A landscape approach to elephant conservation in Mozambique

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Abstract

People and elephants share landscapes throughout Mozambique. Here elephant conservation management focuses on protected areas but fails to address the conflict that exists between elephants and people. In this thesis I develop a landscape approach to conflict mitigation that is designed to accommodate the needs of people and of elephants in human-dominated landscapes.

Mozambique faces a dilemma: politically it is required to reduce poverty while at the same time adhere to international agreements and requirements to protect biodiversity with relatively scarce financial resources. Reactive mitigation of human-elephant conflict (HEC) at the site-specific scale have proven to be costly and with low efficacy. A shift from reactive to proactive HEC mitigation approaches at the county-wide scale (e.g. a district level, the administrative planning body) may provide opportunities to reconcile such apparent contrasting requirements in Mozambique.

The elephant population of Mozambique is fragmented and remnant sub-populations are limited to clusters of protected areas in a matrix of human-dominated landscapes. A metapopulation perspective may accommodate this spatial structuring and allow for a conservation plan that ensures population persistence and moderate impacts with other species in the landscape.

I assessed HEC throughout human-dominated landscapes of Mozambique to examine some assumptions associated with the landscape approach advocated here. I used spatially explicit human activity data, landscape features and elephant distribution at the grid cell of 25 km^2 and at the district scale to test the practicality of landscape approaches to elephant conservation and mitigating HEC in the human-dominated landscapes of Mozambique. I then

tested whether human activities have significant impacts on elephant numbers and distribution across Mozambique. Furthermore I tested if the costs and benefits of sharing space with elephants influenced HEC. Thereafter, I explored at the grain scale of 25 km^2 if the degree of overlap between them on the use of resources can be used to predict the likelihood of HEC across the landscape.

Direct and indirect human activities explained trends and rates of elephant population changes in Mozambique. Because most rural households of Mozambique rely on subsistence farming by extracting or cropping from the land, primarily for their own purposes, living close to elephant refuge areas represented a potential risk to humans. However, conflict with elephants does not centre on food security, but on lifestyle being affected by the presence of elephants, which itself was a function of human density. Rodents and insects are the primary agents responsible for food loss during food storage. HEC was not a function of elephant density – a combination of human density, percent cultivated area and human population growth rate best explained HEC incidences. Although at human densities beyond 60 people/km^2, elephants disappeared, at low levels of land transformation and low human densities people and elephants co-existed, which may induce higher incidences of HEC. Proximity to roads and suitable land for agriculture were the best predictors for HEC in the rural areas of Mozambique. These results imply spatially driven causes of HEC.

These findings supported assumptions that conservation landscapes embedded in different land uses that accommodate ecological needs of people and elephants as well as the likelihood of severity of HEC can ensure elephant conservation without forcing people into poverty. While reactive HEC mitigation actions at site-specific scales are attractive for local communities, proactive measures at the landscape scale may be more effective in the rural context of the distributional range of elephants in Mozambique.

HEC can be mitigated proactively through an effective land-use planning that involves zonation and implementation. To address this I extrapolated the relevant findings from resources selection functions models at the 25 km^2 grain scale for study locations to a country-wide scale and proposed a model of a likelihood of HEC. The country-wide HEC model yielded high predictive power and confirmed protected areas as sites of high elephant dependability. These models indicate focal areas for short to medium term reactive HEC mitigation measures and local community programs at specific site level.

This dissertation suggests that human and elephant co-existence is possible in Mozambique. The apparent increase of HEC is not a function of numbers of elephants but of improper land use planning. In this thesis I argue in favour of a landscape approach to mitigate conflict between elephants and people. This approach should be considered in all national plans that aim to reduce conflict and enhance conservation.

For my parents,

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For your profound amazing love, support and wisdom, and the be late never reached and satisfied dream

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Disclaimer

This dissertation includes four manuscripts, one that has been accepted for publication and three prepared for different scientific peer-reviewed journals, which will be soon submitted. Styles and formatting of all Chapters follow requirements for the journal *Oryx*. This results in some duplication in study area description between Chapters 3 and 4 and methods description between Chapters 5 and 6. Chapter 1 is a general introduction and Chapter 7 summarizes general conclusions. I hereby declare all the work to be my own and that I have acknowledged all those who helped me and contributed in producing this dissertation.

Cornélio P. Ntumi

List of abbreviations and acronyms

AEC	Anuário estatístico da colónia de Moçambique (Annual Statistic of Mozambique)
AGRECO	Agri Ecology Consulting
AIC	Akaike's information criteria
ANE	Administração Nacional de estradas (National Roads Authority)
ARA	Administração Regional de Água (Regional Water Authority)
ARD	Natural Resources Management & Development Portal
AWF	African Wildlife Foundation
BEE	Boletim económico e estatístico (Economic Statistics Bulletin)
CENACARTA	Centro Nacional de Cartografia (National cartography Centre)
CERU	Conservation Ecology Reserach Unit
CESVI	Italian Association for Cooperation and Development
CTV	Centro Terra Viva (Land Center)
DBC	Department of Biological Sciences
DEM	Digital Elevation Model
DINAC	Direcção Nacional de Áreas de Conservação (National Directorate of Conservation Areas)
DINAGECA	Direcção Nacional de Geografia e Cadastro (National Directorate of Geography and Cadastre)
DNEP	Direcção Nacional de Estradas e Pontes (National Directorate of Roads and Bridges)
DNFFB	Direcção Nacional de Florestas e Fauna Bravia (National Directorate of Forestry and Wildlife)
DNTF	Direcção Nacional de Terras e Florestas (National Directorate of Land and Forestry)
ESRI	Environmental Systems Research Institute
FRELIMO	Frente de Libertação de Moçambique (Liberation Front of Mozambique)
GLM	Generalized linear model
GLTFCA	Great Limpopo Transfrontier Conservation Area
GM	Governo de Moçambique (Government of Mozambique)
GPS	Global Positioning System
HEC	Human-elephant conflict
IFAD	International Fund for Agricultural Development
IIPPA	
INE	Instituto Nacional de Estatística (National Statistics Institute)
INGC	Instituto Nacional de Gestão de Calamidades (National Institute of Hazard Management)
INIA	Instituto Nacional de Investigação Agronómica (National

	Institute of Agronomic Research)
LTFCA	Lubombo Transfrontier Conservation Area
MA	Ministério da Agricultura (Ministry of Agriculture)
MICOA	Ministério para a Coordenação de Acção Ambiental (Ministry of Coordination of Environment Affairs)
MITUR	Ministério de Turismo (Ministry of Tourism)
MPF	Ministério de Plano e Finanças (Ministry of Plan and Finance)
NDVI	Normalized difference vegetation index
NGO	Non-Governmental Organisation
NOAA	National Oceanic and Atmospheric Administration
PDF	Probability Density Function
RIHEC	Relative index of Human-Elephant Conflict
RP	República Portuguesa (Republic of Portugal)
RSF	Resource Selection Function
TEP	Tembe elephant Park
TIA	Trabalho de inquérito agrícola (Rural income survey)
UEM	Universidade Eduardo Mondlane (University of Eduardo Mondlane)
UIF	Unidade de Inventário Florestal (Forestry Inventory Unit)
UNFPA	United Nations Population Fund
WCS	Wildlife Conservation Society

Table of contents

Chapter 1

General introduction

The impact of humans on the environment has important implications for conservation (Nagaoka, 2002). Humans have altered natural landscapes through deforestation (McGlone, 1983; van Andel *et al.,* 1990 cited by Nagaoka (2002), have introduced competitive species and new predators, among which they can include themselves (Nagaoka, 2002). People also have fragmented landscapes (McIntyre & Hobbs, 1999; Kretser *et al.*, 2008) and as a result reduced remnant patch sizes, created higher edge:interior ratios, increased patch isolation, and reduced the connectivity between patches. All of these changes have major consequences for the viability of species populations (Gehring & Swihart, 2003). Such landscape modification may alter the spatial structure of vertebrate populations (Gehring & Swihart, 2003), especially because the persistence of many populations depends on the ability of individuals to disperse between patches (Gergel & Turner, 2002; Swihart *et al.*, 2003). The loss of habitat furthermore may reduce the absolute size of a subpopulation, or may divide populations into several subpopulations (Begon *et al.,* 1999) of which the dynamics may be governed by a high levels of demographic, environmental and spatial uncertainty (Caughley & Sinclair, 1994; Begon *et al.* 1999.

Habitat fragmentation may induce patchiness in the availability of resources. Aggregation of animals in response to such patchiness may cause small-scale spatial and temporal differences in population structure (Hanski, 1999). Species-specific habitat requirements may result in some landscapes supporting source populations and others supporting sink populations (Dias, 1996). Thus, favourable landscapes (sources) may support relatively large populations, while unfavourable landscapes (sinks) may support small populations (Pullin, 1988). In this manner species may occur as sets of local populations (Fahrig & Merriam, 1994; Hanski, 1999; Gergel & Turner, 2002) connected by inter-patch dispersal (e.g. Osborn & Parker, 2003). Such connectivity allows for immigration, as well as colonization after local extinctions, thereby buffering species against extinctions (van Aarde & Jackson, 2007).

The current small and isolated populations of elephants in Mozambique are less likely to be viable in the long term, compared with the existent larger elephant populations in Niassa National Reserve and Tchuma Tchato Community Game Farm in Mozambique and all other larger elephant populations bordering the country. The migration and conservation corridors concepts (Cheryl-Lesley *et al*., 2006) offer the hope that connectivity between source and sink elephant populations in Mozambique and bordering countries will reinforce the dynamics of a elephant metapopulation as an entity (van Aarde & Jackson, 2007). Therefore, the development of an approach that integrates population and landscape ecology within the umbrella of metapopulation theory (van Aarde & Jackson, 2007) can potentially contribute to a management plan for the conservation of elephants in Mozambique and elsewhere.

Elephant management is complex and may need a regional scale perspective to be successful (van Aarde, Jackson & Ferreira, 2006). Several of Mozambique's protected areas and those of its neighbouring countries are situated along international borders. Ecologically these protected areas probably function as singular units, thereby sharing the dynamics of elephant populations existing in each country. It thus follows that elephant management may best be dealt with at a regional rather than local scale (van Aarde *et al.,* 2006; van Aarde & Jackson, 2007).

Some 70% of the distributional range of elephants in southern Africa stretches beyond the boundaries of protected areas (see van Aarde & Jackson, 2007). The consequent overlap in resource needs may drive conflict between elephants and people (Parker *et al*., 2007).

The human population of Mozambique has near doubled from about 12 million people in 1980 to around 22 million in 2007 (INE, 2009). The persistent population growth of 2.2% per year (INE, 2009) apparently drives a need for expansion of settlements and other infrastructural developments. Development fragments and destroys habitat and it is thus not surprising that few elephants occur in densely populated provinces in Mozambique (*e.g.* Nampula and Zambézia) (see Ntumi *et al*., 2009). Both official and traditional patterns of settlements do co-exist in Mozambique. Officially, local people live in villages, but there is a strong cohesion between households belonging to same root family, which in turn live close to relatives. Some other families are sparsely distributed across the landscape.

In Mozambique, as in Africa in general, cultivation of the land involves bush clearing and burning (ARD, 2002) which fragment elephant habitat and may deplete their food sources (e.g. Mundia & Murayama, 2009). Commercially driven deforestation also may change elephant migration routes (Rood *et al.*, 2008). Logging provides access to some previously inaccessible areas (e.g. Surovell *et al*., 2005) and may increase killing of elephants by humans.

For some four decades elephant populations in Mozambique apparently declined rapidly (Douglas-Hamilton, 1987; Ntumi *et al*., 2009) while the human population increased and expanded its activities. In response to habitat loss and fragmentation, Mozambique's once continuous elephant population became relatively small, with most remaining elephants presently confined to isolated protected areas. The predicted continuing increases in human population growth and the associated transformation of the natural landscape (INE, 1997; 2009) may enhance human elephant conflict (e.g. Dunham *et al*., 2010).

In Mozambique some of the remaining elephant refuges are inhabited by people, while others are surrounded by human populations and daily management in the all Conservation Areas are based on solving human wildlife conflicts (e.g. Osborn & Anstey, 2002). While almost all Conservation Areas (e.g. Niassa National Reserve, Quirimbas National Park, Tchuma Tchato Community Game Far, Limpopo National Park and Maputo National Reserve) do meet the minimum viable population size recommended for elephants (see Sukumar, 1993) the Mecuburi Forest Reserve (Ntumi *et al*., 2009), others and private concessions (see Magane *et al*., 2009) are too small. Concerns arise for the future persistence of these small fragmented units (Stacey & Taper, 1992; Barnes, 1999; Lacy, 2000).

Addressing HEC through a landscape approach

About 60% of rural Mozambique comprises forests and natural vegetation (UIF, 2007). Given human population trends and development needs these natural landscapes may soon be transformed. Poverty, typical of rural living in Mozambique, induces dependency of natural resources (MPF, 2002; IFAD, 2010) and results in different views to resources and to elephants and calls for alternative approaches to ensure co-existence and to mitigate HEC.

Research on HEC has been concentrated on site specific “fire brigade crisis management type approaches” (Dublin & Hoare, 2004). Researchers and managers have quantified crop damages, examined spatial and behavioural dimensions of HEC and applied a diverse set of toolkits to mitigate HEC. HEC is widely recognized as a real and serious problem

(Dublin & Hoare, 2004; Dunham *et al*., 2010), both inside and beyond protected areas (McIntyre & Hobbs, 1999). We know from elsewhere that HEC involves lone individuals, bulls and cow-calf groups (Dublin & Hoare, 2004). Some complaints about elephants are grossly disproportionate to the real level of the problem (Naughton-Treves & Treves, 2005) and some "aspirin therapies" (Hoare, 2001a&b; Smith & Kasiki, 1999; Sitati & Walpole, 2006) failed while others succeeded (Sitati *et al*. 2005; Sitati & Walpole, 2006). In reality, evidence supporting links between HEC and local elephant numbers or density, or that shooting crop-raiders is effective on the long run is scarce (Hoare, 2001a).

Certainly, integrative approaches (Fernando *et al*., 2004), which most focus on preventing or reducing the frequency or severity of encounters between people and elephants, deal with identified "problem" elephants and increase tolerance for HEC by people living aside elephants (for details see Sillero-Zubiri *et al.*, 2007) will help to mitigate HEC in most rural areas of Mozambique.

In Mozambique protected areas alone do not provide for the spatial needs of elephants. Many of these protected areas are also inhabited by people (Ntumi *et al*., 2009), who may favour the control of elephant numbers and spatial use patterns to ameliorate conflict. However, securing additional land to provide for the spatial needs of elephants and to restore movement patterns through zonation may reduce conflict. Such approaches may only be sensible once the drivers of conflict along both temporal and spatial axes have been identified – this is the primary goal of my thesis.

Because people and elephants share the land, polices supporting poverty alleviation affect elephant distribution and could induce some negative interactions between people and elephants (McIntyre & Hobbs, 1999). Coexistence between people and elephants is possible (see

Parker & Graham, 1989; Hoare & du Toit, 1999; Lee & Graham, 2006), but this needs "win-win" solutions and support from all levels of government and a strong commitment of wildlife management authorities (Dublin & Hoare, 2004). There is a need of integrated national land-use policy and planning which considers and harmonize people and elephant needs.

Given the many socio-economic constraints that Mozambique faces and the decentralization of power that recognizes districts as a pivotal level in policy implementation through the direct link with local communities, there is an opportunity to shift away from reactive site-level approaches to those focusing on the "root causes" of the conflict (e.g. Jackson *et al*., 2008). Researchers therefore should address ecological, socio-economic, technical, policy and political issues, all which may be encapsulated in sensible land use planning that will accommodate conservation and human needs simultaneously at site, district and national levels as a platform of the national conflict mitigation strategy.

Focus of the thesis

I assessed the direct (e.g. trophy hunting and poaching) and indirect (civil war, tsetse fly control, agricultural development and pastoral expansion) impact of humans on Mozambique's elephant population over the last four decades. I then questioned whether HEC in Mozambique is real (actual) or a perception (perceived as a problem) and in which socio-economic context this may occur. Furthermore, I assessed factors associated with HEC incidences in Mozambique. These questions were examined in Chapters 2, 3 and 4 respectively and collectively evaluated the determinants of people and elephant distribution. In Chapter 5, I used Resource Selection Functions to characterize the distribution of people and elephants and to predict the probability of overlap in resource use and HEC in two protected areas in southern Mozambique. My responsibility as a scientist is to inform managers and decision makers, scientific findings from field research and suggest management frameworks. In the Chapter 6 I therefore developed models to predict the likelihood of HEC across all of Mozambique.

Each component is presented separately as either a published paper (Chapter 2) or papers that will be submitted (Chapters 3, 4 and 5) for publication in scientific journals. Chapter 7 summarizes collective scientific findings that contribute to reinforce the landscape approach in HEC mitigation. In support of the scientific effort being undertaken by the Conservation Ecology Research Unity of the Department of Zoology and Entomology, University of Pretoria, my synthesis assumes that land-use planning can help to decrease HEC by recognizing certain areas as potential, prime or under developed elephant habitats; others may account for human activities that are compatible with elephant presence and finally can bring benefit to people who share habitat with elephants. This approach allows elephants to function as spatial entities within megaparks for metapopulations (van Aarde & Jackson, 2007).

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Chapter 2

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A review of historical trends in the distribution and abundance of elephants *Loxodonta africana* in Mozambique

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Right running header: Elephant trends in Mozambique

Abstract

The elephant *Loxodonta africana* population of Mozambique has declined rapidly over the last 4 decades. Historical census data are incomplete but suggest that the impact of human activity on the elephant population increased after the onset of the colonial era. Demands for ivory explains the population decline from 1700 to 1940, and the killing of elephants as part of settlement policies and tsetse fly control programmes further reduced the populations from 1940 to 1960. Land transformation from 1900 onwards may also have contributed to the historical decline in elephant numbers. Our assessment suggests that landscape approaches should be explored in seeking to conserve elephants in modern Mozambique.

Keywords: Elephant, fragmentation, historical trend, ivory trade, *Loxodonta africana*, Mozambique, population

Introduction

Historical accounts (Barreto, 1745; Rodrigues, 1917; Martinho, 1968; Pardal, 1996) suggest that elephants *Loxodonta africana* were once abundant throughout Mozambique. However, trophy hunting, poaching, civil war, tsetse fly control, agricultural development and pastoral expansion induced a sharp decline in elephant numbers (Smithers & Tello, 1976; Douglas-Hamilton, 1984; DNFFB, 1991). Consequently, elephants now exist in relatively small populations both beyond and within Conservation Areas administered by the Direcção Nacional das Áreas de Conservação (DNAC).

The decline of elephant numbers in Mozambique apparently started with the demand for ivory (Dias, 1971) and continued when elephants and other suspected vectors of tsetse-borne trypanosomiasis were eliminated from several regions as part of a programme to control tsetse flies (Dias & Rosinha, 1971; Smithers & Tello, 1976). Elephants were declared a pest in 1936 (Frade, 1950) and later cropped to feed the military (Frade, 1950; Dias, 1973). The establishment of plantations and agricultural development reduced and fragmented habitats and this may further have reduced elephant numbers (Manghezi, 2003). Poaching continues, as does the legal consumptive use through small-scale trophy hunting of elephants (Milliken, 2002; SRN, 2006).

These observations suggest that human activities reduced elephant numbers in Mozambique. Little information, however, is available on elephant numbers, distribution or demography. Few time series of population estimates exist and most estimates are guesses reported in official government reports and NGO documents. Here, however, we compile all available historical data to review the trends in elephant numbers across Mozambique. To establish if trends in numbers could be explained by socio-economic changes we collated historical information on the numbers of elephants and people living in Mozambique, data on the ivory trade and tsetse fly control campaigns, and information on the export of some agricultural products and recent land-use changes.

Study area

Mozambique covers c. 800,000 km^2 along the east coast of southern Africa (Fig. 1a). The human population of 20.5 million people is increasing at c. 2.2 % per year (INE, 2007). Annual rainfall varies from 1,000 mm in the northern and southern provinces to 1,200 mm in the central provinces (Instituto Nacional de Meteorologia, 2007). The country consists of a series of isolated harbours and settlements, each surrounded by a belt of rural estates that traded with the independent hinterland when it became an overseas province of Portugal in 1890 (Liesegang, 1983). The present borders were drawn in 1891 (Hatton *et al*., 2001). Ivory and slaves were widely traded in the 16–19th centuries (Liesegang, 1983).

Dry and moist miombo woodlands are common in the northern and central provinces, and mopane woodlands dominate the Limpopo-Save region and the mid Zambezi valley (Hatton *et al*., 2001). The last two wars (1964–1974 and 1978–1992) devastated large mammal populations in areas of high biological and scenic value (Hatton *et al*., 2001). Currently c. 16,000 elephants (Blanc *et al*., 2007) live in five National Parks, five National Reserves, 13 Controlled Hunting Areas, one Forest Reserve, and in areas beyond protected areas (DNAC, 2006; Fig. 1b). The elephant population of Niassa National Reserve is the largest, with > 10,000 elephants in 2004 (Craig & Gibson, 2004).

Methods

Our primary sources of information on human densities, land-use change and the quantity of ivory exported since the 1700s include the National Archive of Mozambique's History, the National Ultramarine Archive of Portugal, reports held by the former National Directorate of Wildlife Services (DNFFB), reports by NGOs operating in Mozambique, and the libraries of the University of Eduardo Mondlane, the University of Pretoria, South Africa, and the University of Zimbabwe. For information on elephant distribution and relative abundance we relied on descriptions of naturalist travellers, missionaries and professional hunters since the 1500s. Aerial reconnaissance and informed guesses formed the basis of the few elephant population estimates after 1900.

We addressed the historic trends in elephant numbers for the pre-colonial era (before 1500), the colonial era (1500-1975) and the post-colonial era (after 1975). For the pre-colonial era we relied on an interpretation of archaeological information. For the colonial era we found only three elephant censuses and derived likely trends in elephant numbers from records of exported ivory and on the number of elephants killed as part of the tsetse fly control programmes. For the post-colonial era we collated data from structured surveys (n=22) and guesses (n = 32).

We fitted exponential models (Caughley, 1977) to both human (extracted from national censuses) and elephant numbers to identify trends and rates of change since 1900. We used linear regression (Sokal & Rohlf, 1995) to determine if a relationship existed between people and elephant numbers. We examined trends in the ivory trade and agricultural products with available data from the 1700s to 1980, and changes in land use pattern and sizes of areas allocated to agriculture and forest exploitation over 1925-1975.

Results

The pre-colonial era

Our understanding of elephant distribution during this era is based on deductive speculation. Low human densities and relatively inefficient hunting may have allowed elephants to be relatively common and widely distributed over Mozambique (Klein, 1987; Owen-Smith, 1999). Paintings, engravings and excavated artefacts dating back to the Late Stone Age (Deacon, 1984) from archaeological sites in Mozambique (Silva, 1980; Adamowicz, 1987; Sinclair, 1987; Duarte, 1989) as well as the presence of pits, weighted spears and axes that were used to hunt (Duarte, 1989) and rock sketches of elephants in shelters (Dutton & Dutton, 1973; Adamowicz, 1987; Sinclair, 1991) suggest that elephants may have ranged throughout Mozambique (Lewis, 1987; Woodhouse, 1996; Eastwood & Blundell, 1999; Whyte *et al*., 2003).

As elsewhere across southern Africa (Maggs, 1984) the transition from hunting and gathering to food production in Mozambique occurred during the Holocene (Stock & Pfeiffer, 2001; Adamowicz, 1987). By AD 500 people produced crops and kept domestic animals (Maggs, 1984) while living in small, scattered villages (Lee & Graham, 2006). The expansion of human populations and activities during the Iron Age (Harpending *et al*., 1993; Sherry *et al*., 1994) conceivably changed the environment, and increased hunting may have had a modest impact on elephants (Owen-Smith, 1999).

The colonial era

Elephant distribution and abundance in Mozambique changed when merchants arrived and started to supply guns (Gann, 1965). Market demand fuelled by the needs of the Islamic empire (Alpers, 1975) brought specialist and extensive elephant hunting expeditions into Mozambique during 1800-1875 (Hedges, 1978), and the ivory trade flourished at this time (Fig. 2) supporting the notion that elephants were then probably numerous and widespread (Sanderson, 1962; Shepperson, 1965; Bere, 1966; Selous, 1984; Adams & McShane, 1992). At this time c. 340,000 people were taken from Mozambique as slaves (Capela & Medeiros, 1987), most of them from north of the Zambezi River (Capela & Medeiros, 1987) where elephants apparently flourished (Shepperson, 1965; Maugham, 1914).

With the decline of the slave trade from 1845 (Capela & Medeiros, 1987) human numbers started to increase, and agricultural activities expanded and may have reduced elephant populations. From 1880 to 1920 copra and sugar exports increased (Fig. 2) and contributed greatly to revenue. In addition, from 1800 onwards, transport services to neighbouring territories and migrant labour gradually became more important economic activities (Liesegang, 1983).

Land-use activities expanded from 1900 (Fig. 3d) and landscape fragmentation and/or loss of habitat may have compressed elephants into refuge areas (Lyell, 1910,1924; Maugham, 1914; Rodrigues, 1917; Dalquest, 1965) as noted elsewhere in Africa (Lee & Graham, 2006). These refuge areas were mostly in the hinterland but a few were in the country's coastal zones (Chamberlain, 1923). In some of these refuge areas such as the Niassa province, the Luabo district extending south of the Zambezi delta to the Shupanga forest and Cheringoma, and from

Maputo to the Save River, elephant numbers increased from 1930 (RP, 1952) and their distribution expanded again but remained fragmented (Fig. 1c).

Official responses to apparent elephant range expansion and threats to crop production included the declaration of elephants as a pest species in 1936 (Frade, 1950). Further legalization of elephant killing through the replacement of the Conservation Act of 1955 with the Professional Meat and Ivory Hunting Act in 1960 (Dias, 1973; Smithers & Tello, 1976) formalized actions to reduce elephant numbers in areas beyond the protected areas established in the 1960s (Martinho, 1968). The establishment of these areas conceivably relieved elephants from formal and informal persecution and may have resulted in an increase in elephant numbers from the 1960s to 1970s (Dias, 1973).

From the 1960s onwards, elephants from Mozambique also dispersed to neighbouring countries. For example, elephants from Mozambique populated the Kruger National Park (Whyte *et al*., 2003) and elephants in the Chimanimani, Zumbo and Rovuma-Lugenda regions (Fig. 1a) migrated into Zimbabwe, Zambia and Tanzania (Dutton, 1975; Davies, 1999; Hofer *et al*., 2004). The liberation war of 1964–1974 further reduced elephant numbers when both Frente de Libertação de Moçambique and colonial troops killed elephants to feed soldiers and used ivory to fund their campaigns (Dias & Rosinha, 1971).

The post-colonial era

At independence in 1975 many families returned to their villages and started growing crops (Collins, 1978; Lorgen, 1999). This expansion of cultivation reduced elephant ranges further

(Smithers & Tello, 1976; Tello, 1977). Game laws became less restrictive (Taylor, 1981), and probably increased the illegal ivory trade (Milliken, 2002). At that time financial support for elephant conservation in Mozambique was limited (WWF/IUCN, 1980).

The civil war of 1980-1992 may have harmed wildlife (DNFFB, 1991) and further reduced elephant numbers (Dutton, 1992; Hatton *et al.*, 2001). Population estimates were 50,000-65,000 in 1974 (DNFFB, 1991), 54,800 in 1981, 17,000 in 1989 (Barbier *et al.*, 1992) and 13,000 by 1990 (Cumming *et al.*, 1994). From 1975 to 1983, populations in the central and southern regions declined by 65 and 76%, respectively (Douglas-Hamilton, 1984). Rural people populated areas formerly used by elephants. This resulted in the current situation, with a once continuous elephant population fragmented into small populations that mostly live in relatively small conservation areas across a landscape that is dominated by human activities (Fig. 1d).

Recent trends

Several of the elephant population estimates are guesses (Table 1). Few surveys used standard methods and, when they did, the effort and areas covered varied. All survey areas, except the Maputo National Reserve, were poorly delineated or defined. Most of the populations for which estimates are available are small and isolated (Table 1). The current total estimate is 16,000 elephants (Blanc *et al.*, 2007). The best available data suggest that the number of elephants in Mozambique declined exponentially at a mean rate of 3.3 ± SE 0.7% ($F_{1,12} = 22.18$, $P < 0.01$) per annum since 1974. However, estimates post-2000 have not varied significantly ($F_{1,3} = 2.01$, $P = 0.25$; Fig. 3a).

