A spatial analysis of human-elephant conflict in the Tsavo ecosystem, Kenya

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A Report to the African Elephant Specialist Group,
Human-Elephant Conflict Task Force, of IUCN. Gland, Switzerland

January 2000

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Acknowledgements

This report is based on a study of human-elephant conflict in areas adjacent to the Tsavo National Parks in Kenya. This original study was funded by Care for the Wild and we are very grateful for their support and help. We would also like to thank the Director of the Kenya Wildlife Service (KWS) and the KWS GIS staff in Nairobi for their help and advice.

In Tsavo we would like to thank Mr Kio (Assistant Director Tsavo), Mr J. Kagwi (Park Warden TsE) and J. Isiche (Park Warden TsW) for their support. Mr D. Woodley, the Tsavo Parks pilot, and staff of the KWS Community Wildlife Service all provided valuable information on human-elephant conflict incidents and elephant movements within the Tsavo ecosystem. J. Kin'goo, S. Maina, J. Mnjala and S. Muthiani, all staff of the Tsavo Research Station, assisted in many aspects of the fieldwork, and persevered through many hot days and dangerous situations. Dr Barbara McKnight of the Tsavo Elephant Project was a source of great encouragement and support and helped in many ways during the fieldwork.

We recognise the valuable advice and comments given by staff and students of the Durrell Institute of Conservation & Ecology, especially those by Nigel Leader-Williams, Annette Huggins and Matt Linkie. We would also like to thank Mike Baltzer, Richard Hoare and Lisa Naughton for their advice and for providing us with relevant literature. Finally, we would like to thank Holly Dublin, Martina Hoft, Rob Rose, Russell Taylor and Chris Thouless for the comments and advice.

Many different people and organisations helped in different ways during the fieldwork and completion of this report. To all we say thank you.

List of acronyms

AED	African Elephant Database
AfESG	African Elephant Specialist Group
AVHRR	Advanced Very High Resolution Radiometer
CWS	Community Wildlife Service
DEM	Digital Elevation Model
DRSRS	Department of Remote Sensing and Resource Surveys
GIS	Geographical Information System
GPS	Global Positioning System
HETF	Human-Elephant Task Force
KWS	Kenya Wildlife Service
NP	National Park
NR	National Reserve
PA	Protected Area
PAC	Problem Animal Control
SPOT	Système Pour L'Observation de la Terre
TsE	Tsavo East
TsW	Tsavo West
WCMD	Wildlife Conservation and Management Department

Executive Summary

A. Human-elephant conflict and GISs

1) Conflict between humans and African elephants (*Loxodonta africana*) occurs wherever the two species co-exist, especially in the interface between the elephants' range and agricultural land. Most human-elephant conflict (HEC) incidents involve crop-raiding animals that consume or destroy food crops and injure or kill those people trying to protect their fields.

2) As well as directly affecting some of Africa's poorest people, HEC influences the attitudes of people living nearby. These communities often resent the presence of elephants and the conservation authorities and protected areas (PAs) that help to maintain elephant numbers. This can lead to the failure of elephant and biodiversity conservation measures that rely on the support of local people.

3) The Human-Elephant Conflict Taskforce (HETF) was formed in 1997 with the aim of understanding HEC and identifying suitable mitigation measures. Part of this process involves collecting standardised data to quantify levels of HEC and assessing the impact of any mitigation strategies. In addition, the HETF aim to analyse these HEC data to identify which factors determine its occurrence.

4) HEC is a spatial phenomenon and so it is important to investigate the effects of spatially explicit factors on its distribution. Therefore, the HETF have recognised that geographical information systems (GISs) should play an important role in the analysis of HEC. These systems allow the integration and manipulation of a range of spatial data and can be used to predict the effects of HEC mitigation measures.

5) This report describes a GIS-based analysis of HEC data from a region in East Africa. It was completed at the request of the HETF to act as a case study for understanding HEC in savanna ecosystems. In addition, this report aims to comment on the applicability of the proposed HETF database for this type of analysis and to develop a standardised methodology for further research.

B. Human-elephant conflict in Taita Taveta district

1) The Tsavo ecosystem, which is an area of approximately 43 000 km^2 in the south east of Kenya, had an estimated elephant population of 8 100 in 1999. This population had increased dramatically during the 1950s and 60s but a period of drought, followed by extensive poaching, reduced this by 85%, leaving 5 600 elephants in 1988. The control of this poaching has since led to a steady increase in elephant numbers.

2) Taita Taveta district is an area of 5 000 km^2 that makes up part of the Tsavo ecosystem. It is surrounded on three sides by Tsavo East and West National Parks (NPs) and shares 80% of its perimeter with these protected areas (PAs). In 1997 the estimated human population in the ecosystem was 393 250 and the annual growth rate was 3.8%.

3) The recent increase in both the human and elephant populations has led to a similar increase in HEC. During a three year period from July 1994 to June 1997 there were 1448 such incidents in Taita Taveta district, most of which involved crop-raiding elephants.

4) The majority of the crop-raiding elephants travelled in family groups of 6 or more which were often accompanied by mature bulls. Similar studies from Zimbabwe and India found that most crop-raiding elephants were lone bulls and so the factors that determine spatial patterns of HEC at these sites may differ from those of Taita Taveta.

5) In 1996 an electric fence was built to reduce HEC in Taita Taveta at an estimated cost of US $324 000. The fence is 30 km long and is situated along the PA boundary in the north-east of the district, where HEC was most prevalent.

C. The factors that determine HEC in the Taita Taveta

1) Three years of incident data were used to find the factors that determined the spatial pattern of HEC in Taita Taveta. This analysis involved dividing Taita Taveta into 31 study blocks that ranged in size from 8.5 km^2 to 426 km^2. A GIS was used to calculate the HEC incident density and spatial characteristics of each study block and the data were analysed using general linear models.

2) The efficacy of the fence was investigated by using a paired t-test to determine whether the HEC densities in the study blocks were significantly different before and after its construction. In addition, a linear regression model was used to test whether those blocks that were most separated from the NPs by the fence experienced a corresponding reduction in HEC levels.

3) HEC incident density in the study blocks was significantly and negatively related to their mean distance to permanent water, mean elevation and the perimeter that they shared with the NPs. The same three factors were significant when looking at annual patterns of HEC, as well as patterns recorded in the low HEC season, the high HEC season (when crops were ripe), the dry season and the rainy season.

4) HEC levels were significantly lower in those study blocks that bordered the NPs. This suggests that local people and the Kenya Wildlife Service (KWS) are using strategies that are successfully mitigating HEC. KWS tend to focus their problem animal control in these areas and the residents have stopped growing crop types that particularly attract elephants.

5) The significance of distance to permanent water, even during the rainy season, was probably partly due to its correlation with human, crop and elephant density. However, the significance of this factor in all five models, despite large fluctuations in food and water availability, suggests that another, unmeasured factor, may have been responsible for determining the observed spatial patterns.

6) One unmeasured factor could be distance from elephant migration routes as there is a similarity between their position (as identified by previous researchers) and the pattern of HEC. These migration routes tend to avoid steep slopes and higher ground which explains the significance of elevation (which was correlated with slope) in the regression models. It appears that elephants follow these routes throughout the year and crop-raid in neighbouring areas whenever food is available.

7) There was no significant difference in HEC density in the six months before and after the construction of the electric fence. Total levels of HEC were unaffected, as were the HEC densities in those study blocks that were separated from the NPs by the fence.

8) Depending on the interpretation of these results, HEC could be mitigated in Taita Taveta either by manipulating the position of artificial water-points or by allowing elephants to follow their traditional migration routes whilst preventing their access to crops. Further

research is needed to identify which of these interpretations is more relevant and so ensure the success of any mitigation measures.

D. Recommendations for the analysis of HEC data

1) The arbitrary delineation of HEC zone boundaries can have a dramatic effect on HEC density calculations. Therefore, it is important to set these boundaries using a standardised methodology to allow comparisons between HEC zones. One recommended method uses a GIS to divide each study area into a series of grid squares and defines the HEC zone as those squares where HEC had occurred in the previous five years.

2) HEC data should be analysed at two different spatial scales. The first should be at the continental or regional scale and would treat each HEC zone as one data point. This type of analysis would investigate the influence of funding and mitigation strategies on HEC.

3) The second type of analysis should be at the HEC zone scale and would investigate factors that determine patterns of HEC within a zone. Any analysis at this scale should avoid spatial autocorrelation by using a GIS to divide the zone up into a series of blocks and grouping the HEC incident data accordingly. It is suggested that this type of analysis should adopt the grid system used to define the HEC zone boundaries.

4) The co-ordinates of each HEC incident should be recorded using a GPS unit so that these data can be grouped at a later data for analysis at the relevant scale. This could either be done as soon as the incident was recorded or at a later date by someone who would relocate the incident site by following written instructions. This second approach would allow one trained person to visit all the incident sites and so limit the number of GPS units needed to collect this information.

5) The present HETF conflict zone attribute data sheets should be amended so that data are collected for each grid square used in this analysis. Data should also be recorded on the presence and length of any electric fencing in each grid square, the percentage of the square that is cultivated and the mean distance of the square from water and PAs.

6) The HETF should use Landsat 7 TM satellite imagery as a consistent source of the spatial data that is needed for the analysis of HEC. These images would need to be processed by someone with remote sensing skills, working in conjunction with local experts. The resultant GIS coverages should be stored and documented centrally to avoid their loss or unnecessary duplication.

7) If comparisons are to be made between HEC zones then it is important that the data should be analysed using the same set of factors collected at the same scale. In addition, it is important to use the same statistical tests and it is suggested that general linear models should be used in preference. However, this test is not suitable for analysing data from HEC zones where HEC has not taken place in many of the grid squares and in this case logistic regression should be used instead.

8) Experience from Taita Taveta shows that a great deal of information on traditional elephant migration routes can be obtained by consulting with long-term local residents. This information could be mapped by asking people to identify portions of the route and recording the position with a GPS unit. The proposed routes could be validated in the field and this information would be invaluable when planning the position of fences and other HEC mitigation measures.

Chapter 1: An introduction to human-elephant conflict in Africa

1.1 General introduction

The African elephant (*Loxodonta africana*) is the largest living land mammal, weighing several tonnes. It is a relatively unspecialised herbivore that exhibits a diversity of feeding behaviour under different environmental conditions (Laws, 1969a; Laws, 1970; Wyatt & Eltringham, 1974; Barnes, 1982; Eltringham & Malpas, 1980; Ruggiero & Fay, 1994). This species is mainly found in forest, woodland or bushed grassland habitats and it can play a key role in the structuring of these natural vegetation communities, which in turn affects the biodiversity of these habitats (Laws, 1970; Laws *et al*, 1975; Western, 1989; Dublin *et al*, 1997; Cumming *et al*, 1997).

African elephants range over a large area to obtain food and this increasingly brings them into contact with the people who live in neighbouring areas. The resultant interactions are often negative and the people involved tend to view elephants as a threat to their lives and livelihoods. Many of these people want elephant numbers reduced and often resent the protected areas (PAs) that can act as refuges for the species. Therefore, human-elephant conflict (HEC) mitigation is seen as important both for elephant conservation and for improving the acceptance of PAs by local people.

This report focuses on HEC in the Taita Taveta District in southern Kenya and uses a geographical information system (GIS) to analyse the conflict data that has been collected there. This chapter provides an introduction to HEC in Africa and begins by describing population trends in this species. It goes on to review studies on conflict throughout the continent and to describe the recently established Human-Elephant Taskforce (HETF) and the database they have developed to record and analyse conflict data. The chapter finishes by describing the history of conflict in Kenya, where this research took place, and by listing the aims of this report and its overall structure.

1.1.1 Definition of HEC

HEC has been defined as *"any and all disagreements or contentions relating to destruction, loss of life or property, and interference with rights of individuals or groups that are attributable directly or indirectly to elephants" (*Kenya Wildlife Service, 1994).

Numerous factors may lead to HEC but the most important tend to be:

- Uncontrolled elephant movements and migrations, leading to the invasion of human settlement areas, resulting in insecurity and the curtailment of human freedom of movement.
- Loss and damage of agricultural crops.
- Killing or injury of people by elephants.
- Competition for space with human communities.
- Competition with livestock for pasture and water.

- Loss of livestock killed by elephants.
- Destruction of infrastructure (e.g. fences, water supply systems, etc.).
- Damage of natural forests, plantations and seedlings.

(***Kenya Wildlife Service, 1994***)

The importance of these factors may vary in different areas and among different stakeholders but the most publicised cases involve human death or injury and crop damage. Further conflict may occur between conservation authorities and the other stakeholders because of issues of compensation and HEC mitigation.

1.2 Continental trends in African elephant numbers

The African elephant once inhabited most of the African continent, from the Mediterranean coast down to its southern tip (Cumming *et al*, 1990). Today the range of the species consists of a series of scattered, fragmented populations, all of which are found south of the Sahara Desert (Said *et al*, 1995) (Figure 1-1).

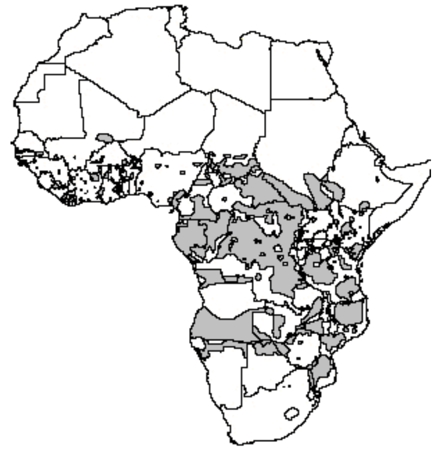

Figure 1-1: The distribution of the African elephant

Several different explanations have been given for this continental decline. Some argue that ivory hunters have affected the population since the 19th century (Milner-Gulland & Beddington, 1993). However, others suggest that the recent decline has often been due to the loss of essential habitats, as well as a result of complex historical processes between humans and elephants (Parker & Graham, 1989a; Barnes *et al*, 1991; Child, 1995).

These authors argue that elephant numbers, like those of species that are unaffected by international trade, have declined in areas of increasing human density. This is supported by results from Zimbabwe where it was found that humans and elephants co-existed until human density reached a certain threshold (Hoare & du Toit, 1999).

Despite this general reduction in elephant numbers and range, some populations on the continent have become locally over-abundant. Conservation biologists are therefore faced with the dilemma of managing a species in urgent need of protection over most of its range, yet which in certain areas is in need of population control or reduction (Caughley *et al*, 1990).

1.3 A review of HEC in Africa

Human-elephant conflict tends to occur whenever people farm in areas that are within the range of elephants. Therefore, it is likely that such incidents occurred well before they were first recorded by colonial officials. Laws *et al* (1975) argue that farmers had to form large, well-defended villages to reduce crop loss and so elephants probably had a dramatic effect on the development of arable farming in pre-colonial Africa (Parker & Graham, 1989). This relationship began to change with the arrival of Europeans who developed the existing international trade routes and introduced colonial government. Elephants were highly valued for their ivory and so there was an added incentive to shoot any individuals that were seen as a threat to human life or property (Hanks, 1979; Eltringham, 1990).

HEC continued to be reported throughout the 20^{th} century, despite the great losses in elephant numbers and range (Hoare, 1999). However, it was only recently that it was identified as a major topic in elephant conservation (Kangwana, 1995; Dublin *et al*, 1997). There are probably several reasons for this shift in focus:

1) It is increasingly recognised that the success of elephant conservation programmes depends on the attitudes of people living in neighbouring areas. Most local people resent the presence of elephants because of HEC and only tolerate them if they see the animals as having some financial value.

2) It is also recognised that any phenomenon, such as HEC, that leads to loss of human life and increased levels of poverty should be mitigated.

3) There has been a rise in levels of HEC in several high profile locations, especially in East Africa. This is because poaching, which decimated the local elephant populations in the 1980s, has been controlled and elephant numbers have increased. In addition, elephants that once avoided human settlements when poaching was prevalent are now returning to these areas to crop-raid.

4) There has also been a large increase in the number of people living around PAs and other elephant refuges. PAs in particular were often situated on land that had little agricultural value (Leader-Williams *et al*, 1990) and so in the past few people lived or farmed nearby. Increasing human population pressure has forced many people to move into these areas where they are much more likely to encounter elephants.

There has been an increase in the reported incidence of HEC in the last decade (Kangwana, 1995). This is probably partly due to the new interest in HEC, as well as an increase in the human-elephant interface that the agricultural expansion has produced. HEC incidents have been reported throughout the elephant range (Hillman-Smith *et al*, 1995; Lahm, 1996; Tchamba, 1995) and this issue is seen as just as important for the conservation of forest elephants (Barnes, 1996). However, until recently most of these reports were descriptive and there is little evidence that HEC has increased in severity, despite the increase in areas that are affected (Hoare, 1999).

1.4 The Human-Elephant Taskforce

1.4.1 Background

In January 1997, the African Elephant Specialist Group (AfESG) initiative on HEC was launched with the first formal meeting of the Human-Elephant Conflict Task Force (HETF). The Task Force set a work programme that began with a multi-regional assessment of sites experiencing HEC. The next objectives were to carry out the following:

- To establish the factors involved in HEC in different biogeographical zones.
- To establish a central information point on HEC, containing a library and standardised data from around the continent.
- To identify the sites where conflict is most likely to become a problem in future.
- To determine the prospects for mediation and mitigation, and carry out field trials in selected sites.

1.4.2 The HETF data protocol

The HETF decided it would be highly desirable to supplement the existing African Elephant

Database (AED) with information on HEC. The protocol for collecting these data is still to be finalised but it will probably consist of three parts (for further details see Annex 2). The first part would describe each individual HEC incident, where it took place and how much damage was caused. This information would be collected in the field by enumerators and collated by local researchers who would base recommendations on them (Table 1-1).

Table 1-1: HETF proposed attributes to describe annual HEC incidents

Elephant damage incidents		
• Total elephant raids	• Food crop damage	• Water supply damage
• Mean raiding group size	• Cash crop damage	• Human injuries
• Raiding group type	• Food store damage	• Human deaths

The other two parts would describe each HEC zone and the elephant populations involved and this information would be collected and recorded by local researchers. Further data on the conflict zone may be supplied by GIS specialists and this information would also be added to the database. The attributes that would be collected are listed below (Table 1-2 & 1-3).

Table 1-2: HETF proposed attributes to describe HEC zone environmental characteristics

HEC zone environmental characteristics		
• Zone name	• Agricultural landuse	• Incursion distance (average)
• Location	• Other commercial activities	• Incursion distance (max.)
• Year of survey	• Habitat	• Conflict season
• Conflict duration	• Water availability	• Interventions - human
• Human population density	• Annual rainfall	• Interventions - elephant
• Human population trend	• Interface type	• Interventions - environment
• Land tenure system	• Interface length	• Other pest species

Table 1-3: HETF proposed attributes to describe HEC zone elephant population characteristics

Elephant population characteristics		
• Elephant population	• Area	• Conservation status
• Population estimate	• Density	• No. of unnatural deaths

1.5 HEC in Kenya

1.5.1 Elephant conservation in Kenya

Kenya has an area of 584 000 km^2, of which 7.5 % has some type of protected area status (Figure 1-2). This protection is either in the form of National Parks (NPs), where human interests are limited to tourism, or National Reserves (NRs) where limited human activity is allowed. NPs are owned by the central government and managed by the Kenya Wildlife Service (KWS), while NRs are owned and managed by local district councils. Kenya has 21 terrestrial NPs and 23 terrestrial NRs. Other areas are currently in the process of being designated as NPs, which will increase the proportion of land under wildlife conservation to about 8% (Kenya Wildlife Service, 1990).

Figure 1-2: The location of Kenya in Africa

KWS is the state organisation charged with conserving and managing the country's wildlife resources. As well as managing all of the NPs, it is legally responsible for wildlife on all NRs and private land. This is of particular importance because it is estimated that 70% of Kenya's large mammal species may be found on private and trust lands (Kenya Wildlife Service, 1994). KWS has focussed particular attention on the conservation of the country's elephant population and has produced several relevant action plans and policies. These include law enforcement to minimise poaching, establishment of an elephant population dynamics database, investigating HEC issues throughout the country and implementing appropriate mitigation measures (Kenya Wildlife Service, 1991a & b).

1.5.2 Human-wildlife conflict in Kenya

A survey of human-wildlife conflict conducted across the country in 1994 identified baboons and monkeys as the most important wildlife pest (Kenya Wildlife Service, 1994). However, elephants are widely considered as the most serious threat because they can destroy crops and property, as well as kill and injure people. In addition, these incidents often affect those people who can least afford the resultant loss of income and labour. HEC in Kenya is a problem wherever elephants are found but it is most intense in agricultural areas, particularly when cropland borders NPs and NRs (Kiiru, 1995a & b) (Figure 1-3).

Between January 1989 and June 1994, wild animals in Kenya killed or injured 448 people, of which elephants were responsible for 173 (Kenya Wildlife Service, 1994). A common view advanced by the people interviewed during the survey was that elephants, secure in their protected status, had increased in number and lost their fear of humans. They had, in turn, become bold enough to invade homesteads and break into food stores and huts. A significant proportion of respondents felt that the Government valued elephants more than people and was reluctant to kill problem elephants (Kenya Wildlife Service, 1994).

1.5.3 Management of HEC in Kenya

Before 1992 the issue of HEC was not an important concern of the Government of Kenya or KWS. To a large extent, authorities managed human-wildlife conflict by avoidance and force. It was generally perceived by affected communities that the former Wildlife Conservation and Management Department (WCMD) used provisions of the law to protect animals but turned to slow and inefficient administrative protocol, inaction and delaying tactics when processing compensation for death, injury or damage to property. This resulted in great discontent with the wildlife authority (Kenya Wildlife Service, 1994).

KWS has responded to these criticisms by introducing several policies to understand and mitigate HEC in Kenya. Mitigation measures have included constructing electric fences and shooting or translocating problem animals. In addition, there has been an increase in the recording of HEC incidents so that long-term patterns can be established and the efficacy of any HEC mitigation strategies can be assessed.

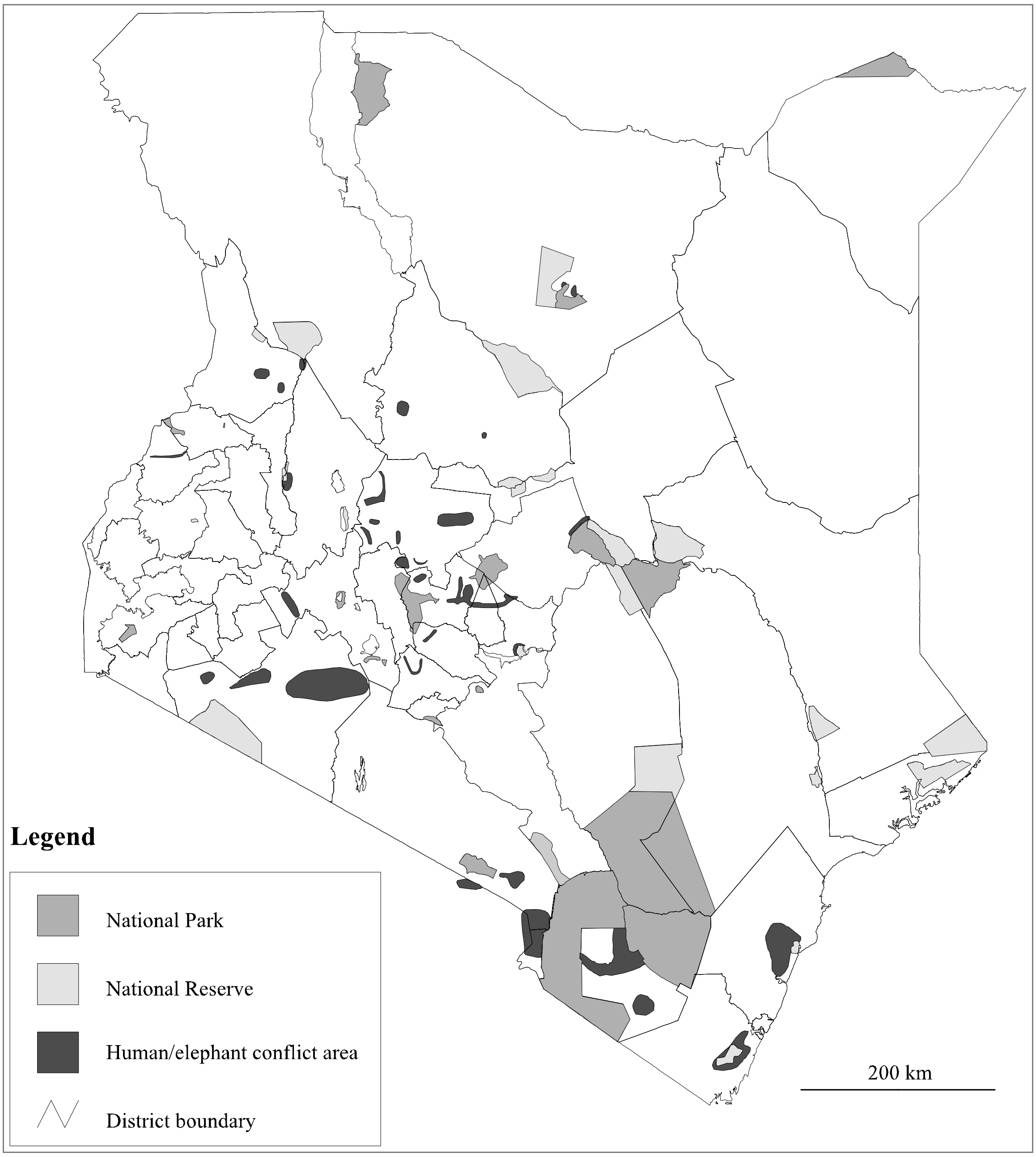

Figure 1-3: Centres of HEC in Kenya

1.6 Objectives

HEC is a spatial phenomenon that depends on the position of the resources that bring humans and elephants into contact and so, any analysis of HEC data will benefit from a spatially explicit approach. Arguably the best way to carry out this type of analysis is to use a GIS which can be used to find the spatial characteristics of any phenomenon of interest. Therefore, this report has the following objectives:

- To review the available literature on GISs and predictive modelling and to identify techniques which may be of relevance to the study of HEC.

