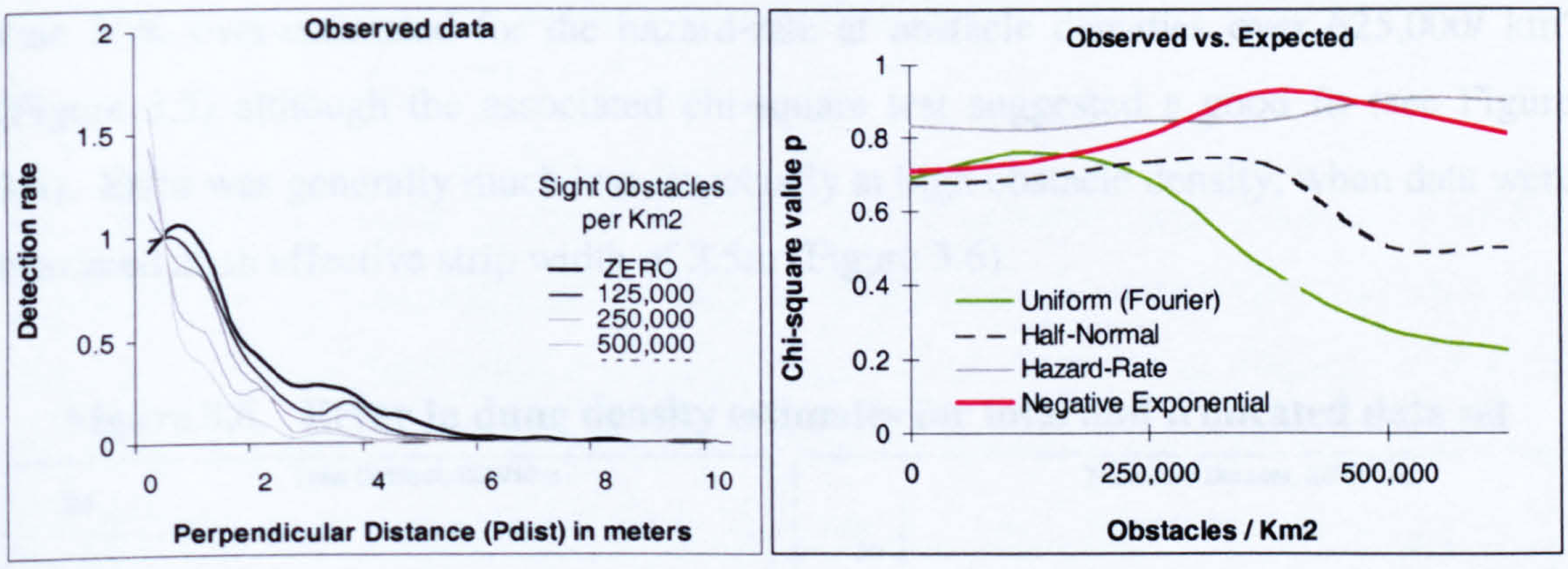
%CV = coefficient of variance

A comparison of results for 1999 and 2001 are shown in Table 3.4. The chi-square tests between the distributions of observed and expected dung piles showed that the negative exponential curve fitted the 1999 data better (x^2 = 0.89, df 4, P = 0.93) than the uniform curve (x^2 = 5.28, df 2, P = 0.07). Given the clustering of dung piles around the centre-line, fitting valid uniform and half-normal curves to the 1999 data was only possible by combining the 0 to 1m pdist values. All curves showed good fits for the 2001 data, suggesting that the short transect data of 2001 is more robust than the long transect data of 1999 (Table 3.4). The hazard-rate for the 1999 data suggested 2,413 (±586) elephants with x^2 = 2.18, df 4, P = 0.70. The best fitting curve for the 2001 data was also the hazard-rate with x^2 = 0.23, df 3, P = 0.97 (Table 3.4). This produced a result of 2,911 (±640) elephants or 1.45 elephants/ km^2 for MK. These results indeed confirm that the previous estimates of 1992, suggesting densities of up to 5.61 elephants/ km^2 (Table 3.1) were very high.

3.3.2.2. The effect of sightability obstacles on Y

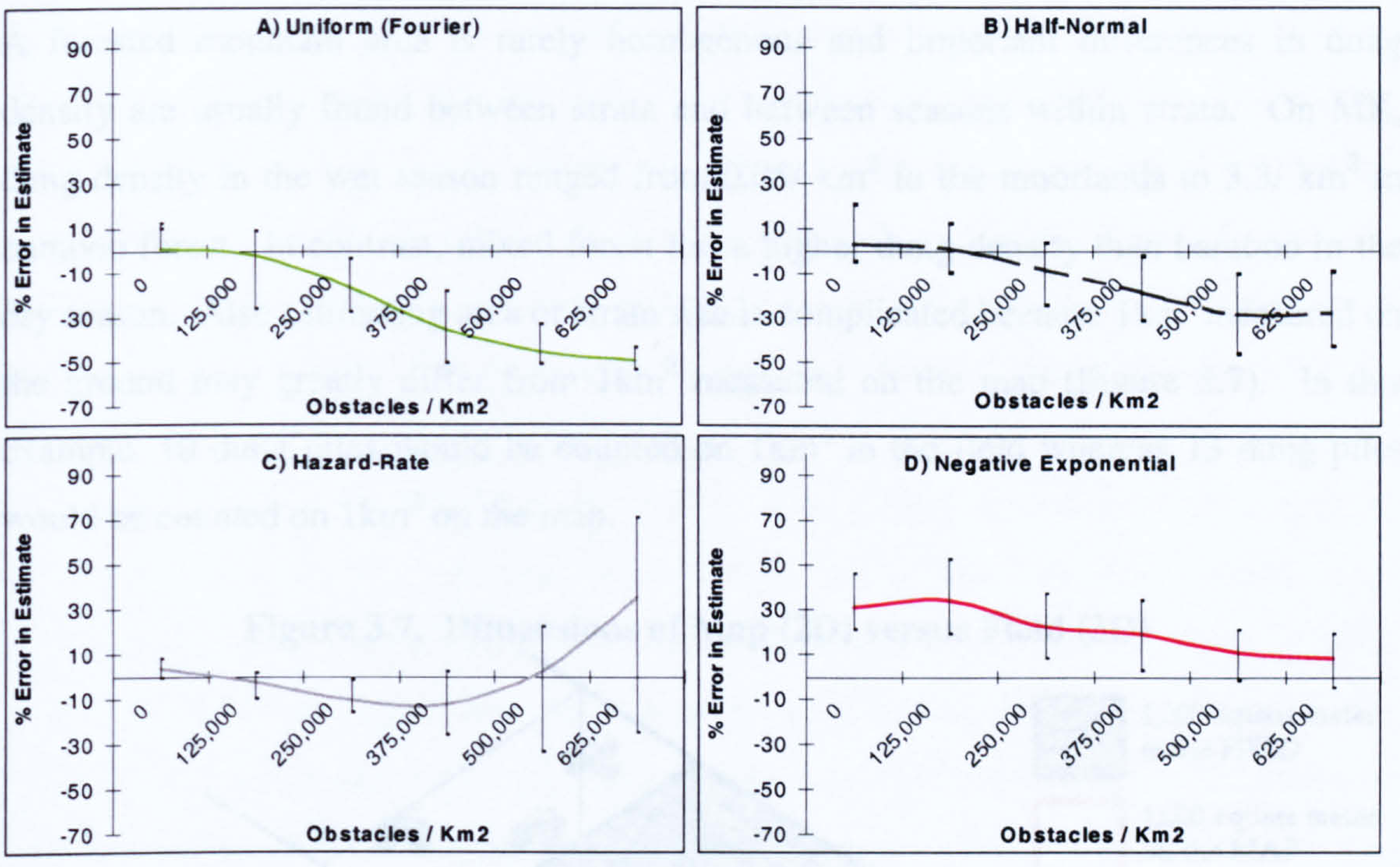
Results from transect simulations showed that the distribution of pdist for observed dung piles changes from a uniform towards a negative exponential with increasing numbers of obstacles (Figure 3.4).

Figure 3.4. Distribution of pdist on terrain with sightability obstacles



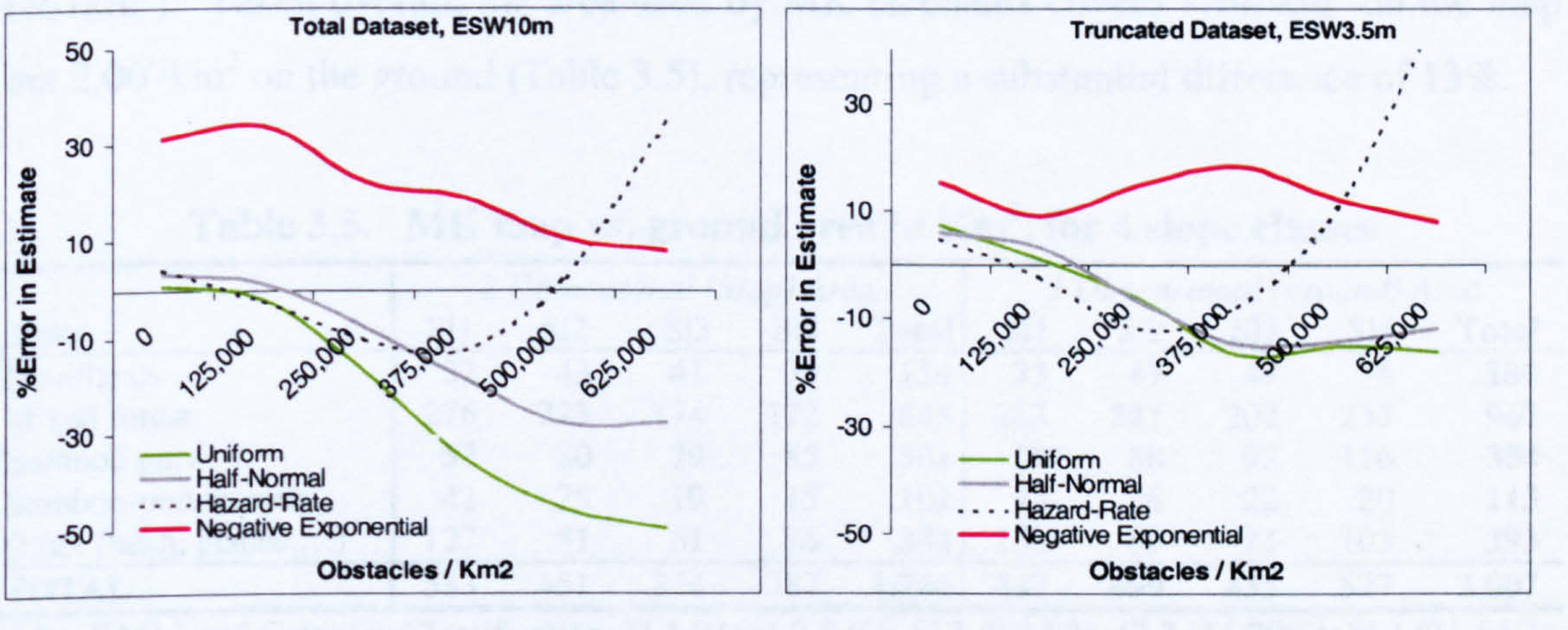
Chi-square tests indicated that, for data collected on terrain with more then 250,000 obstacles/ km^2, the hazard-rate and negative exponential fit better than the half-normal and the uniform curves (Figure 3.4). In contrast, on terrain without physical barriers, the uniform, half-normal and hazard-rate produced accurate density estimates, whereas the negative exponential produced over-estimates of density (Figure 3.5).

Figure 3.5. Error in dung density estimates on terrain with sightability obstacles



With increasing obstacle density, the uniform and half-normal assumptions produced densities that were increasingly under-estimated, whereas the highly over-estimated densities of the negative exponential decreased (Figure 3.5). Dung density was more than 30% over-estimated for the hazard-rate at obstacle densities over 625,000/ km^2 (Figure 3.5) although the associated chi-square test suggested a good fit (see Figure 3.4). Error was generally much less, especially at high obstacle density, when data were truncated at an effective strip width of 3.5m (Figure 3.6).

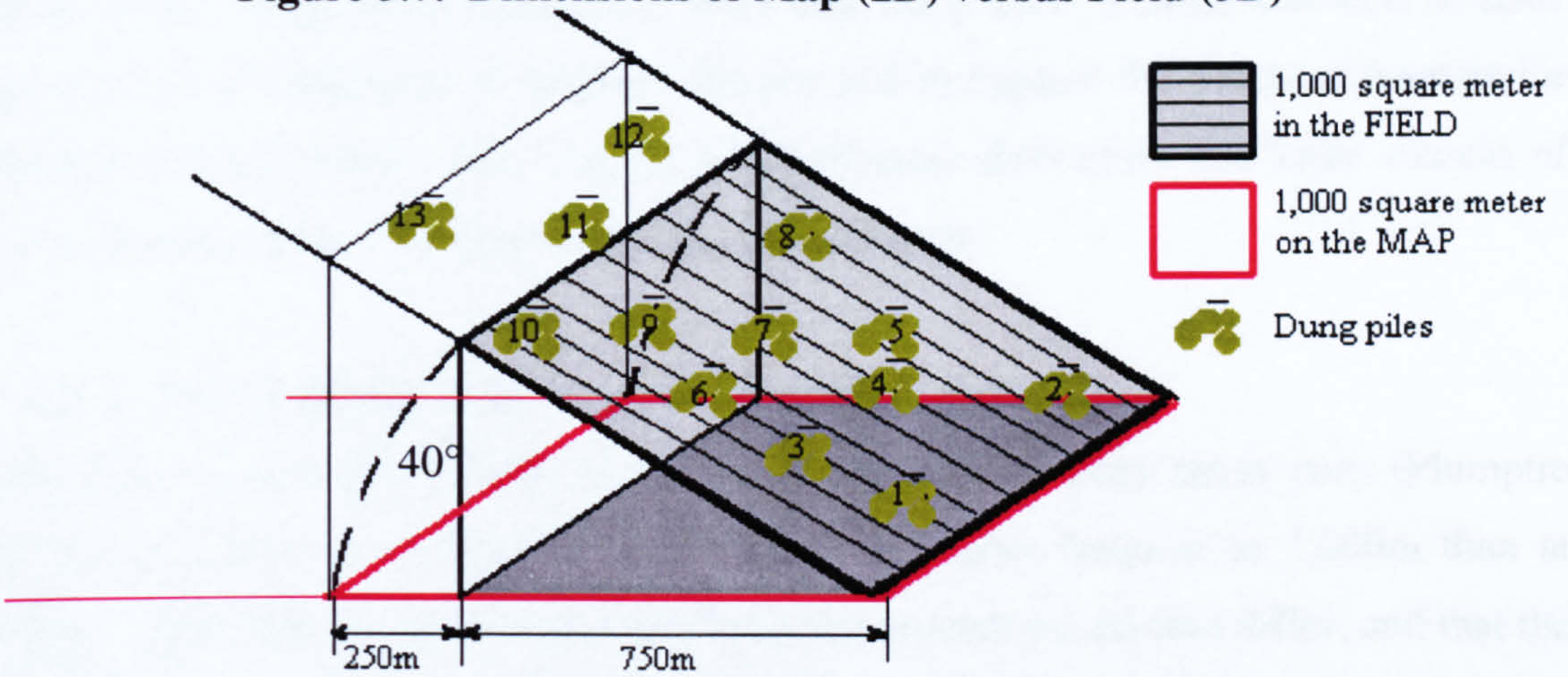
Figure 3.6. Error in dung density estimates for total and truncated data set



3.3.3. Area "a"

A forested mountain area is rarely homogenous and important differences in dung density are usually found between strata and between seasons within strata. On MK, dung density in the wet season ranged from 0.05/ km^2 in the moorlands to 3.3/ km^2 in bamboo forest. In contrast, mixed forest has a higher dung density than bamboo in the dry season. Also estimating area or strata size is complicated because $1km^2$ measured on the ground may greatly differ from $1km^2$ measured on the map (Figure 3.7). In this example, 10 dung piles would be counted on $1km^2$ in the field whereas 13 dung piles would be counted on $1km^2$ on the map.

Figure 3.7. Dimensions of Map (2D) versus Field (3D)



The total surface area of $2,007km^2$ for the three dimensional ground area used by MK elephants, excludes natural barriers such as very steep slopes ($94km^2$) and very high altitudes ($468km^2$), but includes extra terrain covered by the third dimension of slope ($261km^2$). Taken overall, the area used by MK elephants covers $1,746km^2$ on the map but $2,007km^2$ on the ground (Table 3.5), representing a substantial difference of 13%.

Table 3.5. MK map vs. ground area in Km^2, for 4 slope classes

	2 Dimensional (Map) Area					*3 Dimensional (ground) Area*				
Strata	Sl1	Sl2	Sl3	Sl4	**Total**	Sl1	Sl2	Sl3	Sl4	**Total**
Moorlands	32	43	41	39	**154**	33	47	47	54	**180**
Mixed forest	276	223	174	172	**845**	283	247	202	235	**967**
Bamboo pure	57	80	79	85	**301**	59	88	92	116	**354**
Bamboo-podocarpus	42	25	19	15	**101**	43	28	22	20	**113**
Other (bush, glades,...)	127	81	61	76	**344**	130	89	71	103	**393**
TOTAL	533	451	374	387	**1,746**	547	499	435	527	**2,007**

After FAO-Land Category Classification; Sl 1 (slope 0-8 %); Sl 2 (9-14%); Sl 3 (14-20%); Sl 4 (21-56%)

3.4. DISCUSSION

Although line transects can produce more accurate results than aerial surveys (Whitehouse et al., 2001; Barnes, 2002), they can also produce very erroneous results when theory is not implemented vigorously. Dung counts are considered of low quality in the African Elephant Databases (Said et al., 1995; Barnes et al., 1998; Blanc et al., 2003) because errors can be introduced through biased siting of transects, violation of theoretical assumptions in the field, use of erroneous values of the parameters "r", "D", "Y", and "a" in the equation, or from using a wrong detection curve in data analysis (Buckland et al., 2001; Laing et al., 2003). Early dung counts on MK suggested suspiciously high elephant densities of up to 5.61/ km^2 (Table 3.1). Dung counts were repeated along long (4km) transects in 1999 and along short (0.2km) transects in 2001 to provide better estimates of elephant density and to explore the potential reasons for obtaining over-estimates. This chapter explored some difficulties and some sources of error associated with dung counting in mountain forests.

3.4.1. Dung decay rate "r" and defecation rate "D"

Studies have shown that rainfall is a major determinant of dung decay rates (Plumptre and Harris, 1995). Rainfall was much higher and more frequent at 3,000m than at 2,500m. Therefore, it was assumed that dung decay rates would also differ, and that the higher rainfall at high altitudes would accelerate dung decay rates. Nevertheless, there was no difference between dung decay rates at 3,000m and 2,500m altitude. Barnes et al. (1994) also showed that temperature can affect decay, and it may be that colder temperatures at high altitudes on MK could possibly counteract the expected higher dung decay rates as a result of high rainfall.

Small variations in dung decay rate values can introduce considerable bias into density estimates. On MK, the pooled results for altitudes of 2,500 and 3,000m suggest a dung decay rate of 0.0089 per day. A faster rate of 0.013 per day was found in 1992 from monitoring 93 dung piles at altitudes below 2,500m (Reuling et al., 1992). The effect of small differences in decay rate on density can be considerable. For example, using decay rates 0.0089 (this study) and 0.013 (Reuling et al., 1992) per day for MK suggests densities of 0.99 and 1.44 elephants/ km^2, assuming that dung pile density was 2,000 per km^2 and defecation rate was 18 times per day. Because the bulk of the MK elephant range lies between 2,250m and 3,250m altitude, it is advisable to use the decay rate derived from 2,500 and 3,000m asl (Table 3.3) for future overall MK elephant estimates. For studies that focus on estimating density from dung counts on the lower slopes of MK below 2,250m asl, such as in the Imenti forest in the north-east and the Thego forest in the south-west, the Reuling et al. (1992) value derived from monitored dung piles below 2,250m may be more appropriate. Because decay changes between habitats and between seasons, future work should establish a wider set of decay rates for repeatedly surveyed areas, especially for areas with diverse habitat strata.

3.4.2. Dung density "Y"

As described in the African Elephant Database of 1998 (Barnes et al., 1998), the main type of density surveys used in forests are dung counts, mostly of the worst survey quality (3) and of poor survey reliability (D in the range of A for best, to E for worst such as guesses).

Results from this study suggest that transect length and barriers to visibility are the main sources of error. Also use of wrong assumptions over detection probability during the analysis may have contributed to erroneous estimates, especially for counts conducted before 1995, when more advanced analytical programmes like DISTANCE were not yet readily available. DISTANCE was found to be by far the best analytical programme for dung data analysis, because it allows users to explore possible detection curves and pdist intervals (Thomas et al., 2001). However, users who do not know how to explore their data for outliers and clustered data, the programme DISTANCE will produce results that are as erroneous as any other programme using default assumptions.

3.4.2.1. Long versus short transects

Physical obstacles such as deeply incised V-shaped valleys, cliffs and rock formations, limit the possibility of walking long straight line transects on MK. On terrain where there are many physical obstacles, such as in *Arudinaria alpina* forest, elephants will follow routes of least resistance (Vanleeuwe and Gautier-Hion, 1998). Observers who do the same will count high numbers of dung piles near the transect centre-line, producing a negative exponential distribution of pdist. Violating the dead-straight line assumption of line transects will worsen results, with increasing numbers of obstacles and over increasing transect lengths.

Short transects should therefore be used, especially if line transect surveys are to be done at a large scale on difficult terrain by different people with little theoretical expertise. However, the one disadvantage of very short transects is that many of them are needed to reduce variance between transects. On the other hand, short straight transects within the same strata can still be pooled to reduce variance in dung analysis.

3.4.2.2. The effect of obstacles on estimates of Y

Line transect dung counts were simulated for areas without obstacles and for areas with increasing densities of obstacles to sightability, to look at the effect of obstacles on dung detection. The x^2 value between the observed data and the detection curve were applied to expected data for analysis as a Goodness of Fit (GoF) indicator. Results from the simulation were analysed with DISTANCE using different detection curves to look at the GoF and the predicted dung density for comparison with the known dung density. Data produced for the scenario without obstacles fitted the uniform and half-normal detection curves well and produced accurate data on dung pile density. In contrast, applying a negative exponential curve to these data produced a highly over-estimated dung density.

As obstacles like grass, rocks, and trees that blocked the line of sight were added to the scenario, expected dung density was increasingly under-estimated under the uniform and half-normal detection curves. The hazard-rate assumption produced expected dung density estimates that lay very close to the real density, except at very high obstacle densities. The expected dung detection curves inclined towards a negative exponential with clustering near the centre-line, with increasing numbers of obstacles. Much caution must be taken with the negative exponential g(x) assumption for analysis. Also with DISTANCE, the negative exponential curve always produced good x^2 GoF results, although densities were greatly over-estimated at all times. Negative exponential data are considered the result of bad sampling (Buckland et al., 1993), but computer simulated dung counts in this study showed that characteristics of the terrain, namely the number of obstacles reducing sightability, also push the expected detection curve g(x) towards a negative exponential.

If negative exponential data stem from deviating from a dead-straight line, by following a route of least resistance where dung density is clustered, then the area next to this route would have abnormally low dung density. Combining pdist data near the centre-line therefore reduces the inclination of the negative exponential curve. For the MK real transect data of 2001 that was not distributed on a negative exponential curve, combining the data from the centre-line to a pdist of 1m, gave a very similar estimate to the one where data were treated in 2 classes of 0.5m. For the 1999 data that was distributed on a negative exponential curve, combining the data up to 1m resulted in a manageable dataset, while truncating the data to a pdist of 3.5m generally reduced error.

3.4.3. Area "a"

Due to the large range in altitude and exposure of forested mountains, vegetation and animals are usually not homogeneously distributed among strata. Dung density ranged from 0.05/ km^2 to 3.3/ km^2 between vegetation strata on MK, and ignoring this could lead to a serious bias in estimates. Stratification should be based on the variable(s) explaining dung density. This is often best explained by habitat type but in past studies, rainfall and distance from settlement (Barnes et al., 1991; Barnes et al., 1997) were also found to explain elephant density.

Despite its potentially very important effect on estimated elephant numbers, the parameter "area" is often just estimated from maps or taken from the literature. Extrapolating dung counted on the ground to map area is normal practice in density analysis. On geographically pronounced terrain however, $1km^2$ measured on the ground can strongly differ from $1km^2$ measured on the map. On MK, density would be under-estimated by 13% if the effect of slope was not accounted for. To account for the effect of the extra area covered by slope, either the value of dung density must be adjusted, or the value of area per strata must be adjusted. A digital calculation showed that the elephant habitat on MK covers $1{,}746km^2$ on the map and $2{,}007km^2$ when adjusted for slope. Faulty estimations of area have probably contributed to biased estimates of elephant numbers for MK in the past. Reuling et al. (1992) estimated the MK elephant habitat 1,367km^2. In contrast, the same area was estimated at 2,800km^2 by Omondi et al. (1998a). Both studies estimated the population at around 4,000 elephants, although that this translates into a density of 3.11 elephants/ km^2 for Reuling et al. (1992) and 1.43/ km^2 for Omondi et al. (1998) given their respective estimates for the parameter "area".

3.4.4. Re-assessment of elephant numbers on MK

Bias in dung count surveys have led to considerable over-estimates of density for the MK elephant population in the past and indeed for most forested mountains in Kenya (see Table 3.1). The African Elephant Database of 2002 shows that the more up to date results from dung counts are more reliable (Blanc et al., 2003).

Table 3.6. Dung count estimates in Kenya in the African Elephant Database of 2002

Site	Area km^2	Elephant Numbers	Elephant Density	Survey Reliability	Source	AED Year
Aberdare NP	767	1,822	2.38	E	Blom et al., 1990	2002
Arabuko Sokoke	415	184	0.44	B	Litoroh, 2002b	2002
Loroki forest	596	210	0.35	C	Bitok, 1997	2002
Mau Forest	1,267	1,003	0.79	D	Njumbi, 1995	2002
Mount Elgon	1,083	400	0.37	D	Thouless et al., 2003	2002
Mount Kenya	**2,007**	**2,911**	**1.45**	**B**	**Vanleeuwe, 2004**	**2002**
Transmara forest	300	200	0.67	C	Wamukoya et al., 1997	2002

Source: Blanc et al., 2003

Of a total of 26 elephant dung counts in the African Elephant Database of 2002, seven were qualified as B (in the range from A for best to E for worst). The 2001 estimate for MK from this study is 1.45 elephants/ km^2 or 2,911 (±640) elephants. This is currently the most accurate density estimate for MK, and is also considered among one of two most reliable dung count estimates in Kenya, having been allocated B status in the African Elephant Database of 2002 (Table 3.6).

3.5. CONCLUSION

Most estimates of elephant numbers in forested Africa are qualified as poor quality because they were obtained from dung count surveys (Blanc et al., 2003). Dung counts can produce more accurate results than aerial surveys if theory is strictly converted into practice, but minor violations of theory in the field can produce important errors (Kangwana, 1995; Thomas et al., 2000; Buckland et al., 2001). This chapter explored some factors that might bias parameters used in converting dung densities into elephant numbers on forested mountains.

Unlike in lowland forests, higher rainfall at high altitudes did not accelerate dung decay rates, probably because any effect of rainfall was counter-acted by colder temperatures that might help to preserve dung. The possible effect of seasons upon dung decay was not investigated during this study, because not enough fresh dung piles could be found around the MET station and the NaroMoru head quarters at the start of the dry season in December 1999, for a comparative study to the one started at the start of the wet season in March 1999.

Physical barriers make it difficult to walk dead-straight transects, and slight deviations from straight lines are the most common bias on difficult terrain. Many very short transects are better than quasi-straight long transects, and they are more easily applied in the field. Problems with data analysis of short transects can be resolved by appointing a specialist. Field designs on the other hand, need to be adapted for use by less experienced local people (Vanleeuwe, 2004).

Simulation counts showed that obstacles to sightability of dung piles push the expected detection curve g(x) towards a negative exponential assumption, which produced very erroneous results. Negative exponential data can sometimes be transformed to fit another g(x) by fusing pdist data close to the centre-line, and by truncating data to reduce the variance induced by reduced visibility.

Despite its potentially serious contribution to error when estimating elephant numbers, little attention is usually given to stratification, and to establishing strata size or "area".

When slopes are steep and altitudinal range is wide, this in turn creates an array of geographic and climatic conditions, over which elephants spread non-homogeneously, while the size of the area on the map will differ from the actual area on the ground. Elephant densities in different vegetation strata varied several fold. Furthermore, about 30% of the total area available was not actually used by elephants. The sections of the MK environment that were most and least used by elephants in the dry and wet season, were established through predictive GIS modelling from multivariate analysis of line transect data in chapter 4.

Chapter 4

ELEPHANT DISTRIBUTION ASSESSED BY INTEGRATING LINE TRANSECT DATA WITH GIS

4.1. INTRODUCTION

Digital spatial data and geographical information systems (GIS) have become more accessible in the last two decades. Their use for predictive spatial modelling has contributed significantly to problem mitigation and management in a wide range of fields, such as: epidemiology and health care (Kleinschmidt et al., 2001; Desjeux and Alvar, 2003), water, pollution (Alemaw and Chaoke, 2003; Dabrowski and Schulz, 2003), soil erosion, metals in soils (Mati and Veihe, 2001; Lufafa et al., 2003), and global changes through deforestation, fires, agriculture, and over-grazing (Eeley et al., 1999; Hiers et al., 2003; Kinnaird et al., 2003). They are also increasingly being used to identify and monitor biodiversity-rich environments, which have been recognised as a priority in biodiversity conservation (Sanderson et al., 2002; Balmford et al., 2003; Moore et al., 2003).

In biodiversity research, GIS has mainly been used to collect, retrieve, transform, and display remotely sensed data (e.g. Barnes et al., 1991; Hillman-Smith et al., 1995; Thouless, 1996; Barnes et al., 1997). Predictive modelling with GIS in wildlife conservation remains at an early stage (Lenton et al., 2000; Walpole, 2000; Clevenger et al., 2002; Huettmann and Linke, 2003; Linkie et al., 2003; Sitati et al., 2003). Predictive modelling of elephant distribution is a powerful management tool, because elephants play a key role in re-structuring the habitats that they occupy (Chapman et al., 1997; Cristoffer and Peres, 2003; Nchanji and Plumptre, 2003). In open environments, aerial counts can provide accurate data on distribution of elephants. However, in forest environments, knowledge of elephant distribution remains based on tiny sampled sections of the total environment, such as through dung counts along line transects. Hence, predictive GIS modelling appear a powerful tool to improve our knowledge of forest elephants.

Advanced multivariate analysis of line transect data allows the development of explanatory models of density and distribution (Lenton et al., 2000; Barnes, 2001; Broseth and Pedersen, 2001). GIS has the power to extrapolate from small sampled areas to larger non-sampled areas (Crawley, 1993; Guisan et al., 2002; Thuiller et al., 2003). Using Mount Kenya (MK) as an example, explanatory models based on line transect data (Chapter 3) were integrated with GIS to develop the most advanced predictive seasonal distribution maps currently available for elephants in a forested environment. In this chapter, the following questions about integrating line transect data and GIS are addressed:

- How can line transect data be used to establish explanatory models for seasonal dung pile density?
- What is the most appropriate multivariate test to develop explanatory models of seasonal dung pile density?
- What are the criteria of model robustness and model strength and how can models be tested to avoid generating faulty predictions?
- How can explanatory models of seasonal dung pile density be converted to seasonal dung pile density distribution maps in a GIS?
- Can dung pile density distribution maps be used to extrapolate elephant numbers?

4.2. METHODS

The presence of dung piles and characteristics of the environment were collected at 50m intervals along some 150km of line transects around MK at the end of February and May 1999. These data were used both to estimate elephant density (Chapter 3) and to establish explanatory models to develop seasonal elephant distribution maps. Once the data were collected, three main analytical phases preceded the end product:

- Data analysis (bi-variate correlation and GLIM analysis).
- Explanatory model testing for explanatory strength and for spatial auto-correlation.
- Explanatory model integration into a GIS.

Prior to the three main testing phases, line transect data were prepared for multivariate analysis, and the appropriate multivariate test was selected.

Data were collected on 4km line transects walked in February (dry season) and May (wet season) 1999 on the following:

- Dung pile distance along the transect, and their pdist from the transect centre-line;
- vegetation type (veg) in 5 classes: moorlands; mixed forest; bamboo monotypic; bamboo-podocarpus; and, other;
- ground cover (gc) in 3 classes: less than 50cm height; between 50-100cm; and, more than 100cm;
- counts of timber logging sites (tim);
- inclination of the terrain or slope (sl) in 3 classes: flat; rolling hill; and, valley.

Values for rainfall (rain), altitude (alt), distance from rivers (driv), streams (ds), waterholes (w), saltlicks (s), and clearings (cl), were later extracted by superimposing the transects onto digital layers that were generated in a GIS.

The 4km transects were subdivided into 50m transect segments, giving a total of 2,510 segments for the dry season and 2,289 segments for the wet season. The length of segments was determined as 50m to allow exploration of the possible effect of parameter slope on elephant distribution. Lengthier segments would have required averaging the values of slope on this very pronounced terrain, and the effect of a very steep slope next to flat terrain would have been lost. The data were recorded in a matrix for each segment as shown in Table 4.1.

Table 4.1. Data recorded for each segment along transects

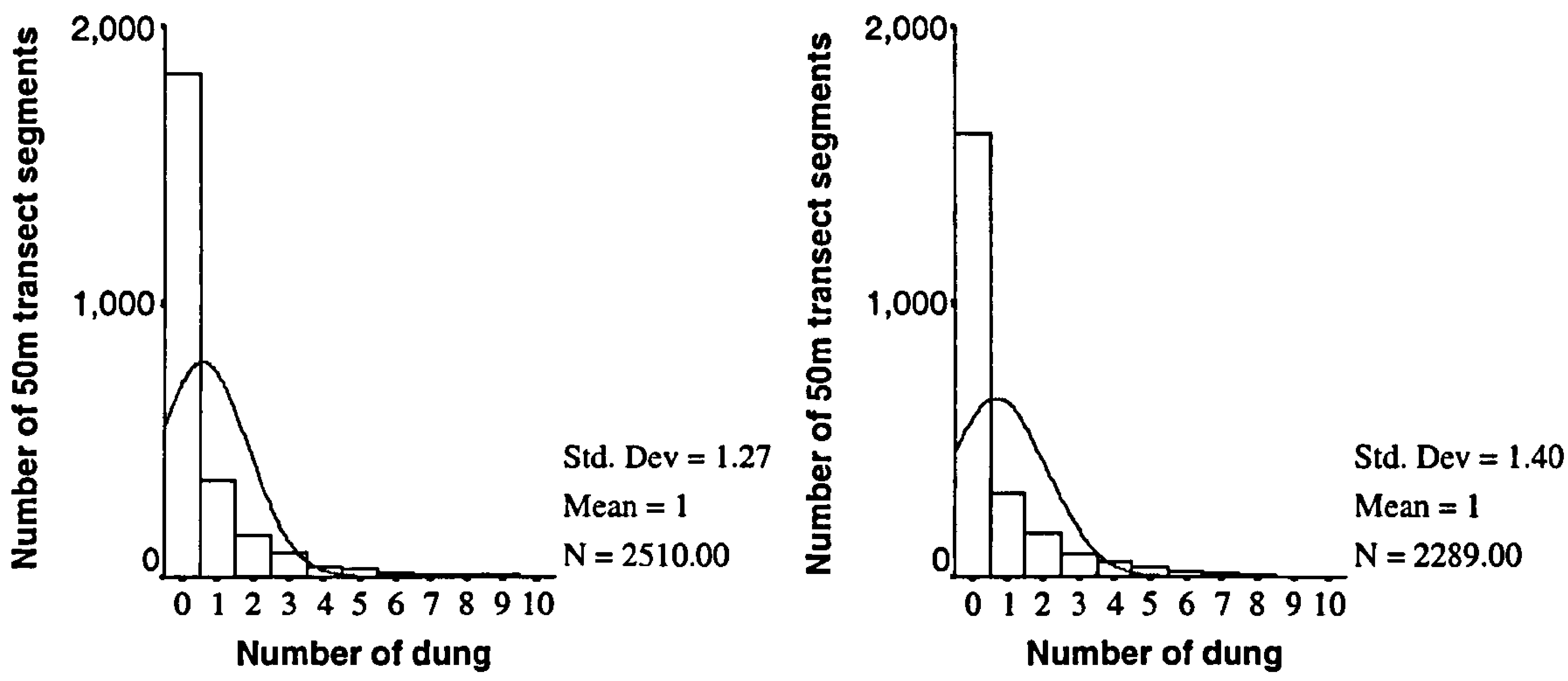
ID	*Dung*	*Veg*	*Gc*	*Sl*	*Tim*	*Driv*	*Ds*	*Alt*	*Rain*	*Cl*	*S*	*W*
Data type: Segment no.	*Scale*	*Nominal*	*Ordinal*	*Ordinal*	*Scale*	*Scale*	*Scale*	*Scale*	*Scale*	*Scale*	*Scale*	*Scale*
1	1	1	1	1	0	2500	300	2901	21	3750	450	450
2	0	1	1	1	0	2550	250	2876	21	3700	400	400
3	0	1	2	2	0	2600	200	2844	21	3650	350	350
4	2	1	2	2	0	2650	100	2809	21	3600	300	300
5	0	1	2	3	0	2700	50	2767	21	3550	250	250
6	0	1	2	2	0	2650	0	2728	21	3500	200	200
7	1	1	1	2	1	2600	50	2775	21	3450	150	150
...	...	...	...	...	...	...	...	...	...	...	...	...

Transect segments used in analysis need to be spatially independent. Five test sets were therefore made, each containing 20% of the segments of the entire dataset. Segments were selected in groups of 5, and a number 1 or 2 was randomly generated to select 1 out of 2 segments, leaving a minimum interval of 3 segments (Figure 4.1). The transect segments from the total dataset that were not used, were retained as training sets.

Figure 4.1. Selection of 50m transect segments in test sets

Many 50m transect segments contained no dung piles, so the response variable "dung" followed a poisson distribution with many zeros and a long tail (Figure 4.2).

Figure 4.2. Distribution of dung in the dry and wet season on MK in 1999



Linear regression analyses are often used regardless of whether or not the response variable is normally distributed. One common approach to transform the response variable to approach a normal distribution is by converting data into presence (1) or absence (0) data, and selecting an equal proportion of each for analysis. Nelder and Wedderburn (1972) worked on a formulation of the traditional linear regression model, namely generalised linear models or GLM, which allow a wider range of assumptions to underlie the linear relationship between the response variable (e.g. dung) and its possible explanatory parameters (Appendix V). GLM are increasingly used in biological and ecological studies and are well reviewed, in particular from work describing the environmental control of species distribution or species richness (Augustin et al., 1998; Vayssieres et al., 2000; Guisan et al., 2002; Miller and Franklin, 2002; Thuiller et al., 2003).

Instead of manipulating the MK data to approach a normal distribution for linear regression analysis, GLM analyses were used instead with the programme GLIM (generalised linear interactive modelling). GLIM was designed to deal with, among other things, poisson distributed data without the need of data transformation (McCullagh and Nelder, 1983; Nicholls, 1991; Crawley, 1993; Francis, 1996). For time series analysis, complex split-plot, nested or confounded designs, GENSTAT is a more complete statistical package. Use of GLIM is unfriendly because all commands have to be entered by hand, but this forces users to understand the analytical procedure, and it was therefore judged appropriate for this study.

4.2.1. Data analysis in SPSS and GLIM

The distribution and bi-variate correlations between parameters in test sets were explored using the statistical program SPSS version 11. This allowed a preliminary exploration of potential parameters explaining elephant distribution, and it allowed comparing these results with those obtained for the explanatory models from GLIM analysis.

The poisson distribution is a one-parameter distribution, specified entirely by the mean. Because the data on dung pile counts are integers, the residuals can only take a restricted range of values. If the estimated mean was 0.5, for example, then the residuals for counts of 0, 1, 2, and 3 could only be -0.5, 0.5, 1.5, and 2.5. Because count data on dung piles have no negative values, the logarithmic link function and poisson error were specified in GLIM, so that the fitted values are antilogs, and therefore cannot become negative (Crawley, 1993).

Once a data table was imported, the response variable identified, and the error specified, parameters were explored using scatter plots or mean dung density tables. When continuous explanatory parameters such as rainfall, altitude, distance, are curved rather than linear, the effect of the curved response can be tested by creating a new parameter with the squared values (e.g. aa = altitude*altitude). Explanatory parameters with independent classes such as vegetation type, were treated as factor variables with x number of levels, by which the effect of each level on the response variable is tested separately.

The null model in GLIM, when no parameters are yet fitted to the model has two values: one value is called "scaled deviance" which varies according to the number of parameters and the robustness of the dataset; and a second value is for degrees of freedom, comprising the data sample size - 1. All parameters and combinations of parameters are then tested for their explanatory strength and robustness. There are two ways of testing the explanatory strength of parameters: 1) by fitting parameters one by one to the nil model; or 2) by fitting all parameters to the nil model and subtracting them one by one. The first method is usually used for data with parameters that are predicted to have potential explanatory strength. The second method is usually applied when users have no idea of the potential explanatory strength of parameters. The end result of using both techniques is the same.

There is no need to exclude parameters that explain one another in GLIM, because the programme automatically excludes them as it builds models. Adding or 'fitting' a parameter to the nil model produces a "change" in the value of scaled deviance. For example, if rain is fitted to the nil model and it also explains altitude, adding altitude would not produce a significant additional effect or change in scaled deviance, and would thus remain excluded. Nevertheless, with rain already fitted to the model, altitude may still contribute to the model when combined with another parameter, for example vegetation*altitude. When combined parameters produce a little extra effect, the simplest model was always prioritised.

One can refer to a statistical table of critical values of chi-square, to test the effect of the "change" produced by parameters and their associated degrees of freedom. Besides testing the explanatory strength of parameters, expressed by change in scaled deviance, it is also possible to test the robustness of parameters. Models contain values of effect, the estimates and standard error "SE" for the estimates, for the linear constant and all parameters in the model (Table 4.2).

Table 4.2. Example model in GLIM

parameters	*Estimate*	*SE*
Constant	-11.39	2.043
Alt*alt or aa	-2.897e-07	6.276e-08
Tim	-0.9127	0.3919
Rain*rain or rr	-0.01630	0.002883
Vegl* rain	0.8686	0.1535
Veg2* rain	0.9139	0.1533
Veg3* rain	0.9412	0.1535
Veg4* rain	0.9530	0.1522

A statistical table of critical values of "F" shows whether the estimate is robust. Parameters that contain few data samples typically produce large SEs. The smaller the SE in proportion to the estimate, the more robust is a parameter, and ideally should be at least 3 times smaller then the estimates. Estimated dung "Y" in the above model (Table 4.2) would be:

$$Y = \exp(-11.39 - (0.0000002897*aa) - (0.9127*tim) - (0.01630*rr) + (0.8686*(veg1*rain)) + (0.9139*(veg2*rain)) + (0.9412*(veg3*rain)) + (0.9530*(veg4*rain)))$$

The exponential (exp) in the equation is needed to obtain the anti-log values, because with poisson errors, the link is logarithmic.

4.2.2. Explanatory strength and spatial auto-correlation

The seasonal explanatory models derived from analysis of the five test sets, were applied to the training sets. The expected values for dung, using the test set formulae, were compared with the observed values for dung of the training sets (Table 4.3).

Table 4.3. Residuals of observed - expected, and spatial co-ordinates per 50m sample

50m segments	*X coord*	*Y coord*	*Obs-Exp*	*Exp dung*	*Obs dung*	*Veg*	*Gc*	*Sl*	*Tim*	*Driv*	*Ds*	*Alt*	*Rain*	*Cl*	*S*	*W*
1	309362	9994593	-0.008	**0.008**	**0**	1	3	2	0	1000	1400	3399	12	2000	10000	10000
2	309327	9994570	-0.008	**0.008**	**0**	1	3	2	0	950	1350	3400	12	2000	10000	10000
3	309293	9994548	-0.008	**0.008**	**0**	1	2	1	0	900	1300	3400	12	2000	10000	10000
4	309224	9994503	-0.008	**0.008**	**0**	1	2	1	0	850	1250	3394	12	2000	10000	10000
5	309155	9994458	-0.010	**0.010**	**0**	1	2	1	0	800	1200	3396	12	1500	10000	10000

The explanatory strength of test set models was expressed as the percentage of correctly expected values for dung, when applying the test set model to its training set. Expected (Exp) dung was grouped for comparison with Observed (Obs) dung as: $< 0.5 = 0$; ≥ 0.5 and $< 1.5 = 1$; ≥ 1.5 and $< 2.5 = 2$; ≥ 2.5 and $< 3.5 = 3$; $\geq 3.5 = > 3$.

For comparison, results were also tested with the ROC curve in SPSS, which are most often used to test probabilities from logistic regression, indicating strength of conviction that a subject falls into one category or another. To test the performance of the models using the ROC curve, expressed as the area under the ROC curve, both the observed and expected dung pile density were transformed to presence or absence data, in which all dung values between 0 and 0.5 were allocated a value of 0, and all values above 0.5, a value of 1.

Models were also tested for spatial auto-correlation because samples used in test sets must be independent. Spatial auto-correlation tests help to avoid faulty predictions through faulty models, by testing the correlation parameter between two differently located events and revealing if there are geographically clumped distributions (Dubin, 2003). Spatial interpolation can be executed with a lower density of samples in the case of high spatial auto-correlation (Lesage and Pace, 2001; Shekhar et al., 2003). Model strength and robustness are not affected by spatial auto-correlation when, either parameters in the model, or model residuals, are spatially auto-correlated (Legendre et al., 2002). However, it must be pointed out that even when independent variables or residuals in multivariate models are not spatially auto-correlated, significance values of explanatory models are likely inflated and error terms reduced when parameters used in the models are strongly spatially auto-correlated (Dr. C. Thomas, Pers. Comms).

CrimeStat 2.0 (Levine, 2002) was used to test for spatial auto-correlation or first-order nearest neighbour randomness, of the transect segments used in the test sets. Doing so requires the X and Y co-ordinates, and the residuals (Observed-Expected) of the segments used in the test sets. Results are expressed by a Moran's I spatial auto-correlation index, which is an index of co-variation between different point locations (e.g. transect segments) and is similar to a product moment correlation coefficient, varying from –1 to +1. The Moran's I statistic calculates the Moran's I, the spatially random or expected I, the standard deviation of I, a significance test of I under the assumption of normality z-test, and a significance test of I under the assumption of randomisation z-test. The z-test calculates the difference between the observed nearest neighbour distance and that expected from a random distribution. Models that are spatially auto-correlated have z-values above 1.96. The models that produced the best explanatory strength and least spatial auto-correlation, were integrated into a GIS to develop distribution maps.

4.2.3. Creating elephant distribution maps

GLIM allows for response variables, such as dung pile density, to be predicted from the linear relation between parameters multiplied by their parameter specific effects. GLIM and GIS were integrated to extend results obtained from measurements along line transects to large non-sampled areas. To integrate GLIM and GIS, geo-referenced raster layers were made for all significant parameters in the formulae. All layers were composed of values and value classes that were used in the GLIM analysis. For example, if slope data used in GLIM analysis was expressed as classes 1,2, 3, and 4, then the same classes were used to express slope in the GIS layer. The layers produced for the MK analysis included:

- Altitude or Digital Terrain Model (DTM): three layers were needed to develop a DTM with the module TOPOGRID in the ArcGIS version 7.2.1. These layers comprised: contours, rivers (with their flow direction), and spot-heights. They were digitised on-screen from 16 scanned topographic sheets at scale 1:50,000.
- Slope: a slope layer was derived from the DTM, using the module 'SLOPE' in Idrisi32. Real values were grouped into classes 1, 2, 3, and 4, after the criteria used in the field. Slope 4 (almost vertical terrain) was considered a natural barrier to elephant movement.
- Vegetation: the LANDSAT TM satellite image of February 2000 was classified in 5 vegetation classes (see General Methods section in Chapter 2).
- Timber logging: this layer showed the location of logging sites, derived from an aerial survey conducted in 1999 (see Chapter 7).
- Rainfall for the wet and dry season: Seasonal rainfall maps were made on my behalf by B Sturm, an MSc student from the University of Berne who developed a programme to create rain maps. These maps were derived from mean 10 day rainfall data over 7 years, collected from > 50 meteorological stations around MK.

- Distance from rivers, streams, saltlicks, waterholes, and clearings: these vector or point layers were converted to boolean raster layers, in which features carry the value 1 and the remaining pixels of the image carry 0. The module DISTANCE in Idrisi32 was used to estimate distance from "feature" layers.
- Squared values of "aa", "rr", "dsds": to create squared layers, such as aa (alt*alt) or rr (rain*rain), either the module OVERLAY or the image calculator was used to multiply appropriate layers together.

Complex across-layer calculations are possible when raster layers are of the same area, have the same spatial reference system, and the same pixel resolution. A raster layer is an image composed of cells or pixels of certain size or resolution. All raster layers for this study were made in, or converted to, a resolution of 30m, meaning that each pixel is 30x30m on the ground. The image calculator in Idrisi32 allows for complex across-layer calculations (to superimpose, multiply, subtract, and add layers; to calculate logs and exponentials of layers). In this study, GLIM model formulae were entered into the image calculator to create elephant dung distribution maps (Figure 4.3).

Figure 4.3. Converting GLIM formula to distribution map

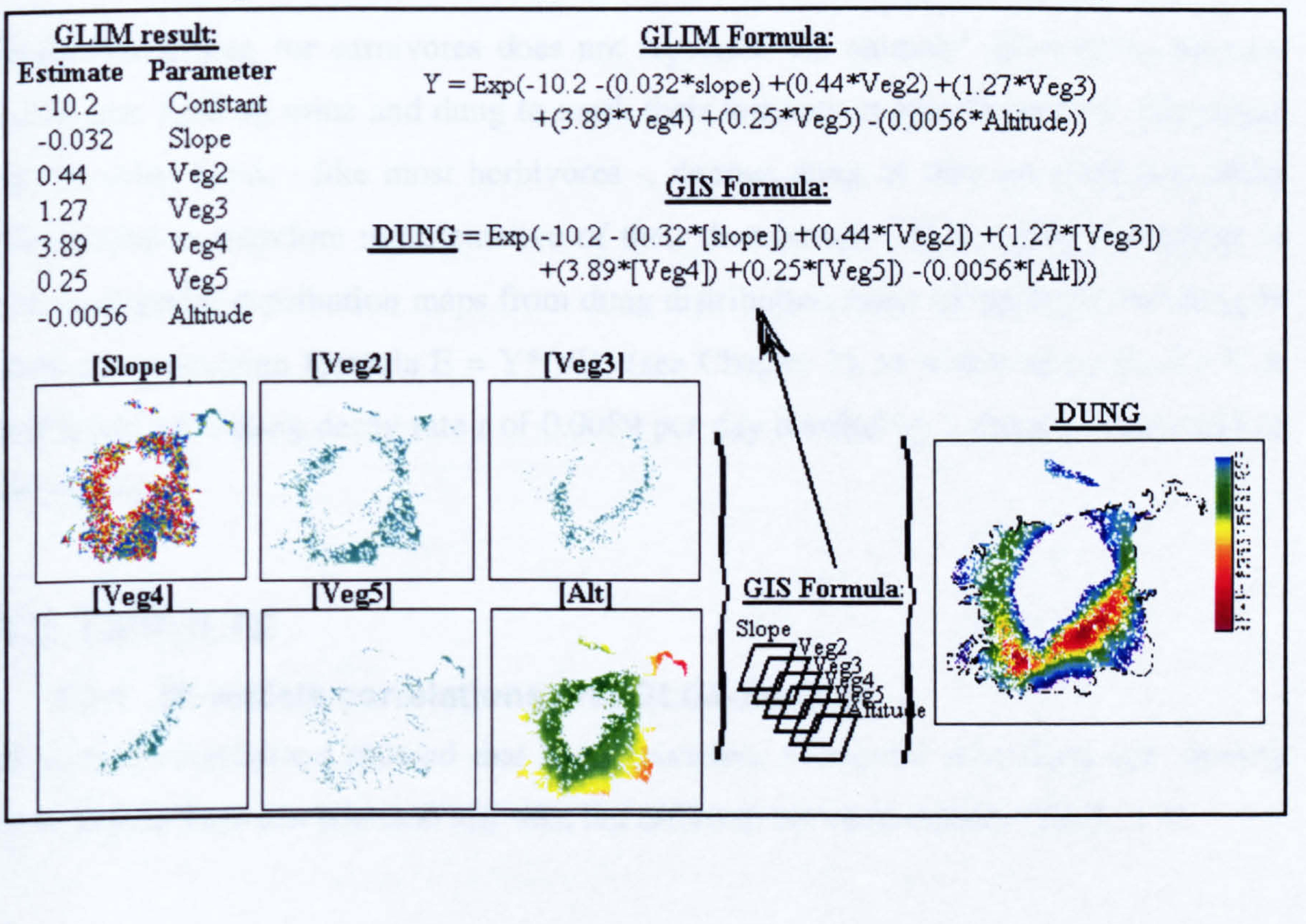


Figure 4.3 shows a fictitious example of a GLIM analysis where the results in the left top corner represent the estimates or explanatory effect of parameters that significantly contribute to the final model. The GLIM formula is in the form that allows predicting values of dung density "Y" to be entered in the image calculator as a GIS formula. The GIS formula is the same, but parameters are replaced by GIS layers. Using three models that differed slightly, and five variations of parameter "estimates" in the models, depending on which of five seasonal test sets was used, 15 distribution maps were made per season.

To conclude, I explored whether the maps could be used to calculate elephant density. To do so, the 15 seasonal distribution maps had to be multiplied by a factor to convert relative presence results to approximate dung density per image pixel. Because the image resolution is 30x30m or 900m^2, whereas the models were derived from 50m transect segments with a pdist of ~2.5m on either side of the transect or ~250m^2, this factor was assumed to be 3.6. The sum of all pixels represented the estimated dung total for MK. Estimates of the 15 seasonal maps were compared to the estimated density as found in Chapter 3.

Dung distribution for carnivores does not represent the animals' distribution because carnivores hold up urine and dung to mark their territory in specific places. Elephants on the other hand, - like most herbivores -, deposit dung as they go along and dung distribution is therefore representative of their distribution. This makes it possible to derive elephant distribution maps from dung distribution maps by applying the dung to elephant conversion formula $E = Y*(r/D)$ (see Chapter 3), in which dung density Y is multiplied by a dung decay rate r of 0.0089 per day divided by a dung defecation D of 18 per day.

4.3. RESULTS

4.3.1. Bi-variate correlations and GLIM analysis

Bi-variate correlations showed that the parameters correlated with dung pile density were similar between seasonal test sets, but different between seasons (Table 4.4).

Table 4.4. Spearman rho correlations between dung pile density and possible explanatory parameters

DUNG	*N*	*Veg*	*Gc*	*Sl*	*Tim*	*Driv*	*Ds*	*Alt*	*Rain*	*Cl*	*S*	*W*
Dry_test set1	502	0.106*					-0.215**	-0.283**	0.241**	-0.173**	-0.288**	-0.096*
Dry_test set2	502	0.136**					-0.117**	-0.337**	0.214**	-0.363**		-0.269**
Dry_test set3	502	0.172**	-0.129*				-0.169**	-0.314**	0.253**	-0.299**		-0.245**
Dry_test set4	502	0.140**			-0.104*		-0.149**	-0.345**	0.263**	-0.272**		-0.203**
Dry_test set5	502	0.138**					-0.097*	-0.306**	0.235**	-0.309**		-0.254**
Wet_test set1	458	0.103*		-0.092*				-0.144**	0.185**			
Wet_test set2	458	0.133**		-0.165**					0.144**	-0.102*		
Wet_test set3	458	0.157**		-0.161**		0.096*		-0.118*	0.164**			
Wet_test set4	458	0.175**		-0.153**			-0.099*		0.119*	-0.117*		
Wet_test set5	457	0.137**		-0.217**				-0.142**	0.124**			-0.106*

* shows the correlation coefficient significance at $p < 0.05$ and, ** at $p < 0.01$ (2-tailed)

Dry season dung pile density mainly correlated with vegetation (veg), altitude (alt), rain, and distances from streams (ds), clearings (cl) and water holes (w). In contrast, wet season dung pile density correlated with vegetation, slope (sl), rain and altitude (Table 4.4). The correlations between dung pile density and distances from streams (ds), clearings (cl), saltlicks (s), and water holes (w), were strong in the dry season only. In contrast, the correlation between dung pile density and slope was strong in the wet season only (Table 4.4).

Many explanatory parameters inter-correlated in the dry and wet seasons, and in some cases in both seasons. The key ones included: distance from saltlicks and from clearings; distance from rivers (driv) and slope; and ground cover (gc) and slope (Tables 4.5 and 4.6). Some of these correlations were self-explanatory. For example, most saltlicks were found in clearings, rivers lie in valleys and slope will therefore become more pronounced closer to rivers, and also the ground cover vegetation is typically greener near fertile riverbeds (Tables 4.5 and 4.6).

Table 4.5. Spearman rho correlations for a test set in the dry season (N = 502)

DRY	*Dung*	*Veg*	*Gc*	*Sl*	*Tim*	*Driv*	*Ds*	*Alt*	*Rain*	*Cl*	*S*	*W*
Dung	1	0.106*					-0.215**	-0.283**	0.241**	-0.173**	-0.288**	0.096*
Veg		1	-0.295**	0.184**		-0.103*	-0.178**	-0.351**	0.170**	-0.211**	-0.379**	0.169**
Gc	-0.032		1	0.154**	-0.105*		0.141**	0.238**	-0.202**	0.095*		-0.223**
Sl	0.026			1		-0.298**	-0.183**			-0.092*	-0.115**	0.211**
Tim	0.001	0.067		-0.049	1			-0.125**	0.224**	-0.138**		-0.129**
Driv	-0.004		-0.036		0.018	1			0.190**	0.212**	0.194**	-0.261**
Ds					-0.021	0.019	1	0.096*	-0.191**	0.135**	0.118**	-0.156**
Alt				0.065		0.008		1	-0.434**	0.298**	0.476**	0.137**
Rain				-0.067					1	-0.112*		-0.386**
Cl										1	0.258**	
S			0.069		0.083				0.065		1	-0.222**
W										-0.063		1

* shows the correlation coefficient significance at $p < 0.05$ and, ** at $p < 0.01$ (2-tailed)

Table 4.6. Spearman rho correlations for a test set in the wet season (N = 458)

WET	*Dung*	*Veg*	*Gc*	*Sl*	*Tim*	*Driv*	*Ds*	*Alt*	*Rain*	*Cl*	*S*	*W*
Dung	1	0.103*		-0.092*				-0.144**	0.185**			
Veg		1			-0.127**	-0.145**	-0.188**		0.293**	-0.171**	-0.312**	
Gc	-0.041	-0.032	1						-0.106*	0.132**		
Sl		0.08		1	-0.103*	-0.390**	-0.146**	0.281**			-0.100*	0.279**
Tim	0.035		-0.038		1			-0.221**				
Driv	0.019		-0.047		0.088	1		-0.138**	-0.215**		0.296**	-0.258**
Ds	-0.071		0.01		0.044	0.041	1		-0.224**	-0.120*	0.195**	-0.147**
Alt		0.079	-0.089				-0.021	1	-0.117*	-0.145**		0.488**
Rain				0.057	0.052				1	-0.290**	-0.655**	0.538**
Cl	-0.068		.	-0.036	0.055	0.025				1	0.205**	
S	0.008		-0.091		-0.023			0.075			1	-0.350**
W	-0.015	-0.017	-0.079		-0.046					-0.024		1

* shows the correlation coefficient significance at $p < 0.05$ and, ** at $p < 0.01$ (2-tailed)

4.3.1.1. GLM analysis with the programme GLIM (Crawley, 1992)

Three potential explanatory models per season resulted from GLIM analysis, with slight differences, depending on which test set was used for the analysis (Table 4.7).

Table 4.7. Three alternative models per season that explain dung pile density

Dry season	*Explanatory Models*	*Wet season*	*Explanatory Models*
Model 1	Tim, alt, ds, veg*(rain+rr)	Model 1	Sl*(rain+rr), veg*(alt+aa)
Model 2	Tim, alt*aa, ds, veg*(rain+rr)	Model 2	Sl*(alt+aa), veg*(rain+rr)
Model 3	Tim, alt*aa, sw*swcl, veg*(rain+rr)	Model 3	Sl*(alt+aa), veg*(rain+rr), s, ss

Most parameters that were significantly correlated with dung pile density in the bi-variate correlation analysis were also found to be significant in GLIM analysis. However, some parameters gained or reduced in explanatory strength in the presence of other parameters in the model.

For the dry season, GLIM results contained the same parameters as in bi-variate correlation analysis, except that timber logging, which was not found significant in the bi-variate correlation analysis, became significant in the GLIM analysis. For the wet season, GLIM results contained the same parameters as in bi-variate correlation analysis, except that distance from saltlicks, which contributed significantly to the GLIM model, was not strongly correlated to dung in the bi-variate correlation analysis. Combined parameters in general gave stronger explanatory effects for the wet season.

When the three seasonal models were applied to each test set that contained a different 20% of the data, slight differences resulted in the parameter estimate and SE values

(Table 4.8). The best three models and the best estimate values of the five test sets were selected out of 15 model test set combinations per season, to develop seasonal elephant distribution maps; by testing for their explanatory strength and for spatial auto-correlation.

Table 4.8. Dry season model 2 from GLIM analysis, applied to the five test sets

Test sets	Test set1		Test set2		Test set3		Test set4		Test set5	
	Scaled deviance	Residual df	Scaled deviance	Residual df	Scaled deviance	Residual df	Scaled deviance	Residual df	Scaled deviance	Residual df
NIL model	898	501	906	501	839	501	873	501	909	501
GLIM	500	488	560	488	562	488	584	488	596	488
	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
Constant	-8.588	2.745	-10.40	2.687	-6.976	2.530	-10.42	2.648	-11.52	2.862
Tim	-0.423	0.348	-0.789	0.389	-0.381	0.371	-2.481	0.714	-1.201	0.460
Ds	-0.0002	0.0001	-0.0003	0.0001	-0.0003	0.0001	-0.0002	0.0001	-0.0002	0.0001
Veg1*rain	0.710	0.271	1.060	0.299	0.554	0.286	1.045	0.269	1.117	0.342
Veg2*rain	0.751	0.203	0.936	0.198	0.591	0.186	0.878	0.195	0.947	0.211
Veg3*rain	-0.157	0.399	1.088	0.322	0.136	0.340	0.268	0.364	0.426	0.381
Veg4*rain	0.592	0.241	0.773	0.234	0.436	0.225	0.878	0.234	0.884	0.252
Veg5*rain	0.610	0.211	0.857	0.211	0.537	0.201	0.755	0.192	0.950	0.223
Veg1*rr	-0.015	0.007	-0.026	0.009	-0.014	0.008	-0.024	0.007	-0.027	0.010
Veg2*rr	-0.014	0.004	-0.018	0.004	-0.011	0.003	-0.016	0.003	-0.017	0.004
Veg3*rr	0.030	0.016	-0.025	0.011	0.011	0.013	0.015	0.014	0.009	0.014
Veg4*rr	-0.006	0.005	-0.011	0.005	-0.004	0.005	-0.015	0.005	-0.014	0.006
Veg5*rr	-0.011	0.004	-0.016	0.004	-0.010	0.004	-0.012	0.004	-0.018	0.005
Alt*aa	-6.3e-11	1.4e-11	-6.4e-11	1.3e-11	-3.8e-11	1.2e-11	-8.1e-11	1.4e-11	-5.9e-11	1.3e-11

4.3.2. Explanatory strength and spatial auto-correlation

The 15 model test set combinations per season, were applied to the training sets, namely the 80% data that was not used to develop the models, to obtain expected values for dung pile density. The expected observed dung pile densities were compared with observed values, and the percentage of correctly predicted densities represented the model explanatory strength (Table 4.9 and 4.10).

Table 4.9 shows that dry season model 1 explained on average 60.9% (range 59.2 – 63.8), model 2 explained 60.8% (range 58.5 – 63.9), and model 3 explained 60.8% (range 55.8 – 63.5) of the observed dung pile density of the training sets. There was very little variation in explanatory strength between models 1, 2, and 3. However, the parameter estimates obtained form GLIM analysis using test set 1, explained the training sets best, with 63.8%, 63.9%, and 63.5% for models 1, 2, and 3, respectively (Table 4.9). Model 2 on test set 1 gave the best results, explaining 63.9% of the observed dung pile density of the training set.

Table 4.9. Explanatory strengths of 3 dry season models (M1, M2 ,M3), applied to 5 training sets (TrS1, TrS2, TrS3, TrS4, TrS5)

M1 TrS1		Observed					
	N=2008	0	1	2	3	>3	Total
Expected	0	1124	124	31	10	12	1301
	1	294	122	56	42	43	557
	2	32	20	19	9	6	86
	3	1	4	5	0	3	13
	>3	9	6	10	9	17	51
	Total	1460	276	121	70	81	63.8%

M2 TrS1		Observed					
	N=2008	0	1	2	3	>3	Total
Expected	0	1126	124	32	12	14	1308
	1	292	122	55	39	41	549
	2	32	20	19	10	6	87
	3	1	4	5	0	3	13
	>3	9	6	10	9	17	51
	Total	1460	276	121	70	81	63.9%

M3 TrS1		Observed					
	N=2008	0	1	2	3	>3	Total
Expected	0	1116	122	34	10	14	1296
	1	315	132	61	45	44	597
	2	17	12	9	5	3	46
	3	3	4	7	1	3	18
	>3	9	6	10	9	17	51
	Total	1460	276	121	70	81	63.5%

M1 TrS2		Observed					
	N=2008	0	1	2	3	>3	Total
Expected	0	1053	98	21	5	8	1185
	1	352	143	67	35	36	633
	2	45	30	21	14	13	123
	3	7	5	7	3	6	28
	>3	8	5	5	9	12	39
	Total	1465	281	121	66	75	61.4%

M2 TrS2		Observed					
	N=2008	0	1	2	3	>3	Total
Expected	0	1053	99	22	4	8	1186
	1	350	142	67	36	36	631
	2	52	30	20	13	13	128
	3	3	5	7	3	6	24
	>3	8	5	5	9	12	39
	Total	1466	281	121	65	75	61.3%

M3 TrS2		Observed					
	N=2008	0	1	2	3	>3	Total
Expected	0	1045	91	21	5	6	1168
	1	358	154	69	36	38	655
	2	50	25	19	12	13	119
	3	5	6	8	3	4	26
	>3	8	5	4	9	14	40
	Total	1466	281	121	65	75	61.5%

M1 TrS3		Observed					
	N=2008	0	1	2	3	>3	Total
Expected	0	988	86	14	8	5	1101
	1	454	182	79	48	55	818
	2	10	13	8	4	4	39
	3	3	4	6	9	18	40
	>3	3	1	3	2	1	10
	Total	1458	286	110	71	83	59.2%

M2 TrS3		Observed					
	N=2008	0	1	2	3	>3	Total
Expected	0	994	82	16	8	3	1103
	1	450	186	77	48	57	818
	2	8	13	8	4	4	37
	3	3	3	6	7	16	35
	>3	3	2	3	4	3	15
	Total	1458	286	110	71	83	59.7%

M3 TrS3		Observed					
	N=2008	0	1	2	3	>3	Total
Expected	0	1064	103	19	9	6	1201
	1	381	169	74	50	54	728
	2	3	9	8	2	4	26
	3	3	5	7	8	19	42
	>3	3	0	2	2	4	11
	Total	1454	286	110	71	87	62.4%

M1 TrS4		Observed					
	N=2004	0	1	2	3	>3	Total
Expected	0	996	87	19	7	7	1116
	1	440	163	68	47	38	756
	2	11	21	19	10	17	78
	3	17	7	10	10	13	57
	>3	0	0	0	0	1	1
	Total	1464	278	116	74	76	59.2%

M2 TrS4		Observed					
	N=2004	0	1	2	3	>3	Total
Expected	0	982	88	19	7	6	1102
	1	453	161	67	46	39	766
	2	23	25	21	11	13	93
	3	6	4	9	10	17	46
	>3	0	0	0	0	1	1
	Total	1464	278	116	74	76	58.5%

M3 TrS4		Observed					
	N=2004	0	1	2	3	>3	Total
Expected	0	910	70	15	3	6	1004
	1	488	165	55	44	32	784
	2	54	36	35	17	18	160
	3	12	7	11	10	19	59
	>3	0	0	0	0	1	1
	Total	1464	278	116	74	76	55.8%

M1 TrS5		Observed					
	N=2004	0	1	2	3	>3	Total
Expected	0	1051	104	25	9	7	1196
	1	377	151	85	42	50	705
	2	21	16	13	2	6	58
	3	6	3	9	10	17	45
	>3	1	1	0	1	1	4
	Total	1456	275	132	64	81	61.1%

M2 TrS5		Observed					
	N=2004	0	1	2	3	>3	Total
Expected	0	1044	104	25	8	7	1188
	1	382	148	81	42	46	699
	2	22	18	17	4	10	71
	3	6	4	9	10	17	46
	>3	1	1	0	1	1	4
	Total	1455	275	132	65	81	60.8%

M3 TrS5		Observed					
	N=2004	0	1	2	3	>3	Total
Expected	0	1039	98	21	7	7	1172
	1	390	161	91	45	51	738
	2	20	11	11	2	5	49
	3	3	4	3	7	11	28
	>3	3	2	5	4	7	21
	Total	1455	276	131	65	81	61.0%

Table 4.10 shows that wet season model 1 explained on average 51.6% (range 50.2 – 53.7), model 2 explained 51.0% (range 50.1 – 52.4), and model 3 explained 53.2% (range 51.2 – 54.7) of the observed dung pile density of the training sets. Model 3 on test set 3 gave the best result, explaining 54.7% of the observed dung pile density of the training set (Table 4.10).

ROC curve analysis in SPSS suggested model strengths that were generally higher but it treated data as presence-absence (see Tables 4.13 and 4.14). The manual calculation of model strength takes the scaled factor of dung pile density into account, and is therefore more precise. Bi-variate correlation tests showed no significant correlation between ROC and manual model strength results, but there was a strong negative correlation between the manually calculated explanatory model strength and spatial auto-correlation of models (Pearsons correlation, Dry: -0.737, N = 15, P = 0.002; Wet: -0.749, N = 15, P = 0.001).