Human population censuses suggest a mean increase of 2.3 ± SE 0.3% ($F_{1,12}$ = 76.42, P < 0.01) per annum since 1900 (Fig. 3b). Data on the links between trends in human and elephant populations are sparse yet elephant numbers declined as the human population increased ($F_{1,3}$ = 66.64, P < 0.01; Fig. 3c). By 1938 farmers had deforested many areas where elephants were once common (BEE, 1925–1970). Such disturbances are continuing (Fig. 3d) and few elephants live in parts of provinces such as Nampula and Zambezia that are densely populated and extensively modified (Wild & Barbosa, 1967; Sinclair, 1987; Saket, 1994; DNFFB, 1999). In less densely populated provinces, such as Niassa, Cabo Delgado and Tete, elephants and other wildlife persist widely, especially close to protected areas such as the Niassa National Reserve, the Quirimbas National Park and the Zumbo region. At present, several small populations of elephants occur throughout the southern provinces, such as those in Maputo (Maputo National Reserve, the Futi River and Magude region), Gaza (Limpopo National Park), and Inhambane (along the Save River; Hatton *et al.*, 2001).

Discussion

The decline in elephant numbers in Mozambique is primarily due to the impact of direct (ivory trade and tsetse control programmes) or indirect human activity (habitat fragmentation and associated factors). People have sought ivory since the early Iron Age (AD 815) and European markets have influenced the ivory trade since the 1400s (Spinage, 1994). Portuguese, Arab and native traders exported 69 tons from Beira (South of Sofala) in 1512-1515 (Spinage, 1994) for India. Dutton (1975) estimated that the ivory taken per year represented c. 1,000 elephants from the region between the Manica and Maputo provinces during the 1500s. By the mid 18th century extensive hunting had expanded onto the interior, with 150-180 tons of ivory taken per year (Sheriff, 1983; Spinage, 1994). These anecdotal descriptions suggest that elephant numbers were high in the 17-19th centuries.

Due to price disagreements the ivory trade apparently collapsed in 1780-1790 (Spinage, 1994) and ivory exports oscillated but declined after 1800 (Liesegang, 1983; Barbier *et al.*, 1992; Spinage, 1994). Much of this variability in exports may have been associated with changes in Mozambique's economy. The ivory and slavery trades that dominated in 1770-1870 (da Silva, 1969) were replaced by other export products (primarily sugar and copra) and ivory accounted for only 32% of exports by 1874 (Liesegang, 1983).

At least half of Mozambique (c. 400,000 km^2) was infected by tsetse flies (*Glossina* spp.) in the 1940s. As part of efforts to eradicate tsetse flies > 3,000 elephants were killed in 1947-1969 at Mutuáli (Nampula), Govuro (Imhambane), Changara (Tete), Massangena (Gaza) and Muda (Sofala; Blair, 1939; Dias & Rosinha, 1971). This followed an earlier campaign in the Rio Maputo valley and Likwati forest (Manghezi, 2003) that eliminated most of the elephants west of the Rio Maputo. These campaigns continued until the early 1970s (Dias & Rosinha, 1971).

Areas cleared of tsetse flies were soon occupied by people and land clearing for agriculture may have prevented coexistence with elephants. Areas earlier cleared of tsetse flies, from Rovuma River south towards Zumbo, Cazula (Macanga District), Marrupa, Balama and Mocimboa da Praia, have now been recolonized by elephants (MINAG, 2006).

More than 80 % of people in Mozambique live in rural areas and depend on natural resources (Del Gatto, 2003). Charcoal production and the collection of wood for fuel are degrading woodlands (Del Gatto, 2003). Although 78.0% of the country was covered by natural forests in 1980-1990s (MICOA, 1997) the national deforestation rate in 1972-1990 was c. 4.2 % (MICOA, 1997). In 1990-2000 closed woodlands decreased by c. 13% (Pereira, 2001). Consequently, habitat available for elephants may be declining and conservation areas are becoming habitat islands in human-dominated landscapes.

Elephants that live in these landscapes may not often come into conflict with people but, at the fine scale, habitat fragmentation may disrupt foraging and breeding and thus lower the population growth rate (Barbault & Sastrapradja, 1995). This may in part explain the historical decline in elephant numbers from 1900 onwards and the links between trends in human and elephant populations, as well as the relationship between exploited areas and the number of elephants.

Elephant conservation in Mozambique faces a range of challenges associated with the relatively fast human population growth rate. These challenges include the genetic constraints that may arise in small and isolated populations and that continuing elephant dispersal into formerly occupied areas may result in human-elephant conflict. Our review suggests that the once continuous elephant population of Mozambique is increasingly being fragmented into relatively small areas. However, many of these areas adjoin larger areas and larger elephant populations in neighbouring countries (South Africa, Zambia, Zimbabwe and Tanzania).

The population in the Niassa National Reserve in northern Mozambique is relatively large and seems to be part of a widely distributed regional population. The recently founded population in the Limpopo National Park that adjoins the population of the Kruger National Park in South Africa illustrates that populations in Mozambique may be founded and maintained through dispersal movements from neighbouring populations. Similarly, the elephant population in the Maputo National Reserve could be reconnected through the Futi Corridor to those living in the Tembe Elephant Park, which is presently fenced (Morley & van Aarde, 2007). The integrity of elephant populations in Mozambique may be best preserved when they are provided the opportunity to be part of larger regional populations. Future conservation of elephants in Mozambique may thus depend on management as several regional populations (van Aarde & Jackson, 2007) in a system of transfrontier conservation areas (Hanks, 2001).

More than 60% of Mozambicans are poor and government poverty alleviation strategies (RM, 2006) may conflict with elephant conservation ideologies that call for the development of dispersal linkages across human-dominated landscapes. There is a need for solutions that integrate the needs of both people and elephants (Lee & Graham, 2006). This may well be possible in the large stretches of land where few people live. Increasing urbanization (Maximiano *et al.*, 2005) and recent changes in human demography and distribution, driven by HIV and associated diseases, and migrations for coastal tourism developments, may provide further options to expand elephant range without confronting people.

Conceptual developments that change the focus of conservation from protected areas to a conservation matrix that comprises a range of land use options across national and international boundaries (van Aarde & Jackson, 2007) could accommodate the needs of both people and elephants. Although land-use options across international boundaries have been considered in the transfrontier conservation initiatives framework (Hanks, 2001), at a national scale a conservation matrix which accommodates the needs of both people and elephants still requires a systematic assessment and evaluation as well as strategic planning and policy changes.

The National Strategy for Elephant Management in Mozambique (DNFFB, 1999) mostly focuses on the apparent increase of elephant numbers and how this may affect other species and humans. Our assessment indicates that this approach, which assumes that elephants require an economic value for local communities to achieve effective elephant conservation (Bell, 1987; Keats, 1991; Hanks, 2001) and highlights the human-elephant conflict dilemmas (Hoare, 2001) is not apprpriate.

Our recent novel solution to elephant management (van Aarde *et al*., 2006; van Aarde & Jackson, 2007) caters for the situation in Mozambique. The mosaic of intact and disturbed landscapes occupied at varying densities by people and elephants provide an opportunity to use a metapopulation metaphor on which to base elephant management strategies. Prime elephant habitat can serve as sources to sustain sinks. Sinks may be areas where people live but that are also used by elephants. However, elephant management that relies on the dynamic spatial interactions, such as dispersal between source and sink populations across human dominated landscapes, needs information on how elephants and people utilize landscapes and on changes in elephant and human numbers. Such management should focus on inducing local elephant population fluctuations while maintaining regional stability in their numbers and minimizing human-elephant conflict. This may mitigate conflict without placing the elephant population at risk and provide further opportunity for the integration of elephant conservation into a regional economic framework.

Conservation and development authorities in Mozambique may have to maintain landscapes occupied by many elephants and few people as prime conservation areas, e.g. the Niassa-Cabo Delgado region, upper Tete region (Magoe and Zumbo) and Greater Limpopo Region. They should also recognize that isolated areas with few elephants such as Gorongoza-

Marromeu Complex, Gilé and Mecuburi can only persist as conservation areas if linked to larger areas where other elephant populations thrive. This may best be achieved by reinstating spatial and temporal processes in a matrix of landscape uses and by establishing formal Transfrontier Conservation Area agreements in areas with many elephants and much space.

Such ongoing transfrontier conservation area projects include those between Mozambique and Tanzania (the Niassa-Selous initiative and the Rovuma Transfrontier Conservation Area), as well as between Mozambique, South Africa and Zimbabwe (the Great Limpopo Transfrontier Conservation Area) and Mozambique, South Africa and Swaziland (the Lubombo Transfrontier Conservation Area). This approach could also best be explored at a national scale in northern Mozambique to involve the Niassa region, the Quirimbas National Park and the planned Rovuma National Reserve.

Sporadic elephant movements are reported between Mecuburi Forest Reserve and Gilé National Reserve, as well as between Zinave National Park and Banhine National Park. In the south of Mozambique elephant conservation may involve the recolonization of areas across the Magude and Moamba districts. In these cases and at the district level, present community based-conservation initiatives would be best explored because they incorporate the interests of people.

The number of elephants in Mozambique has declined since 1970. People's direct and indirect activities fragmented a once continuous elephant population into a few large and several small populations. The remnant populations could recover through the application of our proposed landscape approach, which allows elephants to disperse and populate landscapes that link subpopulations into a functional metapopulation.

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Biographical sketches

Cornelio P. Ntumi is studying landscape approaches to elephant conservation in Mozambique. He has an interest in conservation ecology, with a particular emphasis on spatial and habitat use by species and factors influencing this. Sam M. Ferreira's research focuses on conservation biology and, in particular, temporal dynamics and the factors influencing these. Rudi J. van Aarde's research focuses on the restoration of populations and communities as a contribution to conservation. His research on elephants covers populations in Botswana, Malawi, Mozambique, Namibia, South Africa and Zambia.

TABLE 1 Estimates (with 95% confidence interval) of elephant numbers in conservation areas in Mozambique by survey area and year, with survey method and data source.

Survey area (km^2) / year	Survey method	Estimate (%95CI)	Source
Niassa National Reserve (42349)			
1980	Guess	10000	WWF/IUCN (1980)
1997	Aerial survey	6500 (6000–7000)	Leo-Smith *et al*. (1997)
1998	Aerial survey	8707 (6770–10644)	Gibson (1998)
2000	Aerial survey	11828 (9688–13968)	Gibson (2000)
2002	Aerial survey	13061 (10579–15543)	Craig & Gibson (2002)
2004	Aerial survey	12477 (10355–14599)	Craig & Gibson (2004)
Lugenda-Rovuma Reserve (15000)			
1981	Aerial survey	823	Taylor (1981)
1998	Guess	300	Barnes *et al*. (1999)
Quirimbas National Park (7845)			
2002	Guess	90	Blanc *et al*. (2003)
2004	Guess	1000	Cumming & Jones (2005)
2006	Ground count	1492	Araman & Mahommed (2006)
Mecuburi Forest Reserve (195)			
2000	Guess	5	Blanc *et al*. (2003)
Gilé National Reserve (2100)			
1973	Aerial survey	39	Dutton & Dutton (1973)
2002	Guess	15–18	Martins & Ntumi (2002)
Tchuma Chato Community Area (3815)			
1980	Aerial survey	1274	Mackie & Chafota (1995)
1995	Aerial survey	137	Mackie & Chafota (1995)
1999	Aerial survey	400 (154–646)	Davies (1999)
2000	Aerial survey	1217	Mackie (2001)
2004	Aerial survey	1264 (983–1545)	Mackie (2004)
Marromeu National Reserve (1500)			
1968	Aerial survey	257	Dutton (1994)
1977	Guess	331	Hatton *et al*. (2001)
1978	Guess	361	Hatton *et al*. (2001)
1979	Guess	373	Dutton (1994)
1990	Guess	326	Dutton (1994)
1994	Aerial survey	0	Dutton (1994);
1998	Guess	589	Hatton *et al*. (2001)
2000	Guess	219	Hatton *et al*. (2001)
2001	Guess	421	Hatton *et al*. (2001)
2005	Aerial survey	388	AWF (2005)
Gorongosa National Park (5300)			
1968	Aerial survey	2200	Dutton (1994)
1970	Guess	1900	Hatton *et al*. (2001)
1972	Guess	2542	Tello (1986)
1979	Guess	3000	Hatton *et al*. (2001)
1980	Guess	3500–5000	WWF/IUCN (1980)
1993	Guess	4	Dutton (1994)
1994	Aerial survey	108	Cumming *et al*. (1994)
2000	Guess	163	Hatton *et al*. (2001)
2001	Guess	111	Hatton *et al*. (2001)
2005	Aerial survey	300	Cumming & Jones (2005)

TABLE 1 (Continued)

Survey area (km^2) / year	Survey method	Estimate (%95CI)	Source
Chimanimani-Moribane TCA (735)			
1973	Guess	12	Dutton & Dutton (1975)
2003	Guess	22	Sitoe *et al*. (2003)
Zinave National Park (3800)			
1965	Guess	1500	Dalquest (1965)
2002	Guess	22	Blanc *et al*. (2003)
2007	Aerial survey	0	Stalmans (2007)
Banhine National Park (7000)			
1974	Guess	750–1000	Tello (1986)
1986	Guess	500	Tello (1986)
2002	Guess	8	Blanc *et al*. (2003)
2004	Aerial survey	0	Stalmans (2004)
2007	Aerial survey	0	Stalmans (2007)
Limpopo National Park (10000)			
1974	Guess	15000–20000	Blanc *et al*. (2003)
2002	Guess	150	Blanc *et al.* (2003)
2006	Aerial survey	630	Blanc *et al.* (2007)
Maputo National Reserve (800)			
1911	Guess	300–600	Barrett (1911)
1970	Guess	350	Tello (1973)
1972	Guess	269	Tinley & Dutton (1973)
1974	Guess	350	Tello (1986)
1976	Guess	300	Tinley *et al.* (1976)
1976	Guess	210	Burlinson & Carter (1976)
1979	Guess	80	Klingelhoeffer (1987)
1986	Guess	80–130	Tello (1986)
1995	Guess	137	Ostrosky & Matthews (1995)
1995	Guess	150	Ostrosky & Matthews (1995)
1996	Guess	100–300	Correia *et al*. (1996)
1998	Guess	180	de Boer *et al.* (2000)
1999	Guess	200	Carnie (1999)
1999	Aerial survey	205	Ntumi (2002)
2006	Dung count	311 (198–490)	P.I.Olivier, S.M. Ferreira & R.J. van Aarde (unpubl. Data)

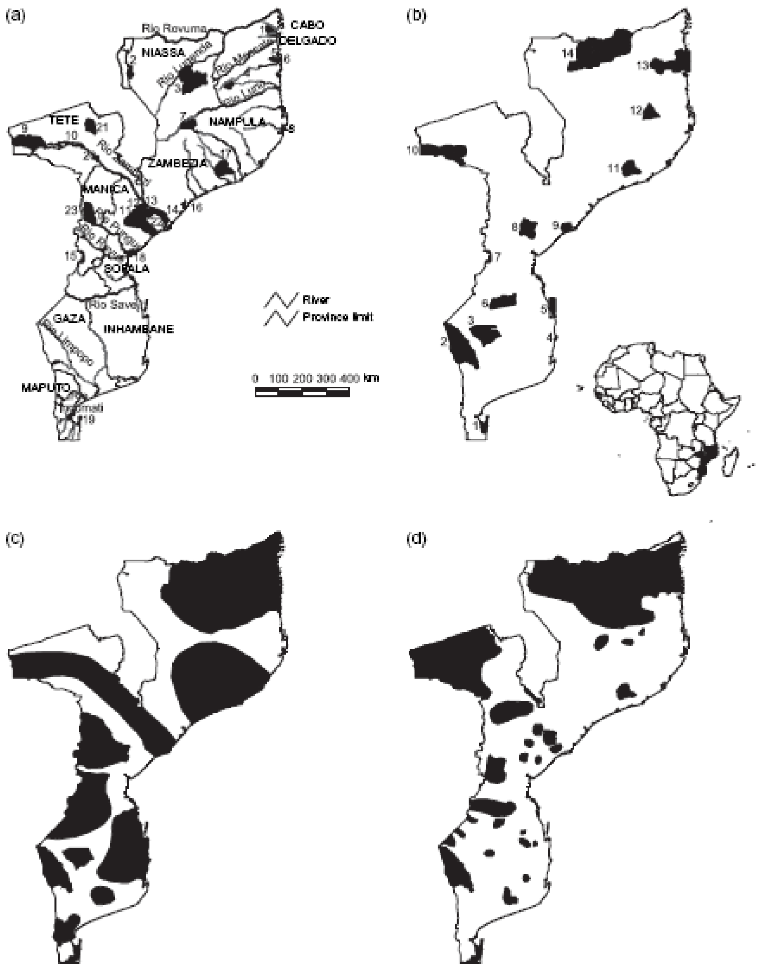

FIG. 1 (a) Mozambique, showing the most relevant historical locations mentioned in the text. 1, Mocimboa da Praia; 2, Metangula; 3, Marrupa; 4, Balama; 5, Quissanga; 6, Quirimbas; 7, Mutuali; 8, Ilha de Moçambique; 9, Zumbo; 10, Songo; 11, Inhaminga; 12, Inhamitanga; 13, Shupanga; 14, Luabo; 15, Chimanimani; 16, Quelimane; 17, Gile´ National Reserve; 18, Beira; 19, Maputo; 20, Tete; 21, Cazula; 22, Cheringoma; 23, Vila Gouveia. (b) National Parks, Reserves and Community Game Farms that harbour elephants in Mozambique (1, 2, 3, 6, 7, 8, 9, 10, 11, 12, 13 and 14), and others (4 and 5) protecting coastal and marine diversity (modified from DNAC official map). 1, Maputo National Reserve; 2, Limpopo National Park; 3, Banhine National Park; 4, Zinave National Park; 5, Pomene National Reserve; 6, Bazaruto National Park; 7, Chimanimani National Reserve; 8, Gorongosa National Park; 9, Marromeu National Reserve; 10, Tchuma Tchato Community Game Farm; 11, Gile´ National Reserve; 12, Mecubúri Forest Reserve; 13, Quirimbas National Park; 14, Niassa National Reserve. (c) Former (1940-1960) elephant range in Mozambique (BEE, 1925-1970; RP, 1952). (d) Reduced and fragmented present elephant range (DNFFB, 1991, 1999; Blanc *et al*., 2003). Inset shows location of Mozambique in Africa.

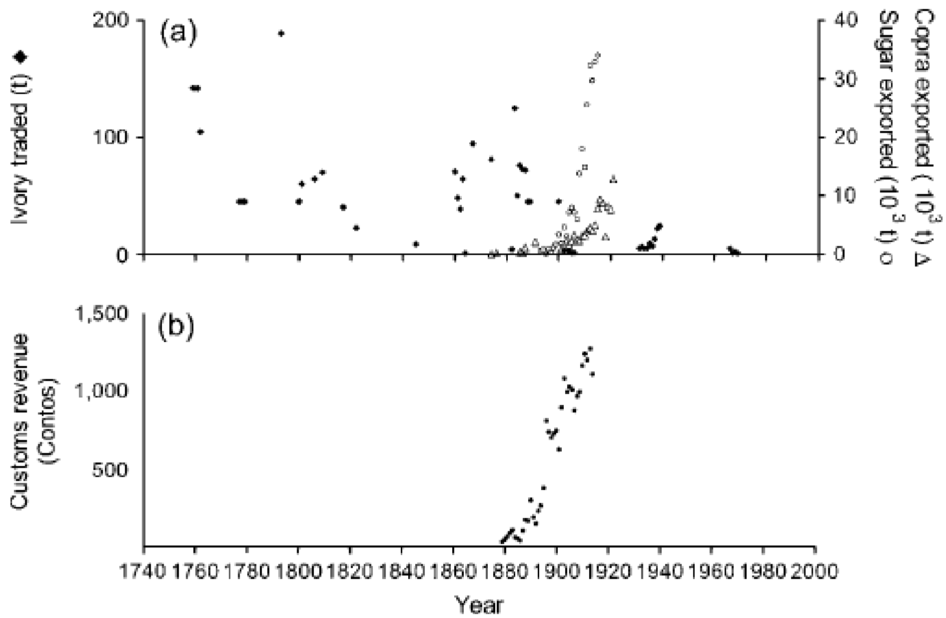

FIG. 2 (a) The amount of ivory traded in Mozambique declined from the 1700s to the late 1900s (data collated from Jordao, 1870; BEE, 1925-1970; AEC, 1926-1973; Hedges, 1978; Liesegang, 1983; Sheriff, 1983; Barbier *et al*., 1992; Spinage, 1994), whilst exports of copra and sugar increased (exports of copra are for Quelimane port; exports of sugar are records of export territories administrated by the State and by the Companhia de Moçambique in Manica and Sofala; data collated from BEE, 1925-1970; AEC, 1926-1973; Liesegang, 1983). (b) Revenue, expressed in contos of reals. Reals (reis) were the colonial currency. The so called weak reals (reis fracos) were introduced in the 18th century. By devaluation weak reals changed to strong reals. A conto corresponds to 1,000,000 reis. Revenue data are the records of the Lourenço Marques port (now Maputo; data collated from BEE, 1925-1970; AEC, 1926-1973; Liesegang, 1983).

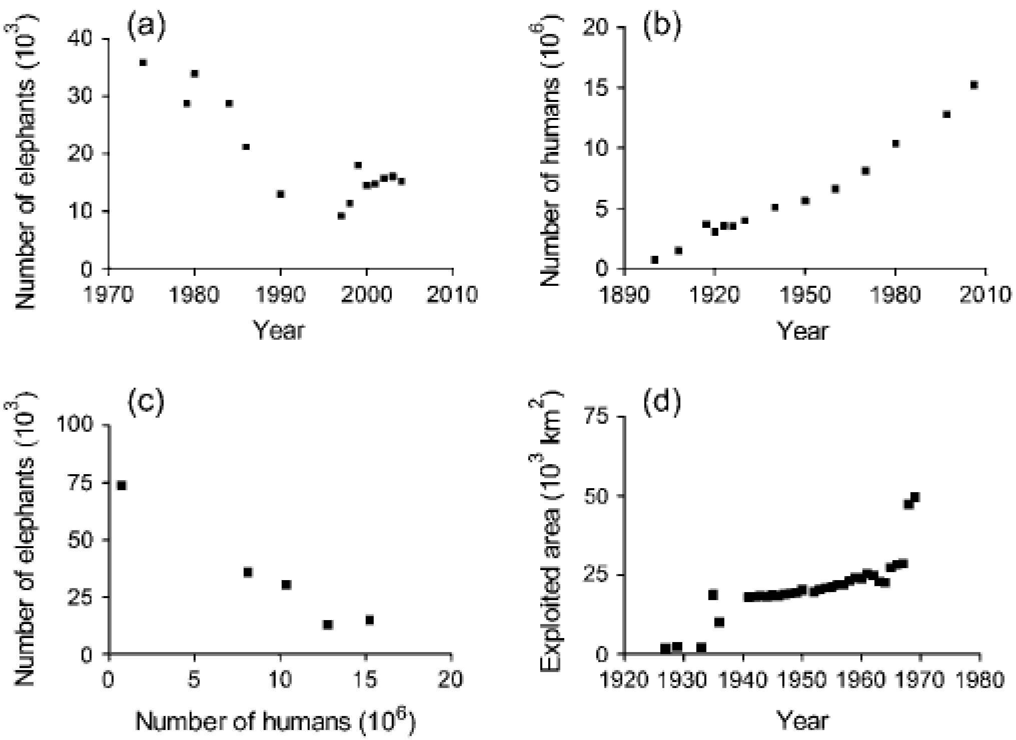

FIG. 3 Estimates of the (a) elephant (1974-2004) and (b) human population (1900-2009) in Mozambique (elephant data: DNFFB, 1999; Cumming & Jones, 2005; Table 1; human data: BEE, 1925-1970; AEC, 1926-1973; INE, 1980, 1999). (c) The elephant population declined as human numbers increased. (d) Exploited areas (agriculture and forestry combined) in Mozambique increased from the 1920s to the 1970s (AEC, 1926-1973).

Chapter 3

The socio-economic context of Human-Elephant Conflict (HEC) in rural areas of Mozambique

Abstract

Conservation efforts throughout the world are challenged by human-wildlife conflict. Such conflict also occurs throughout rural Mozambique. The efficiency of conflict mitigation may be improved when the socio-economic and political context is considered. Thus, understanding the effect of elephants on a household's lifestyle appears crucial. Here, I explore the demographic and socio-economic variables associated with human-wildlife conflict across Mozambique. A comparative assessment of the socio-economic profiles suggests that most households rely on subsistence farming by extracting or cropping from the land, primarily for their own purposes and this differed for households living inside and beyond protected areas. The reproductive parameters of households living inside and beyond protected areas were similar. Whilst mostly often elephants were responsible for crop damage beyond protected areas, rodents and insects were the primary agents responsible for food loss during storage inside these. Conflict with elephants appears not to be over food security, but is more about life styles being affected by the presence of elephants. I argue that efforts to mitigate HEC in rural areas of Mozambique should include strategies that improve household's livelihoods profiles.

Keywords: Households, demographic profile, economic profile, conflict profile, life styles, HEC, Mozambique

Introduction

In Mozambique, efforts to conserve elephants are marred by a noted increase in the reported incidences of human elephant conflict (HEC) (Dunham *et al*., 2010). While some incidences induce injuries or deaths for both species, reported losses of crops and livestock may be influenced by some socio-economic and political factors (see Hill, 2004; Dickman, 2010; Hartter *et al*., 2010). The 16% of Mozambique's area that have been set aside for conservation may not reflect the effectiveness of conservation, simply because most protected areas are inhabited by people that are legally permitted to extract natural resources from these areas. This may nullify conservation outcomes, especially as the Mozambican population is increasing at 2.2% per year (INE, 2009).

Some of the 22,144 elephants recorded during 2009 in Mozambique live beyond the boundaries of protected areas where they also come into conflict with people, a situation not different from protected areas, but where a numerical ratio favours people. Thus, people and elephants are coming into conflict both within and beyond protected areas, but more so within the proximity of protected areas (see Chapter 4).

Conflict conceivably has major consequences for rural people that depend on crops and natural resources for their existence. Solutions for such conflict require detailed information on the consequences thereof and on the environmental and social factors driving the conflict (see De Boer & Baquete, 1998; Hill, Osborn & Plumptre, 2002; Dickman, 2010). To cope with the stresses induced by unemployment, declining yields due to droughts or floods, declining water availability, declines in natural resources, households tends to adopt a mixture of livelihood strategies that may include diversification of lifestyle, claims for compensation and emigration (for details, see Chambers & Conway, 1991). In rural Mozambique, poverty and unemployment are high, flood events and droughts are frequent, and reports on conflicts between people and wildlife are common (Dunham *et al*., 2010). Retaliatory killing of problem animals is commonly allowed (DNTF, 2009).

Human-wildlife conflict and, in particular human-elephant conflict (see Hoare, 1995; Hoare, 1999; Hoare & du Toit, 1999; Jackson *et al*., 2008), occurs through most of Mozambique, both within and beyond protected areas (see Chapter 4). Living in protected areas may be hazardous due to the presence of relatively large numbers of wildlife, while at the same time conferring benefits in terms of the proximity and availability of natural resources to subsidize food from the subsistence cultivation of crops. Living outside protected areas may be less hazardous, but return few natural resource benefits and make such people more reliant on subsistence farming. These two near opposing lifestyle may influence survival and reproduction. Given these different scenarios I expect that the socio-economic profiles, conflict with wildlife profiles, and demography of people living inside and beyond protected areas will differ. I therefore compared these variables based on information obtained through structured surveys conducted in four protected areas and in five non-protected areas. Given to the expected positive relationship between reproductive rates and resources availability (Sibly & Hone, 2002), I expected that (i) people inside protected areas would have bigger families than those living beyond; (ii) survival probability of children inside protected areas would be greater than outside these. Because both inside and beyond protected areas share similarities on the environment and lifestyle, (iii) the socio-economic profiles between them would be similar but, (iv) people inside protected areas would extract a greater variety of natural resources than those living beyond given my expectation on the "park effect", which prohibits a free resource exploitation. I also expected that (v) people living inside protected areas would experience more conflict with large bodied wildlife than those living beyond, which would face primarily small animals and finally, (vi) fields would be more frequently destroyed inside than beyond protected areas.