- To conduct an analysis of the available data from areas that neighbour the Tsavo National Parks in Kenya that integrates spatial, temporal and other factors as a case study for savanna ecosystems.

- To identify the factors which determined this conflict in Tsavo and to assess the effects of present mitigation measures.

- To comment on the suitability of the HETF data collection protocol in the light of this analysis.

1.7 Report structure

This report consists of seven chapters, the first of which contains the introductory information described above. The second consists of a brief introduction to GISs and a review of the different statistical methods that have been used in the conservation and elephant literature. This is followed by a chapter that describes the study site in Kenya and gives details of HEC in that region. The next two chapters describe the methods used to analyse the available data and the results of this analysis. The penultimate chapter discusses these results and suggests how they can be applied to mitigate HEC in this region. The final chapter gives recommendations on how the proposed HETF data protocol could be modified to allow the spatial analysis of HEC data throughout Africa.

Chapter 2: GISs and conservation biology

2.1 An introduction to GIS

Geographical information systems have been defined as '*a set of computer programs, together with associated hardware, that are designed to store, manipulate and display data that are recorded according to geographic location*' (Marble, 1990). The data that they contain can be thought of as a series of digital maps (known as *coverages*) which describe different information about the same study area. This chapter will review the basic principles of GISs and how they have been used by conservation biologists for the predictive modelling of spatial phenomena. It will go on to discuss how GISs have been used in elephant conservation projects and to identify possible future uses.

2.2 A comparison of vector and raster data models

Spatial data are commonly represented in a GIS using one of two geographical data models. One of these is the *vector* data model, which represents space as a series of point, line or polygon units (Figure 2-1). The choice of how to represent a spatial feature depends on the resolution of the data stored in the GIS. For example, a town may be represented by a point entity at a continental level but as a polygon entity at a regional level. Some GIS software also represents spatial entities as arcs, which are lines that have defined beginnings and ends. Arcs are particularly useful when representing lines that have a definite direction.

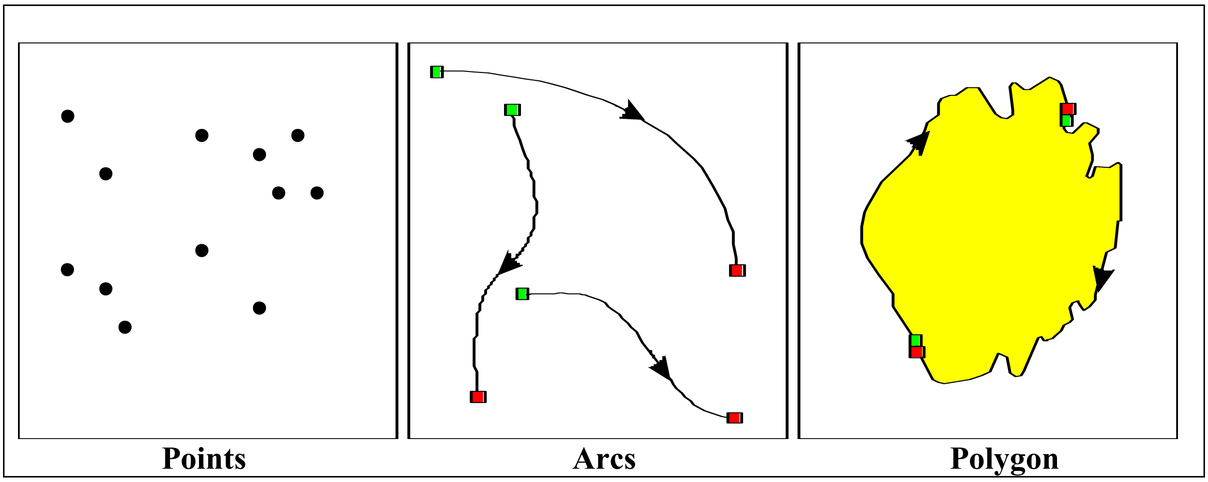

Figure 2-1: The components of the vector data model.

An alternative to this vector system is the *raster* data model that represents space as a grid of equally sized squares (Figure 2-2). Each square, or *pixel*, in the grid has a numeric value that may either indicate its membership to a particular class or describe the value of the measured phenomena at that point. For example, a pixel with a value of 2 may indicate that it contains the predefined vegetation type 2 or that the pixel is 2 km away from a feature of interest.

Commercially available GIS software packages tend to specialise in one of these two data models. Each system has its benefits and it is worth identifying which is best suited for a project before choosing the software to use. In general, vector models are better at representing entities with well-defined boundaries, such as countries, houses or roads. Raster models are better at representing a continuous surface, such as a coverage showing vegetation biomass or elevation. A vector model can only represent these surfaces by dividing them up into polygons that share a range of values; for example, areas that share the same range of elevation values are defined by contour lines.

Vector files tend to have a much more compact data structure as they only contain information about the entities of interest. A raster file contains data on each pixel in the grid, even if most of those pixels represent nothing. The amount of computer memory used by a raster file will also obviously depend on the size of each pixel. Small pixels are much more accurate at representing spatial phenomena (Figure 2-2 B & C). This means that pixel size tends to be a compromise between increasing accuracy and decreasing file size.

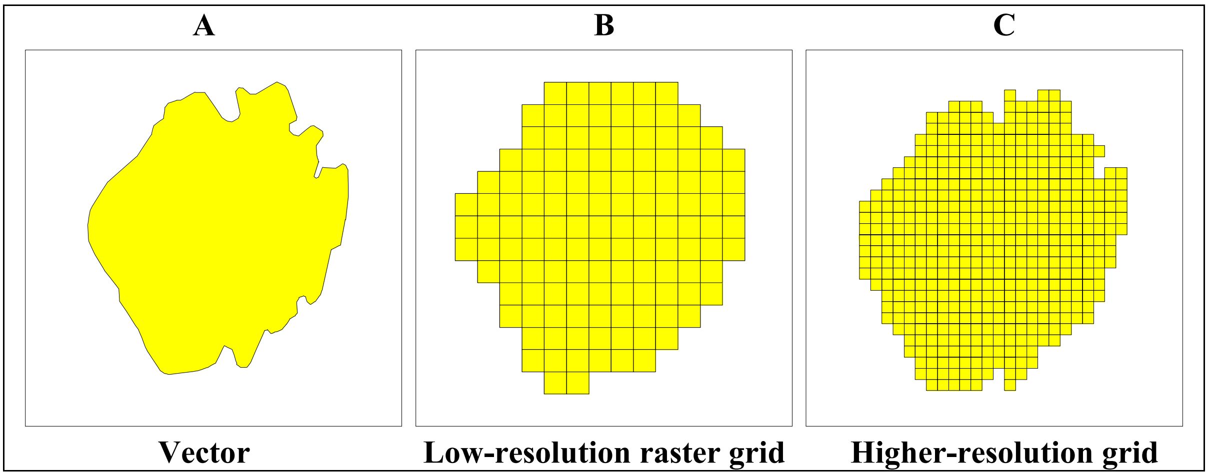

Figure 2-2: A comparison of how vector and raster data models represent a polygon.

2.3 GISs, quality control and error propagation

It is impossible to produce error free spatial data. One unavoidable source comes from the vector and raster data models themselves, which cannot perfectly represent the phenomena of interest. These models also assume that each raster grid cell and vector polygon is a homogenous unit and this is rarely the case (Fisher, 1997). These errors are compounded when coverages that use one data model are converted to another. This is particularly obvious when converting raster data into vectors as the resultant polygons will retain the pixellated appearance of the former (Congalton, 1997).

Other errors can occur at various stages during the process of producing GIS coverages (Burrough & McDonnell, 1998). Some of the most obvious are a result of errors in measuring geographical location, which depends on the accuracy of the instruments used and the surveying skills of the people involved. Global positioning systems (GPS) units are now commonly used to collect spatial data but without mitigating measures their accuracy can be less than 100 metres. Some aspects of collecting data, such as vegetation mapping, may involve mis-classifying objects and this is particularly likely when relying on remotely sensed data such as aerial photographs or satellite imagery.

Converting paper maps into digital data is also a large source of errors. The two main methods that are used to create this digital data are digitising and scanning and both need extensive checking and correcting to produce a viable product. The quality of the data also depends on the age and the resolution of the paper maps that were used. In addition, coverages that describe a continuous surface, such as rainfall, are often based on an extrapolation from a series of point samples. The accuracy of this extrapolation will obviously depend on the number of sampling points, the distance between them and the model that was used.

Despite their ubiquity, errors in spatial data are often concealed because they are associated with poor quality. In addition, GIS products are often judged by their visual appearance and this is rarely dependent on their accuracy. Therefore, a different approach is needed if GIS coverages are to serve any useful purpose. Firstly, it is important to reduce errors by using the best data sources and trained personnel to collect and process this information. However, availability of good quality data is often limited and researchers may have to compromise (Estes & Mooneyhan, 1994). This makes it vital to document the source of all of the spatial data and the methods used to process them. The use of methods that produce accuracy estimates should also be actively encouraged.

2.4 GISs and predictive modelling

GISs were initially developed by geographers in the 1960s but this technology has only been widely adopted by natural scientists in the last 15 years (Burrough, 1986). However, its use by conservation biologists is increasing rapidly, despite a perceived shortage of people with the necessary skills (Preston & Siegfried, 1995). This is partly because conservation biology is often concerned with the ecology of threatened species and ecosystems and most ecological relationships have a spatial element (Haslett, 1990). In addition, conservation managers often need information about where a particular entity or phenomena is found. For example, by knowing the distribution of a rare species it is possible to estimate its population size, to monitor future population changes, to identify impacting land-use transformations or to effectively target management actions.

In some cases it is possible to record most, if not all, incidences of the phenomena of interest. For instance, rhinoceros poaching events in African PAs are generally detected and it would be relatively easy to record their position and date. However, these cases are unusual and the distributions of most phenomena are inferred from a series of sampling points. This strategy is not only much cheaper but it also allows predictions to be made as to how these distributions may be affected by changes in the determining factors. A variety of these modelling techniques are used in conjunction with GISs but they can be grouped into three categories.

2.4.1 Interpolation

Interpolation is the procedure for '*predicting the value of attributes at unsampled sites from measurements made at point locations within the same area*' (Burrough & McDonnell, 1998). Generally, interpolation techniques are used to predict values of the same attribute as that that is measured. For example, a digital elevation model (DEM) is created by measuring elevation at various points and deriving the elevation values between them.

The simplest form of interpolation involves creating *Thiessen polygons*, where it is assumed that any location will have the same attribute value as its nearest sampled point. A more complicated and widely used method is *inverse distance interpolation*. This assumes that the value of the attribute at some unvisited point is a distance weighted average of data points occurring within a pre-defined window. This method is often used to increase the resolution of existing raster coverages but it should be used with caution. This is because it does not produce an error term and so the accuracy of the resultant product cannot be calculated.

Therefore, a better alternative is to use geostatistical methods of interpolation, which are more commonly known as *kriging*. These were developed for use in the mining industry and were designed to produce good results, with measurable accuracy, even with relatively few sampling points. They use a model that assumes that the attribute value at a given point is due partly to an underlying trend, partly to a spatially dependent residual and partly to a spatially independent residual. Kriging can also be used to model the distributions of two or more spatially correlated attributes (a process called co-kriging), where data from each attribute provides information on the other (Isaaks & Srivastava, 1989).

Kriging is rarely used by conservation biologists despite its importance (Rossi *et al*, 1992; Atkinson, 1996). This is probably because few researchers have a background in geostatistics and it will take time for these ideas to establish. They are described here partly to underline their potential and partly because they are used to produce spatial data, such as elevation and climate coverages, that are widely used by the conservation GIS community.

2.4.2 Classification

Classification techniques in GISs have generally been developed for the interpretation of satellite imagery. Most satellites in effect take several 'photographs' of an area, where each 'photograph' records the reflectance values of the Earth for a particular range of light wavelengths. Pixels that contain the same land-cover type tend to have similar reflectance values and so two methods have been developed to group them accordingly.

The first is called an *unsupervised classification* and this involves the GIS software choosing the categories based entirely on their reflectance values. This method is fast but the categories often have little biological relevance. For example, forest may be divided into two categories that have slightly different physiognomic properties whereas grassland may be grouped together with fields of sugar cane.

An alternative method is to use *supervised classification* techniques that allows the user to define the categories which the map should contain. This involves identifying a series of *training sites* that contain known examples of each land-cover type. The GIS software calculates the reflectance values of each type from these and classifies the remaining pixels in the raster image according to that which they most resemble (Lillesand & Kiefer, 1994).

However, in general, it is much more likely that a pixel at a certain location will belong to a particular set of land-cover types. For example, one near a river is far more likely to consist of riverine forest than montane forest. It is for this reason that some GIS software allows the user to predict where each land-cover type is most likely to be found and this information is used to influence how each pixel is classified. This latter technique relies on *Bayesian* statistics, which use conditional and *a priori* probabilities to calculate the probability of an uncertain event occurring. *A priori* probabilities represent what the modeller believes, before testing, to be the probability of an event occurring. This belief can be based on an educated guess, on data from a pilot study or results obtained elsewhere.

This method was used by Aspinall & Veitch (1993) to predict the distribution of a wading bird (the curlew, *Numenius arquata*) in northeast Scotland. They recorded the presence or absence of curlew in a series of training sites and also derived elevation and spectral reflectance values for these sites from satellite imagery and a DEM. These data were used to calculate the probability of the species being associated with different reflectance and elevation values and these results were then used to classify the rest of the study area. A similar approach was used by Hepinstall & Sader (1997) to model the probability of several bird species occurring in the United States, although they used a measure of landscape texture instead of elevation. These methods allowed suitable habitat to be identified without first producing a land-cover map.

2.4.3 Modelling using traditional statistical techniques

Despite their potential, the interpolation and classification methods described above are seldom used by conservation biologists. Instead, most published work uses the statistical tests that are familiar from non-spatial analysis. This familiarity is probably partly responsible for their widespread use but there are advantages in using these techniques. They are ideally suited for identifying which of the measured factors are statistically significant. This increases the predictive powers of the resultant model and allows a greater understanding of the underlying processes.

In the past, these predictive models had limited value for conservation managers but it is now possible to turn these models into maps. The process consists of three steps; determining the characteristics of the sampling points using the GIS, analysing the data using relevant statistical tests and converting the resultant model into a map. For example, Austin *et al* (1996) produced a predictive model for the distribution of buzzard (*Buteo buteo*) nesting areas, which was then used to produce a nesting suitability map. This map could also be used to predict how land-use changes, such as afforestation, would affect the species.

Similar approaches have been used to determine whether elk (*Cervus elaphus*) avoided calving near roads (Bian & West, 1997), to find how burning affected the amount of suitable habitat for black-tailed jackrabbit (*Lepus californicus*) (Knick & Dyer, 1997) and to predict potential habitat for a rare orchid species (Sperduto & Congalton, 1996). These methods have also been used to calculate antelope population sizes in South Africa (Smith, 1996) and to predict the spread of grey wolves (*Canis lupus*) in the United States (Mladenoff *et al*, 1995).

Most of the observational data that these maps are based on are collected either as presence/absence or simple presence data and a variety of statistical tests have been used for their analysis. Logistic regression has generally been used for presence/absence data (Mace *et al*, 1996; Lindenmayer *et al*, 1999), although a range of other methods, including discriminant analysis and principal component analysis have also been used (Dettmers & Bart, 1999). In some cases, the presence data may be categorised into more than one class and so logistic regression is not suitable. For example, Merrill *et al* (1999) identified traditional and temporary leks used by prairie chickens (*Tympanuchus cupido*) and used analysis of variance to determine differences between these two lek types and areas where leks were absent.

Analysing presence data uses less well-established techniques, although the most widely used method is based on the *Mahalanobis* statistic. This is used to produce habitat preference maps and defines the 'optimum' habitat as a multivariate vector of the means of the habitat variables. These means are calculated from the presence data and the habitat quality of each pixel in a GIS can be measured as its similarity to this multivariate mean (Clark *et al*, 1993).

It should be noted that all of these tests rely on the assumption that each sample is independent and so caution is needed when choosing sampling points. Most phenomena show *spatial autocorrelation*, where neighbouring points are likely to share similar values and so are not independent (Koenig, 1999). GIS packages often allow statistical analyses that treat each pixel in a raster image as an independent sampling point and these methods should be avoided. Instead it is important to choose sampling points that are sufficiently far apart to minimise the effects of spatial autocorrelation. An alternative approach is to allow for this autocorrelation in the analysis, which was done by Augustin *et al* (1990) by modifying the logistic regression methodology. This approach has great potential but it has not yet been developed for other statistical tests.

2.5 GISs and African elephant research

There are two main factors that determine the suitability of studying a species using a GIS. The first is the ease with which the position of different individuals can be recorded and the second is the cost of obtaining the relevant spatial data. In both cases, the study of African elephants rates highly. The size of these animals makes them conspicuous in savanna ecosystems and it easy to record their position using GPS units. Identifying their location in forests is more difficult but still possible by recording the position of dung piles. In addition, much work continues to be carried out to estimate elephant population sizes and home ranges and it requires little extra effort to collect these data in a GIS compatible format. The cost of collecting elephant ranging data can be reduced even further by using GPS radio collars and so it is likely that even more data will be available with the development of this technology (Lindeque & Lindeque, 1991; Thouless, 1996a; Douglas-Hamilton, 1998).

This increase in the availability of spatial data on elephant numbers and ranging behaviour has been matched by the availability of free GIS data on the Internet. There are global DEM and land-type coverages available as well as free Advanced Very High Resolution Radiometer (AVHRR) satellite images, which provide information on vegetation biomass. All of these sources have a resolution of 1 x 1 km, which is of limited use for the study of most species. However, African elephants range over very large areas and are habitat generalists so these data are highly suitable. The position of other important factors, such as water-points, roads and villages are easily digitised from paper maps or recorded using a GPS unit. The site of poaching or conflict incidents can also be recorded using GPS units or the study area can be divided into blocks and records kept on when incidents in each block occurred.

To date, GISs have been used in three main ways to study African elephants. They have been used by several authors to plot the movements of radio-collared individuals and to calculate the home range of these animals (Thouless, 1996b; Douglas-Hamilton, 1998). They have also been used to estimate elephant numbers both directly and from dung counts. Gibson *et al* (1998) used a GIS to combine data from several different aerial population counts and to map the spread in distribution of a growing population.

Michelmore *et al* (1994) and Barnes *et al* (1997) found that forest elephant density (as calculated from dung counts) increased with distance from anthropogenic factors. From this they estimated the elephant population size in Central Africa and Gabon respectively by using a GIS that contained coverages describing the roads, rivers and vegetation cover. A final application was demonstrated by Omullo *et al* (1998) who used a GIS to determine the habitat preferences of three mammal species, including elephants, in the Tsavo ecosystem. They found that the presence of elephants was determined by distance to permanent water in the dry season and vegetation biomass in the rainy season.

Despite the advances that have been made, there is still a huge potential for the application of GISs to elephant conservation programmes. The technology could be used to monitor and understand HEC and poaching levels, to relate elephant habitat use to vegetation changes and to accurately estimate population sizes. A GIS could also be used to predict the effects of manipulating artificial water availability, the effect of habitat transformation on elephant numbers and distribution and the effects of new infrastructures, such as roads and fences. More generally, many problems in conservation biology involve land-use issues and GIS software allows these problems to be discussed and resolved in a rational way.

Chapter 3: HEC in Taita Taveta - a case study

3.1 Introduction

This report focuses on HEC in the Taita Taveta District, an area in the south east of Kenya. This district, together with Tsavo East (TsE) and Tsavo West (TsW) NPs, makes up part of the Tsavo ecosystem that is home to the largest population of elephants in the country. This chapter provides an overview of HEC in Taita Taveta and begins by describing the Tsavo ecosystem and its elephant and human population. This is followed by a brief history of human-elephant interactions in the Tsavo ecosystem and a full description of HEC in Taita Taveta. The final sections discuss the methods that are used by local people and KWS to mitigate HEC and suggest the factors that may determine where HEC takes place.

3.2 A description of the Tsavo ecosystem

The Tsavo ecosystem is an area of 43 000 km^2 found between 2° and 4° South and 37.5° and 39.5° East. Its borders are defined by the densely populated parts of Ukambani in the north-west, by Mounts Kilimanjaro, Pare and Usambara in the south-west, and in the south-east by a fairly densely populated coastal hinterland (Wijngaarden, 1985; Cobb, 1976).

The core of this area is formed by TsE and TsW NPs in Kenya, which together occupy about 21 000 km^2 (Figure 3-1), and the Mkomazi Game Reserve (MGR) which occupies about 5 000 km^2 in Tanzania.

Figure 3-1: The position of the Tsavo National Parks within Kenya

3.2.1 Topography and soil fertility

The Tsavo ecosystem has an altitude range of between 200 and 1000 m above sea level, with an even and gradual slope rising upwards from the east (Figure 3-2). In the centre of the ecosystem are the Taita Hills, which rise to 1 500 m above this general landscape. These hills are densely populated due to their much higher rainfall and agricultural potential (Sombroek, 1980). However, in general, the soil in the region has low fertility and Braun's (1980) agro-climatic classification of Kenya identifies much of the Tsavo ecosystem as having marginal, low or no agricultural potential.

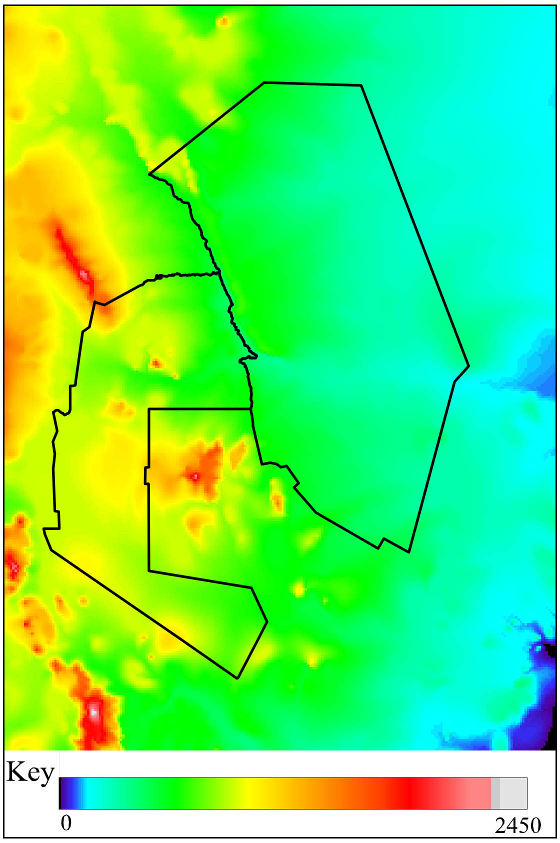

Figure 3-2: An elevation map of the Tsavo ecosystem showing the boundaries of the NPs

3.2.2 Climate

Rain in the Tsavo ecosystem usually falls in two rainy seasons, generally lasting from November to December and from March to May. Although these seasons are usually well defined, rainfall varies considerably in its spatial and temporal distribution. Hence, it is difficult to identify strict divisions between the seasons, as conditions may differ considerably between different areas at any one time. However, the combined length of the two dry seasons are generally longer than the two rainy seasons (Leuthold, 1977a). The mean annual rainfall is 550 mm, although northern TsW receives more rain than the southern part and most of TsE (Cobb, 1976). In contrast to this fluctuating rainfall, temperatures are quite constant over the year, with a mean maximum of 33.3°C in March and a minimum of around 20°C in July (Wijngaarden, 1985).

3.2.3 Water availability

The erratic and generally low rainfall in the Tsavo ecosystem means that the availability of surface water plays a major role in determining the distribution of many species. These water sources can be divided into two main categories described below.

3.2.3.1 Natural water supply in the Tsavo ecosystem

Natural permanent water sources are very limited in the Tsavo ecosystem. Only the Galana, Tsavo and Athi rivers flow all year round, although smaller seasonal rivers such as the Tiva and Voi retain stagnant pools and ground water long into the dry season. In southern TsW, permanent water is also available at Lake Jipe and in TsE, small springs are found along the Yatta plateau and in some places on the dissected plains. Their discharge is small and the water often becomes saline by the end of the dry season (Wijngaarden, 1985) Numerous waterholes, which are usually shallow depressions in the landscape, hold water after the rains and may contain water for several months into the dry season.