Table 4.10. Explanatory strengths of 3 wet season models (M1, M2 ,M3), applied to 5 training sets (TrS1, TrS2, TrS3, TrS4, TrS5)

M1 TrS1

N=1831		Observed 0	1	2	3	>3	Total
Expected	0	811	74	34	12	14	945
	1	402	148	66	36	65	717
	2	68	23	22	17	26	156
	3	8	2	0	3	0	13
	>3	0	0	0	0	0	0
Total		1289	247	122	68	105	53.7%

M2 TrS1

N=1831		Observed 0	1	2	3	>3	Total
Expected	0	789	81	32	9	12	923
	1	419	139	69	42	63	732
	2	63	25	20	17	28	153
	3	15	1	1	0	1	18
	>3	3	1	0	0	1	5
Total		1289	247	122	68	105	51.8%

M3 TrS1

N=1831		Observed 0	1	2	3	>3	Total
Expected	0	847	94	32	12	14	999
	1	344	109	68	36	51	608
	2	81	40	20	20	33	194
	3	17	4	2	0	7	30
	>3	0	0	0	0	0	0
Total		1289	247	122	68	105	53.3%

M1 TrS2

N=1831		Observed 0	1	2	3	>3	Total
Expected	0	760	80	33	10	10	893
	1	461	134	71	36	66	768
	2	59	27	23	11	31	151
	3	11	2	2	3	1	19
	>3	0	0	0	0	0	0
Total		1291	243	129	60	108	50.2%

M2 TrS2

N=1831		Observed 0	1	2	3	>3	Total
Expected	0	737	71	25	11	10	854
	1	493	149	84	35	77	838
	2	51	22	19	14	20	126
	3	10	1	1	0	0	12
	>3	0	0	0	0	1	1
Total		1291	243	129	60	108	49.5%

M3 TrS2

N=1831		Observed 0	1	2	3	>3	Total
Expected	0	843	88	28	11	10	980
	1	348	106	70	31	69	624
	2	98	49	28	18	27	220
	3	2	0	3	0	2	7
	>3	0	0	0	0	0	0
Total		1291	243	129	60	108	53.4%

M1 TrS3

N=1831		Observed 0	1	2	3	>3	Total
Expected	0	774	77	34	11	14	910
	1	476	156	84	48	86	850
	2	30	6	8	4	7	55
	3	7	4	2	2	1	16
	>3	0	0	0	0	0	0
Total		1287	243	128	65	108	51.3%

M2 TrS3

N=1831		Observed 0	1	2	3	>3	Total
Expected	0	800	84	36	14	15	949
	1	442	141	74	42	76	775
	2	45	18	18	9	16	106
	3	0	0	0	0	1	1
	>3	0	0	0	0	0	0
Total		1287	243	128	65	108	52.4%

M3 TrS3

N=1831		Observed 0	1	2	3	>3	Total
Expected	0	868	89	33	11	15	1016
	1	344	112	73	32	62	623
	2	68	38	20	20	25	171
	3	7	4	2	2	6	21
	>3	0	0	0	0	0	0
Total		1287	243	128	65	108	54.7%

M1 TrS4

N=1831		Observed 0	1	2	3	>3	Total
Expected	0	765	59	23	5	9	861
	1	432	136	78	36	54	736
	2	86	42	23	15	32	198
	3	12	4	6	5	9	36
	>3	0	0	0	0	0	0
Total		1295	241	130	61	104	50.7%

M2 TrS4

N=1831		Observed 0	1	2	3	>3	Total
Expected	0	753	59	21	3	9	845
	1	428	136	81	42	54	741
	2	114	46	28	16	41	245
	3	0	0	0	0	0	0
	>3	0	0	0	0	0	0
Total		1295	241	130	61	104	50.1%

M3 TrS4

N=1831		Observed 0	1	2	3	>3	Total
Expected	0	803	70	20	7	11	911
	1	343	111	82	32	54	622
	2	138	55	24	22	37	276
	3	11	5	4	0	2	22
	>3	0	0	0	0	0	0
Total		1295	241	130	61	104	51.2%

M1 TrS5

N=1832		Observed 0	1	2	3	>3	Total
Expected	0	774	64	28	6	10	882
	1	419	151	81	40	56	747
	2	87	34	21	23	32	197
	3	2	1	1	1	1	6
	>3	0	0	0	0	0	0
Total		1282	250	131	70	99	51.7%

M2 TrS5

N=1832		Observed 0	1	2	3	>3	Total
Expected	0	770	70	26	7	15	888
	1	429	141	83	41	50	744
	2	80	38	22	22	32	194
	3	1	0	0	0	1	2
	>3	2	1	0	0	1	4
Total		1282	250	131	70	99	51.0%

M3 TrS5

N=1832		Observed 0	1	2	3	>3	Total
Expected	0	837	85	28	10	16	976
	1	345	123	82	39	48	637
	2	88	35	17	20	31	191
	3	12	7	4	1	3	27
	>3	0	0	0	0	1	1
Total		1282	250	131	70	99	53.4%

Model spatial auto-correlation was calculated from the residuals of (Observed – Expected) dung pile density, versus X and Y geographic co-ordinates of transect segments. Although those parameters in the models were strongly spatially auto-correlated, the residuals of dry season model 2 on test sets 1, 3, and 5 (Tables 4.11), and the wet season model 3 on test sets 1, 3, 4, and 5 (Table 4.12) were not auto-correlated.

Table 4.11. Dry season spatial auto-correlation of the residuals of models 1, 2, and 3

	Test set 1		*Test set 2*		*Test set 3*		*Test set 4*		*Test set 5*	
Dry Season	*Moran's I*	*Norm. z*	*Moran's I*	*Norm. z*	*Moran's I*	*Norm. z*	*Moran's I*	*Norm. z*	*Moran's I*	*Norm. z*
Residuals M1	0.006	* 0.58	0.030	2.36	0.012	* 1.00	0.042	3.25	0.018	* 1.48
Residuals M2	0.006	* 0.56	0.029	2.30	0.012	* 1.02	0.043	3.34	0.017	* 1.41
Residuals M3	0.010	* 0.93	0.032	2.53	0.013	* 1.10	0.047	3.66	0.019	* 1.53
Veg	0.303	22.79	0.329	24.81	0.319	23.80	0.302	22.51	0.292	21.77
Tim	0.074	5.70	0.048	3.71	0.085	6.42	0.128	9.66	0.102	7.68
Ds	0.351	26.42	0.353	26.62	0.353	26.29	0.352	26.20	0.351	26.19
Alt	0.469	35.23	0.469	35.32	0.468	34.84	0.471	35.04	0.471	35.03
Rain	0.523	39.26	0.524	39.46	0.522	38.84	0.523	38.84	0.524	38.97
Cl	0.825	61.85	0.818	61.50	0.837	62.23	0.836	62.01	0.831	61.70
S	0.534	40.11	0.535	40.29	0.535	39.83	0.539	40.02	0.538	40.01
W	0.690	51.80	0.686	51.57	0.700	52.07	0.699	51.91	0.695	51.66

* Norm z < 1.96 are not spatially auto-correlated at $p < 0.05$

Table 4.11 suggests that for the dry season, the residuals of test set 1 were the least spatially auto-correlated (Moran's I = 0.006, z = 0.58), and tests of model explanatory strength showed that model 2 on test set 1 also best explained 63.9% observed dung pile density (Table 4.9). The MK dry season distribution map was therefore developed using the model 2, test set 1 combination.

Table 4.12 suggests that for the wet season, the residuals of test set 3 were the least spatially auto-correlated (Moran's I = 0.002, z = 0.90), and tests of model explanatory strength showed that model 3 on test set 3 also best explained 54.7% observed dung pile density (Table 4.10). The MK wet season distribution map was therefore developed using the model 3, test set 3 combinations.

Table 4.12. Wet season spatial auto-correlation of the residuals of models 1, 2, and 3

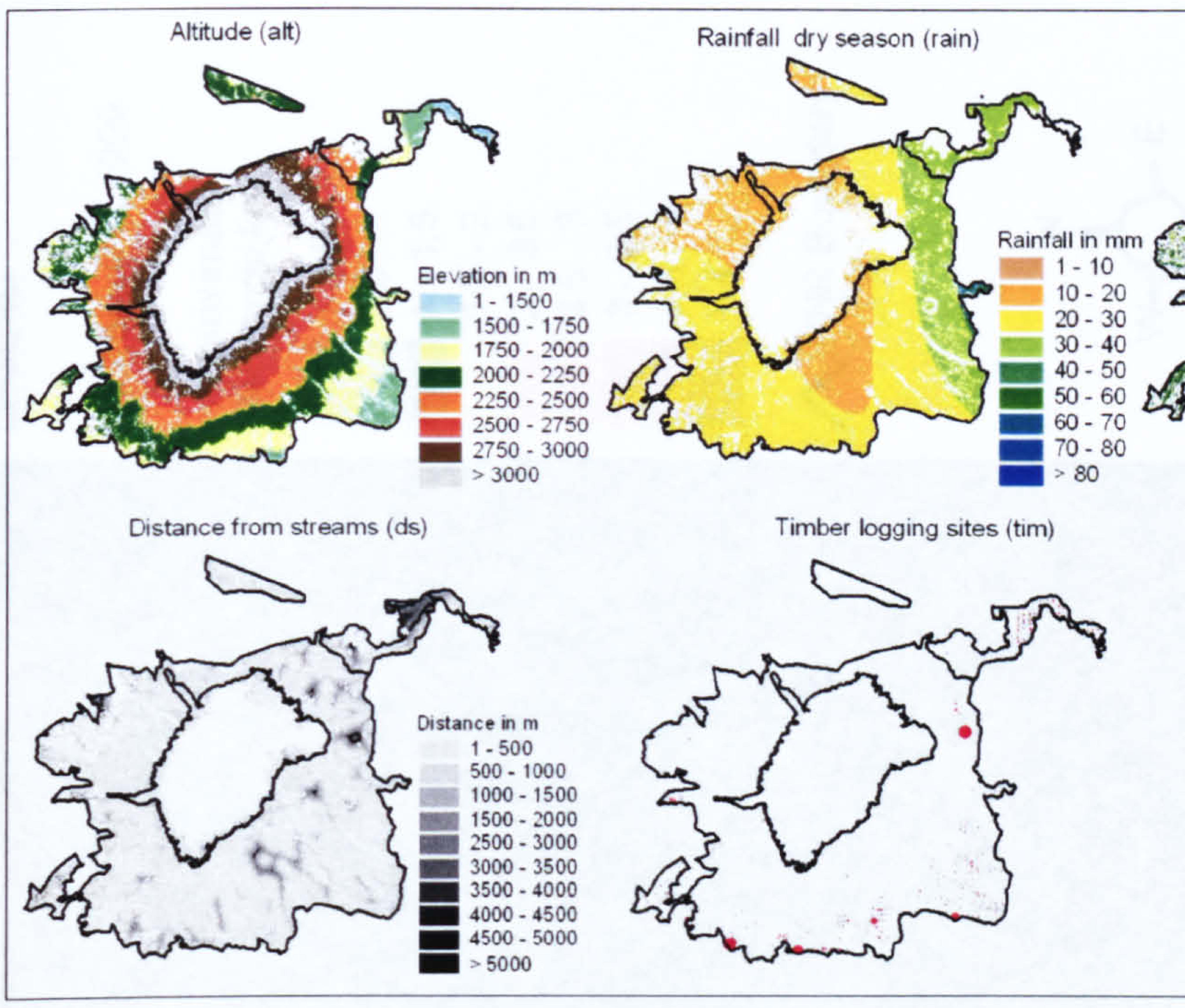
	Test set 1		*Test set 2*		*Test set 3*		*Test set 4*		*Test set 5*	
Wet season	*Moran's I*	*Norm. z*	*Moran's I*	*Norm. z*	*Moran's I*	*Norm. z*	*Moran's I*	*Norm. z*	*Moran's I*	*Norm. z*
Residuals M1	0.008	2.34	0.018	4.78	0.008	2.37	0.013	3.50	0.008	2.31
Residuals M2	0.007	2.12	0.017	4.61	0.007	2.23	0.013	3.62	0.010	2.78
Residuals M3	0.003	* 1.20	0.012	3.31	0.002	* 0.90	0.004	* 1.54	0.005	* 1.60
Veg	0.265	26.84	0.255	25.88	0.256	25.97	0.272	27.52	0.275	27.81
Sl	0.129	13.14	0.157	16.00	0.143	14.62	0.140	14.32	0.137	13.98
Alt	0.500	50.50	0.501	50.55	0.501	50.58	0.495	49.98	0.499	50.31
Rain	0.610	61.59	0.611	61.60	0.611	61.57	0.612	61.69	0.611	61.58
S	0.597	60.29	0.598	60.35	0.599	60.41	0.597	60.22	0.598	60.22

* Norm z < 1.96 are not spatially auto-correlated at $p < 0.05$

4.3.3. Creating elephant distribution maps

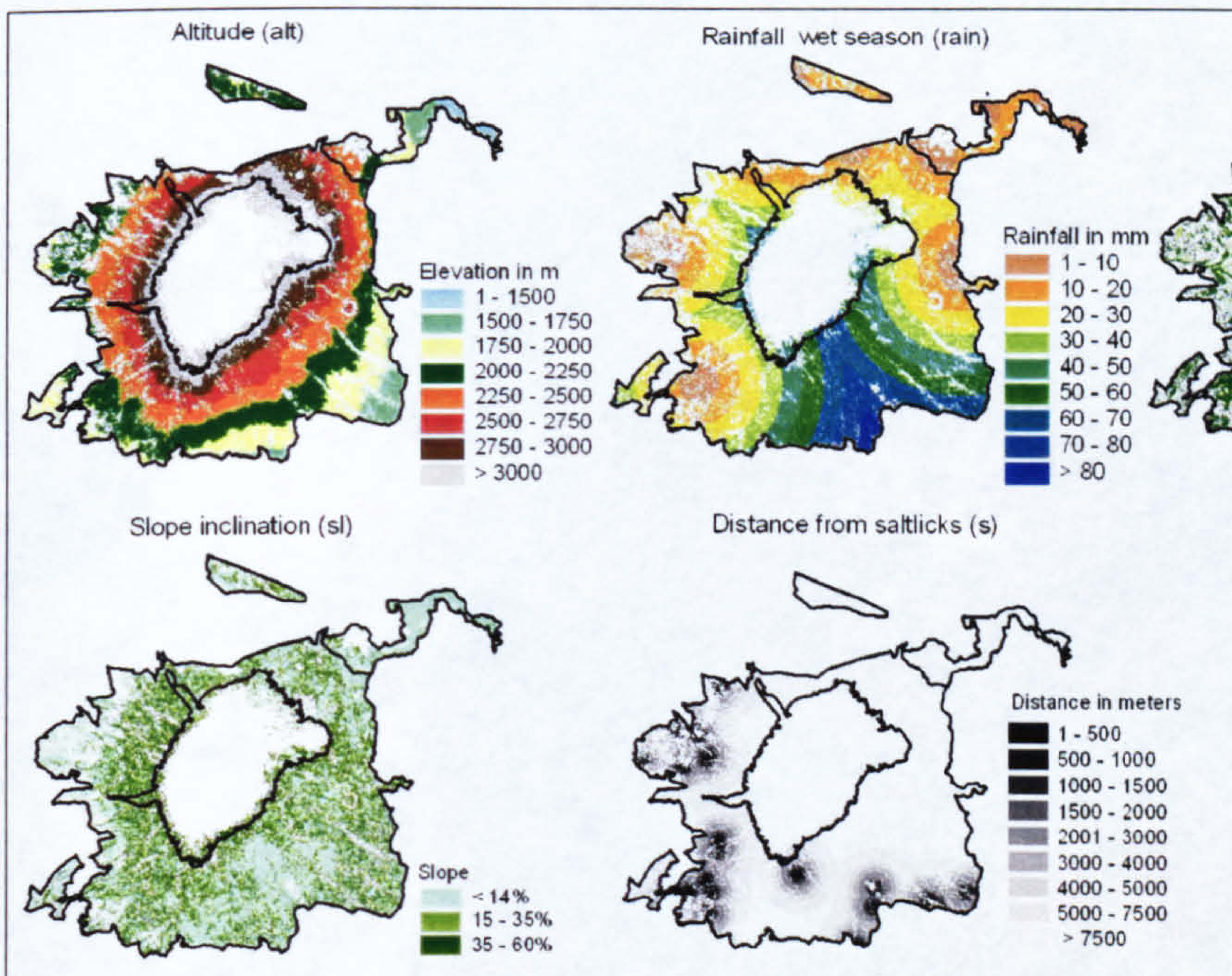
To develop the respective seasonal distribution maps from dry and wet season models, GIS layers were made for the all parameters in the models (Figures 4.4 and 4.5).

Figure 4.4. Main layers used in the dry season elephant distribution map



Estimate	s.e.	parameters
-8.588	2.745	Linear Constant
-.4225	.3480	tim
-.0002262	.0001056	ds
.7103	.2708	veg1*rain
.7509	.2028	veg2*rain
-.1568	.3993	veg3*rain
.5921	.2412	veg4*rain
.6098	.2107	veg5*rain
-.01480	.006736	veg1*rr
-.01425	.003633	veg2*rr
.03020	.01564	veg3*rr
-.006399	.005264	veg4*rr
-.01082	.004261	veg5*rr
-6.262e-11	1.360e-11	alt*aa

Figure 4.5. Main layers used in the wet season elephant distribution map



Estimate	s.e.	Parameters
-18.00	6.893	Constant
-.0003379	.0001026	s
3.291e-8	8.749e-9	ss
.01180	.005192	sl1*alt
.01150	.005027	sl2*alt
.01026	.005091	sl3*alt
-2.361e-6	9.655e-7	sl1*aa
-2.294e-6	9.076e-7	sl2*aa
-1.948e-6	9.737e-7	sl3*aa
-.1707	2.408	veg1*rain
.1372	.04477	veg2*rain
.1581	.03800	veg3*rain
.1823	.03982	veg4*rain
.1391	.04078	veg5*rain
.003137	.09751	veg1*rr
-.001185	.0004328	veg2*rr
-.001411	.0003746	veg3*rr
-.001620	.0003943	veg4*rr
-.001212	.0004254	veg5*rr

Visually, elephant distribution maps made from models of each of the five test sets per season, strongly resembled (Figures 4.7 and 4.9). However, elephant distribution maps between seasons, despite the similar parameters in models of both seasons, visually differed considerably (Figures 4.6 and 4.8).

Figure 4.6. Elephant distribution in the dry season, based on February 1999 data and using model 2 on test set 1

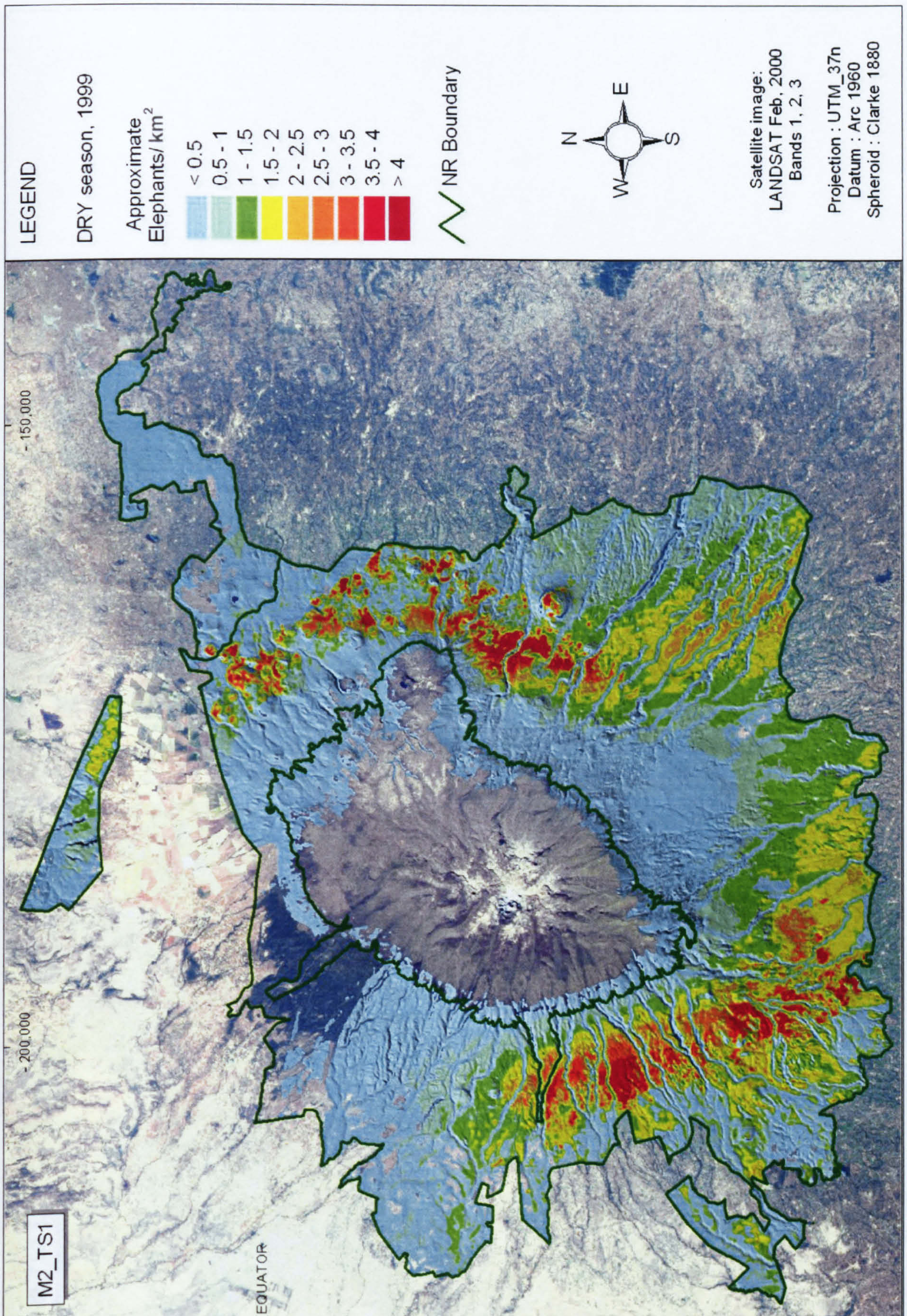
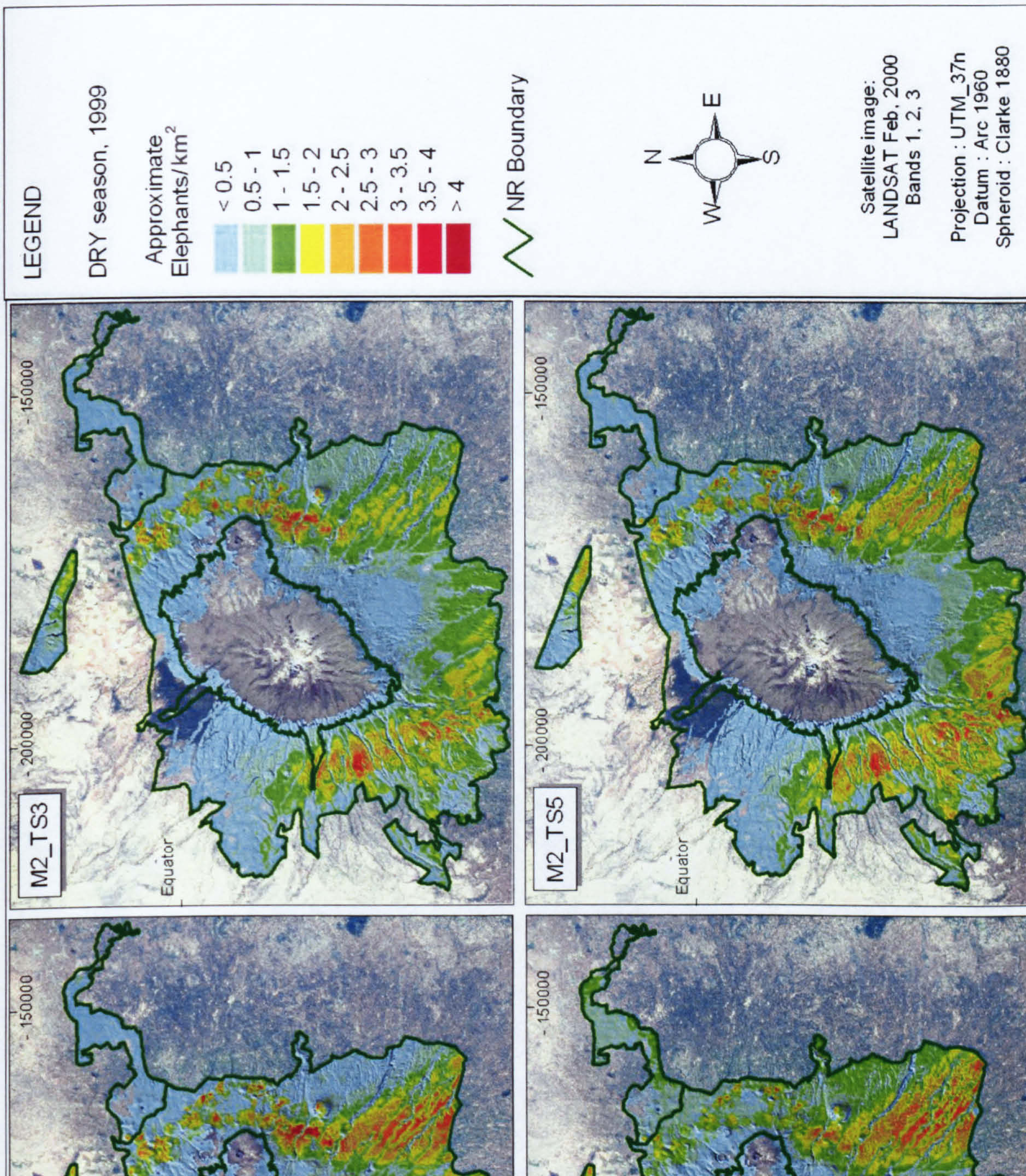


Figure 4.7. Elephant distribution in the dry season, based on February 1999 data and using model 2 on test sets 2, 3, 4, and 5



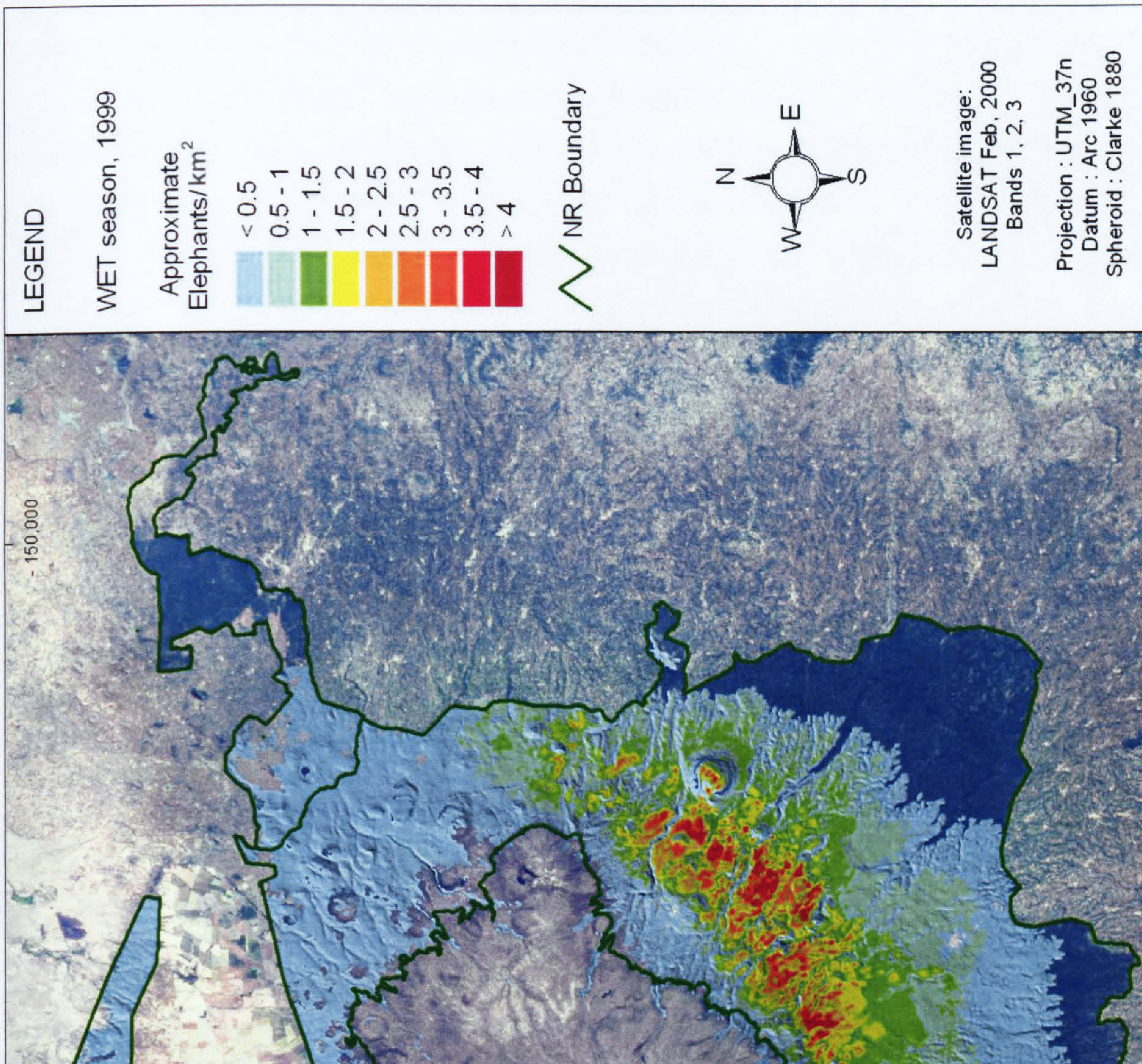
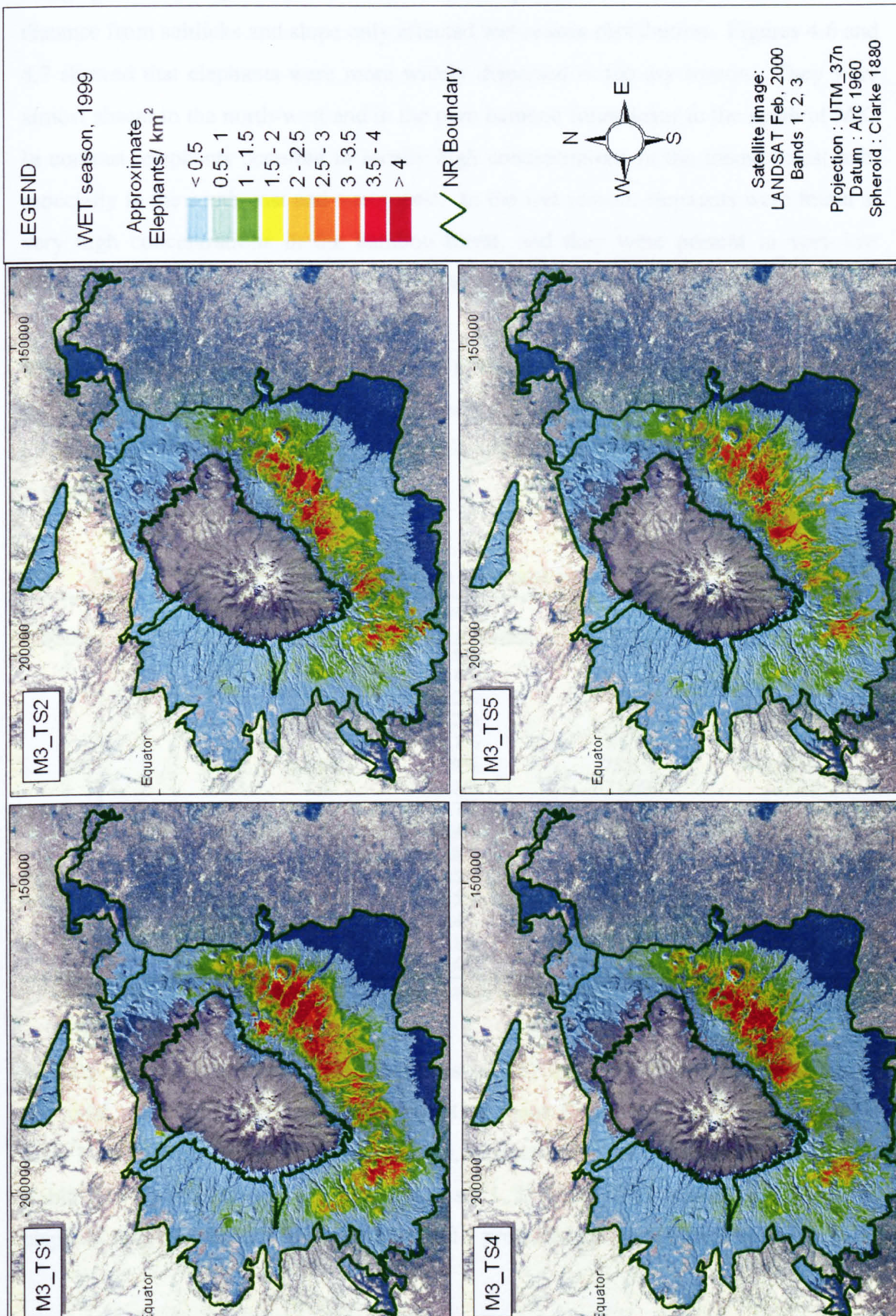


Figure 4.8. Elephant distribution in the wet season, based on May 1999 data and using model 3 on test set 3

Figure 4.9. Elephant distribution in the wet season, based on May 1999 data using model 3 on test sets 1, 2, 4, and 5



Logging activity negatively influenced elephant presence in the dry season, whereas distance from saltlicks and slope only affected wet season distribution. Figures 4.6 and 4.7 showed that elephants were more widely dispersed in the dry season. They were almost absent in the north-west and in the pure bamboo forest layer in the south of MK. In contrast, elephants occurred in locally high concentrations in the mixed forest belt, especially in the south-east and south-west. In the wet season, elephants were found at very high concentrations in the bamboo forest, and they were present in very low numbers on the lower slopes, especially in the south and south-east (Figure 4.8).

Because there was visually little difference in the seasonal models using the parameter estimates of the five different test sets (Figures 4.7 and 4.9), I tested whether estimated elephant density derived from those models would also be similar (Tables 4.13 and 4.14).

Table 4.13. Estimate of dry season elephant numbers from GIS maps

Model	*Test set*	*Elephant Estimate*	*Elephant Density*	**Manual Model* % explained	***ROC Model* % explained	*Spatial Auto-correlation z*
1	1	3381	1.68	63.8%	75.8%	0.58
1	2	3906	1.95	61.4%	71.7%	2.36
1	3	5570	2.78	59.2%	73.1%	1.00
1	4	6647	3.31	59.2%	75.3%	3.25
1	5	5865	2.92	61.1%	74.5%	1.48
2	**1**	**3278**	**1.63**	**63.9%**	**75.8%**	**0.56**
2	2	3763	1.87	61.3%	71.6%	2.30
2	3	3016	1.50	59.7%	73.8%	1.02
2	4	3496	1.74	58.4%	74.7%	3.34
2	5	3181	1.59	60.8%	74.7%	1.41
3	1	1911	0.95	63.5%	75.8%	0.93
3	2	2410	1.20	61.5%	71.4%	2.53
3	3	2468	1.23	62.4%	74.2%	1.10
3	4	2371	1.18	55.8%	74.7%	3.66
3	5	1750	0.87	61.0%	73.2%	1.53

* Manually calculated, and ** presence/ absence, of observed versus expected dung pile density

Density analysis suggested 2,413 elephants (±586) for 1999 (Table 3.4; Chapter 3). Seasonal models produced similar distribution maps (Figures 4.7 and 4.9), but there were large differences in elephant estimates, especially for the dry season (Table 4.13). Table 4.13 shows that only model 3 on test set 1, 2, 3, and 4 fall within the 2,413 ±586 elephant range for the dry season, and model 1 produced the largest over-estimate.

For the wet season, all but model 2 on test set 1 fell within the 2,413 ±586 range. Though generally lower in explanatory strength, the wet season density results varied much less between models and test sets, than the dry season results (Table 4.14).

Table 4.14. Estimate of wet season elephant numbers from GIS maps

Model	Test set	*Elephant Estimate*	*Elephant Density*	**Manual Model* % explained	***ROC Model* % explained	*Spatial Auto-correlation z*
1	1	2876	1.43	53.7	72.4	2.34
1	2	2376	1.18	50.2	69.2	4.78
1	3	2204	1.10	51.3	65.1	2.37
1	4	2435	1.21	50.7	70.7	3.50
1	5	2758	1.37	51.7	73.9	2.31
2	1	3209	1.60	51.8	73.6	2.12
2	2	2421	1.21	49.9	71.5	4.61
2	3	2239	1.12	52.4	67.3	2.23
2	4	2314	1.15	50.1	72.5	3.62
2	5	2526	1.26	51.0	68.5	2.78
3	1	2881	1.44	53.5	75.4	1.20
3	2	2425	1.21	53.4	73.0	3.31
3	**3**	**2198**	**1.09**	**54.7**	**67.8**	**0.90**
3	4	2501	1.25	51.2	73.7	1.54
3	5	2339	1.17	53.4	70.3	1.60

* Manually calculated, and ** presence/ absence, of observed versus expected dung pile density

4.4. DISCUSSION

The development of GIS's and the possibility of integrating explanatory models into a GIS, were a leap forward in assessing hazards and risks like droughts and floods for prevention and famine relief (Messerli, 1986; Ogola et al., 1997; Mati, 1999). Recognition of the potential of GIS in biodiversity management is apparent from the increasing number of studies that use GIS in their work, although GIS predictive modelling has only recently been used in elephant research (Sitati et al., 2003). However, GIS has not been used to predict elephant distribution in forests from line transect data analysis. For MK, data from some 150km surveyed line transects per season were analysed for this purpose.

4.4.1. Data analysis

The response variable of dung pile density and possible explanatory parameters were explored to determine their distribution and bi-variate correlations. Dung pile density followed a poisson distribution and instead of manipulating data to fit a normal distribution for linear regression analysis, a GLM analysis was used instead to establish explanatory models (Guisan et al., 2002; Thuiller et al., 2003). GLIM, a programme designed for GLM analysis (Crawley, 1993) was used to this purpose. GLIM requires the manual definition of every step in model building, and unlike other programmes, it forces users to develop a more critical approach to the model building process.

Bi-variate correlations showed that both dry and wet season dung pile density increased significantly with increasing rainfall and decreasing altitude. Dry season dung pile density also increased with proximity to streams, clearings, saltlicks, and water-holes. GLIM analysis suggested also that timber logging negatively affects dung density and that dung in bamboo forest was reduced. Unlike the dry season, wet season bi-variate correlation analysis showed that dung pile density decreased with increasingly steep slopes, and GLIM analysis suggested that dung increased with proximity to saltlicks. The wet season parameters generally explained dung much better when combined, for example vegetation*rain.

The main difference between the two seasons was that timber logging sites affected the distribution of dung piles in the dry season but not in the wet season. Furthermore, slope significantly contributed to explaining dung pile density in the wet season but not in the dry season. These results were not surprising because logging activity was much less pronounced during the rains, when cutting and transporting timber are difficult. However, thousands of hectares of forest on MK were impacted by logging (Gathaara, 1999; see Chapter 7), and this meant that the area occupied by elephants was greatly reduced in the dry season. That elephants avoided steep slopes in the wet season was also not surprising, as other studies have shown that forest elephants use routes of least resistance and avoid steep slopes when alternatives route are possible (Vanleeuwe and Gautier-Hion, 1998). When daily rains make clay soils in the forest very slippery and lush ground-vegetation is not limited to the steep terrain near rivers, walking along steep slopes would be an unnecessary risk.

Three slightly differing potential explanatory models emerged from GLIM analysis for each season. In all, 15 seasonal model test set combinations were made, and tests of model explanatory strength and spatial auto-correlation identified the most robust models. Depending on which of the five data test sets that the models were applied to per season, parameter estimates varied slightly.

4.4.2. Explanatory strength and spatial auto-correlation

Tests of spatial auto-correlation are important to avoid predicting erroneous relationships between species and their habitats (Vaughan and Ormerod, 2003). Some studies have tested the effect of spatial auto-correlation on model strength using simulations (Augustin et al., 1998; Dubin, 2003), and there are ways to correct for spatial auto-correlation, such as by using a coarser spatial resolution (Shekhar et al., 2002; Sitati et al., 2003). According to Legendre et al. (2002), spatial auto-correlation affects model strength only when both, model parameters, and the model response variable, are spatially auto-correlated.

The predictive strength of seasonal models for the 15 seasonal model test set combinations was tested manually, by comparing the residuals of dung (Observed-Expected) when applying model test sets to the remaining data that were not used to establish the models. All parameters in the MK models were very spatially auto-correlated. For example, logging is typically clustered in timber-rich mixed forest only, and values of altitude, rain, and values of distance (e.g. from streams, clearings, water holes) are by definition spatially clustered. Despite the strong spatially clustered parameters in the models, several of the 15 seasonal model residuals were not spatially auto-correlated. Therefore there was no need to correct for spatial auto-correlation. Like in other studies (Dubin, 2003), model strength and spatial auto-correlation were strongly correlated on MK (Dry: -0.737, $P = 0.002$; Wet: -0.749, $P = 0.001$).

4.4.3. Creating elephant seasonal distribution maps

Through tests of model strength and spatial auto-correlation, the best performing model per season was selected to develop seasonal distribution maps. Although the seasonal models both included the variables of altitude, rain and vegetation, dry and wet season distribution maps were visually very different. In the dry season, elephants were more widely dispersed, with the highest concentrations at lower altitudes. In the wet season, they were highly concentrated at middle elevations and almost absent at low altitudes.

In contrast to distributions between seasons, the distribution maps within seasons, using models derived from different test sets, looked very similar. The difference between models lay in spatial auto-correlation and associated model strength, and variation was greater between test sets than between models, especially for the dry season.

Exploring whether these models could also be used to extrapolate elephant density, the assumption was made that the 50m transects segments used in analysis had a fixed strip-width of 2.5m*2 (250m^2). This allowed converting dung distribution values per image pixel of 900m^2 (30x30m) to relative dung density and in turn to elephant density "E". Although not exact, this allowed comparison of the estimated relative "E's" between the 15 seasonal model test set combinations. Compared with the actual density estimate for 1999 of 2,413 ±586 (Chapter 3), the relative estimated "E's" for the wet season model test set combinations lay much closer to the actual "E" and varied less between model test set combinations (range 2,198 – 3,209) than the dry season estimates of relative "E's" (range 1,750 – 6,647). The estimated wet season model results of 2,198 lies very close to the actual "E" estimate for 1999. Hence, creating explanatory models based on strip transect data could well allow "E" to be estimated from distribution maps.

More tests are needed to adapt distribution models to estimates of "E" and to enable identifying very erroneous estimates of "E", because tests of model strength and spatial auto-correlation showed no correlation with the "E's". Meanwhile, mapping species distribution using explanatory models remains an excellent tool to identify and to monitor poor visibility environments. Considering the rapidly shrinking natural forest habitat of elephants, this is a task that is rightly considered a priority in biodiversity conservation (Sanderson et al., 2002; Moore et al., 2003). For MK, the maps can help the relevant institutions to better manage the MK National Reserve, to decide about siting of fences, and to argue for or against allocation of land for various purposes.

4.5. CONCLUSION

Successful management of environment-species relationships require an understanding of the underlying explanatory factors (Vaughan and Ormerod, 2003). Studies of environment-species relationships in forests are often considered of poor quality because of the use of indirect survey methods, which are prone to bias (Buckland et al., 2001; Blanc et al., 2003). However, it has become apparent with time that line transect data can produce more reliable species density results than aerial counts when implemented with accuracy (Barnes, 2002). Analysis in this chapter also suggest that explanatory models from line transect data can function to map species distribution in forests, given the selection of the appropriate analytical models and tests of model robustness.

To prevent line transect analysis producing erroneous explanatory models, data should ideally not be transformed to fit the normal distribution criteria for linear regression, when alternative tests like GLIM analysis have been designed to deal with non-normally distributed data (Crawley, 1993; Guisan et al., 2002). Tests of spatial auto-correlation of models and parameters of data used in the analysis help to identify model strength and robustness (Dubin, 2003). GIS in turn has the power to integrate explanatory models derived from small sampled areas (line transects) and to extrapolate results to large non-sampled areas. Advanced predictive seasonal elephant distribution maps were developed for MK and were shown to be a powerful tool to improve our knowledge of elephants in forests. Furthermore, results of this chapter suggest that with some adaptations, the distribution maps could also be used to establish elephant numbers.

Maps of elephant distribution are easier for managers to interpret than theoretical models. For MK, maps of the elephant-environment relationships will help to control the area, to plan the siting of low-impact areas for fences, and to discuss or dispute wanted or unwanted allocation of forest land for human uses, such as for settlement, farmland, or for tree plantations. The relationship between elephants and people is one of conflict, which can largely be explained by spatio-temporal patterns of human and elephant land-use (Hoare, 2000; Harcourt et al., 2001; Sitati et al., 2003). In the following chapters the maps are used to locate elephant travel routes and foraging paths, to examine elephant impact on tree plantations inside the MK National Reserve (Chapter 5), and elephant impact on croplands around MK (Chapter 6).

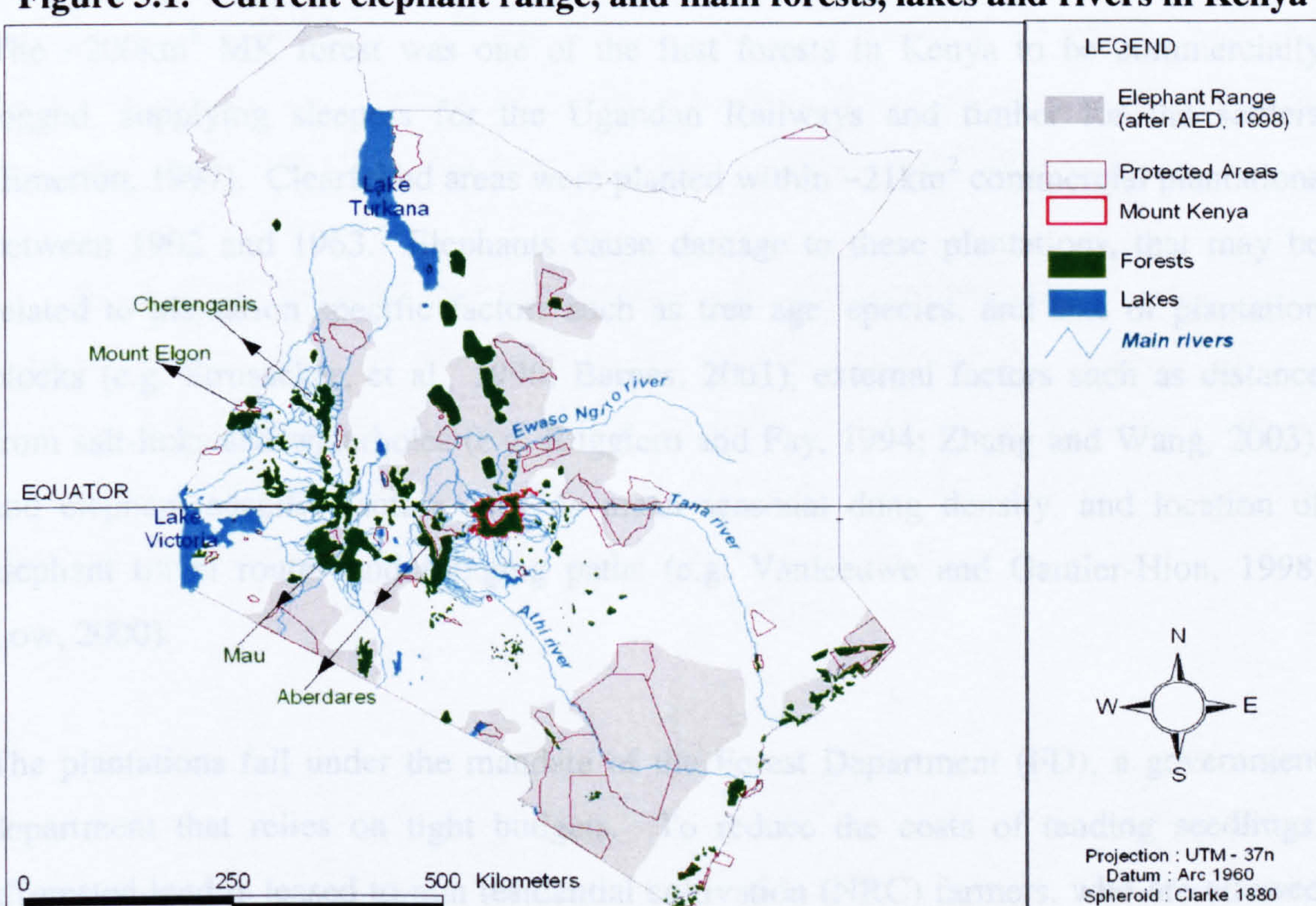
Chapter 5

ELEPHANT RANGING BEHAVIOUR AND TREE DAMAGE

5.1. INTRODUCTION

The relationship between carrying capacity of different habitats, and wildlife density and movements, determines the stability of ecological systems (Onyango et al., 1997; Seydack et al., 2000; Harcourt et al., 2001). Elephants play a key role in structuring environments they inhabit, whether in a positive way through seed dispersal, nutrient cycling and creating waterholes (Viljoen 1989; Hawthorne and Parren, 2000; Cochrane, 2003; Nchanji and Plumptre, 2003), or in a negative way by over-using resources (Ben-Shahar, 1998; Barnes 2001; Pamo and Tchamba, 2001; Calenge et al., 2002). To perform as complete ecological units, areas must be able to accommodate wide-ranging species. Expansion of human habitats has made such areas very scarce, and protecting movement corridors between fragmented wildlife habitats before they become settled, is important to maintain ecosystem functions (Clevenger et al., 2002; Moore et al., 2003; Williams et al., 2003). Accordingly, studies have tried to model least-cost travel of wildlife (Bunn et al., 2000; Ray et al., 2002; Russell et al., 2003). In Kenya today, elephants are found in 26 range fragments (Figure 5.1), of which the 44,732km^2 Mount Kenya - Northern Grazing Area (MK-NGA) fragment is the largest (Sitati, 2003).

Figure 5.1. Current elephant range, and main forests, lakes and rivers in Kenya



Elephant numbers on Mount Kenya (MK) were estimated at 2,911 ±640 in 2001 (Chapter 3). During the dry season, elephants were mainly found on the lower slopes, and in the wet season they were more concentrated at mid-elevations (Chapter 4). In the past, elephants moved freely between MK and the Aberdares mountain range (west of MK) using a straight route from south-west MK, and between MK and the NGA's, using two main routes. One of the MK-NGA routes goes from the north of MK via the Ngare Ndare forest, to the NGA's or to the Aberdares. The other route runs from the north-east via the Imenti and Mukugodo forests, to Samburu and Meru National Parks, which are located in the NGA's. There is no evidence that the south-west route is still active today, but data from GPS-collared elephants confirm the use of the two other routes that connect MK to the NGA's. These last two movement routes are under threat of becoming cut off completely by expanding agriculture. Although the MK elephants are threatened with isolation, nothing is known of their ranging behaviour, movements, or their impact on their almost confined natural habitat.

This chapter seeks to identify movements and ranging behaviour through digital tracing of least-cost travel routes, and to explore all aspects of elephant impact on trees that were surveyed within 626 plantation blocks situated within the MK indigenous forest. The ~200km^2 MK forest was one of the first forests in Kenya to be commercially logged, supplying sleepers for the Ugandan Railways and timber for the settlers (Emerton, 1997). Clearfelled areas were planted within ~21km^2 commercial plantations between 1902 and 1963. Elephants cause damage to these plantations, that may be related to plantation specific factors such as tree age, species, and size of plantation blocks (e.g. Strusacker, et al., 1996; Barnes, 2001), external factors such as distance from salt-licks and waterholes (e.g. Ruggiero and Fay, 1994; Zhang and Wang, 2003), and elephant specific factors such as mean seasonal dung density, and location of elephant travel routes and foraging paths (e.g. Vanleeuwe and Gautier-Hion, 1998; Low, 2000).

The plantations fall under the mandate of the Forest Department (FD), a government department that relies on tight budgets. To reduce the costs of tending seedlings, afforested land is leased to non residential cultivation (NRC) farmers, who are allowed to grow crops until seedlings outgrow crops, in return for tending seedlings at their most vulnerable growth stage (Gathaara, 1999). By 2002, there were about 700 paid FD employees at the 16 forest stations (Hoft, 2002), with whose cooperation, I was able to allowed to survey elephant damage at six stations simultaneously. The survey data are used to establish the explain which factors determine tree damage by elephants through investigation of the following questions:

- What tree species and tree ages are found in the tree plantations, and what tree species and tree ages are damaged by elephants, according to survey reports?
- Which factors determine the location of elephant travel routes and foraging paths and where are routes and paths located in relation to plantations?
- Which factors best explain the extent of tree damage by elephants, as determined through multivariate analysis of factors that characterise trees in plantations, environmental factors, and factors determining elephant distribution and movement?

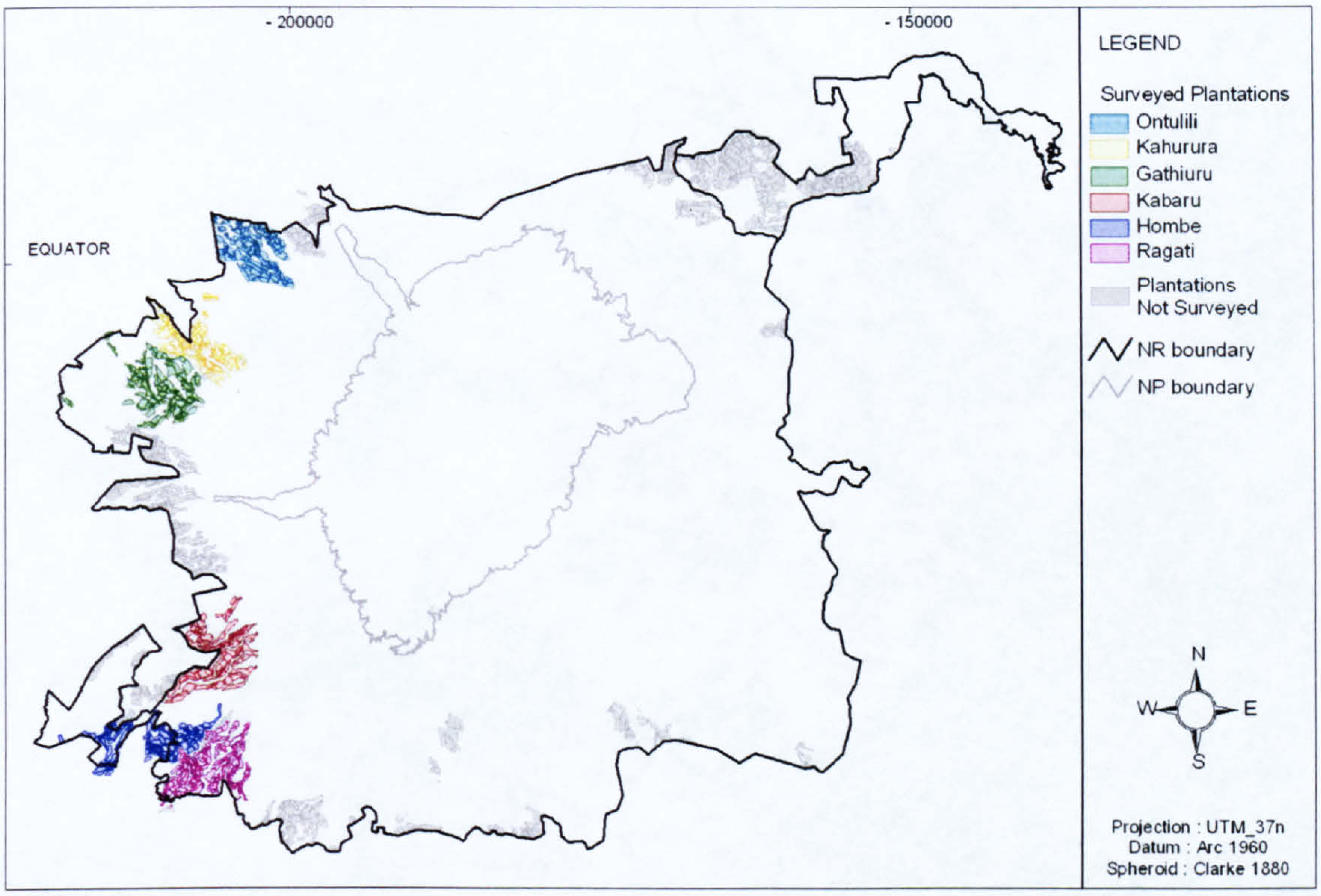
5.2. METHODS

The patterns and extent of destruction of trees by elephants was surveyed at six forest stations between February 2002 and February 2003. "Least-cost" elephant routes and paths were traced, linear regression models were used to explain elephant tree damage, and spatial auto-correlation tests were conducted to define model robustness.

5.2.1. Establishing tree composition in tree plantations

Several hundred blocks of plantation forests on MK fall under the charge of 16 FD stations. Tree plantations comprise 20% of the forest cover in the west and the north, as opposed to only 4% in the south and 0.1% in the east of MK (Kohler, 1986). The surveyed plantation blocks fall under six stations on the west (Figure 5.2).

Figure 5.2. Location of tree plantations under 16 FD stations on MK, highlighting the six surveyed plantations on the west of MK



All stations have 1:10,000 scale maps showing the plantation blocks covered by their station, with the dates of tree planting and clearfelling, the block-identification codes, the size of blocks in hectares and the tree species planted. These maps were digitised and geo-referenced in the geographical information system or GIS ArcGIS.

5.2.2. Field monitoring of elephant damage to tree plantations

Foresters, assistant foresters and field personnel were involved in monitoring fresh elephant damage at each surveyed forest station, although it was mainly field personnel who filled out the specially designed elephant damage data forms. The forms for each station had a map with block ID codes to help field staff identify sites of damage (Figure 5.1). The study used the fixed plantation block ID codes with which field personnel were familiar. For all damaged trees, the day, month, and year of observed fresh damage was recorded to allow allocating extent of damage per season. Also the location of damage (block ID), the species and date of planting of the damaged tree, and the type and extent of damage, were recorded on the back page of the elephant damage form (Table 5.1).

Figure 5.3. The front page of the elephant damage form for Gathiuru station, showing ID's assigned to plantation blocks by the FD

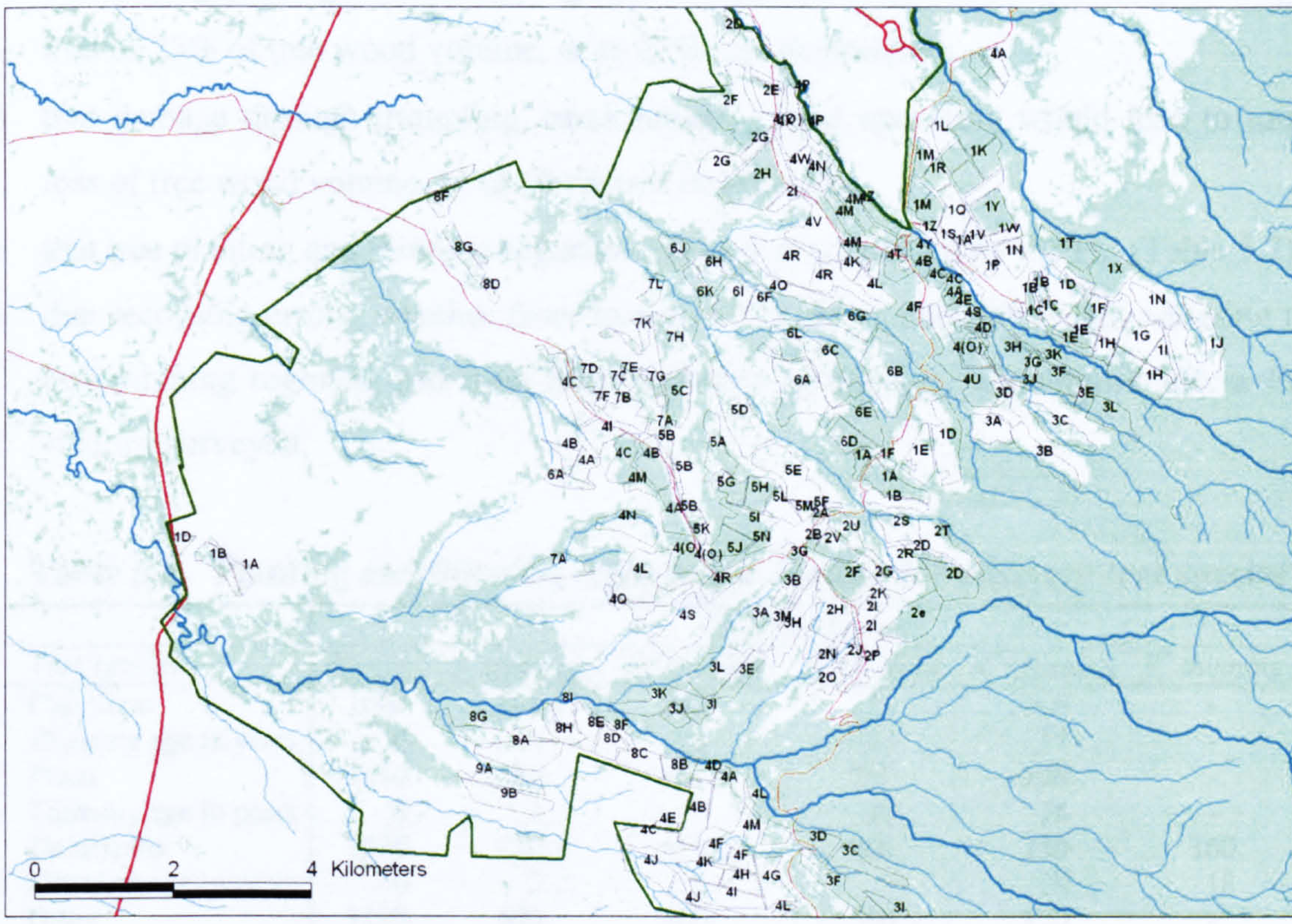


Table 5.1. A partially filled back page of an elephant damage form

Date of Report	*Block ID*	*Tree Species*	*Date of Planting*	*Type of damage BS, BB, TB, U, Tr*	*Extent of damage # trees, acres, ha,*	*Comments*
19/03/02	4C	*Cupressus*	*1989*	BS and BB	3 trees	2 elephants seen
22/03/02	2D	*Pinus*	*2002*	TR	0.5 ha	
26/04/02	2D	*Pinus*	*2002*	TR	20 seedlings	
26/04/02	3B	*Eucalyptus*	*1981*	BS	1 tree	
26/04/02	4C	*Cupressus*	*1989*	BB	1 tree	
...	...	...	...	...	...	...

BS-bark stripping; BB-branch breaking; TB-trunk breaking; U–uprooting, Tr-trampling

If several trees of the same species and the same age adjacent to one another, had the same type and extent of damage, such as for example 20 trampled seedlings, then this was recorded as one incident. On the other hand, the analysis of damage considered the numbers of damaged trees or seedlings, rather than of incidents.

To compare the proportion of trees that were destroyed between stations, the size of plantation blocks, and tree damage, were converted to "relative" (as opposed to real) numbers of trees. For this purpose, the following assumptions were made:

- that there was no double counting of damaged trees;
- that damage through bark stripping and branch breaking would lead to an average loss of 25% of tree wood volume, or to 25% tree destruction;
- that damage through trampling, trunk-breaking, and uprooting would lead to total loss of tree wood volume, or to 100% tree destruction;
- that tree planting and thinning regimes occurred as scheduled by the FD (Table 5.2);
- that recording errors, whether from incorrect FD information, from not adhering to tree thinning regimes, and from more variation in damage, was similar across FD stations surveyed.

Table 5.2. Planting and thinning regimes per hectare for different tree species

	Trees per hectare					
Tree species	*Planting*	*1st thinning*	*2nd thinning*	*3rd thinning*	*4th thinning*	*5th thinning*
Cupressus	1600	888	533	353	266	-
Thinning age in years	0	6	11	15	17	-
Pinus	1110	600	400	250	170	-
Thinning age in years	0	3	5	10	15	-
Eucalyptus	1320	850	600	400	250	160
Thinning age in years	0	3	6	9	10	18
Other	1110	600	400	250	170	-
Thinning age in years	0	3	5	10	15	-

Source: FD for *Cupressus, Pinus, and Eucalyptus*

5.2.3. Predicting elephant routes and GIS generated parameters

Elephants are known to forage on less used routes, and to travel on more regularly used routes (e.g. Vanleeuwe and Gautier-Hion, 1998). Therefore, I sought to map these routes on MK digitally in order to help explain patterns of tree damage. Mapping these routes required a combination of data on elephant distribution, and topography, as well as remotely sensed data on possible barriers to movement, all discussed previously in Chapter 4. In order to map foraging paths and travel routes, I used the modules COST and PATHWAY in Idrisi32. The steps require to produce these maps were as follows:

- to identify targets, from which target images are made, and between which routes were drawn;
- to define friction surface images for both dry and wet seasons;
- based on the target images and the friction surface images, to create cost surface images for each target for both dry and wet seasons;

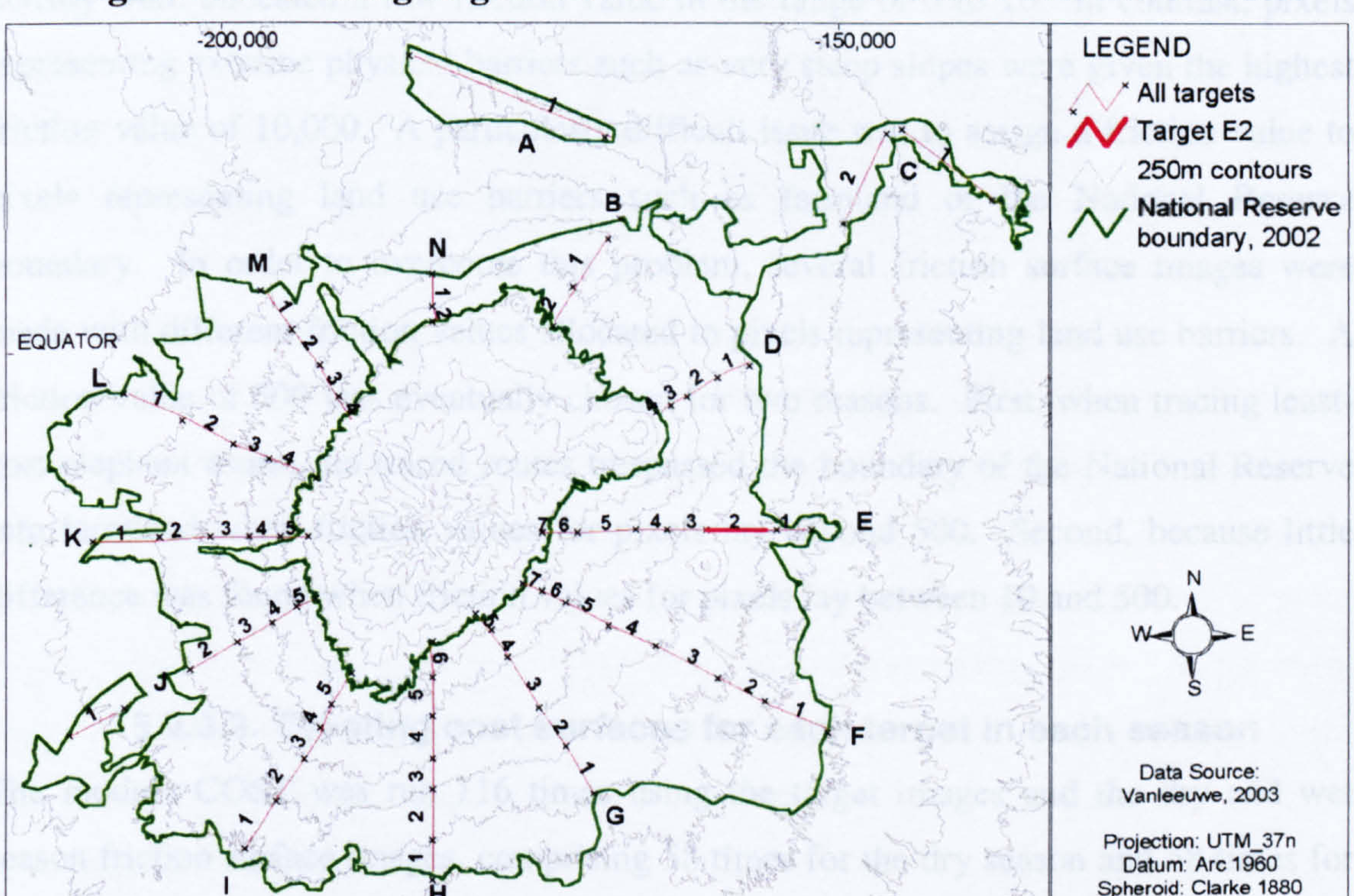
- based on the cost surface images and the remaining targets, to trace paths of least resistance to every other target for both dry and wet seasons; and,
- based on paths of least resistance, to define foraging paths and travel routes for both dry and wet seasons, which are the dependent variables required for an analysis to best explain tree damage.

All the images used for each of these steps were raster images of 30m resolution, meaning that they comprised square image pixels, each representing 30x30m on the ground. I now describe each of these steps in more detail.

5.2.3.1. Identifying targets

Using the module COST, I identified 58 targets below 3,500m asl and above the lower National Reserve boundary, using two steps. First, I superimposed 12 lines onto the mountain surface as in a clock, as well as placing one line in the Ngare Ndare forest and two lines in the Imenti forests. Each line was assigned a letter from A to N (Figure 5.4). Second, I sub-divided each line into 250m segments between the 250m contours. Each 250m segment was assigned a number starting from 1 on each line (Figure 5.4).

Figure 5.4. Defining targets between which to trace least-cost travel routes



Therefore, each of the 58 targets was identified by a letter followed by a number, as shown for E2 (Figure 5.4). For each of the 58 targets, a "target image" was made, in which the target carried image pixels with a value of 1 and the remaining pixels in the image carried a value of 0.