Study Areas

This study was carried out in four officially protected areas (Maputo Elephant Reserve, Banhine National Park, Limpopo National Park, Chimanimani National Reserve) and in five unprotected areas (Futi, Magude-Moamba, Mágoè, Marrupa-Nipepe and Quiterajo) (Table 1 and Fig. 1). People densities varied (INE, 2009) and were lower in protected than non-protected areas, but the inverse was true for elephants (AGRECO, 2008, 2010). People planted crops in all areas, cleared natural vegetation to maintain their shifting agricultural systems, collected wood for the construction of houses, and collected wild fruits, honey and mushrooms to supplement their diets (Pereira *et al*., 2001; Kityo, 2004; Landry, 2009). Human and wildlife conflicts in general and in particular HEC have been reported from all these study sites (see Dunham *et al*., 2010). While Maputo Elephant Reserve, Limpopo National Park, Marrupa-Nipepe and Quiterajo are of particular concern (De Boer & Ntumi, 2001; Foloma, 2005; Garnier, 2006; Dunham *et al*., 2010, Chapter 4), some cases have been reported for the Magude-Moamba and Mágoè and few in Chimanimani National Reserve and Banhine National Park (AGRECO, 2008).

Methods

Structured questionnaire-based surveys to define demographic, economic and conflict profiles of people living in each of the study sites were conducted between 2007 and 2010. In total, 812 households from 100 villages were interviewed. The survey team made a single visit to each of the villages and at least one Portuguese and a local language-speaking interviewer were present in each of the two-person teams that conducted the survey.

Prior to each interview, one of the team members briefly explained to the potential interviewee the aims of the study. Following this, the potential respondent was asked if he (she) agreed to participate in the survey. The interviews proceeded only when the respondent agreed to participate.

The survey focused on interviewing one member of a household (usually the husband). In the Nipepe study site, one interview was terminated by the wife in the household, five refused to participate, while in 10 households no family member could understand Portuguese or English and none of the team members could speak the local language. One of the teams did not succeed in interviewing one household in Banhine National Park, while in the Limpopo National Park, an entire village refused to participate.

Most villages were situated along roads and I spaced sampling points systematically along these. Interviews lasted 30 to 40 minutes and comprised a series of questions to obtain socio-economic information, details of problems the family faced with farming and wildlife, as well as demographic variables (see Appendix1). The questionnaire had five components: basic locality and survey information, questions on human demography (age of each family member, number of children alive, dead or that has emigrated), the economic profile of a household (e.g. what kind of items the household bought) and the conflicts that people may experience (e.g. what kind of animals affect crops and food stores).

Statistical analysis

I entered all the data from the study sites in SPSS spreadsheets for filtering and reduction (e.g. Field, 2009). I constructed a standing age distribution based on the living individuals in 5-year age classes separately for males and females. I also used the techniques of Ferreira and van Aarde (2008) to smooth the standing age distribution irrespective of whether people have left or not. I calculated the age at which women had their first baby and the interval between births. When a woman was over the age of 30 and the time since the birth of her last child exceeded her average birthing interval, I calculated age at last birth. I used Udevitz and Ballacheys' (1998) approach of assuming a stable age distribution (the smoothed age distribution for females) and an independent estimate of fecundity (half the inverse of the birth interval for the ages from first to last birth) to estimate intrinsic population growth. I calculated survival rates following Eberhardt (1988). I used a log-rank test (Krebs, 1999) to assess whether the calculated survival rates inside protected areas differed from those beyond protected areas.

Given that the samples from the nine study sites were independent from each other and differed in size, I thus followed a confidence interval approach (Hepworth, 1996; Fleiss *et al.*, 2003) to calculate a 95% CI for positive respondents for each question. This approach, estimate the proportion *p* of the true population which may fall within a particular range, following the testing of *n* study sites each of *k* individuals interviewed with *x* responding positively to each specific question. The probability of a positive response is then $\pi = 1 - (1 - p)^{\mathrm{k}}$, and the maximum likelihood estimator (MLE) is $\hat{\pi} = \frac{x}{n}$. A simple transformation shows the MLE of *p* to be (Hepworth, 1996):

$$\hat{p} = 1 - (1 - \hat{\pi})^{1/k}.$$

To test whether people living inside protected areas would extract a greater variety of natural resources than those living beyond, I calculated the total number of used resources and the proportion of the used resources based on the positive responses to the questionnaires. Further, I calculated the niche width as a number of resources used for subsistence by people living inside and beyond protected areas, following Hardesty (1975):

$$Niche\ width = 1/\sum_{i}^{n}(pi)^2$$

where, *pi* is the proportion of the total subsistence contributed by resource *i* and *n* is the total number of resources used for subsistence.

I used the confidence interval for proportion calculator available at http://www.dimensionresearch.com/resources/calculators/conf_prop.html to determine the confidence interval level at 95%, given my study sample size of 310 and 502 and positive survey results on each of questions, for protected and non-protected areas respectively.

The theory of this procedure is based on the notion that my sample size of 812 respondents was drawn from a true population, and that the percentage of positive responses (proportion) I obtained from each question may differ from the true proportion. There is a likelihood (confidence level) that the true population proportion would fall within a particular range (confidence interval) around the proportion value yielded by my study sample.

I compared the responses in protected and non-protected areas using contingency table analyses (Zelen, 1971) to assess whether households living in protected areas would be larger, have greater survival probability of children, extract a greater variety of natural resources, but experience more conflict with the large bodied wildlife than people living beyond these areas. I based the contingency table analyses on a two tailed Chi-square statistic without Yates correction (Haber, 1982; Yates, 1984), given the relatively large sample sizes that make little differences to correct Chi-square values.

Results

Human demographic profile of the rural households in Mozambique

The 812 households that responded and that could be included in the survey represented 5,037 individuals of which the age or year of birth was known for 4,129. Of these most were alive (♂♂: 1,926, ♀♀: 1,977), while respondents provided information on the age of 431 people (♂♂: 208, ♀♀: 223) that have died.

On average (± SE), women had their first baby at 21 ± 0.9 years and every 3.5 ± 0.2 years thereafter. Average age at last birth was 36 ± 1.7 years (Fig. 2). These reproductive parameters did not differ between beyond and protected areas (Table 2). Families living beyond and inside protected areas were of similar size (3.9±0.70 and 4.3±0.88, respectively).

Survival during the first year was 0.97 (3,262 births, 99 deaths before the age of 1) and this was not a function of the conservation status of the study site ($U_{4,4}$ = 3 000; p = 0.15). This analysis suggests that the rural population is growing at 2% per annum. However, once I accounted for the people alive that had left the study area *i.e.* emigration at 20.2% males and 21.7% females, the rural population declined at 3% per year.

Annual survival rates differed between inside and beyond protected areas (log-rank test, $\chi^2 = 47.94$, df = 1, p = 0.001; Fig. 2)

Economic profile of the rural households in Mozambique

Most (fequency±95%CI respectively, 68.1±3.2%) respondents were not employed and lead a subsistence lifestyle that involved seasonal crop-production. Some were self-employed (25±3.0%) with small businesses such as fixing bicycles, while even fewer were employed by government (3.7±1.3%) and private sectors (3.0±1.2%) (Fig. 3). With the exception of those employed by government and the private sectors, the employment profiles for people living in protected areas were similar to those living beyond protected areas (Fig. 3). Respondents did get employed by government and private sectors more often inside protected areas than beyond ($\chi^2 = 4.51$, df = 1, p = 0.03; $\chi^2 = 6.20$, df = 1, p = 0.01; government and private sectors respectively).

Most households did buy items of important use (sugar – 87.9±2.3%, salt – 85.6±2.4%, soap – 88.6±2.2% and matches – 70.1±3.2%), while several had luxury items such as stationary (44.6±3.4%), mirrors (44.3±3.4%) and a radio (40.2±3.4%). Bicycles were not commonly owned (19.5±2.7%) and were used to transport products to and from markets in the towns. Forty-two respondents had wheelbarrows and eight had fridges, while 15 owned a motorised vehicle (motor cycle or car). Socio-economic profiles for people living in and beyond protected differed significantly (Fig. 3; Table 3). For example, inside protected areas, most respondents did buy sugar ($\chi^2 = 12.16$, df = 1, p = 0.0005); salt ($\chi^2 = 23.70$, df = 1, p = 0.0001) and matches ($\chi^2 = 14.06$, df = 1, p = 0.0002) more often than those beyond protected areas. Outside protected areas, luxury items such as stationary ($\chi^2 = 15.20$, df = 1, p = 0.0001); mirrors ($\chi^2 = 47.58$, df = 1, p =

0.0001); radios (χ^2 = 37.32, df = 1, p = 0.0001) and bicycles (χ^2 = 12.43, df = 1, p = 0.0004) were bought more frequently than inside protected areas (Table 3)

People used wild plants for the construction of buildings (92.2±.1.8% of households), making of utensils (35.0±3.3%) and as firewood (95.7±1.4%) as well as food (78.6±2.8%) (Fig. 3). Some households used wild plants as medicine (42.6±3.4%), or for producing alcoholic beverages (12.0±2.2%). Other wild products (mushrooms, fruit, honey and fish) were primarily collected for household use (80.2±2.7%), although 19.2±2.7% of households sold wild products for cash. This reliance on natural resources beyond protected areas differed significantly from inside protected area. For instance, wild plants were mostly used as firewood and for alcohol inside than beyond protected areas (χ^2 = 6.86, df = 1, p = 0.009; χ^2 = 50.69, df = 1, p = 0.0001; firewood and alcohol, respectively). Beyond protected areas wild plants were mostly used as food (χ^2 = 11.87, df = 1, p = 0.0006) and utensils (χ^2 = 6.97, df = 1, p = 0.008) than inside protected areas.

Birds (17.0±2.6% of households) and mammals (31.0±3.2%) were the least common wild products that households collected (Fig. 3), but people living in protected areas did collect so more frequently fruit than those living beyond protected areas (χ^2 = 12.46, df = 1, p = 0.0004). They less frequently used fish, birds and animals (χ^2 = 34.76, df = 1, p = 0.0001; χ^2 = 5.05, df = 1, p = 0.02 and χ^2 = 7.76, df = 1, p = 0.005, respectively fish, birds and animals) than beyond protected areas. Wild products were mostly used inside protected areas for subsistence of the household (χ^2 = 83.60, df = 1, p = 0.0001), rather than for cash as was the case beyond protected areas (χ^2 = 21.96, df = 1, p = 0.0001). Relatively few resources were used inside compared to outside protected areas, but this was not significant (Two-tailed t-test; t = 0.94, df = 4, p = 0.40).

Most households (70.2±3.2%) only kept chickens, while goats were the second most commonly kept livestock (47.0±3.4%). Livestock was mostly kept for household purposes (59.5±3.4%), but at least 6.3±1.7% of households bartered livestock for other goods, while 40.2±3.4% of households sold livestock for cash. The keeping of livestock differed significantly between people living in and beyond protected areas (Fig. 3). For instance, keeping of livestock was mainly done inside protected areas (dogs: χ^2 = 36.09, df = 1, p = 0.0001; chickens: χ^2 = 20.10, df = 1, p = 0.0001; cattle: χ^2 = 65.82, df = 1, p = 0.0001; goats: χ^2 = 8.52, df = 1, p = 0.004; sheep: χ^2 = 19.55, df = 1, p = 0.0001; pigs: χ^2 = 7.33, df = 1, p = 0.007) for subsistence (χ^2 = 11.06, df = 1, p = 0.0009), while for cash beyond protected areas (χ^2 = 11.95, df = 1, p = 0.0005).

Farmers grew numerous crops, including cassava (35.7±3.3% of households), maize (64.7±3.3%), beans (36.1±3.3%) and groundnuts (23.0±2.9%) (Fig. 3). Mangoes and water melon were the most commonly grown fruit bearing plants that they cultivated (2.0±1.0% and 8.9±2.0% of households, respectively). Up to 72.0±3.1% of the households used crops for their own purpose, while 7.5±1.8% exchanged crops for something else and 29.4±3.1% sold crop products for cash. Agricultural activities for people inside and beyond protected areas differed (Fig. 3 and Table 3). Respondents living inside protected area reported more frequently maize (χ^2 = 104.25, df = 1, p = 0.0001), groundnuts (χ^2 = 39.45, df = 1, p = 0.0001), beans (χ^2 = 61.51, df = 1, p = 0.0001) and water-melon (χ^2 = 68.26, df = 1, p = 0.0001) than those from outside protected areas, who mainly grew rice (χ^2 = 68.21, df = 1, p = 0.0001). While agricultural activities for people living inside protected areas were mostly for subsistence of the households

(χ^2 = 21.28, df = 1, p = 0.0001), beyond protected areas people used crops for barter (χ^2 = 34.03, df = 1, p = 0.0001) and cash (χ^2 = 34.85, df = 1, p = 0.0001).

The niche width of wild plants and wild products were relatively wide compared to those for bought items, livestock production and agriculture, but the niche width of wild resources from beyond protected areas was similar to that from inside these (Two-tailed t-test; t = 0.94, df = 4, p = 0.40).

Conflict profile of the rural households in Mozambique

My survey focused on defining wildlife conflict in the context of several other factors that may also influence people's lives. Only few incidences of an animal (elephant, crocodile, lion and snakes) causing injury or death to a family member were noted (Fig. 3). Injury or death to a family member due to animals were significantly higher inside than beyond protected areas (χ^2 = 23.12, df = 1, p = 0.0001). Deaths due to diseases (24.1±2.9% of households) were common in the villages and similar for people living in and beyond protected areas (χ^2 = 0.13, df = 1, p = 0.71).

Houses were damaged by wind (16.1±2.5%) or rain/flood (6.9±1.7%) (Fig. 4). On 14 occasions did elephants damage houses, while in four cases monkeys and baboons were also responsible (Fig. 5). While events of wind were more common inside protected areas than beyond (χ^2 = 6.94, df = 1, p = 0.008), floods were more so beyond protected areas than inside (χ^2 = 5.71, df = 1, p = 0.02). Damage due to animals (e.g. elephants, monkeys and baboons) did not differ between inside and beyond protected areas (χ^2 = 0.15, df = 1, p = 0.70).

In terms of critical resources, droughts (29.6±3.1% of households) were most commonly noted as affecting water supplies (Fig. 4). Pollution of water (6.4±1.7%) and mechanical problems as well as distance to water (2.6±1.1%) were also noted as factors that influenced water supplies mainly more inside protected areas than beyond (χ^2 = 7.29, df = 1, p = 0.007; for pollution) while distance did so frequently outside protected areas (χ^2 = 5.21, df = 1, p = 0.02). Only 13.4±2.3% of households reported that their water supply was affected by animals, and in those cases elephants, crocodiles, bush pigs, cattle and hippopotamuses were identified as culprits (Fig. 5). Water supply damages by animals were more common outside than inside protected areas (χ^2 = 6.06, df = 1, p = 0.02).

Food stores of houses were damaged by fire and wind (< 2% of households), as well as animals (27.2±3.0%) (Fig. 4). Damaged by animals inside and beyond the parks was similar, but wind damage inside and beyond protected areas differed (χ^2 = 11.52, df = 1, p = 0.0007). With regards to animals, the key culprits were rats/mice (17.4±2.6% of households) and insects (mostly beetles) (8.5±1.9%) (Fig. 5), which were similar between inside and beyond protected areas (χ^2 = 0.75, df = 1, p = 0.39; χ^2 = 2.23, df = 1, p = 0.14 for insects and rats/mice, respectively). Damage due to monkeys were common inside protected areas (χ^2 = 5.16, df = 1, p = 0.02).

Disease was the most prominent factor damaging livestock (26.4±3.0% of households), but 12.9±2.3% of respondents also noted animals as a livestock damaging factor (Fig. 4). Damage to livestock due to disease, floods and drought were more common inside than beyond protected areas (disease: χ^2 = 15.33, df = 1, p = 0.0001; floods: χ^2 = 4.88, df = 1, p = 0.03; drought: χ^2 = 6.05, df = 1, p = 0.01). Lions, elephants, monkeys, and birds of prey were key culprits, while four respondents had problems with baboons and crocodiles. Elephants were mostly considered as problematic inside protected areas (χ^2 = 23.07, df = 1, p = 0.0001) while lions were mainly reported as problematic beyond protected areas (χ^2 = 9087, df = 1, p = 0.002).

In terms of agricultural production, animals (71.1±3.1% of households) played a more important role compared to damages they caused to family, homes and critical resources (Fig. 4) and these were similar inside and beyond protected areas (χ^2 = 1.74, df = 1, p = 0.19). Elephants were the primary culprit (40.8±3.4% of households), followed by bush pigs (17.7±2.6), monkeys (11.6±2.2%), baboons (8.0±1.9%), rats/mice (6.9±1.7% of households) and hippopotamuses (1.6±0.9%) (see Fig. 5). Rats/mice and baboons were significantly more problematic inside than outside protected areas (χ^2 = 25.23, df = 1, p = 0.0001; χ^2 = 28.87, df = 1, p = 0.0001 for rats/mice and baboons, respectively) while elephants and bush pigs did so more outside than inside protected areas (χ^2 = 76.16, df = 1, p = 0.0001; χ^2 = 24.13, df = 1, p = 0.0001 for elephants and bush pigs, respectively).

Discussion

Rural people in Mozambique rely on subsistence agricultural and the extraction of a variety of natural resources from woodlands and forests. Under these conditions, wildlife conservation needs to address both sustainability of peoples' livelihoods systems and persistence of wildlife populations.

My study started by assessing the demographic profile of households inside and beyond protected areas. I postulated that people inside protected areas would have bigger families than those living beyond and that the survival probability of children inside protected areas would be greater than outside these. My analyses did not support these expectations. This may suggest some lifestyle similarities under which both rural households living inside and beyond protected areas persist. The frontier rural areas of Mozambique may have more land available for people and they thus may not find it difficult for their children to settle in nearby areas. This thus may provide a marginal benefit in labour available to produce crops and collect resources. As a result, people may either have a higher fecundity as suggested by the frontier hypothesis (Easterlin, 1976) and the scarcity of common wild resources hypothesis (Dasgupta, 2000).

The subsistence economy based on the extraction of natural resources contrasts with typical protected area objectives, which itself reduces the net benefits of living inside protected areas and the survival probability of children. But this was not the case in my studied protected areas. For instances, I observed high rates of survival probability of children inside these. The high rates of survival probability of children together with the differences in the annual survival rates in favour of households living inside protected areas may agree with the notion that living inside protected areas in Mozambique may confer some benefits to reproduction and survival, as also predicted by numerical responses (e.g. Sibly & Hone, 2002).

My assessment of household economic profiles illustrated that rural households in Mozambique satisfied basic needs by various resources and activities available to households. For instance, economic profiles showed high level of unemployment while people did buy basic food items (e.g. sugar and salt) and others (e.g. soap and matches). Some luxury items were also acquired by a significant number of households, such as fridges, vehicles and bicycles. This consumer profile is similar to that observed by others (see Sitoe, 2005; Brück & van den Broeck, 2006; Walker *et al*., 2006; Ribeiro, 2008; Landry, 2009) in different parts of Mozambique.

Although a significant number of households have reported self-employment, this was a natural resource-based (e.g thatching grass, baskets, and wood-carvings). Government jobs were those in schools and clinics and private sector opportunities and were very limited. The incomes earned by those in employment vary enormously, but were generally low (Boughton *et al.*, 2006; Brück *et al.*, 2006). Thus, the high level of unemployment, which is associated with a high level of basic requirements within consumer profiles, but low in some luxury items, may suggest some level of dependence on extraction of wild products and/or agricultural production.

Wild products (e.g. wild plants and wild resources) did satisfy subsistence needs of life for rural households. For example, wild plants were harvested for building, firewood, food, medicine, utensils and alcohol. Forests did also provide non-wood products such as, fruits, fish, mammals, mushrooms, honey and birds. While some of these provided basic subsistence needs (e.g. fuel wood, charcoal, raw materials, fruit, fish, etc) others, however, did give opportunities to households for barter and sales.

This profile of wild products use is similar to that observed by Ribeiro (2008) and Landry (2009) in their case studies of Maputo National Reserve and Sanga District, respectively, but with some specific differences across the country (Sitoe, 2005; Salomão & Matose, 2007). For instance, 46 and 30% of households in rural areas of Mozambique are thought to use wild plants for firewood and building, respectively (Sitoe, 2005). However, 90.9% of the households in the Sanga District did use wild plants as firewood (Landry, 2009). Differences on the use of wild products may be much more due to geographical effect of the location of villages on the variability in the use of the natural resources (e.g. Parker, Hessl & Davis, 2008).

As in most African rural areas (e.g. Brigham *et al.*, 1996), the main source of income for households is agriculture. In Mozambique, agriculture offers low productivity and is mostly dependent on rainfall regimes (Sitoe, 2005). Given this, households are increasingly dependent on non-agricultural livelihoods such as charcoal production, firewood collection, fishing and raw material extraction (Kityo, 2004; Ribeiro, 2008) particularly due to the fact that non-agricultural livelihoods have a variety of uses, and are generally more drought tolerant than cropping and livestock options (Ashley & LaFranchi, 1997).

I predicted that people inside protected areas would extract a greater variety of natural resources than those living beyond. However, the niche width (a proxy of the resource variety) of wild plants, livestock and agriculture was similar between inside and beyond protected areas, which suggests some similarities in the environment inside and beyond protected areas (Hardesty, 1975). The wide niche of the wild products beyond protected areas may, however, reflect an uncertainty of household lifestyle (see Hardesty, 1975), due to the resource scarcity dictated by the large number of users. This contrasts to the resources availability inside protected areas, generally exploited by relatively few people living here as illustrated by the relatively narrow niche from all other resources, but wild plants. With high uncertainty in resource exploitation, users tends to expand the number of the resources used (Hardesty, 1975).

The majority of households owned livestock and crops for subsistence living. In the rural areas of Mozambique, chickens, maize, cassava and beans are basic products which make a significant contribution in poverty alleviation of households (Walker *et al.*, 2006; Ribeiro, 2008). This may explain the greater similarity between agricultural production noted from this study and others across the country (Sitoe, 2005; Walker *et al.*, 2006; Ribeiro, 2008; Landry, 2009) as well as the importance given by the households to livestock and crops. During drought, floods and famine events, livestock and crops can be sold to buy staple foods and eventually luxury products (Landry, 2009). The aggregate structure of household's expenditure in Mozambique accounts for higher consumption rates (e.g. 66.8%) rather than bought items and savings, respectively of 22.5% and 10.7% (Benfica, 2006; Tschirley & Benfica, 2001), which is typical of a rural developing economy.

These economic profiles, extracted for the rural population across Mozambique suggest that most households rely on subsistence farming to extract or produce products from the land, primarily for their own purposes. Bartering and cash sales of crops, and to a lesser extent livestock and wild products, provide for consumer items such as sugar and salt.

Agriculture and keeping livestock for subsistence living was more commonly practiced inside protected areas, a contradicting pattern with my expectation. This observation may reflect a small source of income for households living inside protected areas, a situation that necessitate them to crop or/and to keep livestock. Beyond protected areas, people may engage in a cash economy given a wide diversified source of incomes, a situation that reduces cropping and keeping livestock.

The vulnerability to stresses induced by unemployment, declining yields due to droughts or floods, declining water availability, declines in natural resources differed between households and study areas. For example, most injuries and deaths were due to diseases and wind; floods did damage homes. Family dwellings and damage to homes due to animals were less. Some pattern was observed for critical resources such as water, food stores, livestock and crops. For instance, diseases were the major reason for livestock losses; while drought did cause water scarcity and imposed losses on crops. Animals were identified as the main threat to food store and crops.

These results agree with findings from others (e.g. Sitoe, 2005; Walker *et al*., 2006; Landry, 2009). For example, Walker *et al.* (2006) stated that drought followed by floods, theft, birds and insects is the main threat that represents a risk for agriculture in Mozambique. In the Sanga District (Niassa province), Landry (2009) captured from households responses that family dwellings are mostly exposed to hunger, disease, animals and theft. Cycles of droughts, floods and cyclones and theft outbreaks are frequent events in Mozambique (INGC, 2009). Some of these (e.g. droughts and floods) are being linked to some endemic diseases such as malaria (INGC, 2009). It is thus no surprise that rural households of Mozambique are exposed to a great variety of environmental and social hazard events such drought, floods and diseases.

Animals are threatening events to critical resources in general, but specifically to food security. From my results, I did learn that animals did not have significant impact on critical resources, but caused crop damage. Elephants, followed by monkeys, bush pigs, baboons and rats/mice were responsible for crop losses. Contrary to my expectation, elephants and monkeys were more problematic for food store and livestock inside protected areas, while crop damage, injuries and deaths, damage to homes and to water by elephants, lions, rats/mice and insects were mostly beyond protected areas. These observations may agree with the notion that conflict profiles may be due to complex interplays of risks and households coping strategies, which are dependent on the socio-economic context (Hill, 2004; Naughton-Treves and Treves, 2005; Dickman, 2010). People tend to be intolerant to animals that injury and kill human lives and livestock as well as to those animals imposing losses on ´famine´ crops such as cassava, maize and beans (Naughton-Treves and Treves, 2005). This is strongly true for households inside protected areas where income sources are small.

Beyond protected areas, human population density is relatively high and cultivated areas are large. As stated by Newmark, Manyanza, Gamassa & Sariko (1994), people tend to be less effective in controlling small-bodied species at high human population density. De Boer &

Ntumi (2001) and Sitati *et al*. (2003) reported a positive relationship between cultivation and the intensity of crop raiding by elephants at the Maputo National Reserve (Mozambique) and at the Masai Mara National Reserve (Kenya), respectively. These observations may support my results on the sharply increase of crop damage by large bodied wildlife species (e.g. elephants) and food store damage by rats/mice and insects beyond protected areas.

My study sites did cover villages and households which differed in the exposure to risk and capacity to cope with risk. Tolerance to conflicting animals tend to increase with the existence of various alternate incomes, labour availability, wider coping strategies and communities absorbing losses to wildlife (Naughton-Treves & Treves, 2005). As illustrated by my results, rural households in Mozambique had little alternative incomes, high rates of unemployment, few coping strategies and absorb losses to wildlife. These restrictions are more severe inside protected areas.

As elsewhere (see Kangwana, 1993; Lahm, 1996; Naughton-Treves, 1998; Nyhus, Tilson & Sumianto, 2000; De Boer & Ntumi, 2001; Parker & Osborn, 2001; Dunham *et al*., 2010), I did learn from my study that elephants were key to crop losses. But, in general critical resources threats were mostly linked to other animals (e.g. insects, mostly beetles and rats/mices). For example, in the nationwide assessment on human and wildlife conflict, elephant, hippopotamus, buffalo, bush pigs and monkeys were referred as the most problematic animals that imposed losses of crops (Dunham *et al*., 2010). Apart from these, insects and rats/mice did not have any mention.

The perception of people on the risk posed by wildlife tend to focus on rare, extreme damage events such as those by elephants, rather than ´persistent, small losses, which cumulatively may be greater´ (Naughton-Treves & Treves, 2005). More specifically, elephants are large and dangerous; and they raid a greater range of crops at the mature stage mostly at night. Elephant raids seem to be chronic and impose unlimited amounts of losses (Naughton-Treves & Treves, 2005). The description above may explain why elephants are being topped in human and wildlife conflicts elsewhere and in Mozambique, particularly. But, while elephants did represent challenges for households, insects and rats may have represented a similar threat.

In the tropics (e.g. Mozambique), farmer's are exposed to a greater variety of pests, which impose elevated and chronic levels of losses (Porter & Sheppard, 1998 cited in Naughton-Treves & Treves, 2005). The productivity of the rain fed agriculture in Mozambique is low (Kityo, 2004). For example, grain productivity of maize may vary from 56 to 64 kg/ha, depending on the agro ecological zone of Mozambique (Cugala, 2007). Losses in the field due to the larger grain borer, *Prostephanus truncatus*, may vary from 30 to 35% (Cugala, 2007). In rural areas of Mozambique, 1, 500kg of maize are stored in a small scale farmer's storage (Dick, 1988) per year. The mean losses of maize due to insects (e.g. *Prostephanus truncatus*) range from 26 to 62% of these (Cugala *et al*., 2007). Thus, insects represent key factors that would limit the storage of maize in small scale farmers store conditions as well as potential risk and threat for food security (Cugala *et al*., 2007).