3.2.3.2 Artificial water supply in the Tsavo ecosystem

Artificial water points were first created within Tsavo NP in the early 1950s to achieve three objectives. These were to prevent wildlife from moving outside the NPs in search of water, to attempt to distribute wildlife evenly throughout the NPs and to improve the touristic potential of the area (Sheldrick, 1965; Ayeni, 1975). More water-points were created in the 1960s and some of these were supplied by pumping water from the Galana river and by sinking boreholes. However, many of the water-points that were formed by damming rivers silted up and others were affected in the 1970s when lack of funds prevented pump maintenance.

Since 1994, a tourism company has rehabilitated two of these pumps and so artificial water is again available during the dry season. In addition, water development projects, primarily for cattle, were also undertaken outside the NPs, which increased the availability of drinking water in the Tsavo ecosystem. Most ranches have developed their own water supply, either by pumping from the Galana river or by using a supply from the pipeline that runs from Mzima springs in TsW to Mombasa.

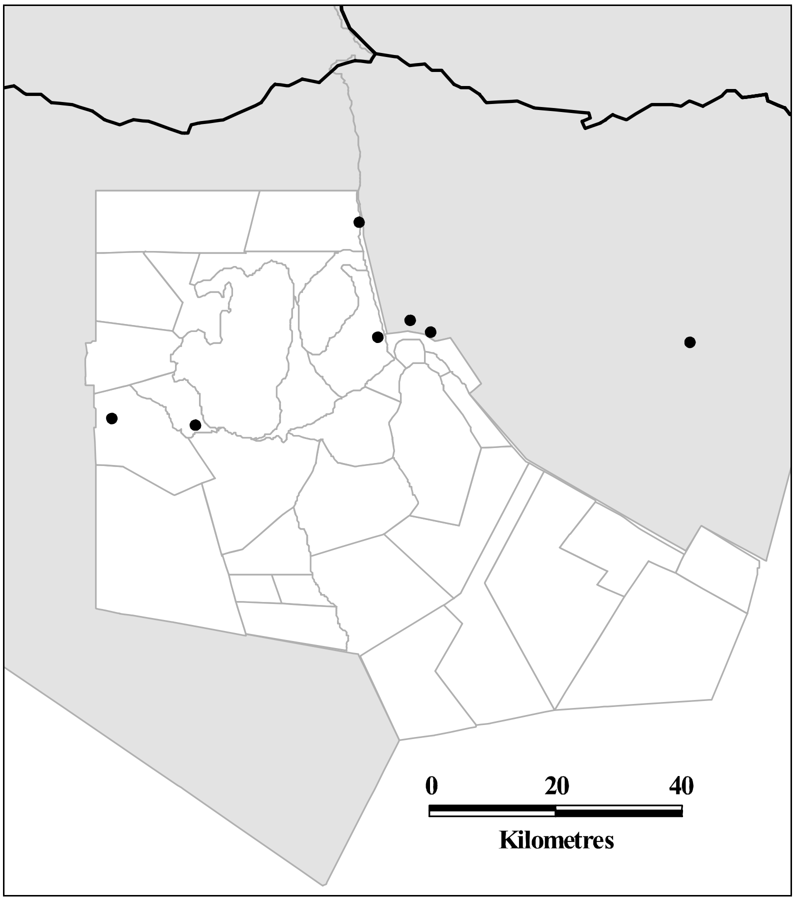

Figure 3-3: The present position of permanent water (shown in black) in Taita Taveta and its surrounding areas

3.2.4 Vegetation

There are three major vegetation types in the Tsavo ecosystem and these are

- Mixed *Commiphora-Acacia* woodland
- Grassland
- Riverine vegetation

The mixed woodland is the dominant vegetation type but it was even more widespread in the past. This change was due to the influence of elephants and fire that converted large areas to grassland (Agnew, 1968; Laws, 1969b; Wijngaarden, 1985). However, recently there has been a slow reversal back to woodland, probably because of the drop in elephant numbers (Leuthold, 1996). The riverine vegetation is found along the banks of the Galana and Tsavo rivers and consists of several species of large trees.

3.3 Tsavo elephant population trends

3.3.1 Before the 1960s

Some of the first written reports about elephants in Tsavo were recorded in the second half of the 19th century by European visitors. Krapf (1860) reported that there were very few elephants in Tsavo and no mention was made of them in reports of the wildlife encountered by those building the Kenya-Uganda railway across Tsavo from 1898 to 1900 (Patterson, 1979). Spinage (1973) suggests that intensive exploitation of elephants between 1840 and 1890 led to a collapse of the ivory supply from over-exploitation. The large-scale introduction of firearms accelerated this decline, an occurrence documented in the accounts of early European explorers in East Africa.

At the turn of the century game laws were introduced that restricted the exploitation of elephants and there was a gradual recovery of the Tsavo population (Parker & Amin, 1983; Douglas-Hamilton, 1987; Poole *et al*, 1992). This increased further with the creation of the Tsavo NPs in 1948 as elephants used the PAs as a refuge. The 1950s and 60s saw the build up of elephant numbers to levels that were so high that they became a cause of concern, leading to what was referred to as the “Tsavo elephant problem” (Glover, 1963; Glover & Sheldrick, 1964; Sheldrick, 1965; Laws 1969b).

3.3.2 Since the 1960s

The first population count of the Tsavo elephants took place in 1962, partly as a response to the population increase. The Tsavo ecosystem contains the largest single elephant population in Kenya and numerous studies have been carried out there since (Glover, 1963; Glover *et al*, 1964; Laws, 1966a & b; Laws, 1967a & b; Laws, 1969a & b; Corfield, 1973; Leuthold, 1977a; Ottichilo, 1981; Wijngaarden, 1985; Douglas-Hamilton *et al,* 1994; McKnight, 1996; Kahumbu *et al*, 1999). The results of these studies, together with other research, has provided a large amount of data on the population size of the Tsavo elephants, although counts for the whole ecosystem are only available for the years 1972, '88, '89, '94 and '99 (Figure 3-4).

Population estimates in the early 1960s placed the total elephant population in the Tsavo ecosystem in the range of 28 000 to 42 000 (Laws, 1969b). However, a severe drought occurred in Tsavo in 1970-71 which resulted in the death of an estimated 9 000 animals (Corfield, 1973), reducing the elephant population to about 25 000 in 1972. The main reason for these deaths was thought to be starvation as no evidence was found for increased poaching activities or disease (Corfield, 1973). The population continued to decline in the early 1970s after the drought, a decrease thought to have been due to loss of a high percentage of breeding females (Corfield, 1973; Leuthold, 1976) (Figure 3-4).

The unprecedented rise in the price of ivory in the mid 1970s, which also coincided with the breakdown of law enforcement of wildlife regulations in Kenya, led to increased elephant poaching in Kenya (Poole *et al*, 1992). In Tsavo the elephant population dropped to an estimated 5 000 in 1988, approximately one fifth of the number recorded in 1972 (Ottichilo, 1981; Olindo *et al*, 1988). However, in 1989 the Tsavo population began to increase and in 1999 it was estimated that the elephant population had reached 8 068 (Kahumbu *et al*, 1999).

Despite fluctuations in the Tsavo elephant population, since 1972 there has been a significant decline in the number of elephants found outside the NPs (Kasiki, 1998). 25% of the elephants were found outside in 1972 but this had dropped to 11% in 1994.

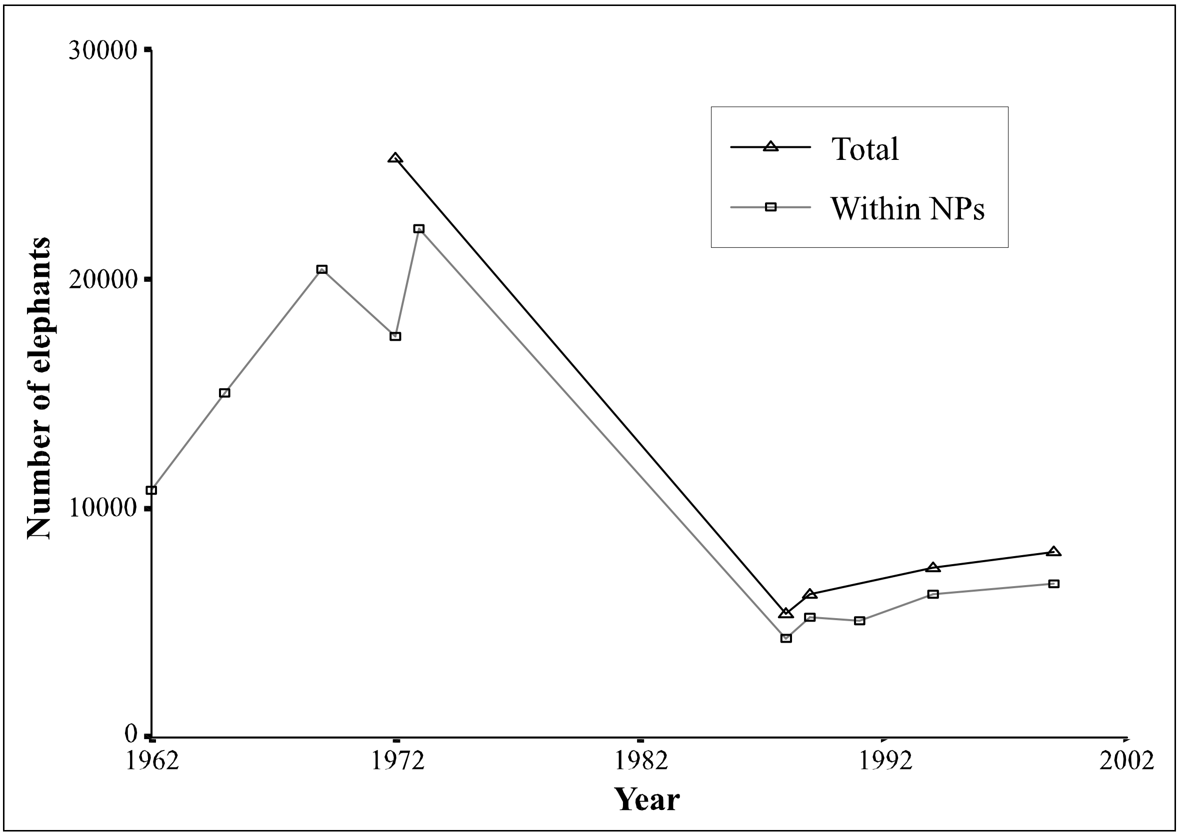

Figure 3-4: Tsavo elephant population from 1962 to 1994

3.4 The human population of Taita Taveta District

3.4.1 Demographic patterns

Trends in human population in the whole of the Tsavo ecosystem outside NPs showed a steady increase between 1948 and 1997 (Table 3-1, Figure 3-5). These patterns have been mirrored by people living in Taita Taveta, where data collected from three sample locations between 1979 and 1997 showed an increase in both human density and number of households (Kasiki, 1998). When the NPs were created the human population was largely distributed according to the agricultural potential of the land. This pattern has now diminished, with the area supporting low densities (<20 people per km^2) falling from 90% in 1948 to 65% in 1997.

This increase has been due to both natural population increase and immigration of people into the ecosystem (and closer to the NPs) from the more densely populated surrounding areas

(Ecosystems Ltd, 1982; Ngure, 1992). This trend is likely to continue as 51.4% of the people living in the ecosystem are under 15 years of age (KCBS, 1996).

Table 3-1: Changes in human population and density in the Tsavo ecosystem 1948 to 1997

Year	1948	1962	1979	1989	1997
Number of people	101 050	154 800	208 550	291 293	393 245
Density/km^2	4.7	7.2	9.7	13.6	18.3

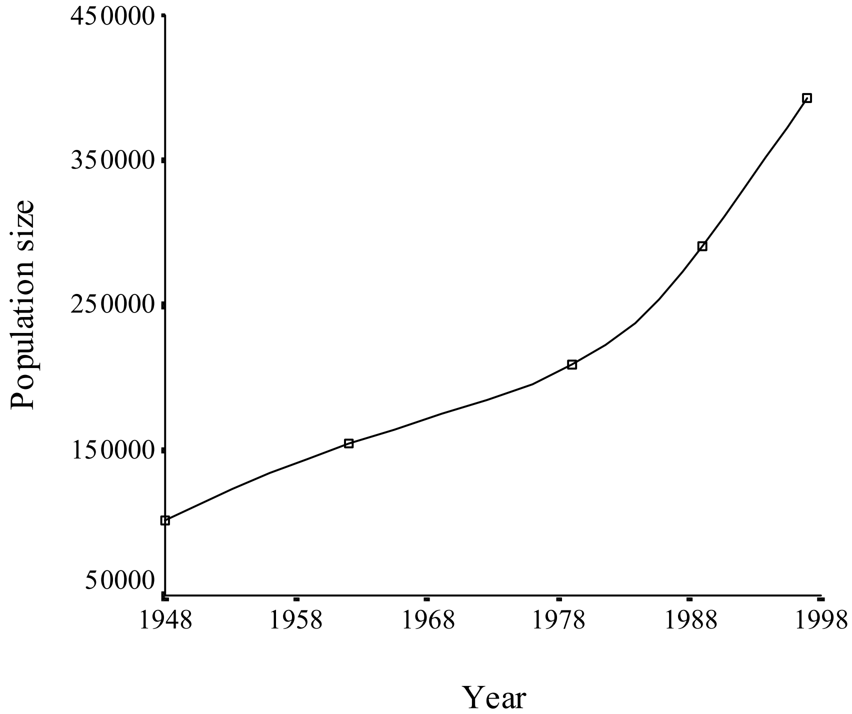

Figure 3-5: Human population size of the Tsavo ecosystem

3.4.2 Economic activities and education levels.

Based on a sample of 312 people, it was found that 78% of the people of Taita Taveta District are subsistence farmers, 18% are in waged employment and the final 4% are involved in trade (Kasiki, 1998). This same survey found that 30% of the respondents had no formal education, 54% had undergone primary school education, 13 % had attained secondary school education and 3% had received professional training at tertiary colleges or universities.

The subsistence farmers depend on small plots of land for their livelihood. Few of them have other options or opportunities and this situation is exacerbated because most have little or no formal education. The poor climatic conditions in most of the Tsavo ecosystem mean that agriculture will not be able to support the majority of the people unless innovative solutions can be found that enhance food production without further environmental damage.

3.4.3 Attitudes towards wildlife resources, KWS and Tsavo NPs

These 312 people were also questioned about whether they felt they benefited from the wildlife resources of the region and the presence of the NPs and the KWS. 62% of these people said that they received no benefits, 8% said that they relied on wild animals for cheap meat (mainly through subsistence poaching of antelope) and 2% benefited by obtaining medicinal substances. Only 11% of the people felt that they benefited from projects and aid given by KWS as part of its Community Wildlife Service (CWS) programme and 16% felt that they benefited from tourism-related industries (Kasiki, 1998).

Therefore, most people perceived the NPs and the animals that they protect as a liability. Very few people received financial or other direct benefits from the money generated from wildlife through tourism, and none of the local people could legally generate wildlife revenues through hunting or other consumptive utilisation. Many people could not understand why they were denied access to former grazing land, traditional holy shrines and water sources and prevented from gathering products for food and house construction. This has resulted in general apathy towards wildlife, and disobedience or downright antagonism to wildlife regulations imposed by KWS (Kasiki, 1998).

3.5 A history of human-elephant interaction in the Tsavo ecosystem

Tribal groups have used the land in the Tsavo ecosystem for thousands of years and these groups include the Watta, Taita, Taveta, Orma, Maasai and Kamba (Sheldrick, 1973; Patterson, 1979; Ecosystems Ltd, 1982; Wijngaarden, 1985; Ville, 1995). Each of these groups has different attitudes towards elephants, which are described below.

3.5.1 Before the creation of Tsavo National Park

The Watta were probably the first inhabitants of the central Tsavo ecosystem. They specialised in elephant hunting, supplying the coastal traders with ivory. Their main weapons were powerful bows and poisoned arrows, and their archery technology was reputed to be one of the best in East Africa (Sheldrick, 1973; Parker & Amin, 1983; Ville, 1995). Their traditional way of life revolved around the elephant, with elephant meat making up a major part of their diet and their hunting patterns probably reduced elephant-pressure on woodland

Most of the other tribes that later settled the region were predominantly pastoralists, such as the Taita, the Taveta, the Orma and the Maasai. The one exception to this was the Kamba who relied on both pastoralism and hunting, including hunting elephants. They eventually became involved with a lucrative ivory trade with the coastal people, which increased their influence in the Tsavo ecosystem (Sheldrick 1973, Parker & Amin 1983, Ville 1995).

3.5.2 Since the creation of the Tsavo National Parks

The Tsavo National Parks were created in 1948 by gazetting a 21 000 km^2 portion of the Tsavo ecosystem. The location of the park was influenced by two main factors, the most important of which was that the area had a small human population consisting of hunter-gatherers and nomadic pastoralists. In addition, the boundaries of the PAs were delineated so that the "boot" of TsW abutted onto the Mkomazi Game Reserve (MGR) in neighbouring Tanzania (Ecosystems Ltd, 1982). For administrative purposes, the park was divided into two sectors, TsE and TsW, the dividing line being the Nairobi-Mombasa railway.

Once proclaimed, the only lawful use of the NPs by the public was for tourism and recreation through game viewing. The people who had occupied and used the area for centuries were evicted. This had a severe effect on the tribes who had habitually used this land for grazing, hunting and other needs. In addition, the authorities made hunting by the Watta illegal but some Watta men ignored this and turned to full time poaching of both elephants and rhinoceroses (Sheldrick, 1973; Ville 1995). The Government responded to this in 1956 by waging a massive anti-poaching campaign to suppress all traditional and tribal hunting throughout the Tsavo ecosystem (Sheldrick, 1973; Wijngaarden 1985).

A major drought occurred in 1971 and a large number of elephants died in Tsavo (Corfield, 1973). Kamba people living in the neighbouring area entered the NPs to profit from the availability of ivory and found that the park staff were unable to keep them out effectively (Ecosystems Ltd, 1982). When the ivory from the elephant die-off became scarce, the Kamba took to poaching the surviving elephants. Their success became widely known and attracted numbers of Somali hunters (Sheldrick, 1973; Parker & Amin, 1983), who later became a major factor in determining the fate of Tsavo elephants.

3.6 HEC in the Tsavo ecosystem

The Tsavo NPs boundaries were chosen without regard to the migration and dispersal of wild animals, especially the elephant, across PA boundaries (Laws, 1969b) (Figure 3-6). When the NPs were created in 1948 the human population density was very low, at less than 5 per km^2 (Ecosystems Ltd, 1982). Over the past five decades the number and distribution of people have expanded continuously and this has had a profound influence on the ecology of the Tsavo ecosystem and patterns of land use within it. Elephants that move out of the NPs onto many of the neighbouring areas now come into conflict with legitimate human interests, whose outcome is intolerable to the poor neighbouring human community.

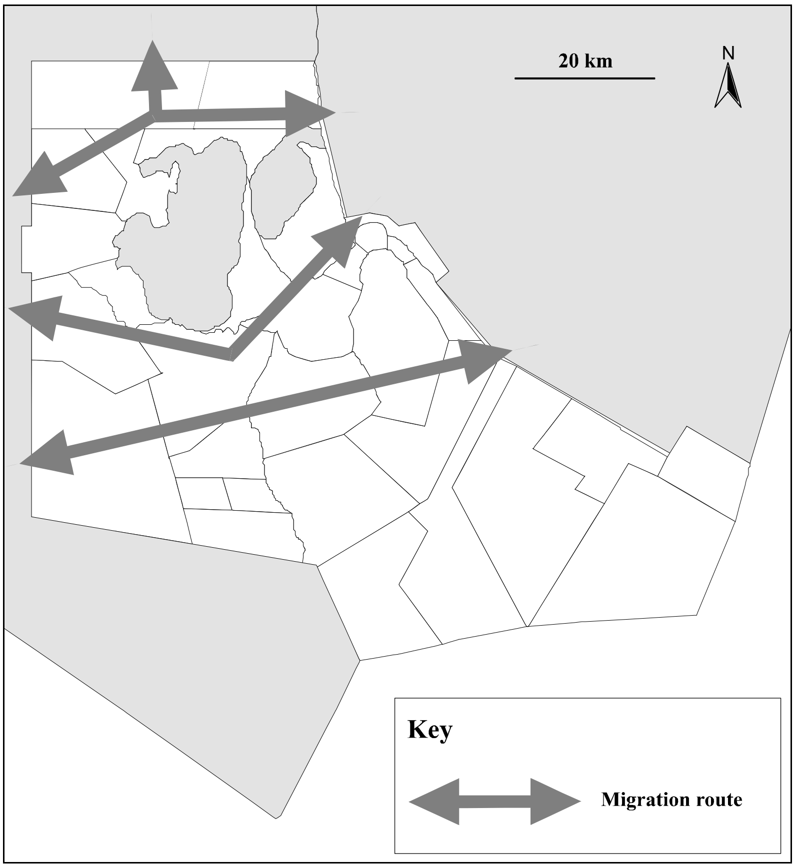

Figure 3-6: Approximate elephant migration routes in Taita Taveta

3.6.1 History of HEC in Tsavo

The earliest records of HEC in Tsavo are from 1916 when the District Commissioner of Voi asked permission from the Government administration for the local people to kill elephants that were damaging crops (Visram, 1987). One local man remembered having killed several elephants to defend his maize and other crops and to sell the ivory in the early 1940s (Kasiki, 1998). An estate manager of a sisal plantation in Voi gives accounts of elephants raiding sisal plantations and cultivated areas adjacent to the Tsavo NPs from the 1950s to the mid 1970s (Visram, 1987). The problem became so intense that growing of food crops and sisal was abandoned altogether in certain areas in the early 1970s. The years 1970 to 1972 were the worst, when a severe drought forced large herds of elephants to leave the Tsavo NPs in search of food and water in the surrounding areas (Visram, 1987).

The large reduction in the elephant population, first from drought and then by poaching, meant that HEC also dropped from the mid 1970s. However, in the late 1980s it was reported that incidents of conflicts between man and elephants in Tsavo were on the increase (Ngure, 1992). KWS responded to this increase by forming a Problem Animal Control (PAC) unit within its CWS department to deal specifically with human-wildlife conflict issues.

3.6.2 Characteristics of the elephants involved in conflict

The sex and group composition of problem elephants in Taita Taveta District was recorded in the field between 1995 and 1997 (Kasiki, 1998). The majority of elephants involved in conflict in Taita Taveta consisted of family groups with or without accompanying mature bulls (Figure 3-7, Table 3-2). Conflict incidents involving bulls only formed 27% (n = 21) of incidents, and the rest were cow-calf or mixed groups. There were no recorded incidents of crop raiding or venturing into the settled area by a single female or a single female with a calf.

According to respondents, 84% of crop-raiding took place at night with groups moving into settled areas between 19:00 hrs and 21:00 hrs. They would then feed in these areas and raid farms most of the night and return back into the NPs between 05:00 hrs and 06:00 hrs. Maize, which was cultivated by all of the farmers, was the main crop eaten by elephants, accounting for 61% (n = 210) of all complaints in Taita Taveta District.

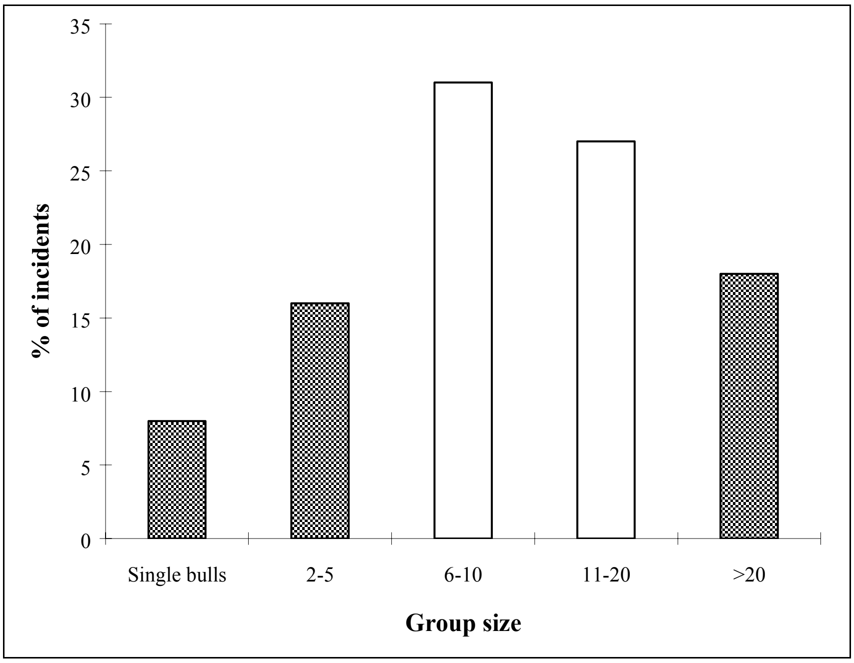

Figure 3-7: Group size of elephants involved in conflict, 1995 to 1997

Table 3-2: Group size and composition of elephants involved in conflict in from 1995 to 1997

Group size	Number of incidents	Group composition
Singles	14	Always bulls
2-5	16	Bulls or cow/calf groups
6-10	25	Bulls or cow/calf groups
11-20	21	Mixed groups
>20	2	Mixed groups, usually aggregations
Total incidents	78	

3.6.3 Intervention methods

3.6.3.1 Methods used by local people

The people of Taita Taveta use a variety of methods to protect their crops and to discourage elephants and other wildlife from their land. Kasiki (1998) interviewed 375 people about which methods they used and how much time and money they spent applying them. Of the total population, 82% used fires, 65% used noise, 63% burnt cow dung and 54% used spotlights. Between 1994 and 1997 there were seven unexplained elephant deaths and it is possible that these were poisoned by local people. The majority of the people used a combination of methods to improve on effectiveness but a few did not use any methods.