5.2.3.2. Defining seasonal friction surface images

To use in the module COST, I next made seasonal friction surface images. To do so, I predicted that the following factors would influence elephant movement:

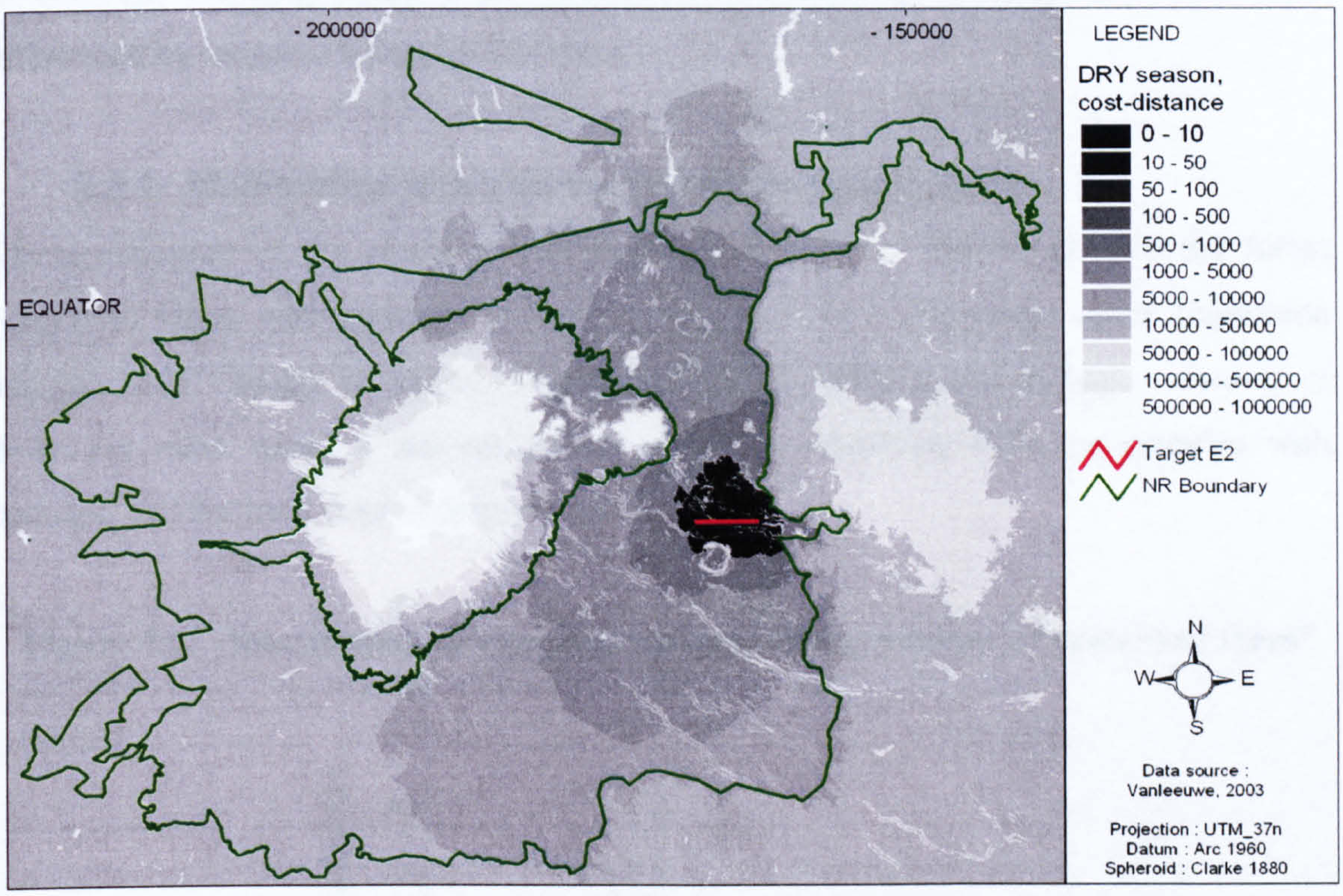
- preferred habitats in different seasons (Chapter 4);
- physical barriers such as extreme slopes, rivers and fences; and,
- land use barriers such as farmland, and the National Reserve boundary.

Each pixel in friction surface images was allocated a friction value that ranged from a minimum of 0 to a maximum of 10,000. A value of 0 represented no friction and no resistance to movement. In contrast, a value of 10,000 represented extreme friction or a total barrier to elephant movement. In order to determine preferred habitats, the seasonal distribution maps of elephants were reversed. Pixels with the highest dung density were allocated a low friction value in the range of 0 to 10. In contrast, pixels representing extreme physical barriers such as very steep slopes were given the highest friction value of 10,000. A particularly difficult issue was to assign a friction value to pixels representing land use barriers such as farmland or the National Reserve boundary. In order to overcome this problem, several friction surface images were made with different friction values allocated to pixels representing land use barriers. A friction value of 500 was eventually chosen for two reasons. First, when tracing least-cost elephant routes, no traced routes trespassed the boundary of the National Reserve into farmland when friction values for pixels lay beyond 500. Second, because little difference was found when friction values for pixels lay between 10 and 500.

5.2.3.3. Creating cost surfaces for each target in each season

The module COST was run 116 times using the target images and the dry and wet season friction surface images, comprising 58 times for the dry season and 58 times for the wet season, to create a total of 116 cost surface images. The value of the cost surface for each pixel was derived by multiplying distance from the target with the seasonal friction surface images. This combined cost from seasonal friction surfaces and distance from the target was called "cost-distance" (Figure 5.5). Thus, a distance of 100km from the target over seasonal friction surface pixels of 10,000 per pixel, could result in the maximum cost-distance of 1million (Figure 5.5).

Figure 5.5. One of 116 cost surface images, made from target E2 and the dry season friction surface image



5.2.3.4. Tracing paths of least resistance

In order to trace least-cost routes over cost surface images for each season, the module PATHWAY was run 58*58 times, departing from each of the 58 targets, to each of the 57 remaining targets. This process resulted in the tracing of 3,364 least-cost routes for each season. For the 58 seasonal route images, a value of 1 was allocated to pixels representing routes, and a value of 0 was allocated to the remaining pixels. In the event, many of these routes overlapped in each season. The image calculator was used to add routes together to locate areas of route-overlap and to distinguish the more, from the less frequently, used routes.

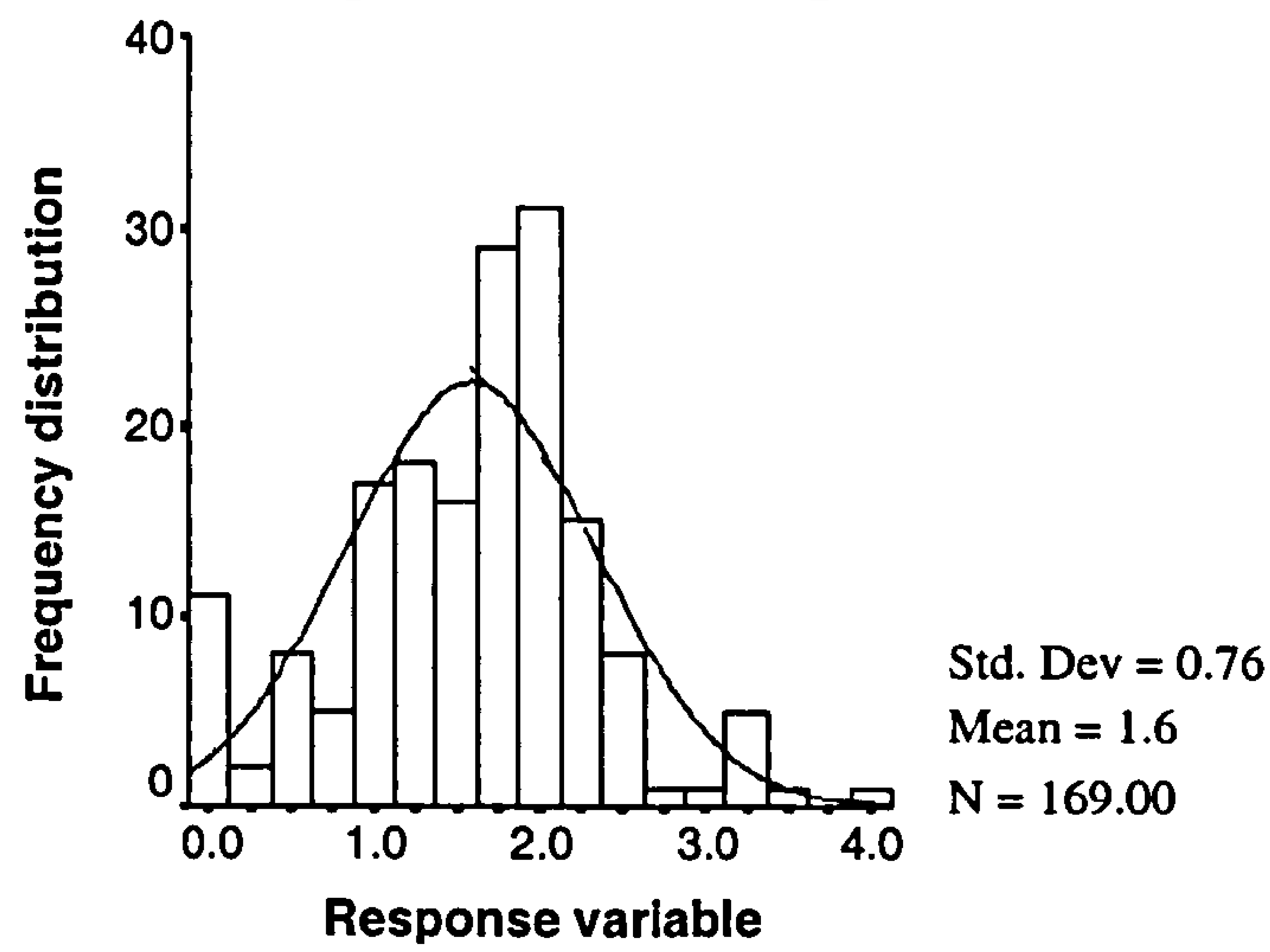
5.2.3.5. Defining travel routes and foraging paths

As a result of adding routes together, it was possible to distinguish two categories of route, namely those that overlapped over 100 times, and those that did not overlap or overlapped less than 10 times. Only a few (<10%) routes overlapped between 10 and 100 times. Based on this clear distinction, the routes that overlapped over 50 times were called "travel routes", while those that overlapped less than 50 times were called "foraging paths". Travel routes would typically be located between steep valleys, which would channel movement, resulting in the strong overlap of routes in these areas. In contrast, foraging paths were assumed to be used for foraging and were more influenced by seasonal habitat preferences.

5.2.4. Multivariate analysis and other statistical tests

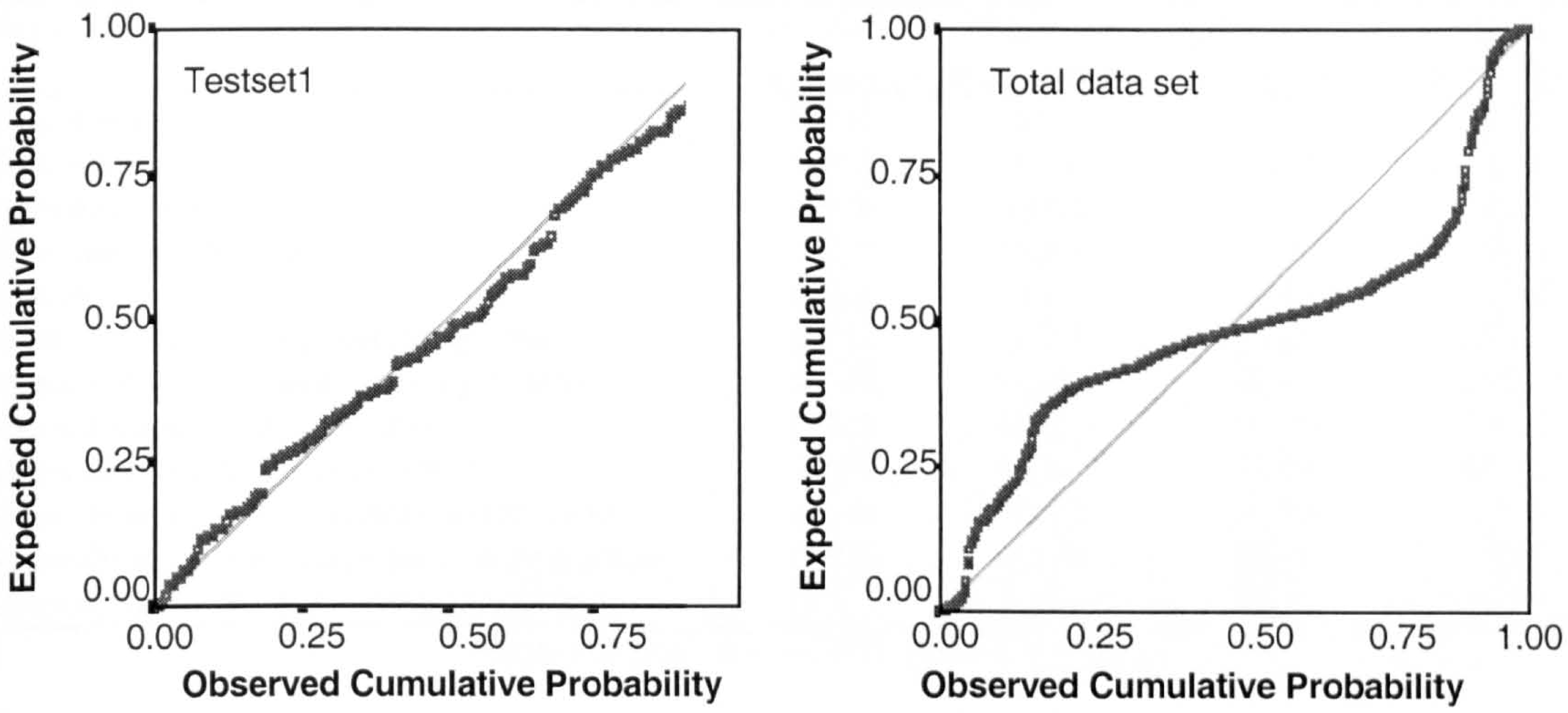
The distribution of the response variable $\log_{10}$ number of destroyed trees per forest plantation block was normally distributed (Figure 5.6). Therefore, linear regression analysis was chosen to create models to explain differences in $\log_{10}$ number of destroyed trees, using a test set named testsetl, comprising only the samples with damage, and the total dataset (Figure 5.7).

Figure 5.6. Distribution of response variable "$\log_{10}$ number of destroyed trees"



Linear regression models explained 44% of variance in $\log_{10}$ number of destroyed trees for testsetl ($R^2 = 0.443$, df = 162, $P < 0.05$) and 68% of variance for the total dataset ($R^2 = 0.682$, df = 162, $P < 0.05$). However, the residuals for testetl were more robust than those for the total dataset (Figure 5.7).

Figure 5.7. Modelled residuals for $\log_{10}$ number of destroyed trees using testset1 and the total dataset, based on observed – expected values



Models were tested for spatial auto-correlation, expressed as a Morans' I index value with associated normality significance z (Norm z). Norm z values need to be less than 1.96 to infer a lack of spatial auto-correlation at $p < 0.05$ (see Chapter 4). Both models were spatially auto-correlated (testset1: Moran's I = 0.03, Norm z = 1.99; the total dataset: Moran's I = 0.04, Norm z = 7.63).

Spatial auto-correlation indicates spatial clustering of samples used in analysis and affects model robustness and strength. Using a lower density or coarser resolution may solve the problem of high spatial auto-correlation (Lesage and Pace, 2001; Shekhar et al., 2003). However, a new test set, namely testset2, was created comprising 200 randomly selected samples, of which 100 out of 311 blocks had suffered elephant destruction, and 100 out of 315 blocks had not suffered elephant destruction.

Explanatory variables tested in the model comprised: tree species; tree age; plantation block size; total number of trees; season with most damage; mean dry and wet season dung density; mean distance from salt-licks; mean distance from water holes; mean distance from elephant travel routes; mean distance from foraging paths; and mean distance from all routes and paths combined. Also $\log_{10}$ parameter values were tested in the models. All parameters, but for plantation block size, were spatially auto-correlated (Table 5.3).

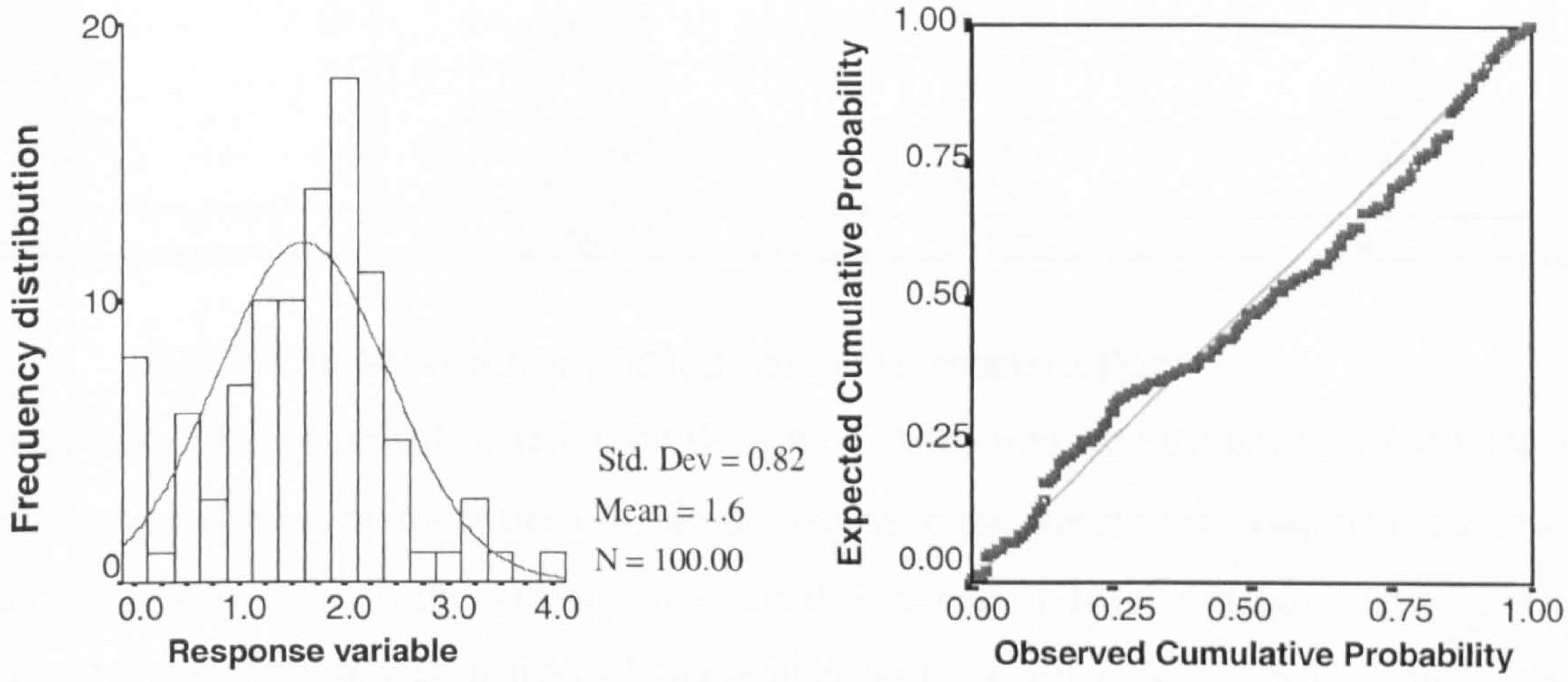
Table 5.3. Spatial auto-correlation of parameters in linear regression analysis of testset2

Parameters	*Moran's I real values*	*Moran's I log_{10} values*	*Norm z real values*	*Norm z log_{10} values*
Tree species	0.031	N/A	2.59	N/A
Tree age	0.092	N/A	7.00	N/A
Plantation block size	0.020	0.038	*1.83	3.12
Total number of trees	0.043	0.063	3.43	4.93
Season	0.052	N/A	4.14	N/A
Mean dry season elephant dung density	0.283	0.143	20.78	10.64
Mean wet season elephant dung density	0.196	0.204	14.51	15.09
Mean distance from salt-licks	0.218	0.410	16.12	29.95
Mean distance from water holes	0.478	0.208	34.80	15.36
Mean distance from elephant travel routes	0.286	0.288	20.99	21.15
Mean distance from elephant foraging paths	0.305	0.268	22.35	19.69
Mean distance from all routes combined	0.307	0.269	22.52	19.73

*Spatial auto-correlation at Norm z > 1.96

The response variable log_{10} number of destroyed trees, was normally distributed and the model residuals appeared robust (Fig 5.8).

Figure 5.8. Distribution of the response variable and modelled residuals for "log_{10} number of destroyed trees" using testset2, based on observed – expected values



The linear regression model for testset2 explained 63% of variance in the observed number of destroyed trees ($R^2 = 0.625$, df = 194, $P < 0.05$), and was not spatially auto-correlated (Moran's I = 0.002, Norm z = 0.858). Each explanatory variable in the model was investigated separately using logistic regression analysis.

5.3. RESULTS

5.3.1. Tree composition and tree destruction in plantations

A total of 626 forest blocks were surveyed, covering an area of 8,532ha. Blocks ranged in size from 1ha to 94ha, with a mean of 13.6ha (SE 0.47). Most forest blocks were planted with one tree species. Using the data on species planting and thinning regimes (Table 5.2), and knowing the age of each forest block, it was estimated that a total of 3,899,694 trees were present in the forest blocks surveyed. Based on 816 reports of different types and extents of tree damage, it was estimated that a total of 33,296 trees were destroyed. The estimated total number of trees destroyed represented less than 1% of the estimated total number of live trees. When compared to the estimated total number of live trees, most destruction (2.04%) was estimated to occur at Hombe, and least destruction (0.25%) to occur at Gathiuru (Table 5.4).

Table 5.4. Estimated numbers of live and destroyed trees per station, 2002 - 2003

Forest Station	*Live trees Total*	*Destroyed trees Total*	*Destroyed trees %*
Ontulili	483,455	2,646	0.55
Kahurura	600,587	5,178	0.86
Gathiuru	579,215	1,439	0.25
Kabaru	603,676	2,744	0.45
Hombe	909,689	18,528	2.04
Ragati	723,072	2,761	0.38
Total	3,899,694	33,296	0.85

5.3.1.1. Seasonality of elephant tree destruction

Least trees (9%) were estimated to be destroyed in the long dry season of December to February, followed by most trees (43%) destroyed in the subsequent long wet season of March to May, 28% in the subsequent short dry season of June to August, and 21% in the subsequent short wet season of September to November (Table 5.5). Except for Gathiuru and Kabaru, where tree destruction was spread evenly throughout the year, destruction at most stations showed a strong seasonal pattern (Table 5.5). At Ontulili and Ragati, most tree destruction occurred in the short dry season. In contrast, at Kahurura and Hombe, most tree destruction occurred in the long wet season (Table 5.5).

Table 5.5. Number of destroyed trees per season per station, 2002 – 2003

Forest Station	*Long dry season Destroyed*	*Long wet season Destroyed*	*Short dry season Destroyed*	*Short wet season Destroyed*
Ontulili	9	0	2,090	547
Kahurura	191	4,816	0	171
Gathiuru	219	487	317	416
Kabaru	672	597	716	759
Hombe	1,351	7,903	4,987	4,287
Ragati	588	354	1,074	745
Total	3,030	14,157	9,184	6,925

5.3.1.2. Species of live and destroyed trees per station

Most of the trees on the six forest stations comprised species of *Cupressus* (*C. lusitanica*, *C. benthamii*, *C. torulosa*), which made up 60 - 81% of trees on different stations, with a mean of 71% per station. *Eucalyptus* (*E. saligna*) and *Pinus* (*P. patula* and *P. halepensis*) comprised 11% and 9% of the total across all stations, respectively. Other species, including *Ocotea usambarensis*, *Vitex keniensis*, *Juniperus procera*, and *Fraxinus pennsylvanica* made up 8% of the total across all stations (Table 5.6). Of the destroyed trees, 73% were *Cupressus*, 15% *Pinus*, 6% *Eucalyptus*, and 6% other trees.

Table 5.6. Number of live and destroyed trees per species per station, 2002 -2003

Forest Station	*Cupressus Live (destroyed)*	*Pinus Live (destroyed)*	*Eucalyptus Live (destroyed)*	*Other Live (destroyed)*
Ontulili	391,874 (1,784)	47,291 (21)	6,830 (114)	37,460 (727)
Kahurura	488,317 (4,812)	29,280 (39)	70,730 (327)	12,260 (-)
Gathiuru	414,980 (804)	67,500 (8)	72,315 (128)	24,420 (499)
Kabaru	433,197 (2,136)	117,846 (486)	7,393 (122)	45,240 (-)
Hombe	619,287 (13,146)	56,184 (4,183)	186,836 (878)	47,382 (321)
Ragati	434,672 (1,684)	47,124 (157)	100,297 (531)	140,979 (389)
Total	2,782,327 (24,366)	365,225 (4,894)	444,401 (2,100)	307,741 (1,936)

5.3.1.3. Age class of live and destroyed trees per station

In 2002, most plantation trees (44%) were < 5 years of age, 17% were ≥ 5 and < 9 years, 10% were ≥ 10 and < 19 years, and 29% were ≥ 20 years (Table 5.7). Hombe, Ragati, and Kabaru had the largest proportion of young trees less than 5 years of age, comprising 82%, 54%, and 49% of each plantation, respectively (Table 5.7). Of 33,296 destroyed trees, 69% were less than 5 years of age, 20% were between 5 and 9 years of age, 3% were between 10 and 19 years of age, and 8% were older than 20 years of age. Most destroyed seedlings and young trees below 5 years of age (76%) were found at Hombe station.

Table 5.7. Number of live and destroyed trees per age class per station, 2002 -2003

Forest Station	*< 5 years old* *Live (destroyed)*	*5 – 9 years old* *Live (destroyed)*	*10 –19 years old* *Live (destroyed)*	*> 20 years old* *Live (destroyed)*
Ontulili	20,620 (1,600)	180,826 (159)	123,556 (130)	158,453 (757)
Kahurura	176,310 (535)	230,736 (4,643)	32,633 (-)	160,908 (-)
Gathiuru	79,180 (398)	131,720 (611)	153,339 (418)	214,976 (12)
Kabaru	293,120 (1,210)	24,400 (256)	33,545 (555)	252,611 (723)
Hombe	744,068 (17,467)	- (-)	- (-)	165,621 (1,061)
Ragati	390,133 (1,671)	101,587 (904)	39,849 (-)	191,503 (186)
Total	1,703,431 (22,881)	669,269 (6,573)	382,922 (1,103)	1,144,072 (2,739)

5.3.2. Predicting elephant ranging behaviour

A total of 3,364 least-cost routes were traced over MK, and many of these dissect plantations, and also trespass across the forest boundary into farmland, especially in the south-west and the north-east (Figure 5.9). Data from a GPS-collared bull sustains the predicted elephant access routes to and from the north-east of MK. Elephant tree damage in different seasons versus elephant routes, salt-licks, fences, and mean seasonal elephant density, are shown for three forest stations in the north-west: Ontulili, Kahurura and Gathiuru (Figure 5.10), and for three forest stations in the south-west: Kabaru, Hombe and Ragati (Figure 5.11).

Figure 5.9. Elephant routes on MK, predicted from 1999 survey data

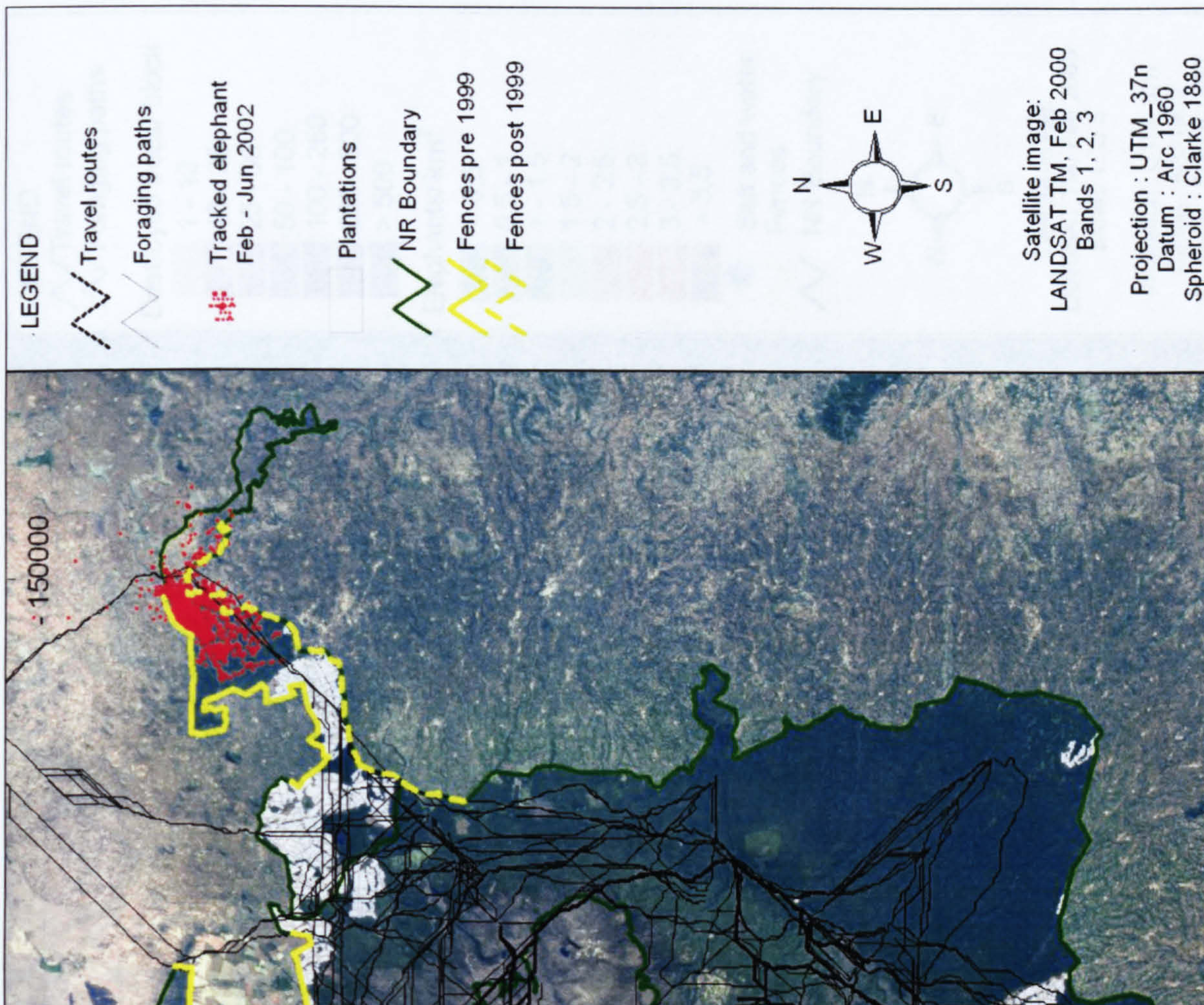


Figure 5.10. Seasonal patterns of tree destruction by elephants at Ontulili, Kahurura and Gathiuru forest stations, 2002 - 2003

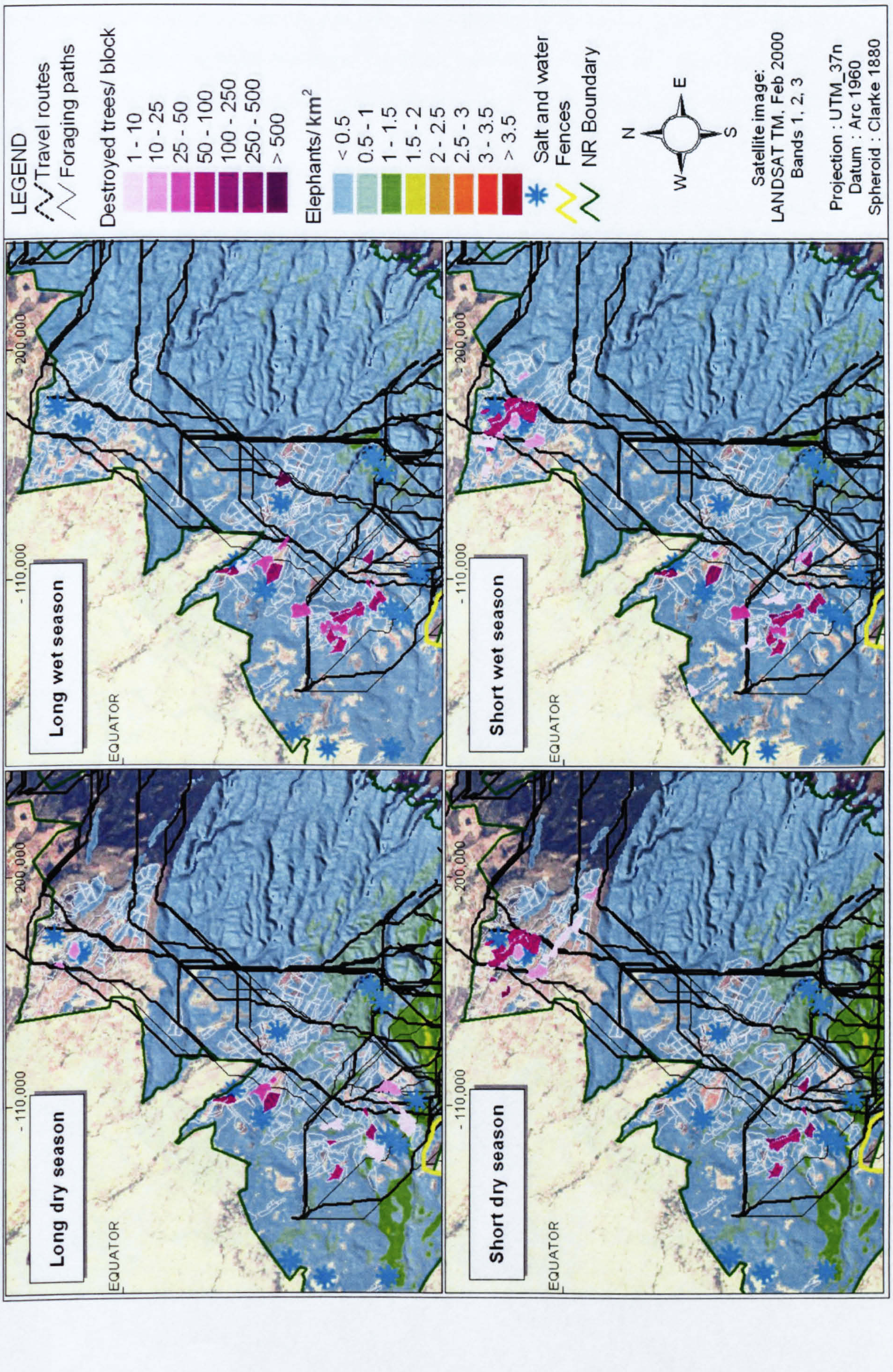
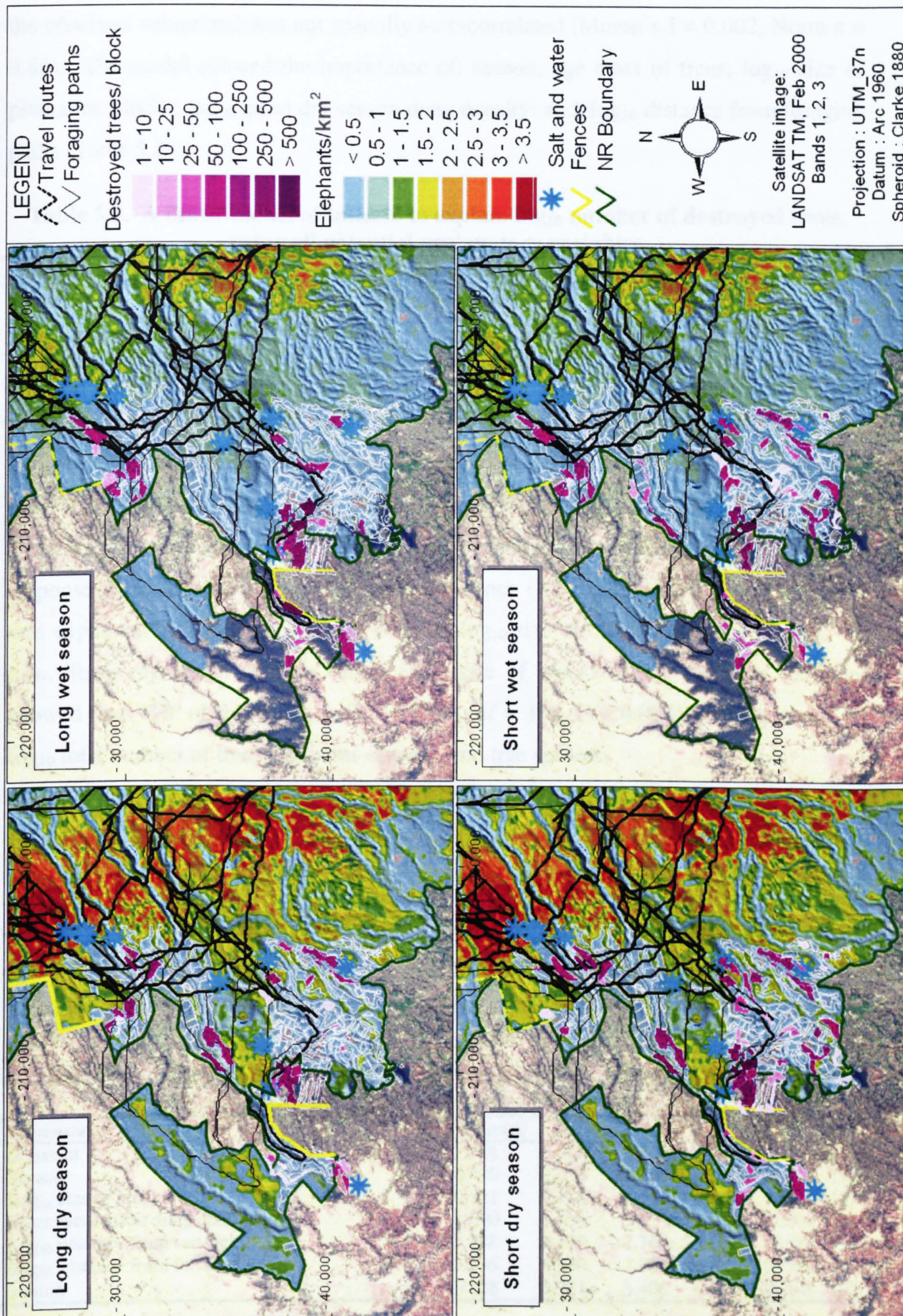


Figure 5.11. Seasonal patterns of tree destruction by elephants at Kabaru, Hombe and Ragati forest stations, 2002 - 2003



A linear regression model to explain $\log_{10}$ number of destroyed trees explained 63% of the observed values and was not spatially auto-correlated (Moran's I = 0.002, Norm z = 0.86). The model showed the importance of: season; age class of trees; $\log_{10}$ size of plantation blocks; $\log_{10}$ mean dry season dung density; and, $\log_{10}$ distance from foraging paths (Table 5.8).

Table 5.8. A linear model of testset2 to explain $\log_{10}$ number of destroyed trees, using all potential explanatory variables

Parameters	*Coefficient(β)*	*SE*	*t*	*P*	R^2	*df2*
Constant	1.421	0.298	4.773	< 0.001		
Season	0.343	0.031	11.026	< 0.001	0.443	198
Age class of trees	-0.250	0.032	-7.897	< 0.001	0.577	197
$\log_{10}$ size of blocks	0.423	0.104	4.078	< 0.001	0.608	196
$\log_{10}$ mean dry season dung density	0.173	0.076	2.289	< 0.05	0.617	195
$\log_{10}$ distance from foraging paths	-0.164	0.082	-1.998	< 0.05	0.625	194

However, the explanatory variables of age class of trees, block size, and total number of trees are inter-related, because the total number of trees per block depends on block size and the age of trees. Therefore, linear regression analysis, using age class of trees as the response variable, showed that 89% of the variance (R^2 = 0.892, df = 196, P < 0.001) was explained by $\log_{10}$ total number of trees, $\log_{10}$ size of blocks, and tree species. In turn, linear regression analysis, using $\log_{10}$ size of blocks as the response variable, showed that 93% of the variance (R^2 = 0.934, df = 196, P < 0.001) was explained by $\log_{10}$ total number of trees, age class of trees, and tree species.

Excluding the variable age class of trees, a linear model to explain $\log_{10}$ number of destroyed trees, explained 55% of the observed values and was not spatially auto-correlated (Moran's I = 0.009, Norm z = 1.64). The model showed the importance of: season; $\log_{10}$ size of blocks; mean wet season dung density; $\log_{10}$ distance from salt-licks; $\log_{10}$ distance from foraging paths; and forest station (Table 5.9).

Table 5.9. A linear model of testset2 to explain $\log_{10}$ number of destroyed trees, excluding the explanatory variable of age class of trees

Parameters	*Coefficient(β)*	*SE*	*t*	*P*	R^2	*df2*
Constant	2.068	0.694	2.979	< 0.01		
Season	0.408	0.033	12.545	< 0.001	0.443	198
$\log_{10}$ size of blocks	0.521	0.114	4.579	< 0.001	0.492	197
Mean wet season dung density	-1.000	0.309	-3.237	< 0.01	0.504	196
$\log_{10}$ distance from salt-licks	-0.548	0.199	-2.760	< 0.01	0.514	195
$\log_{10}$ distance from foraging paths	-0.296	0.100	-2.961	< 0.01	0.539	194
Station	0.105	0.031	3.406	< 0.01	0.548	193

- **The variable "season"**

Of 626 forest blocks that were surveyed, destroyed trees occurred in 311 blocks: 50 blocks for the long dry season; 61 for the long wet season; 100 blocks for the short dry season; and, 100 for the short wet season, respectively. The number of destroyed trees per block was converted into a presence-absence matrix of destroyed trees for logistic regression.

A logistic regression model to explain destruction of trees in different plantation blocks in the long dry season ($N_0 = 576$; $N_1 = 50$) explained 94% of the observed values and was not spatially auto-correlated (Moran's I = -0.003, Norm z = -0.18). The model showed the importance of: proximity to elephant foraging paths; distance from elephant travel routes; forest station; proximity to salt-licks; size of plantation blocks; and, age class of trees. Of the forest stations, Ontulili, Kahurura, and Gathiuru experienced 1.8, 1.8, and 1.2 times less tree destruction, respectively, than Ragati. In contrast, Kabaru and Hombe experienced 1.2, and 0.5 times more destruction, respectively, than Ragati. Seedlings < 2 years old were destroyed 1.4 times more often than trees ≥ 20 years of age. Young trees ≥ 2 and < 5 years of age, those ≥ 5 and < 10 years of age, and ≥ 10 and < 20 years of age, were destroyed 3.7, 3.2, and 2.0 times more often, respectively, than trees ≥ 20 years of age (Table 5.10).

Table 5.10. Results of a logistic regression model to explain destruction of trees in the long dry season

Long dry season parameters	*Coefficient(β)*	*SE*	*Wald*	*df*	*P*
Constant	-4.92	2.98	2.73	1	0.10
Log_{10} distance from elephant foraging paths	-1.10	0.49	5.09	1	< 0.05
Log_{10} distance from elephant travel routes	2.35	0.70	11.11	1	< 0.001
Stations (versus Ragati)			18.14	5	< 0.01
Ontulili vs. Ragati	*-1.83*	*0.94*	*3.79*	*1*	*< 0.05*
Kahurura vs. Ragati	*-1.79*	*0.79*	*5.13*	*1*	*< 0.05*
Gathiuru vs. Ragati	*-1.15*	*0.76*	*2.29*	*1*	*0.13*
Kabaru vs. Ragati	*1.19*	*0.69*	*2.96*	*1*	*0.09*
Hombe vs. Ragati	*0.48*	*0.67*	*0.51*	*1*	*0.47*
Log_{10} distance from salt-licks	-1.69	0.74	5.23	1	< 0.05
Log_{10} size of plantation blocks	1.80	0.53	11.46	1	< 0.001
Age class (versus > 20 years old)			46.44	4	< 0.001
< 2 versus > 20	*1.44*	*0.57*	*6.48*	*1*	*< 0.05*
2 – 5 versus > 20	*3.66*	*0.57*	*41.42*	*1*	*< 0.001*
5 – 9 versus > 20	*3.22*	*0.66*	*23.76*	*1*	*< 0.001*
10 – 20 versus > 20	*1.97*	*0.63*	*9.79*	*1*	*< 0.01*

A logistic regression model to explain destruction of trees in different plantation blocks in the long wet season ($N_0 = 565$; $N_1 = 61$) explained 92% of the observed values and was not spatially auto-correlated (Moran's I = 0.002, Norm z = 1.19). The model showed the importance of: forest station; size of plantation blocks; age class of trees; and, tree species (Table 5.11). Of the forest stations, Ontulili experienced 6.4 times less tree destruction than Ragati. In contrast, Kahurura, Gathiuru, Kabaru, and Hombe, experienced 0.6, 1.9, 2.0, 1.6, and 2.0 times more tree destruction, respectively, than Ragati. Tree destruction increased with size of plantation blocks, and tree seedlings were destroyed 3.3 times more often than trees ≥ 20 years of age. Furthermore, trees ≥ 2 and < 5 years of age, between ≥ 5 and < 10 years of age, and ≥ 10 and < 20 years of age, were destroyed 2.6, 2.5, and 0.9 times more often, respectively, than trees ≥ 20 years of age (Table 5.11). Of the tree species, *Eucalyptus* experienced most destruction, followed by *Cupressus* and *Pinus*.

Table 5.11. Results of a logistic regression model to explain destruction of trees in the long wet season

Long wet season: Parameters	*Coefficient(β)*	*SE*	*Wald*	*df*	*P*
Constant	-7.96	0.98	66.40	1	< 0.001
Stations (versus Ragati)			14.01	5	< 0.05
Ontulili vs. Ragati	*-6.42*	*14.27*	*0.20*	*1*	*0.07*
Kahurura vs. Ragati	*0 .62*	*0.70*	*0.78*	*1*	*0.38*
Gathiuru vs. Ragati	*1.94*	*0.65*	*8.88*	*1*	*< 0.01*
Kabaru vs. Ragati	*2.00*	*0.66*	*9.12*	*1*	*< 0.01*
Hombe vs. Ragati	*1.62*	*0.64*	*6.47*	*1*	*< 0.05*
Log_{10} size of plantation blocks	2.00	0.55	13.22	1	< 0.001
Age class (versus > 20 years old)			55.65	4	< 0.001
< 2 vs. > 20	*3.33*	*0.50*	*43.75*	*1*	*< 0.001*
2 – 5 vs. > 20	*2.60*	*0.55*	*22.52*	*1*	*< 0.001*
5 – 9 vs. > 20	*2.54*	*0.60*	*17.94*	*1*	*< 0.001*
10 – 19 vs. > 20	*0 .92*	*0.58*	*2.55*	*1*	*0.11*
Species (versus Other)			11.69	3	< 0.01
Cupressus vs. Other	*1.02*	*0.70*	*2.13*	*1*	*0.14*
Pinus vs. Other	*0 .43*	*0.89*	*0 .23*	*1*	*0.63*
Eucalyptus vs. Other	*2.12*	*0.74*	*8.22*	*1*	*< 0.01*

A logistic regression model to explain destruction of trees in different plantation blocks in the short dry season ($N_0 = 526$; $N_1 = 100$) explained 85% of the observed values and was not spatially auto-correlated (Moran's I = -0.002, Norm z = -0.16). The model showed the importance of: forest station; mean dry season elephant dung density; salt-licks; size of plantation blocks; age class of trees; and, tree species (Table 5.12). Of the forest stations, Ontulili and Hombe experienced 0.7 and 0.6 times more tree destruction, respectively, than Ragati. In contrast, Kahurura, Gathiuru, and Kabaru experienced 9.1, 1.2, and 0.1 times less tree destruction, respectively, than Ragati. Tree destruction increased with increasing mean dry season elephant dung density, with proximity to salt-licks, and with increasing size of plantation blocks in which destruction occurred. All age classes, namely seedlings < 2 years of age, trees ≥ 2 and < 5 years of age, ≥ 5 and < 10 years of age, and ≥ 10 and < 20 years of age, were destroyed 1.5, 2.9, 2.4, and 1.0 times more often, respectively, than trees ≥ 20 years of age. Of all tree species, most destruction happens to *Eucalyptus*, followed by, other, *Cupressus* and *Pinus* (Table 5.12).

Table 5.12. Results of a logistic regression model to explain destruction of trees in the short dry season

Short dry season: Parameters	*Coefficient(β)*	*SE*	*Wald*	*df*	*P*
Constant	1.09	1.69	0.41	1	0.52
Stations (versus Ragati)			17.17	5	< 0.01
Ontulili vs. Ragati	*0.74*	*0.39*	*3.60*	*1*	*0.06*
Kahurura vs. Ragati	*-9.07*	*14.56*	*0.39*	*1*	*0.53*
Gathiuru vs. Ragati	*-1.23*	*0.52*	*5.57*	*1*	*< 0.05*
Kabaru vs. Ragati	*-0.08*	*0.44*	*0.03*	*1*	*0.86*
Hombe vs. Ragati	*0.59*	*0.39*	*2.22*	*1*	*0.14*
Log_{10} mean dry season elephant density	0.58	0.23	6.27	1	< 0.05
Log_{10} distance from salt-licks	-1.22	0.52	5.54	1	< 0.05
Log_{10} size of plantation blocks	1.22	0.35	12.43	1	< 0.001
Age class (versus > 20 years old)			55.45	4	< 0.001
< 2 vs. > 20	*1.50*	*0.38*	*15.50*	*1*	*< 0.001*
2 – 5 vs. > 20	*2.89*	*0.48*	*35.57*	*1*	*< 0.001*
5 – 9 vs. > 20	*2.40*	*0.48*	*25.13*	*1*	*< 0.001*
10 – 19 vs. > 20	*1.03*	*0.46*	*5.08*	*1*	*< 0.05*
Species (versus Other)			8.98	3	< 0.05
Cupressus vs. Other	*-0.60*	*0.37*	*2.63*	*1*	*0.10*
Pinus vs. Other	*-1.06*	*0.50*	*4.57*	*1*	*< 0.05*
Eucalyptus vs. Other	*0.28*	*0.41*	*0.47*	*1*	*0.49*

A logistic regression model to explain destruction of trees in different plantation blocks in the short wet season (N_0 = 526; N_1 = 100) explained 84% of the observed values and was just not spatially auto-correlated (Moran's I = 0.003, Norm z = 1.86). The model showed the importance of: forest station; total number of trees; and age class of trees (Table 5.13). Elephant tree destruction increased with distance from elephant travel routes. Of the forest stations, Ontulili, and Kabaru, experienced 1.0 and 0.4 times more tree destruction, respectively, than Ragati. In contrast, Kabaru, Gathiuru, and Hombe, experienced 2.0, 0.1, and 0.4 times less tree destruction, respectively, than Ragati. Tree destruction increased with increasing total number of trees in blocks in which destruction occurred, and trees of all age classes were destroyed more often than trees ≥ 20 years of age. Seedlings < 2 years of age, young trees ≥ 2 and < 5 years of age, trees ≥ 5 and < 10 years of age, and ≥ 10 and < 20 years of age, were destroyed 1.1, 1.4, 1.7, and 0.1 times more often, respectively, than trees ≥ 20 years of age (Table 5.13).

Table 5.13. Results of a logistic regression model to explain destruction of trees in the short wet season

Short wet season: Parameters	*Coefficient(β)*	*SE*	*Wald*	*df*	*P*
Constant	-6.67	1.43	21.71	1	< 0.001
Log_{10} distance from elephant travel routes	0.73	0.32	5.09	1	< 0.05
Stations (versus Ragati)			23.61	5	< 0.001
Ontulili vs. Ragati	*0.95*	*0.39*	*5.89*	*1*	*< 0.05*
Kahurura vs. Ragati	*-2.04*	*0.66*	*9.67*	*1*	*< 0.01*
Gathiuru vs. Ragati	*-0.08*	*0.40*	*0.04*	*1*	*0.84*
Kabaru vs. Ragati	*0.44*	*0.43*	*1.06*	*1*	*0.30*
Hombe vs. Ragati	*-0.41*	*0.43*	*0.91*	*1*	*0.34*
Log_{10} total number of trees	0.63	0.26	6.07		< 0.05
Age class (versus > 20 years old)			21.70	4	< 0.001
< 2 vs. > 20	*1.12*	*0.40*	*7.61*	*1*	*<0.01*
2 – 5 vs. > 20	*1.38*	*0.48*	*8.31*	*1*	*< 0.01*
5 – 9 vs. > 20	*1.68*	*0.43*	*15.33*	*1*	*< 0.001*
10 – 19 vs. > 20	*0.09*	*0.38*	*0.06*	*1*	*0.80*

- **The variable "Mean wet season dung density"**

In Chapter 4, I showed that elephant dung in the wet season was found mainly at mid-elevations in the bamboo-podo forest belt, away from the mixed forest belt within which the forests plantations are situated. This may explain why destruction of tree plantations by elephants decreased with wet season dung density.

- **The variable "log_{10} distance from salt-licks"**

Destruction of trees by elephants within plantations increased with proximity to salt-licks. Elephants living in forest environments are known to utilize salt-licks to feed on their mineral-rich soils in forest environments (e.g. Ruggiero and Fay, 1994; Vanleeuwe et al., 1998). Tree destruction in proximity to salt-licks could result from travelling and/or foraging elephants. In other words, tree destruction could result from elephants moving towards salt-licks and feeding on trees as they go along, or from elephants extending their feeding range from the salt-licks to surrounding trees. However, the importance of foraging paths suggests that tree destruction most likely stems from foraging elephants.

- **The variable "log10 distance from foraging paths"**

Foraging paths were distinguished from travel routes by their degree of use. Unlike travel routes, that were assumed to be repeatedly used to travel and to be channelled by physical obstacles of the terrain such as barriers and slope, foraging paths were assumed to be created by foraging elephants and to be more influenced by seasonal feeding preferences. The linear regression model that explained $\log_{10}$ tree destruction in plantations showed that tree destruction increased with proximity to elephant foraging paths, supporting the hypothesis that tree destruction in plantations was more likely the result of foraging as opposed to travelling elephants.

- **The variable "station"**

Tree destruction was found to be explained also by forest station. The differences in the extent of tree destruction at different forest stations were outlined in detail in section 5.2.5.

5.4. DISCUSSION

Elephants are liable to destroy environments that cannot sustain their year-round needs (Campbell et al., 1996; Keesing, 1997; Ben-Shahar, 1998; Barnes, 2001; Pamo and Tchamba, 2001; Calenge et al., 2002; Fritz et al., 2002). Carrying capacity of different habitats depends on patch size and quality, and on elephant density and ranging behaviour within and between confined environments (De Boer et al., 2000; Harcourt et al., 2002; Whitehouse and Schoeman, 2003). Identifying habitat linkages, the effects of elephants on their natural habitat and least cost travel are therefore important for managing elephants in fragmented habitats (Seydack et al., 2000; Parren et al., 2002; Osborne and Parker, 2003; Clevenger et al., 2003). This is especially true for MK, which is under threat of becoming isolated, and where management strategies have included fencing boundaries and corridors without any knowledge of elephant ranging behaviour, or their impact on plantation trees. Filling these gaps in knowledge was the subject of this chapter.

5.4.1. Plantation composition and character of tree destruction

The majority of trees in MK plantations were *Cupressus* (71%), followed by *Eucalyptus* (9%) and *Pinus* (8%), while 44% of all trees were < 5 years of age, and 29% were ≥ 20 years of age. Many young *Cupressus lusitanica* were planted as part of a crash programme initiated in October 2001, after the FD had been publicly accused of neglecting re-afforestation, following an aerial survey in 1999 (Gathaara, 1999). The forest stations of Hombe, Ragati, and Kabaru, all lying in the south-west of MK, have the largest proportion of trees < 5 years of age, with up to 82% in this age group at Hombe.

The very limited financial capacity of the FD causes many problems, including lack of tree thinning equipment and poorly maintained plantations (Hoft, 2002). Financial constraints within government departments are a common problem that affects conservation (Klooster, 1999; Smith et al., 2003). Compared to tree loss from neglecting thinning schedules, or from allowing violation of the periods of non-residential cultivation or NRC on afforested land, which has left many thousands of hectares for several years without trees (see Chapter 7), destruction of trees by elephants is probably negligible by comparison (Table 5.4). Tree destruction by elephants showed strong but contrasting seasonal patterns at different stations, and was most pronounced at Hombe. Both stations in the north-west, where predicted elephant density is generally low (see Chapter 4), both had two seasons with, and two seasons without, tree destruction. The other stations, where predicted elephant density was higher, experienced tree destruction all year round with peaks in one or two seasons.

5.4.2. Tracing elephant routes and identifying ranging behaviour

The natural response of elephants against over-crowding is to move between and within protected habitats (Parren et al., 2002; Singleton et al., 2002; Osborn and Parker, 2003). Several studies have shown that elephants use least cost routes as an optimal energy–saving strategy (Vanleeuwe and Gautier-Hion, 1998; Loehle, 1999; Bunn et al., 2000), and this formed the basis of tracing elephant routes on MK. Digital tracing of least cost routes was based on the assumption that movement would be determined by seasonal habitat use and preferences, by physical barriers like vertical cliffs, and by anthropogenic barriers like farmland.

The extreme geographical features on MK channel elephant movements and produce well-used travel routes, a knowledge of which has long been made use of by poachers who target these routes. Because many elephants will use such routes regularly, the quality of nearby forage will reduce. Hence, the heavily used routes were named travel routes. Routes that were less regularly used were predicted to be created by foraging elephants as they go along, and were named foraging paths. Tracing both travel routes and foraging paths allowed me to locate important areas of heavy elephant traffic, and where they cross both forest plantations and also the forest boundary into farmland.

5.4.3. Multivariate analysis to explain elephant tree destruction

Several studies have focussed on the role of elephants in destroying trees (Strusacker et al., 1996; Calenge et al., 2002; Gadd, 2002). The linear regression model from MK suggested that tree destruction is related to seasonality, and that it increased with decreasing tree-age, with increasing size of plantation blocks, with increasing dry season dung density, and with proximity to elephant foraging paths.

All logistic regression models explaining seasonality of tree destruction also included the parameters of forest stations and age class of trees. Tree destruction differed between stations and showed strong seasonal patterns within different stations. Trees $\geq$ 20 years of age had least tree destruction in all seasons.

Destruction of trees by elephants decreased with distance from travel routes in the short wet season and in the subsequent long dry season, but destruction increased with proximity to salt-licks and foraging paths in the long and short dry seasons. Therefore, tree destruction is more likely to occur close to foraging, as opposed to travelling, elephants. Feeding on salt-rich soils at salt-licks is an important foraging behaviour (e.g. Ruggiero and Fay, 1994), and planting of young trees away from salt-licks may reduce elephant impact on them. In turn, this also suggests that salt-licks can be used as a measure to attract elephants (e.g. Zhang and Wang, 2003). Tree destruction was co-explained by increasing mean dry season elephant dung density in the short dry season, while tree species co-explained tree destruction in both the short dry season and in the preceding long wet season. *Eucalyptus* among *Cupressus, Pinus*, and mixed stands, was the most affected species in both seasons. This further suggests that *Eucalyptus* is not the best species to plant on MK, especially close to salt-licks.

Given the fixed planting and thinning regimes per hectare (Table 5.2), the total number of trees proportional both to the size of plantation blocks, but also to age class and species of trees. Older trees are less often destroyed than very young trees on MK. In contrast, the literature suggests that elephants mainly forage on mature trees and thereby suppress tree growth, while destruction of young trees and seedlings more often depends on small ungulate populations and fires (Ben-Shahar, 1998; Barnes, 2001; Holdo, 2003). Several studies have indicated that when elephant ranges remain unfragmented, elephants have little detrimental impact on the environment (Van de Vijver et al., 1999; O'Connell-Rodwell et al., 2000), and communities of both small selective species like dik-dik, and large bulk-feeding species like elephants, can provide an important service by suppressing shrub encroachment (Augustine and McNaughton, 2004). The results from MK showing that elephants destroy seedlings are not necessarily contradicting this. Elephants on MK do not necessarily aim to destroy tree seedlings. Like the shrubs invading logged areas that attract elephants and thereby suppress tree regeneration in Uganda (Strusacker et al., 1996), non-residential cultivation crops on MK may attract elephants and thereby encourage destruction of tree seedlings that the crops surround. Additionally, elephants are likely to perceive tree plantations as part of their natural habitat given that they are situated in the middle of indigenous forest. Non-residential cultivation (NRC) crops planted in the middle of elephant habitat not only results in crop loss and tree loss, but NRC may also encourage elephants to perceive crops as part of natural forage, which in turn could encourage elephant crop destruction on farms adjacent to forests. Abolishing the NRC system could potentially minimised seedling destruction by elephants, and also many other problems that are associated with the NRC scheme (Chapter 7).

Least cost movements of wide-ranging animals inside and between protected areas, and of the relationship between elephant movements and tree-damage have been the subject of several studies (Strusacker et al., 1996; Loehle, 1999; Singleton et al., 2002; Russel et al., 2003). The fact that plantations are mainly situated on the flatter terrain on the lower slopes of MK, could make plantations good foraging terrain, and could explain why many foraging paths run through them. Foraging paths differ from travel routes in that their location is more influenced by seasonal habitat preferences than by physical barriers. Deep valleys channel elephant movements through narrow routes, which are often targeted by poachers, and blocking routes, for example by fencing, could lead to local pocketing or over-stocking of elephants within heavily confined habitat. Most routes that dissect the boundary into farmland were found in the north-east and the south-west of MK. Evidence from a GPS-collared elephant confirms active use of the predicted access area that connects the Imenti with the NGA's. Over 60km of solar powered elephant fences have been, and are being, raised in the Imenti corridor area. These fences efficiently protect farmland against elephant raids, but more people then settle in the fenced-off protected area. Unless the corridor area is included in further fencing plans, the most important MK movement route will become irreversibly settled.

5.5. CONCLUSION

When elephants occur at high densities, they are liable to destroy their natural habitat, and cause problems to adjacent human habitats (Smith and Kasiki, 2000; Whitehouse and Schoeman, 2003; Sitati et al., 2003). Understanding the factors that explain tree destruction by elephants, and their ranging behaviour on MK and movement, are important in the face of rapidly expanding small-scale farmland around MK, that threaten to isolate the mountain.

Destruction of trees by elephants on MK is best explained by seasonality. It increases with decreasing tree age class and with increasing size of plantation blocks. It also increases with increasing mean dry season dung density and proximity to foraging paths. Tree destruction in different seasons is determined by stations and tree age, with strongly differing seasonal patterns between stations, but with more destruction overall of young trees. Tree destruction decreases with proximity to travel routes but increases with proximity to salt-licks and foraging paths, suggesting that destruction is the result of foraging elephants. Many other studies suggest that, although elephants often suppress growth of mature trees, the survival of seedlings is usually depends on small ungulate populations and fires (Styles and Skinner, 2000; Barnes, 2001). The MK results are not contradictory because NRC, a high biomass of crops that could encourage seedling destruction, surrounds seedlings on MK. Ironically, the FD has often promoted the role of the NRC system to protect tree seedlings from elephant destruction.

Maps and associated information in this chapter can help develop sound management plans. The maps locate movement routes and the most vulnerable areas in different season. Planting and harvesting regimes could be adapted appropriately, while fencing could be sited to avoid local isolation. The maps should be used to protect the two remaining corridors connecting MK with the NGA's. Additional information, such as the elephant-attraction effect of salt-licks and their avoidance of slopes, could help encourage elephants to use routes away from farmland, for example by using artificial salt-licks and by creating river crossings. Relations between elephant ranging behaviour and damage to farms adjacent to the forest are now explored in Chapter 6.

Chapter 6

HUMAN-ELEPHANT CONFLICT AND MITIGATION

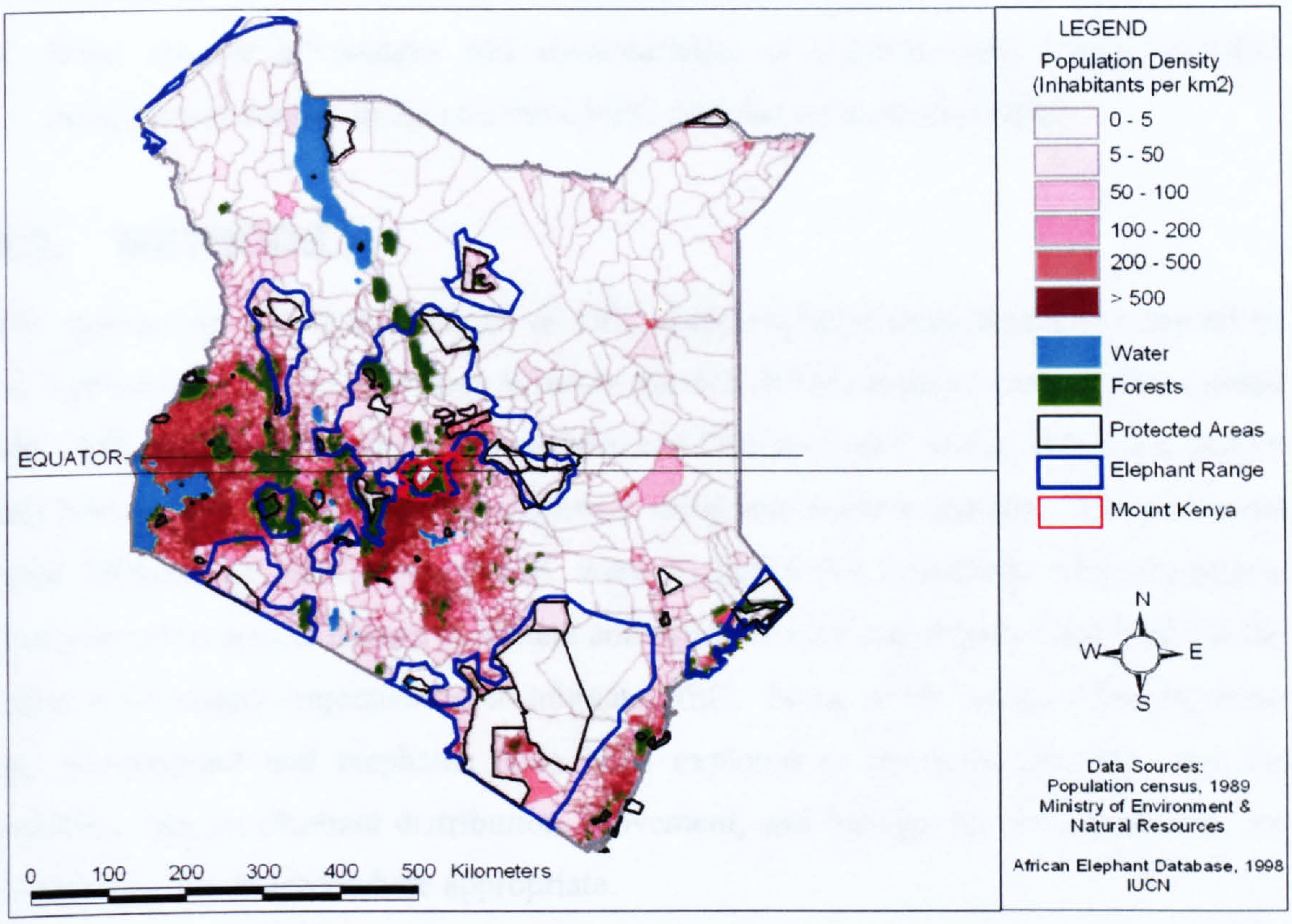
6.1. INTRODUCTION

Several studies have shown that elephant and human densities are inversely related (Parker and Graham, 1989; Eltringham, 1990; Barnes, 1991; Happold, 1995), and that co-existence is possible only in areas with reduced levels of land-cover change and human disturbance (Hoare, 1999; Hoare, 2000; O'Connell-Rodwell et al., 2004). Hoare and du Toit (1999) suggested that, in less productive areas of Zimbabwe, elephants are excluded at human densities of 18.9 people/ km^2, while Graham and Parker (1989) suggested that, in highly fertile areas in Kenya, they are excluded at human densities of 82.5 people/ km^2. As elephants and people compete for land and resources, subsequent human-elephant conflicts (HEC) are most pronounced where they co-exist at the human-elephant interface (Harcourt et al., 2001; Jenkins, 2003; Fritz et al., 2003; Sitati et al., 2003).

More recent studies have investigated site-specific causes underlying the patterns of HEC (Harcourt et al., 2001; Bulte and Horan, 2003; Sitati et al., 2003), have offered ways to help measure HEC (Hoare, 2000; Boone et al., 2002), and have investigated potential solutions to HEC (Kuriyan, 2002; Moore et al., 2003; Osborn and Parker, 2003). Although HEC-mitigation plans have emerged that seek to focus on long-term solutions, most implemented strategies have focused on direct short-term solutions, such as chasing of elephants and elephant translocation (e.g. KWS, 2001; Osborn, 2002; Vollrath and Douglas-Hamilton, 2003).

In Kenya, the problem of elephants causing loss of human life and livelihoods has received increasing attention since the 1990s (Thouless and Sakwa, 1995; Gichohi, 2000; Smith and Kasiki, 2000). Financial compensation was tried and abandoned because of abuse to the system, which also created unsustainable expectations, and which did not reduce crop raiding (KWS, 2001). Although increasing emphasis has been placed on community involvement in mitigation plans (e.g. EC 1992, 1994; KWS, 1995, 2001; Mwathe et al., 1998), translocation and driving out of elephants, control shooting and protective fencing, are temporarily successful, but they rarely address underlying causes of HEC. The interfaces where people and elephant densities are highest in Kenya typically occur around the few fertile forests (Figure 6.1).

Figure 6.1. Elephant range, human population density, and protected areas, in Kenya



Within a ring of 5,000m around the Mount Kenya (MK) Forest Reserve one finds thoroughly transformed small-scale farms, and human densities that are much greater than 82.5 people/ km^2. Furthermore, the MK elephant population was estimated to be the largest highland population in Kenya (Blanc et al., 2003; Chapter 3), and locally high densities of elephants occur at lower altitudes close to farmland during the dry season (Chapter 4). Predictive modelling of least-cost elephant movement routes and foraging paths showed that most elephant routes and paths dissect the forest boundary into farmland in the north-east and in the south-west of MK (Chapter 5). Chapter 5 also suggested that non-residential cultivation or NRC in plantations might attract elephants and encourage them to perceive crops as natural forage. Hence, it was predicted that the distributions of elephants and people at different seasons would explain levels of HEC at the MK human-elephant interface. HEC and HEC mitigation on MK were investigated through the following questions:

- What factors explain elephant crop damage on farms adjacent to the MK forest?

- What are the socio-economic characteristics and the spatial patterns of human and elephant use of land and resources, in the two areas most affected by HEC?
- What are the advantages and disadvantages of implementing fences as HEC mitigation strategies in the two most HEC-affected areas around MK?

6.2. METHODS

The spatio-temporal characteristics of HEC were explored from damages reported in occurrence books (OBs) at Kenya Wildlife Service (KWS) stations and outposts around MK. OB data were combined with archive and GIS generated data to determine factors that best explain crop damage by elephants, using multivariate analysis. The two areas most affected by HEC around MK were explored for household socio-economic characteristics, spatial pattern of human and elephant land and resource use, and for the effect of strategies implemented to mitigate HEC. Some of the relationships between the environment and elephants have been explored in previous chapters, and the resulting data on elephant distribution, movement, and damage on tree plantations are included in this chapter where appropriate.