Forty-seven and 77% of households in the rural areas of Limpopo province (South Africa), which borders Mozambique, considered rodents as a pest for crops in fields and in storages, respectively (Kirsten & von Maltiz, 2005). Rodents were problematic in the two crucial phases of crop growing; at planting, they dig up maize seeds and, the heading stage, rodents damage cobs. Losses due to rodents were estimated at 37% (Kirsten & von Maltiz, 2005).

From my assessment, human-wildlife conflict is a reality in the rural areas of Mozambique. Elephants are often responsible for crop damage, rodents and insects are the primary agents responsible for food loss during storage. Conflict with elephants appears not to affect food security, but it is more about life styles being affected by the presence of elephants. The rural nature of the landscape, with relatively small and widely dispersed agricultural fields in the proximity of villages and embedded in relatively intact landscapes, provide habitat for elephants and other wildlife. Some of this wildlife contribute to the local economy and are taken through hunting, trapping and snaring. Elephants, however, were not killed or poached by local inhabitants and appear to serve as an important icon of the hardships associated with a subsistence lifestyle typical of rural Mozambique. Elephants focus political attention on the destitution of these people and calls from local leaders to find solutions for conflict may detract from the primary drivers of lifestyle insecurities associated with a near settler lifestyle typical of the rural areas of Mozambique.

These results highlight the importance of socio-economic approaches in our effort to understand and find solutions to human and wildlife conflicts in general and HEC in particular. Human and wildlife conflicts may impose a significant impact on rural people's livelihoods and lives. The degree to which people consider these to be an important issue may depend on the alternatives they have to cope with. In my study sites, people may perceived losses on human lives, livestock and crops as threats to household assets, which in turn are key features part of coping strategies to environmental stress and shocks (Chamuene *et al.*, 2007; Landry, 2009). Under this context, human and wildlife conflict mitigation strategies will certainly need to expand the traditional species-based approaches (e.g. Hoare, 2001) and consider socio-economic approaches under which conflicts occur. The decision support system (DSS) (Hoare, 2001), a toolkit for HEC mitigation will need to be combined with such alternatives that generate income and benefits for local people. Ultimately, this will improve people perceptions on support elephant conservation and increase tolerance to HEC (Nelson *et al*., 2003).

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Table 1 Study sites details. Districts from where study sites were selected, with respective population density and percent of cultivated area as well as sampling sites from each study sites and respective number of households and total living population.

Study sites	District	Density	Cultivation (%)	Sampling sites	Households	Population
Matutuine	Matutuine	1.8	1,25	Maputo NR	388	1,940
				Futi Corridor	642	3,210
Magude-Moamba	Magude	7.7	2,48	Mapulanguene	451	1,834
				Motaze	1,606	7,824
				Mahele	511	2,294
				Panjane	768	4,124
	Moamba	12.3	2,84	Pessene	4,354	14,846
				Sabie	3,824	16,041
Limpopo NP	Massingir	2.7	2,34	Mavodze	1,114	8,366
				Zulo	1,568	9,180
	Mabalane	2.0	2,30	Combumune	1,687	9,641
				Ntlavene	1,421	9,160
	Chicualacuala	1.2	1,18	Mapai	2,893	17,616
				Pafuri	798	5,112
Banhine NP	Chigubo	0.8	0,71	Ndindiza	2,102	11,511
	Massangena	1.2	0,90	Mavue	1,067	6,376
Chimanimani NR	Sussungenga	18.3	4,22	Dombe	9,882	49,404
				Muhoa	3,445	17,936
				Rotanda	2,060	10,833
Mágoè	Mágoè	8.3	1,05	Maphende	3,063	13,522
				Chinthopo	5,385	24,860
				Mukumbura	6,755	30,470
Marrupa-Nipepe	Marrupa	3.7	0,63	Marangira	5,287	1,288
				Nungo	5,747	1,390
	Maua	6.1	1,12	Maiaca	3,300	13,355
	Nipepe	6.1	1,20	Muipite	2,336	9,438
Quiterajo	Macomia	19.3	4,19	Quiterajo	2,290	8,571

Table 2 An assessment of demographic parameters of four study sites that were situated inside protected areas (n = 310) and others five study sites that were situated beyond protected areas (n = 502). In the table, MNR = Maputo National Reserve; LNP = Limpopo National Park; BNP = Banhine National Park and CNR = Chimanimani National Park.

Demographic parameters	Study sites																													
	Inside												Beyond															Total/Mean		
	MNR			LNP			BNP			CNR			FUTI			MOAMBA			MÁGOÈ			NIPEPE			QUITERAJO			Overall	Inside	Beyond
Sample																														
Males	229			288			230			359			155			212			268			262			431			2,434	1,106	1,328
Females	190			272			226			378			152			217			296			288			573			2,592	1,066	1,526
Unknown	0			0			0			0			3			3			0			9			0			15	0	15
Families	54			94			66			96			39			52			94			78			239			812	310	502
Family size	5,6			3,7			4,0			3,9			4,4			4,1			4,0			3,9			2,8			4,1	4,3	3,9
Reproduction	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n			
Age at first birth	20,6	0,9	50	20	0,6	83	21,0	1,0	57	19,9	0,7	98	22,3	1,1	34	19,9	0,8	52	21,9	0,95	84	18,2	0,6	55	20,1	0,9	94	21	20	21,9
Age at last birth	34,5	1,4	38	35,3	1,1	36	35,5	1,5	44	39,0	1,3	45	36,4	1,7	19	36,5	1,2	28	33,5	1,7	70	38	3,5	8	33,2	1,3	38	36	36,1	35,8
Interval between births	3,1	0,2	193	3,7	0,2	236	4,5	0,3	173	3,5	0,1	323	3,6	0,2	133	3,2	0,2	183	3,2	0,15	263	3,1	0,2	190	3,4	0,2	257	3,5	3,7	3,2
Population growth																														
Closed	0,03			0,02			0,00			0,01			0,02			0,03			0,01			0,01			0,00			0,02	0,02	0,01
Open	-0,03			-0,03			-0,03			-0,01			-0,07			-0,05			-0,02			-0,02			-0,01			-0,03	-0,02	-0,03
Emigration	0,06			0,24			0,14			0,10			0,41			0,36			0,24			0,19			0,04			0,22	0,19	0,25
Child survival	0,94			0,97			0,99			0,99			0,95			0,97			0,98			0,95			0,99			0,97	0,97	0,97

Table 3 An assessment of socio-economic and conflict profiles of eight study sites and frequency of positive responses with respective 95%CI and range. The table illustrates a breakdown of Matutuine study site into the Futi and Maputo NR sampling sites.

			Study sites										Frequency			
			Futi	MNR	Magude-Moamba	LNP	BNP	CNR	Magoe	Marrupa-Nipepe	Quiterajo	TOTAl				
Total number of interviewees per study site			39	54	52	94	66	96	94	78	239	812	n	%	95% CI	Range
1.0	Employment	Not employed	30	18	41	68	47	70	47	61	171	812	553	68.10	3.21	64.89 – 71.31
		Self-employed	5	36	9	16	13	10	46	9	59	812	203	25.00	2.98	22.02 – 27.98
		Government	3	0	1	1	6	10	1	3	5	812	30	3.69	1.30	2.39 – 4.99
		Private	1	0	0	9	0	6	0	4	4	812	24	2.96	1.17	1.79 – 4.13
2.0	Bought items	Sugar	38	51	48	90	62	85	90	57	192	812	713	87.81	2.25	85.56 – 90.06
		Salt	38	52	5	88	63	86	90	72	201	812	695	85.59	2.42	83.17 – 88.01
		Soap	37	52	49	87	63	81	90	68	192	812	719	88.55	2.19	86.36 – 90.74
		Matches	38	47	45	75	62	57	21	52	172	812	569	70.07	3.15	66.92 – 73.22
		Stationary	16	25	23	32	34	20	85	46	80	812	361	44.46	3.42	41.04 – 47.88
		Mirror	27	14	26	22	50	4	70	32	115	812	360	44.33	3.42	40.91 – 47.75
		Radio	18	13	29	16	43	11	62	45	89	812	326	40.15	3.37	36.78 – 43.52
		Wheelbarrow	0	4	17	4	2	1	3	1	10	812	42	5.17	1.52	3.65 – 6.69
		Bike	4	3	23	11	19	8	4	52	34	812	158	19.46	2.72	16.74 – 22.18
		Fridge	0	0	1	3	0	0	0	0	4	812	8	0.99	0.68	0.31 – 1.67
		Vehicle	3	5	3	1	0	1	1	0	1	812	15	1.85	0.93	0.92 – 2.78
3.0	Wild plants	Building	37	50	49	88	62	92	94	75	202	812	749	92.24	1.84	90.40 – 94.08
		Firewood	23	52	50	92	64	96	94	75	231	812	777	95.69	1.40	94.29 – 97.09
		Food	36	20	28	88	36	80	94	54	202	812	638	78.57	2.82	75.75 – 81.39
		Medicine	18	19	14	62	17	24	94	5	93	812	346	42.61	3.40	39.21 – 46.01
		Utensils	1	28	23	24	29	10	87	47	35	812	284	34.98	3.28	31.70 – 38.26
		Alcohol	2	8	14	44	17	0	6	6	0	812	97	11.95	2.23	9.72 – 14.18
4.0	Wild products	Mushrooms	15	2	3	0	28	27	2	60	40	812	177	21.80	2.84	18.96 – 24.64
		Fruit	37	50	28	88	58	80	80	54	200	812	675	83.13	2.58	80.55 – 85.71
		Honey	36	15	13	19	30	19	20	41	50	812	243	29.93	3.15	26.78 – 33.08
		Fish	24	39	15	20	20	12	12	43	159	812	344	42.36	3.40	38.36 – 45.76
		Birds	4	2	2	19	10	10	10	22	59	812	138	17.00	2.58	14.42 – 19.58
		Animals	24	13	16	15	9	41	30	24	79	812	251	30.91	3.18	27.73 – 34.09
4.1	Use	Household	36	54	35	90	64	91	77	65	139	812	651	80.17	2.74	77.43 – 82.91
		Barter	2	0	0	4	2	1	5	0	15	812	29	3.57	1.28	2.29 – 4.85
		Cash	9	30	2	0	0	4	12	14	85	812	156	19.21	2.17	16.50 – 21.92
5.0	Livestock	Dogs	8	9	24	44	22	21	26	3	7	812	164	20.20	2.76	17.44 – 22.96
		Chickens	27	39	39	70	52	85	74	55	129	812	570	70.20	3.15	67.05 – 73.35
		Guineafowl	1	2	2	1	0	1	0	1	2	812	10	1.23	0.76	0.47 – 1.99
		Cattle	6	4	35	63	32	34	42	1	1	812	218	26.85	3.05	23.80 – 29.90
		Goats	20	32	35	56	31	47	35	15	111	812	382	47.04	3.43	43.61 – 50.47
		Sheep	0	2	3	6	13	2	0	0	4	812	30	3.69	1.30	2.39 – 4.99
		Bush pigs	0	0	0	7	6	2	7	1	0	812	23	2.83	1.14	1.69 – 3.97
		Duck	0	0	10	0	4	0	12	0	6	812	32	3.94	1.34	2.60 – 5.28
5.1	Use	Household	30	43	44	56	56	52	16	57	129	812	483	59.48	3.38	18.37 –23.99
		Barter	4	1	0	1	0	1	12	11	21	812	51	6.28	1.67	56.10 – 62.86
		Cash	19	11	19	37	10	43	66	32	89	812	326	40.15	3.37	4.61 – 7.95
6.0	Crops	Cassava	23	38	19	18	25	21	0	45	101	812	290	35.71	3.30	36.78 – 43.52
		Maize	27	34	45	83	63	88	63	54	68	812	525	64.66	3.29	32.41 – 39.01

Table 3 (Continued)

			Study sites										Frequency			
			Futi	MNR	Magude-Moamba	LNP	BNP	CNR	Magoe	Nipepe-Marrupa	Quiterajo	TOTAl				
Total number of interviewees per study site			39	54	52	94	66	96	94	78	239	812	n	%	95% CI	Range
		Rice	4	0	0	3	1	6	0	15	110	812	139	17.12	2.59	61.37 – 67.95
		Groundnuts	12	21	15	35	41	11	25	9	18	812	187	23.03	2.90	14.53 – 19.71
		Mangoes	2	0	0	0	1	0	0	14	0	812	17	2.09	0.98	20.13 – 25.93
		Beans	22	14	20	62	56	32	4	29	54	812	293	36.08	3.30	1.11 – 3.07
		Sorghum	0	0	3	5	8	22	19	28	11	812	96	11.82	2.22	32.78 – 39.38
		Water-melon	0	0	1	32	28	0	0	0	11	812	72	8.87	1.96	9.60 – 14.04
		Wheat	0	0	0	0	0	14	0	0	0	812	14	1.72	0.89	6.91 – 10.83
6.1	Use	Household	36	47	46	89	45	71	53	70	128	812	585	72.04	3.09	0.83 – 2.61
		Barter	3	0	3	0	2	0	16	15	22	812	61	7.51	1.81	68.95 – 75.13
		Cash	15	5	10	5	19	25	25	46	89	812	239	29.43	3.13	5.70 – 9.32
		Floods	0	0	0	6	0	0	0	0	0	812	6	0.74	0.59	26.30 – 32.56
7.0	Injury and deaths	Animals	1	1	1	4	0	0	0	1	50	812	58	7.14	1.77	0.15 – 1.33
		Fire	0	0	1	0	0	0	0	1	2	812	4	0.49	0.48	5.37 – 8.91
		Disease	9	20	6	27	17	13	0	4	100	812	196	24.14	2.94	0.01 – 0.97
8.0	Damage to homes	Wind	7	24	9	14	22	3	0	8	43	812	130	16.01	2.52	21.20 – 27.08
		Floods	0	3	2	5	3	2	0	12	29	812	56	6.90	1.74	13.49 – 18.53
		Animals	1	1	0	4	0	0	0	2	7	812	15	1.85	0.93	5.16 – 8.64
		Fire	0	2	0	2	3	0	0	1	5	812	13	1.60	0.86	0.92 – 2.78
9.0	Damage to water supply	Drought	20	17	21	24	36	17	0	25	80	812	240	29.56	3.14	0.78 – 2.46
		Animals	1	0	11	30	0	0	0	3	64	812	109	13.42	2.34	26.42 – 32.70
		Pollution	1	17	2	4	1	7	0	7	13	812	52	6.40	1.68	11.08 – 15.76
		Fire	0	0	0	0	0	0	0	0	1	812	1	0.12	0.24	4.72 – 8.08
		Mechanical	1	0	3	0	4	0	2	0	0	812	10	1.23	0.76	-0.12 – 0.36
		Distance	0	3	10	0	0	0	0	8	0	812	21	2.59	1.09	0.47 – 1.99
10.0	Damage to food store	Disease	0	1	0	0	0	0	0	7	0	812	8	0.99	0.68	1.50 – 3.68
		Fire	0	0	0	0	1	0	0	0	0	812	1	0.12	0.24	0.31 – 1.67
		Floods	0	0	2	2	0	0	0	0	0	812	4	0.49	0.48	-0.12 – 0.36
		Animals	22	24	41	15	9	46	2	45	17	812	221	27.22	3.04	0.01 – 0.97
		Pollution	0	0	0	0	0	0	0	0	0	812	0	0.00	0	0.00 –0.00
		Drought	0	0	0	0	0	0	0	0	0	812	0	0.00	0	0.00 –0.00
		Wind	0	0	1	2	5	2	0	0	0	812	10	1.23	0.76	60.47 – 1.99
		Thefts	0	0	0	1	1	0	0	0	1	812	3	0.37	0.42	-0.05 – 0.79
11.0	Damage to livestock	Disease	11	22	20	8	24	52	2	39	37	812	215	26.48	3.03	23.45 – 29.51
		Fire	0	0	0	0	0	0	0	0	0	812	0	0.00	0	0.00 –0.00
		Floods	0	3	0	0	0	0	0	0	0	812	3	0.37	0.42	-0.05 – 0.79
		Animals	9	15	14	18	2	6	2	10	29	812	105	12.93	2.31	10.62 – 15.24
		Pollution	0	0	0	0	0	0	4	0	0	812	4	0.49	0.48	0.01 – 0.97
		Drought	0	0	2	3	4	0	0	0	0	812	9	1.11	0.72	0.39 –1.83
		Wind	0	0	0	0	0	0	0	0	0	812	0	0.00	0	0.00 –0.00
		Thefts	1	0	0	0	0	1	0	0	14	812	16	1.97	0.96	1.01 – 2.93
12.0	Damage to crops	Animals	37	43	33	75	12	82	85	57	153	812	577	71.06	3.12	67.93 – 74.18
		Drought	1	0	13	77	34	9	29	5	22	812	190	23.40	2.91	20.49 – 26.31
		Theft	0	0	0	0	0	4	0	0	0	812	4	0.49	0.48	0.01 – 0.97
		Soils	0	1	1	1	0	4	0	0	4	812	11	1.35	0.79	0.56 – 2.14
		Floods	2	1	1	1	0	2	0	4	4	812	15	1.85	0.93	0.92 – 2.78
13.0	Conflict & homes	Elephants	1	1	0	2	0	0	0	2	8	812	14	1.72	0.89	0.83 – 2.61
		Monkeys	0	0	0	0	0	1	0	0	3	812	4	0.49	0.48	0.01 – 0.97
		Baboons	0	0	0	0	0	1	1	0	2	812	4	0.49	0.48	0.01 – 0.97

Table 3 (Continued)

			Study sites										Frequency			
			Futi	MNR	Magude-Moamba	LNP	BNP	CNR	Magoe	Nipepe-Marrupa	Quiterajo	TOTAl				
Total number of interviewees per study site			39	54	52	94	66	96	94	78	239	812	n	%	95% CI	Range
14.0	Conflict & water	Elephants	0	11	3	20	0	0	0	2	43	812	79	9.73	2.04	7.69 – 11.77
		Cattle	2	0	3	0	0	0	0	0	0	812	5	0.37	0.42	-0.05 – 0.79
		Crocodiles	0	0	6	3	0	0	0	0	0	812	9	1.11	0.72	0.39 – 1.83
		Hippopotamuses	0	0	2	0	0	0	0	1	0	812	3	0.37	0.42	-0.05 – 0.79
15.0	Conflict people	Elephants	0	1	0	9	0	0	0	0	19	812	29	3.57	1.28	2.29 – 4.85
		Crocodiles	0	0	0	1	0	0	0	0	1	812	2	0.25	0.34	-0.09 – 0.59
		Lions	0	0	0	2	0	0	0	0	1	812	3	0.37	0.42	-0.05 – 0.79
		Snakes	1	0	0	0	0	0	0	0	0	812	1	0.12	0.24	-0.12 – 0.36
16.0	Conflict & crops	Elephants	26	41	9	2	5	19	82	27	120	812	331	40.76	3.38	37.38 – 44.14
		Monkeys	11	0	3	0	0	37	0	23	20	812	94	11.58	2.20	9.38 – 13.78
		Bush pigs	28	0	24	3	0	26	20	34	9	812	144	17.73	2.63	15.10 – 20.36
		Rats/mice	0	0	13	0	0	39	0	4	0	812	56	6.90	1.74	5.16 – 8.64
		Insects/beetles	3	0	0	0	1	4	0	2	0	812	10	1.23	0.76	0.47 – 1.99
		Cattle	1	0	2	0	0	0	0	0	0	812	3	0.37	0.42	-0.05 – 0.79
		Baboons	0	0	0	43	2	0	0	20	0	812	65	8.00	1.87	6.13 – 9.87
		Hippopotamuses	7	2	3	1	0	0	0	0	0	812	13	1.60	0.86	0.74 – 2.96
		Birds	7	0	0	0	0	0	0	0	0	812	7	0.86	0.64	0.22 – 1.50
17.0	Conflict & livestock	Elephants	0	0	0	14	0	0	0	0	0	812	14	1.72	0.89	0.83 – 2.61
		Monkeys	0	0	0	0	0	5	0	1	4	812	10	1.23	0.76	0.47 – 1.99
		Birds	3	0	2	2	0	0	0	1	0	812	8	0.99	0.68	0.31 – 1.67
		Lions	0	0	3	3	0	0	0	0	23	812	29	3.57	1.28	2.29 – 4.85
		Baboons	0	0	2	1	0	0	0	0	2	812	5	0.62	0.54	0.08 – 1.16
		Crocodiles	2	1	1	1	0	0	0	0	0	812	5	0.62	0.54	0.08 – 1.16
		Snakes	3	0	0	0	0	0	0	0	0	812	3	0.37	0.42	-0.05 – 0.79
18.0	Conflict and food store	Insects	18	0	25	0	7	16	0	1	2	812	69	8.50	1.92	6.58 – 10.42
		Rats/mice	9	12	40	0	0	34	0	23	23	812	141	17.36	2.61	14.75 – 19.97
		Bush pigs	6	0	0	0	0	0	0	0	0	812	6	0.74	0.59	0.15 – 1.33
		Monkeys	1	0	0	1	0	13	0	1	7	812	23	2.83	1.23	1.69 – 3.97
		Elephants	0	0	0	7	0	2	0	3	8	812	20	2.46	1.07	1.39 – 5.53

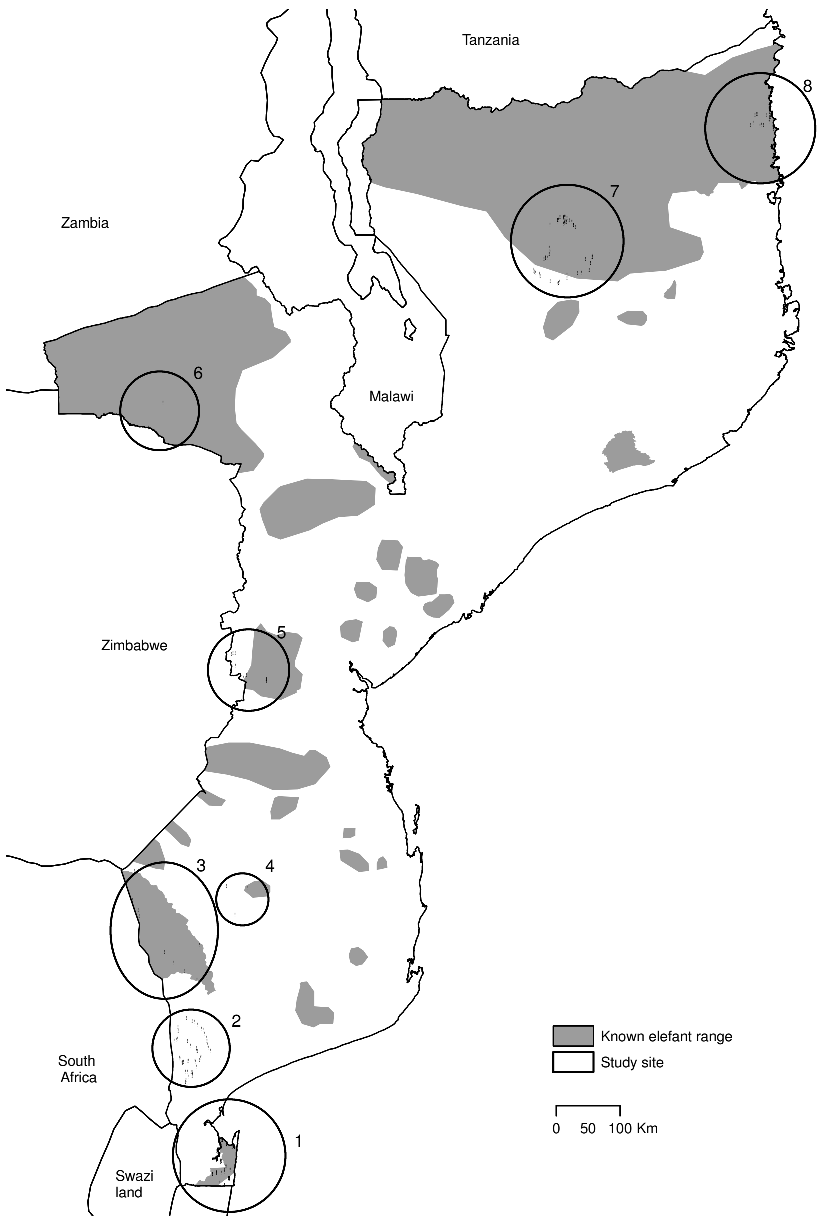

Fig. 1 Line diagrams of Mozambique, showing the location of the eight study sites where the structured questionnaire-based survey were carried out as well as the reduced and fragmented present elephant range with links to Tanzania, Zambia, Zimbabwe and South Africa. Inset shows location of each of study site. 1, Matutuine; 2, Magude-Moamba; 3, Limpopo NP; 4, Banhine NP; 5, Chimanimani NR; 6, Mágoè; 7, Marrupa-Nipepe and 8, Quiterajo. Elephant range was modified from Ntumi *et al.* (2009).

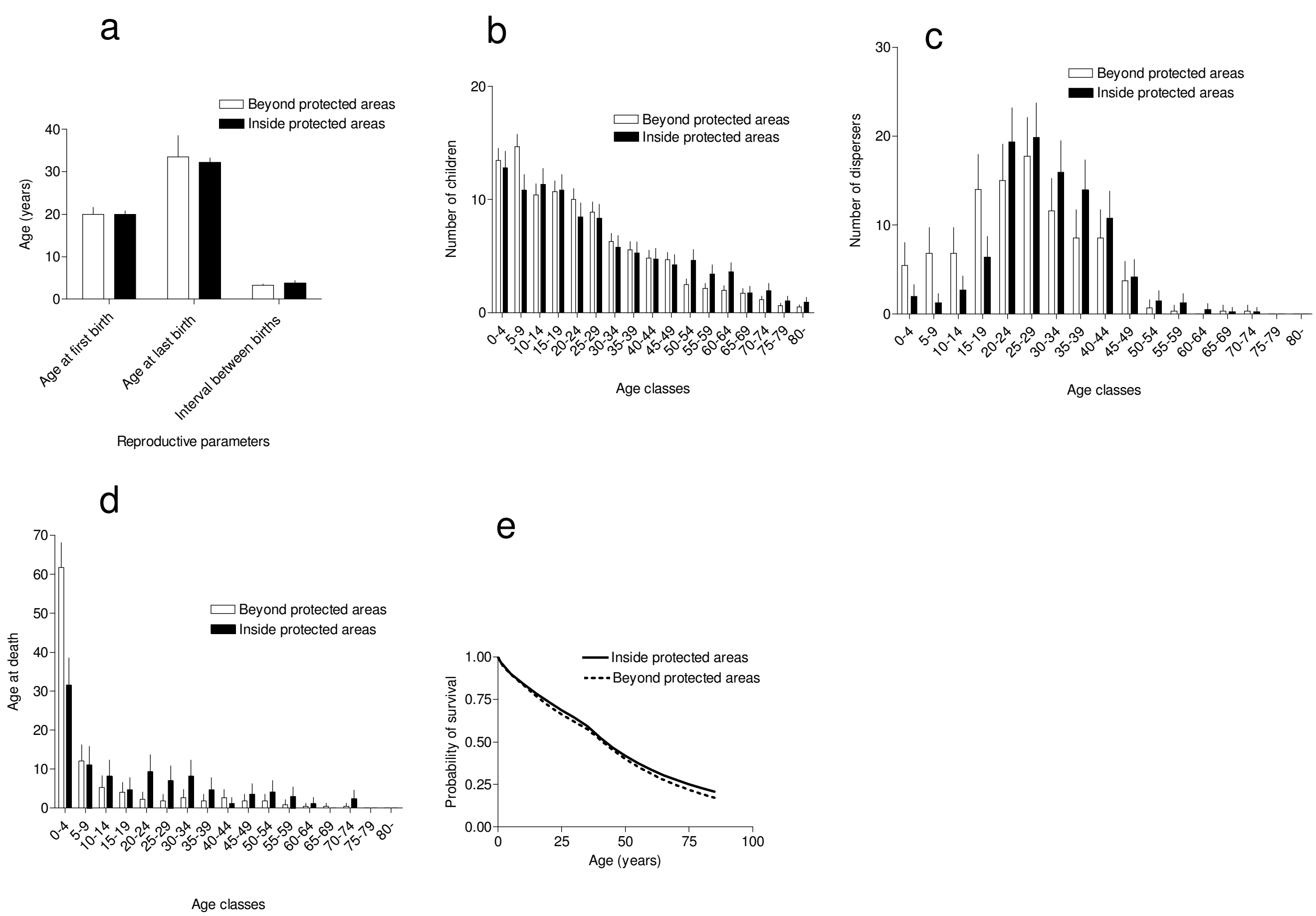

Fig. 2 The demographic profile of rural people living beyond (clear bars, n = 502) and inside (dark bars, n = 310) protected areas of Mozambique. The figure, illustrates the reproductive parameters (a), number of children by age classes (b), number of dispersers by age classes (c), age at death by age classes and (d), the probability of survival (e).