Assessing the cost of crop raiding is difficult in Tsavo, especially as the value of subsistence agriculture cannot be measured in purely economic terms (Kangwana, 1995). However, Kasiki (1998) found that the annual expenditure of most households on materials and services to reduce crop-raiding exceeded their annual income. In addition, each household spent an average of 9.3 hours watching their fields during the crop seasons. This clearly shows that crop-raiding elephants have an enormous effect on the lives of the peasant farmers who neighbour the Tsavo NPs.

3.6.3.2 Method used by KWS

The KWS PAC unit is primarily responsible for dealing with cases of HEC and this consists of a special team of rangers and an officer. They use a variety of methods to drive elephants away from problem areas but the most commonly used methods involve firing thunder-flashes and blank ammunition. The KWS also occasionally shoot elephants and 12 animals were shot between 1995 and 1997. Despite their efforts, the PAC unit appear to have had no significant effect on annual HEC levels. One reason for this is that from 1995 to 1997 the PAC only had access to one truck and two motor bikes and had to cover an area of more than 11 000 km^2. This was clearly inadequate, especially during peak conflict seasons, but the cost of running these vehicles still consumed about 9% of the Tsavo NPs annual budget (Kasiki, 1998).

In 1995/96 an electric fence was constructed between Ndara and Ndi as an additional HEC mitigation measure (Figure 3-8). It is powered by solar energy and runs for 30km along the south east boundary of TsE NP. The fence is 2 m high and consists of six strands of high tensile wire with an average vertical wire spacing of 28 cm. Four of these wires are live, and a barbed wire runs at the bottom of all the other wires to prevent the passage of smaller animals. Its estimated installation cost was US$10 800 per km and the calculated annual cost of maintenance per km is US$1 100. However, this annual maintenance cost was expected to increase as electrical components and fence posts needed replacing (Kasiki, 1998).

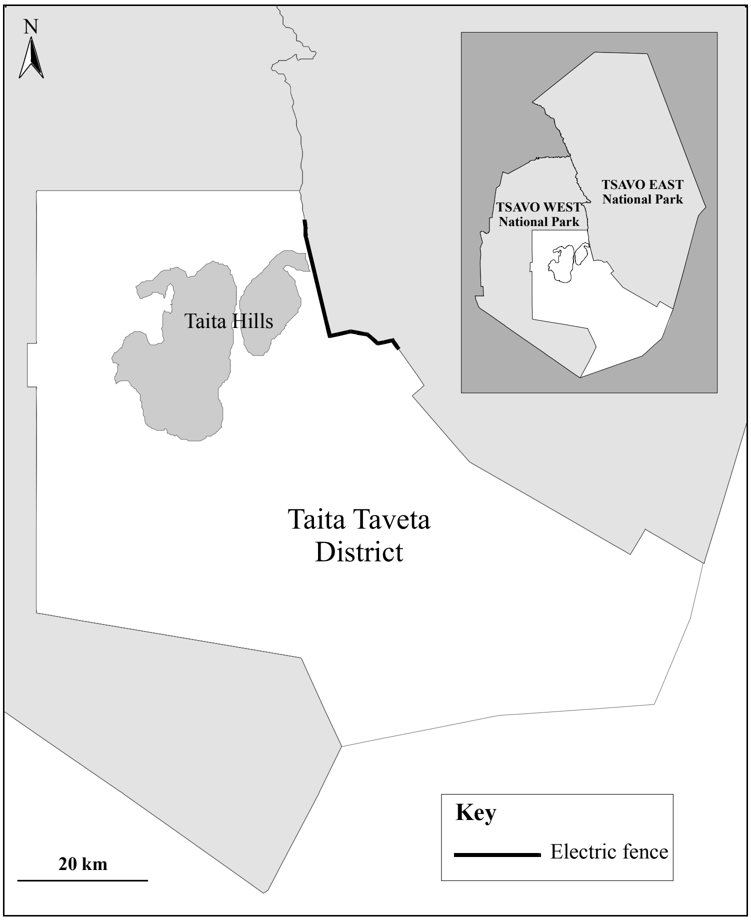

Figure 3-8: The position of the Ndara-Ndi electric fence

3.7 Potential determinants of the spatial pattern of HEC in Taita Taveta

A great deal of information has been collected on HEC in Taita Taveta which makes it possible to carry out a spatial analysis of these data. However, before conducting this analysis it is important to identify factors that may influence the spatial distribution of HEC incidents within this region. This choice of factors should be based on an understanding of the distribution of both humans and elephants in the Tsavo ecosystem, as well as the locations of the resources that both species require. In addition, it is important to identify factors that can be measured within the time frame of this project.

At its simplest level, HEC can take place wherever humans and elephants meet so the density of these two species may play an important role in determining HEC levels. Most HEC incidents in Taita Taveta involve crop-raiding elephants so the presence of agricultural crops may also be important. In addition, the Tsavo ecosystem is generally dry and elephants require large amounts of water, so HEC may be more prevalent in areas that are found close to water. Levels of HEC may also differ between areas that are farmed by small-scale peasant farmers and those that are farmed on a more commercial basis. The people who farm in these two ways may devote different amounts of time and resources to mitigating HEC and so this may also be a factor that determines HEC levels.

Elephants in the Tsavo ecosystem tend to remain within the NPs during the day and enter cultivated fields at night to crop raid. Therefore, it might be expected that elephants are more likely to crop raid in areas that neighbour the NPs and so distance to the PAs may be an important factor in determining HEC levels. In addition, those areas that share a large perimeter with the NPs may be particularly susceptible because elephants have to cross this perimeter when leaving the PAs. A final determining factor may be elevation, as Taita Taveta includes several large hills which may be avoided by elephants and remain uncultivated.

Another factor that may have influenced the spatial distribution of HEC is the presence of the Ndara-Ndi electric fence. This fence was completed towards the end of the study period and so it was decided to exclude data collected after this point from the main analysis. However, there were sufficient data to test whether there was any significant difference between HEC levels recorded before and after the fence's construction. Therefore, the following sections will describe whether this factor, and the others described above, had a significant effect on the spatial distribution of HEC in Taita Taveta.

Chapter 4: Methods

4.1 Introduction

This report is based on HEC data collected during the 42 month period from July 1994 to December 1997. These data were analysed in two main ways, with the first set of analyses investigating the factors that determined HEC conflict density in Taita Taveta District using data collected between July 1994 and June 1997. This avoided using data that were collected after the construction of the Ndara-Ndi electric fence.

The second analysis investigated the effects of this electric fence on HEC incident density and compared data collected before the fence construction (July to December 1996) and after the fence construction (July to December 1997). Data collected in 1998 were ignored as the *el nîno* weather phenomenon produced exceptionally high rainfall in that year.

All of these analyses used data that were either collected in the field or derived from GIS coverages. The chapter begins by describing these data and goes on to describe the statistical methods that were used to investigate HEC in the study area.

4.2 Study block data

The study region was divided into 31 study blocks that ranged in size from 8.5 km^2 to 426 km^2 (Annex 4, Figure 4-1). Some of these were coherent entities that were managed in a particular way, for example for sisal production. Others contained a group of historically linked villages and these had more arbitrary boundaries, often demarcated by roads.

4.2.1 HEC data

The HEC data used in this analysis were derived from reports given by members of the public to KWS wardens and rangers in Taita Taveta. The reliability of this method was tested by collecting information independently for a period of six months at three locations and there was no significant difference between the two sets of data (Kasiki, 1998). The nearest village to each incident was recorded and this information was used to collate the monthly number of HEC incidents for each study block.

The units of HEC in this analysis were measured as number of incidents per km^2 per year ($km^{-2}yr^{-1}$). These units were chosen because they allow comparisons to be made with similar study sites, irrespective of differences in study area size and agricultural or demographic conditions (Hoare, 1999). Therefore, the HEC incident density in each study block was calculated by dividing the number of incidents recorded by the area of the block (in km^2) and the duration of the recording period (in years).

4.2.2 Human density

Data on human population numbers and density were obtained from the Kenya Central Bureau of Statistics (KCBS). Data were available in the form of numbers of males, females and households in each "sub-location". A sub-location is the smallest administrative unit in Kenya and consists of a few households, which are usually in the form of villages. Figures for 1997 were extrapolated from the 1989 census by using the country's annual growth rate of 3.2 % (KCBS, 1996). The human population in the ranches was given as zero as the only people living there were staff members (Figure 4-2, Annex 4).

4.2.3 Land ownership

The type of land ownership was categorised as "Small-holder" when the land was owned by small-scale peasant farmers and "Ranch" when the land was owned by one individual or a group of people and was used for large scale cattle ranching.

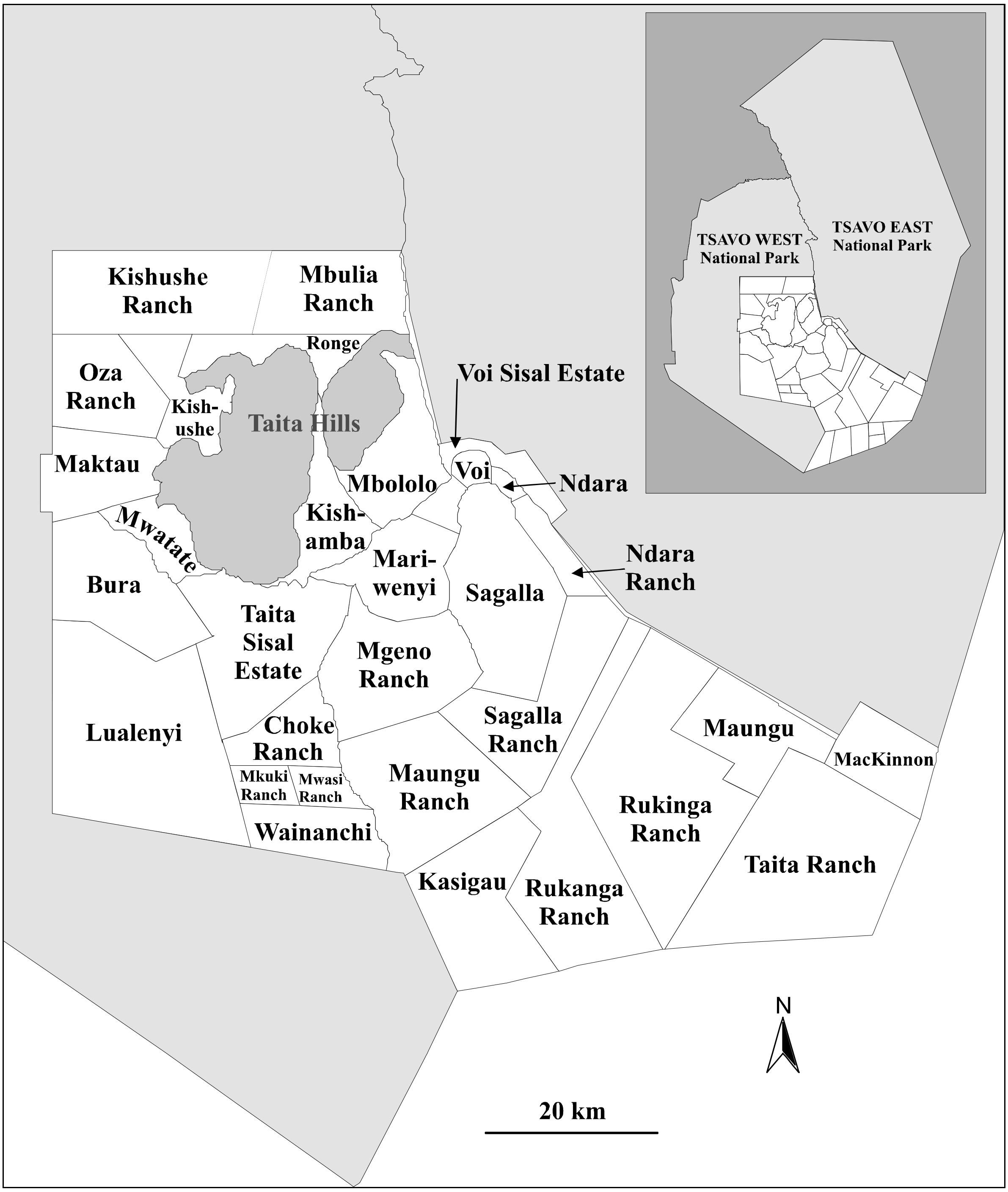

Figure 4-1: The study unit blocks used in the analysis

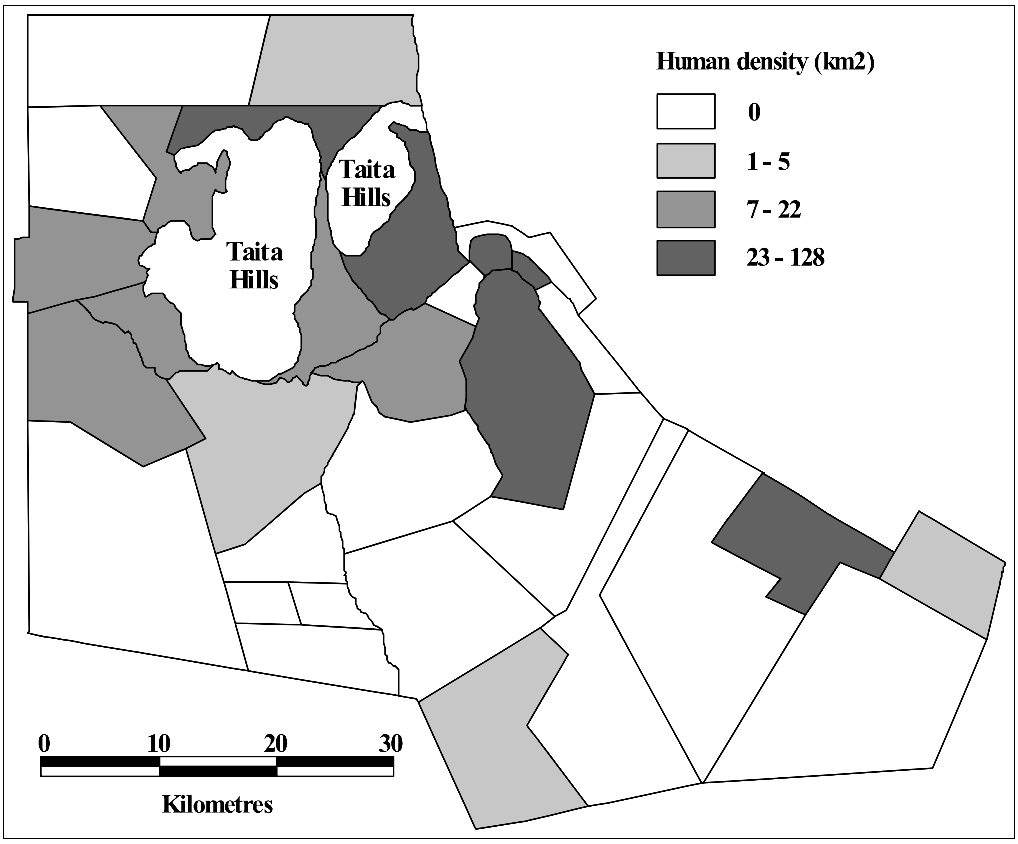

Figure 4-2: The human density of each study block

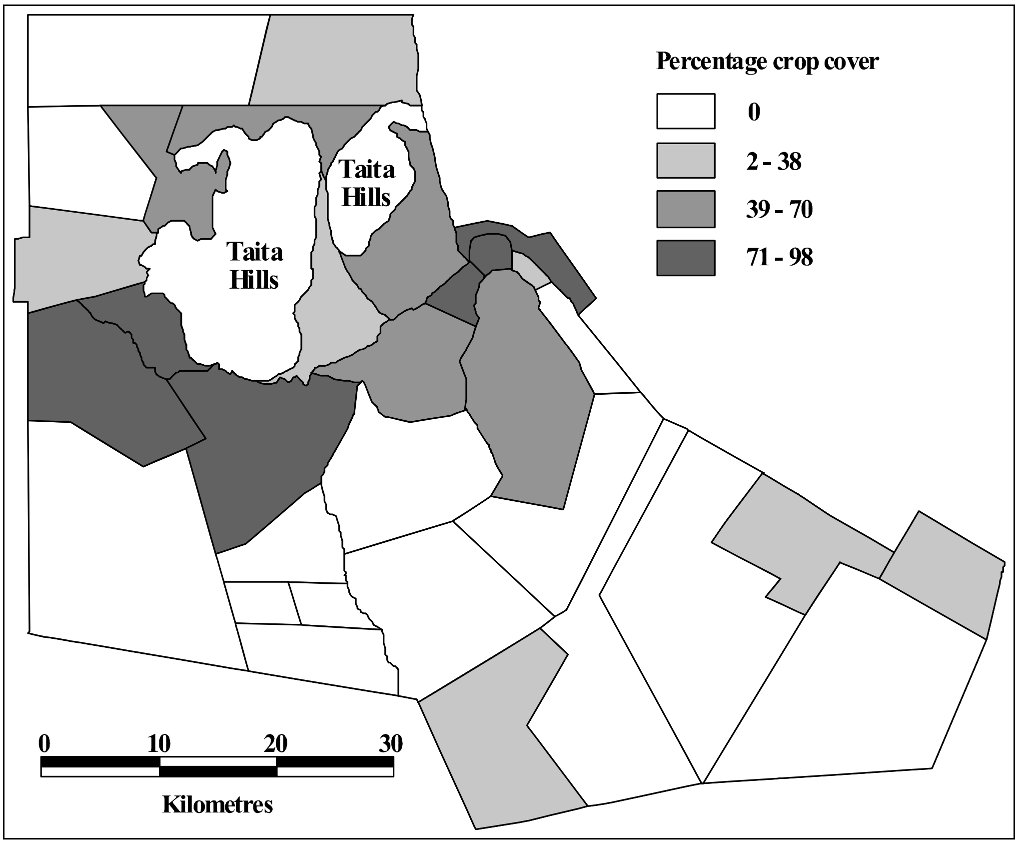

Figure 4-3: The percentage crop cover of each study block

4.2.4 *Levels of cultivation*

The percentage of each block that was cultivated was estimated by using information from records kept by the Survey of Kenya Department and from aerial photographs and a SPOT satellite image taken in 1992 (Figure 4-3, Annex 4).

4.2.5 *Elephant density*

The elephant density was calculated from data collected in 1994 by using a total count aerial census (Douglas-Hamilton *et al*, 1994). This divided the Tsavo ecosystem into a series of blocks, eight of which fell in Taita Taveta. The elephant density in each study block was then assigned according to the census block in which it fell (Figure 4-4).

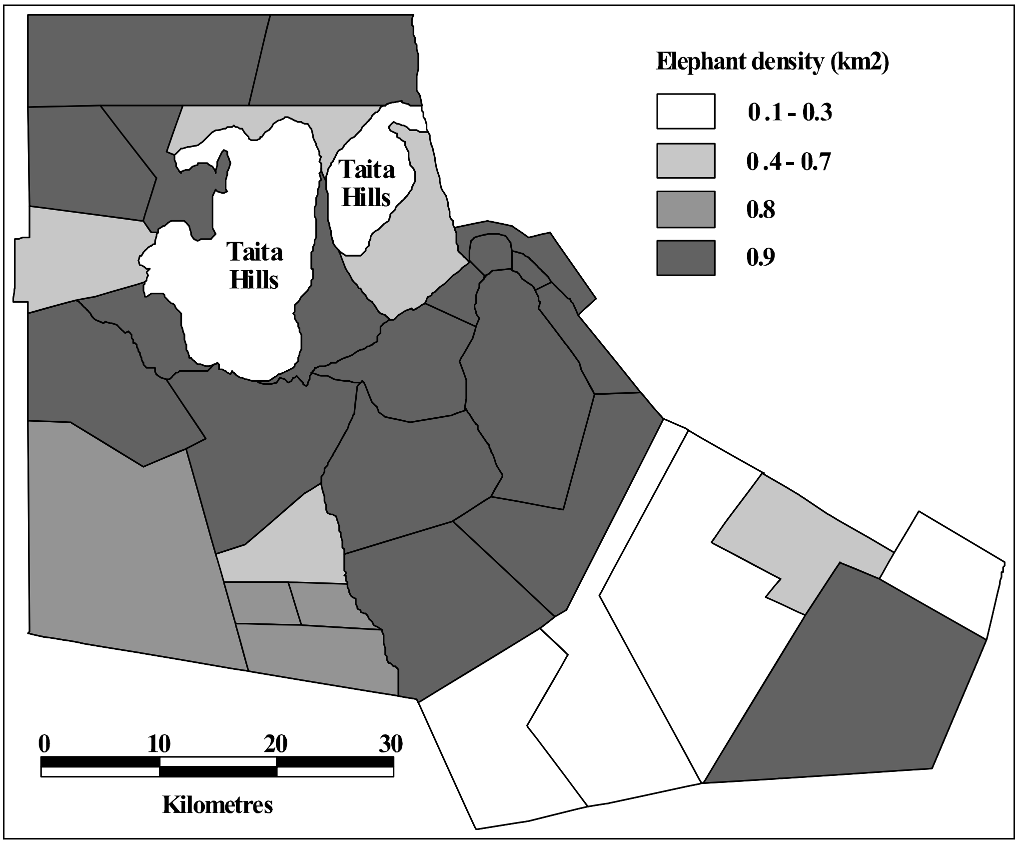

Figure 4-4: The elephant density of each study block

4.3 GIS data

The GIS coverages used in this analysis came from a variety of sources but all were converted to a standard raster format with a resolution of 100m. The resultant coverages consisted of 1050 columns and 1140 rows and used the UTM 37 reference system, which is standard for this part of Kenya (see Annex 3 for details). The data were manipulated and extracted using Idrisi for Windows v2, a raster based GIS software package (Clark Labs) and ArcView v3.1, a vector based GIS software package (Environmental Systems Research Institute).

4.3.1 *Digital Elevation Model and slope coverage*

The DEM was derived from the 1 km resolution data available without charge from the Eros Data Center at **http://edcwww.cr.usgs.gov/landdaac/gtopo30/gtopo30.html**. The resolution of this DEM was increased to 100 m by using the ***RESAMPLE*** module in Idrisi. This calculated the elevation of the newly created pixels by using a linear distance-weighted average of the four closest pixels in the original coverage (Figure 4-5). This DEM was then used to produce a slope coverage using the ***SURFACE*** module in Idrisi.

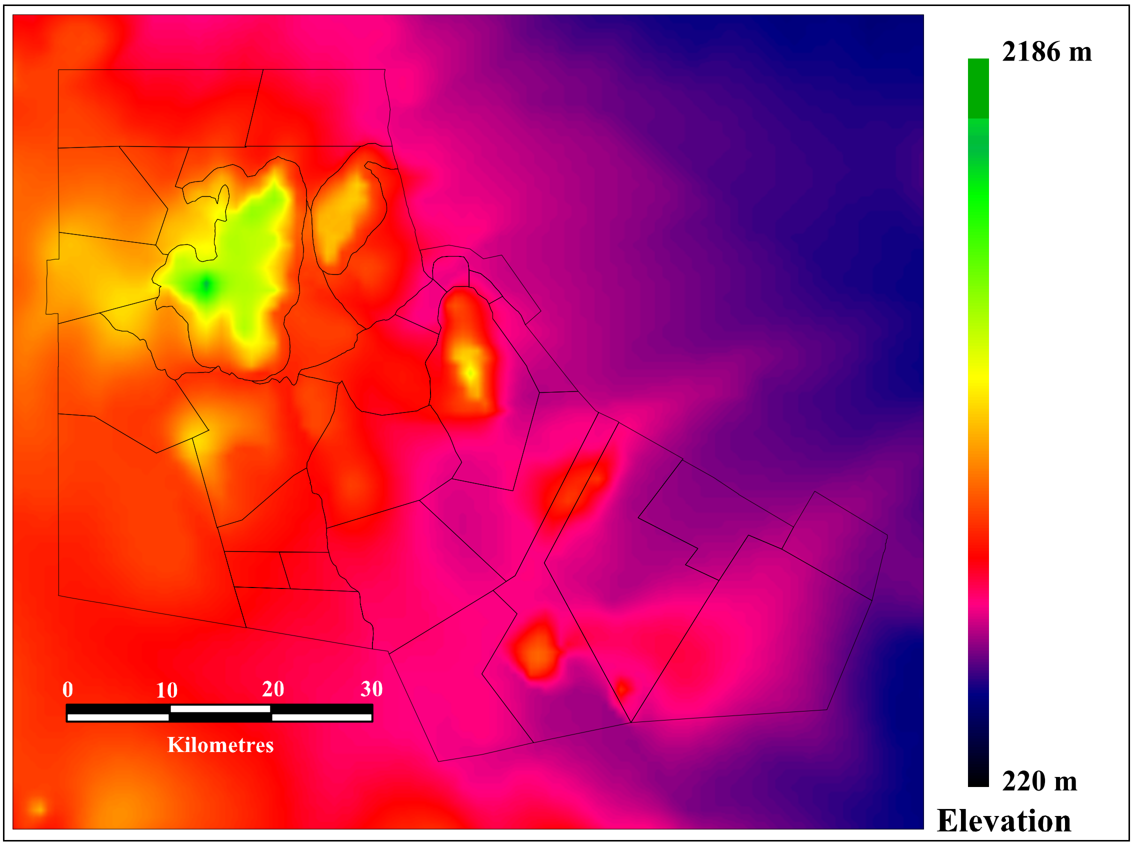

Figure 4-5: Digital Elevation Model of Taita Taveta District

4.3.2 Coverage of the Taita Hills

The position of the Taita Hills was determined from the 1 km DEM using the following method. The elevation data were first imported into ArcView and converted into a slope coverage. This was then converted into a contour coverage by using the ArcView Spatial Analyst function. It was decided to reclass any areas that had a slope of greater than 4° as being unsuitable for elephants. This produced two polygons that were imported into Idrisi and converted to the standard format.