6.2.1. Spatio-temporal characteristics of HEC around MK

Around Mount Kenya, the KWS maintains five larger stations, namely NaroMoru HQ, Meru, Embu, Nanyuki, and Sirimon gate, and several smaller stations and outposts like Marania, Ruthumbi, Chogoria Gate, Chuka, Ndondori, Thambana, Kamweti, Kangaita, Ragati, Mountain Lodge, NaroMoru town, and Nanyuki Safari Club airstrip (see Figure 6.4). Every KWS station and outpost has its own OB in which all events are noted, including the number of bullets used in Problem Animal Control (PAC) and all reported wildlife damages. All human-wildlife conflict OB records from 1999, 2000, 2001, and 2002, were transcribed from the following stations and outposts: Meru station, Chuka outpost, Embu station, Thambana outpost, Ndondori outpost, Kamweti outpost, Kangaita outpost, Ragati outpost, NaroMoru station, and Nanyuki station. Records from the Nanyuki Safari Club airstrip, Mountain Lodge, Marania, Chogoria Gate, and Ruthumbi outposts, were regularly copied into the OBs at the larger stations or outposts, and were thus automatically included. As KWS stations and outposts do not confine themselves strictly to district boundaries, they were grouped to represent districts as follows:

- Meru Central: Meru station including records from Marania and Ruthumbi outposts;
- Meru South: Chuka outpost including records from Chogoria Gate outpost;
- Embu: Embu station, Thambana outpost, Ndondori outpost;
- Kirinyaga: Kamweti outpost, Kangaita outpost;
- Nyeri: Ragati outpost, NaroMoru station including records from Mountain Lodge;
- Laikipia: Nanyuki station.

Between May and July 2002 a case study, that was complementary to the study in this thesis, was conducted by MSc student Mikiko Hagiwara (Hagiwara, 2002). The case study investigated factors influencing the reporting of damage in the OB records at Nanyuki station. Within a radius of 15km around Nanyuki station, almost 100 farmers, both from farms along the MK forest boundary and from farms within Laikipia district away from the MK forest boundary, were interviewed about elephant damage and whether or not damage was reported to KWS. The case study tested potential explanatory factors to reporting behaviour such as distance of affected farms to KWS stations, distance from roads, economic status of affected farmers, family size, owning of property such as radio, telephone, bicycle, vehicle, size of farm, and anti-KWS feelings (Hagiwara, 2002). The case-study concluded that elephant crop damage was the most reported damage, and that OB records correctly indicated spatio-temporal patterns of damage. In contrast, OB records poorly explained actual extent of damages (Hagiwara, 2002).

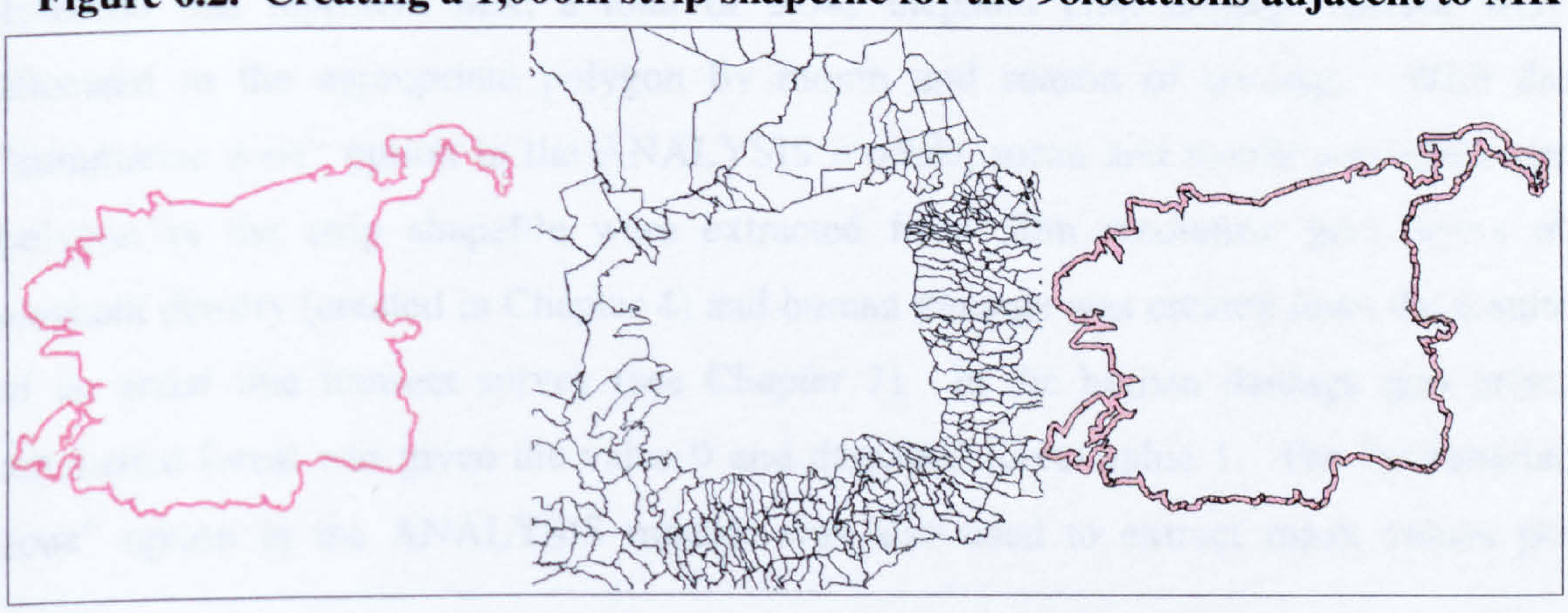
Therefore, this chapter will not focus on actual extent of damage but on spatio-temporal differences, of the distribution of damage reports, between districts, and between years. The species reported to cause damage between districts, the difference of reported damage between years, and the type of reported damage between districts, were addressed. Elephant crop damage, the most common reported damage, was explored in more detail.

6.2.2. Multivariate analysis of OB data and GIS generated data

OB data were combined with archive and GIS generated data for multivariate analysis to establish the explanatory factors to elephant crop damage at district level. Analyses were done for individual locations, the smallest administrative unit at which data on population density are recorded for all districts around MK (e.g. Republic of Kenya, 2000). Because locations vary both in area and in the length of boundary bordering the forest, dividing numbers of reports by the area of locations would result in skewed measures of HEC. To allow a better comparison between locations, the likely assumption was made that all damages occurred within 1,000m of the MK forest boundary.

The area (in km^2) of each location lying within 1,000m of the forest boundary was calculated and numbers of reports were divided by this area. GIS layers (or shapefiles) of the MK boundary, the location of salt-licks, water holes, and KWS stations were developed in ArcView. The option "Create Strips" in the THEME module was used on the MK boundary shapefile, to create the 1,000m strip shapefile. A shapefile of the 98 locations bordering MK was found in GIS archives at Laikipia Research Programme or LRP in Nanyuki (see Chapter 2). Using the option "clip one theme based on another" of the "GeoProcessing Wizard" in the module VIEW, a shapefile was created to represent the 1,000m strip for the 98 locations adjacent to the forest (Figure 6.2). To calculate the area covered per location within a 1,000m strip around MK, the shapefile was imported into the GIS Idrisi32, where it was converted to a raster layer of 30m resolution, and the size was calculated for each polygon using the module AREA.

Figure 6.2. Creating a 1,000m strip shapefile for the 98locations adjacent to MK



The following columns or fields of data, were attached to the shapefile as a table:

- Human population density in locations within 1,000m of the MK boundary, in 1999;
- Area (in km^2) covered by locations within 1,000m of the MK boundary;
- Total number of elephant crop damage records within 1,000m of the MK boundary, for 1999, 2000, 2001, and 2002;
- Total number of reports per month within 1,000m of the MK boundary;
- Total number of reports per season within 1,000m of the MK boundary;
- Reports per month and per season per km^2 within 1,000m of the MK boundary;
- Maximum and mean dry season elephant densities within 1,000m adjacent forest;
- Maximum and mean wet season elephant densities within 1,000m adjacent forest;
- Mean distance of reported damage from nearest salt-lick;
- Mean distance of reported damage from nearest water hole;
- Mean distance of reported damage from nearest salt-licks and water hole combined;
- Mean distance of reported damage from nearest KWS stations;
- Sum of illegal human damaged raster image cells within 5,000m adjacent forest;
- Presence/ absence of a Nyayo Tea Zone Corporation (NTCZ) tea strip between forest and farmland.

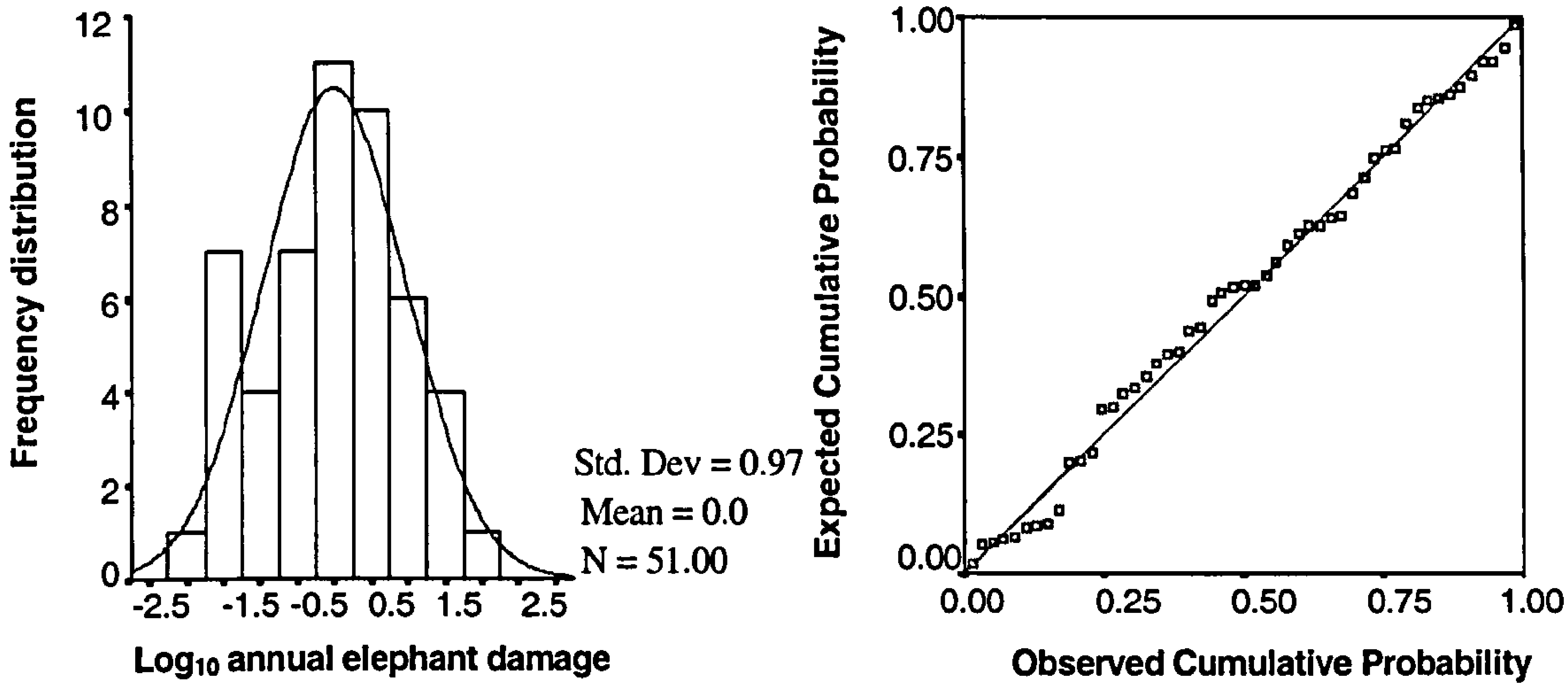
Population densities for the 98 locations were found in the Kenya population census report of 1999, of the Central Bureau of Statistics, Ministry of Finance and Planning. Each location within 1,000m of the MK boundary represented one polygon, of which there are 98 in the 1,000m strip shapefile. Allocating crop damage records per polygon was done by hand. Using data from the OB records and 9 topographic sheets at scale 1:50,000 that represent MK, a total of 2,045 elephant crop damage records were allocated to the appropriate polygon by month and season of damage. With the "summarise zone" option in the ANALYSIS module, mean and maximum values per polygon in the strip shapefile were extracted from 30m resolution grid layers of elephant density (created in Chapter 4) and human damage was created from the results of an aerial line transect survey (see Chapter 7). In the human damage grid layer, untouched forest was given the value 0 and damaged forest value 1. The "summarise zone" option in the ANALYSIS module was also used to extract mean values per polygon from grid layers of distance from salt-licks, water holes, elephant routes, plantation blocks, and KWS stations (created from shapefiles with the option "find distance" in the THEME module) to reported damage.

Finally, a field was added to distinguish polygons that border a strip of planted tea from those without tea. On the rainy side of MK, thousands of hectares of forest were turned into tea plantations in 1986, forming the NTZC strip that physically distinguishes the forest boundary from the air and from satellite images. The NTZC was established as a business to provide employment, infrastructure, and to physically mark the boundary between forest and farmland. The width of the tea strip varies, but it is generally around 100 to 200m wide (see Figure 6.16). The presence or absence of a tea strip in each location was defined by overlaying the location polygon shapefile onto a LANDSAT satellite image.

Data exploration and multivariate analysis were done with the programme SPSSv11. The distribution of the response variable was explored to choose the best multivariate analysis test. For normally distributed data, parametric tests are used, while for non-normally distributed data, non-parametric tests are used (Crawley, 1993; Guisan et al., 2002). For multivariate analysis, the 1,000m strip shapefile was used, resulting in a test set with 98 samples, - named testset98 -, in which each sample represented 1 of 98 locations within 1,000m strip of the MK boundary. Of the 98 locations, 47 did not report elephant crop damage between 1999 and 2002.

Both real values and $\log_{10}$ values for the continuous parameters that were used in multivariate analysis, were tested for distribution and spatial auto-correlation of data samples (Table 6.1). Log_{10} elephant damage for the 51 affected locations was normally distributed (Figure 6.3) and multivariate analysis was therefore done with linear regression.

Figure 6.3. Distribution of the response variable "log10 annual elephant damage", and of the model residuals for Testset98



All parameters used in the model, as well as the residuals of the resulting explanatory model, were tested for spatial auto-correlation with the programme CrimeStatII. Spatial auto-correlation of both model residuals, and of parameters used to establish the model, affect tests of model strength and predictive reliability of models. Therefore, when all parameters in the model are spatially auto-correlated, the explanatory model residuals cannot be in order for the model to be reliable (Legendre et al., 2002). All parameters used in the model, with the exception of "maximum wet season elephant dung density" and "$\log_{10}$ mean wet season elephant density" were spatially auto-correlated (Table 6.1).

Table 6.1. Spatial auto-correlation of parameters in linear regression analysis of Testset98

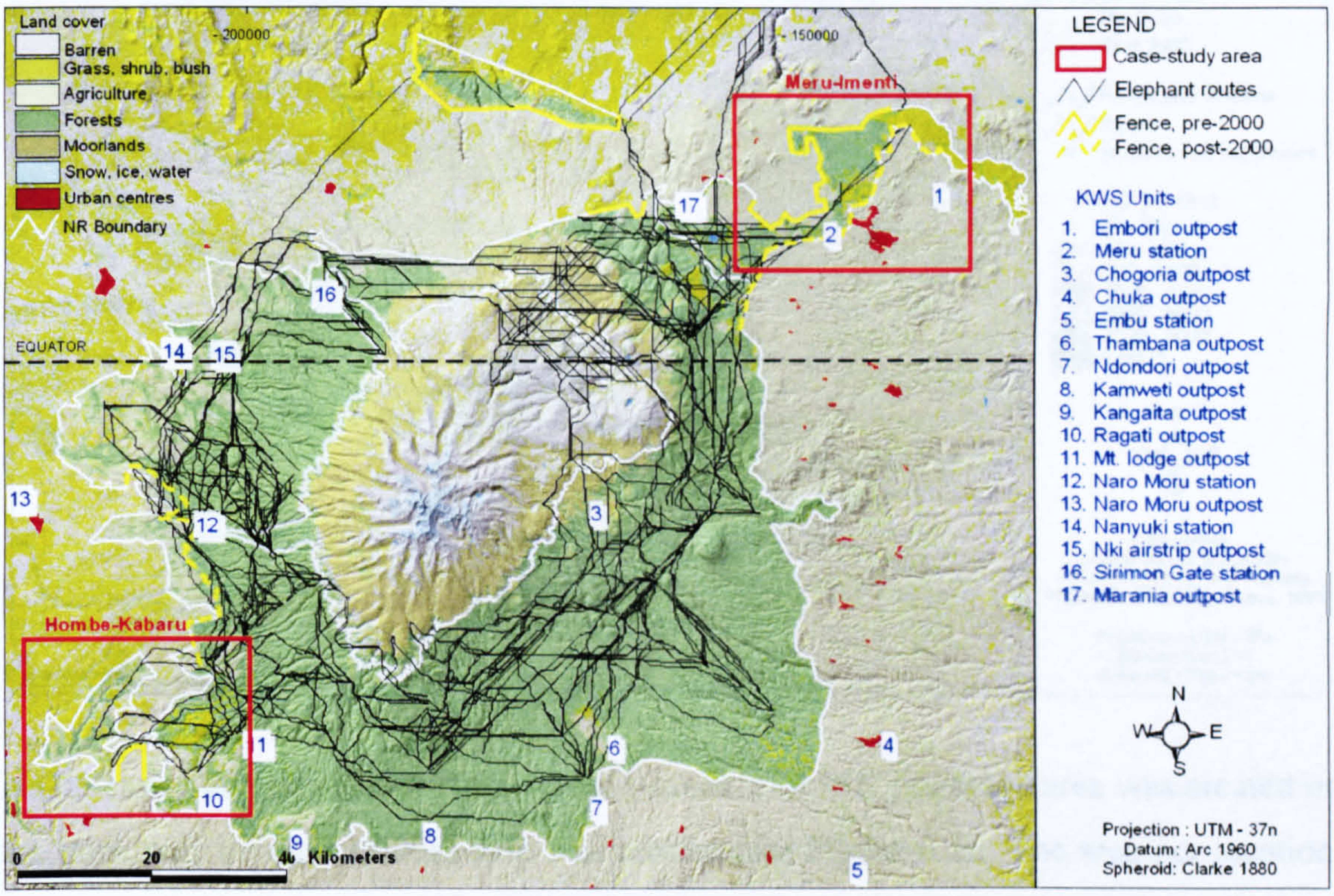
parameters	*Moran's I real values*	*Moran's I log10 values*	*Norm z real values*	*Norm z log10 values*
Season with most damage	0.145	N/A	5.59	N/A
Human population density	0.063	0.114	2.63	4.46
Maximum dry season elephant dung density	0.051	0.100	2.21	3.97
Mean dry season elephant dung density	0.151	0.116	5.83	4.54
Maximum wet season elephant dung density	0.032	0.068	*1.51	2.83
Mean wet season elephant dung density	0.103	-0.011	4.07	*-0.01
Mean distance from salt-licks	0.599	0.602	21.97	22.09
Mean distance from water-holes	0.570	0.463	20.92	17.04
Mean distance from salt-licks and water-holes	0.358	0.281	13.29	10.50
Mean distance from elephant foraging paths	0.268	0.363	10.03	13.44
Mean distance from elephant travel routes	0.258	0.300	9.68	11.19
Mean distance from all routes combined	0.267	0.348	9.98	12.91
Mean distance from KWS stations	0.354	0.369	13.13	13.67
Sum of human damage in adjacent forest	0.081	0.061	3.30	2.52
Presence/ absence of tea strip	0.295	N/A	10.99	N/A

* No spatial auto-correlation at Norm z < 1.96

6.2.3. Socio-economic surveys

Two comparative socio-economic surveys were conducted in Meru-Imenti, in Meru Central District in the north-east, and in Hombe-Kabaru, Nyeri District in the south-west (Figure 6.4). The raw data for the socio-economic survey in Meru-Imenti, in which 75 households were interviewed, was obtained from J. Mathuva (2002) who conducted the original survey.

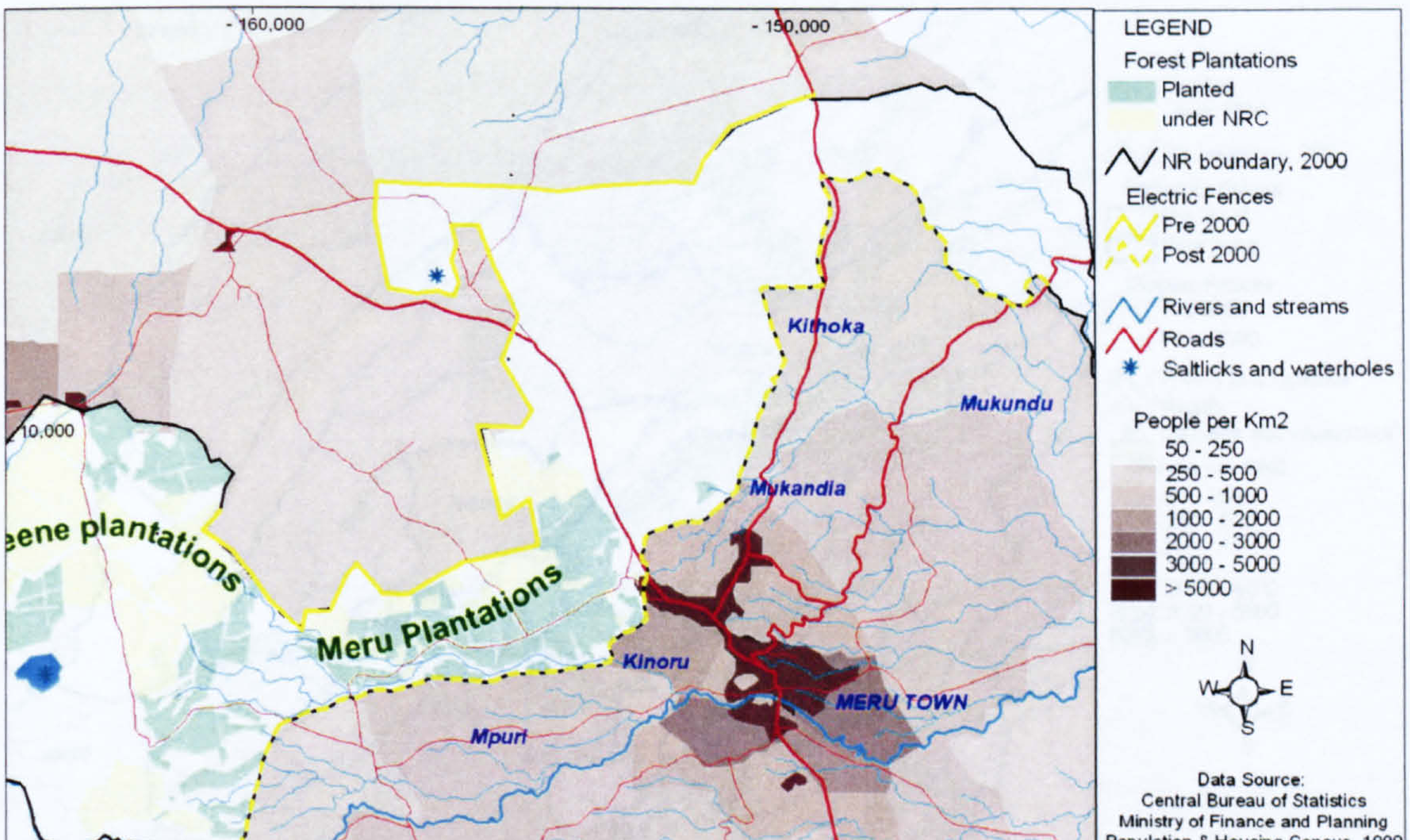
Figure 6.4. The case-study areas Meru-Imenti and Hombe-Kabaru



To obtain comparative socio-economic data, the Hombe-Kabaru area, two-page data sheets were modelled on those used by J. Mathuva in 2002 for the Meru-Imenti survey (Appendix VI). Five trained assistants, chosen among residents because most farmers speak local dialects and are wary of strangers, interviewed representatives of 74 households. The assistants were paid per completed interview, a system that was appreciated by the assistants and the local farmers who did not get paid but were nevertheless very co-operative. Elephant damages on tree plantations were measured at Hombe-Kabaru but not at Meru-Imenti, where access was not granted to the plantations.

The households interviewed in Meru-Imenti came from the locations of Mpuri (N = 9), Kinoru (N = 10), Mukandia (N = 14), Kithoka (N = 26), and Mukundu (N = 16) (Figure 6.5).

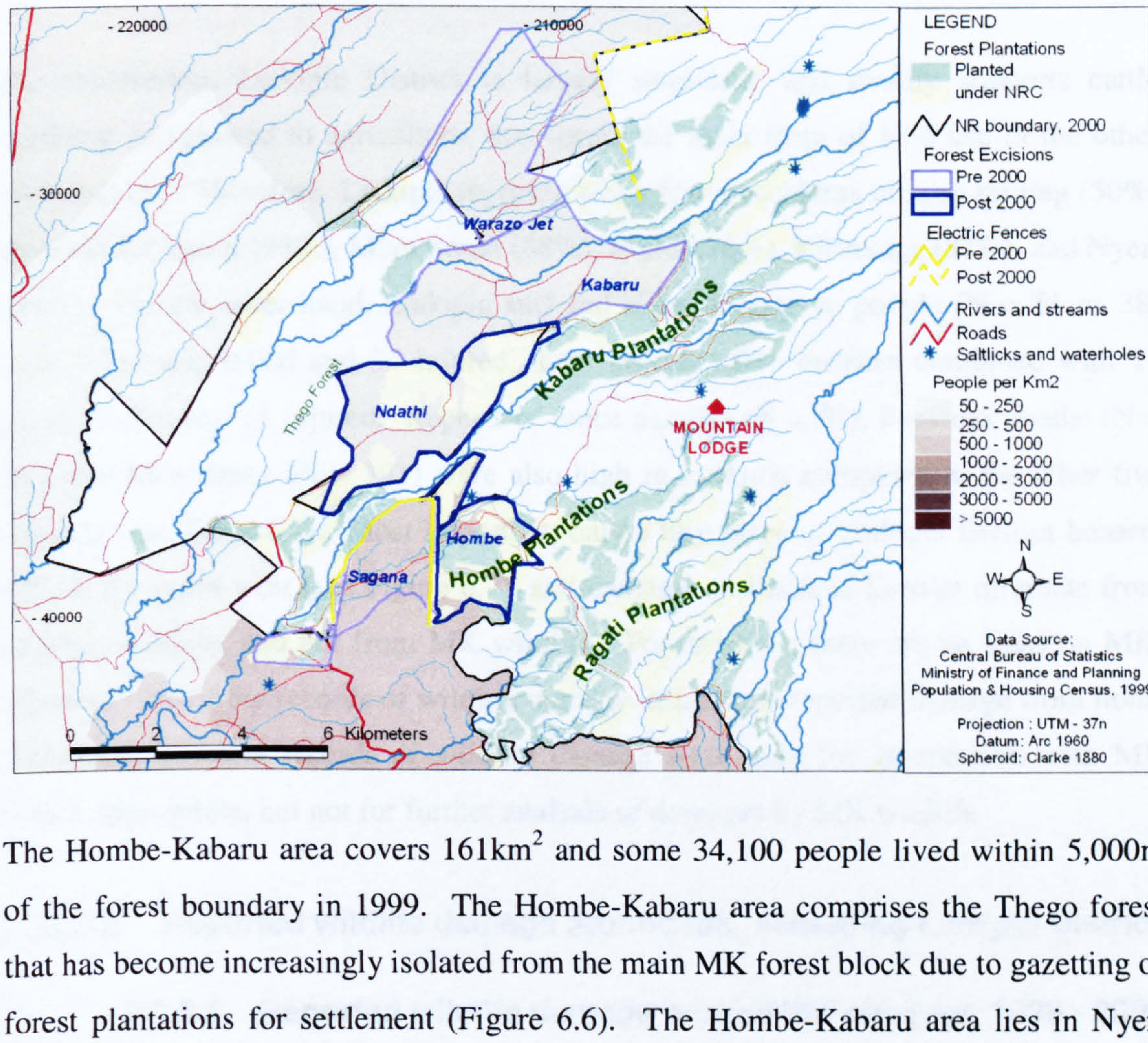
Figure 6.5. The Meru-Imenti area with locations where interviews took place



A GIS raster layer of 5,000m around the boundary of MK protected area was created in the same way that the 1,000m strip was created (see Figure 6.2). The area per location was multiplied by figures of human population density per location derived from the National Bureau of Statistics (Republic of Kenya, 2000) to obtain numbers of people living within the 5,000m strip. The Meru-Imenti area covers 202km^2 and some 117,400 people lived within 5,000m of the forest boundary in 1999. Intensive land-use practices in Meru-Imenti started in the early 1930s and the MK and Imenti forests were declared Forest Reserves in 1932 to protect them against over-exploitation (Emerton, 1999; M'Imanyara, 1992). Expansion of settlement occurred fast but slowed down after 1995 due to saturation of land (Mathuva, 2002). Human density at Meru-Imenti was very high because Meru town, the largest town around MK with 6,097 people/ km^2, lies within the 5,000m strip (Figure 6.5).

The households interviewed in Hombe-Kabaru came from farmers on Hombe plantations under NRC (N = 10), Hombe-Ragati (N = 24), Sagana (N = 20), and Kabaru-Ndathi (N = 20) (Figure 6.6).

Figure 6.6. The Hombe-Kabaru area with locations where interviews took place



The Hombe-Kabaru area covers 161km^2 and some 34,100 people lived within 5,000m of the forest boundary in 1999. The Hombe-Kabaru area comprises the Thego forest that has become increasingly isolated from the main MK forest block due to gazetting of forest plantations for settlement (Figure 6.6). The Hombe-Kabaru area lies in Nyeri District, which was more influenced than the other districts by white colonists, who introduced the practices of commercial agriculture, farming of coffee, tea and rice, and animal husbandry (Ayiemba, 1989; Wanjau, 1997).

6.3. RESULTS

6.3.1. Reported wildlife damage around MK from OB records

Exploration of a total of 3,463 reports of wildlife damage in OBs from January 1999 to December 2002, showed that elephants featured in as much as 78% of the damage reports, primates in 9%, buffalo in 6%, carnivores in 3%, hippopotamus and crocodiles in 3%, and small ungulates and pigs in 1% of the damage reports. However, of these reports, 691 records came from Laikipia District, which is different from the five other districts around MK in several ways, and which may skew the picture of reports of damage caused by MK wildlife.

By comparison, Laikipia District is largely semi-arid, and mainly supports cattle ranching as opposed to agriculture, that forms the main form of land use in the other five districts. Therefore, Laikipia reported many fewer incidents of crop raiding (50%) than Meru Central (95%), Meru South (88%), Embu (76%), Kirinyaga (83%), and Nyeri (89%). On the other hand, Laikipia suffered more damage to people (N = 51 vs 38) with 17 people killed and 34 injured, than the other five districts combined with 17 people killed and 21 injured. Reports of fence damage (N = 92), livestock deaths (N = 80), and harassment (N = 193) were also high in Laikipia compared to the other five districts (see Table 6.4). Most important, only a tiny piece of Laikipia District borders MK in the north-west (see Figure 6.7), and damages in Laikipia District originate from resident wildlife, and not from MK wildlife. For example, there are no lions on MK, whereas 12% of the records of wildlife damage in Laikipia reported damage from lions. Therefore, Laikipia records of wildlife damage were used for comparison with MK where appropriate, but not for further analysis of damages by MK wildlife.

6.3.2. Reported wildlife damage around MK, excluding Laikipia District

6.3.2.1. Reported wildlife damage around MK per year, 1999 - 2002

Some 2,772 wildlife damage events were reported between 1999 and 2002, in the five districts around MK combined, excluding Laikipia District. The number of reports of wildlife damage had increased overall by 215%, from 375 reports in 1999 to 1,246 in 2002. In particular, reports of crop damage, fence damage, and attacks on livestock had increased dramatically (Table 6.2). However, if the 215% increase in reported damage represented a real increase in damage events, the number of fatal encounters would have increased accordingly, as these are always reported due to the financial compensation involved. There was no evidence of this latter increase, and reports of wildlife harassing people even decreased by 48%, suggesting that the observed increase more likely reflects changes in reporting efficiency of crop raiding incidents rather than actual increases in wildlife damage (Table 6.2).

Table 6.2. Annual number of reported wildlife damage, wildlife chased and shot in PAC, and poached and injured wildlife around MK, excluding Laikipia, 1999 - 2002

Year	*Total # Records*	*Crop raids*	*Fence damage*	*People injured or killed*	*Livestock injured or killed*	*People harassment*	*Wildlife chased in PAC*	*Wildlife shot in PAC*	*Wildlife poached*	*Wildlife injured*
1999	375	288	1	11	7	68	178	27	5	2
2000	496	434	1	9	13	39	173	42	13	2
2001	655	581	6	5	36	27	148	12	0	0
2002	1,246	1,113	9	13	65	46	187	20	1	0
% increase	215	286	800	18	829	-48	5	-26	-80	-100

The number of reported KWS problem-animal control or PAC actions, representing the help that KWS gives to farmers by chasing wildlife from their land, had changed little between years (5% increase). The number of animals killed on PAC and the number of wildlife reported poached and injured reduced dramatically after 2000 (Table 6.2). However, an elephant identification study at the Mountain Lodge salt-lick, south-west MK, reported over 20 injured elephants and 2 calves that were euthanised in 2002 alone, suggesting that reporting of injured wildlife in OBs is hugely neglected.

6.3.2.2. Reported wildlife damage around MK per district

Of all reports of wildlife damage for the five districts around MK, excluding Laikipia, elephants featured in 80.2% of damage reports, making out more than 90% of all wildlife damage reports in Kirinyaga District and Meru Central District (Table 6.3). Other species that were reported to cause important (> 5%) damage comprised: primates in Meru South District; primates, and hippopotamus and crocodiles in Embu District; and, primates and buffalo in Nyeri District (Table 6.3).

Table 6.3. OB records per species in different districts, 1999 – 2002

Districts	*Number of reports*	*Elephants*	*Primates*	*Buffalo*	*Hippopotamus and crocodiles*	*Carnivores*	*Small ungulates and pigs*
Meru Central	1,164	94.3	3.9	0.1	0.4	1.3	-
Meru South	64	70.3	25.0	-	1.6	3.1	-
Embu	291	72.6	10.8	1.0	12.8	2.8	-
Kirinyaga	214	98.6	0.9	-	-	0.5	-
Nyeri	1,039	65.4	10.0	22.5	-	1.0	1.1
Total	2,772	80.2	10.1	4.7	3.0	1.7	0.2

Of all reports of wildlife damage for the five districts around MK, excluding Laikipia, crop raids featured in 89% of the reports, wildlife fence damage in 1% of the reports, wildlife attacks on people resulting in human deaths or injuries in 1% of the reports, wildlife attacks on livestock in 5% of the reports, and wildlife harassments featured in 8% of the reports (Table 6.4).

Table 6.4. Damages by MK wildlife for 1999 – 2002, excluding Laikipia

Districts	*Total # Records*	*Crop raids*	*Fence damage*	*People injured or killed*	*Livestock injured or killed*	*People harassment*	*Wildlife shot in PAC*	*Wildlife poached*	*Wildlife injured*
Meru Central	1,164	1,103	1	7	18	37	26	5	3
Meru South	64	56	-	-	43	6	5	-	-
Embu	291	220	-	9	78	50	19	2	1
Kirinyaga	214	177	1	7	2	31	4	1	-
Nyeri	1,039	921	15	15	10	86	47	11	-
Total	2,772	2,477	17	38	151	210	101	19	4

Most reports on poached wildlife (N = 11) and on wildlife shot in PAC (N = 47) came from Nyeri District. Also Meru Central District reported 26 wildlife deaths in PAC. Of the total of 101 reports of animals that were shot in PAC, 66 featured baboons, 17 buffalos, 14 elephants, 3 hyenas and 1 crocodile. Of the 19 reported animals that were found poached, 8 were elephants, 10 leopards, and 1 hippo, and the 4 reported injured animals were all elephants. Of all reports of wildlife damage for the five districts around MK, excluding Laikipia, 83% of reported crop raids were by elephants, 82% of reported fence damage were by elephants, 47% of reported wildlife attacks on people were by elephants, only 2% of reported wildlife attacks on livestock were by elephants, and 74% of reported wildlife harassments were by elephants (Table 6.5).

Table 6.5. Reported damages by MK wildlife, and dead and injured wildlife

Species	*Total # Records*	*Crop raids*	*Fence damage*	*People injured or killed*	*Livestock injured or killed*	*People harassment*	*Wildlife shot in PAC*	*Wildlife poached*	*Wildlife injured*
Elephants	2,243	2,045	14	18	3	156	14	8	4
Buffalo	238	203	3	6	1	32	17	-	-
Primates	198	198	-	1	33	4	66	-	-
Carnivores	36	-	-	4	105	2	3	10	-
Pigs & ungulates	11	11	-	-	-	-	-	-	-
Hippo & crocs	43	20	-	9	8	13	1	1	-
Other	3	-	-	-	1	3	-	-	-
Total	2,772	2,477	17	38	151	210	101	19	4

Table 6.4 shows that elephant crop raids represent as much as 74% of all reported wildlife damages around MK, which will be investigated in more detail next.

6.3.3. Reported elephant crop raids around MK, excluding Laikipia

Of 2,045 reports of elephant crop damage, 647 specified the type of crop that was damaged, of which 48% reported damaged maize, 24% beans, 18% potatoes, and 10% cabbage (Table 6.6).

Table 6.6. Elephant crop damage reports around Mount Kenya, 1999 – 2002

Districts	*All crops*	*Identified crops*	*Maize*	*Potatoes*	*Beans*	*Cabbage*
Meru Central	1,057	183	103	35	39	6
Meru South	40	34	18	6	3	7
Embu	170	156	71	40	23	22
Kirinyaga	175	139	67	25	33	14
Nyeri	603	135	49	47	21	18
Total	2,045	647	308	153	119	67

The types of crops damaged varied between districts (x^2 = 40.37, df = 4, P < 0.001). However, there was no significant difference in elephant crop raid reporting between months (x^2 = 1.45, df = 11, P > 0.05) for the five districts around MK, excluding Laikipia. Maize was the most affected crop for all districts but investigation of crop composition on farms in the Meru-Imenti and the Hombe-Kabaru case study areas, discussed later (6.3.3.1), showed that maize was also by far the most common crop around MK. When proportions of crops grown were examined in relation to proportions damaged, maize did not emerge as any more favoured than potatoes around MK.

The spatio-temporal distributions of elephant crop damage reports per month (Figure 6.7) showed that most crop damage occurred at Meru Central and Nyeri. In contrast, comparatively little damage occurred at Meru South, Embu and Kirinyaga. Meru Central and Nyeri were also the two districts where most GIS traced routes and paths were found to cross the forest boundary into farmland (see Figure 6.2).

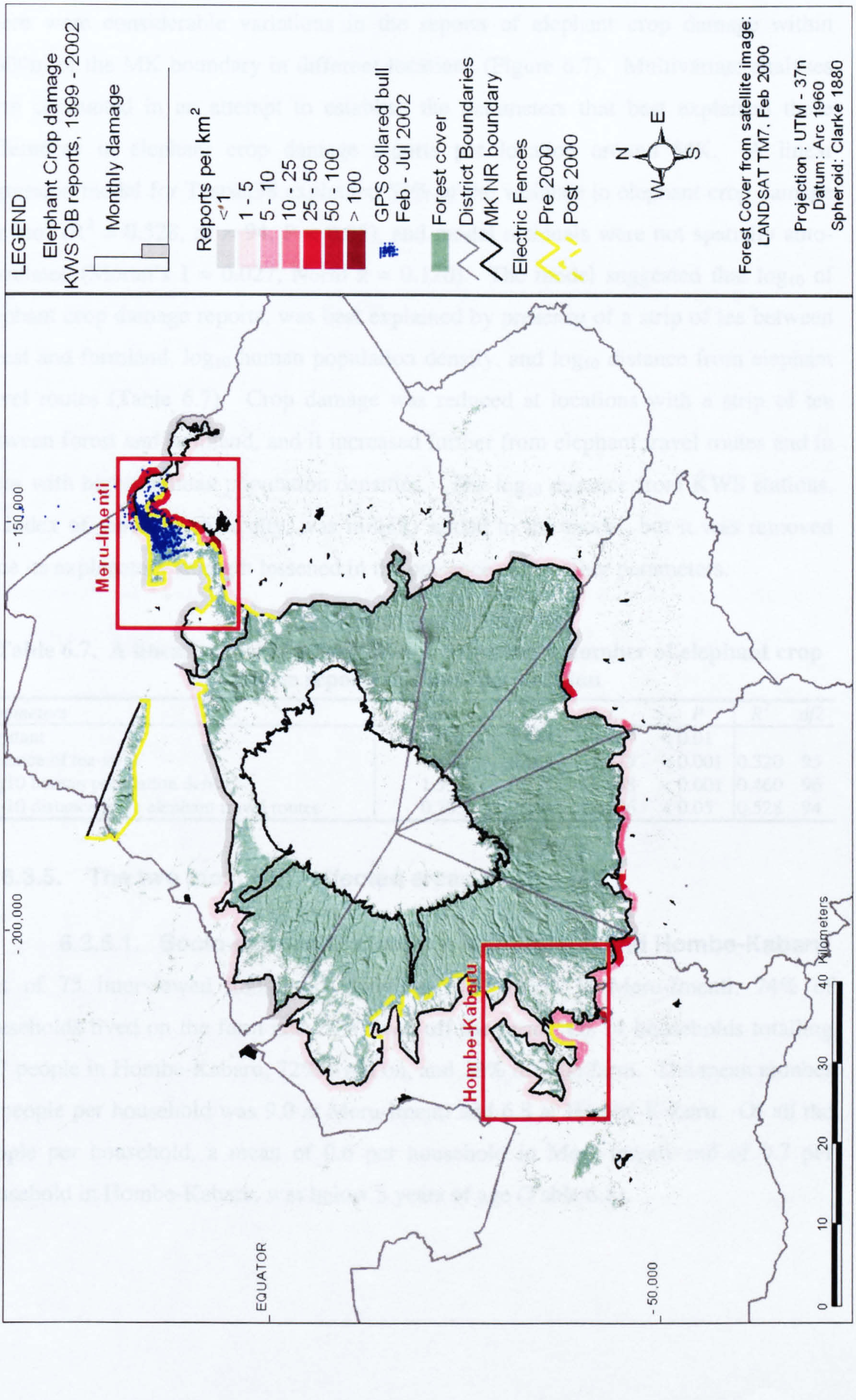


Figure 6.7. Reports of elephant crop damage to farms located within a 1,000m strip around the MK forest boundary, 1999 – 2002

6.3.4. Multivariate analysis of elephant crop damage

There were considerable variations in the reports of elephant crop damage within 1,000m of the MK boundary in different locations (Figure 6.7). Multivariate analyses were conducted in an attempt to establish the parameters that best explained these differences in elephant crop damage reports per location around MK. A linear regression model for Testset98 explained 53% of the variance in elephant crop damage per km^2 ($R^2 = 0.528$, df = 94, $P < 0.05$), and model residuals were not spatially auto-correlated (Moran's I = 0.027, Norm z = 0.120). The model suggested that $\log_{10}$ of elephant crop damage reports, was best explained by presence of a strip of tea between forest and farmland, $\log_{10}$ human population density, and $\log_{10}$ distance from elephant travel routes (Table 6.7). Crop damage was reduced at locations with a strip of tea between forest and farmland, and it increased further from elephant travel routes and in areas with higher human population densities. The $\log_{10}$ distance from KWS stations, an index of reporting difficulty, was initially added to the model, but it was removed once its explanatory strength lessened in the presence of the other parameters.

Table 6.7. A linear model of testset98 explaining log10 number of elephant crop damage reports per km2 per location

Parameters	*Coefficient(β)*	*SE*	*t*	*P*	R^2	*df2*
Constant	-5.343	1.444	-3.701	< 0.01		
Presence of tea-strip	-0.880	0.164	-5.379	< 0.001	0.320	95
Log10 human population density	1.532	0.271	5.658	< 0.001	0.460	96
Log10 distance from elephant travel routes	0.793	0.304	2.606	< 0.05	0.528	94

6.3.5. The two most HEC-affected areas around MK

6.3.5.1. Socio-economic status in Meru-Imenti and Hombe-Kabaru

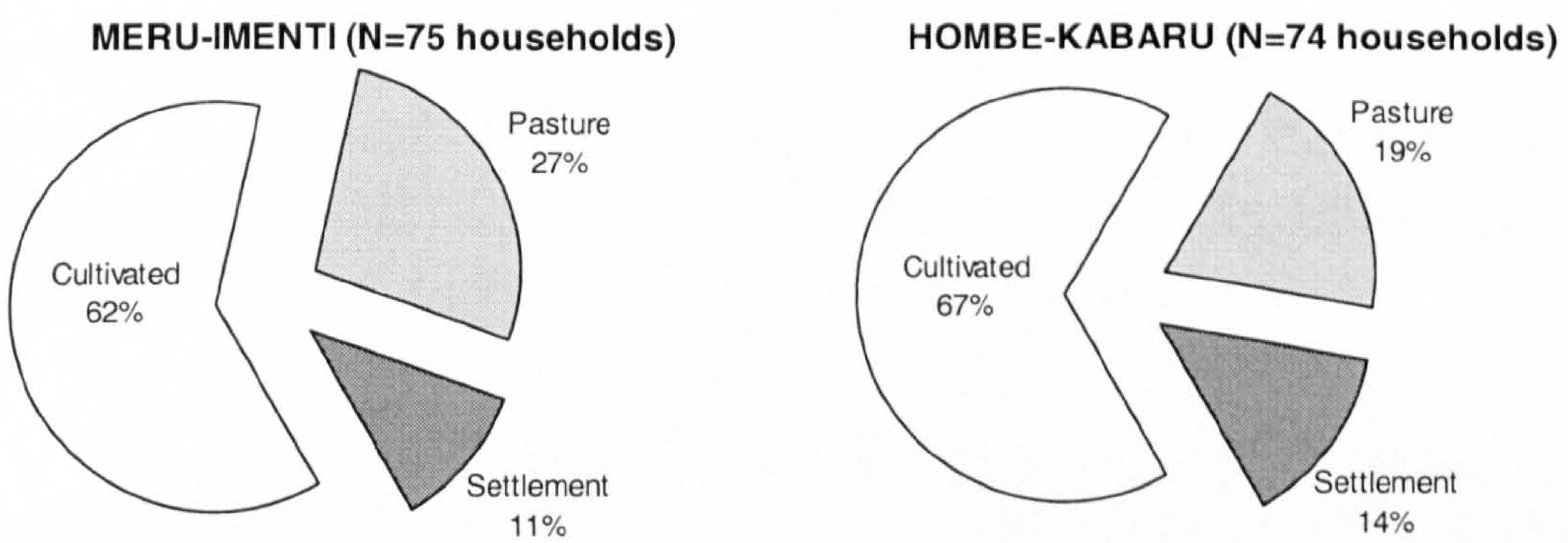
Out of 75 interviewed households totalling 663 people in Meru-Imenti, 74% of households lived on the farm and 26% lived off the farm. Of 74 households totalling 487 people in Hombe-Kabaru, 72% lived on, and 28% off, the farm. The mean number of people per household was 9.0 at Meru-Imenti and 6.8 at Hombe-Kabaru. Of all the people per household, a mean of 0.6 per household in Meru-Imenti and of 0.7 per household in Hombe-Kabaru, was below 5 years of age (Table 6.8).

Table 6.8. Household and farm composition in Meru-Imenti and Hombe-Kabaru

Household characteristics of interviewed farmers, 2002	*Meru-Imenti*	*Range Min - max*	*Hombe-Kabaru*	*Range Min - Max*
No. of interviewed households	75		74	
No. of people in interviewed households	663		487	
No. of people per household	9.0	2 - 33	6.8	1 - 20
No. of children below 5 years of age	0.6	0 - 5	0.7	0 - 4
Size of farm in hectares	1.6	0.2 - 11.2	0.8	0.12 – 2.4
Land value in Kenya Shillings/ hectare	1,501,494	270,000 - 5,400,000	519,114	243,000 - 810,000

The land value at Meru-Imenti was with Kshs 1,501,494 per ha, about 3 times higher than at Hombe-Kabaru. At Meru-Imenti, over 80% of households owned their land, whereas 32% of households in Hombe-Kabaru lived on government-donated land. Most farms at Meru-Imenti and Hombe-Kabaru (73% and 95%) were less then 1.6ha. The average Meru-Imenti farm was 1.6ha in size, whereas the Hombe-Kabaru farm was 0.8ha. Crops occupied 62% and 67%, pasture 27% and 19%, and settlement 11% and 14% of the farm areas at Meru-Imenti and Hombe-Kabaru, respectively (Figure 6.9).

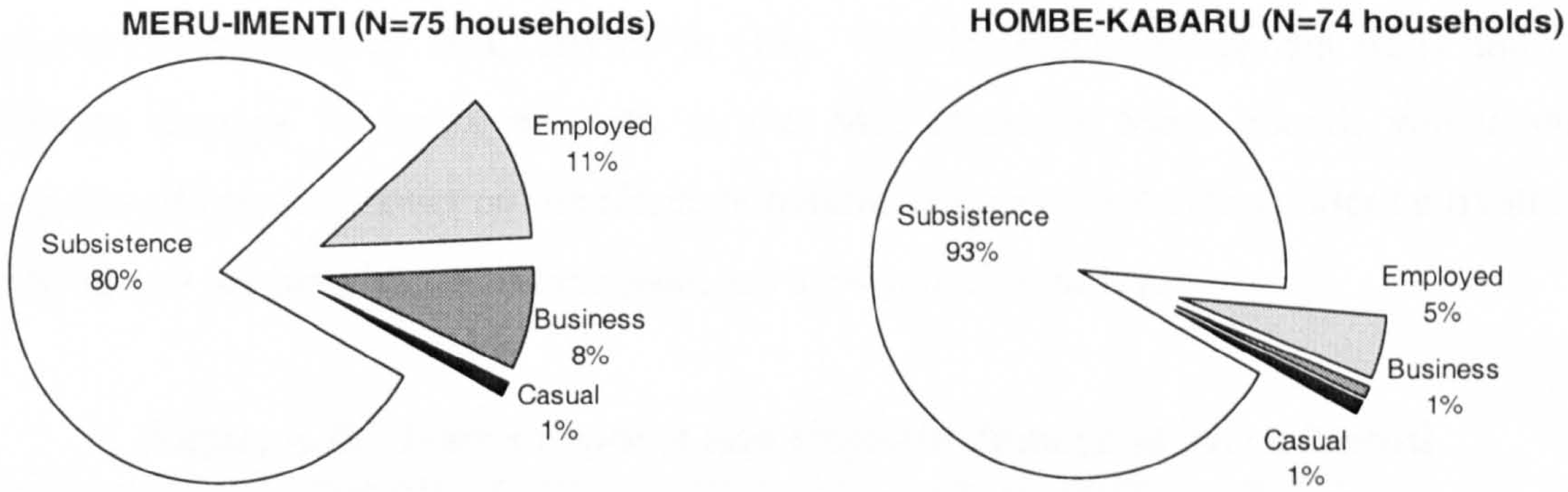
Figure 6.9. Structure of household farms at Meru-Imenti and Hombe-Kabaru



At Meru-Imenti, the most popular crops grown were maize, beans, bananas, Irish potatoes and coffee, with almost 100% of the farms having maize as their first crop, and 89% combining maize with beans, 8% with sorghum and 3% with peas, as their second crop. In contrast, maize was not the overall first crop at Hombe-Kabaru. Although 73% of farms had maize, only 38% had it as their first crop. Some 92% of the Hombe-Kabaru farms cultivated potatoes and 28% had it as their first crop. Other first crops included cabbages (22%), horticulture crops (8%), beans (3%), and tea (1%) at Hombe-Kabaru.

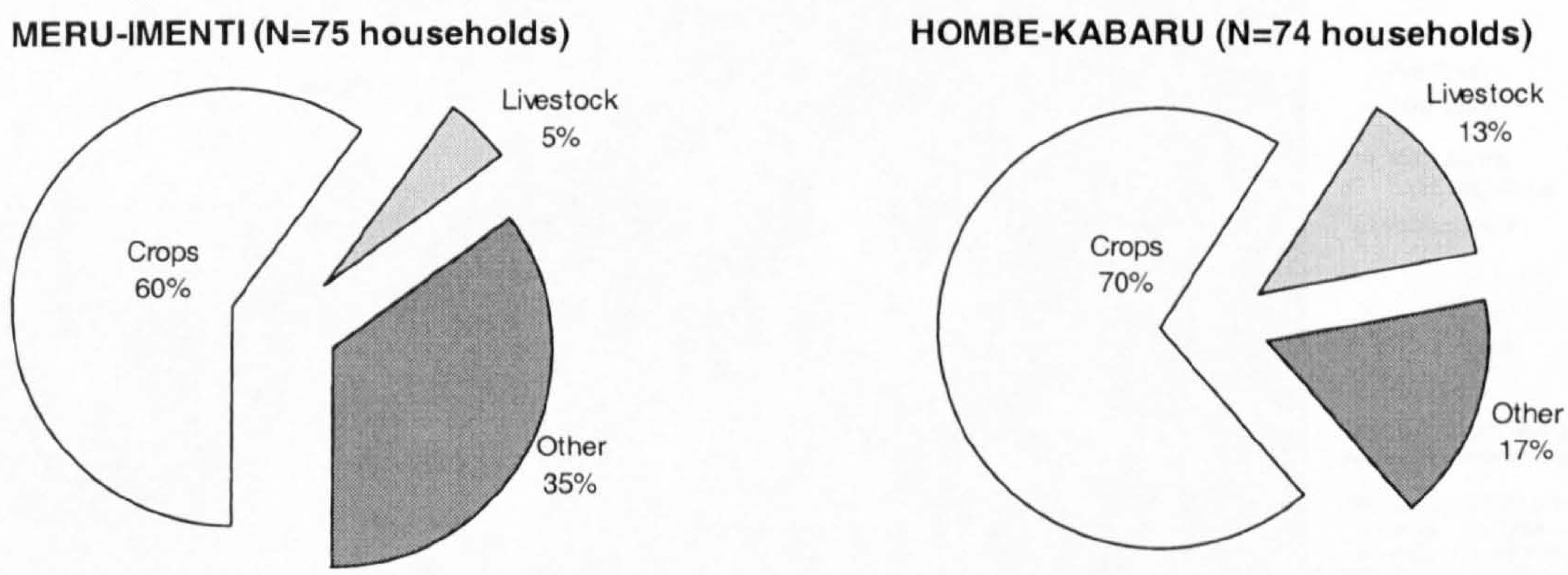
Education has become increasingly important over the last two decades. Very few adults, 7% in Meru-Imenti and 1% in Hombe-Kabaru, had never been to school. Some 46% of adults in Meru-Imenti and 39 % in Hombe-Kabaru had finished primary education, 36% in Meru-Imenti and 56% in Hombe-Kabaru had finished secondary education, and 11% in Meru-Imenti and 4% in Hombe-Kabaru of the adults had been to university. Most adults at Meru-Imenti and Hombe-Kabaru were subsistence farmers, while a few were employed, ran businesses, or had casual jobs (Figure 6.10).

Figure 6.10. Occupation of adults in Meru-Imenti and Hombe-Kabaru household



Subsistence farming was thus the main occupation at both Meru-Imenti and Hombe-Kabaru. Crops accounted for most of all incomes in Meru-Imenti and Hombe-Kabaru, and a large part came from sale of livestock products, and other incomes from remittances from working kin and casual labour (Figure 6.11).

Figure 6.11. Household income at Meru-Imenti and Hombe-Kabaru



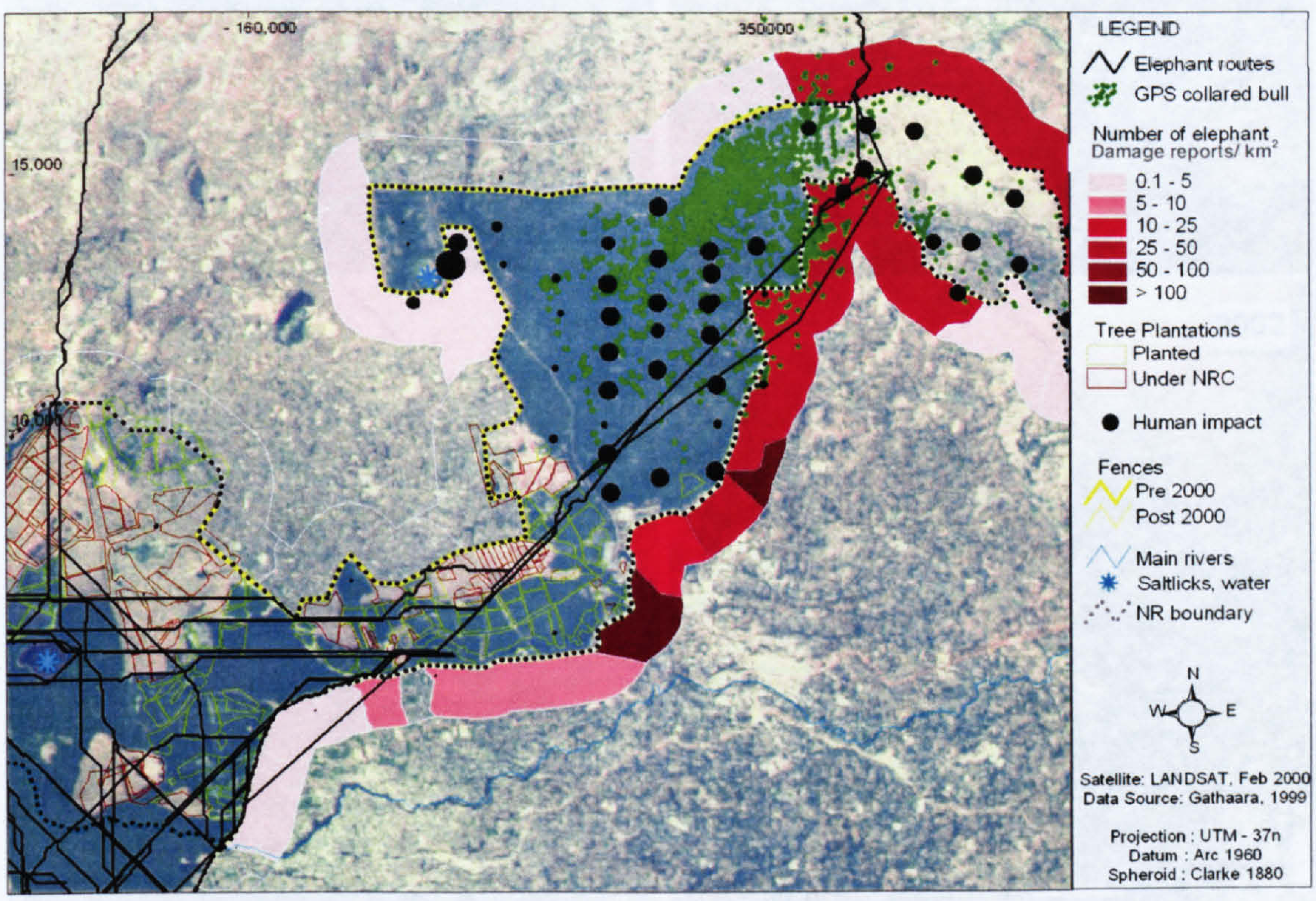
Some 76% of farmers in Meru-Imenti, and 73% in Hombe-Kabaru, kept poultry, 59% and 58% kept dairy cattle, 62% and 49% kept sheep or goats, while 11% and 16% of farms did not keep any livestock at Meru-Imenti and Hombe-Kabaru, respectively.

Some 54% of households at Meru-Imenti and 40% of households at Hombe-Kabaru owned a bicycle, 44% at Meru-Imenti and 40% at Hombe-Kabaru had a television set, while all households had a radio. Although electricity is available in the Meru-Imenti area due to the proximity of Meru Town, it was not extensively used on farms. Assets such as vehicles, telephones, and ox-drawn carts were rare.

6.3.5.2. Use of MK resources at Meru-Imenti and Hombe-Kabaru

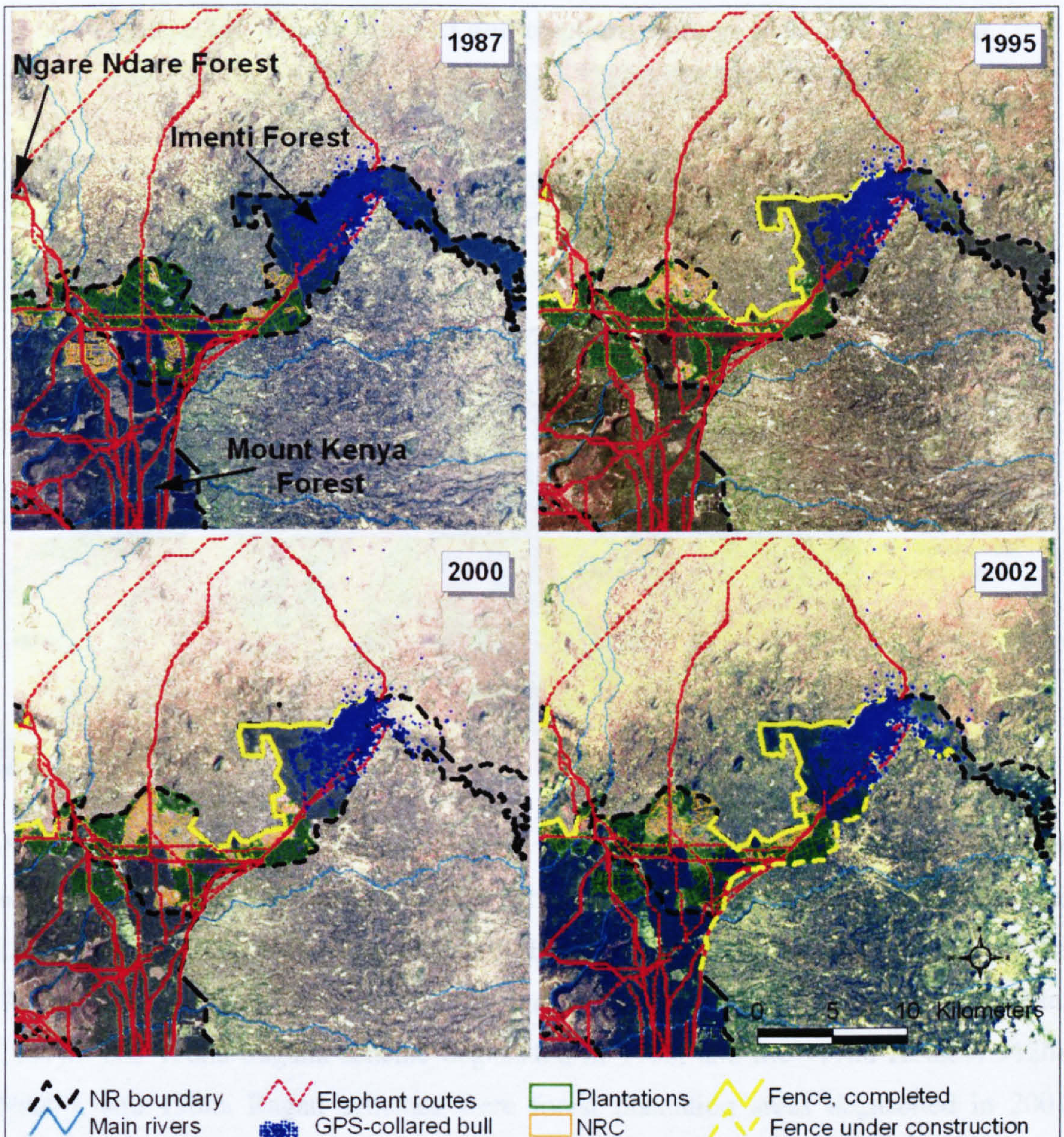
Exploring the spatial patterns of human damage on forest resources and land at Meru-Imenti and Hombe-Kabaru revealed more about the potential causes of HEC than multivariate analysis of HEC reports in OBs. The locations of elephant trails and of elephant damage to farms adjacent to the MK forest at Meru-Imenti, versus the locations of human impact on the elephant habitat, such as plantations under cultivation or NRC and human impact on the forest, are shown in Figure 6.12.

Figure 6.12. Human impact and elephant damage at Meru-Imenti



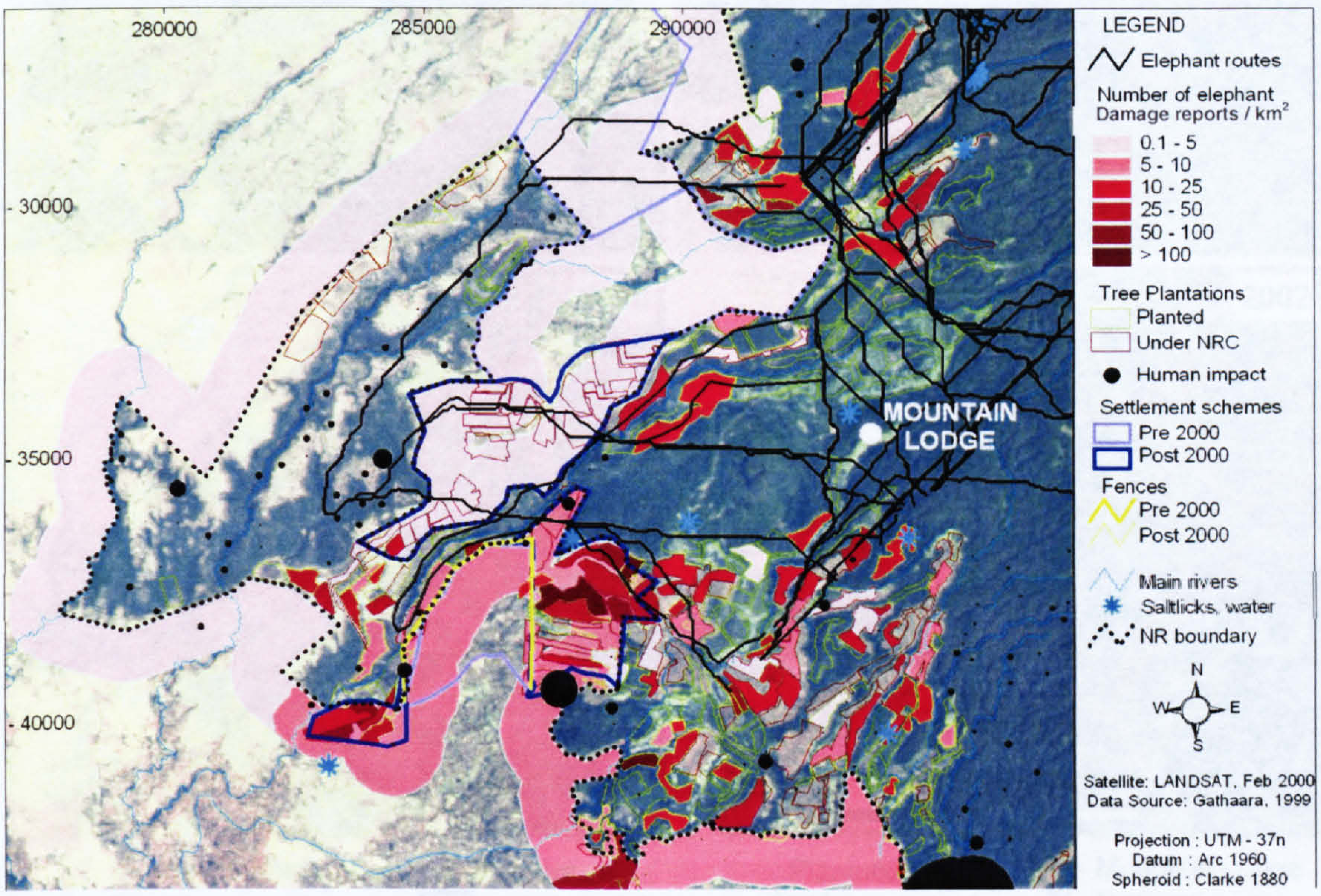
As predicted, elephant damage to farms was pronounced where elephant routes crossed the MK boundary into farmland. Although elephant damage to plantation at Meru-Imenti could not be measured (see methods) it was predicted that damage by elephants in plantations would be substantial, given that many elephant routes pass through them. The data from a GPS collared bull illustrate the routes used by elephants to access and leave MK (Figure 6.12). Currently the strip of forest that connects MK with the Imenti forest is notably thin and almost entirely plantation forest. This thin strip has been under NRC since 1987. In general, few plantation blocks were under NRC in 1987, many blocks were clear-felled and under NRC by 1995 and were still under NRC in 2000, and some were still under NRC in 2002 (Figure 6.13).

Figure 6.13. Elephant and human use of land and resource in Meru-Imenti



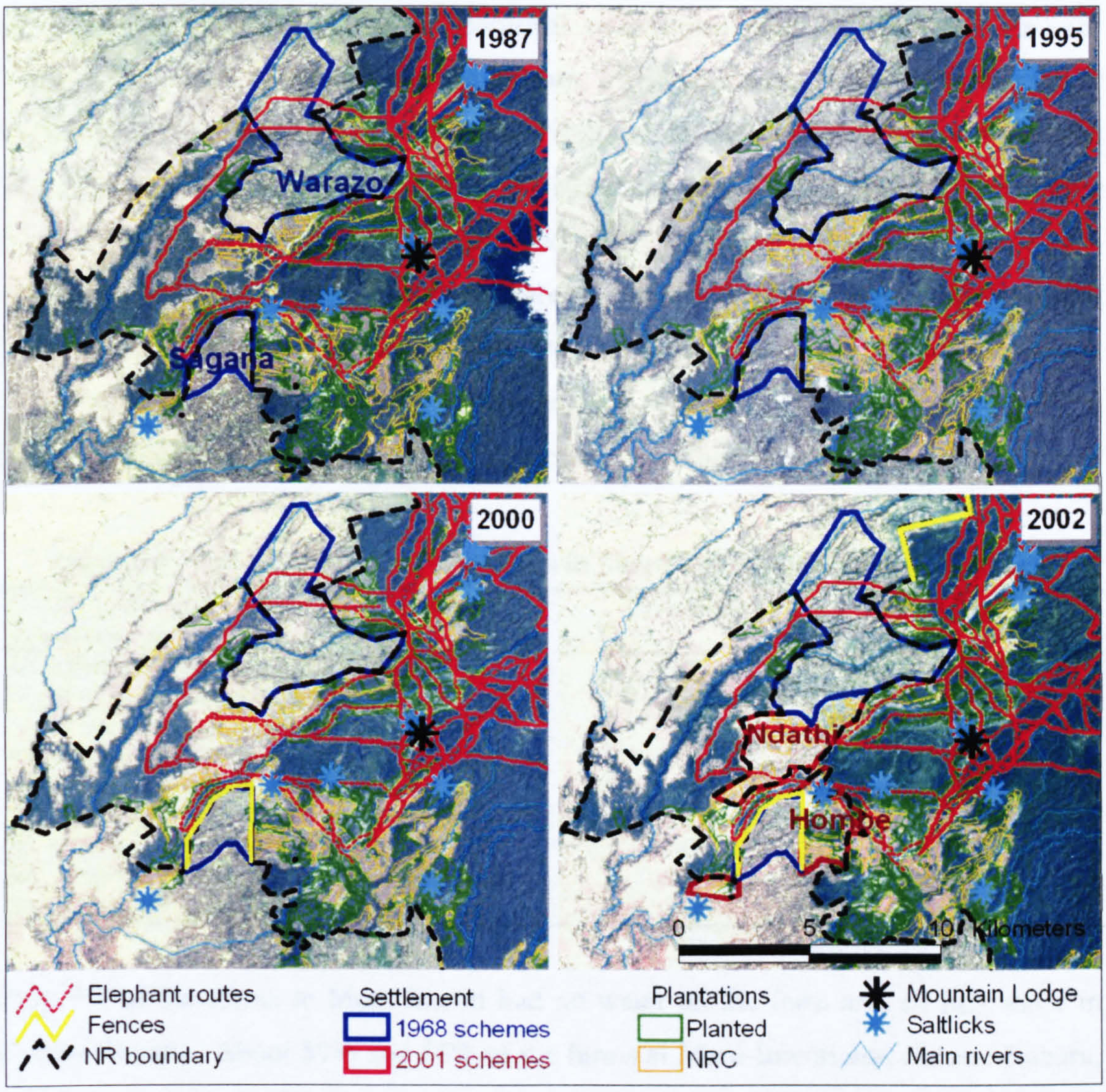
The Hombe-Kabaru situation resembles the Meru-Imenti situation in terms of elephant damage to human resources, with most elephant damage occurring close to elephant routes and to NRC. In contrast to Meru-Imenti, however, the Hombe-Kabaru area also includes the Mountain Lodge salt-lick close to settlement that attracts large numbers of elephants on a daily basis, - as was found from an ongoing elephant identification study launched at the salt-lick and that reported over 500 different elephants visiting the salt-lick in 2002. The strong presence of elephants at the salt-lick may co-determines levels of HEC in plantations and on farmland close to the salt-lick (Figure 6.14).