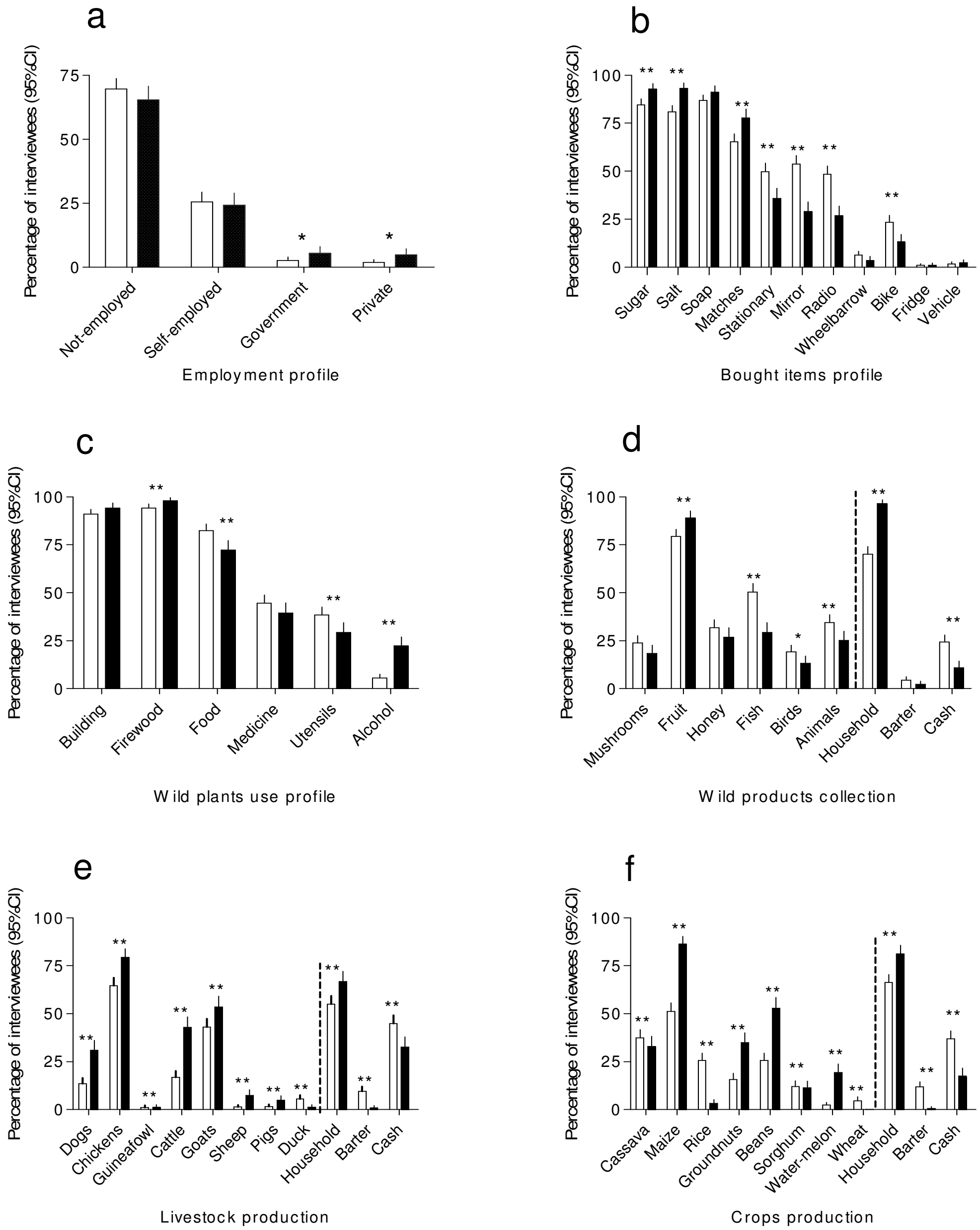

Fig. 3 The economic profile of rural people living beyond (clear bars; n = 502) and inside (dark bars; n = 310) protected areas of Mozambique. The figure, illustrates the consumer profile with (a), employment and (b), bought items; wild product use with (c), wild plants and (d), collection of wild products and agricultural production with (e), livestock and (f), crops (*$p < 0.05$, **$p < 0.001$).

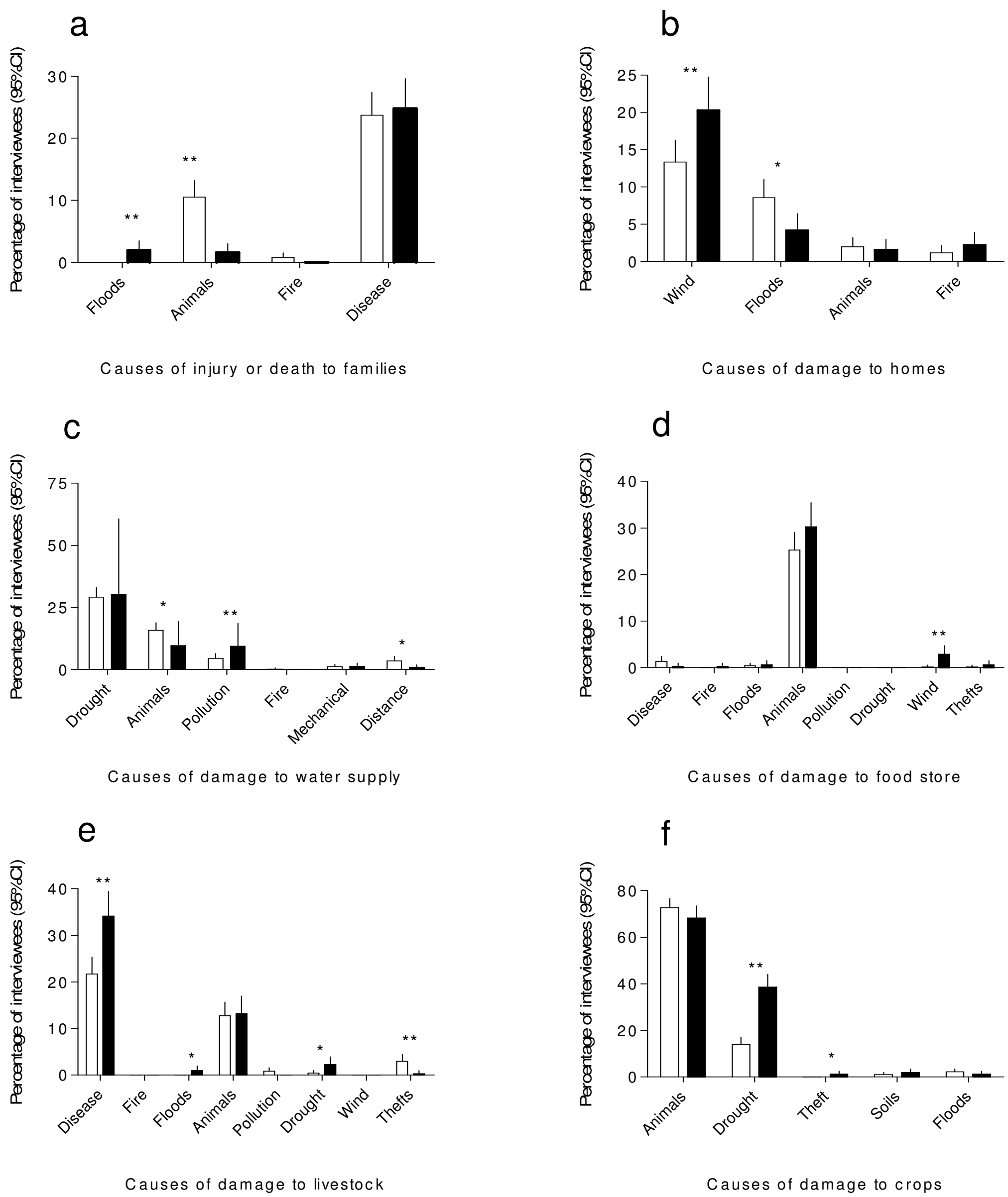

Fig. 4 The conflict profile compiled for 820 rural households living beyond (clear bars; n = 502) and inside (dark bars; n = 310) protected areas of Mozambique. The figure highlights family and dwellings with (a), injury or death and (b), damage to homes; critical resources with (c), damage to water supply and (d), damage to food store; agricultural production with (e), damage to livestock and (f) damage to crops (*p < 0.05, **p < 0.001).

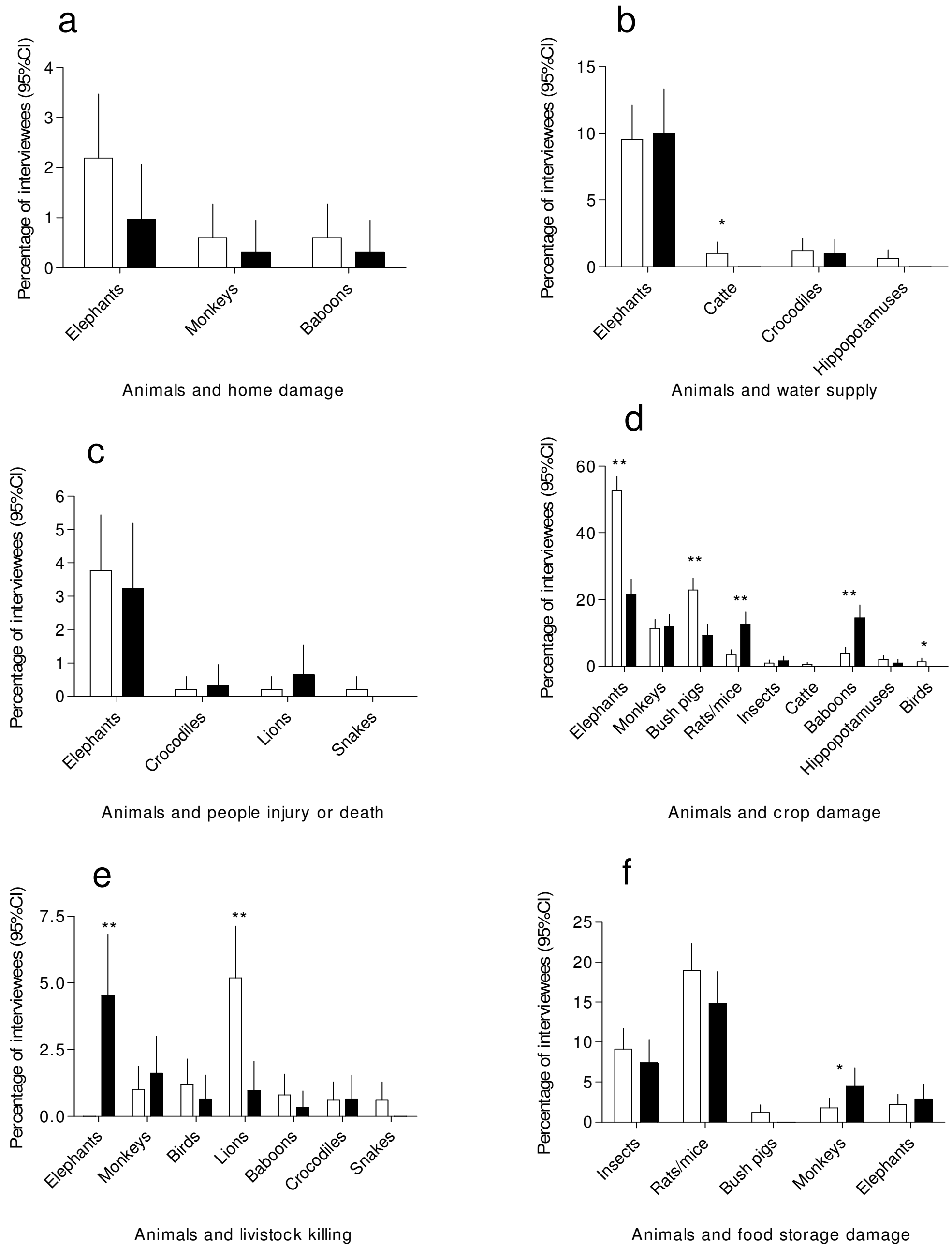

Fig. 5 The conflict profile compiled for 820 rural households living beyond (clear bars; n = 502) and inside (dark bars; n = 310) protected areas of Mozambique. Elephants, monkeys and rat/mices damage crops, while rat/mices and insects damage food stores (*p < 0.05, **p < 0.001).

Appendix 1 The confidential questionnaire for structured surveys used to access the demographic, economic and conflict profiles in the all nine study sites of rural areas of Mozambique between 2007 and 2010.

Reference:

Interviewer……………………………………….

Date…………………………………………………………

GPS coordinates ……………………………Province & Country……………………………………

Demographic profile

1. Year of birth…………………..

2. Age……………………………

3. Gender: male female

4. Ethnic group…………………………

5. Details of spouse:

	Wife 1	Wife 2	Wife 3	Husband 1	Husband 2	Husband 3
Alive						
Age (at death)						

6. Details of children:

	Wife 1				Wife 2				Wife 3			
Child #	Boy / girl	Alive	Age Died	Age Today	Boy / girl	Alive	Age Died	Age Today	Boy / girl	Alive	Age Died	Age Today
1												
2												
3												
4												
5												
6												
7												
8												
9												

7. Place of residence Town Rural village Rural single

8. For how many years were you educated (or not educated)………………..

9. Can you read? Yes No 10. Can you write? Yes No

11. Were you born in the province? Yes No

12. How many of your children: are still at home?........... have moved to a(nother) town or city?................

Economic profile

13. Which of the following animals does your household keep?

Dogs Chickens Guinea fowl Cattle Goats Sheep Pigs None Other……………………..

14. Why do you keep livestock? Household use Non-cash trade (barter) Cash trade

15. Which of the following bought items does your household use?

Sugar Salt Soap Matches Pen / pencils Mirror Radio Wheelbarrow Bike Fridge Motor vehicle

16. Which of the following crops do you grow? Cassava Maize Rice Groundnuts Mangoes Beans Other……………….………….. Other ………..…………………. Other………….

17. What do you grow your crops for? Household use Non-cash trade (barter) Cash trade

18. Do you use wild plants for the following purpose: Building Medicine Firewood Alcohol (beer / wine) Charcoal Household Utensils (mats, kitchen, pounding blocks) Tourist curios (carvings, mats)

19. Which of the following wild produce do you collect: Mushrooms Fruit Honey Fish Birds Animals

20. Why do you collect these products? Household use Non-cash trade (barter) Cash trade

21. How are you employed? Not employed Self-employed Government employed Private sector

22. In which sector are you employed? Agriculture Mining Tourism Conservation Other…………….

23. What is the name of your employer?......................... 24. What is your approximate monthly income………..

Conflict profile

25. Did anything stop access to your regular drinking water supply in the last year? yes no

If yes – water polluted fire drought floods wind mechanical failure animals

Details…………………………………………………..…………………………………………………

26. Did anything damage your home in the last year? yes no

If yes – fire floods / rain wind animals

Details…………………………………………...………………………………………………………

27. Did anything injure or kill anyone in your household in the last year? yes no

If yes – disease fire floods animals other

Details…………………………………………...………………………………………………………

28. Did anything kill or reduce your livestock numbers in the last year? yes no don't keep livestock

If yes – disease fire drought floods wind animals theft ran away

Details…………………………………………...………………………………………………………

29. Did anything damage or reduce your crop harvest in the last year? yes no don't farm

If yes – disease fire drought floods wind hail animals poor soils theft

Details…………………………………………...…………………………………………………………

30. Did anything damage or take produce in your food stores in the last year? yes no don't have a food store

If yes – disease fire drought floods wind theft animals

Details……………………………………...……………………………………………………………

SUMMARY TABLE TO BE FILLED IN FOR QUESTIONS 24-29

Animal	Water	Home	People	Livestock	Crops	Store
Cattle						
Goat / sheep						
Insects						
Birds						
Porcupine						
Rats and mice						
Bush pig						
Monkey						
Baboon						
Kudu						
Elephant						
Other……………………						
Other……………………						

Chapter 4

Socio-ecological and demographic factors associated with Human-Elephant Conflict in Mozambique

Abstract

Human-wildlife conflict, particularly human-elephant conflict, appears to be a growing problem in Africa, and influence both human and wildlife populations. This study aims to identify some of the factors associated with such conflict through a generalized linear model (GLM) exercise.

Based on logistic regression the likelihood of the presence and absence of elephants was a function of human density. Reported incidences of HEC were higher in the proximity of protected areas than further afield, but were not a function of elephant density inside protected areas. The best model to explain incidences of HEC included human density, percent cultivated area and human population growth rate as explanatory variables. I concluded that effective mitigation efforts would consider the ecological, sociological and demographic drivers of conflict.

Keywords: Land transformation, logistic regression, elephants, HEC, landscape approach, Mozambique.

Introduction

Some 22 million people and 22,000 elephants live in Mozambique (INE, 2007; (AGRECO, 2008). Sixty five percent of these people live in rural areas (MPF, 2002) where their livelihoods depend on subsistence farming. Here poverty is integral to life and about 50 percent of the rural population is officially considered poor (MPF, 2002). Rural life in Mozambique is also characterized by conflict with wildlife (see De Boer & Ntumi, 2001). Elephants are of particular concern (Dunham *et al.*, 2010). Based on statistics they extracted from official records for the period 2006 to 2008 conflicts occur across the country. Some 800 incidences reported over a period of four years (2006 to 2009) accounted for the loss of crops on 1,373 hectares, 42 human deaths and 14 injuries to people (MA, 2009). It is thus no surprise that human-wildlife conflict is high on the agenda of the government of Mozambique.

Political action to reduce conflict between people and elephants (HEC) is justified by the popular believe that conflict is induced by high elephant densities and proximity to protected areas (MA, 2008). Consequently, elephants that may be responsible for the loss of life or crops, is often shot. For instance, 85 elephants were killed from 2006 to 2008 to reduce conflict (Dunham *et al.*, 2010). Such killing, however, is often retaliatory of nature and we do not know how effective it is in reducing conflict, nor do we know whether such conflict is associated with proximity to protected areas, or if conflict varies with elephant densities. However, we do know that conflict occur both within and beyond protected areas and that elephants are unevenly distributed across Mozambique where nearly 80% of elephants live in the northern parts of country (Ntumi *et al.*, 2009).

Pro-active measures to resolve conflict seems ineffective because of the tendency of people to ignore governmental regulations (MITUR, 2010). For instance, the zonation of the Niassa province to separate wildlife and people and thus reduce conflict, are ignored by local communities (e.g. MITUR, 2010). Under these conditions of civil disobedience, zonation may not reduce HEC. On the other hand, by identifying the ecological and sociological variables associated with conflict we may be able to design approaches to reduce HEC as has been posited by Naughton-Treves & Treves (2005) for elephants elsewhere in Africa.

From studies elsewhere in Africa, we know that elephants tend to move away from highly settled and developed areas (Parker & Graham, 1989; Hoare & du Toit, 1999; Lee & Graham, 2006; Harris *et al*., 2008) and may concentrate in refuge area (Osborn & Parker, 2003). In Mozambique protected areas may provide such refuge as some 16 percent of the country has been set aside for formal protection (MICOA, 2003). Most of these protected areas are inhabited by elephants and people (see Ntumi *et al*. 2009), but elephants also live in unprotected areas and on communal land that makes up some 50 percent of the area of the country (UIF, 2007). The density (mean±SD) of people inside protected areas (2.69±2.60 people/km^2 ;MITUR, 2010) far exceeded that in rural aereas beyond protected areas (17,86±9,08 people/km^2 ;INE,2007). In Mozambique communal land often surrounds protected areas and human activities may disrupt and isolate populations. Consequently, apart from attempts to reduce HEC in areas that could link fragments of a former more extended elephant population, the design of a network of land use options that can provide for the co-existence of people and elephants may also be considered a priority. In this chapter, I develop a conceptual framework to identify the ecological and sociological factors that may drive HEC. The objective of the chapter is to evaluate the relationship between human presence, human activities, elephant presence and reported incidences of human-elephant conflict. In terms of ecological factors, I asked i) if the presence or absence of elephants is a function of human density, ii) if HEC is a function of distance from protected area, iii) if the likelihood of HEC can be explained by elephant density, and iv) if HEC is a function of landscape transformation. I furthermore used a GLM to determine the abilities of selected variables to explain variability in the incidences of HEC. Here I used a poverty index, human population growth, human density, human dispersion and landscape transformation as predictor variables. I predicted that i) human density determines the presence and absence of elephants, ii) incidences of HEC would be higher in the proximity of protected areas than further afield, iii) incidences of HEC would be a function of elephant density, but iv) be explained by landscape transformation.

A conceptual HEC framework

Human-elephant conflict (HEC) refers to negative interactions between people and elephants that lead to injury or death, as well as the loss of infrastructure and crop damage (e.g. Messmer, 2000; Madden, 2004; Dunham *et al.*, 2010). HEC can be "real or perceived, economic or aesthetic, social or political" (Messmer, 2000) and may be associated with some ecological, social, economical and political factors. HEC may arise when humans and elephants share the same physical space in the landscape (Naughton-Treves, 1998; Sitati *et al.*, 2003). Spatial use is driven by resource needs, but modified by environmental, social and economic variables. Variables dictating spatial use (Sitati *et al*., 2005) thus have consequences for plans to mitigate HEC effectively.

People in rural Mozambique rely on their environment for food, energy, shelter and medicine. Some rural people gain financially by exploiting natural resources such as wood and wildlife (Ribeiro, 2008). Rural agriculture based on the *machamba* system of fertilizing fields through the burning of biomass modifies landscapes while ranching with goats and cattle mostly rely on natural pastures (AGRECO, 2008). Pending on scale these activities may either attract or repel elephants.

Food, water and shelter from weather extremes are key determinants of the distribution of elephants (e.g. Kinahan *et al*., 2007; de Beer & van Aarde, 2008; Harris *et al*., 2008; Loarie *et al*., 2009a & b; Ngene, 2010). Thus, humans and elephant may select for landscapes that provide for economic, physiological, ecological, and behavioral processes (Ntumi *et al*., 2005; Archie *et al*., 2006; Wittemyer *et al*., 2007; Young *et al*., 2009a & b), but all of this may induce conflict between them. Much has been published on the determinants of the distribution of elephants (e.g. Foley, 2002; Ntumi *et al*., 2005; Kinahan *et al*., 2007; de Beer & van Aarde, 2008; Harris *et al*., 2008; van Aarde *et al*., 2008) and these may be of value on determining overlap in distribution and the consequent likelihood of HEC.

Spatial use by humans may reflect a compromise of resource demand, environmental conditions, social structure and cultural factors (Hamilton *et al*., 2007)**.** However, proximity to infrastructure may also be important and in rural areas of Mozambique where people live close to roads, water sources and alluvial soils suitable for agriculture (MPF, 2002). Elephants do also select landscapes based on the productivity of the environment, environment correlates and population biology (Western & Lindsay, 1984; Wittemyer *et al*., 2007; Young *et al.,* 2009a; Young & van Aarde, 2010).

Overlap in spatial use by people and elephants leads to interactions between them. These interactions may be associated with spatial variables such as human density, the extend of land transformation, agriculture practices, the density of roads, and proximity to protected areas (Hoare & du Toit, 1999; Parker & Osborn, 2001; Sitati *et al*., 2003), all of which may be used to predict the likelihood of conflict between elephants and people.

Study area

Mozambique covers about 800, 000 km^2 along the east coast of southern Africa (Fig. 1). Annual rainfall varies from 1, 000 mm in the northern and southern provinces to 1, 200 mm in the central provinces (Instituto Nacional de Meteorologia, 2007). Dry and moist miombo woodlands are common in the northern and central provinces, while mopane woodlands dominate the Limpopo-Save region and the mid Zambezi valley (Hatton *et al*., 2001). Some 22, 000 elephants (AGRECO, 2008) live in five National Parks, five National Reserves, 13 Controlled Hunting Areas, one Forest Reserve, and in areas beyond protected areas (Ntumi *et al*., 2009). The elephant population of Niassa National Reserve is the largest, with >14, 000 elephants in 2004 (Ntumi *et al*., 2009).

The human population is increasing at ~2.2% per year (INE, 2007). People live in all nationally protected areas in Mozambique. Threats to conservation inside and outside protected areas include the uncontrolled establishment of settlements, the clearing of vegetation for agriculture, logging, poaching, cattle and goat farming, non-forestry products extraction, informal mining and fire (ARD, 2002; AGRECO, 2008). Cattle numbers are relatively high in southern and central Mozambique, but low in northern Mozambique (AGRECO, 2008). Land transformation induced by cultivation, clearing of vegetation, logging, charcoal production and firewood collection often follow on the establishment of settlements.

Most elephants in the country are confined to four clusters of protected areas. These include the Maputo-Futi cluster (Southern LTFCA), the Great Limpopo cluster (Southern GLTFCA), the Zambezi cluster (Central) and the Niassa-Quirimbas cluster (Northern). The Southern GLTFCA cluster includes some isolated sub-populations in the south of Inhambane province (e.g. Funhalouro, Govuro, Massinga and Panda) as well as those that roam across the Magude district and into the neighbouring Kruger National Park in South Africa. The Central cluster includes the subpopulations of Moribane and Machaze (close to the Chimanimani-TFCA), as well as those residing in Gilé, Magoe and Zumbo. The Gilé subpopulation includes elephants ranging the Gilé, Maganja da Costa and Pebane districts. Finally, the Northern cluster includes elephants from Nipepe-Lalaua area, the Mecuburi district and northern Cabo Delgado province (e.g. Mocimboa da Praia, Nangade, Palma and Mueda districts) (for details, see Fig. 1a & b).

Data & Methods

Elephant and HEC distribution

I obtained information on the presence and absence of elephants from DNFFB (1999), ARECO (2008) and Ntumi *et al*. (2009) and HEC data from National Directorate of Land and Forest (DNTF) and National Directorate of Conservation Areas (DINAC). I used these to generate maps of district specific elephant occurrences and incidences of HEC. Records from 2006 to 2009 on HEC incidences included names of localities and villages where conflict occurred in each district, the timing of an incidence, the species involved, the damages incurred (e.g. crop damage and livestock), as well as number of persons killed or injured.

I restricted my analyses to the district level because of inconsistencies and gaps at locality and the village scale. For instance, the data from some districts pinpointed exact localities, included detailed descriptions of conflict, while others were vague, and provided limited details on location other than the name of the district. This resulted in the exclusion of six districts from a total of 131. The remaining list of districts was grouped into those where elephants did or did not occur. Districts harbouring elephants were grouped into those with and without protected areas.

I tabulated the number of HEC incidences by district and then corrected for the surface area and human density of each district to estimate a relative index of HEC (RIHEC), where RIHEC = district specific total number of reported HEC/ surface area of district/district specific number of people. These values were superimposed on a map of

Mozambique to facilitate the identification of HEC 'hotspots', which I identified as discrete clusters through the use of density mapping as described by Nielsen *et al*.(2004) and clarified by Wilson *et al*. (2005). I identified chronic hotspots as those areas that experienced conflict during all four years of the study period. Non-chronic hotspots were those that experienced HEC over one or two of the four reporting years. I subjectively considered chronic hotspots as areas where more than 200 hectares of croplands were destroyed and/or people were injured or killed as of top priority for HEC mitigation.

Correlates of HEC in Mozambique

I assessed human dispersion index, percent forest cover, percent cultivated area, human population density, human population growth rate and a poverty incidence index as potential covariates of HEC. I reasoned that 1) human dispersion across the landscape would increase the vulnerability of settlements to elephants (Graham, 2006), 2) an increase in forest cover would attract elephants (Osborn & Parker, 2003), 3) an increase in cultivated area would provide more crop cover that may attract elephants, but once beyond a threshold value (the point where elephants no longer persist) dictated by human density, will then be less attractive to elephants (Mundia & Murayama, 2009), 4) human population growth rate is an indirect measure of the rate of land transformations which may reduce or enhance elephant habitat (Parker & Graham, 1989; Hoare & du Toit, 1999; Surovell *et al*., 2005; Graham, 2006; Lee & Graham, 2006; Rood *et al*., 2008; Ngene, 2010). This may influence elephant home range use either through disturbances or by habitat quality degradation (Parker & Graham, 1989).