4.3.3 Study block coverage

The study block coverage was derived from a 1:50 000 paper map. The vector map of the Taita Hills were added to this coverage and the boundaries of the blocks were modified to exclude any areas that were found on this unsuitable terrain. This meant that each block only contained land that was suitable for elephants. This final coverage was also imported into Idrisi and converted to the standard raster format.

4.3.4 PA frontage

The perimeter that each study block shared with the PAs (known as the PA frontage) was calculated using ArcView.

4.3.5 Distance to protected area coverage

The boundaries of TsE and TsW NPs were also originally digitised from 1: 50 000 paper maps. These were imported into Idrisi and converted into a raster format. It was decided to allow for the impassability of the Taita Hills in the distance coverage so the ***COST*** module was used to calculate the shortest distance of each pixel from the PAs, given a route that could not cross these hills. The ***EXTRACT*** module was then used to calculate this mean distance for each of the study blocks.

4.3.6 Distance to protected area allowing for electric fence coverage

The coordinates of the two ends of the Ndara-Ndi electric fence were recorded in the field using a GPS unit. It was then assumed that the fence followed the boundary of TsE NP and so the part of the vector that fell between these two end points was clipped from the PA coverage and imported into Idrisi. The ***COST*** module was used again to calculate the minimum distance of each pixel from the PAs, given that the shortest route could not cross the fence or go through the Taita Hills.

4.3.7 Distance to permanent water

The distance to permanent water coverage was derived from several sources. The position of the permanent rivers was taken from a coverage that was digitised from 1:50 000 paper maps. The positions of four water points were recorded in the field using a GPS unit (Figure 3-3). It was not possible to visit the remaining water points to record their position as increased poaching levels made it unsafe for KWS staff to collect these data. It was therefore decided to estimate the position of another two known water points. This means that the coverage was not as accurate as was originally planned and may exclude other unknown water points.

4.4 A comparison of different measures of HEC

There are great benefits in displaying HEC incident data in ways that can be easily interpreted by decision-makers and other stakeholders. One way of enhancing this information is to adjust the HEC incident density according to a determining factor. For example, if HEC levels were partly dependent on distance to the nearest PA then multiplying the HEC density in each study block by this distance would allow for this relationship. The resultant maps would show which blocks had higher than expected HEC levels, given their distance to the PA. These blocks could then be the focus of further research or they could be the targets of increased resources to reduce conflict incidents to the expected levels.

Therefore, this approach was tested, using two different possibly determining factors (Hoare, pers. comm.), to compare the results with maps showing unadjusted data. The first method adjusted for distance to the PAs, as mentioned above, by multiplying the HEC incident density of each block by its mean distance from the PAs. The second adjusted the density according to the amount of perimeter that each study block shared with the PAs, by dividing the HEC incident density by the shared perimeter distance.

4.5 Identifying the factors that determine HEC in Taita Taveta

The relationship between HEC and seasonal conditions is a complicated one and not yet fully understood (Kasiki, 1998). This is particularly the case in the Tsavo ecosystem, where rainfall can vary widely throughout the year and have a very patchy distribution. Therefore, it was decided to carry out five different analyses on the HEC data set. The first analysis used all of the available data that was collected between July 1994 and June 1997. Two other analyses looked at data that were collected in the rainy and dry season respectively. In this case the rainy season was defined as occurring in the months of November, December and from March to May. The remaining seven months were defined as the dry season.

The final two analyses looked at data that were collected in the high conflict and low conflict season, respectively. The high conflict season was defined as the six calendar months in each year that during the three-year study period experienced the highest levels of HEC. These six months were February, March, August, September, October and November. The remaining six months were classified as the low conflict season.

These five data sets were all analysed using the same methods which used a general linear model to test whether HEC incident densities were significantly related to the following factors:

- Mean distance from the PAs
- Mean elevation
- Mean slope
- Human density
- Elephant density
- PA frontage
- Mean distance from water
- Proportion of block covered by crops
- Type of block land-ownership

The proportion of crop cover was transformed using the arcsine transformation and all of the continuous variables were transformed logarithmically to meet the assumption of the general linear model test. The analysis was carried out using the SPSS statistical package.

4.6 Determining the effects of the Ndara-Ndi electric fence

The electric fence was completed in June 1997 and so it was decided to compare HEC in each study block before and after this construction. Due to the seasonal nature of HEC, it was decided to use data from July '96 to December '96 as the source of data before construction and from July '97 to December '97 as the source of data after construction. Using data from 1997 had its limitations, as any changes in long-term elephant behaviour would not be recorded. However, it was decided to exclude data collected in 1998 from the analysis as this was affected by the very unusual weather conditions produced by the *el nîno* effect. Therefore, in the following descriptions "before the fence" describes the period from July to December 1996 and "after the fence" describes the six-month period from July to December 1997. This data set was analysed in three different ways that are described below.

4.6.1 A comparison of HEC levels before and after the fence's construction

The most obvious effect of the fence would be if there were significant differences in HEC levels measured before and after the fence's construction. This was tested with a paired t-test that used HEC incident data from each study block.

4.6.2 Determining whether the fence reduced HEC levels in neighbouring areas

A second effect would be to reduce relative HEC levels in those areas that were separated from the PAs by the fence. In fact, this could be seen as a more appropriate test of the fence's efficacy as it would not be influenced by any overall changes in HEC which might be caused by another, unmeasured factor. For example, even if overall levels of HEC increased during 1997, perhaps because of an increase in elephant numbers, those areas that were separated from the PAs by the fence should have experienced a smaller increase than those that were unaffected by the fence.

For the purpose of this analysis, the expected benefit that the fence brought to each block was defined as 'the mean increase in the journey distance that any elephant would have to make from the nearest portion of the PAs', assuming that the animal could not cross the fence after its construction. The significance of this factor, together with those that were used in the analysis described in section 4.5, in determining the change in HEC incident density in each study block was tested using a general linear model. This change in incident density was calculated as the density before the fence subtracted from the density after the fence. Once again, all of the continuous variables were transformed logarithmically and the analysis was undertaken using the SPSS statistical package.

4.6.3 Determining difference in the number of blocks unaffected by HEC

Changes in HEC incident density can also be studied by comparing the number of study blocks where no incidents took place before and after the construction of the fence. This method was very crude but it allowed comparisons to be made that were less affected by overall changes in HEC levels. A Chi-Squared test was used to find whether there was a significant difference in the number of study blocks that were unaffected by HEC before and after the construction of the fence.

Chapter 5: Results

5.1 Introduction

This section describes the results of the analyses discussed in the previous chapter. The first section describes the number and spatial patterns of the HEC incidents in Taita Taveta district. This is followed by a brief section that illustrates two alternative methods of displaying HEC data. The third section describes the results of using general linear models to find the factors that determined the spatial distribution of HEC in the study region. The final section describes the results of the analyses that were used to assess whether the construction of the Ndara-Ndi electric fence had any affect on HEC levels.

5.2 Descriptive statistics

During the three year period from July 1994 to June 1997 there were 1448 human-elephant conflict incidents in the study area. This meant that the overall HEC density in Taita Taveta during this period was 0.101 incidents km^{-2} yr^{-1}. The highest number of incidents were recorded in October, with a mean of 99.67 incidents/month, and the lowest number were recorded in June, with a mean of 2 incidents/month (Table 5-1, Figure 5-1).

Table 5-1: Mean monthly number of HEC incidents

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean incident no	37.33	54.67	63.67	21.33	5.00	2.00	13.67	38.67	86.33	99.67	46.67	13.67
Conflict Season	Low	High	High	Low	Low	Low	Low	High	High	High	High	Low

Months that fall in the rainy season are shaded grey

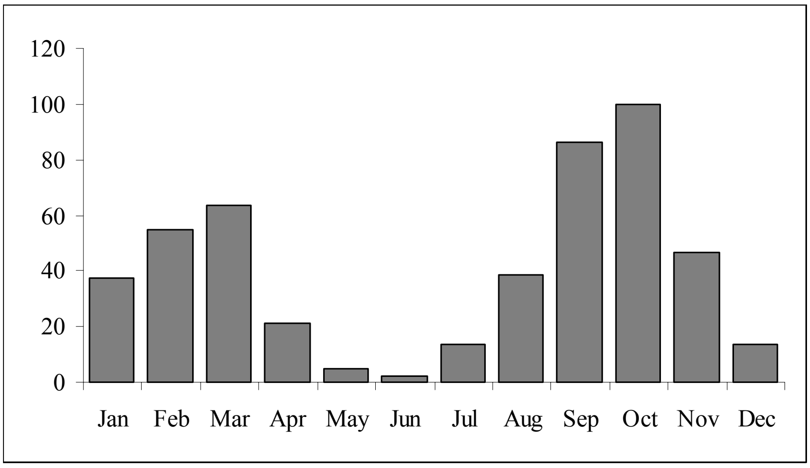

Figure 5-1: The mean monthly number of human-elephant conflict incidents

The density of incidents in each study block ranged between 0 incidents $km^{-2}yr^{-1}$ in 4 blocks to 3.08 incidents $km^{-2}yr^{-1}$ in Voi. Most of the blocks that experienced high levels of HEC were located in the north of the region, around the Taita Hills (Figure 5-2). Similar patterns were shown during the high and low conflict seasons and the dry and rainy seasons, although the incidents were more dispersed in the high conflict and the dry season (Figure 5-3 to 5-6).

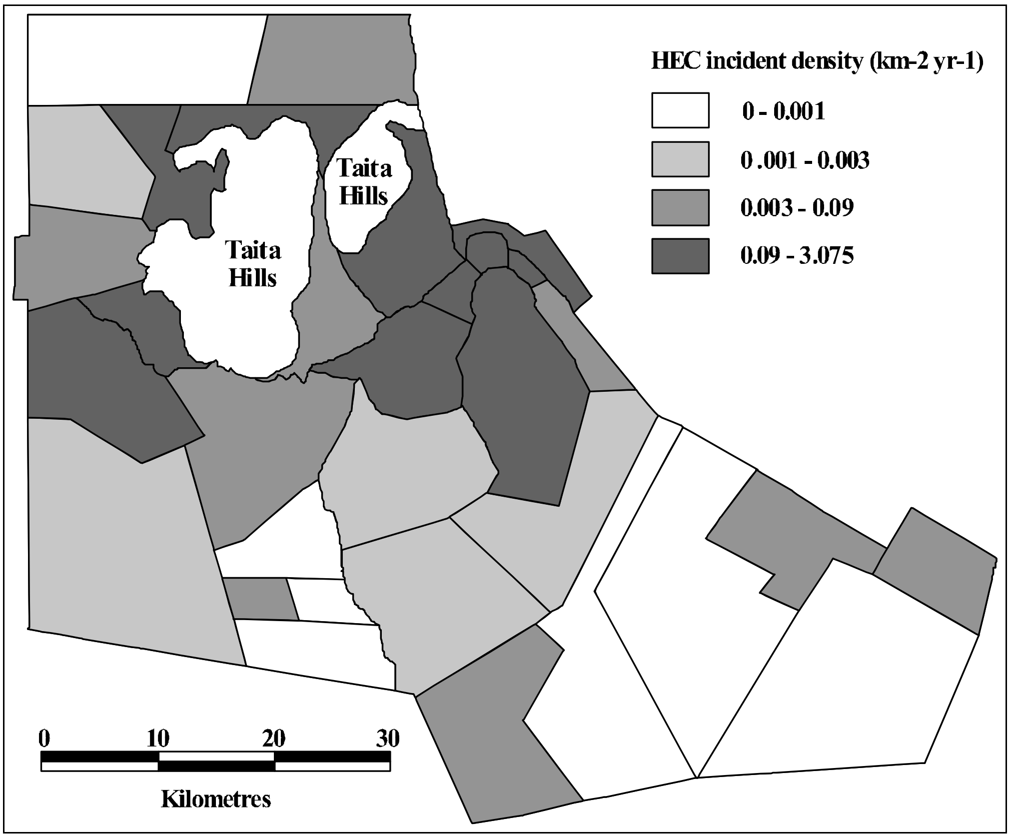

Figure 5-2: Annual HEC incident density in Taita Taveta District

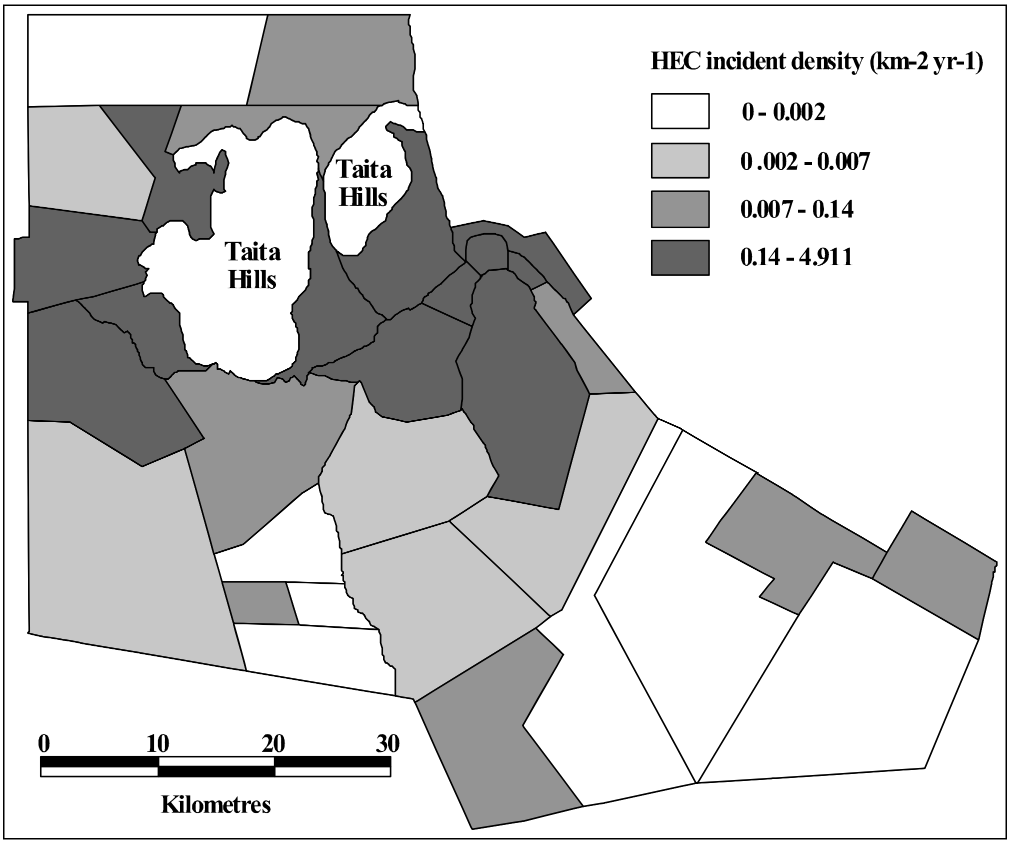

Figure 5-3: HEC conflict density during the high conflict season

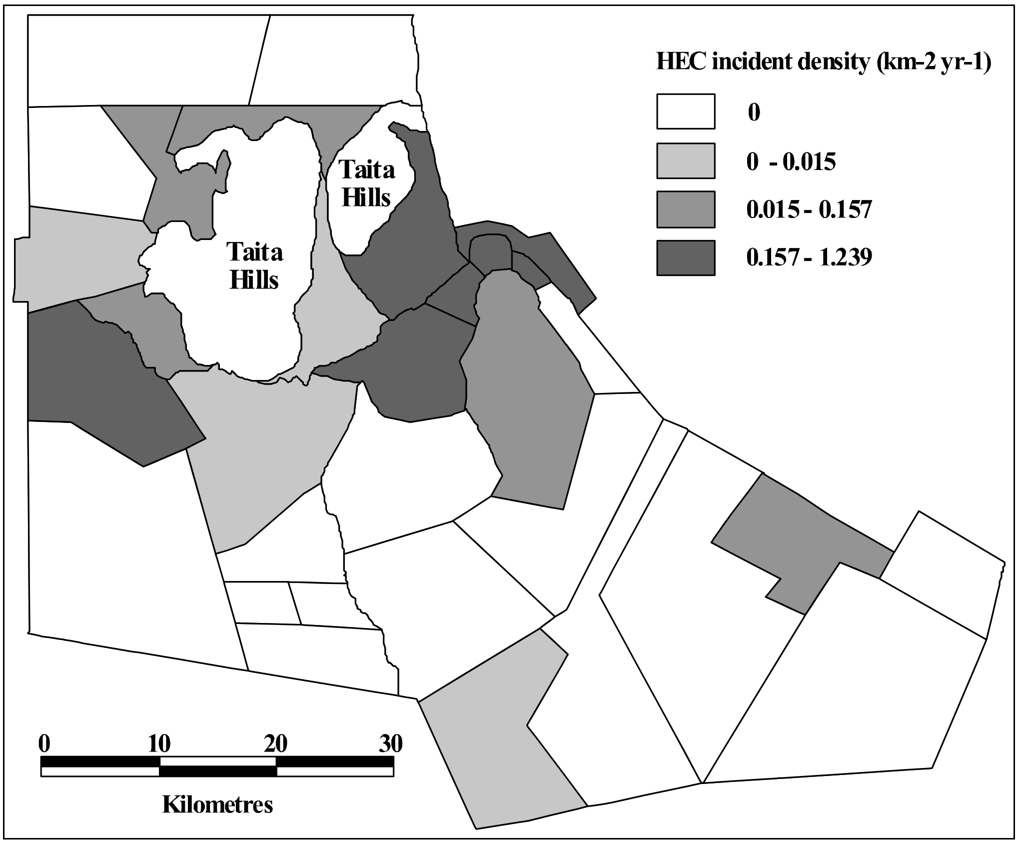

Figure 5-4: HEC conflict density during the low conflict season

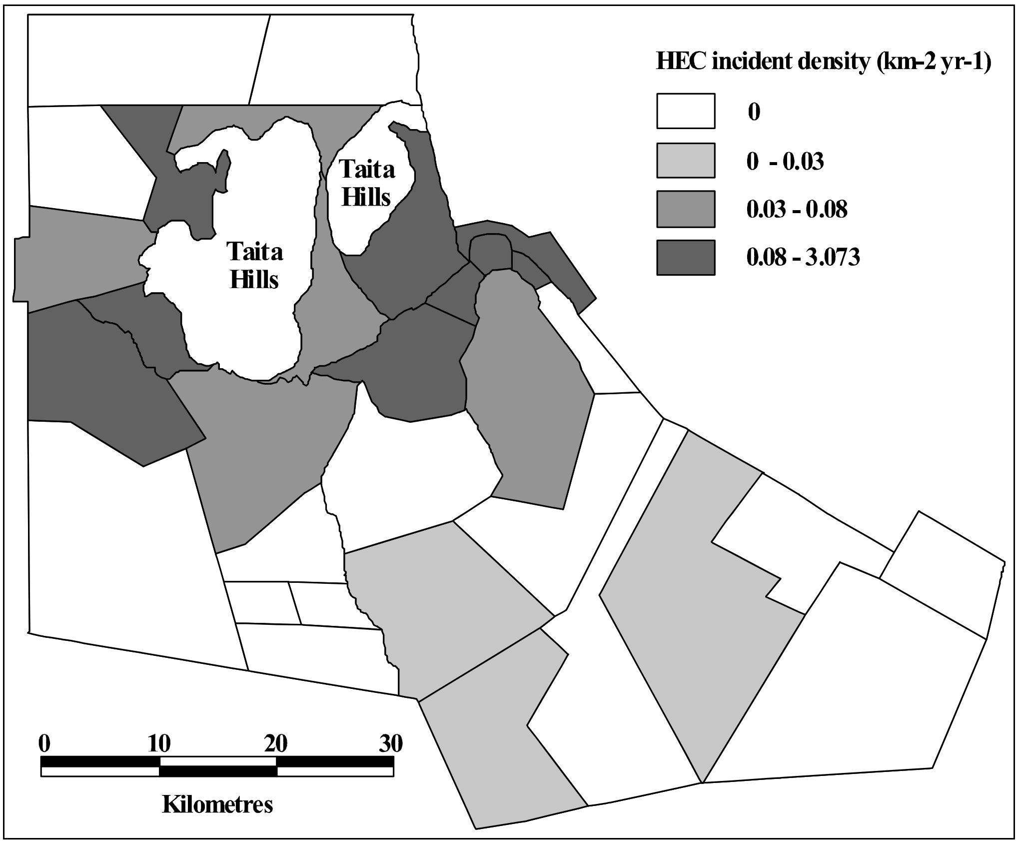

Figure 5-5: HEC conflict density during the rainy season

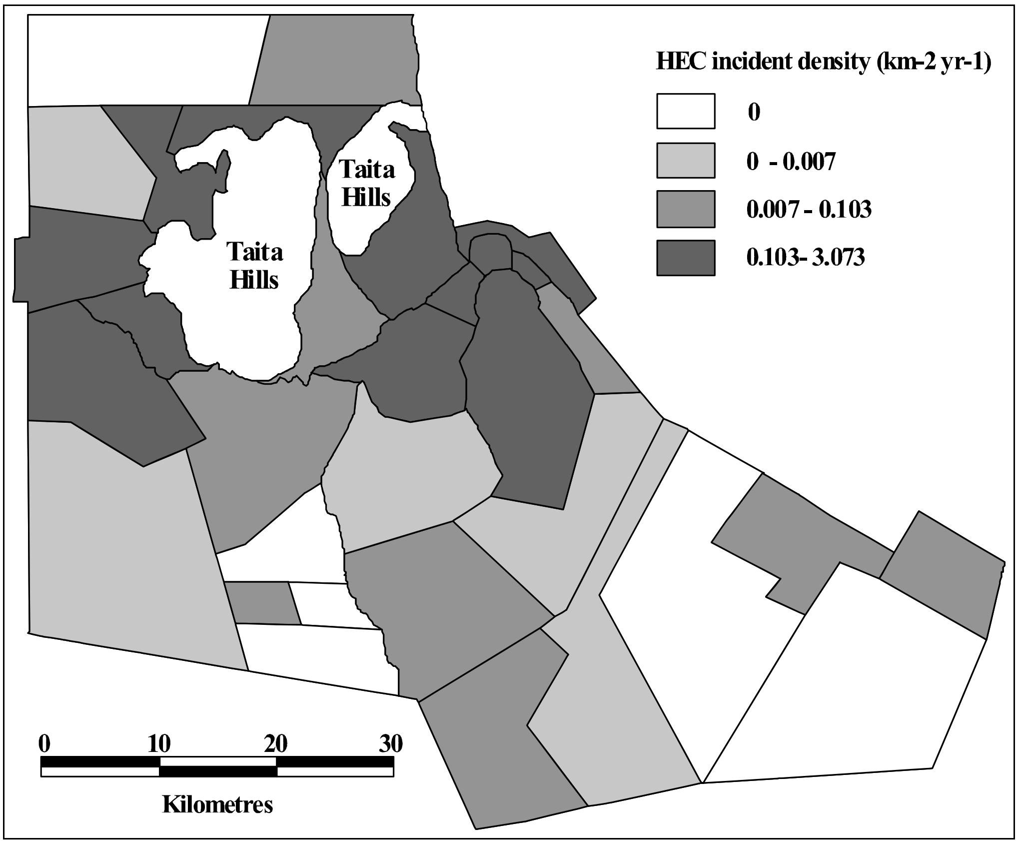

Figure 5-6: HEC conflict density during the dry season

5.3 Alternative methods of displaying HEC data

Two different methods were used to highlight areas that had higher than expected levels of HEC, given the influence of a possibly determining factor and these are described below.

5.3.1 HEC density adjusted for distance to PAs

Adjusting HEC conflict density by the distance of each study block from the PAs produced results that are displayed in Figure 5-7. After the adjustment, Mwatate had the highest levels of HEC and four study blocks still had the lowest levels because they experienced no incidents. The adjusted results further accentuated the pattern that study blocks close to the Taita Hills experienced the highest levels of HEC.

5.3.2 HEC density adjusted for shared perimeter with the PAs

Figure 5-8 illustrates the result of adjusting HEC incident density according to the perimeter that each study block shared with the PAs. Mbololo had the highest levels of HEC and three study blocks experienced no incidents. Fourteen of the study blocks did not share perimeter with the PAs so it was not possible to adjust these data. The highest levels, after adjustment, were again in the north, to the east and west of the Taita Hills.