Figure 6.14. Human impact and elephant damage at Hombe-Kabaru



Additionally, several hundreds of hectares of plantation and indigenous forest areas were degazetted for settlement schemes, which brought people closer to the Mountain Lodge salt-lick, increasing the extent of HEC incidents (Figure 6.15). The 947ha Warazo Jet scheme established in 1968 was unoccupied forest before 1962 (Wanjau, 1997). The 486ha Sagana scheme degazetted in 1968, and the 717ha Hombe, 912ha Ndathi, and 196ha Ragati schemes were forest plantation areas degazetted in 2001 (Figure 6.15). The Hombe and Ndathi excisions have been subject of a series of disputes because the inhabitants are NRC farmers who have violated the allowed period of NRC cultivation since 1990 (Figure 6.15). When this was noticed, the farmers were not evicted from the land but instead, the Government degazetted the forest areas as the Hombe and Ndathi settlement schemes, evoking major protest by conservation NGO's.

Figure 6.15. Elephant and human use of land and resource in Hombe-Kabaru



Human impact on elephant resources was also substantial in Meru-Imenti and Hombe-Kabaru. During an aerial survey conducted in 1999 (Gathaara, 1999), 97 damages were recorded in the Meru-Imenti forest, representing an area of 238ha, of which 23ha was destroyed for charcoal and 209ha for timber. On satellite imagery from February 2000, a large piece of the Imenti forest totally disappeared on the image (north-east of Figure 6.13). At Hombe-Kabaru, some 120ha of forest were destroyed by people, of which

62ha were destroyed for charcoal (concentrated in Thego forest), 40ha from logging, and 16ha through encroachment (Gathaara, 1999).

The human pressure on elephant habitat mainly comes from communities living within 5,000m of the forest boundary, for whom MK represents a direct source of firewood, charcoal, timber, water, grazing, additional cultivation, medicinal herbs, hives, for honey and to some extent also meat (Emerton, 1997; Gathaara, 1999). Trees and water are the main resources. Some 77% farms lying within 5,000m of the MK boundary in Meru-Imenti and Hombe-Kabaru built their housing with timber, and all farms used firewood as their first source of energy. Some 25% of farms in Meru-Imenti and 91% in Hombe-Kabaru said they also used charcoal. Given the problem of illicit charcoal production in Meru-Imenti (Figure 6.12; Chapter 7), the real figure for charcoal use in Meru-Imenti is probably much higher. Some 52% of farms in Meru-Imenti and 53% in Hombe-Kabaru had one or some fuel-trees growing on their farms (Table 6.9).

Table 6.9. Use of MK forest resources in Meru-Imenti and Hombe-Kabaru

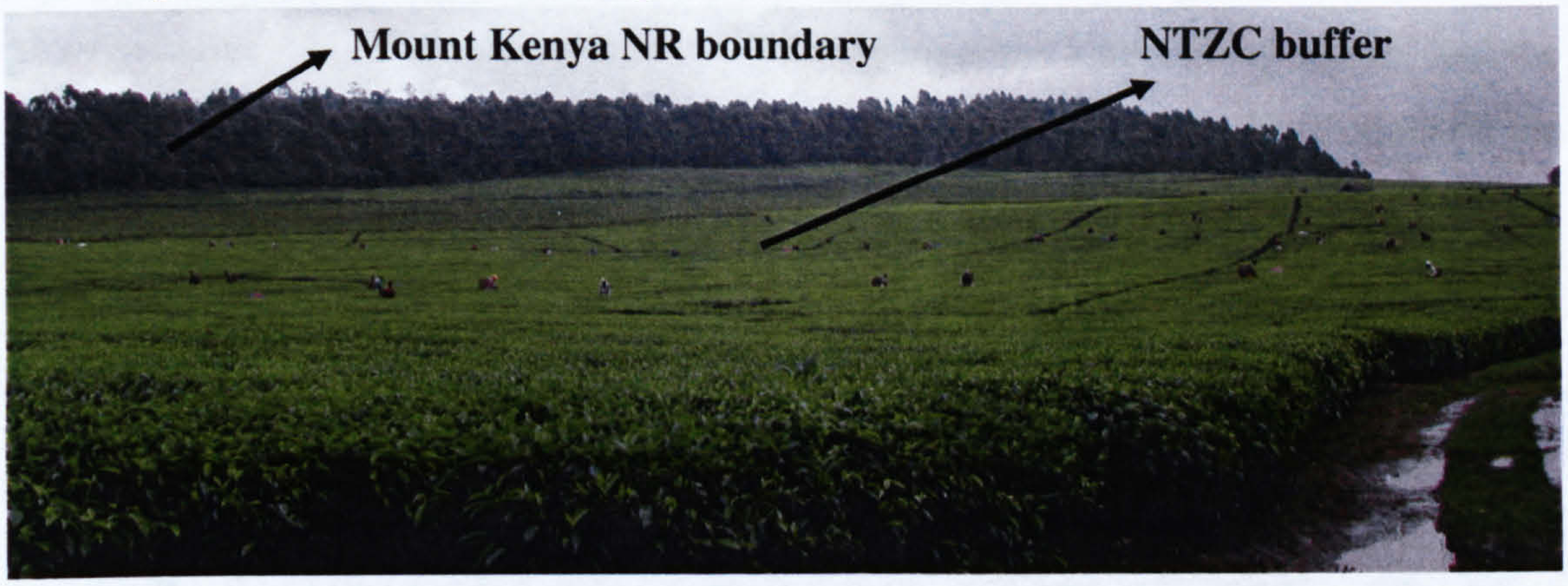
Use of forest resources by interviewed farmers, 2002	*Meru-Imenti*	*Hombe-Kabaru*
No. of interviewed farming households	**75**	**74**
No. of farms building wooden houses	58	57
No. of farms using firewood	75	74
No. of farms using charcoal	19	67
No. of farms having fuelwood trees	39	39
No. of farms having no water on the farm	5	0
No. of farms depending on piped water	44	41
No. of farms depending on river or furrow water	21	22
No. of farms irrigating a section of their crops	49	49

Only 7% of the farms in Meru-Imenti had no water on the farm and all had water in Hombe-Kabaru. About 59% and 55% of the farms at Meru-Imenti and Hombe-Kabaru, respectively, had piped water, 28% and 30% depended on rivers and furrows, and the rest depended on wells and reservoirs. The Hombe-Kabaru area had many problems with water-transmitted diseases from furrows, which are easily contaminated because they are open and run through settlement (JIKA/GOK, 1999). Some 65% of Meru-Imenti farms and 66% Hombe-Kabaru farms had a section of their crops under irrigation (Table 6.8). Although that the irrigated section was usually very small, productivity on irrigated land more than doubled that on rain-fed land, and annual incomes for farms that had a section under irrigation was 40% higher than for farms without irrigation. Both Meru-Imenti and Hombe-Kabaru are located at the edge of the rainy side of the mountain and suffer from dry seasons water shortage.

6.3.5.3. HEC mitigation at Meru-Imenti and Hombe-Kabaru

Several HEC mitigation strategies have been tested at Meru-Imenti and Hombe-Kabaru. Several dozens of on-farm agroforestry projects (Mbora and Simons, 2002) and the NTZC strip are among the few projects that address the underlying cause to HEC around MK. The NTZC strip between the forest and farmland reduced elephant crop damage (see Table 6.6), possibly because exposure discourages elephants from crossing the tea strip (Figure 6.16). However, the NTZC strip only occurs on the rainy side of MK, clockwise from north-east to south-west of MK, and is much less represented in Meru-Imenti and Hombe-Kabaru that are located at the two outer ends of the rainy side.

Figure 6.16. The NTCZ strip between farmland and forest, south of MK



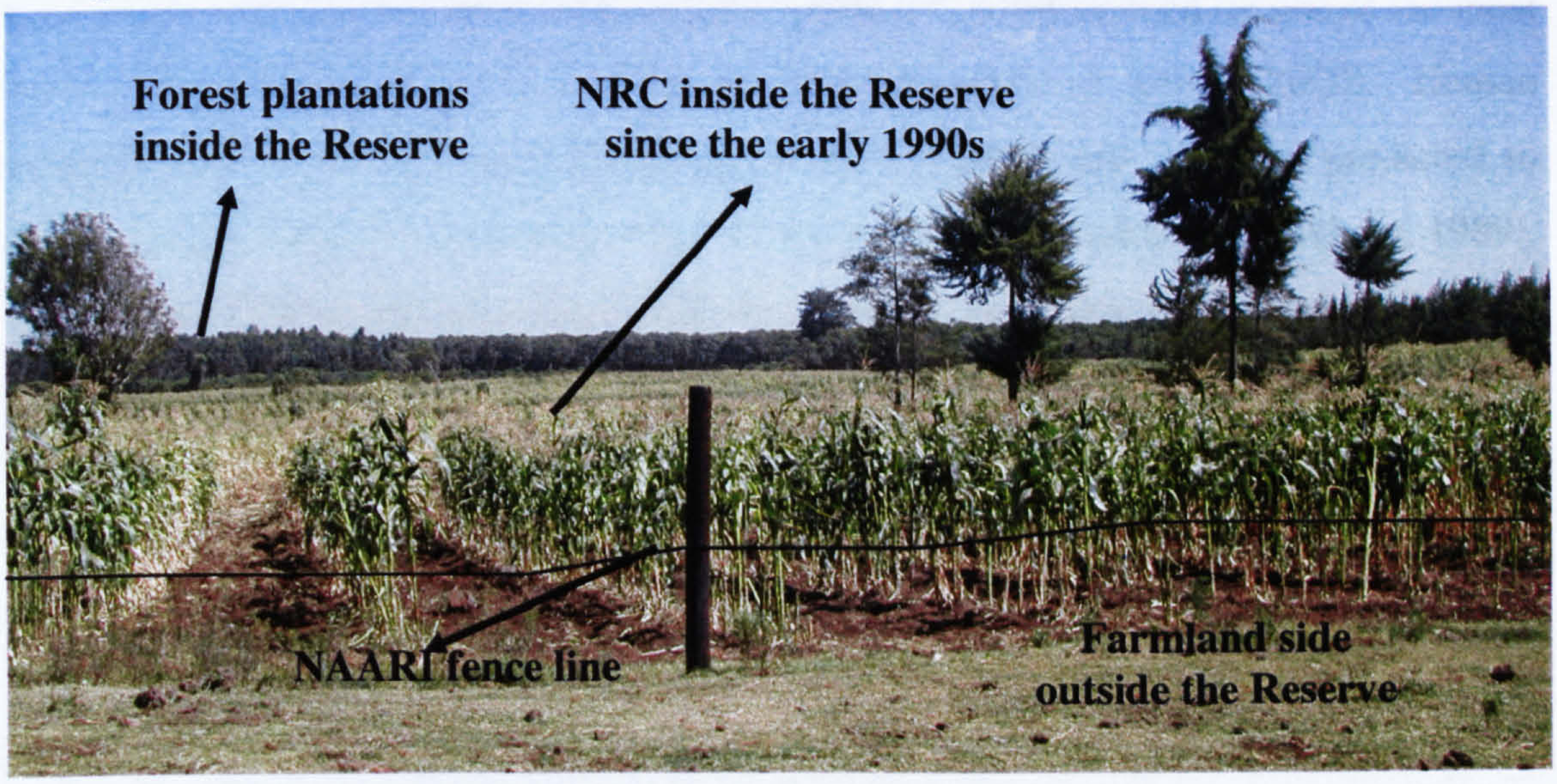
Direct HEC mitigation strategies that have been adopted at Meru-Imenti and Hombe-Kabaru include: placing of rusty nail-traps and poisoned pumpkins in the forest to kill elephants; throwing stones, making fire and noise to drive elephants from farms; rubber bullet gunfire to drive elephants from farms in KWS PAC; shooting of elephants during KWS PAC; and, fencing. These techniques are temporarily successful but none of them have addressed the underlying causes to HEC. Fencing is currently the most favoured HEC mitigation technique on MK and fencing to protect farms is therefore planned by KWS and NGO's, because it reduces elephant damage immediately after installation.

An environmental impact assessment (EIA) completed in 1995 in Naari, at the north-Imenti forest boundary in Meru-Imenti, compared the costs of HEC mitigation through

PAC, versus instalment of a live barrier such as a stone wall or an electric fence (Ngure, 1994; KWS, 1995). It was concluded that fencing would be a good investment and the KWS and the Naari Community Wildlife Association (see Figure 6.13) constructed the 22km Naari solar fence. The KWS covered 75% of the total cost and the communities raised 25% of the funds and participated in fence construction and maintenance. The success the Naari fence in excluding elephants led to the fence being extended by 8km in late 1998, and to beginning the construction of another fence at the Imenti forest southern boundary, as well as to plans to continue extending the Naari and south-Imenti fences. The 30km south-Imenti fence is now under construction by KWS in collaboration with the communities. The fence is being extended by 14km on the MK side by the Beera community, with finances of COMPACT (COMPACT, 2001).

With the Naari and the south-Imenti fences in place, the thin stretch of plantation forest that connects Imenti with MK will be fenced on both sides (Figure 6.12 and 6.13). Maize is planted inside these forest plantations as part of NRC (Figure 6.17). However, this encourages elephant destruction of tree seedlings, the surrounding maize, and the fence. Furthermore, nothing has been done about these fields that have violated the allowed period of NRC of 2 to 3 years since the early1990s (see Figure 6.13).

Figure 6.17. Maize inside the Reserve on plantation land in Meru-Imenti, 2003



In Hombe-Kabaru, ditches and moats were tried out in 1956 but because of the rocky soils, digging and maintaining moats proved labour intensive, especially after elephants learned to break moat walls and fill up moats to cross them. In 1998, a 9km multiple-strand community-based solar fence was installed around the Sagana settlement scheme, and in 2000, a 25km two-strand fence was placed between the Kabaru settlement, running along the boundaries of the NaroMoru plantations and NaroMoru KWS head-quarters, up to the edge of the Gathiuru plantations. The 9km Sagana fence was a community initiative, co-funded by the EU, and it stopped crop damage to Sagana farms. The 25km two-strand fence installed was financed by an NGO, the Bill Woodley Mount Kenya Trust or BWMKT, in collaboration with the KWS and also stopped elephant damage to the farms and plantations protected by it.

Despite the apparent complete success of the fences in Meru-Imenti and Hombe-Kabaru however, investigation of OB reports showed that elephant damage to farming areas adjacent to the fences was extremely high, suggesting that the fences have shifted crop damage to new areas, rather than ameliorating total amounts of crop damage. In contrast, the positive effect of the fences against encroachment is clear by the fact that where the Naari fence ends, the forest had completely been destroyed by illegal charcoal burning and logging by 2000 (Figure 6.13).

6.4. DISCUSSION

MK holds the largest highland elephant population, yet is surrounded by one of the most densely populated rural areas in Kenya by 1999 (Republic of Kenya, 2000). Human densities exceed the estimated maximum of 82.5 people/ km^2 that was predicted to allow human-elephant coexistence in fertile areas in Kenya (Parker and Graham, 1989). The extent of HEC on MK was explored through: investigation of reported elephant damages; multivariate analysis of reports per location; and investigation of characteristics of the two most HEC-affected areas around MK, Meru-Imenti and Hombe-Kabaru.

6.4.1. Reported wildlife damages from OB records, 1999 - 2002

To estimate wildlife damages to people, several studies have used archive records of damage (e.g. Ngure, 1995; Sitati, 2003), while others have attempted to standardise methods to measure damages (e.g. Hoare, 1999; Hoare, 2000). A case-study conducted in 2002 showed that reporting of wildlife damages in KWS OB's around MK incorrectly represented the actual extent of damages, although correctly indicated the spatial distribution of those damages (Hagiwara, 2002). Damages as reported in OB's increased by 215% between 1999 and 2002, with more regular reporting overall after 2000, when KWS took over managing the MK forests (Vanleeuwe et al., 2003). Of all reported wildlife damages on MK, the vast majority (74%) reported elephant crop raids. Elephant crop raiding is a problem that has received increasing attention in many African countries (Hoare and du Toit, 1999; Smith and Kasiki, 2000; Sitati et al., 2003; Weladji and Tchamba, 2003) because it affects elephants, people, and people's attitudes towards conservation (Nyhus et al., 2000; O'Commell-Rodwell et al., 2000).

6.4.2. Multivariate analysis of elephant crop damage OB reports

Multivariate analysis of elephant crop damage may yield a predictive understanding of the underlying processes (Bulte and Horan, 2003; Sitati et al., 2003). A linear regression model explained the observed OB records of elephant damages to farmland around MK, from the parameters of presence or absence of: the NTZC strip between forest and farmland; distance from elephant travel routes; and, human population density. The tea-zone between forest and farmland reduced crop damage to farmland. Crop damage was not the result of travelling elephants (though possibly of foraging elephants; see Chapter 5), and more elephant damage was reported in locations that have more people.

6.4.3. The two most HEC-affected areas around MK

Following the same pattern as found in other studies (Harcourt et al., 2001; Sitati et al., 2001; Fritz et al., 2003; Jenkins et al., 2003), HEC on MK is also typically highest at the human-elephant interface. Most OB reports of elephant crop raids between 1999 and 2002 around MK come from where most GIS-traced elephant routes crossed the boundary into farmland (see Chapter 5), from the Meru-Imenti in Meru Central District in the north-east and from Hombe-Kabaru in Nyeri District in the south-west. Characteristics investigated in Meru-Imenti and Hombe-Kabaru included: the socio-economic status of farming households; their use of MK resources; and the effect of implemented HEC-mitigation strategies. Patterns of HEC at Meru-Imenti and Hombe-

Kabaru show similarities but are also very location-specific. Similar patterns among socio-economic characteristics of the forest-adjacent farming households and in their use of MK resources are found in both areas. However, there are important differences in the factors that determine the spatial distribution of elephants and people in both areas.

6.4.3.1. Socio-economic status in Meru-Imenti and Hombe-Kabaru

Intensive land-use practices in Meru-Imenti started in the early 1930s and the rapid expansion of settlement slowed down after 1995 due to saturation of land (Mathuva, 2002). Human density in the Meru-Imenti area is very high because it includes Meru town with 6,097 people/ km^2, which lies within 5,000m of the MK boundary (Republic of Kenya, 2000). The Meru-Imenti area comprises the Imenti forest, connected to the MK forest with a thin stretch of plantation forests. The Hombe-Kabaru area comprises the Thego forest, connected to MK by a thin strip of riverine forest since the degazettement of the Ndathi plantation forests for settlement in 2001. The Hombe-Kabaru area lies in Nyeri District, and was more influenced than the other districts around MK by white colonists, who introduced coffee, tea, and animal husbandry (Winiger, 1992; Emerton, 1995; Kiteme, 2001).

Farms adjacent to the MK forest in Meru-Imenti and Hombe-Kabaru support households of 9 and 7 people, respectively. Most households own farms of less than 1.6 ha of which, around 65% is cultivated. Education standards are high, with more and more children completing secondary education in rural centres, where many try to find jobs after schooling (Winiger, 1986). Although subsistence farming represents 80% of the adult occupation at Meru-Imenti and 93% at Hombe-Kabaru, more and more of the household income is generated from remittances of family working in rural centres and from small businesses. Businesses include local shops but also sales of illegally harvested forest resources (Emerton, 1996, 1997; Mathuva, 2002; Hoft, 2002). The common profile of the illegal harvester and dealer is one of an educated youngster who wants to earn money fast, having failed to find a job in the rural centres and returned to the family farm (Rheker, 1992; Kiteme, 2001). Because on-farm tree growth is poor, most houses are built of wood, and all households use fuelwood and many also charcoal, the illegal market in timber, fuelwood and charcoal is very lucrative (Gathaara, 1999; Mathuva, 2002).

Farmers also increasingly invest in irrigated horticulture to improve farm productivity (JICA/GOK, 1999). However, the overall shortage of water intensifies associated conflicts between highland and lowland communities (Brunner, 1986; Liniger, 1991; Wiesmann et al., 2000). Both Meru-Imenti and Hombe-Kabaru lie at the outer edges of the rainy side of MK and suffer from water shortage in the dry season. Additionally, most water is abstracted in furrows, which are prone to contamination and to spreading of diseases (Wanjau, 1997). Over-abstraction of water from important sources such as MK leads to more water-shortages, famine and conflicts over other areas of Kenya that consist of arid and semi-arid lands (Speck, 1983; Wiesmann et al., 2000). Although iron roofs could collect rainwater, provide clean drinking water, and reservoirs could store water, it has been known for a while that there can never be enough water to realise intended irrigation plans (Brunner, 1986). Despite this, irrigated farming is still promoted as a way to address economic instability of farmers living around MK (Sanyu Consultants, 1999).

6.4.3.2. Use of MK resources in Meru-Imenti and Hombe-Kabaru

Use of natural resources and the spatial distribution of elephants and people within and around protected landscapes, affect the stability of the triangular relationship between the environment, elephants, and people, and thus affect levels of HEC (Harcourt et al., 2001; Moore et al., 2003; Nchanji and Plumptre, 2003). The stability of the relationship between people and elephants largely depends on how important people judge this to be, and on law-enforcement efficiency, which in turn depends on costs and benefits, and socio-economic status of the local users and governing institutions (Balmford and Whitten, 2003; Hutton and Leader-Williams, 2003; Smith et al., 2003). This is reality in Kenya and on MK (Jenkins, 2003; Sitati et al., 2003; Vanleeuwe et al., 2003).

Patterns of HEC in Meru-Imenti largely depend on the location of settlement versus the MK-NGA's elephant movement corridor, on limitations to movements imposed by fences, and on unsustainable levels of human exploitation of the MK forest. At Hombe-Kabaru, HEC mostly occurs in areas of degazetted plantation forests, which lie close to the Mountain Lodge salt-lick that attracts elephants on an almost daily basis and to some important elephant travel routes and foraging paths. People also extensively exploit MK resources unsustainably at Hombe-Kabaru (see Chapter 7). This exploitation was fuelled by economic instability of surrounding communities and of institutions in charge of MK protection, which in turn has led to inefficient law-enforcement (Chapter 7).

6.4.3.3. HEC mitigation at Meru-Imenti and Hombe-Kabaru

More and more studies value the importance of conservation education and land use management as successful HEC mitigation strategies (Hill, 1998; Hoare and du Toit, 1999; Hoare, 2000; Armsworth and Roughgarden, 2001; Kuriyan 2002; Osborn and Parker, 2003). Nevertheless, deterring elephants as an HEC-mitigation strategy, albeit involving more and more community involvement, is increasingly common in East Africa (de Boer and Baquete, 1998; du Toit, 2002; Vollrath and Douglas-Hamilton, 2002; Osborn, 2002). Most HEC-mitigation strategies on MK focus on deterring elephants from human occupied lands, while much less emphasis is placed on reducing human impact on the elephant habitat (Vanleeuwe and Lambrechts, 1999).

The main projects that address underlying causes to HEC include several dozens of on-farm agroforestry projects, and the introduction of woodlots and energy-saving stoves at boarding schools to reduce people's dependency on MK for firewood (COMPACT, 2001; Mbora and Simons, 2002). These projects seek to reduce pressure on MK resources and thereby reduce competition for natural resources between people and elephants over the long run, although they were not specially designed to reduce HEC. Also the NTCZ mitigates HEC by representing an exposed strip of tea between forest and farmland that elephants seemingly do not like to cross and that reduces the elephant damage on adjacent farmland accordingly. As elsewhere in Kenya (e.g. Ngure, 1995; Butynski, 1999; Vollrath and Douglas-Hamilton, 2002), direct measures to deter elephants are the most commonly used mitigation measures in Meru-Imenti and Hombe-Kabaru, but they rarely address the underlying causes of HEC. Such measures include the making of fires and noise, placing traps, firing of rubber bullets and shooting of elephants in KWS PAC, and the placing of fences to stop elephant access.

In both Meru-Imenti and Hombe-Kabaru, community based fences have been placed, and more fences have been planned (COMPACT, 2001; KWS, 2001). Although very popular among local communities, most fence damage (44 cases of the Naari fence in Meru-Imenti) is not caused by elephants but by people (Mathuva, 2001). For fencing to be a successful mitigation strategy, fence-alignment must be based on an understanding of area-specific HEC processes, they must function to discourage elephant access as opposed to barring access, and be properly maintained (Thouless and Sakwa, 1995; Thouless, 1996). To date fences around MK have been placed as physical barriers and without any knowledge of their potential effect on elephant movement.

Two environmental damage assessments were conducted on the 30km Naari fence that was completed in 1998 in Meru-Imenti (Mwathe et al., 1998; Mathuva, 1999). Both EIA's praised the positive socio-economic benefits for farmers protected by fences, while negative effects identified comprised farmers spending more time in illegal forest exploitation, fence destruction, and NRC farmers suffering more crop damage. The actual assessment of damage on the environment was limited because of negligible qualitative evidence of effects of the fence on the landscape. The potential effect of the fence on elephant MK-NGA migration, the cause to HEC and reason for fencing in the first place, was not addressed (Mwathe et al., 1998; Mathuva, 1999). However, analysis of OB records show that elephant damage is most concentrated where the fences end, suggesting that the problem is simply being displaced. A solution to this is sought by extending fences and putting up more fences (KWS, 2001). However, in doing so in the wrong places, this may cut off the largest of two remaining corridors that connect MK with the NGA's. Fences create safe havens that encourage settlement and irreversible situations for elephant movement when people settle in movement corridors due to mis-alignment of fences. Farmers would settle in the MK-NGA corridor area if the Naari fence is further extended, which would result in isolation, and over-crowding of elephants, and negative impacts on the environment (e.g. Harcourt et al., 2001; Moore et al., 2003; Whitehouse and Schoeman, 2003).

As in Meru-Imenti, fences in Hombe-Kabaru simply displace the problem of elephant damage to farms at the outer edges of fences. Elephants follow the Sagana River to cross it at low altitudes, passing along the fenced Sagana settlement scheme and the Hombe and Ndathi settlement schemes. The Ndathi and Hombe schemes were plantation areas that were clear-felled in the 1990s, never replanted, and degazetted for settlement in 2001. Elephant damage at Ndathi and Hombe was substantial long before degazettement of the areas due to the proximity of the Mountain Lodge salt-lick and presence important elephant travel routes and foraging paths (see Chapter 5). The NGO, Bill Woodley Mount Kenya Trust decided to finance a two-strand fence for Hombe (see Chapter 7).

Damage to the MK catchment area, whether by elephants or people, carries potential irreversible large-scale detrimental consequences. Solutions lie in preventing habitat isolation through identifying and protecting habitat linkages between protected areas (Bunn et al., 2000; Kinnaird et al., 2003; Moore et al., 2003; Williams et al., 2003), and through reducing the unsustainable levels of human resource exploitation (Vanleeuwe et al., 2003).

6.5. CONCLUSION

A linear regression model explaining elephant crop damage reports as found in KWS OBs, comprised factors that explained reporting and factors that explained crop damage. The model suggests that reports of crop damage increase with more people, and that crop damage reports increase with increasing distance from elephant travel routes, though not necessarily of foraging paths (see Chapter 5). The model also showed reduced levels of damage for locations that have a tea strip between forest and farmland, suggesting that the NTZC reduces elephant crop damage.

A case-study that focussed on factors affecting reporting shows that OB records incorrectly indicate the real extent of elephant damage, but correctly indicate the spatio-temporal patterns of damage (Hagiwara, 2002). Around MK most reports came from Meru-Imenti in Meru Central District and from Hombe-Kabaru in Nyeri District. The socio-economic profiles of Meru-Imenti and Hombe-Kabaru households were similar as were household uses of MK resources such as fuelwood, timber, and water. The relation between characteristics of elephant use of the MK environment, such as their seasonal distribution, the location of elephant routes and paths, of salt-licks, and of crop damage, versus characteristics of human use of the MK environment, such as their distribution, the location of settlement and fences, of forest plantations and human damaged sites, explained HEC at Meru-Imenti and Hombe-Kabaru.

Many studies of HEC promote protection of biodiversity-rich environments and major corridors as the best way to ensure long-term survival of migrating species and to reduce HEC. Isolation of the MK elephants would result in over-exploitation of resources, enhanced levels of HEC at the human-elephant interface, while jeopardising the catchment function of the life depending on it. Fences should discourage access but not alter important elephant ranging behaviour, as threatens to happen at Hombe-Kabaru, nor alter migration, as threatens to happen between MK and the NGA's at Meru-Imenti. To avoid this, land-use management plans should focus on long-term benefits for both species, regardless of the short-term disadvantage that this may bring to either. The growing hunger for land and resources had created a very unstable relationship between people and the MK environment by 1999 (Chapter 7).

Chapter 7

PEOPLE AND THE MOUNT KENYA ENVIRONMENT

"Man's greatest enemy has always been his own kind, and upon an understanding of this fact may well depend his future survival" - Pratt and Gwynne, 1977

7.1. INTRODUCTION

Land-fragmentation through human expansion is very pronounced in East Africa, and the remaining natural resources are becoming rapidly depleted to answer immediate demands, regardless of the long-term consequences (Harcourt et al., 2001; Jenkins, 2003). The rapidly shrinking forest cover illustrates the problem well (IUCN, 2003). As many as 95% of the Protected Areas (PAs) in the tropics have reported illegal removal of resources and encroachment by adjacent communities, regardless of their legal protection status (Machlis and Tichnel, 1985; Ashenafi, 2003; IUCN, 2003). Economic instability of communities around PAs and of institutions in charge of PA protection leads to corruption and poor law-enforcement, that reduce the effectiveness of conservation efforts (Smith et al., 2003).

Projects promoting community-based conservation and sanctioned use of PA resources aim to reduce illegal exploitation by involving communities in conservation and offering them benefits from PA conservation (Leader-Williams et al., 1996; Hackel, 1999; Balmford et al. 2000; Bruner et al., 2001). Although a potentially successful strategy, community-based conservation and sanctioned resource use projects are often not successful when the aim of poor people is to survive, as is often the case in Africa (Abbot and Mace, 1999; Anderson, 2001; Soehartono and Newton, 2001).

The Mount Kenya (MK) situation is no different (Emerton, 1997; Gathaara, 1999; Hoft, 2002). Over 50% of Kenya's people and wildlife depend indirectly on MK as a water catchment area (Decurtis, 1992; Liniger, 1992; Wiesmann et al., 2000), and in turn also on the relationship between people at the source and the MK environment. The mountain is surrounded by a growing, and in mostly saturated, ring of agriculture. By 1999, some 500,000 people lived within 5,000m of the Forest Reserve (Republic of Kenya, 2000) including people from communities, forest plantations, managing institutions, and from hotels and lodges, as well as saw millers, squatters and illegal dealers in timber, fuelwood, charcoal, meat, and marijuana (Kohler, 1986; Beentje, 1989; Rheker, 1992). Unsustainable extraction of resources and land hunger have led to serious levels of destruction of the MK natural environment (Bussmann, 1994; Emerton, 1995; Gathaara, 1999).

Over 100 community-based conservation projects and sanctioned resource use projects have been introduced in and around the MK Forest Reserve since the mid 1980's. The projects include among others: plantations that provide employment and timber; Non Residential Cultivation (NRC) on afforested land; the Nyayo Tea Zone Corporation (NTZC) providing jobs; over 50 on-farm agroforestry projects and the introduction of woodlots and low-fuel using stoves at boarding schools that remove pressure from MK; licensed sanctioned use of firewood and medicinal herbs (COMPACT, 2001; Mbora and Simons, 2001; Hoft, 2002). Unlike projects outside the Forest Reserve, those located within the Forest Reserve all very quickly became unsustainable because of inefficient law enforcement and corruption within the Forestry Department (FD), in charge of Forest Reserve protection (Brunner, 1986; Vanleeuwe and Lambrechts, 1999; Vanleeuwe et al., 2003).

In this chapter, time-series analysis of satellite imagery and evidence from an aerial survey will illustrate changes that occurred to the MK environment under FD protection, as a result of human utilisation of land and resources from 1987 up to 2000. After 2000, the Forest Reserve was upgraded to National Reserve and the protection mandate was transferred from the FD to the Kenya Wildlife Service (KWS), of which the effect is the subject of chapter 8. This chapter however, investigates the status of the MK Forest Reserve under the FD protection, and the failure and success of different community-based and sanctioned resource use projects through the following questions:

- Where and to what extent has land inside the Forest Reserve changed through de-gazetting of forest for settlement, violation of NRC in forest plantations, and encroachment, as visible from satellite images of 1987, 1995, and 2000?
- How is water used near the source, what are the pros and cons of water use as proposed by the Kenya Development Master Plan (JICA/GOK, 1999)?
- Where and to what extent is the forest cover inside the MK Forest Reserve affected by exploitation of its resources, as visible from an aerial transect survey in 1999?

7.2. METHODS

Data on the use of land and resources on MK were obtained from: archive data; time-series analysis of satellite imagery; and, data from an aerial survey conducted in 1999. These data were examined using multivariate analysis and associated tests of spatial auto-correlation, to establish the explanatory parameters of human impacts as recorded in the aerial survey.

7.2.1. Archive data

Data on the use of Forest Reserve resources at district level were obtained both from reports of the Kenya Central Bureau of Statistics and from long-term studies (e.g. Emerton, 1995, 1997; Republic of Kenya, 2000). Data on plantations were sourced from reports (Kohler, 1986; Rheker, 1992; Kiteme, 2001; Hoft, 2002). Information on forest excisions came from a report of the IUCN (Matiru, 2000), and reports of the FD and the United Nations Environment Programme (UNEP, 1988; FD et al., 1993; UNEP, 2003). Information on community-based and sanctioned use projects that have been implemented around MK were derived from reports of COMPACT (2001), and Mbora and Simons (2001).

7.2.2. Time-series analysis of satellite imagery

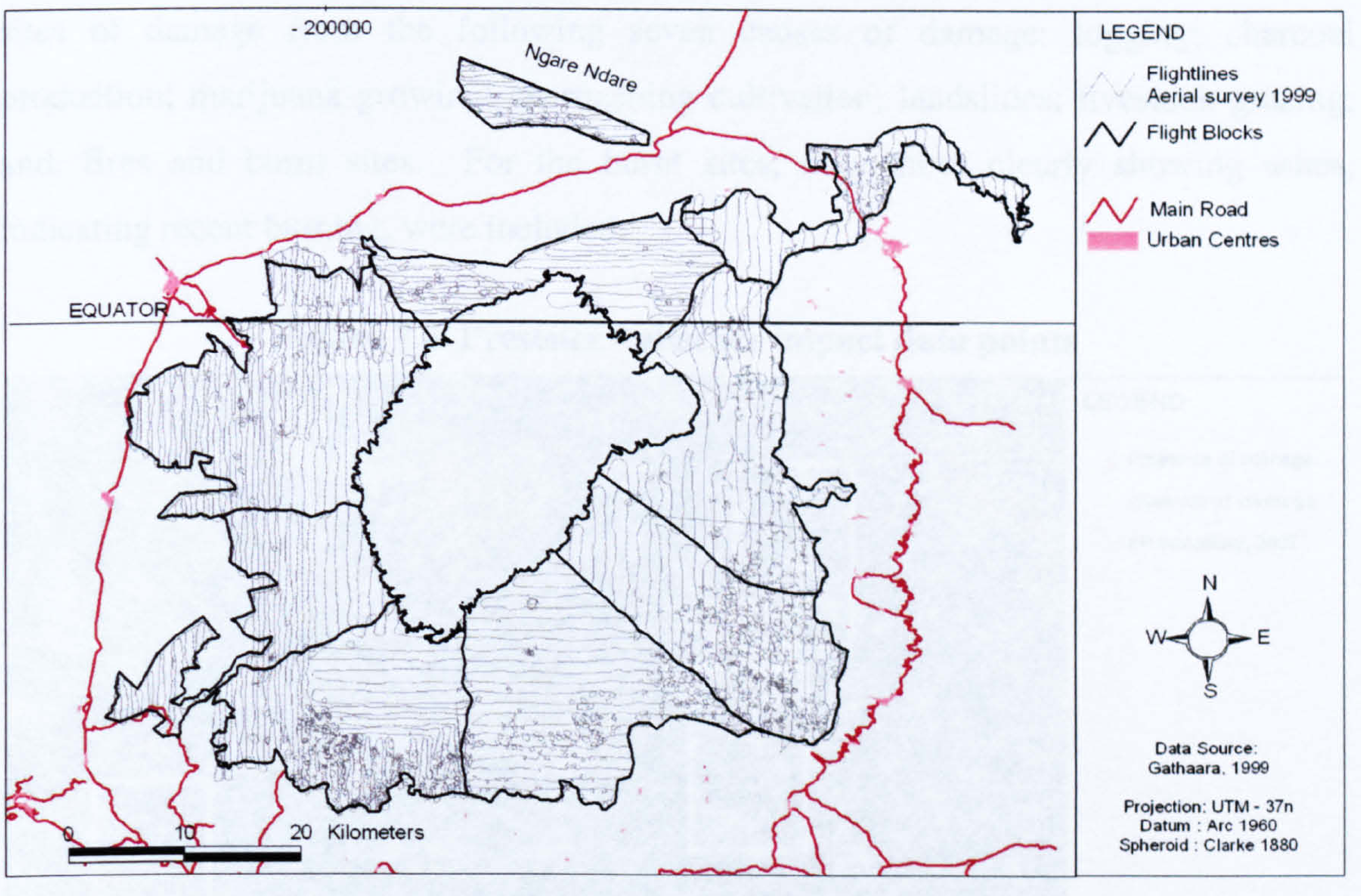
Time-series analyses of three LANDSAT TM satellite images were carried out to establish changes in land cover, using the software ArcGIS. The dates of the satellite images were February 1987, October 1995, and February 2000 (see General Methods section of Chapter 2). All three images had a resolution of 30 meters. For interpretation, the images were presented as "true colour" composite images, in which bands 1, 2, and 3, were allocated as the blue, green, and red bands, respectively.

Land cover changes within forest plantations were established from superimposing digitised plantation blocks onto the satellite images. Using ArcGIS, the plantation blocks were digitised onscreen from scanned and geo-referenced 1:10,000 maps that were obtained from the FD.

7.2.3. The 1999 aerial survey

Public outcry over forest destruction on MK led to an aerial assessment of their status in 1999 by the UNEP and the KWS. The pilot was KWS Senior Warden Mr. B. Woodley and the observer was Mr. C. Lambrechts of UNEP. The area surveyed was divided into 9 blocks, and transect flight-lines were spaced according to visibility. Lines were separated by 500m over dense forest and by 1,000m over more open forest and grasslands (Figure 7.1).

Figure 7.1. Flight-lines of aerial survey in 1999



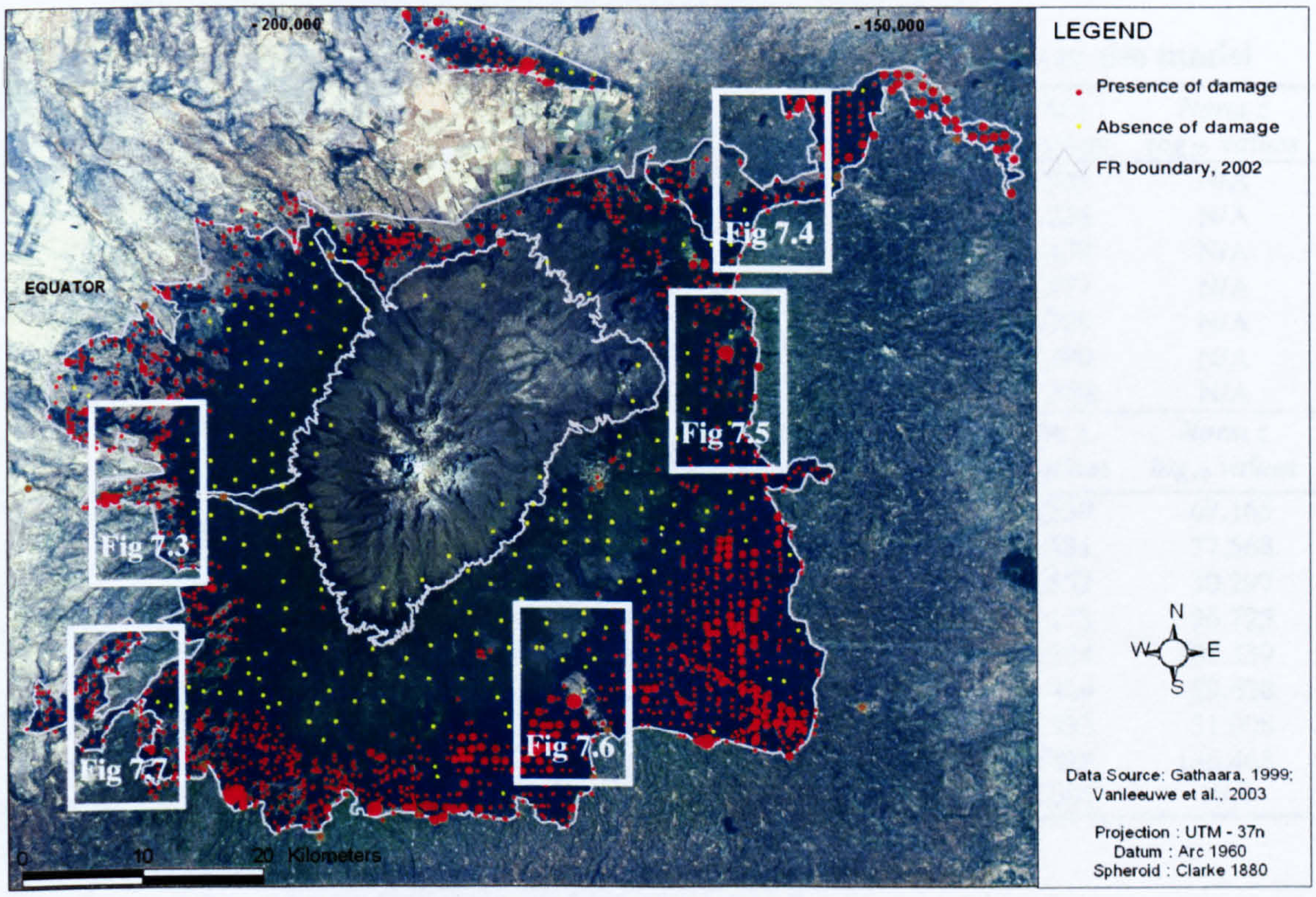
The plane was equipped with a GPS to track flight-lines at 10-second intervals and the whole survey took 52 hours of flying time. For each observed damage, a GPS waypoint was taken, and the type and extent of damage was noted. Recorded damages included sites of: logging; charcoal production; marijuana (*Cannabis sativa*) growing; encroaching cultivation; landslides; livestock grazing; and, fires and burnt sites. The extent of damage was expressed either in numbers of trees for small-scale damage, or in estimated number of damaged hectares for larger-scale damage. The initial results were published in Gathaara (1999), but the raw data were made available digitally, as an

ArcView shapefile with associated information attached to the shapefile database, for further analysis in this study.

7.2.4. Multivariate and spatial auto-correlation tests

For multivariate analysis, a test set was created with data points to indicate presence or absence of damage on MK. Small-scale and larger-scale damage were converted to presence of damage. For the test set, two hundred points where there was no damage were selected to represent the absence data (Figure 7.2). Binary logistic regression analysis aimed to establish the factors that best explained the presence or absence of sites of damage from the following seven causes of damage: logging; charcoal production; marijuana growing; encroaching cultivation; landslides; livestock grazing; and, fires and burnt sites. For the burnt sites, only those clearly showing ashes, indicating recent burning, were included.

Figure 7.2. Presence - absence impact data points



The potential explanatory parameters used in the binary logistic regression analysis included distances from: roads; rivers; streams; plantations; KWS stations; the forest boundary; and, slope; altitude; and vegetation type. Using the same procedures as described in Chapter 4, the values of these parameters were extracted from grid layers using the "Summarise Zones" option in the ANALYSIS module, and distance measurements were created from shapefiles using the "Find Distance" option. Altitude and slope grids were created from a digital elevation model or DEM (see Chapter 4). The shapefile data table was imported into SPSS for logistic regression.

Tests of the response variables and potential explanatory parameters, and the $\log_{10}$ value of those parameters were examined for spatial auto-correlation using CrimeStatII. Spatial auto-correlation affects the strength and robustness of the explanatory models (Legendre et al., 2002). Spatial auto-correlation is expressed as a value of Moran's I, with associated df, and normality z value, of which the latter needs to lie below 1.96 to indicate that no spatial auto-correlation was evident with 95% confidence. With the exception of fires and burnt sites, all causes of damage and parameters were spatially auto-correlated (Table 7.1).

Table 7.1. Spatial auto-correlation of impacts and parameters in the model

Impacts (N=1,873)	*Moran's I real values*	*Moran's I $\log_{10}$ values*	*Norm z real values*	*Norm z $\log_{10}$ values*
Sites of logging (N=1,163)	0.072	N/A	28.985	N/A
Sites of charcoal production (N=144)	0.081	N/A	32.228	N/A
Sites of marijuana growing (N=144)	0.425	N/A	169.139	N/A
Sites of encroaching cultivation (N=133)	0.047	N/A	18.977	N/A
Sites of landslides (N=71)	0.034	N/A	13.729	N/A
Sites of livestock grazing (N=195)	0.035	N/A	14.290	N/A
Fires and burnt sites (N=23)	0.003	N/A	*1.588	N/A
Parameters	*Moran's I real values*	*Moran's I $\log_{10}$ values*	*Norm z real values*	*Norm z $\log_{10}$ values*
Distance from roads	0.253	0.169	100.639	67.165
Distance from rivers	0.282	0.195	112.331	77.568
Distance from streams	0.180	0.076	71.552	30.297
Distance from plantations	0.322	0.243	128.175	96.725
Distance from KWS stations	0.307	0.275	122.134	109.339
Distance from forest boundary	0.242	0.150	96.439	59.628
Slope	0.101	0.080	40.333	31.908
Altitude	0.374	0.368	148.828	146.468
Vegetation type	0.065	N/A	26.085	N/A

*No spatial auto-correlation at Norm z < 1.96

In order to achieve sample independence, I tried to use a random sample of the total dataset or to reduce spatial resolution (Sitati et al., 2003). For logistic regression analysis of the causes of damage that showed spatial auto-correlation, several test sets were made with 100 samples, for comparison of 50 samples with damage with 50 randomly chosen samples without damage. Resulting explanatory models were tested for spatial auto-correlation, and evaluated for their performance.

7.3. RESULTS

7.3.1. Use and abuse of MK land

Two large projects were introduced to promote sanctioned use of land on MK, namely NRC on afforested land in plantations, and the Nyayo Tea Zone Corporation (NTZC) established at the forest boundary on the rainy side of MK.

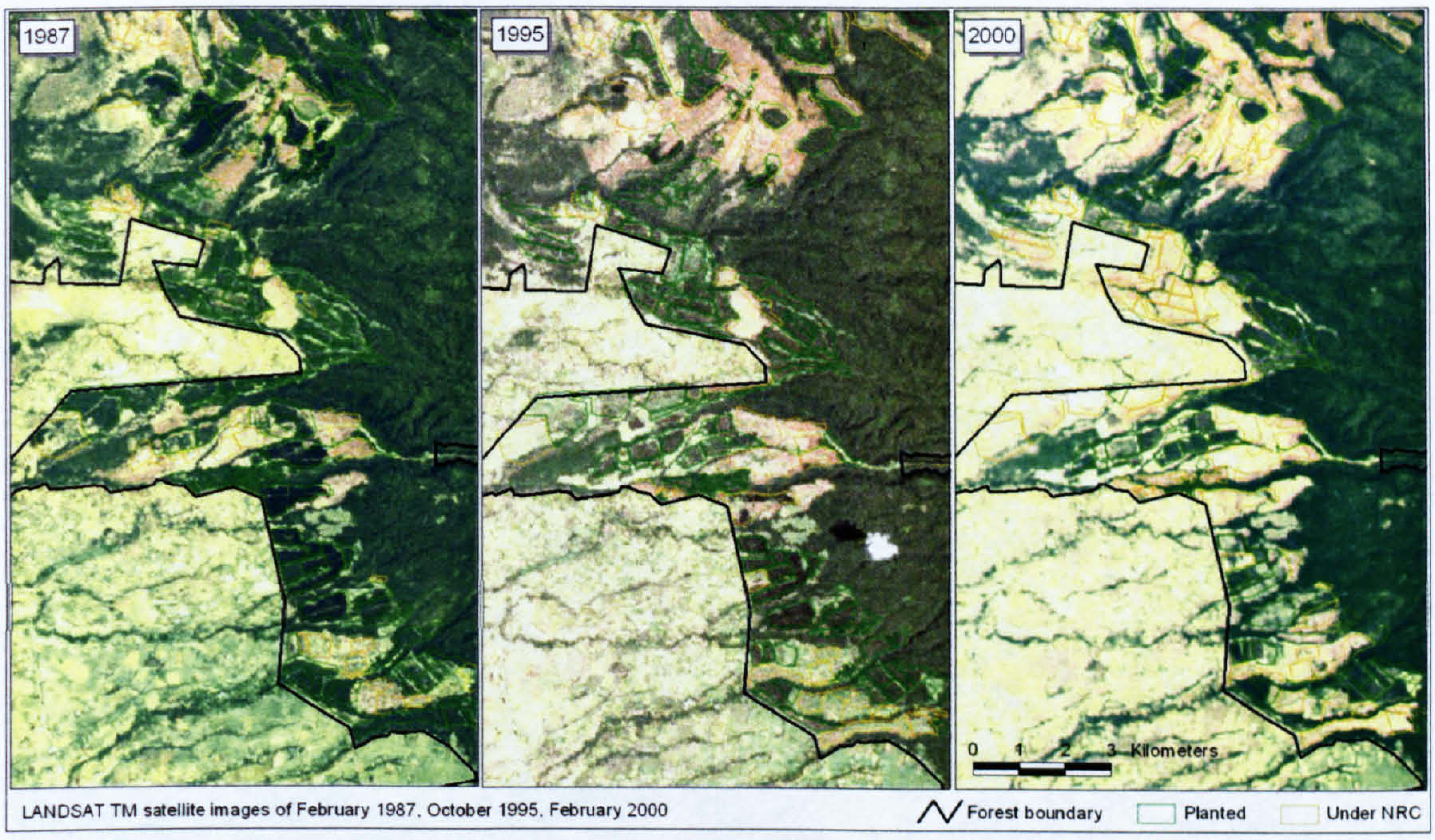
The line between sanctioned use and unsustainable use of land on MK is not clear because sanctioned use is often preceded or followed by unsustainable use. Violation of rules associated with NRC has led to permanent land loss in the form of legal alteration or excising of unsustainably used forest land for settlement.

7.3.1.1. Non residential cultivation or NRC, and encroachment

The oldest and most widespread form of sanctioned use of MK land was NRC in plantations. NRC refers to short-term cultivation (2 to 4 years) of newly afforested land in return for tending tree seedlings between the crops during their most vulnerable stage of growth (Hoft, 2002). NRC is underpinned by rules that seek to protect it from turning into settlement, such as evacuation when saplings outgrow the crops, and prohibition of raising permanent structures, fences, and keeping livestock. NRC mostly occurs where plantations are most extensive, and plantations comprise 20% of the MK forest in the west and the north, as opposed to 4% in the south and 0.1% in the east (Kohler, 1986; see Figure 7.8). Of the estimated annual benefits that the mountain provided in 1997, 13% came from NRC and only 1% came from plantations (Emerton, 1997).

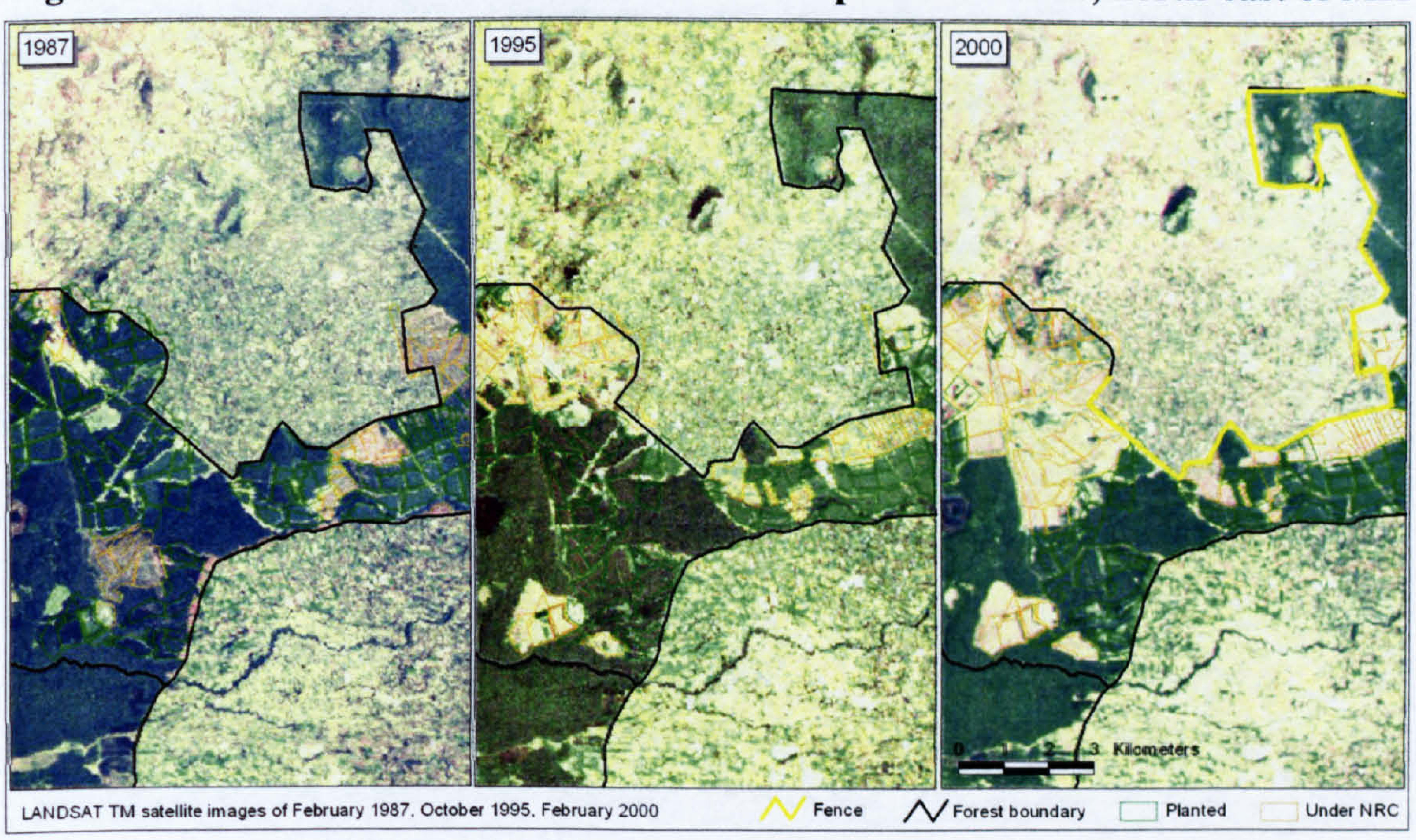
Initially NRC was only practised by FD employees and it ensured an extra income for its poorly paid staff. Later, NRC became a way for FD staff to gain revenues from leasing the land to outsiders, which led to considerable abuse and loss of forest land via corruption of very underpaid FD staff. The most common unsustainable use of NRC occurred through leasing the land for NRC for extended periods of time. For example, plantations clear-felled in 1987 were still under NRC by 2000 (Figures 7.3 and 7.4).

Figure 7.3. Plantations under NRC for extended periods of time, west of MK



The FD has always been in charge of NRC land and enforcement of NRC rules. Large-scale violations remained unnoticed for long periods of time (Figurse 7.4, 7.6 and 7.7).

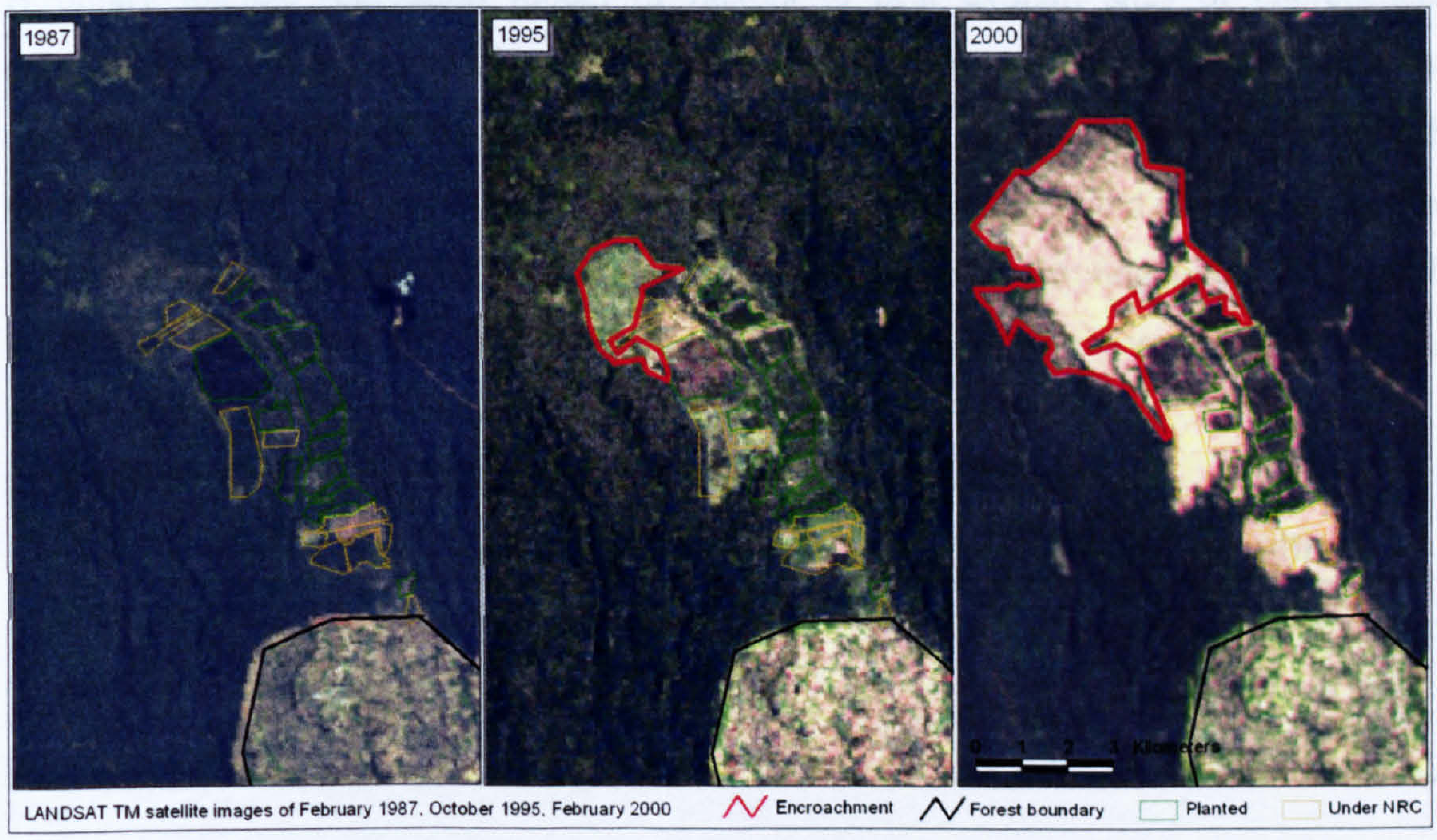
Figure 7.4. Plantations under NRC for extended periods of time, north-east of MK



Under the NRC umbrella, many other illegal practices remained camouflaged, including agriculture encroachment into the indigenous forest via plantations (Figure 7.5 and 7.6). Because this type of agricultural encroachment happened through gradual expansion from NRC into the indigenous forest, the FD must have been aware of the situation, suggesting corruption within the department (Figure 7.5 and 7.6).

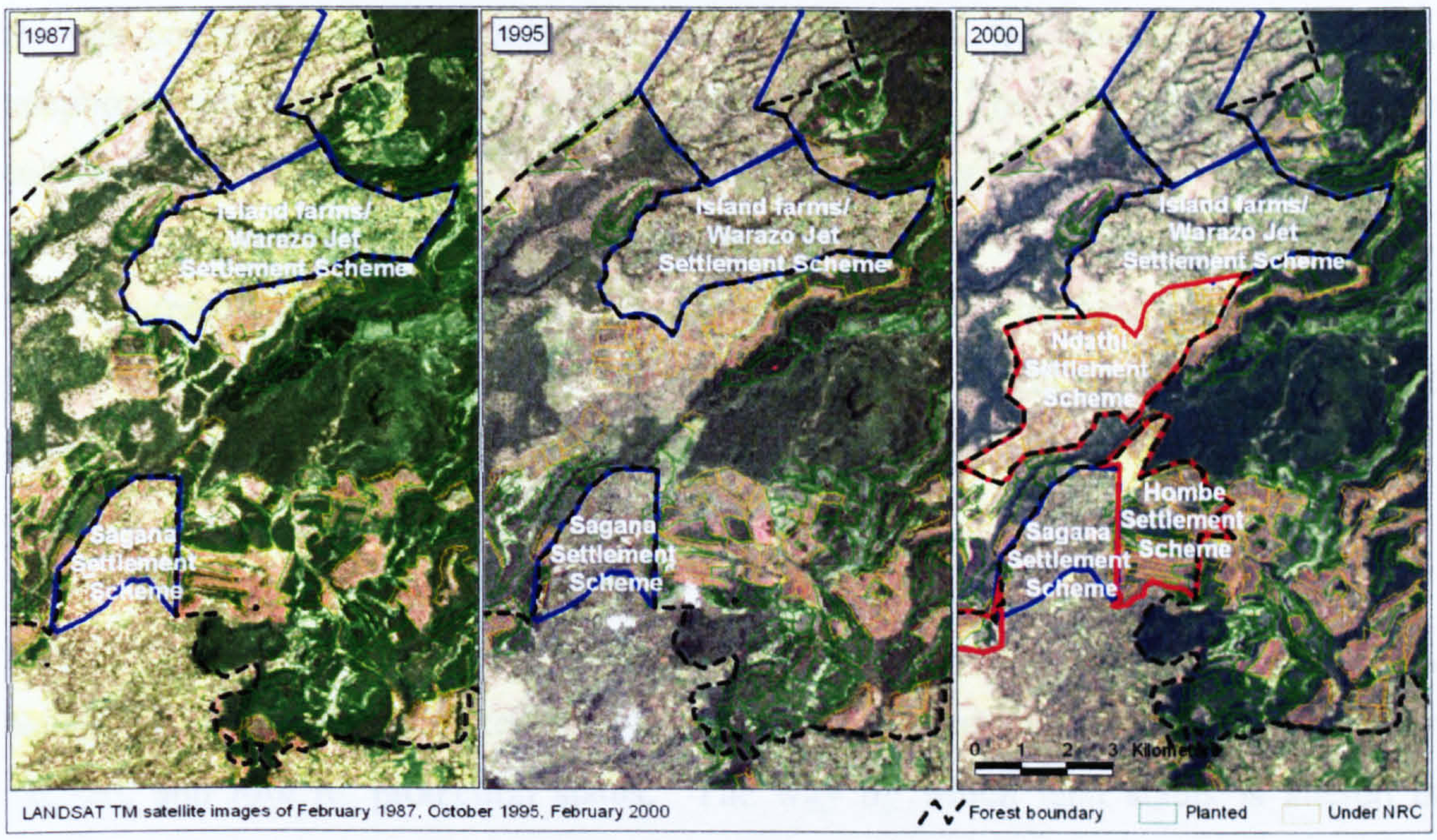
Figure 7.5. Encroachment into indigenous forest via plantations, east of MK

Figure 7.6. Encroachment into indigenous forest via plantations, south-east of MK



Finally, violation of NRC rules over periodical cultivation led to permanent loss of forest in some cases. A case in point was the Hombe-Kabaru area in Nyeri, where unnoticed violation of NRC turned into semi-permanent settlement and finally into legal excision that transformed 18.45km^2 of former plantations into settlement in 2001. Plantation land under NRC was never replanted after 1987 (Figure 7.7).

Figure 7.7. Permanent loss of plantations for settlement, south-west of MK



A binary logistic regression model of factors to best explain sites of encroached cultivation on MK accounted for 87% of observed incidences of encroachment, and was not spatially auto-correlated (Moran's I = 0.015, Norm z = 1.12). The model showed the importance of: distance from roads; distance from plantations; and distance from the forest boundary (Table 7.2). Because the coefficients were negative, the model suggested that encroached cultivation increased with proximity to roads, plantations, and the forest boundary (Table 7.2).

Table 7.2. Results of a logistic regression model to explain encroached cultivation

Parameters	*Coefficient(β)*	*SE*	*df*	*Wald*	*P*
Distance from roads	-0.0006	0.0003	1	3.968	0.0464
Distance from plantations	-0.0001	-7.7e-5	1	3.531	0.0602
Distance from forest boundary	-0.0006	0.0002	1	8.818	0.0030
Constant	3.1684	0.6427	1	24.305	0.0000

7.3.1.2. The Nyayo Tea Zone Corporation (NTZC)

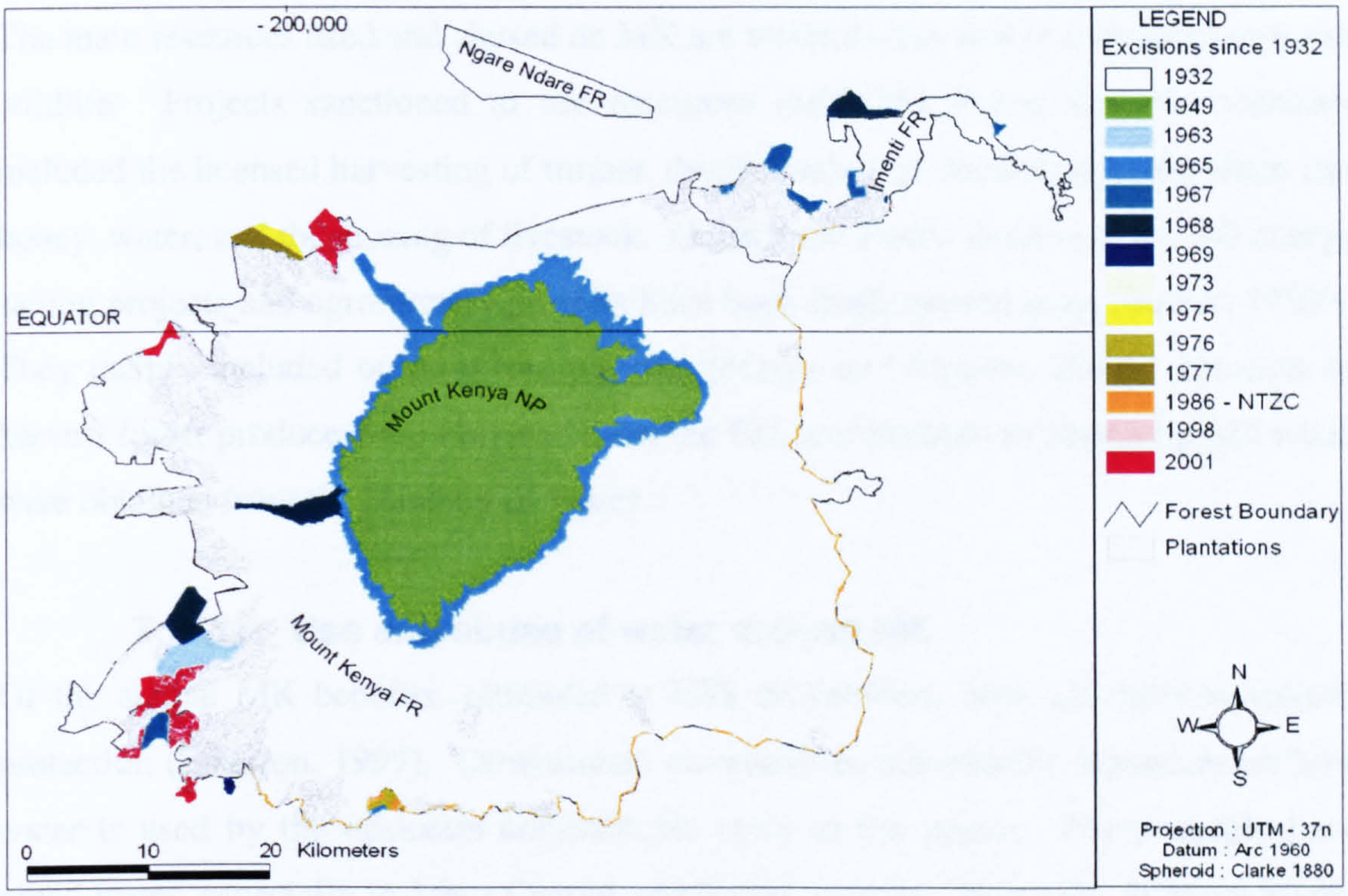
The NTZC was established on MK in 1986 through LN285 under the State Corporations Act for which 61.54km^2 of forests were cleared. The NTZC represents a buffer zone of tea around the Forest Reserve boundary between farmland and forest on the rainy side (Figure 7.8). The objectives of NTZC were to: protect indigenous forests from human encroachment; provide alternative sources of earnings through employment in intensively managed tea and fuelwood plantations; and, develop rural infrastructure through construction and maintenance of roads, bridges, tea factories, staff houses, telephone communication, electricity and water supplies. The tea zone has provided a successful barrier demarcating the Forest Reserve boundary, making encroachment very difficult, and it has also been shown to reduce elephant crop damage (Chapter 6). NTZC infrastructure, factories and other facilities are among the best in Kenya and the NTZC provides many jobs locally. On the other hand, illegal exploitation of Forest Reserve resources was highest on the NTZC side of MK (see Figure 7.11).