I used information from Ntumi *et al*. (2009) to calculate the densities of elephant in each of the protected areas and tabulated all reports of HEC incidences from inside each of the protected areas and in ten 2km wide buffer zones around each of these areas.

I used the location of villages and human dwellings as an indicator of distribution of people based on information yielded by the 2007 national census dataset (INE, 2007). I determined the fraction of 5X5 km pixels that were occupied by villages or dwellings in each district as functions of the total number of pixels that covered each of the districts. Finally, I estimated the proportion of occupied pixels following Azuma, Baldwin & Noon (1990): $p=n_1/n*f(v)$; where p=estimate of proportion of occupied units; n_1=number of sampled pixels that were occupied; n=the number of pixels sampled out of the population size and f(v) = function of average number of censuses.

I used a district specific landcover map developed by the Ministry of Agriculture dataset (UIF, 2007) from TM Landsat images for 2002 and 2004 to estimate the percentage area covered by intact forests. I obtained the percent of cultivated area per district from the Instituto Nacional de Estatística (INE) database estimated from the Censo Agro-Pecuário (INE, 2005).

The human population densities was taken from the total number of people for each district as recorded in the 2007 national census (INE, 2007) and the district surface area reported in UIF (2007). I used the number of people for each district as recorded in the 1997 and 2007 national censuses (INE, 1999; 2007) to calculate intrinsic population growth rate using Caughley & Sinclair (1994) as $\mathbf{r = log_e (N_{t+1}/N_t)}$, where r = growth rate, N_t = population size in 2007 and N_0 = population size in 1997.

I extracted a poverty incidence index for each district from the Ministry of Finance country dataset (MPF, 2002) produced from two National Surveys (MPF-UEM-IIPPA, 1998; INE, 1997).

Statistical analyses

To test my predictions, I subjected my dataset to logistic regression analysis (Sokal & Rohlf, 1995) to access the influence of human population density on the probability of elephant being present or absent. Prior to this analysis the data were checked for assumptions of the linear regression (Holmgren, 1995). Residuals were tested for normality through a normal probability plot of the residuals. This analysis is appropriate for binary data and provides a probit model through which the probability of presence or absence can be modelled to generate parameters for the maximum likelihood estimates (e.g. Keating & Cherry, 2004; Chatterjee & Haidi, 2006). To do this I used the statistical package R (R Development Core Team, 2008). I conducted a hierarchical partitioning with the linear regression method and R^2 as the goodness-of-fit measure. I used the McFadden's index (McFadden, 1973) to calculate R^2, by using the equation: **R = (Null-Residual)/Null**; where Null = initial -2 log-likelihood statistics; Residual = model -2 log-likelihood statistics. McFadden's index is conceptually similar to the coefficient of determination of ordinary least square regression analysis, is independent from the base rate, and allows comparisons across models that comprise of different predictors (Menard, 2000). R^2L indicates how much the inclusion of the independent variables in the model reduces the badness-of-fit (Menard, 1995) and varies between 0 (independent variables are useless in prediction of dependent variable) and 1 (independent variables in model predict the dependent variable perfectly).

I used a two-tiled t-test (Sokal & Rohlf, 1995) to statistically access differences on human density, human dispersion index, human population growth rate, percent forest cover, percent cultivated area and HEC incidences between districts where elephants were present and those where elephants were absent. I used the same approach to compare these variables for districts harbouring elephants but without protected areas and districts with elephants and protected areas. I assessed the statistical significance of the human density on presence and absence of elephants at given district by using the Z-scores for the distribution of randomized independent contributions from 100 permutations.

I used Pearson correlation (Sokal & Rohlf, 1995) to relate the distances from protected areas and the number of reported incidences of HEC as well as to test the influence of human density on the extent of cultivation (% of areas of district cultivated) and on forest cover (% of area of district covered by intact vegetation). A least square regression analysis of percent cultivated area on human density yielded an expected level of habitat transformation at the density of people where the likelihood of presence of elephants was 0.5, 0.25 and 0. I also used two tailed t-tests to test for statistical differences between human densities, human dispersion index, percent cultivated area and RIHEC of districts harbouring elephants but with or without protected areas.

Furthermore, I used a generalized linear model (GLM) (see Boyce & Waller, 2003) to evaluate the best subsets of human dispersion index, percent of forest cover, percent of cultivated area, human population growth rate and poverty incidence index to explain incidences of HEC and RIHEC. Prior to running the GLM I subjected these predictors to p-p plot analysis to access the need for data transformation with both stepwise and forward selection (Holmgren, 1995). Thus, human dispersion index and percent of cultivated area were log transformed while percent of forest cover, human population growth rate and poverty incidence index were square root transformed. I then calculated AIC, ΔAIC and AIC_{wi} to assess support for the best predictive model for HEC and RIHEC in rural districts of Mozambique. Values of ΔAIC ranging from 0 to 2 indicate substantial support; values of 4–7 less support and values > 10 no support (Burnham & Anderson 2002). I calculated AIC_{wi} to indicate the probability that each model was the most likely model of all candidate models to represent my dataset.

Results

Human-Elephant Conflict in Mozambique

Elephants occurred across 77 of the 125 rural districts included in this study. Most (71) of the districts inhabited by elephants reported HEC, but six recorded no such incidences. HEC incidents comprised 74 % (N = 1, 036) of all human and wildlife conflict incidents and resulted in the destruction of 1,563 hectares of croplands (87.8 % of the area destroyed by wildlife between 2006 and 2009). Between 2006 and 2009 elephants were responsible for 19.6% of all wildlife related reported deaths, a value three fold less than that ascribed to crocodiles.

Reports of incidences of HEC came from some 62 percent of the area of Mozambique, thus suggesting that 30.7 percent of people living in the country may be exposed to conflict with elephants. Reported incidences of HEC were widespread, but most records thereof came from Gaza, Maputo, Cabo Delgado, Manica and Inhambane provinces (Table 1; Fig. 2a). Reports of incidences of HEC decreased with increased density (Pearson correlation, $r = -0.24$; $p = 0.008$). Differences in the area of provinces and human densities may determine the number of reported incidences of HEC. Correcting for area and density yielded indices of the number of incidences per person per unit area. The apparent skew in incidences is clear from Fig. 2a & b, illustrating that between 2006 and 2009 most conflict occurred in Gaza, Niassa, Inhambane, Maputo and Cabo Delgado provinces (see Table 1). The districts most affected by HEC were those bordering protected areas, but for the Funhalouro district in the Inhambane province. For instance, the Mecula district in Niassa province bordered the Niassa NR; Quissanga district in Cabo Delgado bordered the Quirimbas NP; Massingir and Chicualacuala districts in Gaza province bordered the Limpopo NP and Matutuine district in Maputo province bordered the Maputo NR.

Presence and absence of elephants in rural districts of Mozambique

Elephants apparently were absent from districts with high human densities and where much of the land had been transformed to cultivated areas. For instance, a logistic regression confirmed that the presence of elephants was strongly affected by human density (logistic regression, $z = -0.171$, $df = 109$, $p = 0.001$). The R^2L value of 0.57 for this regression suggests a moderately strong association between human density and the presence/absence of elephants in given rural district of Mozambique (Fig. 3a).

People transformed the natural landscape and human density was positively correlated with the percent of cultivated area (Pearson correlation, $r = 0.68$; $p = 0.001$) and negatively affected the percent of forest cover (Pearson correlation, $r = -0.37$; $p = 0.001$). The 50% threshold of the probability to encounter elephants at a given district in Mozambique was at 30 people/km^2 (see Fig. 3b), which corresponded to some 6.7% of cultivated area (based on a linear regression analysis ($r^2 = 0.467$, $F_{123} = 107.8$, $p < 0.0001$). Similar interpolations for 25 and 0% likelihood of presence yielded values of 38 and 60 persons/km^2. At these densities, the expected extent of cultivation would have been ~8 and ~11%, respectively.

Districts with elephants had significantly lower human densities ($t_{123} = -4.67$, $p = 0.0001$), less of their areas cultivated ($t_{123} = -3.79$, $p = 0.0002$) and a higher dispersion index ($t_{123} = -6.39$, $p = 0.0001$) than those without elephants. Some districts did report HEC incidences, despite the apparent absence of elephants, albeit at significantly lower levels than districts where elephants were present ($t_{123} = 4.53$, $p = 0.0001$).

HEC in landscapes beyond protected areas

Land cover and HEC profiles for districts with elephants and protected areas differed from those with elephants but without protected areas. For instance, percent forest cover (35.9±21.2) and cultivated area (6.03±6.1) in the districts without protected areas were significantly higher ($t_{76} = 2.15$, $p = 0.03$ & $t_{76} = 2.59$, $p = 0.01$ respectively) than those with protected areas (25.3±14.97 & 2.57±2.07 respectively). However, human density (t_{76} = 1.88, p = 0.06), human dispersion index (t_{76} = 1.69, p = 0.09), poverty incidence index (t_{76} = -0.61, p = 0.54) and human population growth rate (t_{76} = 0.23, p = 0.82) for these two categories of districts were similar. Significantly more HEC incidences (16.8 ± 28.1) and higher RIHEC values (5.0 ± 9.9) were recorded in the districts with protected areas than those without protected areas (6.8 ± 7.9; 0.90 ± 2.08, respectively; HEC incidences: t_{76} = -2.78, p = 0.007: RIHEC: t_{76} = -2.98, p = 0.004).

Some 59% of Mozambique is covered by forests and natural vegetation (UIF, 2007). The Niassa, Cabo Delgado, Tete and Zambezia provinces had higher forest cover than the other provinces, notably Sofala, Gaza and Maputo where values for several districts were <5%. The level of clearance of natural vegetation varied between districts and ranged from 0.5% to 25. When combining the data for all districts that harboured elephant and reported incidences of HEC, the extent of cultivation, forest cover, human density, human dispersion index, human population growth rate and poverty incidence index on its own failed to explain the incidences of HEC and RIHEC (Fig. 4 and 5). Some synergistic effects therefore may explain the variability in HEC and RIHEC.

Based on ΔAIC and AIC_{wi}, percent cultivated area and human population growth rate (Table 2a) best predicted the likelihood of HEC incidences, while percent forest cover, percent cultivated area and human population growth rate explain the likelihood of RIHEC (Table 2b). The best model to explain levels of HEC in districts without protected areas included fewer variables than districts with protected areas. For the former only two variables (human dispersion index and percent cultivated area) returned the best fit, while five variables (human population density, human population growth rate, percent cultivated and percent forest cover) returned the best fit for the latter (Table 2).

HEC in the protected areas

Protected areas and the 16 km wide buffer zones around them accounted for about two thirds (696 of 1, 036 reports) of all reported incidences of HEC in Mozambique. Of these most occurred within an 8 km wide zone around the protected areas (see Fig. 6). For example, the Maputo National Reserve reported 102 HEC incidences, 40 from within and 62 from the surrounding 16 km buffer - the Limpopo National Park reported 109 incidences from within the park and the same number for the surrounding buffer. HEC incidences decreased with increased distances from protected areas (Fig. 6), but within protected areas the incidence of HEC was not a function of elephant density, nor of human density (Fig. 7 and Table 2). Generalised linear modelling also suggested that neither elephant nor human densities explained incidences of HEC (Table 2). Other social and demographic variables were not available for assessment.

Discussion

Human-Elephant Conflict in Mozambique

Between 2006 and 2009 elephants and incidences of HEC in Mozambique were widespread but mostly occurred in the Gaza, Maputo, Cabo Delgado, Manica and

Inhambane provinces. All but the Inhambane province supported protected areas that accounted for most of the countries elephants (see Chapter 2). Dunham *et al*. (2009) also illustrated the widespread occurrence of HEC but based their assessment on three years (2006 to 2008) of data. I included an additional year (2009) in my assessment.

Several earlier papers suggest that elephants disappear from human dominated landscapes due habitat degradation associated with a threshold of human density (Parker & Graham, 1989; Hoare & du Toit, 1999; Graham *et al*., 2009). Some elephants then may find refuge in protected areas while others continue to occupy unprotected areas in landscape dominated by people. Thus, the extent of landscape transformation induced by people may modulate the interactions between them and elephants (Newmark *et al*., 1994; Hoare, 1999; Smith & Kassiki, 1999; Sitati *et al*., 2003; Lee & Graham, 2006; Graham *et al*., 2009).

My study suggested a threshold of human density (60 people/km^2) four times greater than the value proposed by Hoare & du Toit (1999). The difference may be due to my analytical approach (logistic regression) differing from theirs (regression analysis of transformed data), or due to the density related extent of cultivation in Mozambique being lower than recorded by them in Zimbabwe. Unfortunately, the analysis in Hoare & du Toit (1999) does not provide for such comparison. In Mozambique much of the natural landscape was relatively intact across most districts and cultivation seldom exceeded 25% (median = 4.85 with 25 and 75 percentile values of 2.23 and 9.73 respectively). At this level of cultivation human density approximated 20people/km^2 and this density the likelihood of elephants being present was about 80%. This oversimplified interpretation may be criticized for valid reasons (as also supported by my GLM analysis) but provide a first approximation that may explain the widespread incidences of HEC across Mozambique, albeit mainly occurring in zones adjacent to protected areas.

Human densities were lower in the northern (e.g. Niassa and Cabo Delgado) than southern (Maputo, Gaza, Inhambane) provinces of Mozambique. Consequently much of the northern provinces comprised natural vegetation with little habitat degradation and low intensity and extent of cultivation. The mean human density and the area of habitat transformation due to agriculture activities in these provinces are well below the threshold of 60 people/km^2 and 11%, respectively. This may explain the persistent presence of elephants in most rural districts in Cabo Delgado and Niassa provinces (Ntumi *et al*., 2009) as the likelihood of elephants being present at the typical densities of these provinces (see Table 1) exceeded 80% (Fig. 3). Thus, low levels of land transformation at low human densities in northern Mozambique may allow people and elephants to co-exist, which may induce higher incidences of conflict (HEC) than in areas where human densities are beyond the threshold of 30 people/km^2 implied by the 50% likelihood of elephants being present. This scenario was typical across southern Mozambique at the time of my study, but even there the incidences of HEC were relatively high.

Provinces (Maputo, Gaza and Inhambane) in southern Mozambique in general had human densities and percent cultivated areas greater than those in the north, and close to the half of the predicted threshold (30 people/km^2) for the persistence of elephants. However, my assessment of the incidence of HEC suggested higher levels of conflict across southern than northern Mozambique – variables other than those associated with human density and the associated transformation of land may therefore be responsible for high incidences of HEC.

Studies elsewhere in Africa (e.g Newmark *et al*. (1994) in Tanzania; Naughton-Treves (1997) in Uganda and a review (Twine & Magome, 2008) suggest that the proximity to protected areas may drive conflict with wildlife, in particular, HEC. This may also hold for Mozambique, especially across the southern provinces where several protected areas (Maputo National Reserve, Limpopo National Park, Banhine National Park, Zinave National Park) are located. In Mozambique, nearly two thirds of all reports on HEC came from within a distance of 16 km from the boundaries of protected areas and about half from areas within 8 km of the borders of protected areas. Proximity to protected areas thus may well explain HEC incidences across Mozambique (see Fig. 6). However, a relatively large proportion of incidences came from within protected areas and here variability in the rates of conflict (both HEC and RIHEC) could not be ascribed to either human or elephant densities. Incidence of HEC in the 8 km buffer around protected areas also was not a function of elephant density in protected areas (results not shown), primarily due to the extra-ordinary levels recorded in the buffer zones around both the Maputo National Reserve (relatively high elephant density) and the Limpopo National Park (relatively low elephant density). These protected areas also experienced more incidences of HEC from within than from around, a situation opposite to that experienced at other protected areas.

Social factors may further complicate the interpretation of incidences of HEC. For instance, the Banhine National Park (bordered by the Gaza and Inhambane provinces) and Zinave National Park (Inhambane province) have no resident elephants (Stalmans,

2007) and elephant densities were low in the Inhambane Province (see DNFFB, 1999), yet one (Funhalouro) of the 12 districts in this province returned extreme high levels of HEC, an anomaly that needs further investigation.

During my study, elephants were more likely to occur in districts where human densities were low. This may be due to the impact of humans on landscapes. The significant increase in cultivated area with an increase in human density imply a loss in habitat for elephants, would it be due to fragmentation of habitat degradation. Parker & Graham (1989) and Hoare & du Toit (1999) also have noted density related habitat degradation or loss. Parker & Graham (1989) suggested a linear decline in elephant density with an increase in human density, but at a finer (district level) resolution Hoare & du Toit (1999) suggested a threshold of 15.6 persons/km^2, after which a resident elephants disappear. This value is nearly four times greater than the value I inferred through logistic regression, a discrepancy that may be due to differences in land use practices in the different study areas. In Mozambique, landscape clearing for agriculture involves relatively small patches in a matrix of natural landscapes, while such clearing in Zimbabwe and Kenya often involves large swatches of land in relatively small matrices of natural landscapes. Country specific differences in the determinants of HEC thus may be expected, but this requires further investigation.

Nearly 60% of the landscapes of most of the provinces of Mozambique were intact. These large swatches of natural vegetation provide habitat for elephant, but for a variety of reasons very few elephants occurred there and most of Mozambique's elephants were limited to protected areas (see Chapter 2). People also live in protected areas and much of the conflict between people and elephants occurred within and around these areas. The relatively high incidence of conflict in the immediate vicinity of protected areas may be a function of the uneven distribution of people across Mozambique, especially if more people live in the proximity of protected areas then further afield. I do not know if this is the case and the resolution of data at my disposal did not allow for such an analysis. This lack of fine scale data introduces other complications, many of these at the conceptual level that often rules political decision taking. For instance, apparent idiosyncratic patterns at the district level persisted, possibly due to the presence of protected areas that provided matrices of natural landscapes in which people also lived. In other districts, where there were no protected areas, matrices of unnatural landscapes dominated by humans still comprised sufficient habitat for elephants. In the former, the presence of elephants may be considered ‘natural’, but in the latter, they may be considered ‘an invader’. Actions to resolve conflict will thus also be idiosyncratic.

The presence or absence of elephants and of protected areas was obvious drivers of HEC. This may be due to differences in human density and percent cultivated areas between these. However, the presence of elephants may be driven by human densities (see above), which in turn were higher in provinces without protected areas than those with protected areas. Nevertheless, within protected areas the incidence of HEC was not a function of elephant or human density. This notion is also mooted by Hoare (1999) and Warner (2008). However, the increased reports on HEC incidences from districts with protected areas, may also highlight the proximity to protected area effect (Newmark *et al*., 1994; Naughton-Treves, 1997; Twine & Magome, 2008), which also was observed in this study. Living close to protected areas which harbours elephants, particularly those surrounded by densely settled agricultural areas, as appears to be the case of Mozambique, may represent a risk for HEC due to the higher probability of human-elephant encounters at the edge of protected areas (also see Twine & Magome, 2008; Warner, 2008). Protected areas alone are inadequate for sustaining elephants (Warner, 2008) and frequently, elephants move beyond refuges to feed and may destroy fields (Graham *et al*., 2010). Proximity to protected areas may be an added plausible explanation of HEC incidences in the rural districts of Mozambique. An effective land-use plan should thus accommodate distance from protected areas to enable the co-existence of humans and elephants in human dominated landscapes.

Correlates of human and elephant conflict in Mozambique

Few studies have used generalized linear modelling to predict HEC. Graham *et al*. (2010) recently used logistic regression analyses to illustrate the influence of settlement density, distance from refuge areas and percent cultivated area on the number of crop raiding incidents. Their findings are similar to those of my study. My use of the generalized linear modelling suggested that a combination of demographic and spatial variables may be used to predict incidences of HEC.

Human population density, human population growth rate and the extent of cultivation best predicted the likelihood of incidences of HEC as well as RIHEC across rural districts in Mozambique. These variables, however, were not linearly related due to elephants not being present once a threshold density of 60 people/km^2 has been exceeded – very few incidences of HEC then occurred. Below the threshold density, the incidence of HEC may best be explained by a combination of demographic and spatial variables. These variables, however, were closely linked and landscape transformation increased with increased density and population growth rate. Where elephants persisted despite landscape transformation, the incidence of HEC increased with increased human density, population growth rate and habitat transformation until the threshold density is reached. Human dispersion index may then also be important to predict incidences of HEC.

My modelling approach excluded poverty as a potential determinant of HEC and therefore RIHEC. This partly agrees with the suggestion of Dunham *et al*. (2010) that HEC is not a function of poverty. However, in rural Mozambique poverty increases with density (MPF, 2002). From my analysis, we also know that land transformation increased with density. All these variables therefore were closely linked but mostly driven by density. In spite of this density on its own did not serve as a predictor of HEC.

Forest cover improved the ability of my modelling exercise to predict HEC. Elephants are attracted to intact landscapes possible because few people live there (see Harris *et al*., 2008). The incidence of HEC thus should decrease with increased forest cover. My general linear modelling exercise supported this notion for RIHEC in the rural districts of Mozambique where elephants were present. My calculation of RIHEC corrected for the effect of human density and it is thus not surprising that forest cover were then the most important determinant of RIHEC.

Management implications

The mitigation of HEC is high on the political agenda of Mozambique (DNTF, 2009). Innovative solutions are much sought after and should be driven by approaches that deal with the causes rather than the symptoms of HEC. Elephants are iconic of the successes and failures of conservation incentives and of actions to reduce animal wildlife conflict in general. Systemic approaches to reduce the conflict between people and elephant may thus well reduce conflict between people and species other than elephant.

My assessment suggested that HEC in Mozambique predominantly occurred in and around protected areas that made up a relatively small proportion of rural Mozambique. In relative terms few people were affected but the livelihoods were often threatened. Reducing or even removing conflict thus makes social, economic, conservation and political sense. Retaliatory actions such as the shooting of elephants make little sense in a scenario where elephants and people are sharing the same land.

In Mozambique elephants predominantly occurred in the rural parts of districts with protected areas and where fewer than 40 people/km^2 lived. In some rural areas, people do not adhere to regulations imposing the zonation of their activities and consequently infringe on to land that has originally been set aside for elephants and other wildlife. Policy and regulations to minimize conflict thus exist but are often ignored with consequent ill effects on both people and elephants (see Muller, 2010).

Given that the Mozambique government is committed to "…. *maintain and, where possible, increase numbers and range of elephant populations*………"(MITUR, 2010), conflict mitigation can no longer continue to focus on elephants *per se*, but need to address the demographically associated spatial utilization activities of people. From my analysis it follows that elephants avoid densely populated and intensely transformed rural areas. People settling in new areas where elephants live will experience conflict. The obvious option then is to forbid such settlement or any other form of settlement in areas demarcated or earmarked as elephant habitat (see Chapter 5). Law enforcement and improved knowledge through dedicated education programs thus may assist in dealing with the causes rather than symptoms of the conflict.

Providing for the spatial needs of both elephants and people through active zonation of land use activities may further defuse conflict (see Joshi & Singh, 2009; Graham *et al*., 2010). People settling in the vicinity of protected areas, especially in a buffer zone of some 8 km from the borders of these protected areas, have a high likelihood of experiencing conflict with elephants. Incentives to attract people to settle in areas further away from protected areas therefore should be encouraged. These may range from the provision of facilities (e.g. roads, schools, clinics, hospitals) or infrastructure for agricultural development such as water irrigation systems. Incentives to reduce dependency on natural resources that force people onto the land earmarked for elephants should be encouraged. This calls for incentives to clump rural agriculture into blocks away from protected areas, rather than having small patches of fields scattered across a matrix of intact landscapes where elephants occur. Regulations to achieve this may already be in place (see DNTF, 2009) and it thus is a matter of implementation rather than policy that need to be the focus of further mitigation in Mozambique.

I fully appreciate that conflict profiles may be site specific and for instance differ between protected and non-protected areas. Site specific solutions for the conflict therefore may also differ but in principle should focus on demographic and spatial variables of humans. For instance, encouraging low levels of dispersion onto natural or semi-natural landscapes may provide the means to reduce the likelihood of conflict.

My country-wide assessment of demographic and spatial co-variates of HEC identified human density related variables as important determinants of conflict, albeit not human density on its own. Proximity to protected areas enhances the likelihood of conflict. People may live close to protected areas as these provide opportunity to extract natural resources and may benefit social development (Wittemyer *et al*., 2008). Such extraction is legally permitted in Mozambique (GM, 1999), much depending on the type of protected area. National reserves are generally earmarked for such extraction while at the same time having been set aside to provide for the needs of elephant. This sets the platform for conflict. Reducing conflict under these circumstances thus may call for legislation changes and or for the enforcement of laws that restrict scattering of people activities across landscapes earmarked for conservation.

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Table 1: Summary of mean values (± standard error) of human population density, population growth rate, percent forest cover, percent cultivated area, rate of deforestation, HEC incidents and RIHEC across Mozambique as quoted in this study (see methods section) and the rate of deforestation as estimated by UIF (2007).