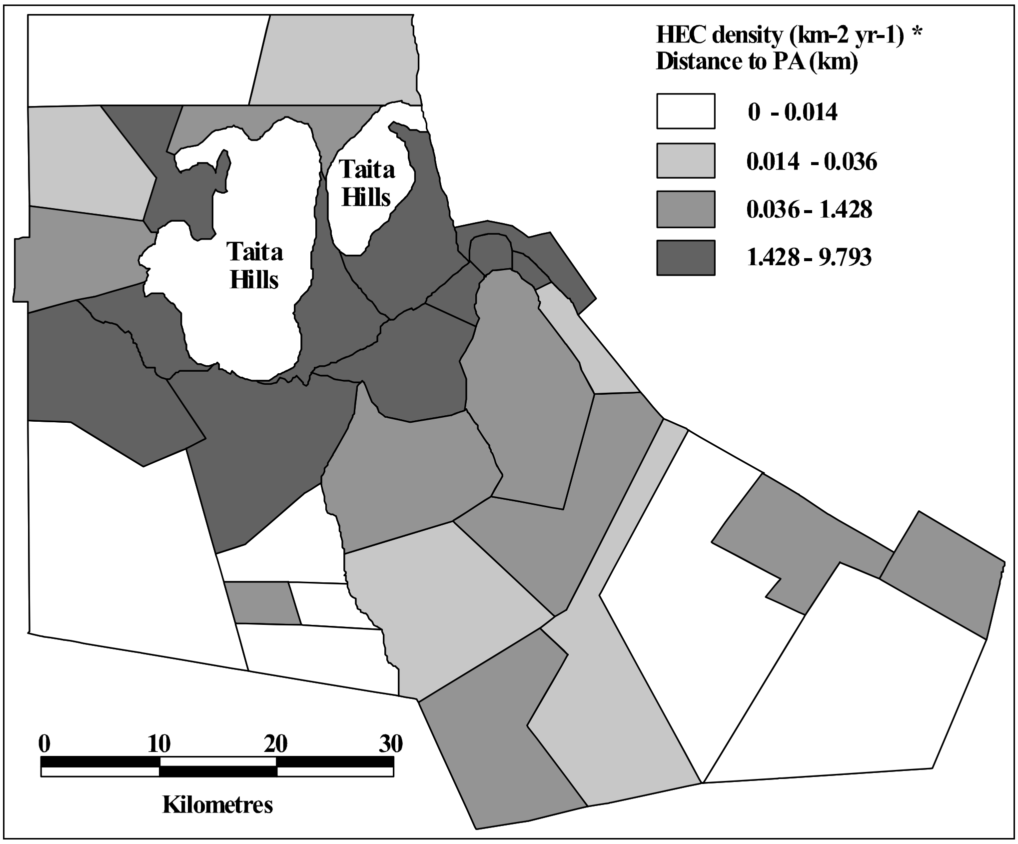

Figure 5-7: Relative HEC density after adjustment for distance to the PA

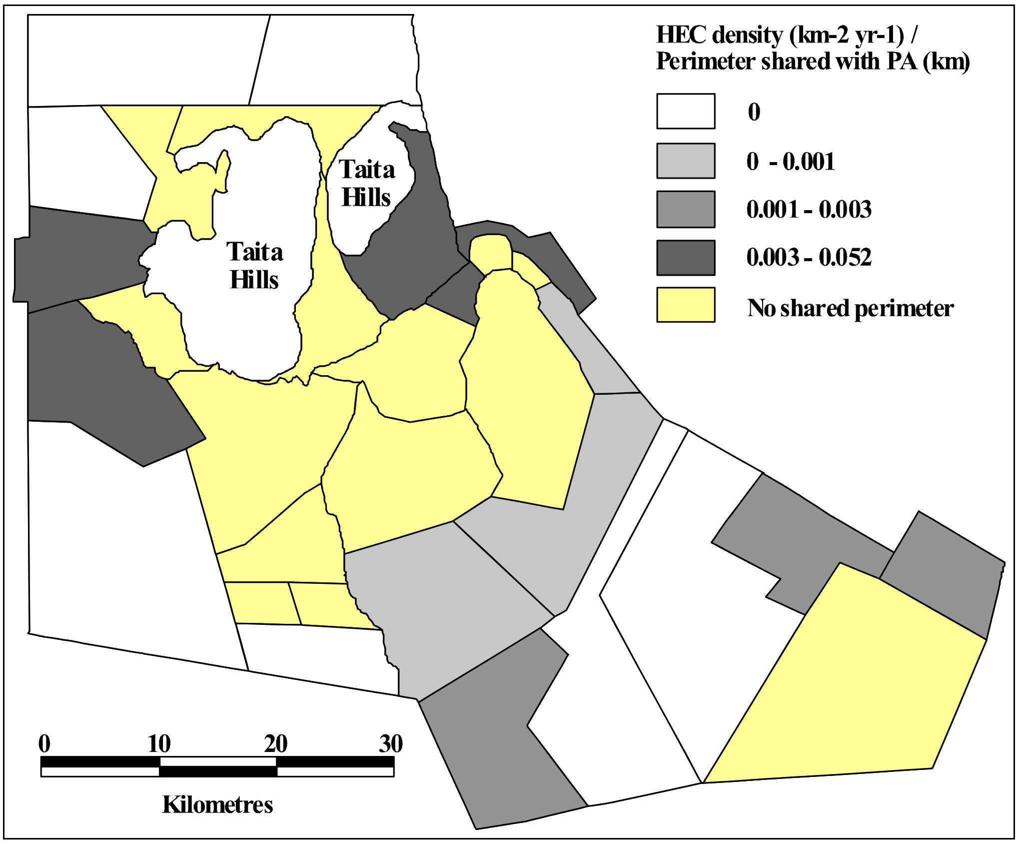

Figure 5-8: Relative HEC density after adjustment for perimeter shared with PA

5.4 Finding the factors that determine human-elephant conflict

5.4.1 Correlations between factors used in the analysis

There were significant linear correlations between all eight of the factors used in the analysis. The log_{10} of distance to water was significantly correlated with the log_{10} of human density ($p < 0.001$), the log_{10} of elephant density ($p = 0.013$), the log_{10} of slope ($p = 0.001$) and the log_{10} of proportion crop cover ($p < 0.001$). The log_{10} of percentage crop cover was significantly correlated with the log_{10} of human density ($p < 0.001$) and the log_{10} distance to PAs was significantly correlated with the log_{10} PA frontage ($p = 0.001$) (Table 5-2). In addition, the log_{10} of slope was correlated with the log_{10} of human density ($p = 0.004$), log_{10} of elevation ($p = 0.001$) and the log_{10} PA frontage ($p = 0.038$).

Table 5-2: Correlations between log_{10} of factors used in analysis

Factor (log_{10})		Elephant density	Prop crop cover	Distance to PAs	Elevation	Slope	Distance to water	Perimeter
Human density (km^{-2})	*Pearson correl.*	0.130	0.697	-0.040	0.198	0.501	-0.557	-0.308
	Sig.	ns	**	ns	ns	**	**	ns
Elephant density (km^{-2})	*Pearson correl.*	-	0.130	0.181	-0.113	0.120	-0.443	-0.255
	Sig.		ns	ns	ns	ns	*	ns
Prop crop cover	*Pearson correl.*		-	0.044	0.295	0.495	-0.602	-0.187
	Sig.			ns	ns	**	**	ns
Distance to PAs (m)	*Pearson correl.*			-	0.296	0.284	0.337	-0.580
	Sig.				ns	ns	ns	**
Elevation (m)	*Pearson correl.*				-	0.448	-0.352	-0.164
	Sig.					**	ns	ns
Slope (°)	*Pearson correl.*					-	-0.546	-0.375
	Sig.						**	*
Distance to water (m)	*Pearson correl.*						-	0.046
	Sig.							ns

* = $0.05 \geq p > 0.01$ ** = $p \leq 0.01$

5.4.2 The factors that determined the spatial distribution of HEC in Taita Taveta

The five separate analyses of the annual, low conflict season, high conflict season, rainy season and dry season data showed similar results. In each case the log_{10} of the incidents km^{-2} yr^{-1} was significantly and negatively related to the log_{10} of the mean distance of the block to permanent water, (Figure 5-9) the mean elevation (Figure 5-10) and PA frontage (Figure 5-11) (Table 5-3).

The adjusted R^2 of the model using all the data was 0.703, whereas the adjusted R^2 values for the models derived from the high and low seasons data were 0.716 and 0.651 respectively. The adjusted R^2 of the rainy season model was 0.615, whereas the adjusted R^2 of the dry season model was 0.739 (Table 5-4).

In all five cases, there was no significant relationship between HEC density and the study blocks' ownership status or the $\log_{10}$ mean human density, elephant density, slope, proportion of crop cover or distance from the PAs.

Table 5-3: Details of the factors that significantly determined HEC incident density

	Annual HEC incident density			HEC incident density in low season			HEC incident density in high season		
Factor ($\log_{10}$)	**B**	**t**	**Sig.**	**B**	**t**	**Sig.**	**B**	**t**	**Sig.**
Dist. to water (m)	-0.368	-8.224	0.000	-0.196	-7.244	0.000	-0.488	-8.516	0.000
Elevation (m)	-0.495	-3.453	0.002	-0.326	-3.759	0.001	-0.593	-3.232	0.003
Perimeter (km)	-0.006	-2.598	0.015	-0.003	-2.446	0.021	-0.008	-2.611	0.015
Constant	2.619	6.810	0.000	1.509	6.493	0.000	3.355	6.819	0.000

	HEC incident density in rainy season			HEC incident density in dry season		
Factor ($\log_{10}$)	**B**	**t**	**Sig.**	**B**	**t**	**Sig.**
Dist. to water (m)	-0.316	-6.728	0.000	-0.401	-9.006	0.000
Elevation (m)	-0.430	-2.860	0.008	-0.525	-3.681	0.001
Perimeter (km)	-0.006	-2.437	0.022	-0.006	-2.686	0.012
Constant	2.257	5.601	0.000	2.824	7.386	0.000

Table 5-4: The adjusted R^2 values of the five regression models

Regression model	**All data**	**High conflict season**	**Low conflict season**	**Rainy season**	**Dry season**
Adjusted R^2	0.703	0.716	0.651	0.615	0.739

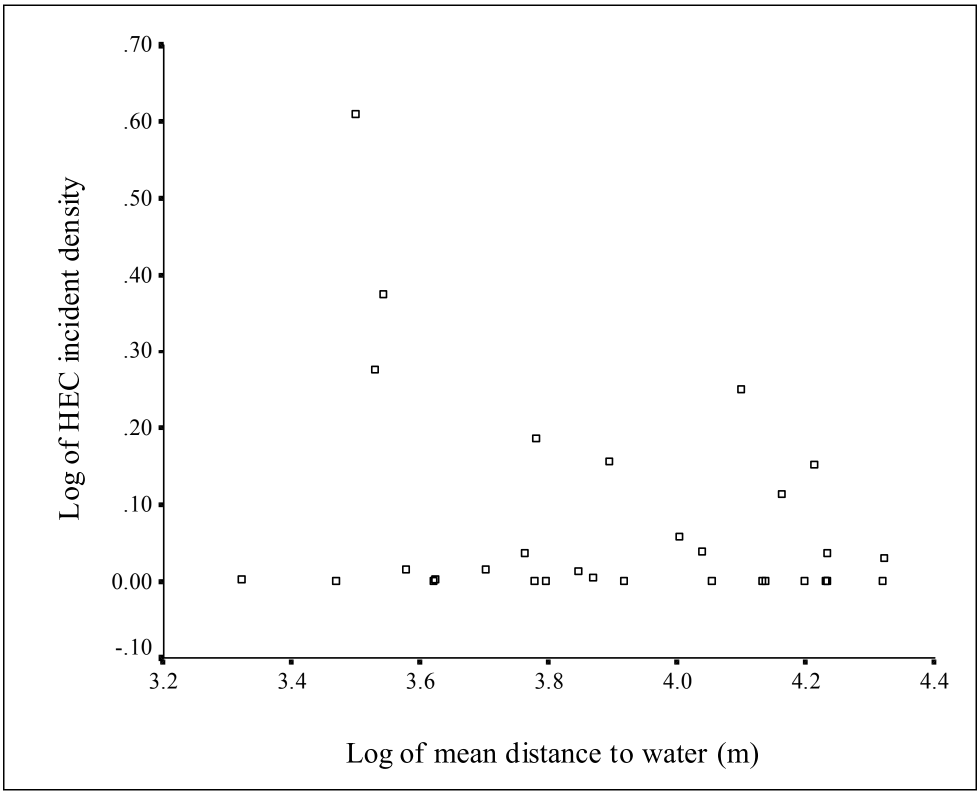

Figure 5-9: The relationship between distance to water and annual HEC incident density

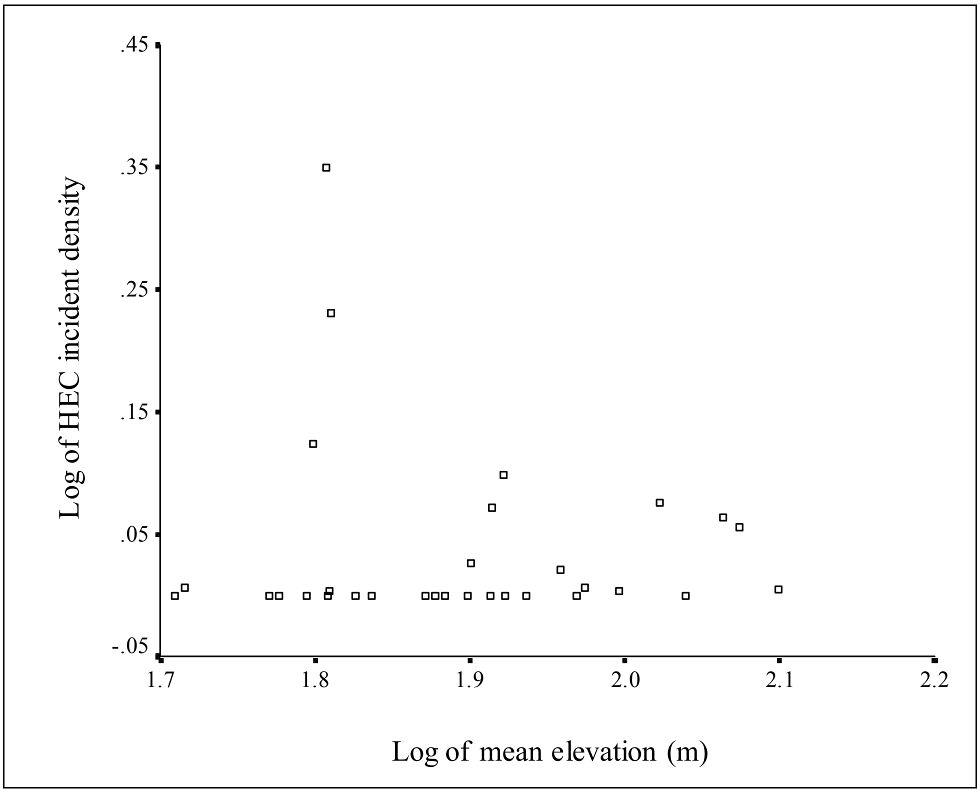

Figure 5-10: The relationship between elevation and annual HEC incident density

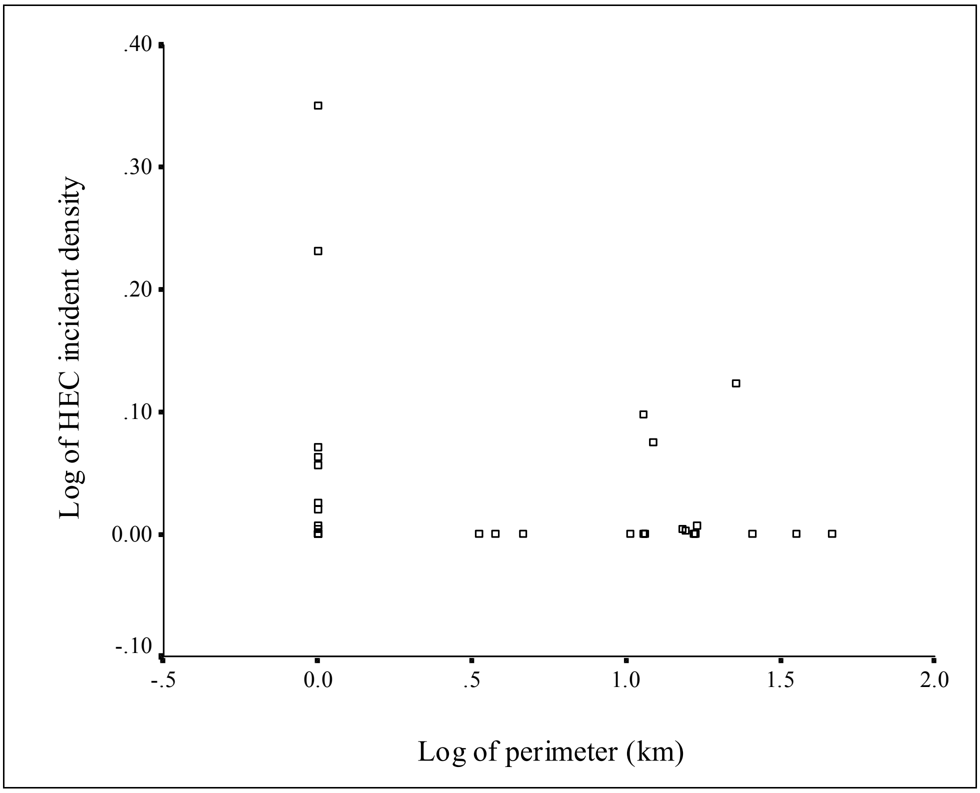

Figure 5-11: The relationship between PA frontage and annual HEC incident density

5.5 The effects of the Ndara-Ndi electric fence

There were 277 HEC incidents recorded between July '96 and Dec '96 (before the construction of the fence) and 261 incidents recorded between July '97 and Dec '97 (after the construction of the fence). The highest block density before the fence was 3.972 incidents km^{-2} yr^{-1} in Voi and 13 blocks experienced no incidents (Figure 5-12). The highest block density after the fence construction was 2.81 km^{-2} yr^{-1} in Ndara and six blocks experienced no incidents (Figure 5-13). The mean HEC density before the fence was 0.338 incidents km^{-2} yr^{-1} (s.d. = 0.793), whereas after the fence it was 0.298 km^{-2} yr^{-1} (s.d. = 0.613).

There was no significant difference in the HEC incident density in each block before and after the fence construction ($p = 0.623$, $t = 0.497$, $n = 31$). There was also no significant relationship between changes in density in each block before and after the fence and the increase in distance from the PAs caused by the construction of the fence (Figure 5-14). This was still the case when other factors, such as human density, ownership type, elevation and distance to water where included in the analysis. There was a significant difference in the number of study blocks where no HEC incidents took place before and after the construction of the fence ($p > 0.001$, $\chi^2 = 10.13$, df = 1). Thirteen study blocks experienced no incidents in the six-month study period before the construction of the fence, whereas only six were affected after its construction (Table 5-5).

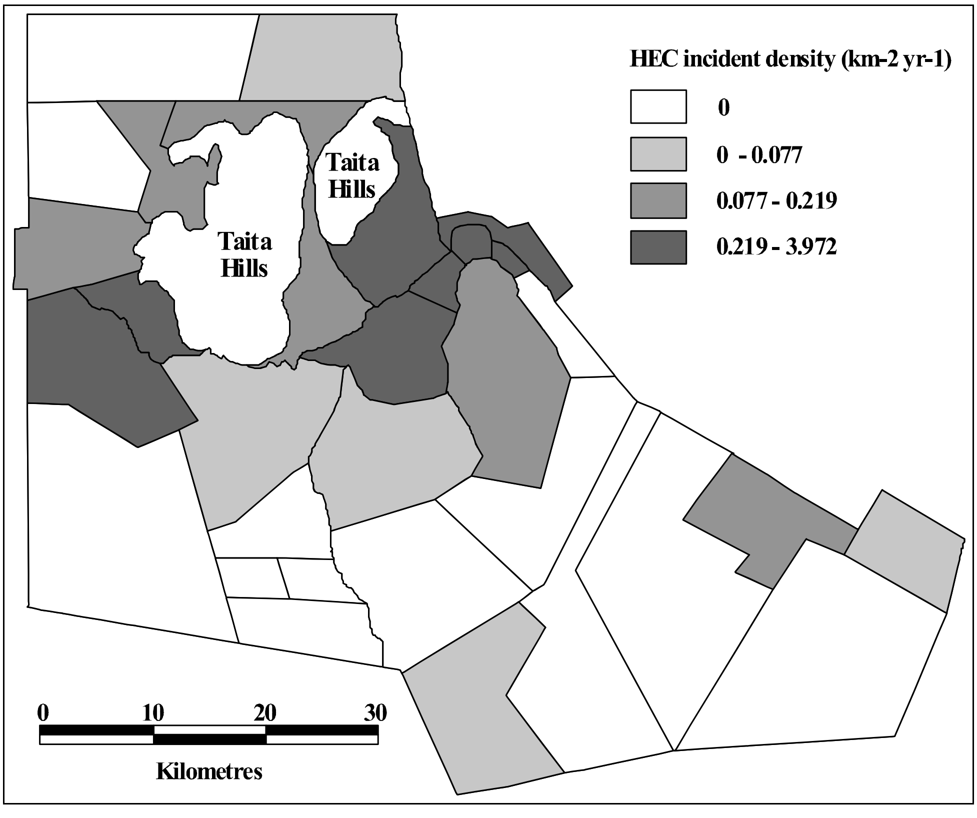

Figure 5-12: HEC density before the construction of the electric fence

Table 5-5: Distribution of HEC in study blocks before and after fence construction

	Blocks with no HEC incidents	Blocks with HEC incidents
Before fence	13	18
After fence	6	25

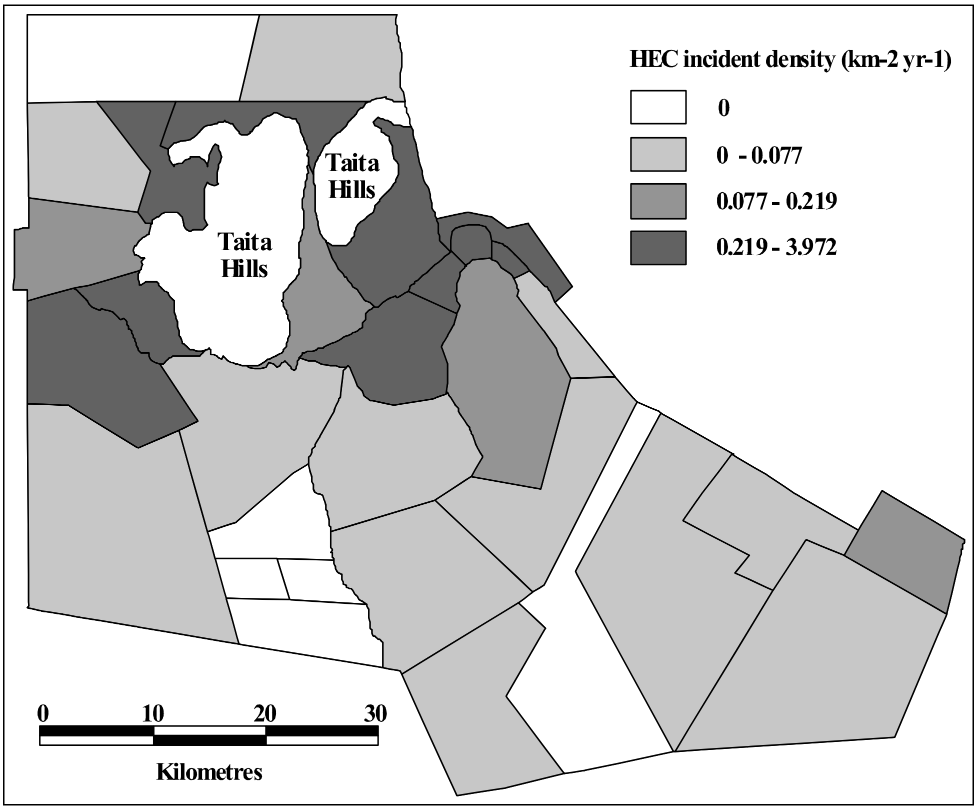

Figure 5-13: HEC density after the construction of the electric fence

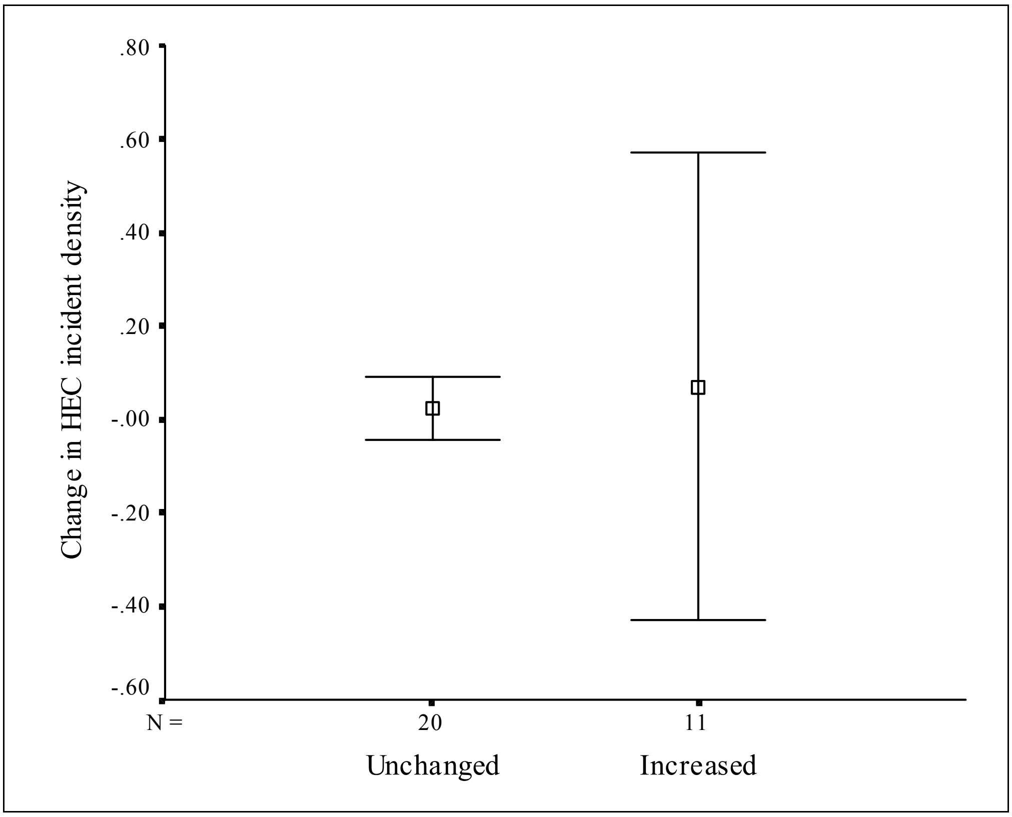

Figure 5-14: The mean (and 95% confidence intervals) change in HEC density in study blocks where the fence increased distance to PAs with those where it did not.