7.3.1.3. Forest excisions

Forest land in Kenya can be given protection status as any one of National Park, National Reserve, or Forest Reserve. Equally, all protected land also be de-gazetted or excised, and lose its protection status. The way by which land status is altered is through a Legal Notice (LN) and Gazette Notice (GN) in the Kenya Gazette. The Forest Act allows the Minister to (de-)gazette a Forest Reserve when it was published in the Kenya Gazette 28 days before the change is implemented.

The whole MK forest area was declared a Forest Reserve in 1932 and so was managed by the FD. Subsequently, the Forest Reserve section above 11,000 feet was declared a National Park through LN069 of 1949 in the Kenya Gazette, and came under protection of the KWS (Figure 7.8). Through LN181 and LN182 of 1965, and LN183 of 1968, the National Park boundary was lowered from 11,000 feet to 10,500 feet, and the Sirimon and NaroMoru tourist tracks were added (Figure 7.8). Since 1968, the National Park has covered an area of 715km^2.

Figure 7.8. Boundary alterations of the MK Forest Reserve



The lower boundary of the Forest Reserve has been continuously altered to allow for the growing demand for land (Appendix VII). Of a total of 6,938ha of altered MK forest that was excised for settlement, 34% was excised soon after Kenya's Independence, between 1963 and 1969, 19% was excised between 1975 and 1977, and the remaining 47% was all excised in 2001 (Appendix VII; Figure 7.8, Table 7.3).

Table 7.3. Areas excised in successive decades from the MK and Imenti Forest Reserves

DATE	*MK Forest Reserve (in km^2)*	*Imenti Forest Reserve (in km^2)*	*TOTAL (in km^2)*
1960 – 1969	23.54	11.91	35.45
1970 – 1979	13.43	None	13.43
1980 – 1989	None	None	None
1990 – 1999	None	0.53	0.53
2000 – 2003	32.41	None	32.41
TOTAL	69.38	12.44	81.82

Data sources: Matiru, 2000; Hoft, 2002

The 2001 excisions have been the subject of continuous debate and litigation as they are believed to have been a political stunt to seek votes for the elections. In 2000, the Forest Reserve changed its status to a National Reserve and its protection was transferred from the FD to the KWS.

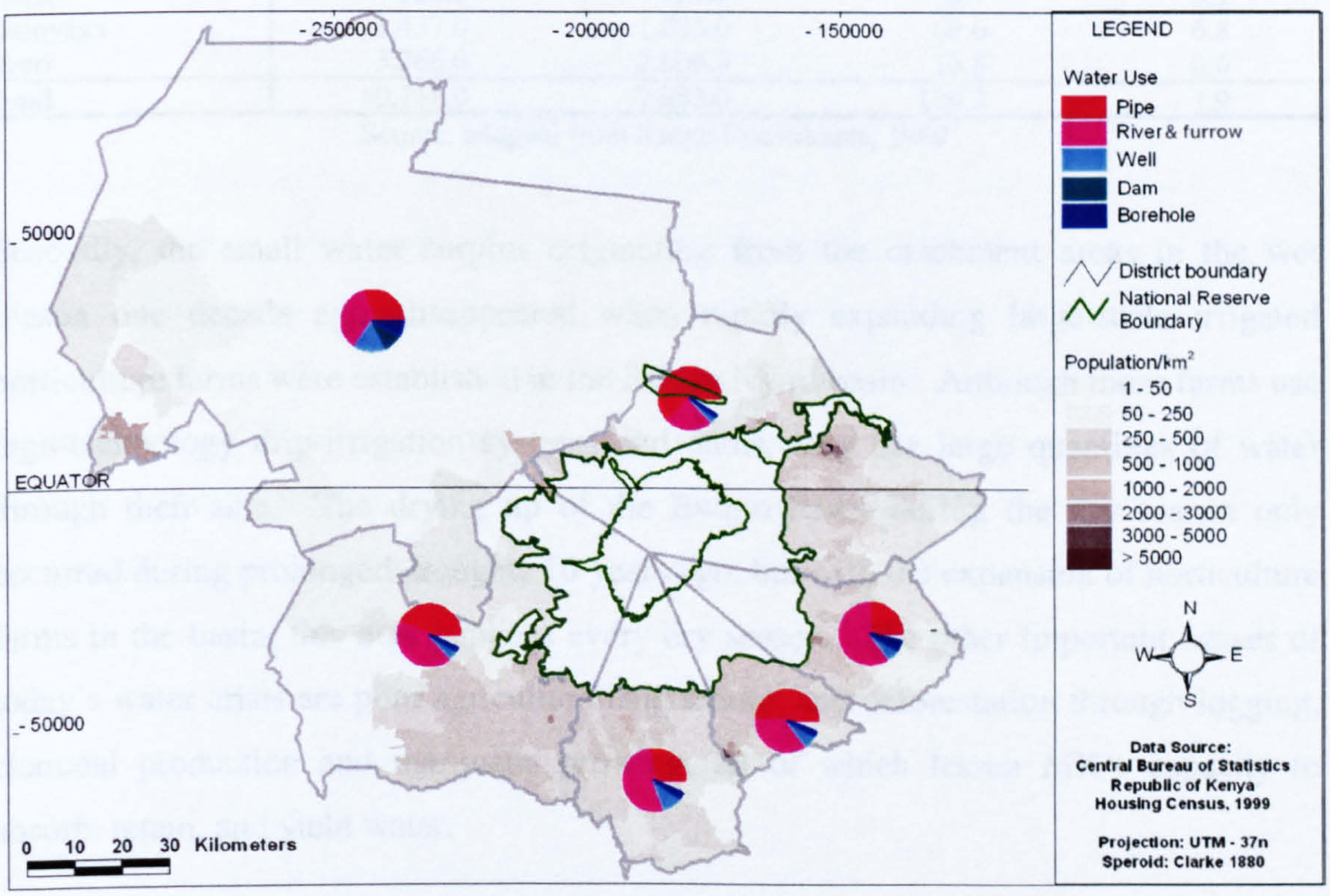
7.3.2. Use and abuse of MK resources

The main resources used and abused on MK are water, forest, and to a lesser extent also wildlife. Projects sanctioned to use resources inside the Forest Reserve boundary included the licensed harvesting of timber, thatch, fuelwood, medicinal herbs, fruits and honey, water, and the grazing of livestock. Outside the Forest Reserve, over 100 energy saving projects and agroforestry projects have been implemented since the mid 1980's. They mainly included on-farm tree planting (Mbora and Simons, 2002). Licences to harvest forest produce were obtained from the FD, and licences to abstract piped water were obtained from the Ministry of Water.

7.3.2.1. Use and abuse of water around MK

Of the annual MK benefits, estimated at US$ 26.7million, 36% are from watershed protection (Emerton, 1997). Downstream communities are entirely dependent on how water is used by the upstream communities close to the source. Many people have piped water, especially in Meru Central and Embu districts. However, in Meru South, Kirinyaga, Nyeri, and Laikipia districts, at least as many people take water straight from rivers and from furrows (Figure 7.9).

Figure 7.9. Water abstraction around MK



With the exception of Laikipia District, wells and boreholes only provide water to a small segment of the population. Dams are more popular in Laikipia where most of them are found on large scale white-owned cattle ranches (Figure 7.9). Today, the use of water by people at the source greatly exceeds the amount of water produced on MK. In turn, this results in increasingly tense disputes between upstream and downstream communities (Wiesmann et al., 2000). The reasons for the water problems are many.

Water problems start with historical misuse of land. The many European ranches that were abandoned before independence in 1963 were subdivided into thousands of small plots that were sold to Kenyans without taking into account the location of existing water systems or the distance from water sources (see Chapter 2). Kenyan farmers who bought the land now irrigate only a small section of it (Table 7.4), but the water-abstraction technique used for irrigation is the traditional open furrow system, which causes much water to be wasted through evaporation and percolation.

Table 7.4. Irrigated area per district around MK, 1999

Districts	*Total area in km^2*	*Arable area in km^2*	*Irrigation area in km^2*	*% irrigated*
Meru Central	3,012.0	2,165.0	40.8	1.9
Meru South	2,295.0	1,561.0	2.4	0.2
Embu	708.0	496.0	0.7	0.1
Kirinyaga	1,437.0	1,025.0	69.6	6.8
Nyeri	3,266.0	2,606.0	16.8	0.6
Total	10,718.0	7,853.0	130.3	1.9

Source: adapted from Sanyu Consultants, 1999

Secondly, the small water surplus originating from the catchment areas in the wet season one decade ago, disappeared when rapidly expanding large-scale irrigated horticulture farms were established in the Ewaso Nyiro basin. Although these farms use high-technology drip-irrigation systems and dams, they use large quantities of water through their size. The drying up of the Ewaso River during the dry season only occurred during prolonged droughts 10 years ago, but with the expansion of horticulture farms in the basin, this now happens every dry season. The other important causes of today's water crisis are poor agriculture land tenure, and deforestation through logging, charcoal production and marijuana growing, all of which lessen MK's capacity to absorb, retain, and yield water.

7.3.2.2. Use and abuse of the forest resources

Licensed use of certain resources is allowed in National Reserves and Forest Reserves. The forests of MK have traditionally provided important economic benefits through sanctioned access to building materials, household and industry energy, fodder and fruits, and direct employment. In contrast, charcoal production, marijuana growing, and poaching have featured among illegal uses. Some 91% of the households around MK used fuelwood, 53% used construction materials, 47% used medicines, 44% used wild foods, 37% grazed cattle, 34% collected tools, 19% collected honey, and 10% took charcoal from the Forest Reserve (Emerton, 1997; Table 7.5). Of the annual benefits gained from MK in 1997, 2% came from licensed timber and 4% from licensed non-timber extraction, though much more came from illegal extraction of timber (Emerton, 1997).

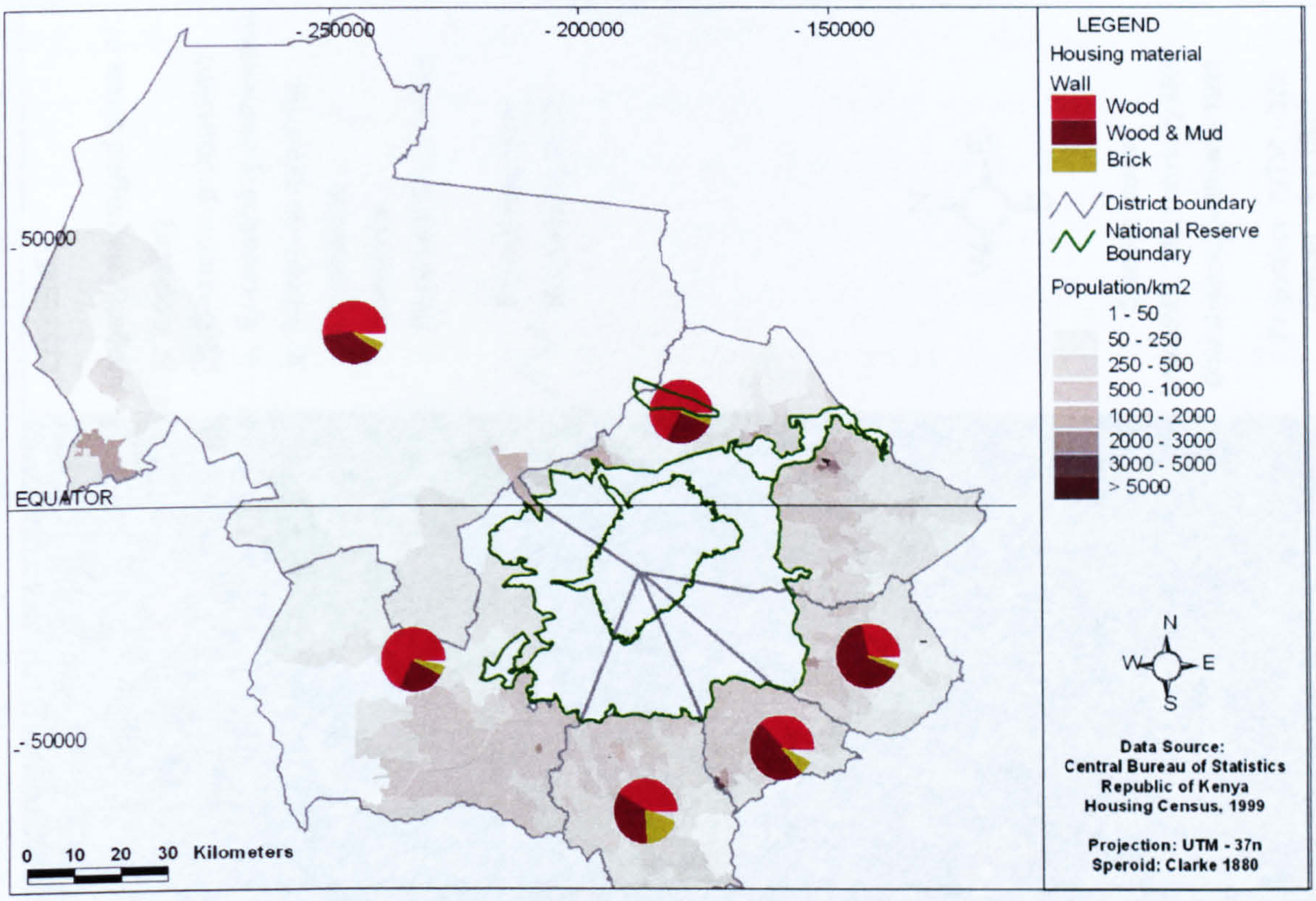
Table 7.5. Percentage of households using MK forest resources per district

Resources	*Meru Central* %	*Meru South* %	*Embu* %	*Kirinyaga* %	*Nyeri* %	**Total** %
Fuelwood	91	76	96	95	95	91
Charcoal	2	5	27	14	N/A	10
Construction material	26	71	74	56	39	53
Tools	29	54	32	25	28	34
Wild foods	11	57	58	42	52	44
Fodder and grazing	47	40	38	32	27	37
Medicines	46	63	47	42	37	47
Hives and Honey	7	41	28	16	4	19

Source: adapted from Emerton, 1997

Households, industries, schools and hospitals used Forest Reserve fuelwood and charcoal for energy and timber for poles, and the construction of fences, furniture, and houses. Housing is an expression of wealth. The cheapest houses have a wooden frame, are filled with stones and plastered with mud. The most expensive ones are made of brick. Wooden houses were dominant in Laikipia, Meru Central and Nyeri districts. Meru South and Embu districts had most houses in wood and mud, and Kirinyaga had most brick houses in brick in 1999 (Figure 7.10).

Figure 7.10. The use of wood in housing around MK



An aerial survey in 1999 located 1,873 damaged sites and indicated that the illegal extraction of trees for timber, fuel, and charcoal was very extensive (Table 7.6).

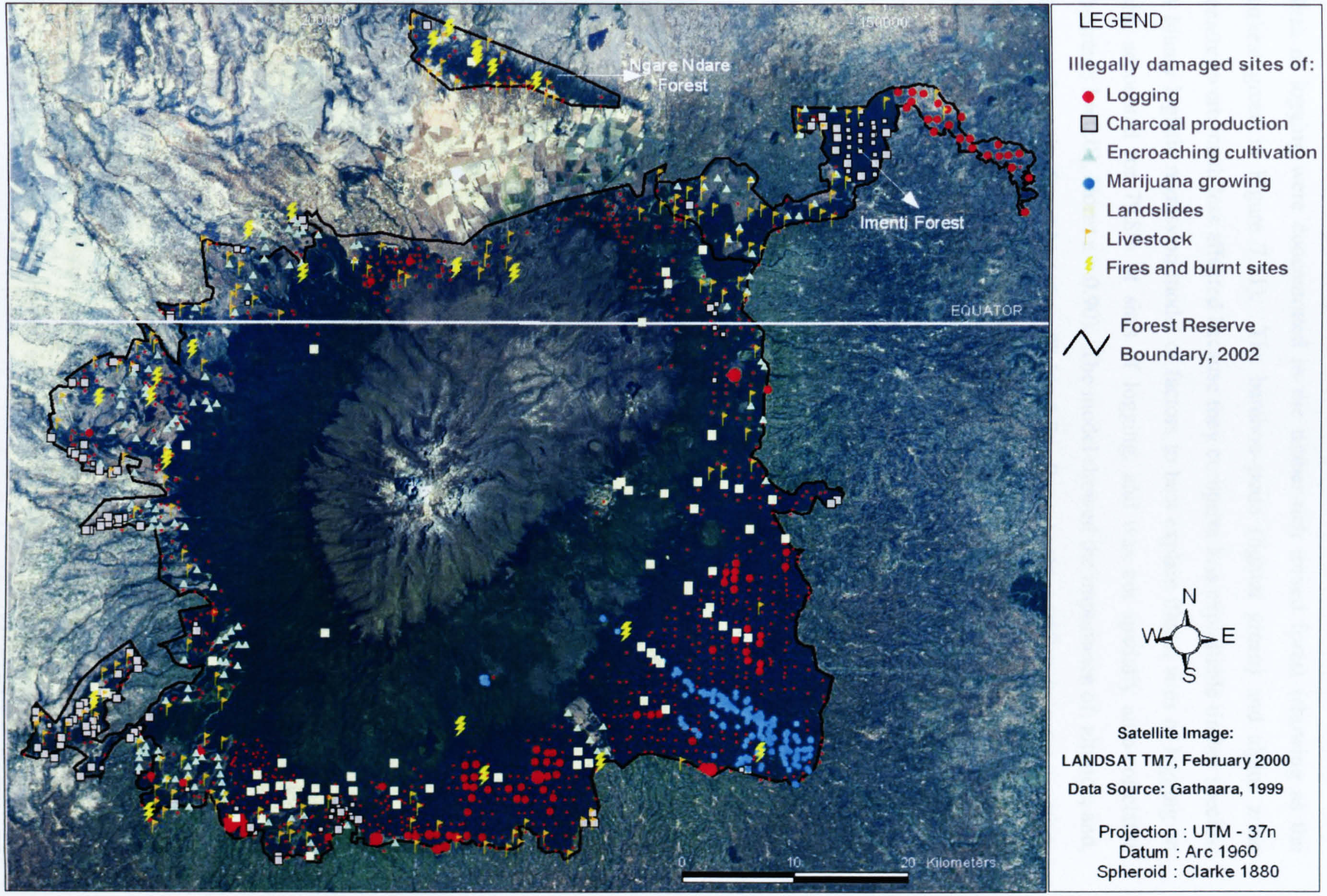
Table 7.6. Number of GPS fixes of damaged sites in the MK, Ngare Ndare and Imenti Forest Reserves per district, aerial survey 1999

Per District	*Sites of Logging*	*Sites of Charcoal production*	*Sites of Encroached cultivation*	*Sites of Marijuana growing*	*Sites of Landslides*	*Sites of Livestock grazing*	*Fires and burnt sites*	**Total**
Meru Central	267	18	26	1	17	46	5	380
Ngare Ndare	*40*	*1*	-	-	*1*	*24*	*6*	*72*
Imenti Forest	*60*	*34*	*15*	-	-	*41*	-	*150*
Meru South	196	1	-	132	14	1	2	346
Embu	98	5	7	7	5	4	1	127
Kirinyaga	205	14	6	4	12	20	2	263
Nyeri	297	71	79	-	22	59	7	535
Total	**1,163**	**144**	**133**	**144**	**71**	**195**	**23**	**1,873**

Source: adapted from Gathaara, 1999

Some 1,873 GPS fixes translated into 17,484 recorded damage events, as one fix could range from a few trees to several hectares of trees. Total damage from logging alone was estimated at 14,662 trees plus 8,279 clear-felled hectares. Logging had totally destroyed the tip of the Imenti, which had become indistinguishable from surrounding farmland on the satellite image of February 2000 (Figure 7.11).

Figure 7.11. Illegal human damage on MK, based on an aerial survey conducted in 1999



Sites of logging

Sites of logging were concentrated in the timber-rich mixed forest (showing as the darkest green in Figure 7.11). The bamboo–podo (lighter green) and alpine zone (centre) were much less affected because they comprise less exploitable timber species. A binary logistic regression model of factors to best explain illegal sites of logging on MK accounted for 79.8% of sites of logging, and was not spatially auto-correlated (Moran's I = 0.01, Norm z = 0.90). The model showed the importance of: altitude; and, distance from the forest boundary (Table 7.7). Because the coefficients were negative, the model suggested that most sites of logging occurred at lower altitudes, near the forest boundary (Figure 7.12).

Table 7.7. Results of a logistic regression model to explain sites of logging

Parameters	*Coefficient(β)*	*SE*	*df*	*Wald*	*P*
Altitude	-0.0027	0.0011	1	5.834	0.016
Distance from forest boundary	-0.0003	0.0001	1	5.230	0.022
Constant	7.5011	2.4426	1	9.431	0.002

Figure 7.12. Sites of logging on MK

7.3.2.2.1. Sites of charcoal production

Some 2,465 sites of charcoal production were counted on MK in 1999, of which 1,842 were found in the Imenti Forest (Table 7.6). A binary logistic regression model of factors to best explain sites of charcoal production on MK accounted for 91.9% of sites of charcoal production, and was not spatially auto-correlated (Moran's I = 0.05, Norm z

= 1.77). The model showed the importance of: slope; and, distance from the forest boundary (Table 7.8). Because the coefficients were negative, the model suggested that sites of charcoal production sites increased on flatter terrain and with proximity to the forest boundary. Sites of charcoal production were most concentrated around the north-east, south-west, and west of MK (Figure 7.13)

Table 7.8. Results of a logistic regression model to explain sites of charcoal production

Parameters	*Coefficient(β)*	*SE*	*df*	*Wald*	*P*
Slope	-0.1490	0.0599	1	6.181	0.0129
Distance from forest boundary	-0.0015	0.0004	1	14.418	0.0001
Constant	4.3323	0.9291	1	21.742	0.0000

Figure 7.13. Sites of charcoal production on MK

7.3.2.2.2. Sites of marijuana growing

Some 144 sites of marijuana fields covering 199 hectares were counted on MK in 1999 (Table 7.6). A binary logistic regression model of factors to best explain sites of marijuana growing on MK accounted for 96.8% of sites of marijuana growing, and was not spatially auto-correlated (Moran's I = 0.02, Norm z = 0.01). The model showed the importance of: altitude; and, distance from the forest boundary (Table 7.9). Because the coefficient for altitude was negative, the model suggested that sites of marijuana growing increased at lower altitudes. In contrast to the other damage causes, the coefficient of for distance from forest boundary was positive, suggesting that sites of marijuana growing increased with distance from the forest boundary. Fields were heavily clustered in the south-east (Figure 7.14).

Table 7.9. Results of a logistic regression model to explain sites of marijuana growing

Parameters	*Coefficient(β)*	*SE*	*df*	*Wald*	*P*
Altitude	-0.0147	0.0045	1	10.551	0.0012
Distance from forest boundary	0.0007	0.0003	1	4.507	0.0338
Constant	27.2917	8.0901	1	11.380	0.0007

Figure 7.14. Sites of marijuana growing on MK

7.3.2.2.3. Sites of landslides

Some 71 sites of landslides were counted on MK in 1999 (Table 7.6; Figure 7.15). A binary logistic regression model of factors to best explain sites of landslides on MK accounted for 81.0% of the observed sites of landslides, and was not spatially auto-correlated (Moran's I = 0.04, Norm z = 1.49). The model showed the importance of: altitude; distance from rivers; distance from plantations; and, distance from the forest boundary (Table 7.10). The coefficients for altitude, distance from rivers, and distance from forest boundary, were negative, suggesting that sites of landslides increased with decreasing altitude, and with proximity to rivers, and the forest boundary. The coefficient for distance from plantations was positive, suggesting that sites of landslides increased with distance from plantations. Sites of landslides are most often the result of logging in riverine forest and have substantial impact on water retention and yield (Figure 7.15).

Table 7.10. Results of a logistic regression model to explain sites of landslides

Parameters	*Coefficient(β)*	*SE*	*df*	*Wald*	*P*
Altitude	-0.0024	0.0009	1	7.895	0.0050
Distance from rivers	-0.0014	0.0005	1	8.604	0.0034
Distance from plantations	0.0002	6.4e-5	1	10.028	0.0015
Distance from forest boundary	-0.0002	0.0001	1	5.458	0.0195
Constant	6.9403	1.9843	1	12.234	0.0005

Figure 7.15. Sites of landslides on MK

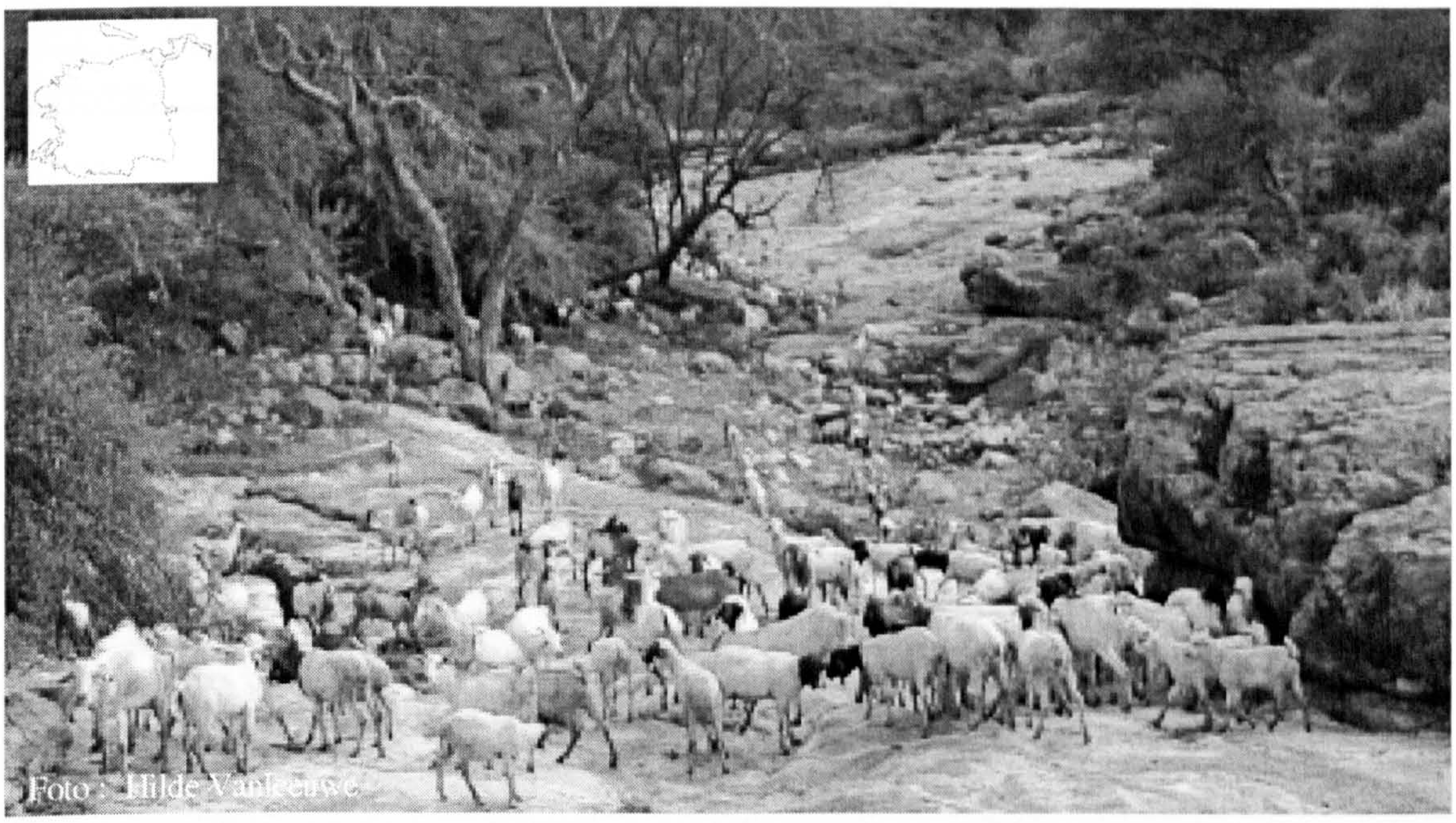
7.3.2.2.4. Sites of livestock grazing

Some 195 herds, representing 4,258 heads of livestock were counted on MK in 1999 (Table 7.6; Figure 7.16). A binary logistic regression model of factors to best explain sites of livestock grazing on MK accounted for 84.0% of the observed sites of livestock grazing, and was not spatially auto-correlated (Moran's I = 0.04, Norm z = 1.48). The model showed the importance of: distance from the forest boundary. The coefficient for distance from forest boundary was negative, suggesting that sites of livestock grazing increased with proximity to the forest boundary (Table 7.11).

Table 7.11. Results of a logistic regression model to explain sites of livestock grazing

Parameters	*Coefficient(β)*	*SE*	*df*	*Wald*	*P*
Distance from forest boundary	-0.0010	0.0002	1	20.740	0.0000
Constant	2.7167	0.5534	1	24.102	0.0000

Figure 7.16. Site of livestock grazing on MK



7.3.2.2.5. Fires and poaching

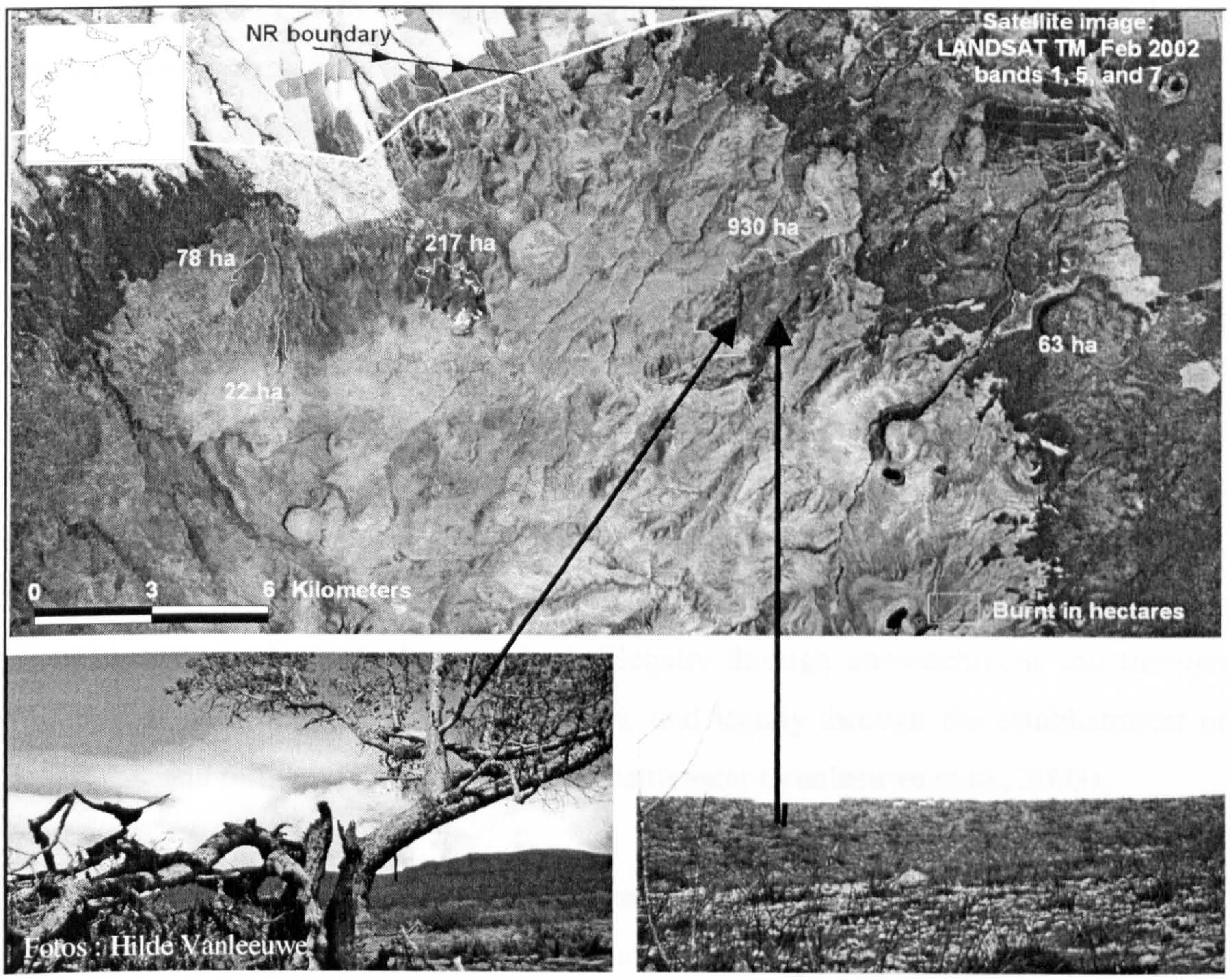
There was little poaching of large mammals on MK in 1999, although snare-poaching for meat was very common around the Mountain Lodge clearing in the south-east (see Chapter 6; Vanleeuwe and Lambrechts, 1999). Poaching in the forest cannot be seen from the air but the areas of burnt moorland were often the result of arson by poachers. Poachers burn the tussock grasses to attract grazing animals to young green grasses that sprout from the ashes within a few weeks after burning. Some fires were caused accidentally during charcoal production or during honey hunting when smoking bees from their hives. However, arson by poachers is a common hunting technique that destroys many hectares of moorlands in the dry seasons every year (Figure 7.17).

Some 23 fires and freshly burnt sites were counted on MK in 1999 (Table 7.6; Figure 7.17). A binary logistic regression model of factors to best explain fires and burnt sites on MK accounted for 73.9% of the observed fires and burnt sites, and was not spatially auto-correlated (Moran's I = 0.01, Norm z = 0.42). The model showed the importance of: distance from the forest boundary. Because the coefficient for distance from forest boundary was negative, the model suggested that fires and burnt sites increased with proximity to the forest boundary (Table 7.12).

Table 7.12. Results of a logistic regression model to explain fires and burnt sites

Parameters	*Coefficient(β)*	*SE*	*df*	*Wald*	*P*
Distance from forest boundary	-0.0004	0.0001	1	9.674	0.0019
Constant	1.5967	0.5701	1	7.844	0.0051

Figure 7.17. Fires and burnt sites on MK



7.4. DISCUSSION

Despite enjoying theoretical protection status, land and natural resources are used and abused in 95% of the PAs in developing countries (IUCN, 2003). Exploration of the use and abuse of land and resources illustrate the scale of human impact upon MK. Both sanctioned use of land and resources and community-based projects are suggested as possible solutions to improve relationships between people and the environment

(Balmford et al., 1999; Armsworth and Roughgarden, 2001; Kokko, 2001; Osborn and Parker, 2003) and have been applied on MK. However, without effective control, sanctioned use of land and resources often becomes unsustainable in the hands of poor people who aim to improve their economic prospects (Abbot and Mace, 1999; Anderson, 2001; Soehartono and Newton, 2001). Several studies have focussed on the advantages and dangers of projects promoting sanctioned use of land and resources (Balmford and Whitten, 2003; Hutton and Leader-Williams, 2003; Williams et al., 2003). The following discussion will focus on the reasons why sanctioned use has turned into abuse and to what extent sanctioned resource use and community-based projects have worked or failed to work on MK.

7.4.1. Use and abuse of MK Forest Reserve land

Management of land loss, landscapes, and land use, are subjects of contemporary concern in biodiversity conservation (Harcourt et al., 2001; Sanderson et al., 2002; Moore et al., 2003). Time-series analysis of satellite images have been used world-wide to identify land-cover changes (Thompson et al, 1998; Di Gregorio and Jansen, 2000; Willard et al., 2000). The shortage of agriculturally viable land in Kenya has resulted in an acute pressure on the fertile land around MK (Gathaara, 1999; Kiteme, 2001; Hoft, 2002; Jenkins, 2003). Despite its protection status, this pressure has led to serious land-cover changes in the last 15 years, both illegally through encroachment and through violation of NRC regulations on plantations, and legally through the establishment of the NTCZ, and through forest excisions for settlement (Vanleeuwe et al., 2003).

7.4.1.1. Non residential cultivation (NRC)

NRC was adapted from the Taungya land transformation system devised by the colonial forest administration in Burma, and introduced to East Africa around 1914. It was introduced to promote sanctioned use of clear-felled afforested land in plantations and was practised with success for decades after its inception in the early 20^{th} century (Hoft, 2002). While forest workers were given the opportunity to cultivate for 2 to 4 years on afforested land, the FD benefited from free maintenance of seedlings between the crops (Gathaara, 1999; Kiteme, 2001). However, problems started when NRC land was leased to outsiders during times of increased afforestation activities (Rheker, 1992). In the north-west alone, there were more than 2,000 outsiders cultivating in the forest during the 1970's and the demand for land greatly exceeded available afforested land (Kohler, 1986). Another problem came from rapidly expanding families of forest workers at forest stations, whose many young dependants constituted 25% of the adults at some stations, and who engaged in illegal exploitation of the indigenous forest around the plantations to earn money (Kohler, 1986; Rheker, 1992).

NRC was banned between 1986 and 1994 because of land-hungry cultivators and because of poor capacity within the FD that led to serious planting backlogs (Hoft, 2002). The Kenya Government decided to evict 17,500 squatters from forest stations in 1989 but NRC was re-instated in 1995 to alleviate the difficulties associated with establishing exotics (Gathaara, 1999; Kiteme, 2001; Hoft, 2002). However, violations increased after NRC was re-instated, and clear-felled areas exceeded the capacity to replant at all stations. Additionally, illegal cultivation inside the indigenous forest or encroachment, was often shown to start in plantations, as crops from NRC-appointed land gradually expanded into the indigenous forest. Based on logistic regression analysis, illegal cultivation in the indigenous forest was generally close to roads and to the forest boundary, and also to plantations.

7.4.1.2. The Nyayo Tea Zone Corporation (NTCZ)

The NTZC excised from the Forest Reserve in 1986, and replaced a thin stretch of forest totalling some 14.8km^2 with tea on the rainy side from the north-east to south-west along the MK boundary (Emerton, 1997). The NTCZ aimed to provide employment and infrastructure, and to mark the MK boundary, the aims of which all succeeded very well (Hoft, 2002). Many hundreds of people work on the NTCZ, their infrastructure is one of the best in Kenya, and tea physically and effectively marks the forest boundary through which encroachment is readily noticed. The NTZC buffer between forest and farmland also helps to reduce elephant crop damage to farmland (see Chapter 6), although it does not reduce human impact on natural resources. Human impact is most pronounced on the NTCZ side of MK, though this could just be because it lies on the same side as most of the timber-rich forest. Although that the NTZC has planted its own woodlots for tea-production, it has not been established whether or not NTCZ staff are involved in illegal offtake of MK timber. If there was corruption within the NTCZ, the excellent infrastructure would surely help to get forest produce out quickly.

7.4.1.3. Forest excisions

Much land has been excised from PAs in response to the demand for land as a result of rapidly expanding populations (Harcourt et al., 2001; Kinnaird et al., 2003). More MK forest land was excised for settlement in 2001 than in the previous 30 years combined. The 2001 excisions include the disputed Hombe (7.17km^2), Ndathi (9.12km^2), Ragati (1.96km^2), Ngushishi-Sirimon (7.96km^2), and Gathiuru (6.20km^2) schemes, that were established to resettle the landless and squatter communities (Kiteme, 2001; Hoft, 2002). In reality, allowing legal settlement has rewarded abuse of land. The Sirimon scheme sought to resettle squatters from long-standing encroachment at the northern MK boundary. Instead, other people have settled it, and the Gathiuru excision represented another long-standing encroachment that was legalised through excision. The Ndathi, Ragati and Hombe schemes were plantation forests where NRC had been violated for extended periods of time (Vanleeuwe et al., 2003). Settlement of forest land is a nation-wide problem. Serious inconsistencies between the size of proposed versus excised areas reflect substantial corruption in forest land allocations (Matiru, 2000).

7.4.2. Use and abuse of MK resources

The main resources used on MK are water and trees (Emerton, 1995, 1996, 1997; Gathaara, 1999; Kiteme, 2001). The effects of tree loss on biodiversity have been well-documented (Abbot and Mace, 1999; Kapos et al., 2000; Seydack et al., 2000; Silori and Mishra, 2001; Soehartono and Newton, 2001; Jacquemyn et al., 2003), as well as the effect of biodiversity loss on ecological processes (Wilson et al., 1996; Schlapfer et al., 1999; Young, 2000; Downing and Leibold, 2002; Ostroumov, 2002).

7.4.2.1. Use and abuse of water on MK

The importance of MK as a water catchment in Kenya have been the subject of several studies (Liniger, 1992; Ojany, 1993; Wiesmann et al., 2000; Mwaura and Mutunga, 2003). MK and the neighbouring Aberdare mountain range are the sources of Kenya's largest river, the Tana River, that supports seven hydro-electricity power dams and three irrigation schemes (COMPACT, 2001). They are also the sources of Kenya's second largest river, the Ewaso Nyiro River, on which pastoralists from the dry north depend. Several factors have induced the current critical water situation that fuels conflicts between highland communities close to the water sources and the lowland communities from the dry north (Wiesmann et al., 2000).

Historically, water problems were introduced when large former ranches were divided into small plots without taking subsequent water use into consideration. Irrigating one acre per plot would require quantities of water that exceeds dry-season river flows by 3 to 4 times (Brunner, 1986). In addition, the number of large wealthy horticulture farms in the Ewaso basin have increased over the past decade. These farms affect the water supply through their large size, and through storing river water in the dry seasons to fill up their dams. These farms also invest very little in solving the indirect impacts that they bring to the Forest Reserve, because many hundreds of their employees squat in the Forest Reserve, harvest timber and fuel, and poach wildlife for meat. Furthermore, despite the water shortage, irrigated horticulture is promoted to reduce economic instability of the Forest Reserve adjacent small-scale farmers by the Kenyan Development Master Plan (JICA/ GOK, 1999). Not only is there not enough water to irrigate, but small-scale farmers extract water through furrows, which lose water through percolation and evaporation, while also spreading water-borne diseases such as amoebiosis (Winiger, 1986).

Lack of technical knowledge among responsible water organisations has created a desperate water situation (Leibundgut, 1986). At national level, discussions about improved management begin at times of tense water supply, but as soon as the rains have started, they are forgotten (Decurtis, 1992). Water permits continue to be issued, despite the fact that water is so scarce that competing extractors destroy each others' water pipes.

7.4.2.2. Use and abuse of forest products on MK

Deforestation affects water catchment functions and important ecological processes (Rehder, 1992; Bussmann, 1996; Tengberg et al., 1999). Trees are also of major importance in catchment areas because tree roots help water retention and gradual water release, and the rain catchment surface of leaves and stems is much greater than that of barren environments and cropland. However, the law to protect water catchment areas that forbids clear-felling of trees for cultivation on slopes over 35%, was relaxed to 55% to address the demand for fertile cultivation land (Winiger, 1986).

Sanctioned use initiatives have allowed people to harvest forest products from the MK Forest Reserve such as timber, firewood, medicinal herbs, thatch, fruits and fodder, under licensed agreement with the local FD authorities (Emerton, 1995, 1996, 1997). At local level, revenues are generated on an as-needs basis from selling small-scale, illegally extracted products, and more important revenues are gained from large-scale illegal timber and charcoal (Gathaara, 1999; Kiteme, 2001; Mathuva, 2001). Many projects have been launched on MK since the mid 1980's to reduce human pressure and dependency on the Forest Reserve. They include over 100 projects of on-farm agroforestry, re-afforestation, and the introduction of fuel-saving stoves (COMPACT, 2001; Mbora and Simons, 2002).

Aerial transect surveys have been widely used to count animals in open environments (Tchamba and Elkan, 1995; Clancy et al., 1998; Walter and Hone, 2003) and to a much lesser extent to count trees (Southwell et al., 1999; Bowman et al., 2001). On MK, an aerial survey counted sites of: logging; charcoal production; marijuana growing; encroached cultivation; landslides; livestock grazing; and, fires and burnt sites (Gathaara, 1999).

Although some 150 timber enterprises were licensed on MK by the mid 1980's, many more operated illegally. This led to a total ban on logging of indigenous trees through a Presidential Decree in 1986, but illegal logging still continued (Emerton, 1997). Although charcoal production on MK is illegal, the Imenti forest in the north-east, the Thego area in the south-west, and the Gathiuru area in the west were littered with charcoal production sites in 1999 (Gathaara, 1999). Traditional fast-built chacoal kilns often suck in air during the production process, which can lead to over 70% loss of tree volume during charcoal production. Over 90% of Kenyans use fuelwood and over 50% also use charcoal on a daily basis, such that Kenya consumes two million tons of charcoal per annum. However, 0.001km^2 of woodland is needed to produce one ton of charcoal using traditional kilns, whereas 0.0005km^2 would be needed using efficient kilns (Walubengo, 2002). Legal charcoal production would also allow the use of tree-saving kilns but it would have to happen outside PAs to prevent legal use turning into hidden abuse.

Some 2km^2 of forest on MK were clear-felled for marijuana growing, even though production and consumption of marijuana in Kenya are subject to severe punishment. Therefore, it is not surprising that marijuana is grown away from the forest boundary and often hidden in valleys in riverine forest (Gathaara, 1999; Vanleeuwe et al., 2003). Landslides are signs of serious erosion that are indirectly the result of deforestation in riverine forests.

There were not enough staff to control licensed livestock grazing, so almost all grazing was done without a licence. Cattle compete directly with wild ungulates for food. Goats cause erosion by eating vegetation to their roots, while their hooves cut tunnels in the ground.

Snare-poaching is particularly pronounced around the Mountain Lodge clearing in the south-west, which attracts large numbers of animals on daily basis feeding on its mineral-salt-rich soils (Vanleeuwe and Lambrechts, 1999). Poaching is also common in the moorlands above 3,500m asl.

Arson by poachers is hard to control in the moorlands, which are difficult to access, while fires spread incredibly fast in the dry season with the usual strong winds in the alpine areas. Accidental fires in forested areas caused by honey-hunters are also common. However, in 2002, a community-based bee-keeping project was launched by Honey Care Africa that involves a technique of honey retrieving through Langstroth hives, without the risk of fires (COMPACT, 2001). Honey Care Africa is a rapidly growing international business that has around 12,000 hives in Kenya. They provide training, hives, and buy honey from farmers, as well as market the honey. Their initiative on MK was funded by Global Environmental Facility's Small Grants Programme of UNDP, and its success still has to be assessed. However, if it works, this project may be the first of many community-based conservation project located inside the Forest Reserve that works.

In general, most community-based projects outside the MK Forest Reserve have shown success, and reduced pressure from the Forest Reserve (COMPACT, 2001). In complete contrast, all projects of sanctioned use of resources inside the Forest Reserve have failed due to the lack of any financial and material capacity to control offtake, combined with a financially poor and corrupted institution, the FD, in charge of law enforcement (Vanleeuwe et al., 2003). Because the human population around MK has more than doubled in the last 20 years, the offtake of resources has become unsustainable. Most subsistence farmers are generally poor and seek to improve their financial status (Sottas and Wiesmann, 1993), while there is a high national demand for forest products, especially for timber, fuelwood and charcoal, which fuels the success of illegal markets. Levels of deforestation from illegal harvesting is severe in all forests in Kenya (e.g. Lambrechts et al., 2003).

7.5. CONCLUSIONS

Solutions to land-hunger and economic instability have been addressed through sanctioned use initiatives inside the Forest Reserve and through community-based projects at the boundary and outside the Forest Reserve. MK has the capacity to support sanctioned use of its land and resources, but a lack of control has turned well-intended sanctioned use projects into opportunities for abuse.

Abuse of land has occurred through violation of regulations that are associated with NRC on afforested land in plantations, which has led to hidden encroachment and permanent land loss for settlement. At local and at national level, solutions have been sought in lucrative but unsustainable systems of land and resource use, such as through continuing to sell water permits for over-utilised rivers and allowing cultivation on riverbanks in water catchment areas, by promoting irrigated agriculture despite the water shortage, by de-gazetting of forest land for settlement. The indirect effects of over-exploitation of the MK forest by adjacent communities jeopardise MK's capacity to yield and retain water, and its ground structure through sediment loss.

Failure of sanctioned resource use and community-based projects under similar conditions of poverty, combined with growing demand for resources, a thriving illegal market, and economic and political corruption, is not new. The only type of projects to have succeeded on MK are those that are spatially separated from the PA, such as the NTCZ initiative at the MK Forest Reserve boundary, the community-based fences at the boundary (Chapter 6), and the many on-farm agroforestry projects. Projects that have failed and led to irreversible damage were those of licensed use of trees and land (legal logging, NRC) inside the Forest Reserve. In July 2000, management of the MK indigenous forest transferred from the FD to the KWS, and I will investigate the effect of the change in managing institutions on the conservation status of MK in Chapter 8.

Chapter 8

THE EFFECTIVENESS OF INSTITUTIONS MANAGING MOUNT KENYA: FOREST DEPARTMENT (FD) VERSUS KENYA WILDLIFE SERVICE (KWS)

8.1. INTRODUCTION

The survival of ecosystems relies on a stable relationship between biodiversity and people, in which people play the dominant role. The vast majority of forested protected areas (PAs) suffer from illegal offtake of resources (Leader-Williams and Albon, 1988; Klooster, 1999; McAlpine, 2003; WWF, 2004) and inadequate legislation, funding and governance (Bruner et al., 2001; Balmford and Whitten, 2003; Smith et al., 2003; Olowu, 2003). Lack of PA benefits for surrounding communities cause reduced community tolerance towards wildlife and managers of the resources (Du Toit, 2002; Balmford and Whitten, 2003; Williams et al., 2003). Community-based conservation and systems of sanctioned resource use have been promoted to address these problems (Thouless, 1993; Leader-Williams et al., 1996; Agrawal, 1997; Hackel, 1999; Kokko, 2001; Hutton and Leader-Williams, 2003), because the top-down approach of PA protection adversely affects livelihoods, encourages illegal resource extraction, and entails high management costs (Balmford et al., 2000; Hutton and Leader-Williams, 2003; Osborn and Parker, 2003). More recently, economic justifications have emerged, in which ecosystems are fully valued for the economic benefits they can produce to improve overall economic stability in developing countries, and to reduce their dependence on donor funds (Armsworth and Roughgarden, 2001; Smith et al., 2003).

Financial capacity often determines the level of corruption in governing institutions, as the history of the Wildlife and Conservation Management Department (WCMD) and the FD in Kenya confirms. The earliest forest legislation in Kenya, and the establishment of the FD, date from 1902. The earliest wildlife legislation dates from 1898, and the Game Department was established in 1908. By 1908, the main forest blocks of Kenya had been declared Forest Reserves and the first National Park was established in 1946. The Game Department and a Board of Trustees in charge of wildlife protection merged into the WCMD in 1976. Hunting was banned in 1977, but because of tight government funds, combined with high black market prices for ivory and rhino horn, corruption was rife in the WCMD during its administration between 1976 and 1991. This led to 85% loss of elephants and 97% loss of rhinos in Kenya through poaching, mostly by WCMD employees (Wass, 1995; Hoft, 2002). With tourism as Kenya's top foreign exchange earner in the 1980's, this industry became threatened by the deteriorating insecurity.

Hence, the Government of Kenya established the Kenya Wildlife Service (KWS) as a parastatal organisation in 1991. Unlike government institutions that rely entirely on government funds from the national treasury, parastatals can raise and retain their own funds that remain within the institution. Accordingly, the financial and material capacity of, and the salaries within, the new institution in charge of wildlife increased substantially. In the case of Kenya, most importantly, the effectiveness of law enforcement greatly improved under the KWS and large-scale poaching stopped.

Several studies have shown that principles of sanctioned resource use in hands of poor people and/or corrupted governance, may become unsustainable (Abbot and Mace, 1999; Soehartono and Newton, 2001). In Uganda, the sharing of National Park tourist revenue with surrounding communities encouraged people to settle around parks, and introduced new levels of corruption because many stakeholders were involved and were controlled by a local elite (Archabald and Naughton-Threves, 2001). Farmers harbour ideas of corruption (Ekbom et al., 2001), as do local authorities even when there are plenty of funds (Huber, 2001) because economic development is generally valued as more important than conservation. For this reason alone, sanctioned use, community-based conservation, and benefit sharing, can only protect the environment when promoted as a duel strategy with strict law enforcement, as in the case of Mount Kenya (MK). Forest destruction on MK under FD management was pronounced and was made public through an aerial survey in 1999 (Gathaara, 1999), which caused the Forest Reserve to be upgraded to National Reserve and the responsibility for its protection to be transferred from the FD to the KWS in July 2000. The effects of management transfer on the protection of MK was investigated through the following questions:

- How does the financial and material capacity of the FD and the KWS compare?
- How does reporting of human-elephant conflicts in KWS occurrence books change between 1999 and 2002?
- Where and to what extent has land cover on MK changed, as visible from satellite images of 2000 and 2002?
- Where and to what extent is forest cover on MK affected by human exploitation, as visible from aerial transect surveys in 1999 and 2002?

8.2. METHODS

The financial capacities of the FD and KWS were compared, and the human-elephant conflict (HEC) reports at KWS stations around MK for 1999, 2000, 2001, and 2002 were compared. Time-series analyses were conducted of satellite images to establish spatio-temporal patterns of land cover changes in 2000 and 2002. Changes in the extent and distribution of human damages on MK forest resources were investigated by comparing two aerial surveys conducted in 1999 (Gathaara, 1999) and in 2002 (Vanleeuwe et al., 2003).

8.2.1. Comparison of FD and KWS financial capacity

Data on the financial and associated material capacities and on workforce of the KWS and the FD, were extracted from the Mount Kenya Management Plan 2002-2007 (Hoft, 2002) and from archive data and reports (e.g. Wass, 1995; Emerton, 1997; Gathaara, 1999; Kiteme, 2001; KWS, 2001; KWS, 2002).

8.2.2. Comparison of HEC records from KWS occurrence books

All of five larger KWS stations and thirteen KWS outposts around MK have their own occurrence book (OB) in which all complaints, activities and events are recorded (Chapter 6, Section 6.2.1). People around MK can report damages to their property from elephants to any of the KWS stations or outposts. Many farmers stopped reporting elephant crop damage because of the lack of financial compensation for elephant crop damage (e.g. Hagiwara, 2002). Financial compensation for crop loss by wildlife in Kenya ceased to exist because the system raised unsustainable expectations, did not stop wildlife from damaging crops, and was abused. However, financial compensation is still paid for human injuries and deaths, and such incidents are always reported.

HEC reports as found in the KWS OBs were analysed and discussed in detail in Chapter 6. For this chapter, reports on crop damage by elephants to farms adjacent to MK were collated from all KWS occurrence books for 1999, 2000, 2001, and 2002, to compare reporting per district and per year.

8.2.3. Comparative satellite image analysis

Two LANDSAT TM7 satellite images of MK, one of February 2000 and one of February 2002, were compared to identify land cover changes. For interpretation, "true colour" composite images were created in which bands 1, 2, and 3, were allocated as the composite blue, green, and red bands, respectively (Chapter 2, Section 2.2.3). Using ArcGIS, the contours of the MK plantation blocks were digitised onscreen from scanned and geo-referenced 1:10,000 scaled topographic sheets that were obtained from the FD. The digitised contours of plantation blocks were superimposed onto the satellite images, to distinguish planted from clear-felled plantation blocks. We flew at very low altitude above these areas to validate the results of the interpretation of satellite images.

8.2.4. Comparative aerial surveys

An aerial survey conducted in 1999 was compared with one from 2002. However, the financial budget in 2002 did not allow for the same total area to be surveyed as in 1999. Only 300km^2, or roughly 15% of the total area covered in 1999, could be surveyed in 2002. To pick up any potential spread of new threats, many small areas were surveyed, rather than a few large areas. The smallest square that could be properly surveyed using line-transects was 3x3km. Because threats were clustered in 1999 (Moran's I = 4.96, Norm z = 12.73), the distribution of the 30 squares of 3x3km totalling 270km^2 in 2002 (Figure 8.2) were chosen in proportion to threat amplitude in each block in 1999, although making sure that at least 10% of each block was surveyed (Figure 8.1). Squares above the tree line were rejected and redrawn.

The "Clip one theme based on another" option of the "GeoProcessing wizard" was used In ArcView to extract the data from the aerial surveys of 1999 and 2002 for the 30 squares of 3x3km. The data tables were imported into SPSS for paired sample t-tests and chi-square analysis, to examine possible differences between the 1999 and 2002 data. Damages and changes of damages were tested for spatial auto-correlation in CrimeStatII. Spatial auto-correlation is expressed as a value of Moran's I with associated normality z (Norm z), indicating no spatial auto-correlation at 95% confidence when below 1.96.

Figure 8.1. Flight lines and damages recorded during an aerial survey in 1999, and thirty selected squares of 3x3km surveyed in 2002

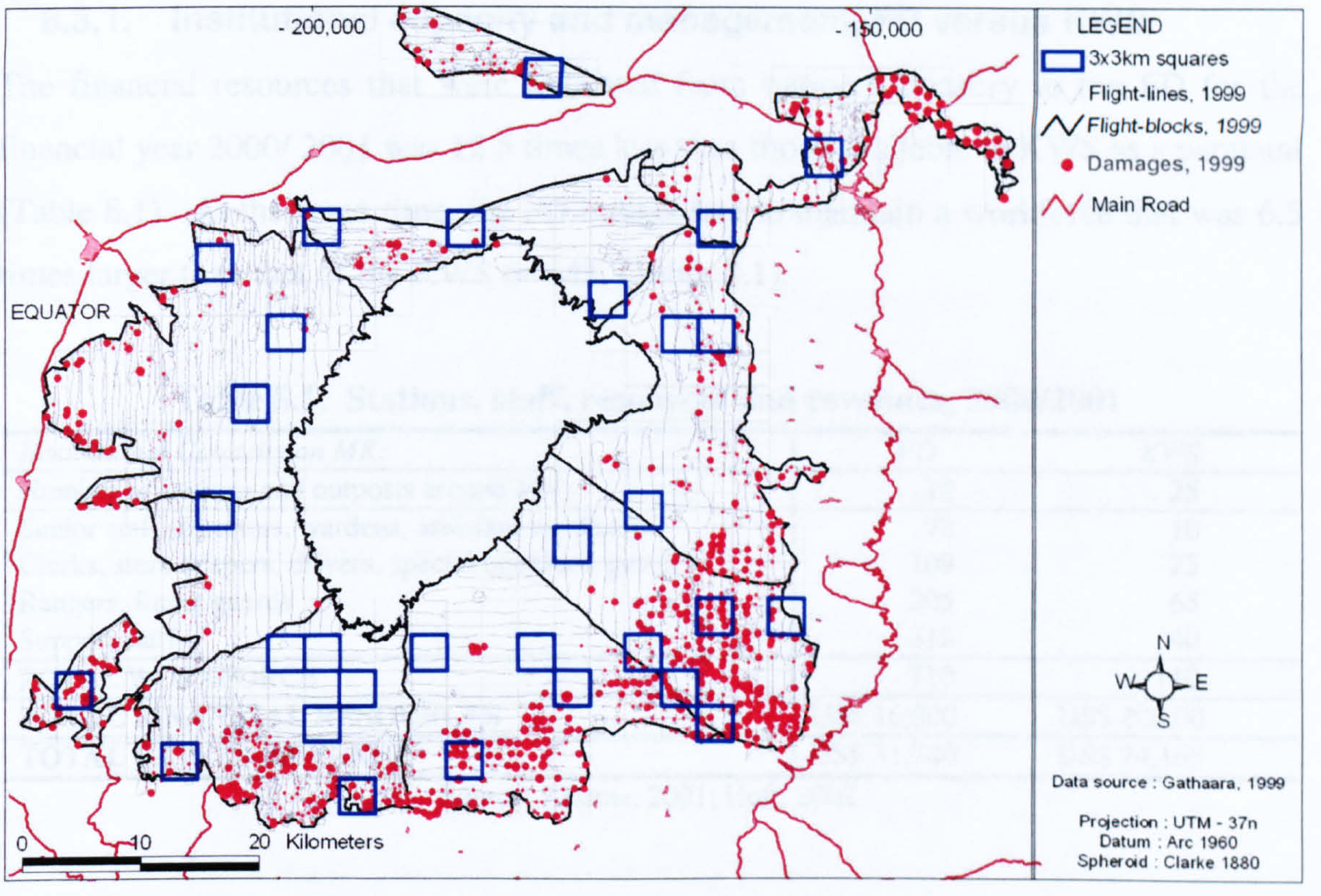
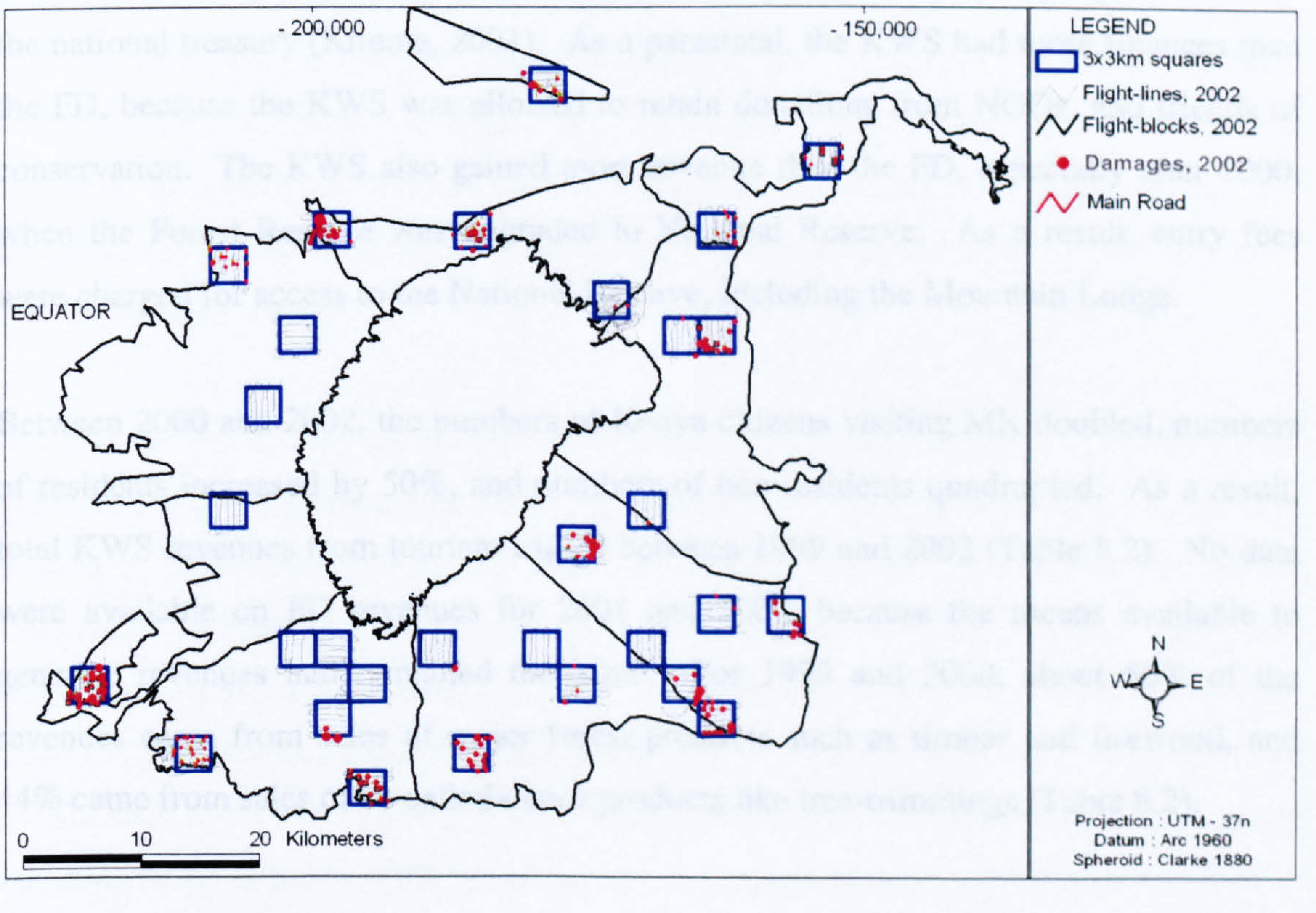


Figure 8.2. Flight lines and damages recorded during an aerial survey in 2002



8.3. RESULTS

8.3.1. Institutional capacity and management, FD versus KWS

The financial resources that were allocated from national treasury to the FD for the financial year 2000/ 2001 was 12.5 times less than those available to KWS as a paratatal (Table 8.1). At the same time, the FD budget had to maintain a workforce that was 6.5 times larger than that of the KWS on MK (Table 8.1).

Table 8.1. Stations, staff, resources and revenues, 2000/2001

Institutional Capacity on MK:	*FD*	*KWS*
Number of stations and outposts around MK	18	25
Senior staff (foresters, wardens, assistant wardens)	78	10
Clerks, store keepers, drivers, special operation group	109	25
Rangers, forest guards	205	65
Support staff	318	40
TOTAL WORKFORCE	710	110
TOTAL FINANCIAL RESOURCES	US$ 16,000	US$ 200,00
TOTAL GAINED REVENUE	US$ 31,740	US$ 74,168

Source: Kiteme, 2001; Hoft, 2002

Matters became worse for the FD during the mid-year budget review in 2000/ 2001, when the financial resource allocations were halved because of declining resources at the national treasury (Kiteme, 2001). As a parastatal, the KWS had more finances than the FD, because the KWS was allowed to retain donations from NGOs, and friends of conservation. The KWS also gained more revenue than the FD, especially after 2000, when the Forest Reserve was upgraded to National Reserve. As a result, entry fees were charged for access to the National Reserve, including the Mountain Lodge.

Between 2000 and 2002, the numbers of Kenya citizens visiting MK doubled, numbers of residents increased by 50%, and numbers of non-residents quadrupled. As a result, total KWS revenues from tourism tripled between 1999 and 2002 (Table 8.2). No data were available on FD revenues for 2001 and 2002, because the means available to generate revenues had remained the same. For 1999 and 2000, about 56% of the revenues came from sales of major forest products such as timber and firewood, and 44% came from sales of so-called minor products like tree-trimmings (Table 8.2).

Table 8.2. KWS versus FD annual revenues on MK

	KWS revenues from tourism				FD revenues from licensed sales		
Year	*# of citizens @ US$1.33*	*# of residents @ US$6.67*	*# of non-residents @ US$ 15*	TOTAL US$	*Major forest products*	*Minor forest products*	TOTAL US$
1999	4,896	1,326	2,227	48,773	26,114	21,664	47,778
2000	6,110	2,395	3,337	74,168	17,587	13,828	31,415
2001	9,791	4,418	11,788	219,328	??	??	??
2002	12,033	3,078	13,205	226,717	??	??	??

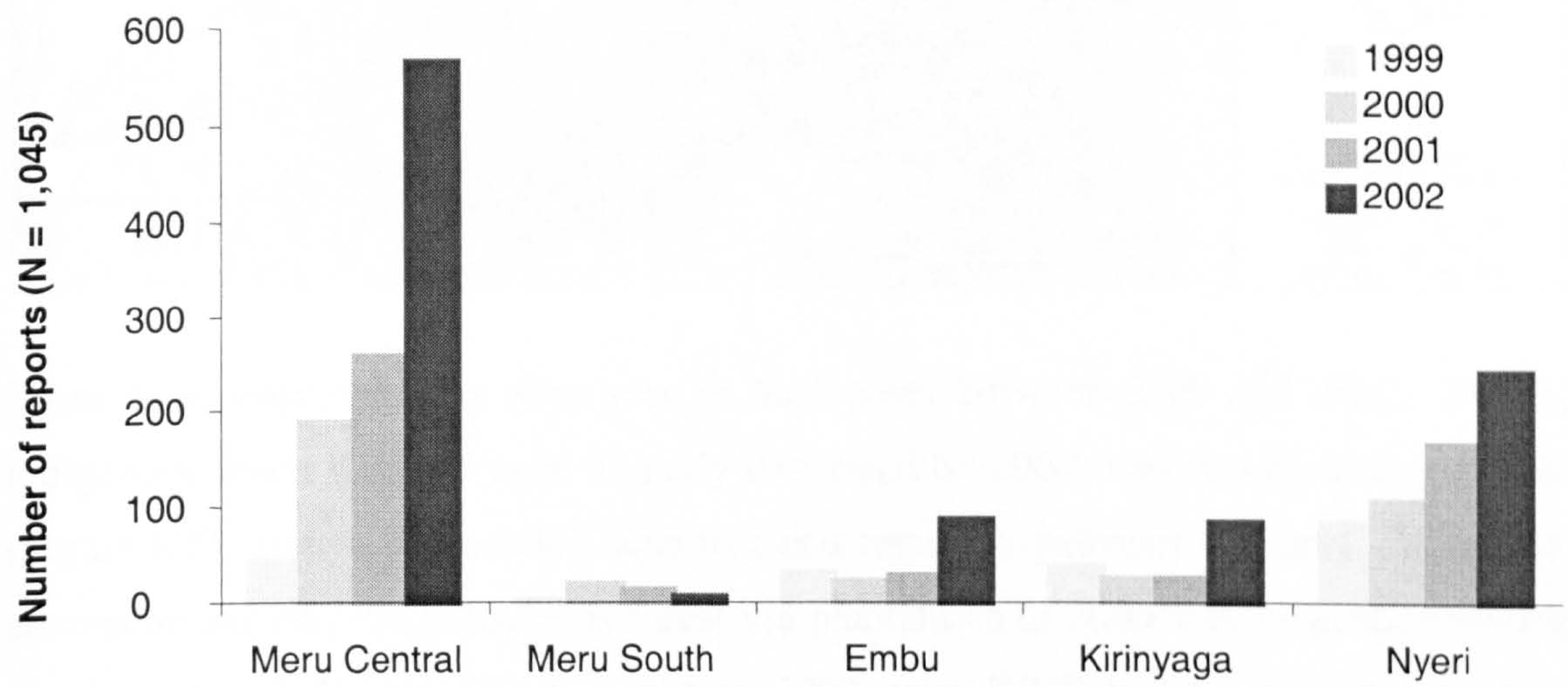
Given the differences in financial capacities, the KWS was better equipped than the FD. The FD had a dozen vehicles and poorly maintained trailers and tractors that were shared between all stations. Tree-thinning equipment was either very badly maintained, broken, or absent. Salaries were often less than US$ 30/ month and the only available means of communication was via privately owned cell-phones. Even this only became an option with the installation of reception masts by Safaricom and Kencell in 2000, and before that there was almost no communication between stations. Nevertheless, FD foresters and assistant foresters attempted to run their stations despite the poor conditions. To operate and react to emergencies, foresters not only used their own cell-phones but also had to make deals with the army based in the area and local technicians for repairs to vehicles, tractors, and roads, in return for some firewood or other forest products. The dividing line between such small deals and larger ones was diffuse. Because of its lack of material capacity and financial capacity, FD control of people accessing the indigenous was inefficient. The levels of economic corruption within the FD with the selling of licences for the offtake of forest resources were serious, and resulted in the deterioration of MK forest status, as illustrated in the aerial survey of 1999 (Gathaara, 1999).