Province	Human population density	Population growth rate	Percent forest cover	Percent cultivated area	Rate of deforestation	HEC incidents (2006-2009)	RIHEC
Cabo Delgado	23.12±12.07	0.09±0.04	37.17±13.91	5.70±3.74	0.54	9.6±10.18	0.83±1.20
Niassa	12.23±11.71	2.41±2.10	55.49±25.28	2.41±2.10	0.22	3.67±4.75	1.80±5.36
Nampula	44.91±21.87	0.13±0.04	28.96±14.50	9.53±4.31	1.18	0.56±1.29	0.02±0.06
Zambézia	41.14±20.93	0.14±0.05	38.11±17.58	6.67±3.62	0.71	2.46±7.26	0.09±0.20
Tete	23.87±27.77	0.22±0.07	32.30±4.60	4.62±8.22	0.64	6.33±9.62	0.74±1.04
Manica	22.80±17.37	0.01±0.22	31.20±12.60	4.81±3.54	0.75	7.56±6.09	0.79±0.85
Sofala	22.24±18.16	0.14±0.06	20.73±15.64	4.70±3.50	0.63	2.92±7.96	0.19±0.40
Inhambane	27.87±23.08	0.01±0.03	15.71±13.62	9.60±7.71	0.52	6.92±12.80	1.55±4.31
Gaza	18.25±20.02	-0.18±0.05	25.09±19.07	9.70±10.03	0.33	16.73±32.13	6.61±12.71
Maputo	61.87±73.06	0.17±0.17	19.73±16.61	9.20±6.61	1.67	11.71±18.36	1.44±2.72
Mean for country	29.42±27.94	0.11±0.13	31.72±19.35	6.62±5.99	0.58	6.20±13.13	0.11±0.13

Table 2: Candidate best models with the best HEC incidences explaining variables (a) and RIHEC explaining variables (b) developed for a country-wide through generalized linear models. For each model the number of parameters (K), Akaike's Information Criterion (AIC), differences in Akaike's Information Criterion scores (ΔAIC), LRatio X^2, p and Model rank are shown. For each group of sites, the most plausible model selected according to my selection criteria (see Methods) is shown in bold text. Models are listed in order of decreasing AIC (wi).

a)

Candidate models	**K**	**AIC**	**ΔAIC**	**AIC$_{wi}$**	**LRatio X^2**	**p**	**Model rank**
Districts with elephants but without protected areas							
Human density	1	-134.36	0.00	1.04	2.69	0.101	1
Human dispersion index	1	-133.27	1.09	0.42	1.59	0.207	2
Human density + Human dispersion index	2	-132.41	1.95	0.12	2.73	0.256	3
Districts with elephants and with protected areas							
Human density + Percent cultivated area + Human population growth rate	**2**	**-36.59**	**0.00**	**1.66**	**15.02**	**0.002**	**1**
Percent cultivated area + Human population growth rate	2	-33.77	2.82	0.18	10.19	0.006	2
Human population growth rate	1	-33.71	2.88	0.08	8.14	0.004	3
Human density + Human population growth rate	2	-31.83	4.76	0.03	8.26	0.016	4
Percent cultivated area	1	-28.04	8.55	0.00	2.47	0.116	5
Human density + Percent cultivated area	2	-27.01	9.58	0.00	3.44	0.179	6
Human density	1	-26.70	9.89	0.00	1.13	0.289	7
All districts with elephants combined							
Percent cultivated area + Human population growth rate	**2**	**-143.50**	**0.00**	**30.71**	**17.20**	**0.001**	**1**
Human population growth rate	1	-136.11	7.39	0.02	7.81	0.005	2
Percent cultivated area	1	-133.77	9.73	0.00	5.46	0.019	3
Protected Areas							
Elephant density + Human density	2	-6.97	0.00	0.84	2.13	0.144	1
Human density	1	-6.37	0.60	0.51	1.54	0.214	2
Elephant density	1	-5.38	1.59	0.14	2.53	0.282	3

b)

Candidate models	K	AIC	ΔAIC	AIC_{wi}	LRatio X^2	p	Model rank
Districts with elephants but without Protected Areas							
Human dispersion index + Percent cultivated area	**2**	**86.26**	**0.00**	**1.93**	**19.71**	**0.001**	**1**
Human dispersion index	1	88.28	2.02	0.32	15.69	0.001	2
Percent cultivated area	1	90.01	3.75	0.11	13.96	0.001	3
Districts with elephants and with Protected Areas							
Percent forest cover + Human population growth rate	**2**	**51.67**	**0.00**	**72.33**	**23.23**	**0.001**	**1**
Human population growth rate	1	60.24	8.57	0.01	12.67	0.001	2
Percent forest cover	1	71.43	19.76	0.00	1.47	0.225	3
All districts with elephants combined							
Percent forest cover + Percent cultivated area + Human population growth rate	**3**	**422.61**	**0.00**	**461.61**	**40.81**	**0.001**	**1**
Percent cultivated area + Human population growth rate	2	435.32	12.29	0.00	26.10	0.001	2
Percent forest cover + Percent cultivated area	2	444.11	21.50	0.00	17.31	0.001	3
Percent cultivated area	1	452.24	29.63	0.00	7.18	0.007	4
Human population growth rate	1	453.07	30.46	0.00	6.35	0.012	5
Percent forest cover + Human population growth rate	2	454.99	32.38	0.00	6.43	0.040	6
Percent forest cover	1	458.23	35.62	0.00	1.19	0.275	7
Protected Areas							
Elephant density	1	62.90	0.00	0.62	0.47	0.492	1
Area of Protected area	**1**	63.26	0.36	0.47	0.11	0.741	2
Elephant density + Area of Protected area	**2**	63.37	0.47	0.43	2.00	0.368	3

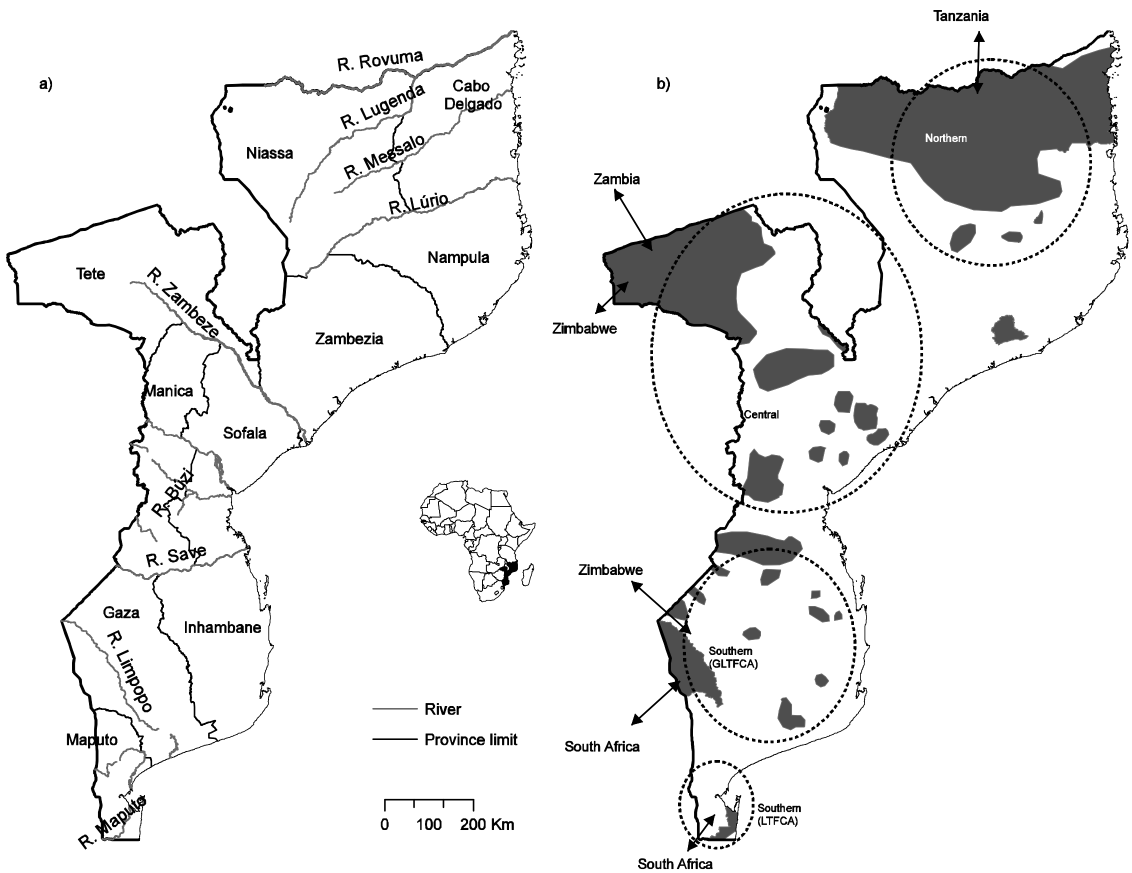

Fig. 1 Line diagrams of Mozambique, with (a) showing the most relevant rivers and provinces; (b) illustrating present elephant range, structured in the four main clusters (dashed lines) with links to Tanzania, Zambia, Zimbabwe and South Africa (modified from Ntumi *et al*., 2009).

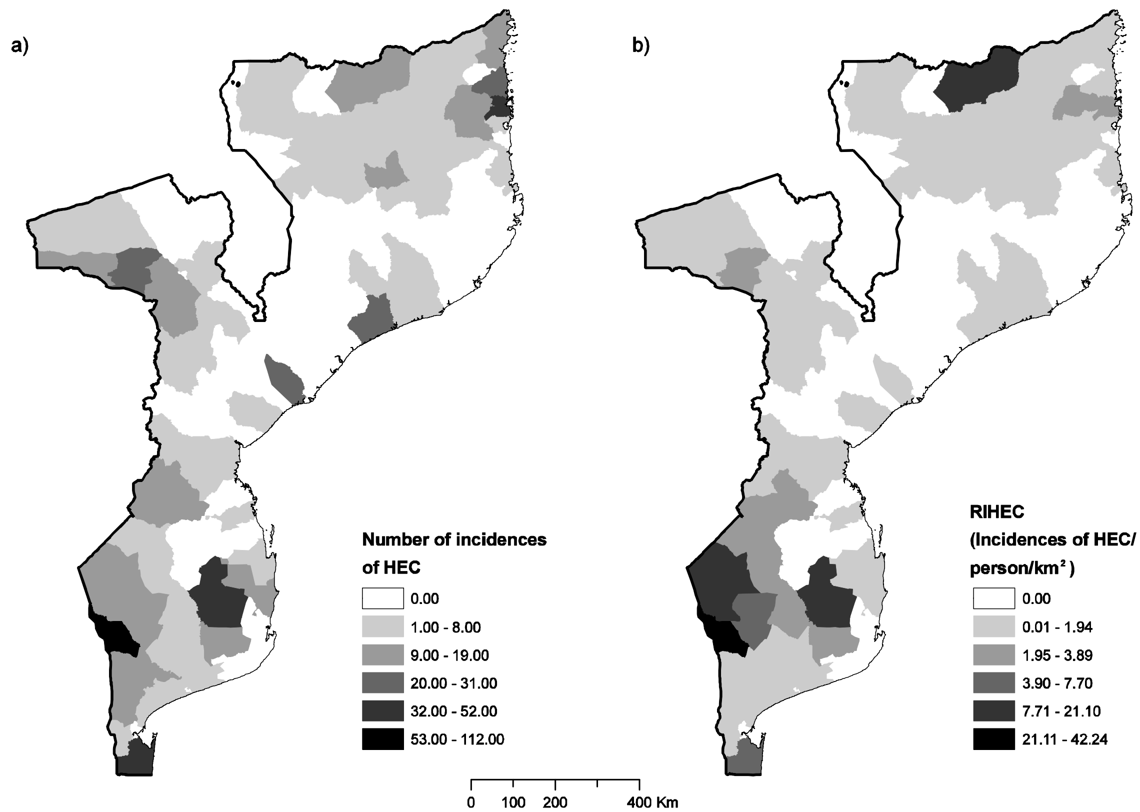

Fig. 2 Line drawings of Mozambique illustrating (a) the number of HEC incidences per district reported from 2006 to 2009, and (b) RIHEC as an index of conflict that corrects for district area and human density.

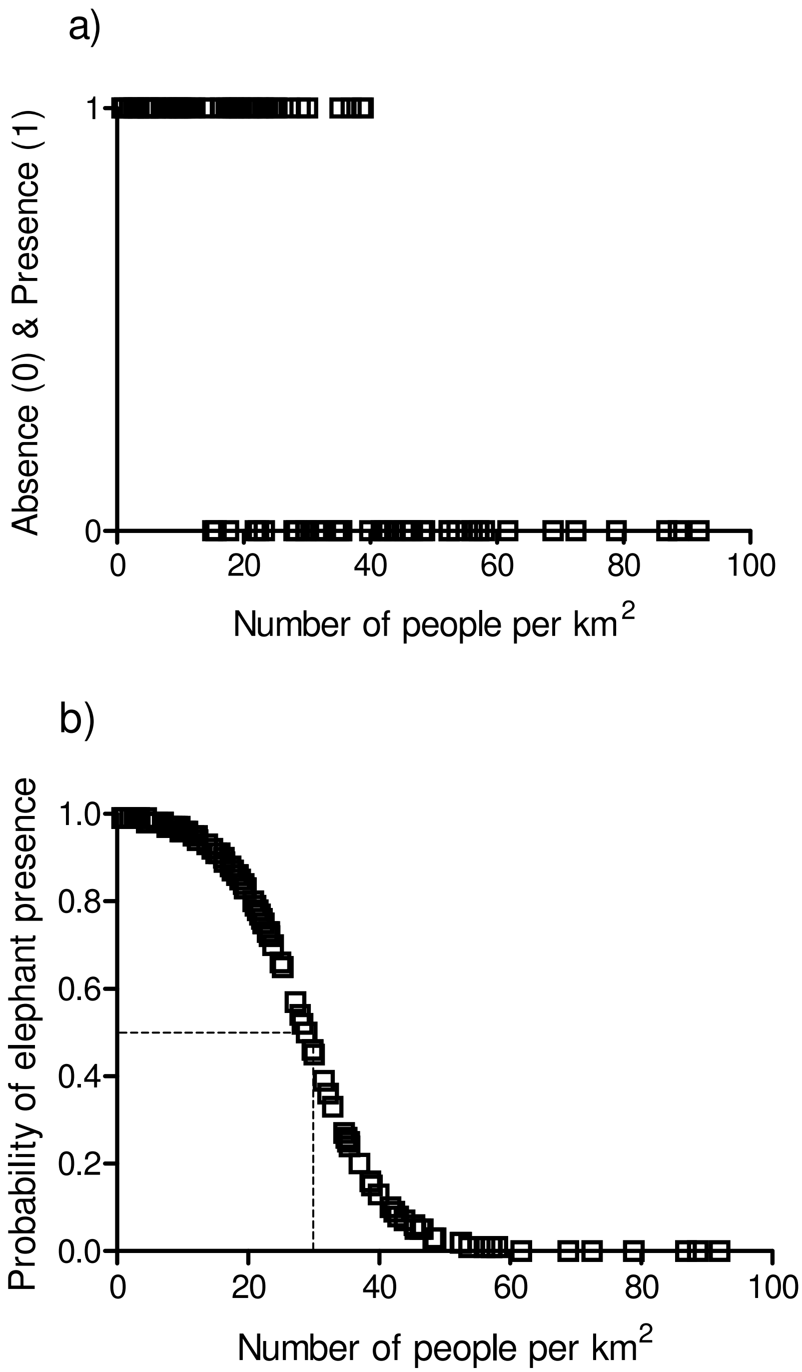

Fig. 3 The presence and absence (a) and the likelihood of presence of elephants (b) as a function of human density (people per km^2) across the rural districts of Mozambique. Likelihood estimates were based on logistic regression analysis.

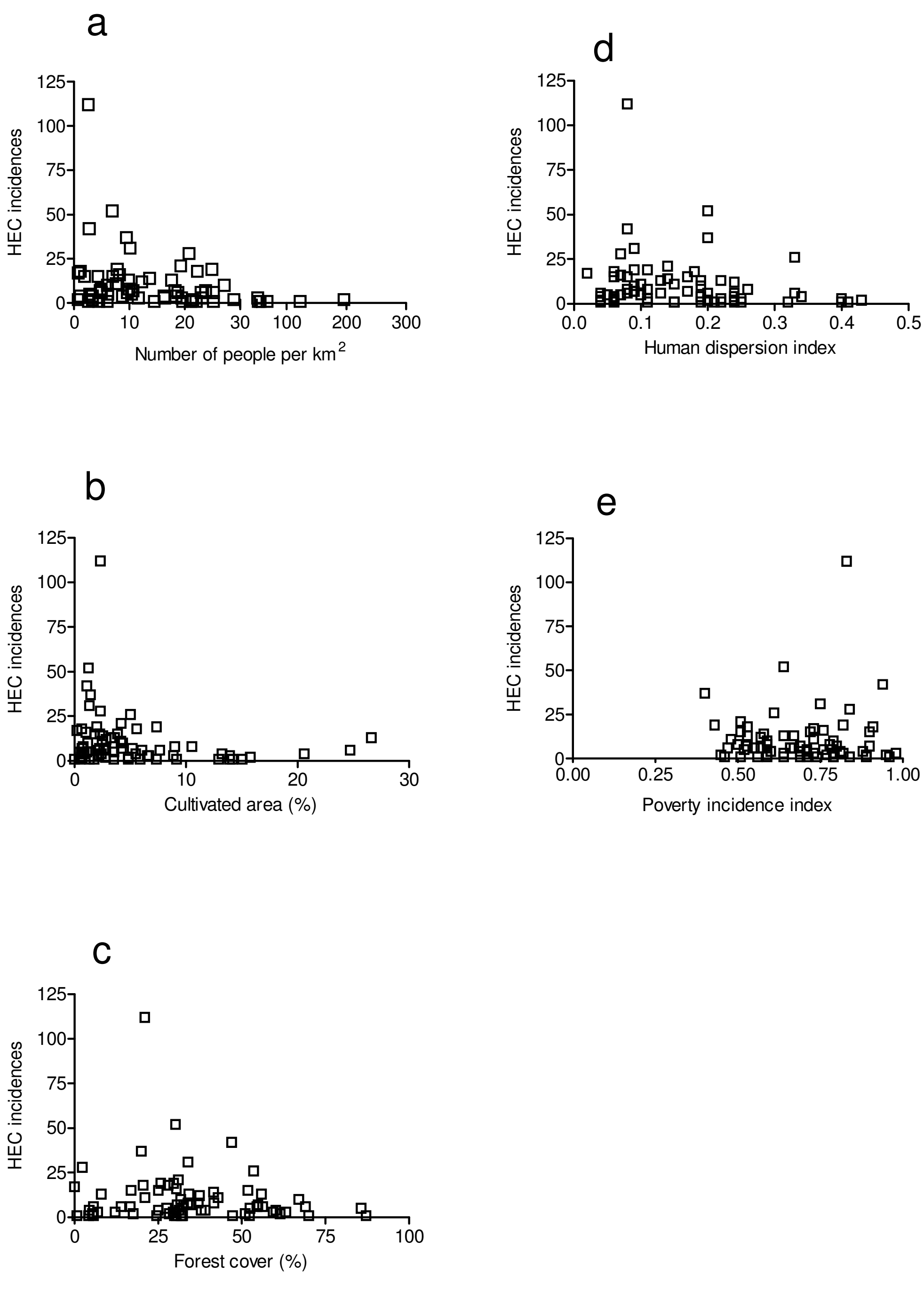

Fig. 4 District specific HEC incidences as a function of (a) human density (people/km^2), (b) cultivation (%), (c) forest cover (%), (d) human dispersion index and (e) poverty incidence index.

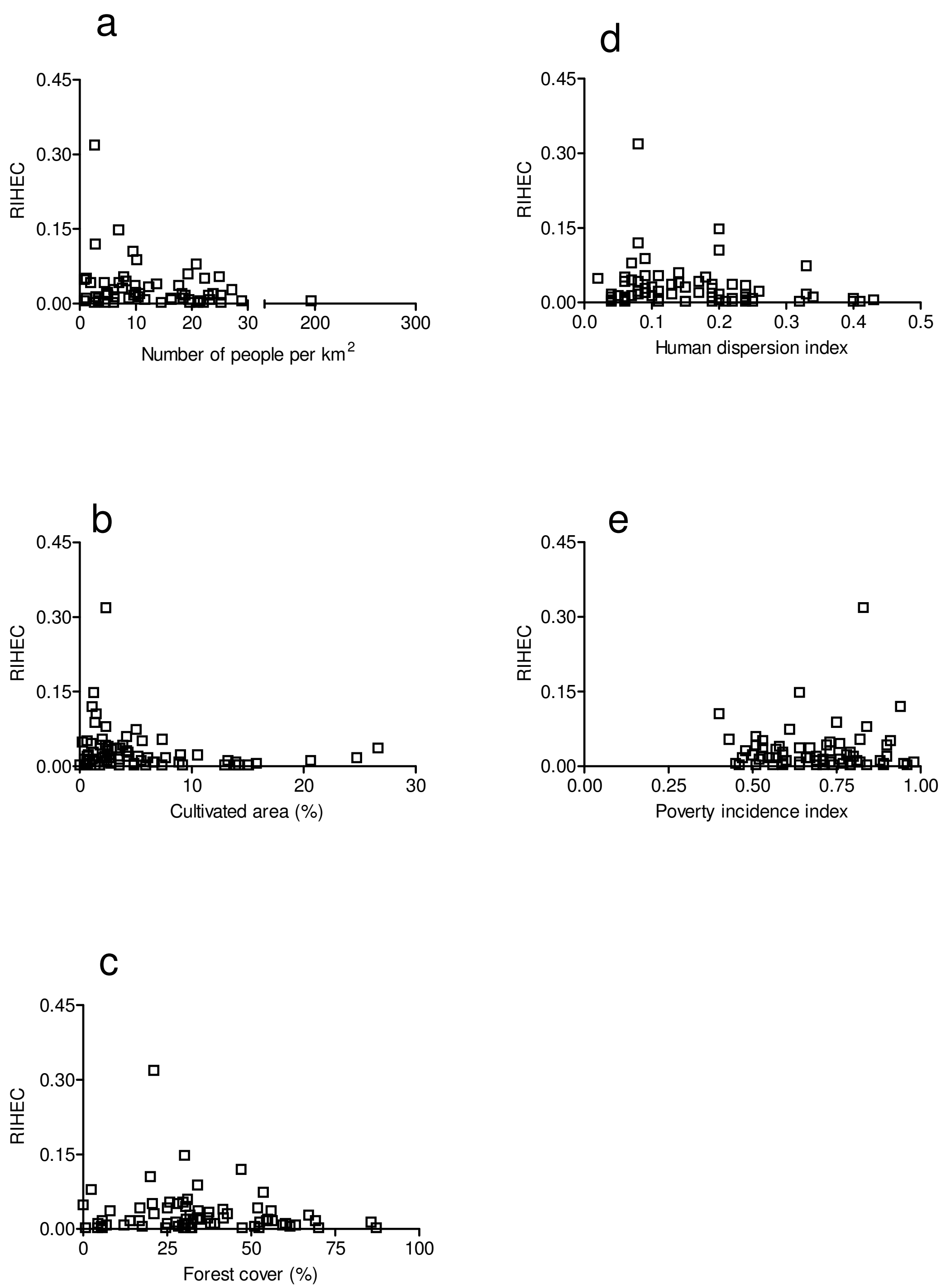

Fig. 5 District specific RIHEC as a function of (a) human density (people/km^2), (b) cultivation (%), (c) forest cover (%), (d) human dispersion index and (e) poverty incidence index.

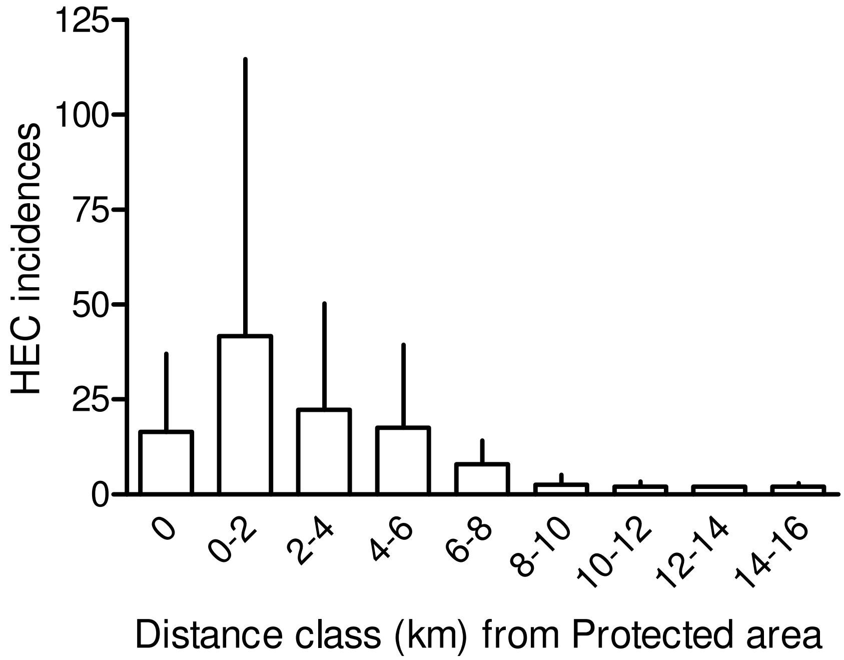

Fig. 6 Mean plus one standard deviation of the mean number of reported HEC incidences as a function of distance from protected areas where the event occurred. I retrieved 696 reports of the locations of HEC incidences from in and around Niassa NR, Quirimbas NP, Gilé NR, Mecubúri FR, Tchuma-Tchato Community Area, Marromeu NR, Gorongosa NP, Chimanimani-Moribane TFCA, Zinave NP, Banhine NP, Limpopo NP and Maputo NR.

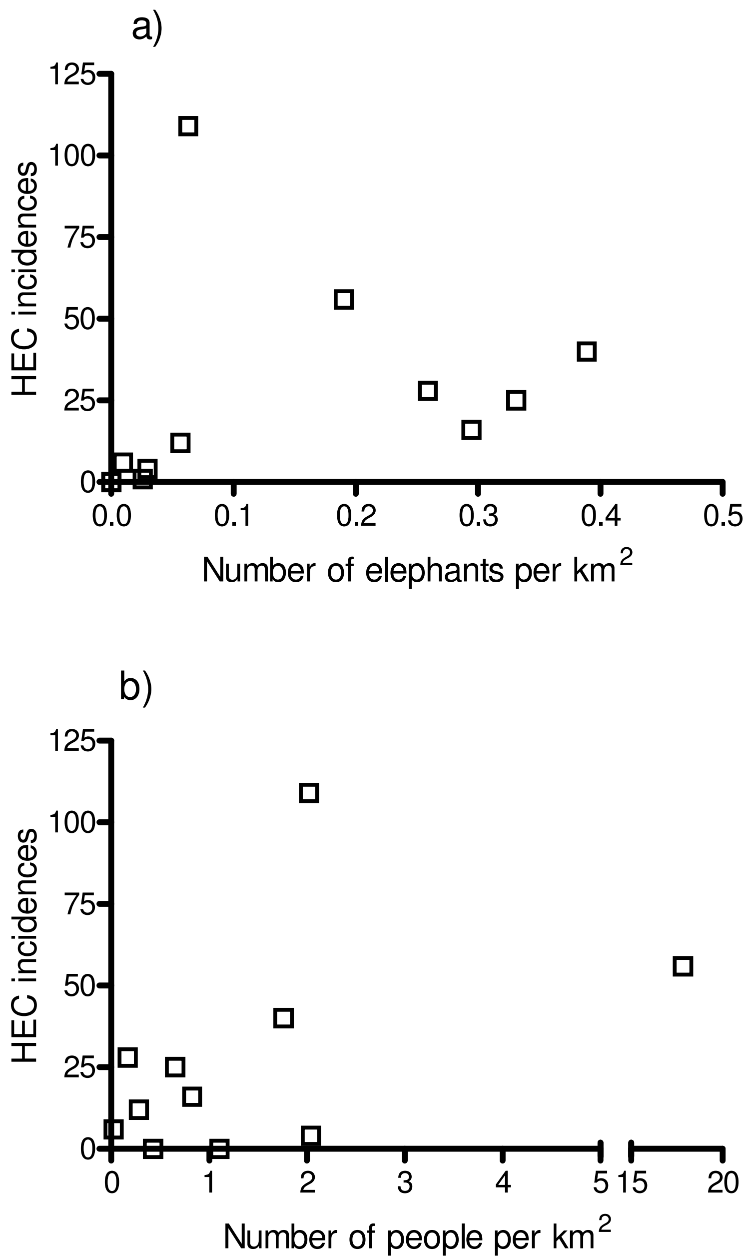

Fig. 7 HEC incidences as a function of elephant density and human density in 10 protected areas across Mozambique where elephants live. Protected areas include the Niassa NR, Quirimbas NP, Gilé NR; Mecubúri FR; Tchuma-Tchato Community Area; Marromeu NR; Gorongosa NP; Chimanimani-Moribane TFCA, Limpopo NP and Maputo NR.

Chapter 5

The use of resource selection models to predict Human-Elephant Conflict in southern Mozambique

Abstract

Protected areas in Mozambique are often inhabited by people and consequently people and wildlife often come into conflict. I used resource selection function models (RSF) to characterize the distribution of people and elephants and to predict the probability of overlap in resource use and Human-Elephant-Conflict (HEC) in two protected areas in southern Mozambique. I overlaid locations of both species onto the landscape map with a set of specific features and resources in the ArcGIS environment and then run GLM for RSF models at the grid cells scale of 5 X 5 km. I validated these models with observed location records and questionnaires to assess HEC. Changes in landscape features induced by people, followed by habitat characteristics and frequency of occurrence of preferred food items of elephants, explained elephant distribution, while the distribution of people depended on proximity to roads and suitable land for agriculture. Predictors of people presence were also the best predictors for HEC. My modelling of the distribution of HEC yielded a Kappa Statistic of 0.83. The elephant range predicted by the RSF model agreed with the proposed boundaries of the Futi Corridor. I conclude that this landscape approach to identify resource needs for humans and elephants can be used in conservation plans to mitigate HEC.

Keywords: HEC, landscape approach, RSF models, conservation, TFCA

Introduction

Most conservation areas in the world are embedded in a matrix of human-dominated landscapes (Western, 2001; Ehrlich & Pringle, 2008; Prugh *et al*., 2008). Consequently, wildlife and people that transgresses the boundaries of these areas may come into conflict, mostly as a consequence of overlap in spatial requirements (Bagchi *et al*., 2004; Coppolillo *et al*., 2004; DiStefano, 2005; Jensen *et al*., 2008; Kittur *et al*., 2009).

Conservation can benefit from landscape approaches that identify the diverse needs of wildlife (e.g. elephants) and people, human threats to the persistence of other species and actions to reduce the conflict between people and wildlife (Treves & Naughton-Treves, 1999). The development of megaparks to address the spatial needs of elephants and the identification of corridors that can link elephant populations reflect on landscape approaches that may induce local fluctuations in elephant numbers and reduce impact on other species and conflict (see Cheryl-Lesley *et al*., 2006; van Aarde & Jackson, 2007).

Conflict between people and elephant usually arise when resource requirements induce spatial overlap (Sitati *et al*., 2003; Jackson *et al*., 2008). This is of particular interest in Mozambique where several protected areas occupied by elephants are also inhabited by people. People living in these areas mostly rely on subsistence agriculture (Hughes, 2005; Ribeiro, 2008; Smith *et al*., 2008) and are often coming into conflict with wildlife, would it be through crop raiding, impairment of movement, destruction of households and even death (Dunham *et al*., 2010). The apparent increase in such conflict, commonly referred to as 'Human-Elephant Conflict' (HEC) have political, socio-economic and conservation implications and requires renewed scientific initiatives to develop approaches to reduce the likelihood of conflict. The development of models that can predict the likelihood of conflict and that can be used to enhance zonation of activities of people and elephants to reduce conflict, could achieve this (Sitati *et al*., 2003). Such approaches have been used elsewhere. For instance, Sitati *et al*. (2003) developed maps to predict the incidences of HEC by using a grid-cell approach in the Transmara (Kenya) and Smith & Kasiki (1999) built HEC models through ArcGIS routines. In Mozambique, Nhancale (2005) relied on the proximity to roads and likelihood of cultivation to predict incidences of HEC in Maputo National Reserve and the surrounding areas. Conflict that results from overlap in spatial occupation may be quantified through the use of resource selection functions (*vide* Boyce & McDonald, 1999; Boyce *et al*., 2002). These functions can be used to predict interspecific spatial and temporal overlap (see Johnson *et al*., 2000) and can therefore serve as a first step to locate and identify regions where conflict may arise.