Chapter 6: Discussion

6.1 General discussion

Geographical information systems have been used by conservation biologists to investigate a wide range of problems but this project is the first to apply this technology to the analysis of HEC data. The results from this work have shown that this approach has great potential for understanding HEC and these will be discussed in detail in this chapter.

The first section compares HEC levels in Taita Taveta with results from similar studies and goes on to describe the benefits of using maps to display weighted HEC levels to identify areas which are particularly affected. The second major section discusses the results from the analysis of HEC incident density in Taita Taveta and suggests two different ways that these can be interpreted. This is followed by a discussion of the efficacy of the Ndara-Ndi electric fence. The final two sections suggest ways in which the results from this project could be applied to mitigate overall HEC levels and discuses how the spatial analysis of these data could be improved.

6.2 HEC in Taita Taveta

6.2.1 Comparisons with other HEC zones

The overall HEC incident density in Taita Taveta during the period of July 1994 to June 1997 was 0.101 incidents km^{-2} yr^{-1}. In the study blocks these densities ranged between 0 incidents km^{-2} yr^{-1} in Choke Ranch, Kishushe Ranch, Mwasi Ranch and Wanainchi and 3.08 incidents km^{-2} yr^{-1} in Voi. In comparison, Hoare (1999) found that densities in 21 study blocks in the Sebungwe region of Zimbabwe ranged between 0 and 0.81 incidents km^{-2} yr^{-1}. These results seem generally lower but the mean size of the study blocks was much larger in Sebungwe (442 km^2, compared to 152 km^2 in Taita Taveta). In fact, the HEC incident density for the whole of Sebungwe was almost three times higher than that of Taita Taveta.

There were also important differences in the group size and composition of crop-raiding elephants in Sebungwe and Taita Taveta. In Sebungwe, studies of crop-raiding elephant groups showed that 79% of the incidents involved lone bulls or male groups (Hoare, 1999). These results were similar to findings from south-east Asia (Sukumar, 1990) and another region of Zimbabwe (Osborn, 1998) where it was also found that HEC tended to involve male elephants travelling alone or in small groups. In contrast, most (62%) HEC incidents in Taita Taveta involved groups of six or more elephants that often included females.

One possible explanation for this difference is that elephants in the Tsavo NPs are attracted into the surrounding farmland by the presence of water. Leuthold (1977) found that the seasonal distribution of elephants was related to rainfall and surface water availability and recent research has confirmed this pattern (McKnight, 1996; Kasiki, 1998). The Tsavo ecosystem receives little rainfall (the mean annual rainfall is 550 mm, as compared to 680-750mm in Sebungwe) and so the presence of artificial water-points outside the PAs is likely to attract elephants of both sexes into the surrounding agricultural land. Alternatively, it may that elephants cross Taita Taveta when moving between TsE and TsW NPs and that these individuals are representative of the whole elephant population. This second explanation is discussed in more detail in section 6.3.2.

6.2.2 Displaying the data

Maps are an extremely important management tool as they can display complex information in a form that is quickly understood. They have a particularly important role when illustrating results from HEC research as the potential audience may have a wide range of educational backgrounds. The most obvious approach to displaying HEC data is to produce maps which illustrate levels of HEC incident density and this has been adopted for most of this report. However, there are alternatives and in some situations it may be preferable to identify areas which have higher incident levels than expected, given the influence of another factor.

This approach was used to weight HEC data from Taita Taveta using two factors that were identified as being important in predicting HEC incidents throughout Africa (Hoare, pers. comm.). These factors were distance to the nearest PA and the PA frontage. The weighted results for the first map were calculated by multiplying HEC density by distance from the PA (Figure 5-7), whereas the results for the second map were calculated by dividing HEC density by the PA frontage (Figure 5-8). These new maps showed that weighted HEC densities tended to be higher around the Taita Hills, although these areas could also be identified as important from the non-weighted maps.

In general these maps served a useful purpose but they had three limitations:

1) Distance to the PAs was not a significant factor in predicting HEC density in Taita Taveta. This suggests that it will be difficult to identify universal factors that play a role in determining HEC in every HEC zone.

2) Only 11 of the 31 study blocks in Taita Taveta shared a perimeter with the PA and so the weighted densities of the other 20 blocks could not be calculated or displayed. It would be preferable to use factors that allow a value to be calculated for each study block.

3) The linear weighting chosen for these maps was entirely arbitrary and this greatly affected the resultant map. HEC density could, for instance, be multiplied by the square of distance to the PA, increasing the apparent importance of study blocks at the centre of the district.

In conclusion, producing maps showing weighted HEC incident density can be a useful management tool but the potential lack of universal determining factors and the arbitrary nature of the type of weighting may limit their value.

6.3 Interpreting the factors that determined HEC density in Taita Taveta

The spatial analysis of HEC data identifies which factors have a significant effect on the patterns of conflict observed. These factors may directly determine where HEC incidents occur but they may act instead as a surrogate for other unmeasured factors. This analysis found that HEC incident density in a study block was significantly and negatively related to the distance of that block from permanent water, its PA frontage and its mean elevation (Table 5-3, Figures 5-7 to 5-9). Therefore, HEC density was highest in those blocks that were close to water, shared no border with a PA and were found at a low altitude.

This section will interpret the significance of these three factors in two different ways. The first assumes that each of the factors is directly responsible for determining HEC levels and interprets the results accordingly. The second is based on the observation that the HEC patterns seem to be related to the position of the elephant migration routes that cross Taita Taveta.

6.3.1 A direct interpretation

Any interpretation of the significant factors must allow for whether they were correlated with any other measured factors. Some correlations may be trivial, as is illustrated by the relationship between PA frontage and distance to the PAs. This is because those blocks that shared a boundary with the NPs will always tend to be closer to the PAs than other blocks.

Other correlations may be more important and this is probably illustrated by the correlation between mean distance to permanent water with mean human density, elephant density and crop cover. All four of these factors are likely to influence HEC levels and this should be considered when explaining the significance of distance to water. Similarly, mean elevation in each block was correlated with mean slope and the significance of one may be partly dependent on its correlation with the other.

Possible explanations for the significance of the three factors are as follows:

A) Distance to permanent water

Elephants in Taita Taveta are attracted to areas where water and food is available. In general, these areas tend to be close to artificial water-points and these areas also have the highest human densities. Therefore, the significance of distance to water in predicting HEC levels seems obvious as this factor is related to the presence of the two resources over which humans and elephants compete.

B) Elevation

The majority of elephants that crop-raid in the Tsavo ecosystem spend the daylight hours in the PAs. At night, some of the elephants move from these low-lying areas into Taita Taveta where they seem to prefer areas with similarly low elevation. These areas also tend to be flat which suggests that the elephants avoid the effort of walking uphill when crop-raiding.

C) PA frontage

Any elephant that moves from the PAs into Taita Taveta crosses a NP boundary so it might be expected that these areas would experience high levels of HEC. In fact, the opposite occurred which can be explained in the following ways:

- People in these areas are more aware of the proximity of the PA and spend more time and effort defending their crops.
- There is more PAC effort in areas close to the PAs
- People have stopped cultivating crops, such as sugar cane, mangoes and bananas, which are particularly preferred by elephants.

There is anecdotal evidence to support all three of these explanations which suggests that the strategies used both by the KWS PAC unit and local people have had some effect in reducing HEC levels.

6.3.2 The regression models and elephant migration routes

The direct interpretation given above suggests reasons for the significance of the three factors but it does not explain one puzzling feature of the results. This is that all four of the regression models that described the seasonal patterns of HEC contained the same three factors. This is despite great seasonal differences in crop and water availability. It might be expected that distance to water should be significant during the dry season and the high conflict season (when crops were ripe) but not during the rest of the year. In fact, the regression models from those two seasons explain more of the observed variance than the models from the wet and low conflict season (Table 5-4) which supports this expectation. However, the significance of these three factors throughout the year suggests that another, unmeasured, factor plays a role in determining the pattern of HEC.

One suggestion for the identity of this unmeasured factor comes from comparing the maps of HEC in Taita Taveta with those showing the position of the traditional elephant migration routes in the district (Figure 6-1). This section will explore the hypothesis that elephants in Taita Taveta are still using these migration routes and that those study blocks that are crossed by them experienced higher levels of HEC. This hypothesis is based on conjecture but it is possible to suggest methods to test its validity and to explain how one of these factors, elevation, could predict the position of these migration routes.

Before this explanation, it is important to repeat that the identification of these traditional routes is not based on a co-ordinated piece of research. Instead, Kasiki (1998) used results from radio telemetry work carried out by Leuthold & Sale (1973), together with evidence from KWS pilots, PAC unit members, tracking on the ground and from talking with local people. This combined information is of great value but the resultant map should be seen as a schematic representation, not a precise description.

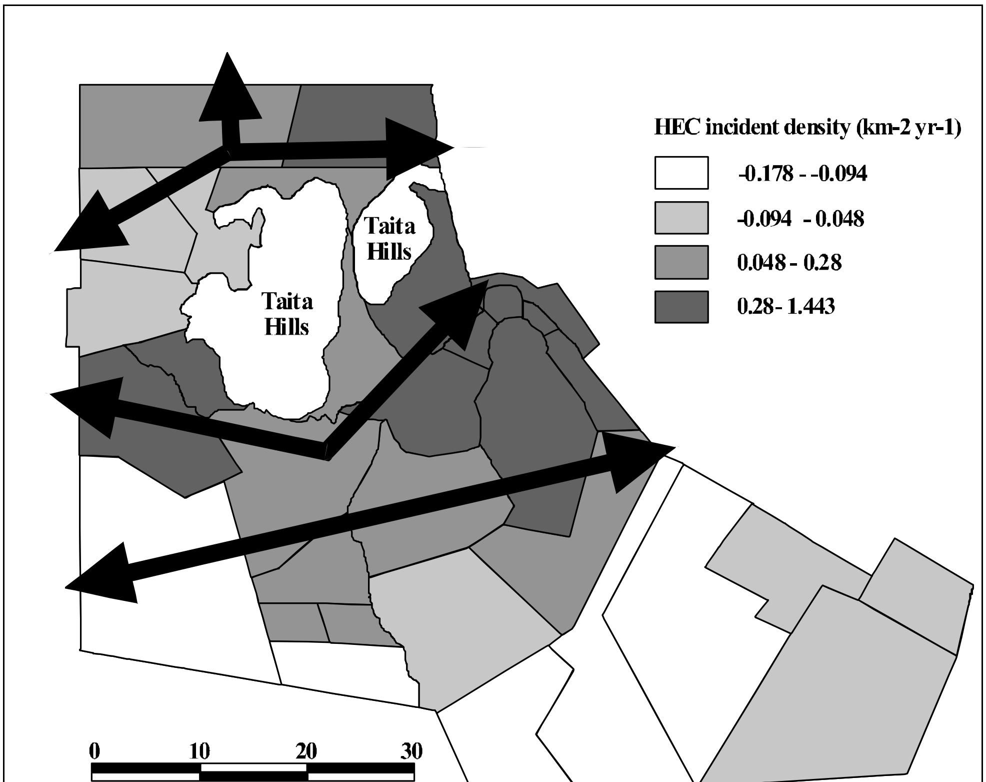

Figure 6-1: Modelled annual HEC density and the elephant migration routes

Of the three significant factors, it would still be expected that distance to water and PA frontage play a direct role in determining the patterns of HEC in Taita Taveta. This is because HEC is likely to occur wherever humans and elephants compete for resources (which is related to distance to water) and is less likely to occur wherever successful mitigation measures are being practised (which is related to PA frontage). However, it seems likely that elevation is acting as a surrogate for the position of these elephant migration routes, presumably because elephants avoid high and sloping ground when moving across the district. This theory would explain why HEC incidents continue to occur in the same locations, even when there are no crops present and surface water is freely available.

However, this does not necessarily mean that elephants crop-raid on an *ad hoc* basis and they could be using the migration routes in the following three ways:

1) Elephants follow the old migration routes when moving across Taita Taveta and remember the position of growing crops and water-points. They then return to these locations when the crops are ripe or surface water is in short supply.

2) Elephants follow the old migration routes when moving across Taita Taveta and opportunistically take advantage of the resources that they pass.

3) Elephants do not cross Taita Taveta using the old migration routes but they do use them to move from and to the PAs in the search for crops and surface water.

These three explanations and the whole hypothesis could be tested by tracking the movements of individual elephants using GPS radio collars (Douglas-Hamilton, 1998). This would allow data on the nocturnal movements of these animals to be recorded but collecting enough information from enough individuals (at least five) would be costly. However, such a study would be enormously valuable and should be seen as a long-term goal.

However, a more cost-effective method could be used to identify the position of these migration routes. This would involve gathering the large amount of anecdotal evidence that is generally available on where elephants are seen when moving through an area. This evidence could come from the PA staff, as well as from people who have lived in the area for many years. By asking different people to identify portions of the route, this can be recorded using a GPS unit and mapped using a GIS. It would then be possible to measure signs of elephant presence (such as dung or browse damage), both along the proposed route and at varying distances from it. If these signs decrease in frequency with distance from the route then it can be assumed that elephants are using it to move between sites.

6.3.3 Comparisons with other studies

Research from other sites has found that HEC density tends not to be related to factors that determine the distribution of people and elephants at the scale of the HEC zone. For example, Hoare (1999) found that HEC density in the Sebungwe region of Zimbabwe was unrelated to elephant density, proximity to the nearest PA, area of human settlement, human density or local rainfall. This was despite recording HEC incidents over a three year period. Naughton-Treves (1998) also found that elephant crop-raiding incidents in the fields that surrounded Kibale Forest in Uganda were unrelated to distance to the PA, in contrast to the other major crop-raiding species that were found there.

Hoare (1999) argues that HEC incidents in Sebungwe were irregular and unpredictable because they mostly depended on the behaviour of a few individual male elephants. This may explain why HEC incident density in Taita Taveta was related to several of the measured factors, as the elephants involved seemed much more representative of the whole population. Alternatively, it might be that the factors used in this analysis were related to the traditional migratory routes used by elephants in the Tsavo ecosystem. This hypothesis was discussed in more detail in section 6.3.2 but it is given support by a finding from Kibale Forest. Naughton-Treves (1998) found that elephants crop-raided in only three of the six study sites she used and that these same sites had experienced persistent elephant damage since at least 1951. This suggests that large-scale factors may determine the position of HEC incidents and that elephants continue to return to these sites even when these factors change.

6.4 Assessing the effectiveness of the Ndara-Ndi electric fence

An electric fence could have two effects that would justify its construction; it could either reduce the absolute number of HEC incidents in a HEC zone or it could alter the pattern of HEC so that areas close to the fence were less at risk. The results from this report show that the Ndara-Ndi fence appeared to do neither. However, these results should not be seen as definitive and any final judgement should be based on further analysis.

The results showed that there was no significant difference in HEC densities before and after the construction of the fence. One problem with this analysis was that it was based only on six months data recorded before and after the fence. It was felt that equal time periods, recorded during the same months of year, should be used in the analysis and the only data available after the construction of the fence was collected from July to December in 1997. It may be that a future analysis, using more data, would show significant differences, especially as this would allow more time for the elephants to adapt their behaviour.

Another problem with this type of analysis is that it does not allow for other factors that would change overall levels of HEC. It would only take differences in elephant density, food availability or a variety of other factors for any changes caused by the electric fence to be masked. However, this should not be the case for the analysis that looked at whether those study blocks that should have benefited from the fence experienced a relative decrease in HEC levels. The electric fence meant that elephants would have to travel further to reach these blocks but there was no significant relationship between this increase in journey time and any changes in HEC density.

The only significant change was that there were far fewer study blocks that experienced no HEC incidents after the fence construction. This could be seen as a benefit as there was no significant increase in overall HEC levels, so the impact of elephants in each block was reduced. People tend to resent elephants because they cause huge local damage and so spreading the impact may reduce this hostility (Naughton-Treves 1998). Alternatively, it could mean that more people would be affected and so resentment would rise further. It should also be noted that this analysis was based on an arbitrary definition of classes, i.e. study blocks which experienced HEC versus study blocks which did not. These categories were chosen because this pattern was noticeable from mapping the results (Figures 5-13 and 5-14) and the significance of any differences could change if other, equally arbitrary, classes were chosen.

Therefore, it appears that the Ndara-Ndi electric fence had no significant effects on HEC in Taita Taveta district. One reason for this could be that some elephants have been observed crossing the fence at two isolated points where it was not functioning. This would obviously reduce the fence's efficacy but it might be expected that it would still have some effect. Another possible reason is that the fence is 30 km long, whereas the length of the boundary with the PAs is 270 kilometres. Elephants have well established home ranges in the Tsavo ecosystem and the extra distances that they would have to travel due to the electric fence may not act as a deterrent (Leuthold, 1977). Anecdotal evidence suggests that this was the case and that elephants learnt to walk around the ends of the fence during the initial period after the fence construction (Kasiki, 1998).

The fact that elephants walked around, and not through, the fence may suggest that constructing a longer fence would ultimately reduce HEC. However, this longer fence would be much more expensive to build and maintain and might force the elephants to break through it to maintain their traditional home ranges. In addition, Hoare (1995) found from studies in Zimbabwe that such a strategy was ineffective and that fencing in small groups of villages was much more successful. Thouless & Sakwa (1995) found that the success of electric fences in Laikipia District in Kenya was not necessarily dependent on fence construction, design or voltage. They argue that it is much more important to make elephants associate crossing the fences with an unpleasant experience as the physical barrier itself is not enough to discourage them. Therefore, the success of any electric fencing in the Tsavo ecosystem is probably dependent on effective PAC whenever an animal breaks through.

6.5 Implications for the management of HEC in Taita Taveta

The results from the analysis of HEC in Taita Taveta can be interpreted in two ways, as has been described in section 6.3. Each interpretation can be used as a basis for a HEC mitigation strategy, both of which are discussed in the following sections.

6.5.1 A strategy derived from the direct interpretation

HEC levels in Taita Taveta were dependent on three different factors, two of which (PA frontage and elevation) cannot be modified. However, the third (distance to water) could be manipulated and the model would predict that this would reduce levels of HEC. One strategy would be to create new water-points within the PAs and build barriers around the water-points in Taita Taveta. This should encourage elephants to stay within the NPs and so levels of HEC would diminish.

However, there are several reasons why this strategy would not be a guaranteed success. Firstly, areas in Taita Taveta that were close to water also had a high crop cover and these crops might continue to attract elephants, even if water was not available. In addition, it may be difficult to build a barrier around a water-point that would keep out a determined elephant while allowing access to people and livestock. Caution is also needed when building new water-points in PAs as this can have a dramatic effect on the biodiversity of the surrounding area (Owen-Smith, 1996).

6.5.2 A strategy derived from an assumption that elephants follow traditional routes

An alternative interpretation of the results is that elephants follow migration routes through Taita Taveta and that the regression models happened to describe these routes. This interpretation would have great implications for the management of HEC in Taita Taveta. One approach would be a *laissez-faire* strategy that accepts that elephants will always prefer some areas and these should be managed in a compatible way, perhaps by changing the land-use to cattle farming. This idea is supported by results from Lualenyi Ranch, which contains no crops and few people and experiences little HEC despite neighbouring TsE NP (Figure 4-1).

However, this approach has several disadvantages. Firstly, people often cultivate land in the full knowledge that it is more susceptible to crop-raiding because no other land is available. Relocating these people, or providing them with an alternative source of income would be a complicated process. In addition, if elephants were allowed to move unhindered through these 'buffer zones' then they would soon become an extension of the PAs and may act as a base for crop raiding in adjoining areas.

Another approach would be to manage the whole of Taita Taveta so that elephants are encouraged to follow their traditional migration routes but are discouraged from crop-raiding and moving into neighbouring farmland. The first stage would be to map these corridors and to stop the farming of palatable crops along them. In addition, in some places it might be suitable to use fencing to delineate these corridors. The focus of PAC units should then be to stop animals deviating from these routes and people living in neighbouring areas should be encouraged, possibly financially, to stop elephants from moving through their property. This would be a huge task, but an approach that allows for the traditional movement of elephants may be more successful than one that tries to force them to find new routes. This planning exercise would benefit greatly from the use of a GIS that could incorporate all the available information and allow the different stake-holders to agree on a final strategy.

6.6 Limitations of the GIS

As with most GIS projects, obtaining and processing the necessary spatial data was one of the most time-consuming aspects of this work. Coverages were obtained from several sources and these had to be edited before they could be combined. Some data, such as the position of the water-points and the electric fence had to be collected in the field using a GPS unit and this was also very time-consuming. In addition, attempts to collect this GPS data was hampered by the arrival of armed poachers in Taita Taveta, which made it dangerous for KWS staff to travel around the district. Therefore, it was not possible for the co-ordinates of all of the water-points to be recorded. Instead, the positions of two water-points were estimated and it is possible that others remained unrecorded. This is of particular importance, given that distance from water was one of the factors that were significantly related to HEC densities.

Another possible limitation of the GIS was that the study blocks varied in shape and size, making any comparison less valid. For example, Lualenyi Ranch, the largest study block, was fifty times larger than Ndara, the smallest. A particular concern is that each ranch was treated as one study block and so their data were recorded at a greater scale and had less influence in the final analysis. A preferable alternative would have been to divide Taita Taveta into a series of equal-sized grid squares but this was not possible in the available time. This improved methodology is described in more detail in the following chapter.

Chapter 7: Recommendations

7.1 General introduction

The African Elephant database (AED) is a GIS that maintains and updates information on elephant numbers and distribution throughout Africa. The information in this database is extremely important and would become more so if data on HEC were added. Therefore, the HETF have designed a protocol for obtaining and analysing this additional information (Annex 2). The protocol is in its preliminary stages and is currently being reviewed by the HETF and AfESG members.

This chapter will discuss this protocol, based both on insights provided by the Taita Taveta case study and from a broader perspective. It starts by suggesting a method for defining the boundaries of HEC zones, as any inconsistencies will strongly influence further analysis. It goes on to argue that the study of HEC is scale dependent and that the available data should be analysed at a continental and HEC zone level. Finally, it describes the benefits and limitations of these two approaches and ends with a summary of the recommendations made.

7.2 Defining the boundaries of HEC zones

One of the issues that concern the HETF is how to determine the boundaries of the HEC zones that will be described in the AED (Hoare, pers. comm.). This concern is understandable, as changes in zone boundaries will have a dramatic effect on their HEC incident densities. For example, it is quite possible that two zones with similar levels of HEC would appear to have different HEC densities if their boundaries were defined using different criteria. Particular problems would be encountered if existing political or natural boundaries were adopted. In this case, varying proportions of each zone would be made up of land that experienced no HEC and this would make comparisons between them meaningless.

The following method is one way to overcome this problem:

1) A map of the study region that shows the position of any PAs, roads, rivers and human settlement should be obtained. This map must have a planar projection, such as UTM, that measures the co-ordinates in metres. This map should ideally be digitised and entered into a GIS but this is not strictly necessary.

2) The study area should be divided up into a series of grid squares. The size of these grid squares should be pre-determined and agreed by members of the HETF and the AfESG. The co-ordinates of the corners of each square should be exactly divisible by the length of the grid square. For example, if a 5 km grid square was used in Taita Taveta then the co-ordinates of one corner of one square could be 425000, 9615000. This would ensure that the location of each grid square was chosen objectively.

3) The HEC zone should be defined as all of those grid squares where at least one HEC incident has taken place there in the previous 5 years. This should be based on the available HEC incident records and the knowledge of any relevant researchers. In addition, any part of a square that falls within a PA should be excluded from the HEC zone (Figure 7-1).

This method has several advantages, the most obvious of which is that it avoids any subjectivity in deciding the position of the grid squares and how to define whether a square is part of the HEC zone. This method can also be repeated whenever necessary and allows changes in the size of the HEC zone to be measured. The whole process should ideally involve using a GIS, especially when calculating how much of each square falls within any PA. However, if a GIS is not available the process can still be completed using paper maps with little loss of accuracy.