In contrast, the KWS had among other facilities, a well-maintained aircraft, several vehicles and drivers, tractors, trailers, a grader, stores, a garage, camping equipment, as well as permanently manned radio-rooms at all main stations and hand-held radios for field missions, and guns and ammunition for all rangers. All rangers were housed, had uniforms, and had a basic salary of around US$ 80/ month, excluding field allowances. Control of actions and events was rigourous, with everything, from the number of bullet rounds used in problem-animal control (PAC), community complaints, to rangers going on leave, being noted in KWS occurrence books, provided at all stations and outposts.

8.3.2. Comparison of HEC records in KWS occurrence books

The reporting of HEC in KWS OBs by farmers living adjacent to the forest increased steadily between 1999 and 2002 (Figure 8.3). This was probably the result of more regular reporting of elephant damage, rather than any increased occurrence of HEC (Chapter 6). With the exception of Meru South, the number of reports of elephant crop damage in the four other districts around MK doubled, at the least, between 1999 and 2002 (Figure 8.3). Most reports of elephant crop damage came from Meru Central and Nyeri districts, and comparatively few reports came from Meru South, Embu, and Kirinyaga districts (Figure 8.3).

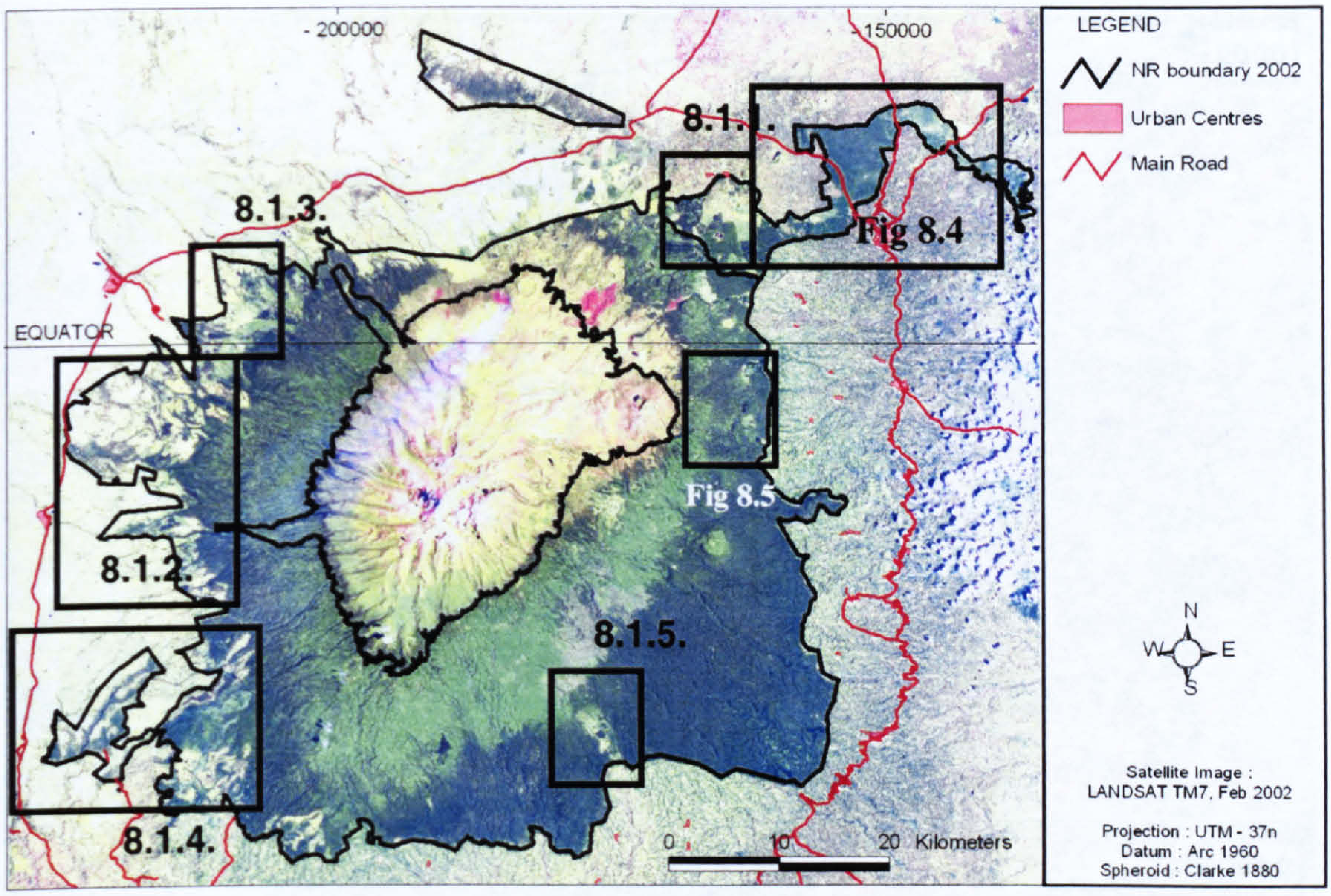
Figure 8.3. Reports of elephant crop damage in OB's, 1999 - 2002



8.3.3. Time-series analysis of satellite imagery, 2000 and 2002

Land cover changes between 2000 and 2002 are well illustrated on satellite imagery. Comparison of the images showed that large areas of clear-felled indigenous forest in 2000 were regenerating in 2002, that encroachment seen in 2000 had disappeared by 2002, and also that long-standing NRC lands in 2000 had been replanted in 2002. For better interpretation, selected areas of MK shown in Figure 8.4 were enlarged.

Figure 8.4. Location of enlarged figures, 2000 - 2002



Three main improvements were seen in land cover between 2000 and 2002. Firstly, indigenous forest that had been illegally destroyed by 2000, was regenerating by 2002 (Figure 8.5), after KWS evicted squatters and regularly patrolled the area. Secondly, encroachment into the indigenous forest via plantations in 2000 was reduced, allowing regeneration of the indigenous forest in 2002 after KWS had evicted the squatters (Figures 8.6 and 8.7). Thirdly, long-standing violations of NRC land in forest plantations in 2000 were replanted by the FD in 2002, as a result of the heavy criticism that the FD had received on NRC abuse (Figures 8.8, 8.9 and 8.10). NRC land had previously witnessed violations of the period of allowed cultivation (Chapter 7). NRC was restored by a crash planting programme in October 2001 (Hoft, 2002), but some of the violated NRC land was excised for settlement in 2001 (Figure 8.11).

Figure 8.5. Regeneration of vegetation at the lower Imenti Forest Reserve

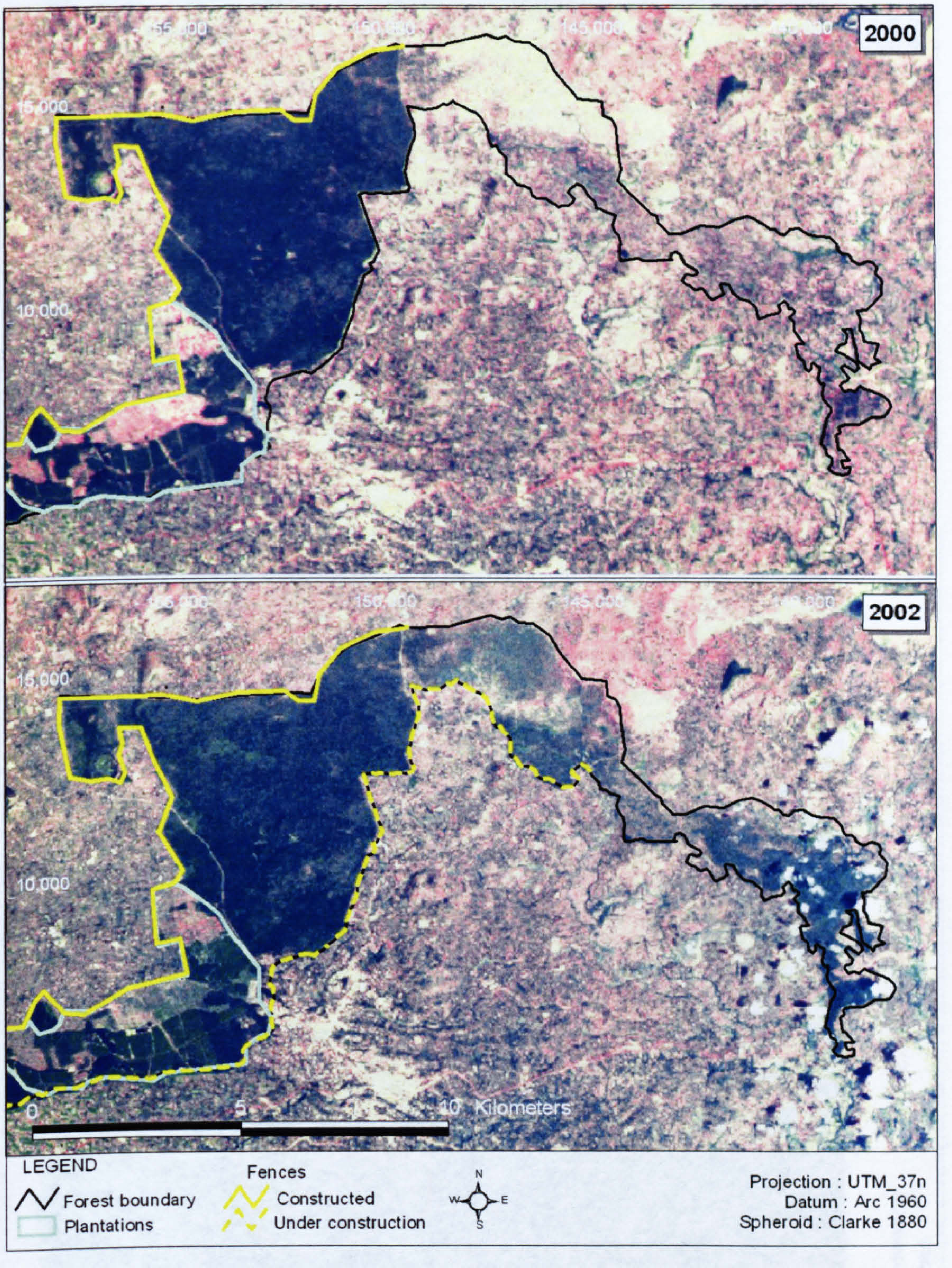


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Figure 8.6. Encroachment from plantations in the east

Figure 8.7. Regeneration of vegetation at Thambana

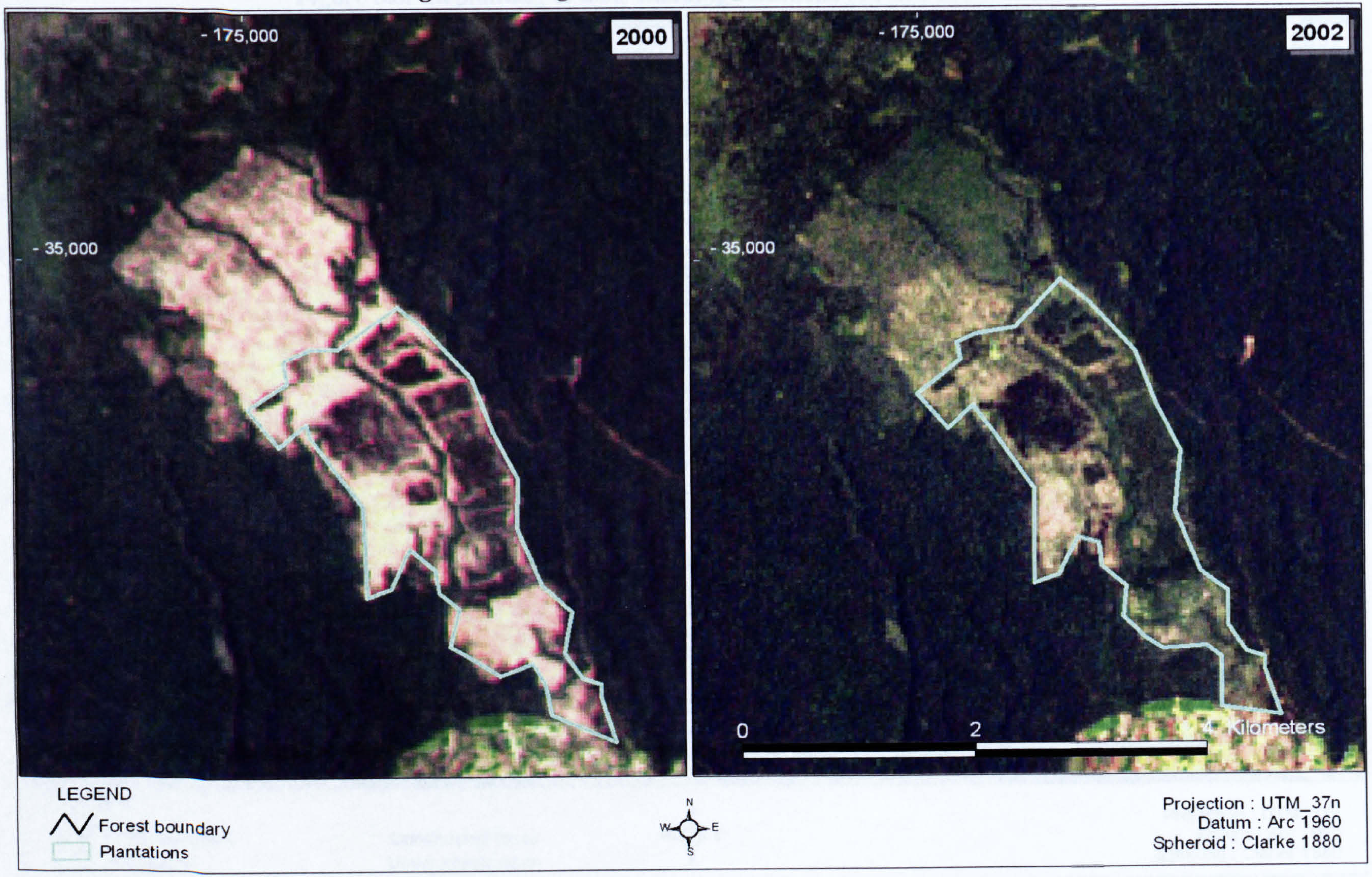

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Figure 8.8. Replanting of long-standing violations of NRC at Mucheene

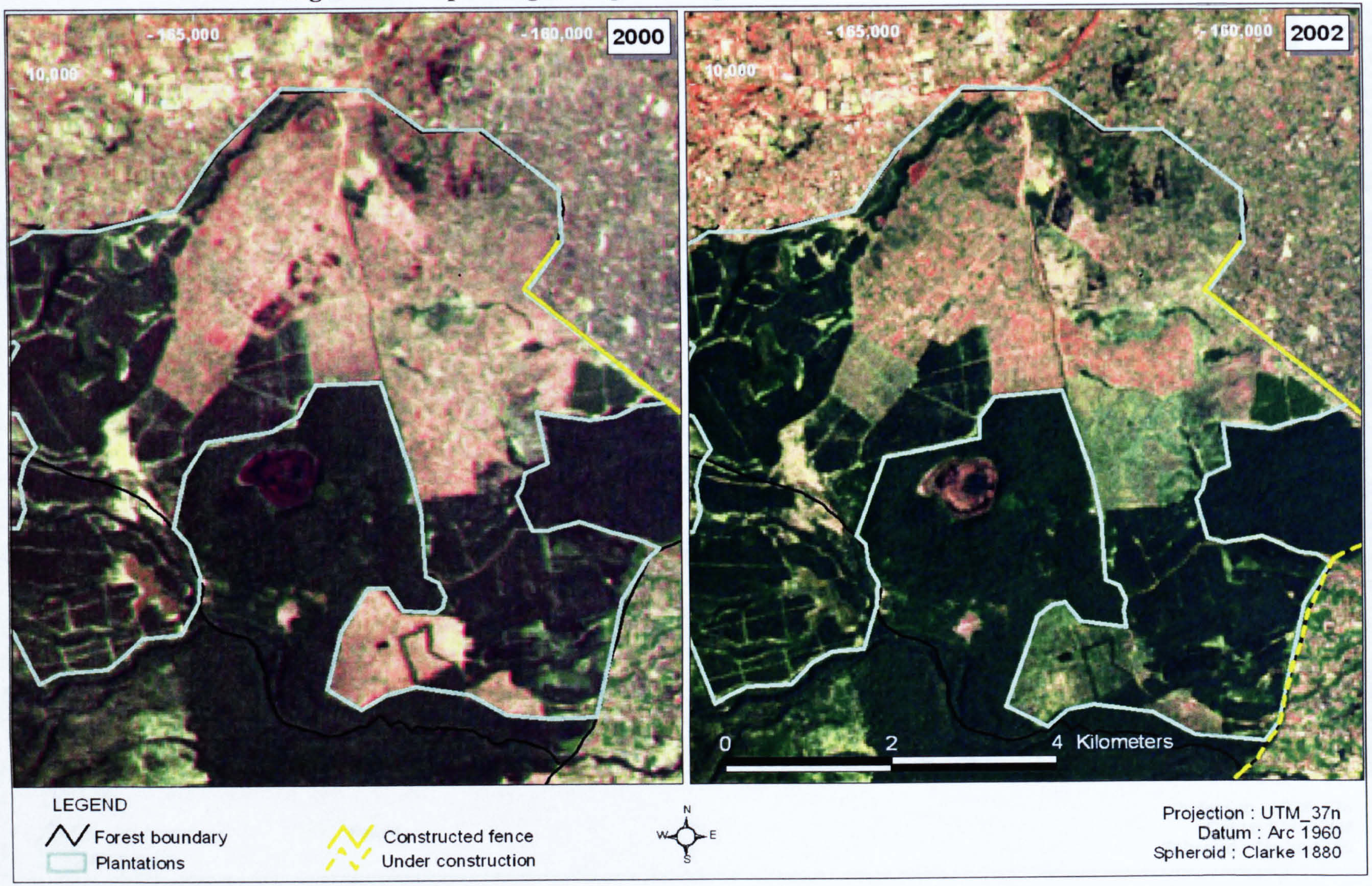

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Figure 8.9. Replanting of violations of NRC at Gathiuru-NaruMoru

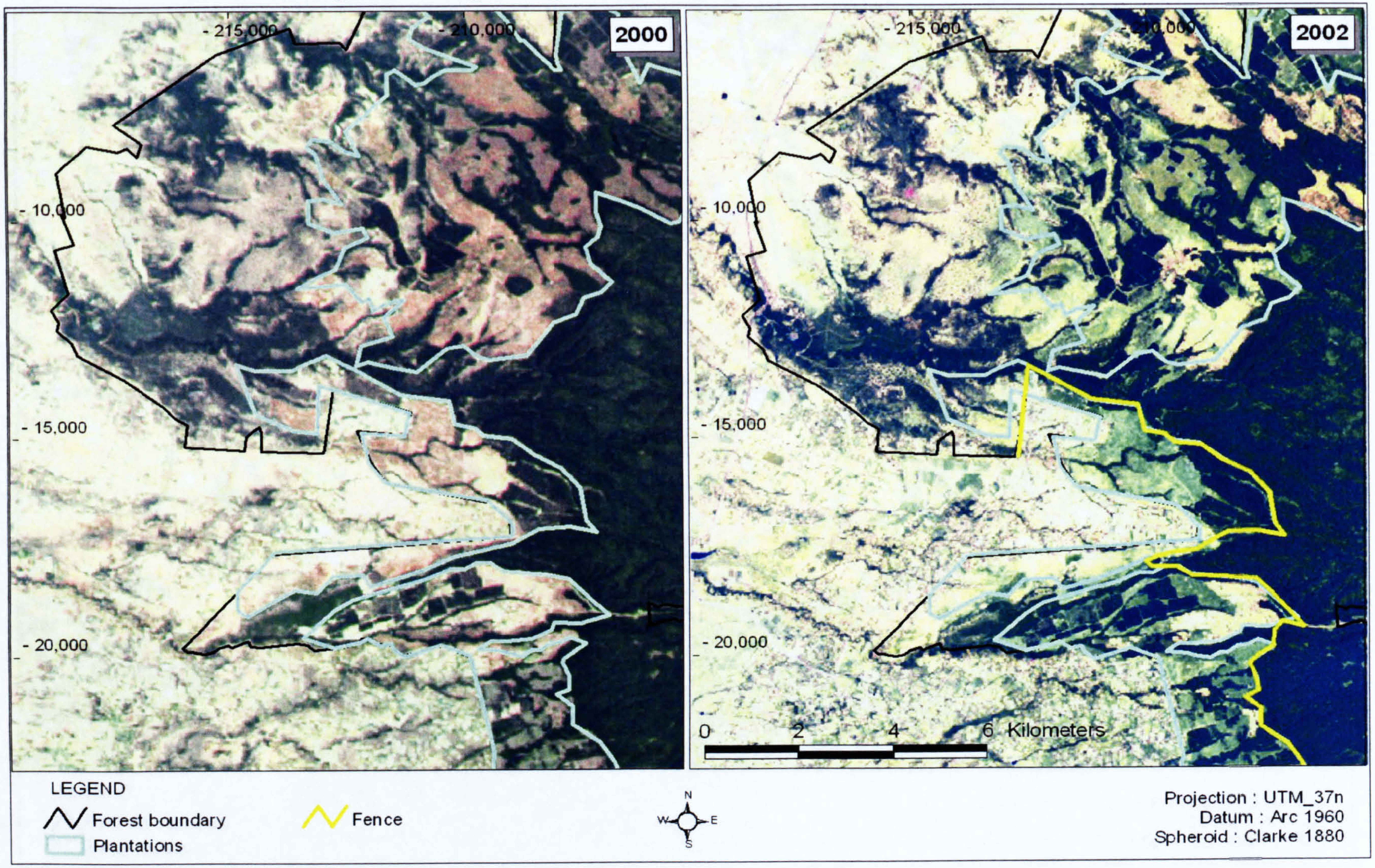

Figure 8.10. Replanting of NRC at Ontulili

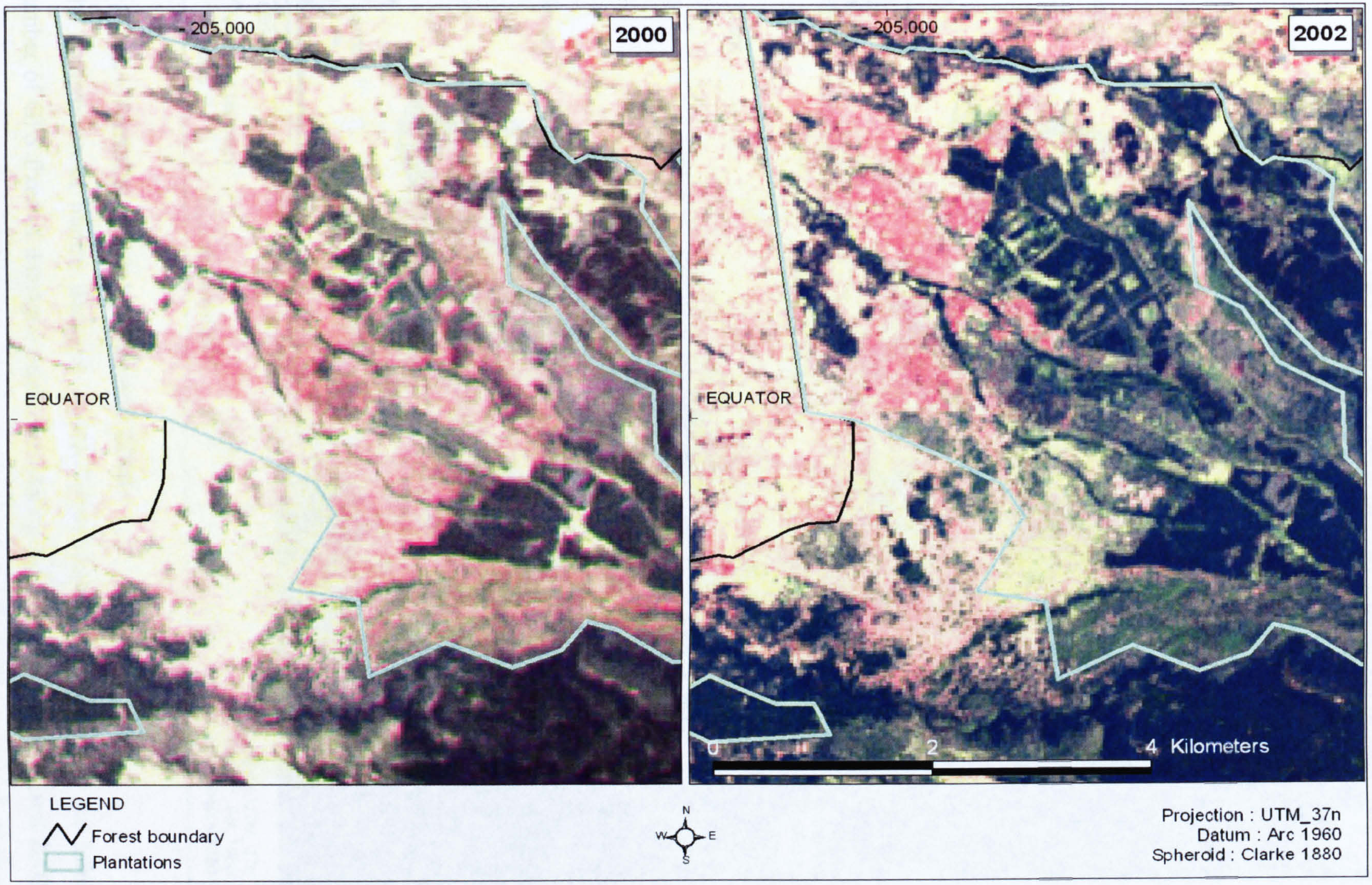

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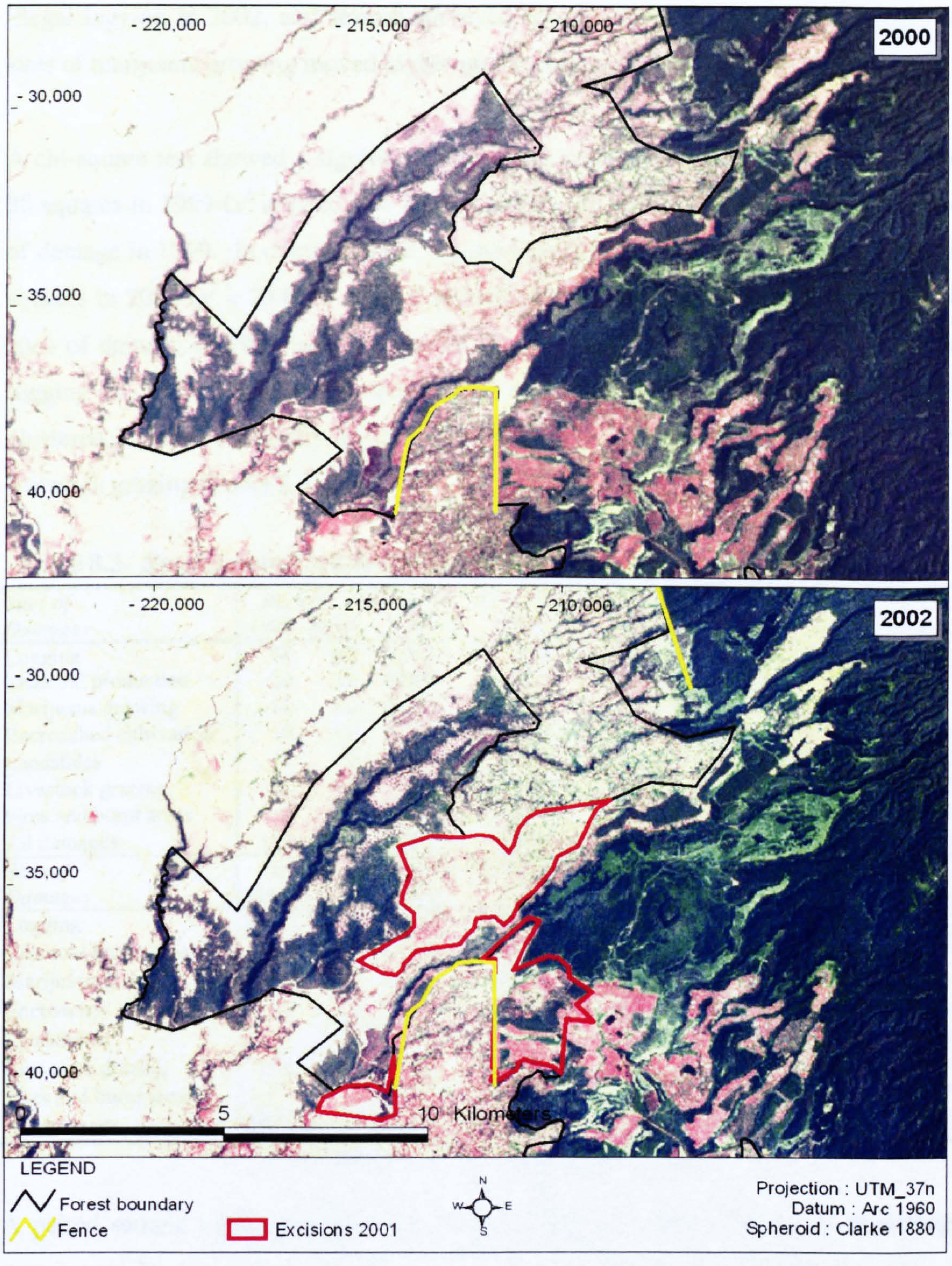
Figure 8.11. Forest land loss through forest excision in 2001 at Hombe-Kabaru



8.3.4. Aerial surveys in 1999 and 2002

The comparison of human damages to MK forest resources showed that the same number of GPS fixes of damages were taken during aerial surveys in 1999 and 2002. However, Figure 8.12 shows that the "extent" or amplitude of the associated damage differed between 1999 and 2002. There was a significant reduction in the extent of illegal logging in 2002, and several surveyed squares showed no damage. However, sites of marijuana growing moved higher up the mountain (Figure 8.12).

A chi-square test showed a significant difference in the extent of damage between the 30 squares in 1999 (x^2 = 42.5, df = 16, P < 0.001) suggesting spatial clustering in sites of damage in 1999. In contrast, there was no significant difference in damage between squares in 2002 (x^2 = 23.0, df = 14, P > 0.05), suggesting that the spatial clustering of sites of damage in 1999 had disappeared due to overall reduction of mainly sites of logging in 2002. Spatial auto-correlation tests confirm that damages were more clustered in 1999, especially for the extent sites of: logging; marijuana growing; and, livestock grazing (Table 8.3).

Table 8.3. Spatial auto-correlation of records of damages and extent of damages

Sites of Damages	*Records 1999*	*Records 2002*	*Moran's I 1999*	*Moran's I 2002*	*Moran's I change*	*Norm z 1999*	*Norm z 2002*	*Norm z change*
Logging	98	60	0.062	-0.035	-0.009	1.817*	-0.009*	0.470*
Charcoal production	22	35	0.009	-0.023	-0.055	0.814*	0.221*	-0.382*
Marijuana growing	15	16	-0.028	-0.012	-0.010	0.124*	0.416*	0.458*
Encroached cultivation	10	11	0.100	-0.026	0.017	2.536	0.158*	0.960*
Landslides	1	5	-0.043	0.018	0.016	-0.163*	0.988*	0.946*
Livestock grazing	24	44	0.072	0.034	-0.019	2.010	1.281*	0.284*
Fires and burnt areas	2	1	-0.024	-0.020	-0.015	0.192*	0.279*	0.367*
All damages	172	172	0.050	0.002	0.051	1.594*	0.678*	1.613*
Sites of Damages	*Extent 1999*	*Extent 2002*	*Moran's I 1999*	*Moran's I 2002*	*Moran's I change*	*Norm z 1999*	*Norm z 2002*	*Norm z change*
Logging	2,753	183	0.238	-0.034	5.189	5.122	0.002*	0.242*
Charcoal production	525	198	-0.006	-0.010	-0.010	0.536*	0.457*	0.459*
Marijuana growing	20	19	0.127	-0.034	0.003	3.033	0.001*	0.698*
Encroached cultivation	22	29	-0.054	0.001	-0.000	-0.374*	0.659*	0.640*
Landslides	7	12	-0.010	0.006	-0.067	0.467*	0.762*	-0.608*
Livestock grazing	582	1,127	0.080	0.046	-0.007	2.144	1.506*	0.508*
Fires and burnt areas	3	1	-0.024	-0.020	-0.039	0.204*	0.279*	-0.077*
All damages	3,912	1,569	0.084	0.022	0.137	2.236	1.063*	3.216

* No spatial auto-correlation at Norm z < 1.96

A paired sample t-test confirmed that the amplitude or extent (Table 8.3) of damage represented by the records of 1999 and 2002 was significantly different for sites of logging (t = 0.811, df = 29, P = 0.004) and livestock grazing (t = -2.189, df = 29, P = 0.037). There was a large reduction in logging sites but an increase in sites of livestock grazing (Table 8.3). The total number of damages from all causes reduced significantly (t = 3.374, df = 29, P = 0.002) between 1999 and 2002.

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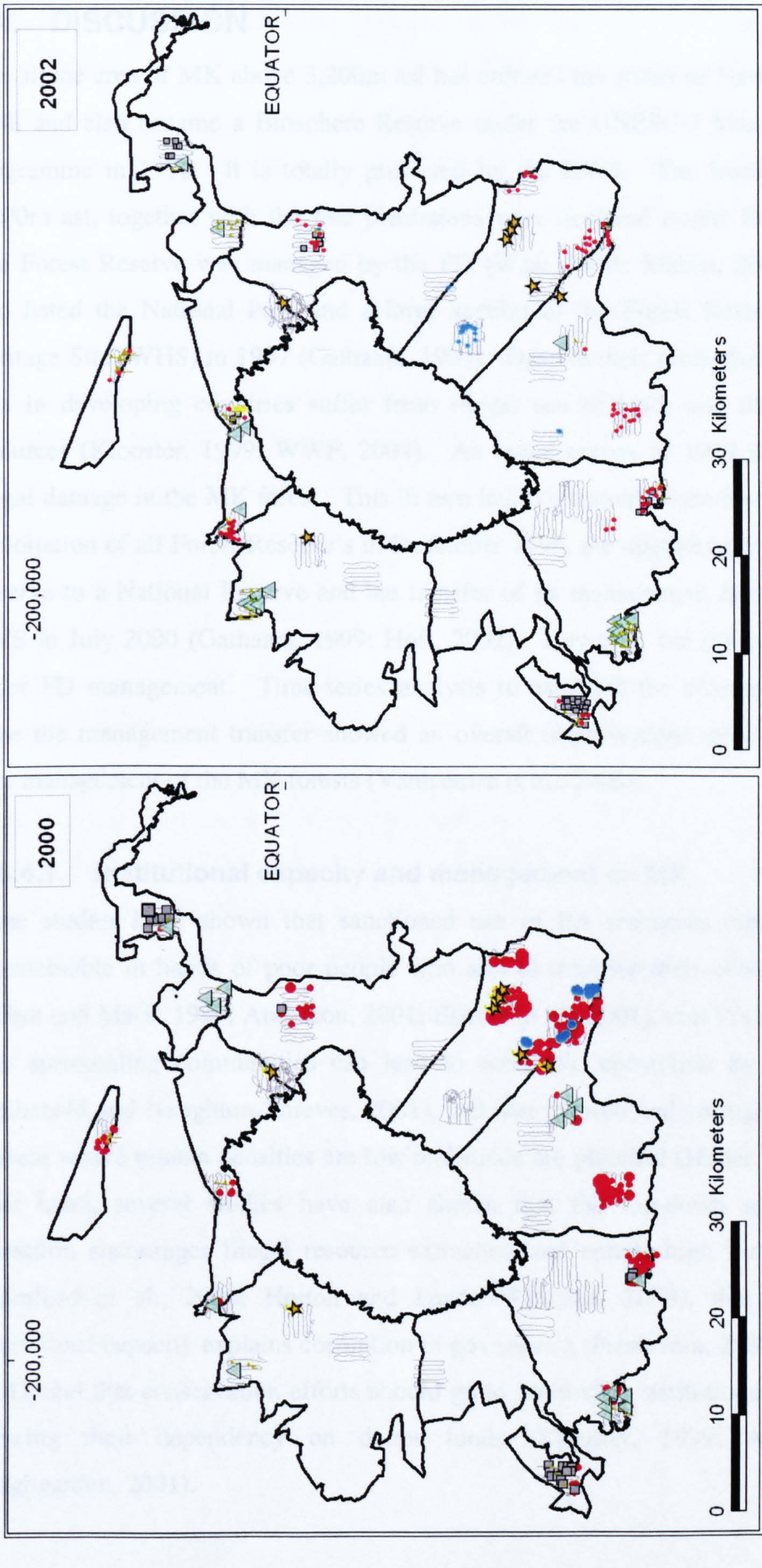
Figure 8.12. Human damages for 30 squares of 3x3km^2, 1999 and 2002



8.4. DISCUSSION

The alpine area of MK above 3,200m asl has enjoyed the status of National Park since 1948 and also became a Biosphere Reserve under the UNESCO Man and Biosphere programme in 1978. It is totally protected by the KWS. The forested area below 3,200m asl, together with the tree plantations were declared Forest Reserve in 1932. The Forest Reserve was managed by the FD (Wass, 1995; Matiru, 2000). UNESCO also listed the National Park and a large section of the Forest Reserve as a World Heritage Site (WHS) in 1997 (Gathaara, 1999). Despite their protection status, 95% of PAs in developing countries suffer from illegal use of land, and illegal offtake of resources (Klooster, 1999; WWF, 2004). An aerial survey in 1999 illustrated heavy illegal damage in the MK forest. This in turn led to a country-wide ban on commercial exploitation of all Forest Reserve's in December 1999, the upgrading of the MK Forest Reserve to a National Reserve and the transfer of its management from the FD to the KWS in July 2000 (Gathaara, 1999; Hoft, 2002). However, the plantations remained under FD management. Time-series analysis to establish the changes that occurred since the management transfer showed an overall improvement since the KWS took over management of the MK forests (Vanleeuwe et al., 2003).

8.4.1. Institutional capacity and management on MK

Some studies have shown that sanctioned use of PA resources can often become unsustainable in hands of poor people who aim to improve their economic prospects (Abbot and Mace, 1999; Anderson, 2001; Ekbom et al., 2001), that PA revenue sharing with surrounding communities can lead to economic corruption by the local elite (Archabald and Naughton-Threves, 2001), and that institutional corruption also occurs in areas where human densities are low and funds are plentiful (Huber, 2001). On the other hand, several studies have also shown that the top-down approach of PA protection encourages illegal resource extraction and entails high management costs (Balmford et al., 2000; Hutton and Leader-Williams, 2003), that poor financial institutional capacity explains corruption in governance (Primavera, 2000; Bruner et al., 2001), and that conservation efforts should go to improving institutional capacities and reducing their dependency on donor funds (Klooster, 1999; Armsworth and Roughgarden, 2001).

Differences in financial capacity between the FD and the KWS largely explain the failure of the FD, and the success of the KWS, in management of the MK forests. Improved finances can translate into better salaries, improved means of transport and communication, and better equipment, all of which are needed for management efficiency. In the same way that a lack of financial capacity has led to corruption within the WCMD in the past, so too has the current tightly funded situation with regards to the FD in Kenya. In Zambia, levels of illegal killing of elephants were explained by resource allocation to law enforcement in terms of manpower and budget, with optimum levels of input estimated at one scout per 23.8km^2 and an expenditure of US$ 82.2/ km^2 per annum (Jachmann and Billiouw, 1997). Levels of expertise and competition between the FD and the KWS also influence management success on MK. KWS staff have training and expertise in law enforcement and rescue, whereas FD staff have training and expertise in forestry issues.

Strict law enforcement by KWS has already played an important role in conservation of MK, even though it is often incorrectly accused of affecting sustainable development. On the other hand, achieving compliance entirely through a policing institution like the KWS is equally detrimental. Competition between the FD and KWS on MK ensures that violations surface much faster than if only FD or KWS was in overall charge. The expectation that the KWS could also efficiently manage the plantation forests, and water use, and issue licences for controlled exploitation of resources, and guide community development projects, as has been proposed by the 2002-2007 MK Management Plan (Hoft, 2002), appears inappropriate.

8.4.2. Comparison of HEC records in KWS occurrence books

A study conducted around MK in 2002 showed that HEC records as found in KWS occurrence books did not reflect the extent of actual elephant damage, although the records did correctly indicate spatio-temporal distribution of HEC (Hagiwara, 2002). In contrast to Meru Central and Nyeri districts that had a lot of HEC reports, the districts of Meru South, Embu, and Kirinyaga had very few reports. The districts less affected by HEC have a tea buffer between forest and farmland (see Chapters 6 and 7).

There were few reports of HEC in KWS OBs in 1999, when the FD was still in charge of the MK forests. Numbers of reports doubled, but remained proportionally similar between districts, after KWS took over management from the FD in 2000, with the exception of Meru South. The increase in reporting between 2001 and 2002 may have been partly the effect of our investigations of HEC matters around MK during this study. Regardless of the effect of tea as an elephant barrier, the least reporting of HEC is from districts where illegal logging is most pronounced (Gathaara, 1999). Peoples' attitudes towards conservation in developing countries tend to incline towards corruption over economic development (Abbot and Mace, 1999; Anderson 2001; Archabald and Naughton-Threves, 2001). Furthermore, human factors like willingness, intention, and temptation, co-determine levels of corruption (Ekbom et al., 2001; Collar, 2003). Given the benefits and costs associated with illegal logging on the one hand, and with reporting HEC on the other hand, the latter is less financially worthwhile, given that there is no financial compensation for crop damage.

8.4.3. Time-series analysis of satellite imagery

Time-series analysis of satellite images have been used worldwide to examine land cover changes (Chavez and Kwarteng, 1989; Dumayak et al, 1997; Willard et al., 2000). Time-series analysis of satellite images of MK showed how very large clear-felled indigenous forest areas in 2000 were regenerating in 2002, how encroachment into the indigenous forests in 2000 had disappeared by 2002, and how long-standing violations of NRC land in plantations in 2000 were being replanted in 2002. Improvements to the overall forest-cover conditions are the result of KWS patrols and eviction of squatters, providing evidence of efficient law enforcement (Vanleeuwe et al., 2003).

The success of FD replanting of long-standing violations of NRC land in forest plantations in 2002 remains uncertain. The plantations are in a lamentable state because of neglect of planting and thinning schedules, and of violation of the NRC system. Given the poor financial capacity of the FD, however, the outcome of the FD crash planting programme in October 2001 may lead to more poorly maintained plantations that will be harvested before maturity and sold below realistic market prices (Hoft, 2002).

8.4.4. Aerial surveys in 1999 and 2002

Aerial transect surveys have been widely used to count animals (Tchamba and Elkan, 1995; Carretta et al., 1998; Miller et al., 1998; McDaniel et al., 2000; Walter and Hone, 2003), and to a lesser extent to count trees (Southwell et al., 1999; Bowman et al., 2001). On MK, aerial surveys were used in 1999 and 2002 to count sites of human damage (Gathaara, 1999; Vanleeuwe et al., 2003). Recorded sites of forest degradation are the result of surrounding farmers who illegally harvest on an as-need basis, from unemployed youngsters producing charcoal as a source of income, from large-scale illegal timber exploiters and all those working for them, from corrupt FD staff taking bribes and becoming involved in illegal activities (Emerton, 1997; Kiteme, 2001; Hoft, 2002; Mathuva, 2002).

Aerial surveys are expensive and were estimated to cost US$ 2.30 per km in 1995 (Tchamba and Elkan, 1995). Studies have therefore focused on ways to reduce sampling effort by surveying only parts of the environment (e.g. Chen et al., 2002). Some studies have compared surveying stratified random strips with squares and suggested that squares provided the best results (Pojar et al., 1995), and that replicates should be randomly drawn up each year of the survey to avoid serial correlation in the estimates (Eggeman et al., 1997). Due to financial restrictions, thirty squares of 3x3km on were surveyed MK in 2002 instead of surveying the entire MK National Reserve as in 1999.

Results from the aerial time-series analysis indicate that the overall status of the MK forests improved under KWS management (Vanleeuwe et al., 2003). The most important damage to the MK forest in 1999 came through illegal exploitation, primarily through large-scale illegal timber logging. Comparing the same areas for 1999 and 2002, counts of logging sites significantly reduced by 2002 as a result of repeated stopping of lorries and intercepting of thousands of tons of timber during KWS patrols. In contrast, the numbers of sites of charcoal production had not reduced by 2002, despite the almost daily patrols in highly affected areas. According to the Senior Warden of MK, B Woodley, charcoal production is more difficult to stop than logging because it is done quickly and at small scale close to the forest boundary. The sites of marijuana growing disappeared from their 1999 location because of KWS patrols, but new fields were found higher up the mountain. Levels of other causes of damage that were counted, such as sites of landslides and fires and burnt areas, remained the same in 1999 and 2002. Counts of sites of livestock grazing almost doubled by 2002, probably as a result of the prolonged drought of 2000 during which time the MK forests was made available for pastoralists to graze their cattle, and many herders remained after the drought.

The status of the MK forests has improved since the transfer of management responsibility from the FD to the KWS in 2000, and the reason for this was efficient and strict KWS law enforcement (Vanleeuwe et al., 2003). Expertise and institutional financial capacity have played a major role in law enforcement efficiency within KWS. However, the MK Management Plan of 2002-2007 (Hoft, 2002) has misinterpreted the success of management on MK by over-stating the capacity of KWS. KWS staff know very little of land tenure, water use, on-farm agroforestry, energy use, development and education. Anti-KWS feelings around MK (e.g. Hagiwara, 2002) suggest that few members of the communities around MK would appreciate or accept involvement of the KWS in development issues. Development and law enforcement, although complementary, are difficult subjects for the subsistence farmer. Therefore, in order for development projects to be successful, they should not be the responsibility of the KWS, especially when there are plenty of community-based organisations (CBOs) and non-governmental organisations (NGOs) with expertise in development issues around MK (e.g. COMPACT, 2001; Mbora and Simons, 2002).

8.5. CONCLUSION

Rapid economic development is often favoured over sustainable development, especially when economic stability is absent (Abbot and Mace, 1999; Ekbom et al., 2001; Huber, 2001). The land and natural resources of MK would be rapidly depleted without strict law enforcement. Lack of financial capacity combined with a thriving black market in forest products, led to inefficient law enforcement, institutional economic corruption, and deterioration of MK under FD control. In contrast, with a financial capacity of over 10 times that of the FD, the KWS enjoys better material capacity and salaries, which has led to more efficient law enforcement and the gradual restoration of the integrity of MK under KWS control. Therefore, the MK management plan of 2002-2007 proposes that the indigenous forest, as well as plantations, the leasing of a proposed 1,000m buffer/ multiple-use zone, and water abstraction allowances, should all be controlled by the KWS (Hoft, 2002). This, however, will not address the underlying causes of FD corruption, nor address the demand for resources, as well as demand efforts that lie far beyond KWS' expertise and current capacity. The FD mandate over the indigenous forest up to July 2000 has shown that control by one institution allows for potential abuse to remain hidden for extended periods of time.

A more sustainable solution lies perhaps in combining expertise of both institutions, of NGOs, and CBOs, in combining principles of community-based conservation, benefit sharing, and institutional capacity building, in systematic monitoring to control the status of MK, and in co-ordination of it all by an influential body that could also facilitate project implementation in accordance with priority conservation policies (Chapter 9).

Chapter 9

CONCLUSIONS AND RECOMMENDATIONS

9.1. CONCLUSION

This thesis has explored many aspects of land use and resource use by elephants and people, the resulting conflicts, and different management strategies that have been applied on MK. The goals that were formulated and addressed in each chapter have included:

- Identifying the problems and defining the goals and study aims for management of the MK protected area for the benefit of elephants and people (Chapter 1);

- Creating a complete picture of the MK environment, in terms of geology, hydro-climatology, altitudinal zones, biodiversity and protection, human distribution, human land use, as well as its economic potential (Chapter 2)

- Estimating elephant numbers and investigating the problems and sources of error encountered with estimating elephants in forested environments like MK (Chapter 3).

- Developing strong explanatory models to determine factors important in elephant seasonal distribution from transect data, using adapted methods, tests of model strength and robustness, and integrating explanatory models and GIS to create distribution maps (Chapter 4).

- Predicting the location of elephant travel routes and foraging paths, based on least-cost travel assumptions, and investigating the relationship between elephant movement patterns and elephant tree destruction in plantations (Chapter 5).

- Modelling spatio-temporal patterns of elephant impact on farms adjacent to the forest, from conflict reports, and investigating HEC mitigation in more detail for the two most affected areas around MK (Chapter 6).

- Quantifying and illustrating the uses and abuses of land and resources under FD management of MK until July 2000, and exploring the success and failure of implemented strategies of sanctioned use of land and resources (Chapter 7).

- Identifying and explaining the effects of different governing institutions on the status of the MK protected areas through comparison of the state of the MK environment before and after July 2000, when MK management changed from the FD to the KWS (Chapter 8).

- Combining all conclusions, to provide recommendations for future management of the MK protected areas for the benefit of elephants and people (Chapter 9).

9.1.1. Study introduction and thesis structure (Chapter 1)

Kenya comprises 80% arid and semi-arid lands and less than 3% of forest. MK is the largest of five main forest complexes that represent the water catchment areas and the fertile havens upon which the water supply and agriculture in Kenya depends (Matiru, 2000). MK also holds the largest highland elephant population in Kenya (Blanc et al., 2003), and the districts surrounding MK comprise some of the most densely populated human communities in Kenya (Republic of Kenya, 2000). Associated problems have been defined by an increasingly unstable triangular relationship between the environment, elephants, and people, with people playing the main role as users, and decision makers (Gathaara, 1999; Vanleeuwe and Lambrechts, 2000).

To address human-elephant conflicts, financial impoverishment, and the demand for fertile land and resources, rapid economic development and immediate solutions to problems are most often chosen in favour of sustainable development and conflict mitigation strategies that address underlying causes (Archabald and Naughton-Treves, 2001; Ekbom et al., 2001; Huber, 2001). Abuse of systems of sanctioned use and over-exploitation of MK lands and forest resources have led to deterioration of the MK environment (Gathaara, 1999). HEC has been mitigated through fencing without the knowledge and consideration of the longer term negative consequences that fence misalignment may entail (Mathuva, 1999; Mwathe et al., 1998). Furthermore over-exploitation of MK land and resources can irreversibly damage the water catchment, and further random barrier fencing can aggravate HEC from habitat fragmentation and isolation of the MK environment. Nevertheless, the transfer of management over the MK indigenous forest from the FD to the KWS in 2000 has reduced levels of deterioration of the forest (Vanleeuwe et al., 2003).

Future successful management of MK lies in harnessing efficient KWS law enforcement efforts in the indigenous forest with community-based projects and projects of sustainable use to reduce pressure on MK land and resources. Development projects should be implemented by institutions and NGO's with appropriate expertise. Improving institutional and financial capacity of the FD is essential to improve its management efficiency, and systematic monitoring of the status of MK and ongoing projects is essential to adapt management plans and to allow rapid intervention with relapses of abuse.

9.1.2. The MK environment and problem identification (Chapter 2)

The altitude range and exposure on MK creates diverse biotopes with distinct floral and faunal compositions, making MK a mega-diverse centre of international interest that has been studied since 1885 (Beentje, 1989; MKEP, 1993; Winiger, 1986). Bussmann (1994) identified 882 plant species, sub-species and varieties belonging to 479 generis of 146 families (Appendix I). Young (1993) identified 67 mammal species belonging to 22 families and including 6 species of international conservation interest, namely black rhino, leopard, giant forest hog, bongo, black-fronted duiker, and elephant (Appendix II). The indirect ecological functions of biodiversity-dependant processes, such as carbon sequestration and water catchment, reach far beyond the protected area boundary of MK (Bussmann, 1994; Speck, 1986; Wiesmann et al., 2000; Winiger 1992).

MK is the largest of five forested water towers that fuel Kenya's two largest rivers (Beentje, 1991; Decurtis, 1988; Matiru, 2000). These fertile islands (<3% of the Kenya land surface) in a sea of arid and semi-arid lands (> 80% of the Kenya land surface) determine availability of water and associated levels of famine and conflict between people over water (Liniger, 1992; Wiesmann et al., 2000). The fertile areas around the water towers comprise all the agriculture in Kenya, the country's main revenue earner (Republic of Kenya, 1998; UNEP/WMO, 1998). Forested mountains determine levels of conflict between pastoralists and wildlife over water and distribution patterns and movements of wildlife in the lowlands (Kapos, 2000; McCarty et al., 2002). In turn this determines wildlife tourism, Kenya's second main revenue earner (Republic of Kenya, 1998). On a daily basis a forested mountain like MK provides timber, fuelwood, water, and employment to some 17,500 households living within 5,000m of the protected area boundary (Emerton, 1997; Kiteme, 2001; Republic of Kenya, 2000).

These functions are threatened by habitat fragmentation and by sanctioned and illegal over-use of land and resources (Emerton, 1997; Gathaara, 1999; Vanleeuwe et al., 2003). Land fragmentation, poor tenure, deforestation, and deterioration of the remaining natural environments typically result from rapid human demographic growth (Downing and Leibold, 2002; Jenkins, 2003; Kinnaird et al., 2003). Several studies have investigated the consequences of this and concluded that, for the longer-term greater benefit of both people and wildlife, the remaining biodiversity-rich islands and their linkages must be secured (Loehle, 1999; Moore et al., 2003; Osborn and Parker, 2003; Williams et al., 2003). Systematic monitoring of the status of confined PAs should enable rapid intervention where PA resources are deteriorating either because of people or over-crowded wildlife (Balmford et al., 2003; Broseth and Pedersen, 2000; du Toit, 2002). The restriction of elephant ranges can result in local over-crowding and over-utilisation of natural resources in the confined habitats (Bulte and Horan, 2003; Harcourt et al., 2001; Kapos, 2000; Whitehouse and Schoeman, 2003).

9.1.3. Elephant density (Chapter 3)

Establishing elephant numbers is a basic requirement to investigate relationships between elephants and the environments that they inhabit, and fluctuations in numbers of elephants in the same environments over time (Blanc et al., 2003). Establishing elephant numbers in forests where visibility and accessibility are poor can only be done through indirect survey methods, of which the dung counting method along line-transects is the best developed technique (Barnes and Jensen, 1987; Barnes, 2002; Laing et al., 2003). Dung counts can produce more accurate density estimates than aerial counts, when theory underlying these methods is strictly converted to practice. However, minor violations of theory, and bias in parameters in the dung to elephant conversion equation, can produce grave errors in estimates (Buckland et al., 2001; Kangwana, 1995; Thomas et al., 2000). The wide array of errors that can be introduced into elephant estimates derived from dung count are the reason why results from dung counts are often considered of low quality in the African Elephant Databases (Barnes et al., 1998; Blanc et al., 2003; Said et al., 1995).

In absence of better methods to count elephants in forests, dung counts are essentially the best available method to produce estimates of sufficiently high quality to identify sudden fluctuations in elephant numbers in forests (e.g. Litoroh, 2004). To achieve this, traditional line-transect designs must be adapted so they are less prone to the errors most commonly made in the field. Elephants on MK were estimated at 2,911 (±640) or 1.45 elephants/ km^2 in 2001 using the dung count method, and difficulties and sources of error with applying the dung count method on MK were identified.

Although several studies have indicated a positive correlation between rainfall and dung decay rate (Barnes et al., 1994; Plumptre and Harris, 1995; White, 1995), the higher rainfall that occurs at higher altitudes does not accelerate dung decay on MK, probably because decay is counter-acted by cold temperatures that would help to preserve dung.

Deviating from a straight transect line results in clustering of dung near the centreline, or a negative exponential distribution of the expected dung detection curve g(x), and indicates poorly conducted surveys that are problematic for analysis (Buckland et al., 2001; Thomas et al., 2001). Maintaining a straight line for many very short transects of 200m was more easily achieved than maintaining a straight line for fewer long transects of 4,000m. Therefore, systematic repeatable surveys in PAs should favour designs with many very short transects instead of fewer long transects, especially when it is intended that surveys should be conducted by less experienced local ground forces, such as rangers and guides. Simulation dung counts in environments with different densities of obstacles blocking the line of sight, like trees, stones, and ground vegetation, show that increasing densities of obstacles pushes g(x) towards a negative exponential distribution of g(x), suggesting this effect is not necessarily only related to poor monitoring (Vanleeuwe, in press).

Finally, miscalculation of the parameter "area" and neglecting stratification has resulted in a serious bias in estimated elephant numbers for MK in the past (i.e. Omondi et al., 1998; Reuling et al., 1992). Map area greatly differs from the ground area, with up to one third of the MK habitat representing extreme slopes and extreme altitudes that are not used by elephants. Elephant densities also differ seasonally between vegetation strata on MK.

9.1.4. Elephant distribution (Chapter 4)

Several studies have shown that successful management of environment-species relationships require an understanding of the explanatory factors of these relationships, which tends to have a spatio-temporal character (Sitati et al., 2003; Vaughan and Ormerod, 2003). Potential explanatory factors of species distribution, such as altitude, rainfall, slope, vegetation, distance from salt-licks and waterholes, distance from rivers, settlement and roads, can be geographically modelled, predicted, and mapped with a GIS. For this reason, GIS is increasingly used for predictive modelling for land-use management and problem mitigation in a wide range of fields (Dabrowski and Schulz, 2003; Hiers et al., 2003; Lufafa et al., 2003). However, the use of GISs for predictive modelling for land-use management and problem mitigation in wildlife conservation remains at its very early stages (Clevenger et al., 2002; Huettmann and Linke, 2003).

Multivariate analysis of GIS generated data, combined with data collected during dung count censusing, established models that explained the seasonal distribution of elephants on MK. Generalised linear model analysis were used as the multivariate test to avoid the need for data transformation to fit a normal distribution for linear regression analysis, because generalised linear models can readily deal with skewed data (Crawley, 1993; Guisan et al., 2002; Lehman et al., 2002; Appendix V). Tests of model robustness and strength were developed to avoid erroneous predictive modelling, such as spatial auto-correlation tests of parameter and model residuals (Dubin, 2003; Legendre et al., 2002). The best models explaining seasonal elephant distribution on MK were integrated into a GIS to develop elephant distribution maps for the dry and the seasons on MK. For MK, the elephant distribution differed greatly between seasons.

Predictive GIS modelling of elephant distribution in forests opens a world of information as it allows predictions derived from tiny sampled areas on line-transects to large non-sampled areas (McCullagh and Nelder, 1983; Nicholls, 1991; Sitati et al., 2003). To institutions that have to manage problem mitigation, maps of elephant distribution are easier to interpret than theoretical models. Maps of elephant-environment relationships can help to control the area, to help plan fence allocation, and to discuss or dispute wanted or unwanted allocation of forest land for human settlement or plantations.

9.1.5. Elephant movement patterns and tree destruction (Chapter 5)

Elephants depend on plants, and their mobility allows them to optimise the relationship between their needs and the environmental carrying capacity (e.g. Kapos et al., 2000). Elephants are liable to cause rapid deterioration of their natural habitat, and to adjacent human-occupied habitats when elephants are over-crowded (Sitati, 2003; Smith and Kasiki, 2000; Whitehouse and Schoeman, 2003). Promoting protection of biodiversity-rich areas and major corridors is a way to ensure long-term survival of migrating species and to reduce associated conflicts (Kinnaird et al., 2003; Moore et al., 2003; Williams et al., 2003). For this purpose, several studies have focused on defining least-cost travel routes, both inside PAs (ranging behaviour) as well as between PAs (migration) (Harcourt et al., 2001; Osborn and Parker, 2003).

Predicted elephant routes on MK were traced digitally, based on the assumption that elephant travel routes and foraging paths are defined by: physical barriers such as vertical cliffs and electric fences; by the same factors that determine seasonal distribution (Chapter 4) inside the MK Reserve; and by anthropogenic barriers such as the forest boundary and farmland. The distribution of tree damage in plantations on MK shows different damage intensity between plantation stations and between seasons. However, overall most damage occurs to young trees, but damage decreases close to elephant travel routes, but increases close to elephant foraging paths and saltlicks.

The increase observed in the destruction of younger trees on MK differs from other studies that suggest that seedling destruction is usually the result of fires or raids by smaller mammals (Augustine and McNaughton, 2004; Barnes, 2001; Styles and Skinner, 2000). In normal conditions, providing that elephants ranges are not cut off, elephants determine the size distribution of trees more than density (Ben-Shahar, 1998; Calenge et al., 2002; Van de Vijver et al., 1999). However, seedlings in plantations on MK are surrounded by non-residential cultivation (NRC) crops. Therefore, higher levels of elephant damage are found close to foraging routes, and NRC crops around young trees may well be perceived as forage that attracts elephants, just as the invading vegetation in logged areas in Uganda attracts elephants (Strusacker et al., 1996).

NRC was introduced as a on afforested land in return for tending seedlings and protecting them against wildlife damage during their most vulnerable stage (Kiteme, 2001). NRC was banned in 1980s due to abuse of the system, but it was re-installed in 1995 because "wildlife damage was suppressing the re-establishment of exotics" according to the FD (Hoft, 2002). This study disputes such reasoning.

9.1.6. Elephant impact to farmland and mitigation (Chapter 6)

Conflicts between elephants and people on MK can largely be explained by patterns of human and elephant land use, as elsewhere in Africa (Harcourt et al., 2001; Nyhus et al., 2000; Thouless, 1996). Conflict around MK is typically most pronounced at the human-elephant interface, where elephant and human ranges overlap (Hoare, 2000; Sitati et al., 2003; Tchamba, 1996). Multivariate analysis of elephant impact records partly explained reporting behaviour and elephant crop damage. Reporting increases in more populated areas, and further from travel routes, suggested that crop damage is not the result of travelling elephants, though it is possibly of foraging elephants (see Chapter 5). Elephant crop damage is much less pronounced on farms in locations that have a tea buffer between forest and farmland, suggesting that the NTZC reduces crop damage by elephants.

Elephant damage reported in KWS occurrence books incorrectly shows the real extent of damage, but correctly indicates spatio-temporal patterns of damage (Hagiwara, 2002). Elephant damage around MK was most pronounced in Meru-Imenti in the north-east, and in Hombe-Kabaru in the south-west, where most elephant routes are also predicted to cross the forest boundary into farmland. The socio-economic factors in farming households adjacent to the forest in the Meru-Imenti and Hombe-Kabaru areas are similar, and explain the importance of MK resources, as well as the patterns of use of those resources. The distributions of elephant, their routes, their hotspots such as salt licks, versus the distribution of people, explain elephant damages on farmland in Meru-Imenti and Hombe-Kabaru. The main mitigation strategy adopted to elephant damage in both areas has been to erect solar-powered fences that stop elephant access (e.g. Hoft, 2002; Mathuva, 2001). Fences should guide but not alter important elephant travel routes and foraging paths inside and between PAs (Kapos et al., 2000; Osborn and Parker, 2003; Thouless and Sakwa, 1995; Whitehouse and Schoeman, 2003). Important elephant travel routes and foraging paths inside the MK forests are threatened to become blocked by fences and new settlement in the Hombe-Kabaru area, and between MK and other PAs in the Meru-Imenti area. Fences currently stop elephant impact to farms that are protected by the fences but elephant impact increases where the fences end. Solutions may be sought in extending existing fences and in implementing more fences. However, this does not consider the potential longer term consequences of isolating elephants behind fences (Thouless and Sakwa, 1995; Whitehouse and Schoeman, 2003). Misalignment of fences may also result in irreversible settling of people in corridor areas.

9.1.7. Human impact on the environment (Chapter 7)

Despite their protection status, 95% of PAs in developing countries suffer from illegal offtake of resources (Ashenafi, 2003; IUCN, 2003; Kinnaird et al., 2003; Smith, 2003). The environment of MK has deteriorated rapidly, despite the national and international status of its protection. Causes of deterioration include: abuse of projects of sanctioned use; institutional corruption; poor law enforcement; opting for immediate solutions to address human-wildlife conflicts and economic impoverishment; and, illegal exploitation of resources and land (Bussmann, 1996; Gathaara, 1999; Vanleeuwe et al., 2003). Projects of sanctioned use, community-based conservation, and benefit provision, have been adopted around MK (COMPACT, 2001; Mbora and Simons, 2002). The resources of MK could cope with systems of sanctioned use of land and resources, but currently there is a lack of any control, and economic institutional corruption has turned well-intended projects of sanctioned use into unsustainable use. Failure of sanctioned use, community-based conservation projects, and of benefit provision have been observed to be related to poverty, combined with growing demand for resources, thriving illegal markets, and economic and political corruption of governing institutions (Abbot and Mace, 1999; Anderson; 2002; Archabald and Naughton-Threves, 2001; Soehartono and Newton, 2001).

The type of projects that work on MK, are those that are spatially separated from the National Reserve, such as the NTCZ and the community-based fencing at the boundary, and the many on-farm agroforestry projects (COMPACT, 2001; Mbora and Simons, 2002). However, even projects outside the National Reserve are not spared from difficulties, such as cases of vandalism that temporarily destroyed the Naari fence in Meru-Imenti (40 cases of stealing wires and posts; Mathuva, 2001) and the Sagana fence in Hombe-Kabaru (stealing of generator). Likewise, initiatives to share PA revenue with surrounding communities in Uganda became an incentive to live next to the PAs, and most benefits ended up with corrupted local elite (Archabald and Naughton-Treves, 2001).

Many projects on MK typically focus on direct solutions but do not solve the causes of problems. Direct solutions to HEC on MK come in the form of protective fencing and control shooting, which does not solve the underlying causes of conflict (KWS, 2001; Mathuva, 1999; Mwathe et al., 1998). Fencing and degazetting of forest for settlement threatens to fragment the protected area and to isolate the MK elephants (Harcourt et al., 2001; Jenkins, 2003).

Direct solutions to economic instability and demands for resources and land come in the form of illegal exploitation of resources and encroachment, degazetting of forest for settlement and violation of NRC rules on afforested land in plantations, and through encouraging irrigated farming and issuing permits to extract water despite evident water shortages (Brunner, 1986; JICA/GOK, 1999; Wass, 1995; Wiesmann et al., 2000).

Deforestation affects the capacity of MK to retrieve, store and yield water, but laws prohibiting cultivation on hillsides with an inclination over 30% in catchment areas were nevertheless relaxed to 55% (Gathaara, 1999; Liniger, 1992; Pestalozzi, 1986). The little remaining forest that constitutes less than 3% of Kenya's land surface continues to be de-gazetted for settlement (Hoft, 2002; Kiteme, 2001; Matiru, 2000; Appendix VII). Violation of NRC regulations on afforested land in plantations has been the main cause of land degradation, hidden encroachment, and land fragmentation through permanent loss of forest land for settlement (Matiru, 2000; Vanleeuwe et al., 2003). Deforestation, over-exploitation of water, and poor land-tenure around MK, lead to water shortage, erosion, sediment loss, silting of dams, and interference with biodiversity and ecological functions (Brunner et al., 2001; Emerton, 1995; Kapos, 2000; Wiesmann et al., 2000).

9.1.8. The effect of governing institutions on MK (Chapter 8)

The MK forested area was declared Forest Reserve in 1932. Licensed sustainable exploitation of forest resources in the MK Forest Reserve remained possible, and was managed by the FD. The MK alpine area above 3,200m asl was declared a National Park in 1949. No exploitation is allowed in the MK National Park, access is limited to paying tourists and licensed researchers, and its protection and access are managed by the KWS (Matiru, 2000). The MK National Park and a large section of the Forest Reserve were declared Biosphere Reserve in 1978, and World Heritage Site (WHS) in 1997 by UNESCO (Gathaara, 1999). Financial capacity has been identified as a key factor in economic institutional corruption that counteracts conservation efforts (Brunner et al., 2001; Primavera, 2000; Smith et al., 2003). MK suffered crucial forest loss under FD management because very tight government funds render the FD inefficient, which encouraged economic corruption. In an attempt to stop forest loss, the Forest Reserve was upgraded to National Reserve and its management was handed over from the FD to the KWS in July 2000 (Vanleeuwe et al., 2003).

As a parastatal, KWS' financial capacity exceeds that of the FD by over 10 fold, resulting in better salaries and material capacity of transport and communication. The state of the forest has improved substantially under KWS management, sustaining the effectiveness of law enforcement efforts and showing that successful conservation efforts are linked to financial capacity (e.g. Smith et al., 2003).

The immediate positive effect of the transfer in management responsibility from the FD to the KWS led the MK management plan of 2002-2007 to propose that the plantations, the leasing of land, and water abstraction licences, all be controlled by the KWS (Hoft, 2002). Taking such responsibility lies well beyond the current KWS capacity and expertise, and would not address the underlying causes of FD corruption, nor address the demand for resources. Klooster (1999) found that a policy of institutional capacity building enhances the success of community-based conservation and reverses resource degradation. However, several studies have also shown that finances alone are not a sufficient guarantee against corruption (Abbot and Mace, 1999; Ekbom et al., 2001; Huber, 2001). With only one institution in charge, the potential for corruption can remain unnoticed for extended periods of time. This was the reason why abuse on MK under the FD remained unnoticed for so long. As an alternative to total KWS control, some recommendations for management are proposed.

9.2. RECOMMENDATIONS

This study has explored many aspects of the triangular relationship between the environment, elephants, and people. I now make some recommendations for land use management for the long-term benefits of elephants and people, regardless of the short-term disadvantages that this may bring to either. People directly threaten MK's ecological functions and isolated populations of elephants indirectly threaten to over-use its resources. The triangular relationship is increasingly unstable and there is no overall solution because problems arise from a large variety of factors. While implemented problem mitigation strategies have been well intended, some have had unanticipated and detrimental consequences.

For MK management, the FD and the KWS have always been the main government stakeholders. Having two institutions in charge of management is fundamentally better than opting for total control by the KWS. Perhaps the FD should remain in charge of management of the MK plantation forests, but their institutional and financial capacity and accordingly, their material capacity and management efficiency, should be improved. Through official recognition of the proposed Forestry Bill 2000, NRC could be abandoned in favour of low-cost community-based agroforestry initiatives, plantations could be privatised, and the FD could become a parastatal like the KWS, the KFS, thereby improving its financial capacity and its associated material capacity, salaries, and efficiency.

For MK development, future success lies in sharing tasks among institutions, CBO's and NGO's with appropriate expertise, according to a logical plan that facilitates project implementation and control over project development. Systematic monitoring of the status of MK forests and ongoing projects could reduce the potential window for corruption. MK needs a transparent and repeatable monitoring programme to evaluate the status of land and resources, to identify fluctuations, deterioration of the environment, and practices of unsustainable use. Given the international interest in MK, I recommend that monitoring design, fund-raising for monitoring, and co-ordination and evaluation of monitoring activities, are overseen by an international body with appropriate expertise, yet lacking political or economical interest in MK (e.g. World Bank, UNEP or UNDP, EC). Alternatively, an assessment unit could be funded to operate under their watchful eye.

A monitoring plan should be an obligatory condition for the main stakeholders on MK, such as ICRAF for agroforestry, Rural Focus or NRM3 for water extraction, and the KWS for aerial surveying and elephant monitoring. The project co-ordination and management unit should share results from assessments with all stakeholders, and aim to discourage projects with short-term or/ and direct advantages, when they may in turn entail long-term or/ and indirect disadvantages. This could be done through warning, and by providing a project co-ordination and management unit with the mandate to request for extra EIA's and to put projects on hold, based on annual re-assessments. The project co-ordination and management unit could also facilitate the process of obtaining project permits needing to by-pass inefficient district offices, the cause of impressive delays in project implementation.

Based on the insight that was gained from fieldwork and data analysis between 1999 and 2003, applied recommendations for surveying MK elephants systematically, for managing elephant impact, and for managing human impact, are outlined separately in Appendix VIII.

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Appendix I : Plant list for Mount Kenya (after Bussmann, 1994)

ACANTHACEA	*Acanthospale pubescens* *Acanthus eminens* *Asystasia mysorensis* *Barleria ventricosa* *Dicliptera laxata* *Dyschioriste clinopodioides* *Hypoestes aristata* *Hypoestes triflora* *Isoglossa gregorii* *Justicia striata* *Mimulopsis alpina* *Phaulopsis imbricata* *Thunbergia alata*
ADIANTHACEAE	*Adiantum poiretii* *Cheilanthes farinose* *Cheilanthes tecta* *Didymochlaena truncatula* *Doryopteris kirkii* *Pellea quadripinnata* *Pellea viridis* *Pityogramma aurantiaca* *Pteris catoptera* *Pteris cretica* *Pteris dentate* *Pteris pteridioides*
ALANGIACEAE	*Alangium chinense*
ALISMATACEAE	*Alisma plantago-aquatica*
AMARANTHACEAE	*Achyranthes aspera* *Aerva lanata* *Alternanthera pungens* *Celosia anthelmetica* *Cyathula cylindrical* *Cyathula mannii* *Cyathula polycephala* *Pupalia lappacea*
AMARYLLIDACEA	*Scadoxus multiflorus*
ANACARDIACEAE	*Rhus natalensis*
ANNONACEAE	*Monanthotaxis parviflora* *Monanthotaxis schweinfurthii*
ANTHERICACEAE	*Chlorophytum comosum*
APOCYNACEAE	*Acokanthera achimperi* *Carissa edulis* *Landolphia buchananii* *Landolphia kilimanjarica* *Tabernaemontana stapfiana* *Rauvolfia caffra* *Rauvolfia mannii*
AQUIFOLIACEAE	*Ilex mitis*
ARACEAE	*Arisaema mildbaedii* *Culcasia falcifolia* *Impatiens pseudoviola*
ARALIACEAE	*Cussonia barberi* *Cussonia holstii* *Cussonia spicata* *Polyscias fulva* *Polyscias kikuyuensis* *Schefflera volkensii*
ASCLEPIADACEAE	*Cynanchum abyssinicum* *Cynanchum altiscandens* *Cynanchum sp.* *Dregea schimperi* *Gomphocarpus fruticosus* *Periploca linearifolia* *Secamone punctulata* *Thylophoropsis heterophylla*
ASPARAGACEAE	*Asparagus africanus* *Asparagus falcatus* *Asparagus racemosus* *Asparagus setaceus*
ASPHODELACEAE	*Kniphofia thomsonii*
ASPIDIACEAE	*Arachnoides foliosa* *Dyopteris antartica* *Dryopteris fadenii* *Dryopteris kilemensis* *Dryopteris manniana* *Polystichum fuscpalaeacum* *Polystichum setiferum*
ASPLENIACEAE	*Asplenium abyssinicum* *Asplenium aethiopicum* *Asplenium boltonii* *Asplenium bugoiense* *Asplenium elliottii* *Asplenium erectum* *Asplenium friesiorum* *Asplenium hypomelos* *Asplenium linckii* *Asplenium loxoscaphoides* *Asplenium monanthes* *Asplenium protensum* *Asplenium sandersonii* *Asplenium strangeneum* *Asplenium stuhlmannii* *Asplenium theciferum* *Asplenium uhligii* *Asplenium sp.*
ATHYRIACEAE	*Athyrium scandicum* *Cystopteris fragilis* *Deparia boryana* *Diplaxium memorale* *Diplaxium zanzibaricum*
BALSAMIACEAE	*Impatiens fischeri* *Impatiens hochstetteri* *Impatiens hoechnelii* *Impatiens meruensis* *Impatiens mildbraedii*

Impatiens tinctoria

BASELLACEAE
Basella alba

BEGONIACEAE
Begonia keniensis
Begonia meyeri-johannis

BERBERIDACEAE
Berberis holstii

BIGNONIACEAE
Jacaranda mimosifolia
Markhamia lutea
Spathodea campanulata

BLECHNACEAE
Blechnum attenuatum
Blechnum invohibense
Blechnum tabulare

BORAGINACEAE
Cordia africana
Cynoglossum amplifolium
Cynoglossum coeruleum
Cynoglossum geometricum
Cynoglossum lanceolatum
Ehretia cymosa
Heliotropium scotteae
Lithospermum afromontanum
Myosotis abyssinica
Myosotis keniensis

CAESALPINIACEAE
Pterolobium stellatum

CALLITRICHACEAE
Callitriche stagnalis

CAMPANULACEAE
Cannaria eminii
Wahlenbergia arabidifolia
Wahlenbergia krebsii
Wahlenbergia pusilla

CANNELLACEAE
Warburgia ugandensis

CAPPARACEAE
Ritchiea albersii

CAPRIFOLIACEAE
Sambucus africana

CARYOPHYLLACEAE
Cerastium adnivale
Cerastium afromontanum
Cerastium indicum
Cerastium octandrum
Drymaria cordata
Sagina abyssinica
Sagina afroalpina
Silene burchellii
Stellaria sennii
Uebelinia crassifolia
Uebelinia rotundifolia

CELASTRACEAE
Elaeodendron buchananii
Maytenus acuminatus
Maytenus heterophyllus
Maytenus undata
Mystroxylon aethiopicum

CHENOPODIACEAE
Chenopodium procerum

Helichrysum foetidum

COMMELINACEAE
Aneilema aequinoctiale
Aneilema pedunculosum
Commelina africana
Commelina benghalensis
Commelina diffusa
Commelina latifolia
Commelina purpurea

COMPOSITAE
Acanthospermum australe
Acmella calirhiza
Ageratum conyzioides
Anthemis tigrescens
Artemisia afra
Berkheya spekeana
Bidens flagellata
Bidens pilosa
Botriocline amplifolia
Botriocline fusca
Brachylaena huillensis
Carduus afromontanus
Carduus chamaecephalus
Carduus keniensis
Carduus kikuyuensis
Carduus millefolius
Carduus nyassanus
Cinereria grandiflora
Cirsium vulgare
Conyza sp.
Conyza floribunda
Conyza newii
Conyza pallidiflora
Conyza schimperi
Conyza subscaposa
Conyza steudelii
Conyza theodori
Conyza tigrensis
Conyza vernonioides
Conyza welwitschii
Cotula abyssinica
Crassocephalum crepidioides
Craasocephalum montuosum
Crassocephalum picridifolium
Crassocephalum vitellinum
Crepis carbonaria
Crepis oliveriana
Dicrocephala alpina
Dicrocephala chrysanthemifolia
Dicrocephala integrifolia
Echinops hoehnelii
Erigeron alpinus
Ethulia vernonioides
Euryops brownie
Galinsoga parviflora
Gnaphalium rubridiflorum
Guizotia reptans
Gutenbergia fischeri
Gynura scandens
Haplocarpha rueppellii
Haplocarpha schimperi
Helichrysum argyranthum
Helichrysum brownei
Helichrysum chionoides
Helichrysum citrispinum
Helichrysum ellepticifolium

	Helichrysum formosissimum
	Helichrysum forskahlii
	Helichrysum gerberifolium
	Helichrysum globosum
	Helichrysum glumaceum
	Helichrysum guilelmi
	Helichrysum kilimanjari
	Helichrysum meyeri-johannis
	Helichrysum nandense
	Helichrysum newii
	Helichrysum odoratissimum
	Helichrysum schimperi
	Lactuca glandulifera
	Laggera brevipes
	Microglossa pyridifolia
	Mikaniopsis bambuseti
	Piloselloides hirsute
	Prenanthes subpeltata
	Pseudognaphalium luteo-album
	Pseudognaphalium undulatum
	Psidia punctulata
	Senecio hadiensis
	Senecio lyratus
	Senecio jacksonii
	Senecio johnstonii
	Senecio keniensis
	Senecio keniophytum
	Senecio keniodendron
	Senecio moorei
	Senecio purtschelleri
	Senecio roseiflorus
	Senecio ruwenzoriensis
	Senecio schweinfurthii
	Senecio syringifolius
	Siegesbeckia abyssinica
	Solanecio angulatus
	Solanecio mannii
	Solanecio nandensis
	Sonchus afromontanus
	Sonchus bipontini
	Sonchus luxurians
	Sonchus oleraceaus
	Sphaeranthus napierae
	Sphaeranthus suaveolens
	Stoebe kilimanscharica
	Tagetes minuta
	Taraxacum officinale
	Tolpis capensis
	Vernonia galamensis
	Vernonia hochstetteri
	Vernonia lasiopus
	Vernonia urticifolia
CONNARACEAE	*Agalaea heterophylla*
	Jaundea pinnata
CONVOLVULACEAE	*Convolvulus kilimandscharica*
	Cuscuta kilimanjari
	Dichondra repens
	Ipomea tenuirostris
	Ipomea wightii
CORNACEAE	*Afrocrania volkensii*
	Eleocharis marginulata

CRASSULACEAE	*Bryophyllum proliferum*
	Crassula alsinoides
	Crassula granvikii
	Crassula schimperi
	Kalanchoe densiflora
	Sedum crassularia
	Sedum meyeri-johannis
	Sedum ruwenzoriense
	Umbillicus botryoides
CRUCIFERAE	*Arabis alpina*
	Arabis glabra
	Arabidopsis thaliana
	Barbarea intermedia
	Capsella bursa-pastoris
	Cardamine africana
	Cardamine hirsuta
	Cardamine oblique
	Lepidium bonarense
	Oreophytum falcatum
	Subularia monticola
	Thlaspi alliaceum
CUCURBITACEAE	*Lagenaria abyssinica*
	Momordica foetida
	Momordica frieseorum
	Oreosyce africana
	Peponium vogelii
	Zehneria scabra
	Zehneria sp.
CUPRESSACEAE	*Cupressus lusitanica*
	Juniperus procera
CYATHEACEAE	*Cyathea humilis*
	Cyathea manniana
CYPERACEA	*Abligaardia setifolia*
	Carex chlorosaccus
	Carex cognata
	Carex cognata sp.
	Carex conferta
	Carex conferta sp.
	Carex elgonensis
	Carex erythrorrhiza
	Carex johnstonii
	Carex monostachya
	Carex peregrina
	Carex petitiana
	Carex vallis-rosetto
	Cyperus atroviridis
	Cyperus dereilema
	Cyperus dichroostachys
	Cyperus distans
	Cyperus erectus
	Cyperus impubens
	Cyperus kerstenii
	Cyperus nigricans
	Cyperus plateilema
	Cyperus rigidifolius
	Cyperus rotundus
	Cyperus sesquiflorus
	Ssp. Appendiculatus
	Cyperus tomaiophyllus

	Isolepis costata
	Isolepis fluitans
	Isolepis setacea
	Schoenoplectus confusus
	Schoenoxiphium lehmannii
DAVALLIACEAE	*Oleandra distenta*
DENNSTAEDIACEAE	*Blotiella glabra*
	Blotiella stipitata
	Histiopteris incisa
	Hypolepis goetzei
	Hypolepis sparsisora
DICHAPETALACEAE	*Dichapetalum madagascariense*
DIPSACACEAE	*Dipsacus pinnatifidus*
	Scabiosa columbaria
DRACAENACEAE	*Dracaena afromontana*
	Dracaena columbaria
EBENACEAE	*Agauria salicifolia*
	Euclea divinorum
	Diospyros abyssinica
ERICACEAE	*Blaeria filago*
	Blaeria johnstonii
	Erica arborea
	Erica excelsa
	Erica whyteana
ERIOCAULACEAE	*Eriocaulon schimperi*
	Eriocaulon volkensii
EUPHORBIACEAE	*Acalypha racemosa*
	Acalypha volkensii
	Clutia abyssinica
	Clutia robusta
	Croton alienus
	Croton macrostachys
	Croton megalocarpus
	Croton sylvaticus
	Drypetes gerrardii
	Erythrococca bongensis
	Euphorbia candelabrum
	Euphorbia depauperata
	Euphorbia engleri
	Euphorbia obovalifolia
	Euphorbia schimperiana
	Euphorbia wellbyi
	Euphorbia ugandensis
	Macaranga kilimandscharica
	Neoboutonia macrocalyx
	Phyllanthus boehmii
	Phyllanthus fischeri
	Phyllanthus muellereana
FLACOURTIACEAE	*Casearia battiscombei*
	Dovyalis abyssinica
FUMARIACEAE	*Corydalis mildbraedii*
	Fumaria abyssinica
	Poa annua
GENTIANACEAE	*Sebaea brachyphylla*
	Swertia crassiuscula
	Swertia kilimandscharica
	Swertia lugardae
	Swertia scandens
	Swertia subnivalis
	Swertia volkensii
GERANIACEAE	*Geranium aculeatolum*
	Geranium arabicum
	Geranium arabicum sp
	Geranium elamellatum
	Geranium kilimandscharicum
	Geranium vagans
GESNERIACEAE	*Streptocarpus glandulosissimus*
	Streptocarpus montanus
GLEICHENIACEAE	*Dicranopteris linearis*
	Gleichenia elongata
GRAMINEAE	*Acritochaete volkensii*
	Andropogon amethystinus
	Agrostis keniensis
	Agrostis leptophylla
	Agrostis schimperiana
	Agrostis sclerophylla
	Agrostis trachyphylla
	Agrostis volkensii
	Aira caryophyllea
	Anthoxanthum nivale
	Brachypodium flexum
	Bromus adoensis
	Bromus leptoclados
	Calamagrostis epigejos
	Chloris picnotrix
	Chloris virgata
	Cynodon dactylon
	Deschampsia caespitose
	Deschampsia flexuosa
	Digitaria scalarum
	Digitaria ternate
	Digitaria velutina
	Ehrharta erecta
	Eragrostis Amanda
	Eragrostis minor
	Eragrostis tenuifolia
	Exotheca abyssinica
	Festuca abyssinica
	Festuca costata
	Festuca pilgeri
	Harpanche schimperi
	Helictotrichon milanjanum
	Helictotrichon umbrosum
	Koeleria capensis
	Oplismenus burmannii
	Oplismenus hirtellus
	Panicum calvum
	Panicum pusillum
	Paspalum camersonii
	Pennisetum catabasis
	Pennisetum clandestinum
	Pentaschistis borussica
	Phalaris arundinaceae

	Poa leptoclada
	Poa schimperiana
	Setaria megaphylla
	Setaria plicatilis
	Setaria sphacelata
	Sinarundinaria alpina
	Sporobulus africanus
	Sporobulus agrostoides
	Stipa dregeana
	Streblochaete longiarista
	Themedea triandra
	Vulpia bromoides
GRAMMITIDIACEAE	*Xiphopteris flabelliformis*
	Xiphopteris strangeana
HYPERICACEAE	*Garcinia volkensii*
	Harungana madagascariensis
	Hypericum afromontanum
	Hypericum peplidifolium
	Hypericum revolutum
	Hypericum revolutum sp.
HAMAMELIDACEAE	*Trichocladus ellepticus*
HYMENOPHYLLACEAE	*Hymenophyllum capillare*
	Hymenophyllum kuhnii
	Hymenophyllum tunbringense
	Trichomanes borbonica
	Trichomanes melanotrichum
HYPOXIDACEAE	*Hypoxis villosa*
ICACINACEAE	*Apodytes dimidiata*
IRIDACEAE	*Aristea alata*
	Dierama pendulum
	Gladiolus newii
	Gladiolus watsonoides
	Hesperantha petitiana
	Romulea fischeri
	Romulea keniensis
JUNCACEAE	*Juncus dregeanus*
	Juncus effuses
	Juncus inflexus
	Juncus oxycarpus
	Luzula abyssinica
	Luzula johnstonii
LABIATAE	*Achyrospermum carvalhi*
	Achyrospermum schimperi
	Ajuga remota
	Becium capitatum
	Becium obovatum
	Leonotis nepetifolia
	Leonotis ocymifolia
	Leucas glabrata
	Leucas grandis
	Leucas martiniensis
	Leucas volkensii
	Mentha aquatica
	Mentha longifolia
	Nepetea azurea
	Ocimum gratissimum
	Ocimum kilimandscharicum
	Ocimum lamiifolium
	Plectranthus albus
	Plectranthus assurgens
	Plectranthus edulis
	Plectranthus kamerunensis
	Plectranthus laxiflorus
	Plectranthus longipes
	Plectranthus luteus
	Plectranthus pauciflorus
	Plectranthus sylvestris
	Pycnostachys meyeri
	Salvia merjamie
	Salvia nilotica
	Satureia abyssinica
	Satureia biflora
	Satureia kilimandscharica
	Satureia pseudosimensis
	Staureia simensis
	Stachys bambuseti
	Stachys subrenifolia
LAURACEAE	*Ocotea kenyensis*
	Ocotea usambarensis
LEGUMINOSAE	*Adenocarpus mannii*
	Aeschyomene schimperi
	Albizzia gummifera
	Argyrolobium friesianum
	Astragalus atropilosus
	Crotalaria agatiflora
	Crotalaria axillaris
	Crotalaria chrysichlora
	Crotalaria incana
	Crotalaria keniensis
	Crotalaria lanchocarpoides
	Crotalaria mauensis
	Crotalaria natalitia
	Dahlbergia lacteal
	Desmodium repandum
	Dolichos kilimandscharicus
	Kriosema jurionianum
	Kriosema scioanum
	Glycine wightii
	Indigofera arrecta
	Indigofera atriceps
	Indigofera nairobiensis
	Kotschya recurvifolia
	Lotus corniculatus
	Lotus goetzei
	Medicago lupulina
	Otholobium foliosum
	Parochetus communis
	Rhynchosia hirta
	Tephrosia interrupta
	Trifolium burchellianum
	Trifolium cryptopodium
	Trifolium semipilosum
	Trifolium tembrense
	Vigna parkeri
	Vigna schimperi

LEMNACEAE	*Lemna minor*
LENTIBULARIACEAE	*Utricularia livida*
LILIACEAE	*Bulbine abyssinica* *Wurmbea tenuis*
LINACEAE	*Linum volkensii*
LOBELIACEAE	*Lobelia aberdarica* *Lobelia bambuseti* *Lobelia baumannii* *Lobelia deckenii* *Lobelia duriprati* *Lobelia gibberoa* *Lobelia holstii* *Lobelia minutula* *Lobelia telekii* *Lobelia stellarioides*
LOGANIACEAE	*Anthocleista zambesiaca* *Buddleia polystachya* *Nuxia congesta* *Nuxia floribunda* *Strychnos usambarensis*
LOMARIOPSIDACEAE	*Elaphoglossum acrostichoideus* *Elaphoglossum angulatum* *Elaphoglossum aubertii* *Elaphoglossum conforme* *Elaphoglossum deckenii* *Elaphoglossum hybridum* *Elaphoglossum lastii* *Elaphoglossum ruwenzorii* *Elaphoglossumsubcinnamoneum*
LORANTHACEAE	*Arceuthobium juniperi-procerae* *Englerina woodfordioides* *Loranthus ulugurense* *Oncocalyx sulphurous* *Phragmanthera usuiensis* *Taphinathus brunneus*
LYCOPODIACEAE	*Huperzia mildbraedii* *Lycopodium cernuum* *Lycopodium clavatum* *Lycopodium saururus*
LYTHRACEAE	*Lythrum royundifolium*
MALVACEAE	*Abutilon longicuspe* *Hibiscus macranthus* *Hibiscus vitifolius* *Malva verticillata* *Favonia patens* *Favonia urens* *Sida ternate* *Sida tenuicarpa*
MARATTIACEAE	*Marattia fraxinea*
MELATOSTOMATACEAE	*Dissotis senegambiensis*
PIPERACEAE	*Peperomia abyssinica*
MELIACEAE	*Ekerbergia capensis* *Lepidotrichilia volkensii* *Trichilia dregeana* *Trichilia emetica* *Turraea holstii*
MELIANTHACEAE	*Bersama abyssinica*
MENISPERMACEAE	*Cissamphelos friesiorum* *Cissamphelos mucronata* *Stephania abyssinica* *Tiliacora funifera*
MIMOSACEAE	*Newtonia buchananii*
MONIMIACEAE	*Xymalos monospora*
MORACEAE	*Dorstenia thihaensis* *Ficus thoningii*
MYRICACEAE	*Embelia keniensis* *Myrianthus holstii* *Myrica salicifolia*
MYRTACEAE	*Eucalyptus saligna* *Syzygium guineense*
OCHNACEAE	*Strombosia scheffleri*
OLEACEAE	*Jasminum abyssinica* *Olea capensis* *Olea europaea*
OLINIACEAE	*Olinia rochetiana*
ONAGRACEAE	*Epilobium stereophyllum*
ORCHIDACEAE	*Cynorkis anacamptoides* *Cyrtorchis arcuata* *Disa deckenii* *Disa stairsii* *Disperis nemorosa* *Epipactis africana* *Eulopia horsfallii* *Habenaria bracetosa* *Polystachya cultriformis* *Polystachya latilabris* *Polystachya transvaalensis* *Satyrium crassicaule* *Satyrium robustum*
OROBANCHACEAE	*Orobanche minor*
OXALIDACEAE	*Oxalis corniculata* *Oxalis obliquifolia*
PASSIFLORACEAE	*Adenia gumifera* *Adenia rumicifolia* *Passiflora subpeltata*
PHYTOLACCACEAE	*Phytolacca dodecandra*
PINACEAE	*Pinus patula* *Pinus radiata*

	Piper capense
	Piper umbellatum
PLANTAGINACEAE	*Plantago palmate*
PODOCARPACEAE	*Podocarpus falcatus*
	Podocarpus latifolius
POLYGONACEAE	*Oxygonum sinuatum*
	Polygonum afromontanum
	Polygonum nepalense
	Polygonum pulchrum
	Polygonum setosum
	Rumex ruwenzoriensis
	Rumex steudelii
POLYGALACEAE	*Polygala sphenoptera*
POLYPODIACEAE	*Drynaria volkensii*
	Loxogramme abyssinica
	Lepisorus excavata
	Lepisorus schraderi
	Pleopeltis lanceolata
	Pleopeltis macrocarpa
PRIMULACEAE	*Anagallis serpens*
	Ardisiandra wettsteinii
	Lysimachia ruhmeriana
PROTEACEAE	*Faurea saligna*
	Protea caffra
PTERIDIACEAE	*Pteridium aquilinum*
RANUNCULACEAE	*Anemone thomsonii*
	Clematis brachiata
	Clematis simensis
	Delephinium macrocentron
	Ranunculus aberdaricus
	Ranunculus multifidus
	Ranunculus oreophytus
	Ranunculus stagnalis
	Ranunculus volkensii
	Thalictrum rhynchocarpum
RESEDACEAE	*Caylusea abyssinica*
RHAMNACEAE	*Rhamnus prinoidea*
	Rhamnus staddo
	Scutia myrtina
RHIZOPHORACEAE	*Cassipourea malosana*
ROSACEAE	*Alchemilla argyrophylla*
	Alchemilla cryptantha
	Alchemilla cyclophylla
	Alchemilla ellenbeckii
	Alchemilla fischeri
	Alchemilla gracillipes
	Alchemilla johnstonii
	Alchemilla rothii
	Cliffortia nitidula
	Prunus africana
	Bartsia petitiana
	Rubus apetalus
	Rubus frieseorum
	Rubus keniensis
	Rubus pinnatus
	Rubus rigidus
	Rubus scheffleri
	Rubus steudneri
	Rubus volkensii
RUBIACEAE	*Anthospermun herbaceum*
	Anthospermum usambarensis
	Canthium keniense
	Canthium oligocarpum
	Canthium schimperi
	Galiniera coffeoides
	Galium aparinoides
	Galium glaciale
	Galium hamatum
	Galium hochstetteri
	Galium kenyanum
	Galium ossirwaense
	Galium ruwenzoriense
	Galium spurium
	Galium thunbergianum
	Heinsenia dierveilloides
	Lasianthus kilimandscharicus
	Mitragyna rubrostipulata
	Moussaenda odorata
	Oldenlandia johnstonii
	Oldenlandia monanthos
	Parapentas battiscombei
	Pauridiantha holstii
	Pavetta abyssinica
	Pavetta hymenophylla
	Pavetta oliveriana
	Pentas lanceolata
	Psychotria fractinervata
	Psychotria orophila
	Psydrax schimperiana
	Rubia cordifolia
	Rhytigynia uhligii
	Spermacoce princeae
	Vangueria infausta
RUTACEAE	*Calodendrum capense*
	Clausena anisata
	Fagaropsis angolensis
	Teclea nobilis
	Teclea simplicifolia
	Teclea trichocarpa
	Toddalia asiatica
	Zanthoxylum gillettii
SANATLACEAE	*Osyris compressa*
SAPINDACEAE	*Allophyllus abyssinicus*
	Allophyllus cuneatus
	Dodonaea viscose
SAPOTACEAE	*Aningeria adolfi-friederici*
	Chrysophyllum gorgunosanum
SCROPHULARIACEAE	*Bartsia kilimandscharica*
	Bartsia longiflora

	Celsia floccosa *Craterostigma pumilum* *Diclis bambuseti* *Halleria lucida* *Hebenstretia angolensis* *Hedbergia abyssinica* *Limosella aquatica* *Rhamphicarpa Montana* *Sibthorpia europaea* *Verbascum sinaiticum* *Veronica abyssinica* *Veronica anagallis-aquatica* *Veronica glandulosa* *Veronica gunae*
SELAGINACEAE	*Selago thomsonii*
SELAGINELLACEAE	*Selaginella abyssinica* *Selaginella kraussiana*
SIMAROUBACEAE	*Brucea antidysenterica*
SMILACACEAE	*Smilax anceps* *Smilax aspera*
SOLANACEAE	*Datura stramonium* *Discopodium eremanthum* *Discopodium penninervum* *Physalis peruviana* *Solanum aculeastrum* *Solanum aculeatissimum* *Solanum benderianum* *Solanum incanum* *Solanum nigrum* *Solanum schumannianum* *Solanum sessilistellatum* *Solanum terminale*
STERCULIACEAE	*Cola greenwayii* *Dombeya goetzii* *Dombeya torrida*
THELYPTERIDACEAE	*Amauropelta bergiana* *Amauropelta oppositiformis* *Christella dentate* *Pneumatopteris unita* *Pseudophegopteris aubertii* *Stenogramma pozoi*
THYMELEACEAE	*Gnidia glauca* *Peddiea fischeri* *Peddiea volkensii* *Struthiola thomsonii*
TYPHACEAE	*Typha latifolia*
TILLIACEAE	*Grewia similes* *Sparmannia ricinocarpa* *Triumfetta macrophylla* *Triumfetta rhomboidea*
ULMACEAE	*Celtis africana* *Celtis gomphophylla*
UMBELLIFERAE	*Agrocharis incognita* *Alepidae peduncularis* *Anthriscus sylvestris* *Apium leptophyllum* *Centella asiatica* *Cryptotaenia africana* *Haplosciadium abyssinicum* *Heracleum inexpectatum* *Heteromorpha trifoliate* *Hydrocotyle mannii* *Hydrocotyle monticola* *Oenanthe procumbena* *Oreophyton falcatum* *Peucedanum elgonense* *Peucedanum friesiorum* *Peucedanum kerstenii* *Pimpinella frieseorum* *Pimpinella orophila* *Pseudocarum eminii* *Sanicula elata* *Torilis arvensis*
URTICACEAE	*Droguetia debilis* *Droguetia iners* *Elatostema monticola* *Giardinia diversifolia* *Laportea alatipes* *Pilea rivularis* *Pilea johnstonii* *Pilea usambarensis* *Urera hypselodendra* *Urtica massaica*
VALERIANACEAE	*Valeriana capensis* *Valeriana kilimandscharica* *Valerianella microcarpa*
VERBENACEAE	*Clerodendrum johnstonii* *Lantana trifolia* *Lantana viburnioides* *Premna maxima* *Verbena officinalis* *Vitex keniensis*
VIOLACEAE	*Viola abyssinica* *Viola eminii*
VISCACEAE	*Viscum fischeri* *Viscum schimperi* *Viscum turbeculatum*
VITACEAE	*Cissus olivieri* *Cyphostemma kilimandscharicum* *Cyphostemma maranguense* *Helinus integrifolius*
VITTARIACEAE	*Vittaria volkensii*
ZINGIBERACEAE	*Afromomum keniense*

Appendix II: Mammal list of Mount Kenya (after Young, 1993)

Forest dependent species

Order	*Family*	*Genus*	*Sub-genus*	*Common Name*
ARTIODACTYLA	Bovidae	*Tragelaphus*	*euryceros*	Bongo
	Bovidae	*Neotragus*	*moschatus*	Suni
	Bovidae	*Cephalophus*	*nigrifrons*	Black-fronted Duiker
	Bovidae	*Cephalophus*	*harveyi*	Harvey's Duiker
	Suidae	*Hylochoerus*	*meinertzhageni*	Giant Forest Hog
	Suidae	*Potamochoerus*	*porcus*	Bushpig
HYRACOIDAE	Procaviidea	*Dendrohyrax*	*arboreus*	Tree Hyrax
INSECTIVORA	Soricidae	*Sylvisorex*	*granti*	Forest Shrew
PRIMATES	Cercopithecidae	*Colobus*	*guereza*	Black and White Colobus
	Cercopithecidae	*Cercopithecus*	*mitis*	Sykes' Monkey
	Loricidae	*Galago*	*crassicaudatus*	Greater Bushbaby
	Loricidae	*Galago*	*senegalensis*	Lesser Bushbaby
RODENTIA	Muridae	*Cricetomys*	*gambianus*	Giant pouched Rat
	Sciuridae	*Paraxerus*	*ochraceus*	Huet's Bush Squirrel
	Sciuridae	*Heliosciurus*	*rufobrachium*	Red-legged Sun Squirrel
	Muridae	*Lophiomys*	*imhausili*	Maned Rat
	Muridae	*Grammomys*	*gigas*	Thicket Rat
	Muridae	*Rattus*	*tullbergi*	Short-haired Rat
	Muridae	*Rattus*	*denniae*	Climbing Wood Mouse
	Muridae	*Hylomyscus*	*stella*	Stella Wood Mouse

Generalist species

Order	*Family*	*Genus*	*Sub-genus*	*Common Name*
ARTIODACTYLA	Bovidae	*Sylvicapra*	*grimmia*	Common Duiker
	Bovidae	*Tragelaphus*	*scriptus*	Bushbuck
	Bovidae	*Tragelaphus*	*oryx*	Eland
	Bovidae	*Kobus*	*ellepsiprymnus*	Waterbuck
	Bovidae	*Redunca*	*fulvorufola*	Mountain Reedbuck
	Bovidae	*Syncerus*	*caffer caffer*	Savannah Buffalo
CARNIVORA	Felidae	*Panthera*	*pardus*	Leopard
	Hyaenidae	*Crocuta*	*crocuta*	Spotted Hyena
	Hyaenidae	*Hyaena*	*hyaena*	Striped Hyena
	Canidae	*Canis*	*mesomelas*	Black-backed Jackal
	Viverridae	*Genetta*	*tigrina*	Large-spotted Genet
	Viverridae	*Civettictis*	*civetta*	Civet
	Viverridae	*Herpestes*	*sanguineus*	Slender Mongoose
	Viverridae	*Atilax*	*paludinosus*	Marsh Mongoose
CHIROPTERA	Rhinolophidae	*Rhinolophus*	*geoffroyi*	Horseshoe Bat
INSECTIVORA	Soricidae	*Crocidura*	*fumosa*	Dusky Shrew
	Soricidae	*Crocidura*	*turba*	(Shrew)
	Soricidae	*Crocidura*	*occidentatis*	(shrew)
LAGOMORPHA	Ochotonidae	*Lepus*	*capensis*	Cape Hare

PERISSODACTYLA	Rhinocerotidae	*Diceros*	*bicornis*	Black Rhinoceros
	Equidae	*Equus*	*burchelli*	Common Zebra
PRIMATES	Cercopithecidae	*Papio*	*annubis*	Olive Baboon
PROBOSCIDAE	Elephantidae	*Loxodonta*	*africana africana*	African Savannah Elephant
RODENTIA	Hystricidae	*Hystrix*	*cristata*	North African Porcupine
	Thryonomidae	*Thryonomys*	*swinderianus*	Giant Cane Rat
	Thryonomidae	*Thryonomys*	*gregorianus*	Lesser Cane Rat
	Muridae	*Oenomys*	*hypoxanthus*	Rufous-nosed Rat
	Gliridae	*Graphiurus*	*murinus*	Tree Dormouse
	Muridae	*Lemniscomys*	*striatus*	Striped Grass Mouse
	Muridae	*Rhabdomys*	*pumilio*	Four-striped Grass Mouse
	Muridae	*Mus*	*gratus*	(Pygmy Mouse)
	Muridae	*Mus*	*triton*	(Pygmy Mouse)
	Muridae	*Lophuromys*	*aquilus*	Harsh-furred Mouse
TUBULIDENTATA	Orycteropodidae	*Orycteropus*	*afer*	Aardvark

Grassland/ moorland species

Order	*Family*	*Genus*	*Sub-genus*	*Common Name*
*ARTIODACTYLA	Bovidae	*Alcelaphus*	*buselaphus*	Hartebeest
*CARNIVORA	Felidae	*Acinonyx*	*jubatus*	Cheetah
	Felidae	*Felis*	*serval*	Serval Cat
	Felidae	*Felis*	*silvestris*	Wild Cat
	Mustelidae	*Icotonyx*	*striatus*	Zorilla
HYRACOIDAE	Procaviidea	*Procavia*	*johnstoni mackender*	Rock Hyrax
INSECTIVORA	Soricidae	*Crocidura*	*allex*	Pygmy Shrew
	Soricidae	*Suridisorex*	*polulus*	Mole Shrew
RODENTIA	Muridae	*Tachyoryctes*	*splendens*	Mole Rat
	Muridae	*Otomys*	*typus*	(Groove-toothed Rat)
	Muridae	*Otomys*	*tropicalis*	(Groove-toothed Rat)
	Muridae	*Dendromus*	*isignis*	Striped Tree Mouse
	Muridae	*Dendromus*	*melanotis*	(mouse)

*occasional moorland species

Appendix III: Bird list for Mount Kenya (after UNESCO, 1996)

Order	*Family*	*Scientific name*	*Common name*
GALLIFORMES	Phasianidae	*Francolinus psilolaemus*	Moorland Francolin
	Phasianidae	*Francolinus squamatus*	Scaly Francolin
	Phasianidae	*Francolinus jacksoni*	Jackson's Francolin
ANSERIFORMES	Anatidae	*Anas sparsa*	African Black Duck
PICIFORMES	Lybiidae	*Pongoniulus bilineatus*	Yellow-rumped Tinkerbird
BUCEROTIFORMES	Bucerotidae	*Tockus alboterminatus*	Crowned Hornbill
	Bucerotidae	*Ceratogymna brevis*	Silvery-cheeked Hornbill
CORACIIFORMES	Cerylidae	*Megaceryle maxima*	Giant Kingfisher
	Meropidae	*Merops oreobates*	Cinnamon-chested Bee-eater
CUCULIFORMES	Cuculidae	*Cuculus solitarius*	Red-chested Cuckoo
	Cuculidae	*Chrysococcyx klaas*	Klaas's Cuckoo
	Cuculidae	*Chrysococcyx cupreus*	African Emerald Cuckoo
PSITTACIFORMES	Psittacidae	*Poicephalus gulielmi*	Red-fronted Parrot
APODIFORMES	Apodidae	*Schoutedenapus myoptilus*	Scarce Swift
	Apodidae	*Tachymarptis melba*	Alpine Swift
	Apodidae	*Tachymarptis aequatorialis*	Mottled Swift
	Apodidae	*Apus niansae*	Nyanza Swift
STRIGIFORMES	Tytonidae	*Tyto capensis*	African Grass-owl
	Strigidae	*Bubo capensis*	Cape Eagle-Owl
	Strigidae	*Strix woodfodii*	African Wood-Owl
	Strigidae	*Asio abyssinicus*	Abyssinin Owl
COLUMBIFORMES	Columbidae	*Columba arquatrix*	African Olive-Pigeon
	Columbidae	*Columba delegorguei*	Eastern Bronze-naped Pigeon
	Columbidae	*Columba larvata*	Lemon Dove
	Columbidae	*Streptopelia lugens*	Dusky Turtle-Dove
	Columbidae	*Streptopelia semitorquata*	Red-eyed Dove
	Columbidae	*Treron calva*	African Green-Pigeon
CICONIIFORMES	Scolopacidae	*Gallinago media*	Great Snipe
	Scolopacidae	*Gallinago gallinago*	Common Snipe
	Scolopacidae	*Gallinago nigripennis*	African Snipe
	Scolopacidae	*Lymnocryptes minimus*	Jack Snipe
	Scolopacidae	*Tringa nebulararia*	Common Greenshank
	Scolopacidae	*Tringa ochropus*	Green Sandpiper
	Charadriidae	*Vanellus melanopterus*	Black-winged Lapwing
	Accipitridae	*Aviceda cuculoides*	African Baza
	Accipitridae	*Milvus migrans*	Black Kite
	Accipitridae	*Gypaetus barbatus*	Lammergeier
	Accipitridae	*Gyps rueppellii*	Rueppell's Griffon
	Accipitridae	*Circus aeruginosus*	Western Marsh-Harier
	Accipitridae	*Circus macrourus*	Pallid Harrier
	Accipitridae	*Circus pygargus*	Montagu's Harrier
	Accipitridae	*Accipiter tachiro*	African Goshawk
	Accipitridae	*Accipiter melanoleucus*	Black Goshawk
	Accipitridae	*Buteo oreophilus*	Mountain buzzard
	Accipitridae	*Buteo augur*	Augur Buzzard
	Accipitridae	*Aquila nipalensis*	Steppe Eagle
	Accipitridae	*Aquila verreauxii*	Verreaux's Eagle

CICONIIFORMES	Accipitridae	*Hieraaetus ayresii*	Ayres's Hawk-Eagle
	Accipitridae	*Stephanoatus coronatus*	Crowned Hawk-Eagle
	Sagittariidae	*Sagittarius serpentarius*	Secretary Bird
	Falconidae	*Falco naumanni*	Lesser Kestrel
	Falconidae	*Falco tinnunculus*	Common Kestrel
	Falconidae	*Falco biarmicus*	Lanner Falcon
	Falconidae	*Falco peregrinus*	Peregrine Falcon
	Threskiornithidae	*Mesembrinibis cayennensis*	Green Ibis
	Ciconiidae	*Ciconia ciconia*	White Stork
PASSERIFORMES	Tyrannidae	*Empidonax oberholseri*	Dusky Flycatcher
	Corvidae	*Corvus albicollis*	White-necked Raven
	Corvidae	*Oriolus nigripennis*	Black-winged Oriole
	Corvidae	*Terpsiphone viridis*	African Paradise Flycatcher
	Corvidae	*Laniarius aethiopicus*	Tropical Boubou
	Corvidae	*Platysteira peltata*	Black-throated Wattle-eye
	Muscicapidae	*Monticola saxatilis*	Rufous-tailed Rock Thrush
	Muscicapidae	*Monticola rufocinereus*	Little Rock Thrush
	Muscicapidae	*Zoothera piaggiae*	Abyssinian Ground Thrush
	Muscicapidae	*Zoothera gurneyi*	Orange Ground Thrush
	Muscicapidae	*Turdus olivaceus*	Olive Thrush
	Muscicapidae	*Pogonocichla stellata*	White-starred Robin
	Muscicapidae	*Cossypha caffra*	Cape Robin Chat
	Muscicapidae	*Cossypha semirufa*	Rueppell's Robin Chat
	Muscicapidae	*Saxicola torquata*	Common Stone Chat
	Muscicapidae	*Oenanthe oenanthe*	Northern Wheatear
	Muscicapidae	*Oenanthe pileata*	Capped Wheatear
	Sturnidae	*Poeoptera kenricki*	Kenrick's Starling
	Sturnidae	*Cinnyricinclus sharpii*	Sharpe's Starling
	Paridae	*Pardus albiventris*	White-bellied Tit
	Hirundinidae	*Riparia paludicola*	Plain Martin
	Hirundinidae	*Hirundo fuligula*	Rock Martin
	Hirundinidae	*Hirundu rustica*	Barn Swallow
	Hirundinidae	*Psalidoprocne holomelas*	Black Sawwing
	Pycnonotidae	*Pycnonotus tricolor*	Dark-capped Bulbul
	Cisticolidae	*Cisticola hunteri*	Hunter's Cisticola
	Cisticolidae	*Apalis jacksoni*	Black-throated Apalis
	Cisticolidae	*Apalis porphyrolaema*	Chestnut-throated Apalis
	Cisticolidae	*Apalis cinerea*	Greay Apalis
	Sylviidae	*Bradypterus cinnamomeus*	Cinnamon Bracken Warbler
	Sylviidae	*Phylloscopus umbrovirens*	Brown Woodland Warbler
	Sylviidae	*Phylloscopus trochilus*	Willow Warbler
	Sylviidae	*Illadopsis abyssinica*	Abyssinian Hill Babbler
	Sylviidae	*Sylvia atricapilla*	Blackcap
	Nectariniidae	*Nectarinia mediocris*	Eastern Double-collared Sunbird
	Nectariniidae	*Nectarinia tacazze*	Tacazze Sunbird
	Nectariniidae	*Nectarinia reichenowi*	Golden-winged Sunbird
	Nectariniidae	*Nectarinia famosa*	Malachite Sunbird
	Nectariniidae	*Nectarinia johnstoni*	Red-tuffed Sunbird
	Passeridae	*Motacilla cinerea*	Grey Wagtail
	Passeridae	*Motacilla clara*	Mountain Wagtail
	Passeridae	*Anthus cervinus*	Red-Throated Pipit
	Passeridae	*Nigrita canicapilla*	Grey-headed Negrofinch
	Passeridae	*Cryptospiza salvadorii*	Abyssinian Crimson Wing
	Passeridae	*Estrilda quartinia*	Yellow-bellied Waxbill
	Passeridae	*Estrilda atricapilla*	Black-headed Waxbill
	Fringillidae	*Serinus burtoni*	Thick-billed Seedeater
	Fringillidae	*Linurgus olivaceus*	Oriole Finch

Appendix IV: Morphological stages of elephant dung decay

Dung	*Dung Decay at 3000m altitude*								*Dung*	*Dung Decay at 2500m altitude*							
ID	days	A	B	C1	C2	D	D+	End	ID	days	A	B	C1	C2	D	D+	End
1	141	1	2	35	7	42	49	5	31	165	1	2	7	49	84	21	1
2	104	1	2	28	0	7	62	4	32	146	1	2	7	63	70	0	3
3	167	1	2	28	28	42	63	3	33	165	1	2	7	63	70	21	1
4	112	1	2	7	42	14	42	4	34	139	1	2	7	42	42	42	3
5	135	1	2	14	21	21	70	6	35	58	1	2	7	35	7	0	6
6	110	1	2	21	21	7	56	2	36	139	1	2	7	35	28	63	3
7	110	1	2	7	28	0	70	2	37	85	1	2	28	14	7	28	5
8	103	1	2	28	7	7	56	2	38	118	1	2	28	14	28	42	3
9	135	1	2	21	28	35	42	6	39	139	1	2	28	14	14	77	3
10	159	1	2	42	21	63	28	2	40	86	1	2	28	14	14	21	6
11	116	1	2	35	7	21	49	1	41	58	1	2	21	14	14	0	6
12	147	1	2	35	0	49	56	4	42	78	1	2	28	7	7	28	5
13	116	1	2	21	21	21	49	1	43	85	1	2	7	7	35	28	5
14	116	1	2	7	35	7	63	1	44	51	1	2	7	28	7	0	6
15	110	1	2	7	28	14	56	2	45	85	1	2	21	21	35	0	5
16	110	1	2	28	7	21	49	2	46	139	1	2	21	21	35	56	3
17	103	1	2	14	21	0	63	2	47	139	1	2	14	28	14	77	3
18	65	1	2	7	35	7	7	6	48	58	1	2	7	28	7	7	6
19	129	1	2	28	7	7	84	0	49	85	1	2	7	35	14	21	5
20	167	1	2	28	7	14	112	3	50	51	1	2	7	21	7	7	6
21	65	1	2	28	7	7	14	6	51	51	1	2	7	28	7	0	6
22	116	1	2	14	21	49	28	1	52	171	1	2	7	35	21	105	0
23	98	1	2	14	14	7	56	4	53	171	1	2	21	21	17	109	0
24	116	1	2	28	7	0	77	1	54	139	1	2	21	35	21	56	3
25	91	1	2	14	35	7	28	4	55	165	1	2	21	35	12	93	1
26	58	1	2	7	28	14	0	6	56	165	1	2	21	35	14	91	1
27	135	1	2	7	35	21	63	6	57	139	1	2	21	28	7	77	3
28	65	1	2	0	7	28	21	6	58	78	1	2	14	28	7	21	5
29	65	1	2	7	14	14	21	6	59	78	1	2	14	21	14	21	5
30	167	1	2	7	6	77	70	4	60	85	1	2	21	21	7	28	5

'End' = random number between 1 and 7 (the days after that dung was last recorded as stage D+)

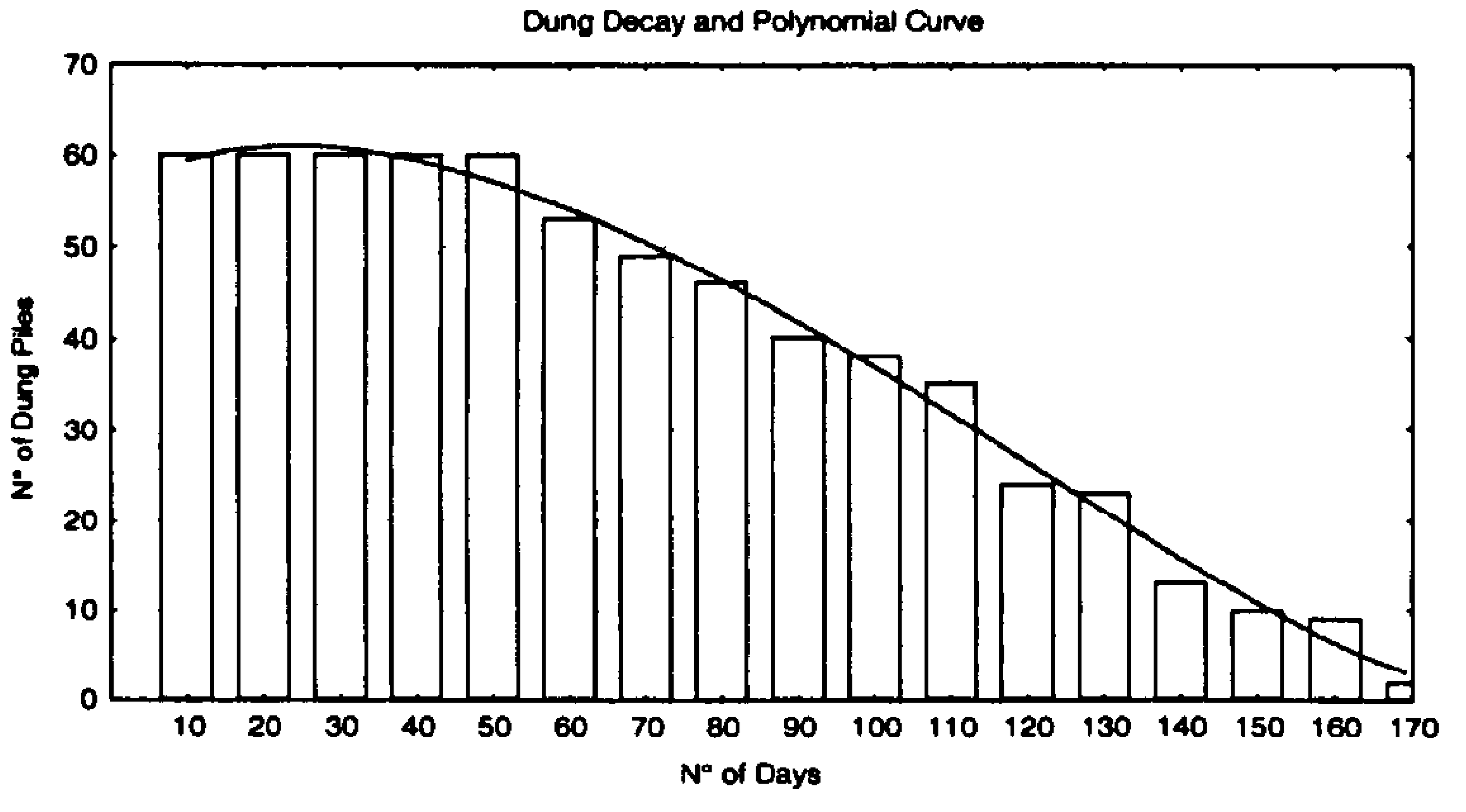
Dung decay rate values (r) from different equations

- **The Bootstrap Mean decay rate**

The Bootstrap Mean decay of the pooled sample (N = 60) suggests a value of r = 0.0089 (Var 0.00000016, SE 0.000792, 95% CL 0.000792)

- **The Polynomial assumption**

The Polynomial equation calculates the predicted Number of dung piles (N) that will have died after (t) days: $\frac{\sum(Nt-N_{t+1})}{\sum Nt}$ and suggest a rate r = 0.0086

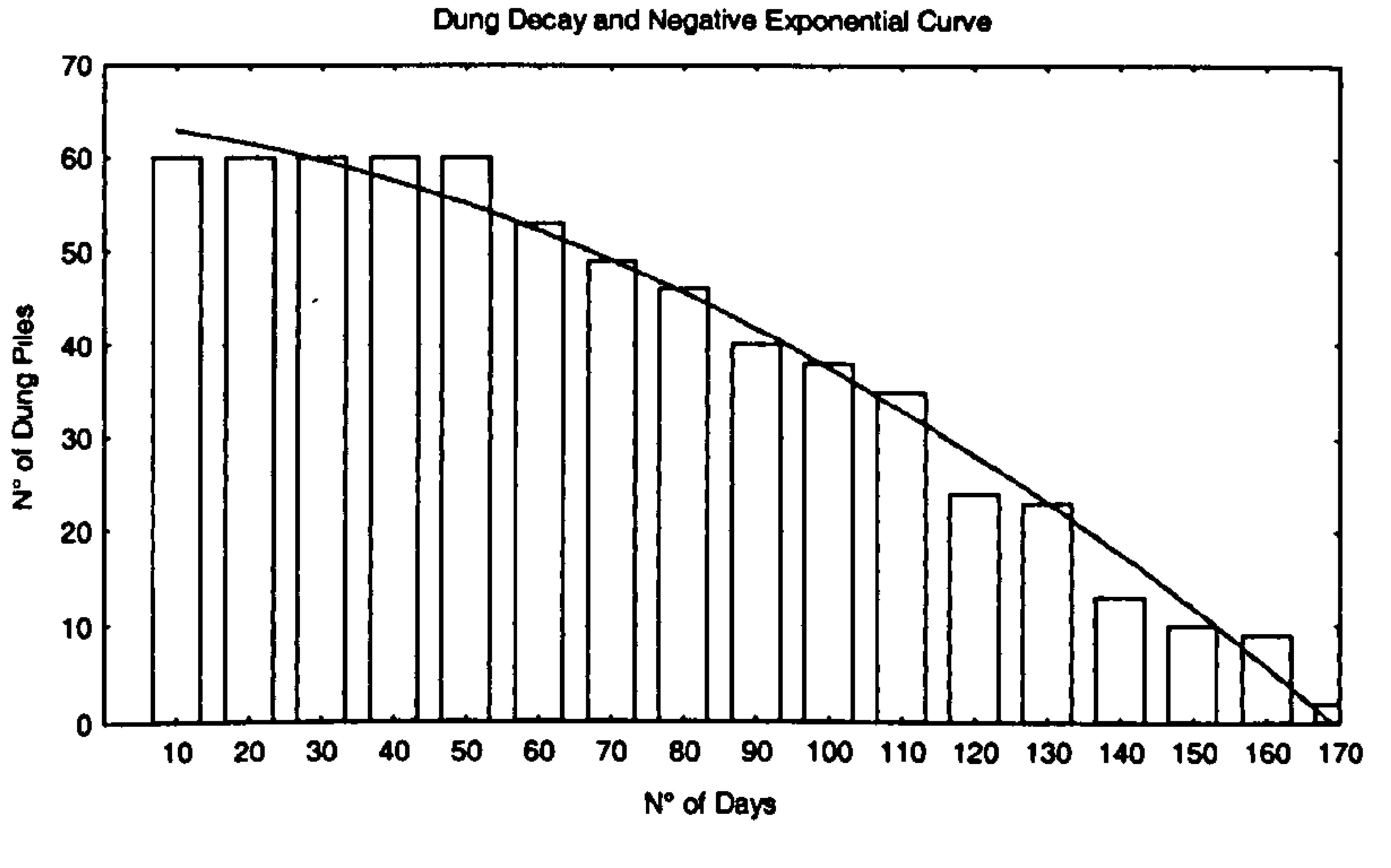


- **The Negative Exponential assumption**

$$r = \frac{LN(\sqrt{No}) - LN((\sqrt{Nt})}{t}$$

where, No = is the square root of the initial number of droppings,
Nt = the square root of the number of dung piles left after (t) days,
LN = a natural log.

also fits the data well and suggests a value of r = 0.0094, where the square root of No = 2.047, Nt = 1.414, and t = 170



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Appendix V: What is GLM (after Nicholls, 1991; and Crawley, 1993)

The use of traditional regression models requires a normal distribution of data, and transforming skewed data to approach a normal distribution is common practice. The standard Normal errors least squares regression model is of the form $Y_i = a + b.x_i + e_i$, where Y_i is the observed response, x_i the predictor variable, a and b the parameters describing the relationship between $a + b.x_i$ and e_i is the difference between the prediction of $a + b.x_i$ and the observed response given by Y_i. There are 3 components in this model:

- the observed response, Y_i;
- the systematic component, $a + b.x_i$;
- the random component or noise, e_i.

There are 2 assumptions in this model (Nicholls, 1991). The first one is that the e_i's are independent and Normally distributed with mean of zero and variance of s^2. The second is that the expected or predicted value of Y_i namely u_i is equal to the systematic part of the model, $u_i = a + b.x_i$. What this means is that multiple observations made at the same value of the predictor variable need to be independent and identically distributed Normally with mean u_i and an estimate of s^2. Nelder and Wedderburn (1972) worked on the generalized linear models (GLM), which allow a wider range of assumptions to underlie the response variable. Linear models do not need to have a straight-line relationship between the response variable and the explanatory variables. Non-linear models can be linearized by transformation. $Y = exp\ (a+bx)$ on taking logs of both sides, is $ln\ Y = a + b.x$. Non-linear relationships are possible while retaining the linear form of the systematic component:

$$l = a + b_1.x_1 + b_2.x_2 + \ldots + b_k.x_k$$

where l is known as the linear predictor, related to the predictor with a link function.
There are thus 3 components to the generalized linear model:

- one or more response variable(s) from the same distribution; normal, poisson, binomial;
- a set of parameters and explanatory variables;
- a link that relates the linear predictor to the predicted value.

Appendix VI: Socio-economic survey of farming households

District...............Division:...............Location:............Sub-location...............
Name of Interviewed Farmer (optional): ....
Interview date:.....................

Respondent's relationship to the Household Head - HHH (circle the right response):

HHH Wife Son Daughter other relative

Main occupation of HHH (circle the right response):

Farmer Casual labourer Business person Other (specify)

Marital status of the respondent (circle the right response):

Married Single Separated Divorced Widowed

No of people in the household:

	Males	Females	younger then 5	between 5 – 15	between 15 – 20	Older then 50
TOTAL						
Number live ON farm						
Number live OFF farm						

How many of the adults in the household have had (Fill in):

No education : Primary : Secondary : University :

Distance of farm from the forest boundary .... (km or metres)

When did you or your family settle here? .... (year)

How did you acquire this land (circle the right response):?

Bought Inherited Others (specify: ....)

Do you have a title deed (circle the right response): Yes No

What is the current pricing of land per acre in this locality? .... (Ksh.)

Materials of main house (circle the right response):

Walls : wood mud mud&wood brick

Roofs: grass mabati tiles other

Floor: mud wood concrete other

What type of water do you use (circle the right response):

Piped furrow reservoir well river: at minutes walk?

Do you have on the farm (Fill in yes or no, or a number if more then 1):

Toilets:	Electricity:	Bicycle:	Number of Cattle:
Water taps:	Radio:	Motorbike:	Number of Goats:
Fuelwood trees:	TV:	Vehicle:	Number of Donkeys:
Stores:	Telephone:	Pull Cart:	Number of Chickens:

Details about your land (specify if square meters, acres or ha):
Overall land size :................
Settled, built area :................
Cultivated area :................ Area irrigated:..................
Land under fodder /pasture : ....

What crops do you have - order of importance 1st, 2nd, 3rd (Circle right response):

1st crop:	Maiz	Beans	Cabbage	Potatoes	other (specify)
2nd crop:	Maiz	Beans	Cabbage	Potatoes	other (specify)
3rd crop:	Maiz	Beans	Cabbage	Potatoes	other (specify)

Have you suffered crop damage during the last 2 seasons? Yes No

If yes, what is the reason (specify) ....

<u>Socio- Economic details per household:</u>

Household Income	**Approximate per year in Ksh.**
From crops (excl. self-consumption)	....
From livestock	....
From family working outside	....
From other source (specify)	....
Household expenditure	**Approximate per year in Ksh.**
Self-consumption	....
Schooling of children	....
Medicine people	....
On fertilizer/ farm produce	....

Our household uses the forests to .... (Yes or No)

• collect firewood	Yes	No	• collect wild fruits, vegies	Yes	No
• collect charcoal	Yes	No	• collect fodder for lifestock	Yes	No
• collect poles	Yes	No	• to use as grazing area	Yes	No
• collect fencing material	Yes	No	• to collect medicinal herbs	Yes	No
• collect thatch	Yes	No	• to collect livestock medicine	Yes	No
• collect wood for furniture	Yes	No	• to place hives	Yes	No
• collect material for baskets	Yes	No	• to collect wild honey	Yes	No
• collect weapons or tools	Yes	No	• collect water, use the rivers	Yes	No
• collect ropes	Yes	No	• to use for additional shambas	Yes	No

<u>Household energy sources (i.e. 50% from farm, 30% from forest, 0% bought)</u>

What Type? i.e.Fuelwood, Charcoal, Parrafin	**% from farm**	**% from forest**	**% bought**
1st	....	....	....
2nd	....	....	....
3rd	....	....	....

Appendix VII: Excisions for Mount Kenya and Imenti Reserves

Date	*Legal Notice*	*Gazette Notice*	*Location*	*Size in Ha.*
??/??/1963	?	?	Mt. Kenya (Island farms)	800.00
14/12/1965	LN 336	?	Mt. Kenya	56.25
03/11/1967	LN 220	GN 3440	Meru (Upper Imenti)	209.22
03/11/1967	LN 221	GN 3442	Meru (Lower Imenti)	33.18
03/11/1967	LN 222	GN 3439	Meru (Upper Imenti)	219.74
03/11/1967	LN 223	GN 3438	Meru (Upper Imenti)	250.91
03/11/1967	LN 223	GN 3438	Meru (Upper Imenti)	64.75
03/11/1967	LN 226	GN 3443	Mt. Kenya	485.63
15/03/1968	LN 076	GN 0600	Meru (Upper imenti)	413.19
*21/06/1968	LN 182	GN 3769	*Mt. Kenya (NP)	10,522.05
*21/06/1968	LN 183	?	*tourist tracks (NP)	2,124.64
11/10/1968	LN 309	GN 3065	Mt. Kenya	946.98
17/01/1969	LN 012	GN 1656	Mt. Kenya	65.56
16/05/1975	LN 068	GN 3228	Mt. Kenya	384.10
09/01/1976	LN 011	GN 3229	Mt. Kenya	186.50
09/01/1976	LN 013	GN 2871	Mt. Kenya	9.41
18/03/1977	LN 061	GN 2575	Mt. Kenya	20.43
13/05/1977	LN 107	GN 0049	Mt. Kenya	546.20
05/08/1977	LN 222	GN 1761	Mt. Kenya	195.90
??/??/1986	LN 285	?	Mt. Kenya (Nyayo Tea Zone)	??
03/04/1998	?	GN 1765	Meru (Upper Imenti)	40.47
29/05/1998	?	GN 2898	Meru (Upper Imenti)	12.14
08/10/1998	?	GN 5845	Meru (Upper Imenti)	0.3629
16/02/2001	?	?	Mt. Kenya (Gathiuru)	620.00
16/02/2001	LN 029	GN 5847	Mt. Kenya (Ngusishi-Sirimon)	796.04
19/10/2001	LN 147	?	Mt. Kenya (Hombe)	717.00
19/10/2001	LN 149	?	Mt. Kenya (Ndathi)	912.10
19/10/2001	LN 150	?	Mt. Kenya (Ragati)	196.05
??/??/1976	LN 013	GN 2871	Mt. Kenya addition	7.32

*upgrading status from Forest Reserve to National Park

Appendix VIII: Applied recommendations for systematic elephant surveying, mitigation of elephant impact, and mitigation of human impact on Mount Kenya

Systematic elephant surveying

Monitoring of elephant density and distribution is key information for management. To allow results from line transect dung counts to be used to identify changes in elephant numbers on MK, theory need to be applied in the field with rigorously, and be repeated systematically on an annual or bi-annual basis. The protocol followed for monitoring MK elephants should be adapted for use by less experienced personnel, who will most likely be in charge of repeated monitoring. On MK, it was found much easier to accurately measure transects and to walk very straight transects along very short (200m) transects intersected by 1,000m routes of least resistance, than along long (4,000m) transects. Density estimates derived from the 200m transects were more robust (Chapter 3). To facilitate repeatable systematic annual or bi-annual elephant counts on MK, the following guidelines may be of use:

- Monitoring should be done at the end of a respective season because dung piles remain visible for about 112 days on MK. Therefore, dung found at the end of each season will be representative of elephant distribution of the previous season;
- To help organise logistics and ensure repeatability, sample independence, and unbiased allocation of transects, I recommended that 5 or 6 roughly repeatable trajects should be established that run from the moorlands to the lower slopes. Transects should cross all altitudes, vegetation types, and valleys, and rivers and roads should be crossed perpendicular, to avoid unconscious biased sampling. They could for example run from Old Moses to the NaroMoru KWS Head Quarters; from the Police post above the MET station to the Mountain Lodge; from the moorlands above Castle Lodge to Thambana; from the moorlands above Thambana or alternatively from Rutundu to Chogoria forest post; from Chogoria Gate to Meru; and, from Meru to Marania.
- Along each traject, a very straight 200m transects should be walked, intersected by routes of least resistance of 500m or 1,000m. The total number of surveyed transects should be proportional to the occurrence of strata through which they run. For MK, some 120 straight transects of 200m suffice to establish elephant

density accurately, I recommend that 10 are located in the moorlands, 40 in mixed forest, 15 in monotypic bamboo, 20 in bamboo-podo, 12 in clearings, 13 in plantations, and 10 in degraded land. Furthermore, some 15 of 120 transects should lie above 3000m, 20 between 3000 - 2750m, 25 between 2750 - 2500m, 30 between 2500 - 2250m, and 30 below 2250m.

- The 200m transects must dissect all obstacles that are in the way, unless it can be said with 100% certainty that no dung will be found, such as when transects dissect a large river. Care should be taken that the transect location is not biased towards flat terrain, for example, by adopting the criteria from the onset that all transects follow a compass bearing that runs perpendicular to the nearest river;
- Along the transects, distance along the transect and perpendicular distance from dung to the centre-line should be recorded for all dung piles encountered. Vegetation type and slope should be recorded every 50m, to allow samples of each 50m, 100m, or 200m transect segments to be used for analysis. However, no dung should be recorded along the routes of least resistance.
- The entire traject should be tracked by GPS at 10 minute intervals or less, and GPS waypoints should be taken for all encountered streams, rivers, roads, and human impact sites, along both transects and routes of least resistance. Because canopy obstructs satellite reception, GPSs should track as many satellites as possible before entering forest and whenever a clearing is encountered. A Garmin 12XL GPS model performs well under canopy.
- Problems with data analysis could be resolved by training one or two people at the KWS Head Quarters in Nairobi to properly use distance analysis, and have them analyse all dung counts for Kenya.
- Until then, those analysing their own data should know that outlier transects should be omitted from analysis, and that analysis should be done per vegetation strata (see Table 3.7; Chapter 3).
- Fusing pdist measurements up to 1m to smooth skewed data is better than applying the negative exponential curve to data for analysis, which can produce very erroneous results and should not be used. The hazard-rate curve produced the best results for the MK dung count analysis in this study. Truncating data at pdist 3.5m may reduce variance induced by poor visibility.

- The dung decay rate value of 0.009 should be used to count dung to elephant density for MK. This value excludes dung of age-class E (flat, lost form, > 75% deteriorated), meaning that dung of this age-class should also not be counted along transects in the field.

Other data such as slope, ground cover, vegetation type, and the location of human impacted sites, rivers and streams can be collected when encountered, to include in multivariate analysis that seek to explain the distribution of dung pile densities. The step of integrating explanatory models into GIS to produce predicted elephant distribution maps is shown in Chapter 4. This step was made possible because a copy of all digital layers of potential explanatory parameters that were made in this thesis, were provided to Mr C Lambrechts of UNEP and are available on request. These layers include mean dry and wet season rainfall, altitude, slope, vegetation cover, roads, rivers, streams, and plantations.

Mitigation of elephant impact

Elephant damage reports at KWS stations and outposts were found to poorly reflect the real extent of elephant crop damage, although they can be used to distinguish the more from less affected areas, which typically correspond to the areas that lie in close proximity to heavily used elephant habitats like salt-licks and foraging routes. Currently, elephant crop raiding in those areas is addressed by measures that give immediate results, such as control shooting and construction of electric fences. However, fences on MK shift the problem to neighbouring communities and shooting elephants may lead to population imbalances. Fences should drive or discourage access but not alter important elephant ranging behaviour (Whitehouse and Schoeman, 2003; Thouless and Sakwa, 1995) nor migration (Osborn and Parker, 2003). The elephant distribution maps that were developed in Chapter 4 and the maps illustrating elephant routes in Chapter 5 help distinguish the more from less elephant impact-vulnerable areas per season. These maps and associated information could be used to:

- Adapt planting and harvesting periods according to spatio-temporal patterns of elephant distribution near the forest boundary;

- Avoid that fences are constructed in areas where this could lead to fragmentation of elephant ranges and local over-crowding of elephants;
- Avoid fences that block important elephant movements, which will likely lead to the need for high fence maintenance, and shift elephant pressure to neighbouring communities;
- Locate and protect the MK-NGA corridor area to avoid MK and its elephants becoming irreversibly isolated by expanding settlement;
- Use the knowledge that elephants are seasonally attracted to salts and that they avoid steep slopes, to encourage use of elephant routes away from farmland (e.g. via temporarily adding salts, or making crossing of valleys away from farmland easier by smoothing or digging large steps in valley walls).

It is highly recommended that the MK-NGA corridor area is protected, and the use of this migration route by elephants is encouraged, to remove the growing pressure from elephants on the surrounding people and natural resources. The corridor area should be provided with some form of protection status and be potentially fenced to protect it from encroachment. This very important matter is of great urgency because settlement is rapidly expanding in the corridor. However, realisation of this can only happen by impending donor interests, perhaps in collaboration with the Lewa Conservancy, because the new Kenya Government does not consider the corridor a priority issue.

Mitigation of human impact and management

People play by the dominant role in protecting the environment as decision makers, as well as causing the loss of natural environments through habitat fragmentation, and over-exploitation of remaining fragments. For example, vegetation cover can change dramatically through land loss or through restoration of degraded land. Illegal human impact could get worse or better, disappear or change in location. Also additional human factors that were not significant in the 1999 analysis, such as location of fences, could become significant. The only way to rapidly notice and stop human abuse of the environment is through systematic monitoring of the status of the environment, and of associated problem mitigation projects. In practice this could be done by:

- Annual or bi-annual aerial sample surveys for time-series analysis of the status of MK tree cover and to locate the main areas of damage;
- Annual or bi-annual comparison of LANDSAT satellite images of MK, taken at the same time of year, to identify changes in land-cover through encroachment;
- Overlaying plantations onto the satellite images to identify changes in plantation status and to locate NRC that exceeds its allowed period of cultivation;
- Comparison of measurements of rainfall and water debits of the main rivers and some important smaller rivers on the mountain, and at different distances from the mountain, during the dry and wet seasons;
- Comparison of tree-cover and the expansion of agriculture outside the Reserve, especially of the large irrigated horticultural farms, from LANDSAT satellite images, and comparison of these changes with water debits of the main rivers;
- Assigning a quantitative score to the success of ongoing agroforestry projects by an institution with expertise in these areas like ICRAF;
- Assigning a quantitative score to the state of plantations for comparison by an institution with expertise in these matters like KEFRI;
- Comparison of KWS data on the time, location, amplitude, and frequency of arrests and confiscation of goods from illegal practices, such as snares from de-snaring patrols, intercepted skins, lorries, timber, weapons, poachers, loggers, and so on;
- Comparison of the annual income and expenditure by MK NGO's and governing institutions on specific conservation efforts such as fencing, afforestation, improved land-tenure, water abstraction systems, law-enforcement, transport, communication, and maintenance;

Systematic monitoring and co-ordination does not guarantee conservation on its own, but independent assessments can highlight actions that need to be implemented to help ensure more effective conservation. The KWS management plan has proposed that everything should be run by KWS, thereby over-estimating KWS' capacity and expertise. Instead, the success of implementation of conservation action on MK should lie in co-ordinating and combining the expertise of institutions, NGOs, and CBOs, and ensuring the principles of community-based conservation, benefit-sharing, and in institutional capacity building are encompassed within the actions taken. The principles of adaptive management should ensure that initiatives that have shown successful are retained, others should be stopped, others adapted, and new ones created.

Law-enforcement by the KWS has shown to be very efficient since July 2000. However, capacity could still be improved by increasing the KWS staff complement to ensure a more permanent field presence. Implementation of the proposed Forestry Bill 2000 could tackle the underlying cause of FD institutional inefficiency and corruption. The Bill promotes elimination of NRC in favour of alternative low-cost, community-based agroforestry initiatives, the possibility of privatising plantations, and promoting the idea that the FD becomes a parastatal like the KWS. Legal logging and NRC should be abandoned on MK. Two-strand fencing should be promoted over full-strand fences because they are moveable, and fencing should be avoided in areas where this can lead to irreversible loss of wildlife migration and important ranging behaviour. Successful ongoing on-farm agro-forestry projects, the introduction of energy friendly stoves around MK boarding schools, and other successful projects that remove pressure from MK should be strongly promoted and supported. A potential new project could include the establishment of woodlots for legal charcoal production outside the National Reserve to undercut the illegal prices, managed perhaps by local specialized NGOs like Chardust and Kengen.