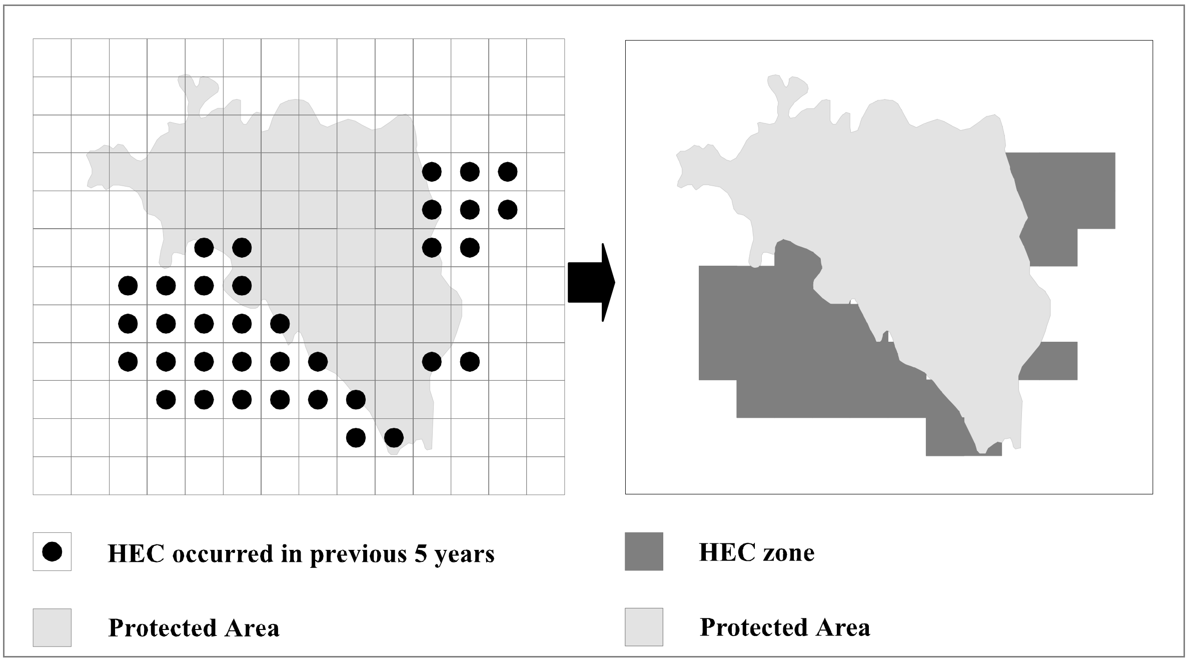

Figure 7-1: An illustration of a possible method for defining the boundaries of a HEC zone

The speed of this process could be greatly enhanced if the position of all HEC incidents were recorded using a GPS unit. It would then be very easy to determine whether HEC had occurred in a particular grid square in the previous 5 years and to calculate the HEC incident density within that block. Storing the data in this format would also have great advantages if the size of the grid square needed to be changed or if data were needed on the number of incidents that took place within a certain political unit or distance from a feature of interest.

The proposed HETF "Elephant damage report form" records the nearest village to each incident and asks for the map grid reference. This information would be extremely valuable, especially if a GPS unit was not available. In this case, the co-ordinates of each village and grid square could be recorded using a GPS unit at a later date. However, it would be preferable for all relevant personnel to carry and use GPS units so that they can accurately record the position of any HEC incidents, as well as any other information such as the position of elephant herds, water points, signs of poaching, etc.

7.3 HEC analysis - a question of scale

The second chapter of this report argued that data derived from a GIS should be analysed using standard statistical tests that assume independence between the different data points. These tests are widely known and can be used to find which factors determine the spatial pattern of interest. However, most phenomena show a property named spatial autocorrelation, where neighbouring points are not independent (Koenig, 1999). This means that, for example, 20 incidents of HEC in one study block should be grouped together and not represented as 20 data points in any analysis.

A more rigorous approach is to divide the study area into a series of grid squares that are large enough to be spatially independent. The data collected within each block can then be combined, for example by calculating HEC incident density, and the resultant analysis will include a data point from each block. This type of analysis is ideal for looking at HEC within one study area but it does not allow comparisons between different sites. This requires that each HEC zone is represented as one data point in the analysis and so all the relevant information from each HEC zone needs to be pooled.

Therefore, HEC data needs to be analysed in two different ways. The first treats each HEC zone as one data point and so investigates HEC at a regional or continental scale. This could be used to guide national and continental policy, as well as to investigate the influence of different funding and management strategies. This analysis should identify broad continental trends and would allow the identification of HEC zones that deserve further attention. The second type of study would analyse data at the level of the HEC zone and would be used to understand the factors that determine where HEC incidents take place and to judge the effects of particular management strategies. This involves using a GIS to divide the focal HEC zone into a series of blocks and pooling data so that each block within the zone is represented as a data point in the analysis.

When discussing results, the difference between these two types of analysis should be clearly explained and findings from one scale should not influence policy at another. There are several reasons for this, but the most important is that an explanatory model may not necessarily identify which factors directly determine HEC. It may be that the significant factors act in combination as a surrogate for another, unmeasured factor. The correlation between these surrogates and the determining factor may be case specific and so caution is needed when applying results from one scale, or indeed one HEC zone, to another.

In addition, the continental scale analysis cannot identify changes in HEC patterns within each zone. It may be that a particular management strategy does not change the overall HEC density but instead spreads it more evenly. This may lead to fewer people losing all their crops to elephants, which seems to be a major factor in the unpopularity of the species with local people (Naughton-Treves, 1998). The effectiveness of this strategy could only be determined at the HEC zone scale, either by comparing HEC densities before and after its implementation or by setting up a control area where the strategy would not be applied.

7.4 Continental analysis and the HETF protocol

The HETF data protocol is ideally suited for the analysis of HEC data at the continental scale. The proposed attributes are listed in chapter one (Table 1-1, 1-2 and 1-3, Annex 2) and these would provide a large amount of relevant information for each HEC zone. The following sections list a few suggested amendments and discuss the relevance of GISs in providing these data.

7.4.1 Amendments to the HETF protocol

Several of the attributes listed in the HETF data protocol are categorical and this raises problems when classifying a large area like a HEC zone (Hoare, pers. comm.). For example, there are several types of agricultural landuse in Taita Taveta but the protocol requires only the main method to be recorded. One solution to this problem would be to record instead the proportion of land in each class within each HEC zone. For example, in one HEC zone it may be that the agricultural land-use proportions, based on area, were 0.5 for 'irrigated cropping', 0.32 for 'livestock' and 0.18 for 'mixed farming'.

There are benefits in reducing the number of factors used in an analysis, especially when dealing with a small number of data points. In this case, the information on each class in a category can be used to identify which should be used to represent the situation in the HEC zone. This could not be done if the data were only stored in the categorical format.

Several attributes could be added to the data sheet used to describe the environmental characteristics of the HEC zone. It would be useful to know if any electric fencing was used and, if so, its length and the proportion of the PA frontage this constitutes. It would also be useful to add information concerning the amount of money and human resources that were spent in mitigating HEC.

7.4.2 Continental analysis and GISs

This broad scale analysis is not heavily reliant on the use of a GIS. The HETF have proposed 21 attributes to describe each HEC zone (Table 1-1) and of these, only three have spatial properties. In addition, one of these attributes (interface length) could be measured on the ground and the remaining two (mean and maximum incursion distance) could be approximated. It may be beneficial to carry out this analysis quickly, using estimated spatial parameters, rather than waiting for each HEC zone to be equipped with a functioning GIS. However, once the GIS has been completed it could be used to produce this more accurate data and to calculate other zone characteristics, such as habitat fragmentation levels, which may be of importance.

7.5 HEC zone analysis and the HETF protocol

The proposed HETF data collection and analysis protocol is not suitable for the analysis of HEC but the present system can be adapted easily. This type of analysis involves dividing the study area into blocks and it would seem sensible to use the grid system described in section 7.2. Adopting this grid system would also reduce concerns about comparing results from different HEC zones, as the data would be collected at the same scale. When dealing with small HEC zones it may be necessary to divide these grid squares further so that the analysis involves at least 30 data points. The following sections suggest how the HETF protocol should be adapted to allow analysis at this scale and recommends methods for obtaining the necessary spatial data.

7.5.1 Amendments to the HETF protocol

At present, the proposed HETF data protocol only requires researchers to provide information that describes the whole HEC zone. The protocol should be adapted so that the same attributes that are recorded for each HEC zone should also be recorded for each grid square within that zone. Obviously, some factors are only relevant at the scale of the whole zone so attributes such as "Human Population trend" and "Other commercial activities" should be excluded. Attributes that could be added include:

- Poaching incident density
- Crop cover
- Distance to water
- Distance to the nearest PA
- Distance to roads
- Vegetation biomass (derived from free AVHRR satellite imagery)
- Elevation

Much of this information could only be provided by using a GIS and it seems sensible that the GIS specialist, together with the researcher who completed the zone attribute data sheet, should complete the relevant data sheets. They should also record the source of all the spatial data, together with the age and scale of the original information.

7.5.2 HEC zone analysis and GISs

Obtaining the spatial data needed for this type of analysis can be a very expensive and time-consuming exercise. In addition, the coverages used are often derived from different sources, recorded at different scales and have differing levels of quality. It is for these reasons that the HETF are considering purchasing recent satellite images on which to base much of the necessary spatial data (Hoare, pers. comm.). This is an excellent suggestion that would markedly improve the quality of the data used in any analysis. However, this accuracy is dependent on the processing of these images and the following lists a suitable methodology:

1) The HETF should purchase Landsat TM images recorded by the recently launched Landsat 7 satellite. These images include a 15 metre resolution panchromatic band that should be the base of any derived data.

2) The panchromatic image should be printed out by the GIS specialists as a series of laminated A3 sheets that should be sent to researchers working in the field. These researchers should draw on these sheets to identify features of interest, such as major and minor roads, rivers, human settlements and water-points. This should reduce the chances of mis-interpretation, a problem that is prevalent in satellite imagery classification.

3) It is vitally important to geo-reference the satellite image before using it. The purchased image will be roughly geo-referenced but not to the necessary level of accuracy. Therefore, the field researchers need to identify points that are easily recognisable both on the image and on the ground. The most commonly used points are road junctions but other features, such as railway lines and buildings can be used. Natural features, such as river bends and lake edges, are much less reliable as they may change over time but they can be used if no other alternatives are available. The points should also be well spaced apart and should cover the whole region of interest.

   The field researchers then need to visit these points and record their position with a GPS. The GPS unit should ideally allow differential correction or at least have an averaging facility that will produce results with higher levels of accuracy. An alternative it to use fine-scale geo-referenced aerial photographs and to measure the position of the points on a digitising board. The position of these points should also be recorded on the A3 maps, which should be returned together with a list of the point co-ordinates, to the GIS specialists. This information should then be used to geo-reference the satellite image.

A large amount of time and effort is needed to produce accurate GIS coverages. Therefore, it is vitally important that these data are stored in a safe place that can easily be found by the relevant people. Conservation organisations often develop GISs in an *ad hoc* fashion and it is common for coverages to be lost or unnecessarily replicated. Therefore, it is highly recommended that the HETF establish a central store for all relevant GIS data, together with a meta-database that describes these coverages.

Obviously, this could only be done with the full co-operation of the local conservation organisation and their wishes should be respected. Any researcher who would want access to a particular coverage would have to gain permission from the HETF and from the organisation that may have helped produce the coverage, as well as the local conservation organisation. The coverages should be stored on a *file transfer protocol* (ftp) site that would allow anyone to download the relevant files once they had been given a password. The HETF should also provide the data on CD-ROMs for those who are not able to access the ftp site.

7.6 Summary of recommendations

The following recommendations for changes or additions to the proposed HETF data collection and analysis protocol are listed below:

7.6.1 General recommendations

- The HETF should encourage analysis of HEC data at two different spatial scales: at a continental level and at a HEC zone level.

- The co-ordinates of each HEC incident should be recorded using a GPS unit so that these raw data can be grouped at a later data for analysis at the relevant scale.

- The HETF should suggest a standard grid size that would be used to divide up each HEC zone. The area of each HEC zone should then be defined as all those grid squares where at least one HEC incident has occurred in the previous 5 years.

- The HETF should purchase the relevant Landsat 7 TM satellite images of each HEC zone and work with relevant field staff to process this imagery.

- The HETF should store all of the available relevant GIS coverages of each HEC zone on a file transfer protocol (ftp) site and maintain a meta-database that describes these coverages. This data should be available to anyone who receives permission from the HETF and the organisations that were responsible for their production.

- The HETF should produce a protocol, or recommend an existing text, to standardise the use of GPS units in collecting data and to standardise the production of GIS coverages.

7.6.2 Recommendations for continental HEC research

- The length of electric fencing used in the HEC zone should be recorded as an attribute, as well as the proportion of the PA frontage that this constitutes.

- An initial analysis at a continental scale should not be dependent on the development of a GIS in each HEC zone. However, once completed the GIS should be used to determine levels of habitat fragmentation in each zone.

- The cost of any problem animal control, both in monetary value and time should be recorded.

- Attributes should be recorded using continuous variables whenever possible.

7.6.3 Recommendations for HEC zone research

- The HETF should encourage the analysis of HEC data at the scale of one HEC zone. This should involve analysing the data collected in each of the grid squares used to identify the boundaries of the HEC zone.

- The HETF conflict zone attribute data sheet should be adapted and used to describe the attributes of each grid square used in the analysis. This information should be completed by the GIS specialist who derived the spatial data, together with the researcher who completed the zone attribute data sheet.

- The grid square attribute data sheet should include information concerning the elephant density and HEC density in each grid square, in addition to data on poaching incident density, crop cover, distance to water, distance to the PA (or other elephant refuges) and distance to roads.

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Annex 1: Terms of reference

Purpose:

The purpose of this consultancy is to investigate the relative importance and interaction of spatial, temporal and other factors (e.g. different land-uses) in predicting human-elephant conflict.

Activities:

The consultants will:

1) Familiarise themselves with other work on predictive GIS modelling

2) Collect relevant human-elephant conflict data from one site

3) Comment on the suitability of the HETF data collection protocol

4) Develop spatial analyses that integrate spatial, temporal and other factors and propose how such analyses might provide guidance for land-use planners and elephant managers in problem areas in savanna ecosystems.

5) Develop provisional human-elephant conflict GIS model based on data collected

Outputs:

A GIS model incorporating the interrelationship of factors determining human-elephant conflict, which will be the basis for a predictive model.

Annex 2: Proposed HETF data sheets

FORM 1. ELEPHANT DAMAGE REPORT FORM

REGION ………… ………… ………… ………… ………… **FORM No** ………… …………
DISTRICT ………… ………… ………… ………… …………
SUBDIVISION ………… ………… ………… …………
VILLAGE ………… ………… ………… **MAP GRID REFERENCE…** ………… ………… …………
ENUMERATOR NAME ………… ………… ………… **DATE OF INCIDENT** ………… …………
COMPLAINANT(S) NAME(S) ………… ………… ………… ………… ………… ………… …………
………… ………… ………… ………… ………… ………… …………
DATE OF COMPLAINT ………… ………… ………… ………… ………… ………… …………

CROP DAMAGE		**QUALITY BEFORE DAMAGE** (Tick one category)			**AGE OF GROUP** (Tick one category)		
CROP	TYPE	GOOD	MEDIUM	POOR	SEEDLNG	INTERM.	MATURE
CROP 1	…………	…………	…………	…………	…………	…………	…………
CROP 2	…………	…………	…………	…………	…………	…………	…………
CROP 3	…………	…………	…………	…………	…………	…………	…………
CROP 4	…………	…………	…………	…………	…………	…………	…………
CROP 5	…………	…………	…………	…………	…………	…………	…………

DIMENSIONS (Paces) OF **TOTAL FIELD** WHERE DAMAGE OCCURRED
LENGTH ………… PACES
WIDTH ………… PACES

DIMENSIONS (Paces) OF **ACTUAL DAMAGED PORTION** OF FIELD
LENGTH ………… PACES
WIDTH ………… PACES

OTHER DAMAGE TICK AND SPECIFY DETAIL

FOOD STORE ………… ………… ………… ………… ………… ………… …………
WATER SUPPLY ………… ………… ………… ………… ………… ………… …………
THREAT TO LIFE ………… ………… ………… ………… ………… ………… …………
HUMAN INJURY ………… ………… ………… ………… ………… ………… …………
HUMAN DEATH ………… ………… ………… ………… ………… ………… …………
OTHER SPECIFY ………… ………… ………… ………… ………… ………… …………

ELEPHANTS INVOLVED	**NUMBER**	**VISUAL ID**	**(Tick)**	**TRACK ID**
GROUP SIZE (TOTAL)	…………	…………		…………
Adult Male	…………	…………		…………
Adult Female	…………	…………		…………
Subadult / Calf	…………	…………		…………

YOUR COMMENTS: ………… ………… ………… ………… ………… ………… …………
………… ………… ………… ………… ………… ………… ………… ………… ………… …………
………… ………… ………… ………… ………… ………… ………… ………… ………… …………
Was This Report Forwarded?
To Whom? ………… ………… ………… Where? ………… ………… ………… …………
When? ………… ………… ………… How?

Table 1: Characteristics of Human - Elephant Conflict Zones

ENVIRONMENTAL CHARACTERISTICS			
Attribute	**Units**	**Description / Coding**	**Data**
Zone name	Text	Country District/Province Name of conflict zone	
Location	Lat/long co-ordinates	Geographic location of conflict zone preferably to be drawn on a geo-referenced topographic map.	
Year of survey	Year	Year(s) for which data are applicable	
Conflict duration	Years	Provide years of conflict duration or leave blank if unknown	
Population Density	no. / km^2	Human population density	
Human Population trend	Code	Current population trend 1 = Increasing 2 = Decreasing 3 = Constant	
Land tenure system	Code	Main land tenure system within the conflict zone 1 = Communal 2 = Leasehold 3 = Freehold 4 = State owned 5 = If other, specify	
Agricultural landuse	Code	Main agricultural land use within the conflict zone 1 = Irrigated cropping 2 = Rainfed cropping 3 = Livestock 4 = Mixed farming 5 = If other, specify	
Other commercial activities	Code	Major human activities e.g. 1 = Irrigated cropping 2 = Rainfed cropping 3 = Livestock	
Habitat	Code	Dominant habitat type within conflict zone 1 = Dense forest 2 = Patched forest 3 = Savanna woodland 4 = Shrubland 5 = Grassland 4 = Semi-desert 5 = Desert	
Water availability and annual rainfall	Code and mm / yr	Availability of water resources 1 = Perennial (no shortage) 2 = Intermittent (temporary shortage) 3 = Scarce (general shortage)	mm / yr

ENVIRONMENTAL CHARACTERISTICS			
Attribute	**Units**	**Description / Coding**	**Data**
Interface type	Code	Type of interface between human settlements & elephants 1 = 'Hard edge' (e.g. park) 2 = Isolated settlement 3 = Mosaic 4 = Shifting 5 = If other, specify	
Interface Length	km	Total length of interface (1 or 2 above only)	
Incursion distance (average)	km	average distance of elephant raids from a permanent refuge for elephants	
Incursion distance (maximum)	km	maximum distance of elephant raids from a permanent refuge for elephants	
Conflict season	Code Mark months	Peak of conflict season 1 = Dry season 2 = Wet season 3 = Wet & dry season	J F M A M J J A S O N D
Interventions human*	Text, Code	Provide max 3 data pairs describing type of human interventions and their effectiveness on a scale of 1 (high) - 3 (low) Examples given:-	Noise/Alarms Fire Watchmen Missiles Compensation Land zonation Other specify
Interventions elephant*	Text, Code	Provide max 3 data pairs describing type of elephant interventions and their effectiveness on a scale of 1 (high) - 3 (low) Examples given:-	Disturbance shooting Wounding Kill by shooting, residents Kill by shooting, authorities Poisoning attempts Irritant sprays Infrasound calls Translocation Other specify
Interventions environment*	Text, Code	Provide max 3 data pairs describing type of environmental interventions and their effectiveness on a scale of 1 (high) - 3 (low) Examples given:-	Home made barriers Stone wall Ditch/Moat Wire fence, home made Wire fence, conventional Wire fence, electrified Vegetation barrier Other specify

ENVIRONMENTAL CHARACTERISTICS			
Attribute	**Units**	**Description / Coding**	**Data**
Other pest species	Text, Code	Rank elephant with other pest species in descending order of ***perceived importance***. Provide max 5 data pairs on a scale of 1 (high) - 5 (low), e.g. (baboon, 1), (elephant, 2) (rodents, 5) Examples given:-	Primates Suids Rodents Birds Insects Carnivores Other specify

* For a classification of interventions see the AfESG journal: Pachyderm 19 (1995) pp. 67-70

List any relevant literature references to human - elephant conflict in the area:

Please add any comments and observations you may have on human-elephant conflict in your area as well as suggestions on how to improve the collection of relevant data.

Table 2: Elephant populations involved in human - elephant conflict

2A	ELEPHANT POPULATION CHARACTERISTICS		
Attribute	**Units**	**Description / Coding**	**Data**
Elephant population	Code (AED 1995)	Input zone code for elephant population	
Population Estimate	Number	Estimate for elephant population	
Area	km^2	Range area of elephant population	
Density	no. / km^2	Provide mean elephant density or leave blank if unknown	
Conservation Status	Code	Conservation status of elephant population 1 = Protected 2 = Unprotected 3 = Both 4 = Unknown	
Unnatural Mortality of Elephants	Code with estimated annual no. of deaths from each source	1 = Problem Animal Control 2 = Poaching 3 = Safari hunting 4 = None 5 = Unknown	

2A	ELEPHANT DAMAGE INCIDENTS		
Total elephant raids	Number/ year	Approx annual number of Elephant damage incidents	
Mean raiding group size	Number	Average size of raiding elephant group	
Raiding group type	Code. Quantify each annual total if known	Rank group code in descending order (i.e. commonest to rarest) 1 = Single bull 2 = Male group 3 = Cow - calf group 4 = Mixed group (i.e. 2+3) 5 = Aggregate group (>50)	
Foodcrop damage	Text Nos.	Rank food crops damaged in descending order (i.e. commonest to rarest). Quantify each annual total of incidents if known.	
Cashcrop damage	Text Nos.	Rank cash crops damaged in descending order (i.e. commonest to rarest). Quantify each annual total of incidents if known.	
Foodstore damage	Text Nos.	Rate damage to foodstore structures (e.g. granaries) by type and number of incidents per year	
Water supply damage	Text Nos.	Rate damage to water supply structures by type and number of incidents per year	
Human injuries	Number per year	Annual number of human injuries	
Human deaths	Number per year	Annual number of human deaths	

Annex 3: Details of GIS reference system

Reference system:	UTM zone 37 (Kenya)
Projection:	Transverse Mercator
Datum:	Arc 1960
Delta WGS84:	136 -108 -292
Ellipsoid:	Clarke 1880
Major s-axis:	6378249.1453260
Minor s-axis:	6356514.9667204
Origin longitude:	39
Origin latitude:	0
Origin X:	500000
Origin Y:	10000000
Scale factor:	0.9996
Units:	metres
Parameters:	0

Annex 4: Description of study blocks

Table A-1: Attributes of the study blocks in Taita Taveta district

Ranch name	Area (km^2)	Ownership	Human density (km^{-2})	Elephant density (km^{-2})	Crop Cover (%)
Bura	186.65	Small holder	22	0.9	75
Choke Ranch	84.51	Ranch	0	0.5	0
Kasigau	202.32	Small holder	4	0.3	38
Kishamba	89.36	Small holder	16	0.9	31
Kishushe	82.35	Small holder	19	0.9	70
Kishushe Ranch	229.05	Small holder	0	0.9	0
Lualenyi Ranch	426.12	Ranch	0	0.8	0
MacKinnon	94.33	Small holder	4	0.3	27
Maktau	118.29	Small holder	7	0.4	35
Mariwenyi	119.45	Small holder	16	0.9	47
Maungu	128.64	Small holder	27	0.7	30
Maungu Ranch	233.90	Ranch	0	0.9	0
Mbololo	120.89	Small holder	54	0.6	68
Mbulia Ranch	155.15	Ranch	1	0.9	2
Mgeno Ranch	201.25	Ranch	0	0.9	0
Mkuki Ranch	30.29	Ranch	0	0.8	0
Mwasi Ranch	31.09	Ranch	0	0.8	0
Mwatate	59.57	Small holder	21	0.9	71
Ndara	8.54	Small holder	41	0.9	23
Ndara Ranch	42.11	Ranch	0	0.9	0
Oza Ranch	126.47	Ranch	0	0.9	0
Ronge	68.15	Small holder	91	0.7	57
Rukanga Ranch	274.60	Small holder	0	0.1	0
Rukinga Ranch	390.89	Ranch	0	0.1	0
Sagalla	227.97	Small holder	23	0.9	61
Sagalla Ranch	193.54	Ranch	0	0.9	0
Taita Ranch	394.88	Ranch	0	0.9	0
Taita Sisal Estate	233.77	Ranch	5	0.9	98
Voi	15.61	Small holder	128	0.9	71
Voi Sisal Estate	60.87	Ranch	0	0.9	92
Wanainchi	91.39	Ranch	0	0.8	0