I studied two cases: the Mozambican component of i) the Great Limpopo Transfrontier Conservation Area (GLTFCA) and ii) the Lubombo Transfrontier Conservation Area (LTFCA) (Fig. 1). Both of these areas have been inhabited by elephants and people for a long time (see Dalquest, 1965; Ntumi *et al*., 2009), albeit at relatively low numbers. Both areas have been earmarked d as transfrontier conservation areas that aimed at improved conservation and alternative livelihood options for local communities (Spenceley, 2006).

In this chapter I address three specific questions: 1) Do human and elephant resource selection models predict overlap in their spatial and temporal distribution? 2) Can resource selection functions be used to predict the likelihood of HEC? 3) What are the implications of overlap in resource selection for the management of HEC?

Based on the findings in Chapter 4, I expected that elephants will avoid areas densely occupied by people and where the natural landscape has been transformed to agricultural fields.

Furthermore, I expected people to prefer/occupy areas in the proximity of infrastructure that support socio-economic activities, such as roads and land close to tourism infrastructures, plantations and agricultural areas that provide employment opportunities. I also expected that HEC would depend on proximity to settlements, habitat availability and agricultural suitability. I developed resource selection models for elephants and people and use these to predict the likelihood of HEC. I also constructed maps and validated these predictions based on field verifications and geo-referenced reports of incidences of conflict between people and elephants.

Study Area

The study focused on the Great Limpopo Transfrontier Conservation Area (GLTFCA) and the Lubombo Transfrontier Conservation Area (LTFCA). The GLTFCA was gazetted in 2002 while the LTFCA came into being in 2005 (see Fig. 1). The declaration of these areas as conservation entities reflects on a recent conservation paradigm shift from an approach that focus on strictly protected areas (Wright, 1996) to the Peace Parks Foundation's Transfrontier Conservation Area ideologies (see Hanks, 2000).

At the time of the study, the GLTFCA covered an area of 35, 000 km^2 that linked the Limpopo, Banhine and the Zinave National Parks in Mozambique, the Kruger National Park (South Africa) and the Gonarezhou National Park (Zimbabwe) as core conservation areas. These core areas were surrounded by another 64 800 km^2 of land set aside for multiple use such as forest concessions and community game areas (Spenceley, 2006), as well as several controlled hunting areas and community-management areas, all based in Mozambique. The total area of

GLTFCA was 99 800 km^2 (Spenceley, 2006). I focused on the Mozambican component of this GLTFCA.

In the LTFCA, the Futi Corridor (FC) formed a link between the Maputo National Reserve (Mozambique) and the Tembe Elephant Park as well as the Ndumo Game Reserve in South Africa. The LFTCA also included the Ponta de Ouro-Kosi Bay Marine and Coastal TFCA (between Mozambique and South Africa), the Nsubane-Pongola TFCA (between South Africa and Swaziland), the Lubombo Conservancy-Goba (between Mozambique and Swaziland) and the Songimvelo-Malolotja TFCA (between South Africa and Swaziland). I studied only the Maputo National Reserve (MNR) and the Futi Corridor (FC) and surrounding areas in Mozambique.

Both GLTFCA and LTFCA areas supported similar cultures, biophysical properties and histories of conservation. Wild & Fernandes (1967) recognized seven main plant communities in the GLTFCA. These include sand dunes with sparse, salt and wind tolerant vegetation; Save river and associated floodplain; hydromorphic grassland with palm and termitaria thickets; savanna; miombo/dambo woodland; mopani (*Colophospermum mopane*) woodland and ironwood (*Androstachys johnsonii*) woodland. These communities exist as a mosaic of patches dependent on soil types, entrapment of water and the soil water balance (Tinley, 1977).

Within the LTFCA, De Boer *et al*., 2000) recognized seven plant communities inside the MNR and FC: mangroves border Maputo Bay and surround the deltas of the Maputo River and Bembe Canal; dune pioneer vegetation; dune thickets and coastal dune forest; grasslands (some of them are inundated during the rainy season); forests; open woodlands; and the riverine vegetation along the Futi River that is frequently covered in reeds.

Local residents have a long history of deriving food, medicine, and building materials from indigenous species (Cunningham, 1987). *Strychnos spinosa*, *Sclerocarya caffra*, *Adansonia digitata*, *Hyphaene natalensis*, *Phoenix reclinata*, *Syzigium cordatum*, *Landolphia kirkii*, *Mimusops caffra* are trees that provide fruits while the palm *Hyphaene natalensis*, and fruits of *Sclerocarya caffra*, *Garcinia livingstonei*, *Artabotrys brachypetalus* and others are used as alcoholic drinks (Cunningham, 1987). Toothbrushes with antiseptic qualities are made from *Euclea schrimperi* and indigenous species with curative properties (*Aloe* leaves, *Salvadora persica* leaves, roots of *Hyphaene natalensis* and others) have medicinal use. Fibres derived from the palm *Hyphaene natalensis* and the *Sterculia rogersii* trees are utilized to produce rope, baskets and sleeping mats (Cunningham, 1987).

The Mozambican side of the GLTFCA has been virtually inaccessible until the 1940's (Dalquest, 1965). Large mammals in general and elephants in particular were abundant throughout the area (RP, 1952; Dalquest, 1965) specifically small groups of elephants at the Banhine National Park (Tinley, 1972 cited by Stalmans, 2004) and around 1,500 in and around the area that is now Zinave National Park (Dalquest, 1965). In the LTFCA, elephant numbers varied considerably over the last decades in the Maputo National Reserve and Futi Corridor (see Ntumi *et al*. 2009 for details). In both TFCAs wildlife declined until recently has been ascribed to some direct and indirect human impacts (Hatton *et al*., 2001). More recent surveys suggest that elephant populations are recovering (Ntumi *et al*., 2009, Olivier *et al*., 2009).

Both study areas were once inhabited only by the Thonga tribe (Junod, 1927) but now by people from several other tribes. People usually lived in relatively big villages (up to 11 houses) dispersed over the land and chaired by a headman (Junod, 1927). Thonga people are subsistence agriculturalist (Morris, 1972). Exhaustion of the fields, superstition of witchcraft, high incidences of lightning and death of the headman (Junod, 1927; Morris, 1972) as well as the recent village police settlement and war eroded this former structure and resulted in people now living in dispersed and discontinuous settlements (Coelho, 1998). Human density ranged from 1 to 20 individuals/km^2 with about 100 000 people inhabiting the Mozambican side of the GLTFCA (CESVI, 2002; Spenceley, 2006) and around 1 900 lived in the FC and MNR of the LTFCA (INE, 2007; Ribeiro, 2008). Poverty and illiteracy are high and both agriculture and forest exploitation based-economy dominate the region (Ribeiro, 2008). Soils are poor with low agriculture potential and the production is dependent on rainfall (Dear, 2008).

Methods

Elephant and human location data

Adult male (n=6) and female (n=10) elephants were immobilized by darting from a helicopter following standard sedation procedures (see Fowler & Mikota, 2006). Five elephants from the FC and the MNR (Maputaland cluster) were fitted with ST-14 Platform Transmitter Terminals (Mesa, Arizona,U.S.A.) collars while another five and six from the LNP (Limpopo cluster) were fitted collars housing a Garmin GPS receiver and Vistar satellite unit (Africa Wildlife Tracking, Pretoria, South Africa) for satellite transmission of geographic locations. S-TT Telonics units were programmed to download fixes once every three days and uploaded to ImmarSat low orbiting satellite, but with relatively low (<150 m) accuracy. Only data with an accuracy of ≤350 m where analyzed. The Garmin GPS collars were programmed to download three fixes every day and they returned an accuracy of about 10m (Ott & van Aarde, 2011). At the Maputaland cluster five elephants were tracked for only one year (1999), while five others were tracked for a

3-year period between 2000 and 2002 (Table 1). At the Limpopo cluster two elephants were tracked for only one year (2004), while three others were tracked for 3-year periods between 2004 and 2006 and one for 4-years between 2004 and 2007 (Table 1). To reduce autocorrelation of elephant locations retrieved from the Garmin GPS collars, I included in my analysis only one location per day for each elephant (see Loarie *et al.*, 2009b). Following this filtering my data comprised 7, 870 locations from 16 elephants (Table 1).

Human distribution data were generated from the 1997 and 2007 national censuses made by the National Institute of Statistic (INE, 1999; INE, 2009). GPS (Global Positioning System) units were used during the national censuses to locate settlements over the census area. These data were augmented by using the annual census (since 1996) of TIA (Trabalho de Inquérito Agrícola) conducted by the Ministry of Agriculture. As part of the TIA procedures settlements in the study area were also located with GPS units. Only settlement locations recorded between 1999 and 2002 in the Maputaland cluster and between 2004 and 2007 in the Limpopo cluster were used. In total 2, 612 locations of settlement (812 for Maputaland cluster) and 1,800 for the Limpopo cluster were generated (Table 1).

Landscape attributes

I selected landscape attributes known from previous studies to influence human (Junod, 1927; Hudson, 1969; Morris, 1972; Huffman, 1986) and elephant landscape use (Parker & Graham, 1989; Hoare & du Toit, 1999; Ntumi *et al.*, 2005; Archie *et al.*, 2006; Lee & Graham, 2006; Kinahan *et al.*, 2007; Smit *et al.*, 2007a & b; Wall *et al.*, , 2006; Wittemyer *et al.*, 2007; de Beer

& van Aarde, 2008; Harris *et al*., 2008; Loarie *et al*., 2009a & b; Young *et al*., 2009a & b; Ngene, 2010 and Chapter 4). These landscapes attributes included human density (number of people per cell (25 km^2), distance to settlement (kilometres), distance to roads (kilometres), distance to water (kilometres), topography (meters above sea level), forest cover (hectares per cell), forest fragmentation (mean area of forest fragments per cell), NDVI (derived from Landsat set images provided by CENACARTA), frequency of elephants (number of elephant locations per cell), soil type (classes from soil map provided by INIA), agricultural suitability index (developed by INIA), frequency or abundance of preferred or harvested species by humans (based on vegetation maps and species abundances obtained from ground surveys in quadrates of 20X20m in all habitats other than grasslands where quadrates ere 10X10m), frequency or abundance of species used by elephants (based on de Boer *et al*., 2000; Smallie & O'Connor, 2000; Gadd, 2002) (see Table 2).

Hydrology, road systems and soil characteristics were assessed through the databases made available from the Ministry of the Coordination of Environmental Affairs (MICOA). These files were digitized from existing maps of hydrology (INIA, 1995), road systems (DNEP, 1997) and soil (INIA, 1995). INIA (1995) used maps of soil characteristics to develop an agriculture suitability index based on an existing agriculture likelihood model for Mozambique (INIA, 1995). Topography was derived from 100-m digital elevation model (DEM) for each location (Table 2).

I used a landscape map produced by CERU from the Landsat Thematic Mapper (TM) image dated 2002 (see Harris *et al*., 2008) covering both the MNR and Futi corridor (FC). Landscape classes were generated from digital remotely sensed data through the process of a supervised digital image classification (Rué, 2008). Supervised classification and accuracy was based on 150 ground checkpoints both in the MNR and FC; digital topographic maps of the study area (INIA, 1995; DINAGECA, 1998); the existing vegetation map of the MNR (DBC, 2000) and some ancillary data (CENACARTA, 1999). Six habitat type's classes were generated with an overall habitat class accuracy of 80%, based on the agreement ratio between ground checkpoint classes (Poulin *et al*., 2002) and the landscape classes from the previous landscape map produced by CERU.

A habitat map for the Limpopo cluster was produced from the existing three landscape maps of the Limpopo National Park (Stalmans *et al*., 2004), Banhine National Park (Stalmans & Wishart, 2005) and Zinave National Park (Stalmans, 2003). These landscape maps were checked and compared for corrections and improvement with Landsat Thematic Mapper (TM) image dated 2005 covering the Limpopo National Park, Banhine National Park, Zinave National Park and the area in between, following the methodology described above as well as by using the land use cover map provided by the Ministry of Agriculture (UIF, 2007). A total of 190 verification points were surveyed, which gave six habitat classes with an overall habitat class accuracy of 78%, based on the agreement ratio between ground checkpoint classes and the landscape classes from the previous landscape map.

A dry season tasselled-cap transformation (Crist, 1985) Landsat Thematic Mapper (TM) image at 30 X 30 pixels dated 2004 was used to derive NDVI values (for details, see Young *et al*., 2009a) across the two study areas. Using dry season NDVI values the study areas showed a gradient of 8 classes of greenness from areas of high vegetative reflectance and leaf area index (LAI) (Pontailler *et al*., 2003) to non-vegetated areas.

Frequency and abundance of species on which elephants feed and those harvested by people, plant biomass and canopy closure were determined during field surveys. I first listed plant species known from previous studies to be used by humans (Cunningham, 1987; Ribeiro, 2008; Shaffer, 2009) and elephants (de Boer *et al*., 2000; Smallie & O'Connor, 2000; Gadd, 2002; O'connor *et al*., 2007). Frequency of species used by elephants and harvested by humans and plant biomass and canopy closure were estimated following Bonham (1988). Canopy closure was determined as described in Kent & Coker (1992). Twenty 20X20 m quadrates were established in each of six habitat types in each of the study areas. All species were listed, and DHB as well as height of candidate species (i.e. those plant species listed before) measured. Canopy closure was estimated at each quadrate by assigning the Kent & Coker (1992) scale of 25 %, 50%, 75% and 100%.

Analytical approach

For the RSF study I used the design of Thomas & Taylor (2006) and recorded 7, 870 locations logged for 16 elephants and 2, 612 locations of settlements. I used a 5 x 5 km grid cell scale to define resource units associated with human and elephant occurrence (see Fig. 2). I reasoned that the availability of resource units to each elephant and group of elephant's locations as well as to locations of settlements remained unchanged in size and shape over space and time. The relevant data (see Table 1) were imported as points (human and elephant locations), line (roads system and rivers), or polygon features (soil characteristics, habitat types) or as raster data (e.g. plant biomass, plant cover, preferred plant species density and abundance). I generated data for grid cells of 5 X 5 km size and I assumed that people influenced areas up 10 km from the centroid of a settlement. This approximates the distance that an elephant may cover daily (see Loarie *et al*., 2009b).

I considered three levels of scale when developing a model to predict HEC (see Fig. 3). Each predictive level (landscape, grid cell and location) included several landscape variables, elephant locations and human locations. Landscape variables and environmental features in the cells where elephants and humans occur were compared to randomly selected cells within the study area were elephants and humans did not occur. Each cell and each elephant and human location were regressed through a GLM to each predictor variable (e.g. habitat intensity use, human density, distance to settlement, soil intensity use, habitat fragmentation, habitat availability, distance to roads, distance to water, topography, NDVI, agricultural suitability and frequency of the most preferred species).

For habitat, soil types, agricultural suitability index and NDVI classes use, I first deployed all human and elephant locations onto the landscape map. I then determined the number of locations in each category in each cell by subjecting the landscape map to the ArcGIS routines (Zeiler, 2001) available at Habitat Digitizer 3.1 (National Oceanic and Atmospheric Administration, 2002) extension to ArcView 3.2 (ESRI Inc.). I considered habitat availability as the extent of each habitat type in each cell. Habitat fragmentation was determined in accordance to Ripple *et al.* (1991) by calculating the ratio between the perimeter and area of each fragment of forest in each cell and further determining the mean ratio from the different fragments. Frequency of occurrence of preferred species was the ratio resulting from the number of individuals of preferred species recorded in each habitat type divided by the total number of preferred species recorded in the study area.

I calculated human density as the number of settlements, multiplied by the number of inhabitants in each settlement and in each cell. Finally, I determined the distances of each settlement, each cell and each elephant and human location from roads and water by using

ArcGIS routines (Zeiler, 2001) available at Spatial Analyst (NOAA, 2002) extension to ArcView 3.2 (ESRI Inc.).

Resource Selection Function (RSF) modelling procedures

I separated the elephant locations for males and females separately into wet (December to March) and dry (June to September) core seasons in accordance to rainfall regime as suggested in Young *et al*. (2009a). I then developed the elephant RSF models for each of the study areas, season and sex and for humans separately. Elephant and human locations were superimposed on the grids overlain on maps of each of the study areas. Each grid cell was then assigned with a code that designated presence and absence (e.g. cells where both elephants and humans were absent; both elephants and humans were present; only elephants were present and where only humans were present). I then overlaid a suite of landscape covariates onto these maps at the scale of 5 x 5 km.

I related elephants and humans' occupancy and explaining environmental variables by running a GLM model (Boyce & McDonald, 1999; Manly *et al*., 2002):

$$\mathbf{w = exp\,[\beta_0 + \beta_1(A) + \beta_2\,(B) + \beta_3\,(C) + \ldots\beta_n\,(N)]}$$

where:

w = is the probability of use, $\beta_0, \beta_1, \beta_2, \beta_3 \ldots \beta n$ = coefficients, and A, B, C …N = habitat variables used by an elephant in a specific season and by settlements. I used STATISTICA Release 8 (StatSoft, 2008) to develop the Generalized Linear Models. To screen the large number of potential predictor variables, I initially subjected each variable to univariate tests of significance and eliminated all variables with *p* values ≥0.1 based on regression analysis. I then used univariate logistic regressions to model the probability of species presence based on each of the remaining variables to check the co-linearity between them. I excluded all variables proven to be strongly correlated and selected those with high-impact access (Nielsen *et al*., 2002). I subjected the remaining predictors to p-p plot analysis (Holmgren, 1995) to access the need for data transformation prior to running the GLM for each species with both stepwise and forward selection. I used a constrained model selection approach (Lee & Doong, 2008) to select a constant set of variables to compare the models. This was done by using AIC_c to rank models based on Akaike weights for each model (MacKenzie *et al*., 2002). I used the sum of all Akaike weights for each covariate to rank covariates in order of importance following Burnham & Anderson (2002). Values of ΔAIC ranging from 0 to 2 indicate substantial support; values of 4–7 less support and values > 10 no support (Burnham & Anderson, 2002). I calculated AIC_{wi} to indicate the probability that each model was the most likely model of all candidate models to represent my dataset.

The selected best models were then used to predict elephant and human distribution across the landscape by running kernel probabilities in ArcGIS animal movement extension through a spatial interpolation by krigging (see Palma *et al*., 1999) to overlay the gradient of predictive indices of elephant and human occupancy. Using ArcGIS spatial analyzer extension, I multiplied the elephant and human occupancy models to generate probability of human-elephant co-occurrence across the landscape. These probabilities were then used as a proxy for Human elephant conflict (HEC) based on the assumption according to which, HEC likelihood may be potentially predictable in cells where both elephants and humans occur with relatively high probability.

I overlaid these probabilities of co-occurrence onto the maps of study areas and run a GLM model (Boyce & McDonald, 1999; Manly *et al.*, 2002) against the identified variables in each cell. I subjectively reasoned that cells with low probabilities of co-occurrence, hence with low HEC gradients, but with a high probability for the presence of elephant may be part of potential corridors to link elephant populations.

Validation of HEC model

I evaluated the predictive performance of all models using k-folds cross-validation (Boyce *et al.,* 2002) comparing the predictive probability of the model and field observations. I conducted 121 random interviews in 31 settlements or villages in the study areas. In each settlement, four households were selected randomly and questioned whether the household recorded any interaction with elephants during the last five years. On the validation procedure I reasoned that households located in the areas predicted to be potential for HEC in my RSF models would report high incidences of HEC. I also used HEC dataset provided by DINAC (Direcção Nacional das Áreas de Conservação) based on records made between 2003 and 2007 for both the Maputaland and Limpopo clusters. I regressed the incidences of HEC reported during the surveys as well as those from DINAC with HEC probabilities from my modelling exercise for same villages or settlements. Additionally, using locations from where HEC were reported and HEC probabilities from my model exercise, I assigned K statistic value following (Landis & Koch, 1977).

I then mapped the probability of HEC using ArcGIS by the deployment of the gradient of HEC probabilities for each of the clusters. I added to this map, the gradient of probabilities of elephant and humans occupancy PDF (Probability density functions) models (Diggle, 2001). Using these probabilities and the dataset of the observed HEC incidences in each cell, I calculated the residuals of HEC in these cells following Chan (2004) and mapped them. I identified potential movement corridors as those cells that had low probabilities of HEC and high probabilities for elephants to be present.

Results

People and elephants in the southern Mozambique

Elephants and people were more widely distributed across the Maputaland cluster than Limpopo cluster (Fig. 4). Most of the environmental variables in cells that were used differed from those not used, both for elephants and people (Table 3). The GLM suggests that elephants in the Maputaland cluster avoided areas where people have settled, but were mostly close to roads away from settlements (Tables 4a and 5). In the Limpopo cluster, elephants were mostly away from roads but close to settlements and water. Settlements were mainly along the rivers (Fig. 4) but also along most of the roads, albeit that these areas may not have been suitable for agriculture (see Table 4b and 5).

RSF modelling

Elephants

Based on my GLM modelling exercise, distance to settlement, distance to the roads, NDVI and biomass of food species of elephants were the most important determinants of resource use by elephants in the Maputaland cluster (Table 4a). These variables were included in 77.7%, 63.6%, 45.5% and 45.5% of the models, respectively. Distance to settlement, distance to the roads and distance to water were important for elephants in the Limpopo cluster (Table 4b) where each of these variables accounted for 57.1% of the candidate models. Model coefficients for the variables for the Maputaland cluster were either positive (distance to settlement and biomass of preferred species) or negative (distance to the roads, NDVI). Variables included in the highest-ranked model for elephants in the Limpopo cluster had either negative (distance to settlement and distance to water) or positive coefficients (distance to the roads) (see Table 5).

For the Maputaland cluster RSF for bulls and cows were similar, but for the Limpopo cluster it differed as the variables included in the modeling exercise did not yield a significant RSF explaining variables.

Season specific RSF for elephants in the Maputaland cluster were similar, but did differ in the Limpopo cluster where distance to water became an important explanatory variable and where elephants tend to be closer to rivers during the dry season than during the wet season (Tables 4 and 5). During the dry season elephants mostly used cells in the proximity to water and avoided roads.

Settlements

The number of elephant locations and forest fragmentation explained resource use by people in the Maputaland cluster (Table 4a), while distance to roads and the agricultural suitability index were important for people in the Limpopo cluster (Table 4b). Model coefficients for the variables for the Maputaland cluster were either positive (forest fragmentation) or negative (number of elephant locations). The two variables included in the highest-ranked model for people in the Limpopo cluster had negative coefficients (distance to roads and the agricultural suitability index) (see Table 5).

HEC

The best HEC (likelihood of HEC taken as cells where elephant locations and the location of settlements overlapped) predictive model was explained by the distance to settlement, forest cover and agricultural suitability index (Table 6). Model coefficients for these variables were either positive (agricultural suitability index) or negative (distance to settlement and forest cover). The potential elephant ranges (=corridors) were those cells with low human disturbances. Model coefficients for explaining variables were either positive (distance to roads and forest cover) or negative (forest fragmentation and agricultural suitability index) (Table 6). Agreement between the spatial distribution of predicted Human Elephant Conflict actual incidences of HEC based on a questionnaire for both study areas were low (Fig. 5).

Validation of the HEC model

The HEC model validation trial for both clusters showed significant ability to predict HEC. Validation trials for the Maputaland and the Limpopo clusters based on least square regression analyses were significant ($r^2 = 0.55$, $F_{13} = 15.86$, $p = 0.002$ and $r^2 = 0.53$, $F_{15} = 16.99$, $p = 0.001$, respectively; see Fig. 6). The K statistic for the best HEC model validation had a value of 0.83. Some HEC residuals indicated that in some specific areas, HEC incidences were more frequently reported than expected based on the model (Figs 7 & 8). The model yielded modest specificity (0.67) and sensitivity (0.73) which suggests a substantial power of positive and negative discrimination.

Discussion

Resource Selection Functions

People and elephants were more widely distributed across the Maputaland cluster than the Limpopo cluster. At the Maputaland cluster, water is widely distributed (de Boer *et al*., 2000) and not driving the distribution of elephants (de Boer *et al*., 2000; Ntumi *et al*., 2005 and Harris *et al*., 2008), nor along the western boundary of Futi Corridor for people (Shaffer, 2009). However, in the Limpopo cluster, water is scarce and mainly limited to rivers along the boundary of the reserve. Most cultivation occurs along these rivers and most settlements were in the proximity of the floodplains of the rivers. From work elsewhere we know that in arid and transitional savannas water is an important determinant of the distribution of elephants, especially during the dry season (e.g. Chamaillé-Jammes *et al*., 2007; Chamaillé-Jammes *et al*.

2007a & b; Smit *et al.,* 2007b; Harris *et al*. 2008, de Beer & van Aarde, 2008, Loarie *et al*., 2009a) as is also supported by my modelling exercise. The distribution of water also determines the patterns of settlement by people (e.g. Smith, 1983) and it is often in the proximity of water where elephants and people overlap in their distribution and where conflict occurs (see Sitati *et al*., 2003; Jackson *et al*., 2008). In mesic savannas such as the Maputaland cluster this is not the case as water is here more widely distributed and available, both to people and elephants. The likelihood of overlap in the distribution of elephant activity and settlements is here thus expected to be relatively low. It is therefore not surprising that variables other than water explained RSF for people and elephants in this cluster. Furthermore, here the two species overlap little in their distribution and most people live on the eastern side while elephants were mainly active in the central parts – to the drier west people mainly settled along the Maputo river floodplains that is highly suitable for agriculture. Given the differences in the distribution of water and suitable soils for agriculture it is not surprising that people and elephants were less widely dispersed across the Limpopo than the Maputaland cluster.

My modelling exercise often included NDVI as an explanatory variable in the best predictive models. NDVI is a proxy for food availability and quality (see Young *et al*., 2009b; Young & van Aarde, 2010) and others also have used it or the related EVI to predict habitat selection by elephants, including case studies on elephants living in the Maputaland cluster (e.g. Harris *et al*., 2008: Loarie *et al*., 2009b) and the Kruger National Park (Young *et al*., 2009a & b) that is situated adjacent to the Limpopo cluster and where water distribution and vegetation in some parts are similar to the Limpopo cluster that I studied. These authors all identified NDVI as an important driver of selection, especially during the dry season, although variability in NDVI seems more important during the wet season. In my study, contrary to that of others the relative contribution of NDVI as an explanatory variable of resource selection decreased with increased NDVI, an apparent anomaly that needs further investigation at a finer resolution and scale. The scale at which I used NDVI ($25km^2$) is much greater than the 1 to 5 km^2 used by others - this may have masked the role of NDVI as a predictor variable in RSF modelling.

Elephants most used cells with low human influence and relatively covered by forest. People settlement however, did avoid cells intensively used by elephants and set close to relatively clay and moderate soils for agriculture. These results most highlight the close association between changes in landscape features induced by people and elephant persistence (see Chapter 4) and that the settlement pattern across the landscape was in accordance to the central place theory (Smith, 1983), which states that people tend to live close to main resources.

In the Maputaland cluster the variables predicting RSF during the wet and dry season were similar and also for bulls and cows. These, however did differ in the Limpopo cluster, once again emphasizing that determinants of resource use resource differ from area to area, though distance to water and away from settlements seem to be important throughout the distributional range of elephants (also see Harris *et al*., 2008: Loarie *et al*., 2009a). Differences in resource use functions for cows and bulls comes as no surprise due to both gender related differences in behaviour and resource needs, and the constraints placed by calves on the movement patterns of breeding herds (Vancuylenberg, 1977; Stokke, 1999; Smith *et al*., 2007a; van Aarde *et al*., 2008). Differences in the roaming behaviour of bulls and cows may also be explained by the so-called 'bull hypothesis' (Sukumar & Gadgil, 1988; Sukumar, 1991; Sitati *et al*., 2003, Smith *et al*., 2007a) that suggests that bulls tend to take more risk than cows and explore areas in vicinity of people.

Livelihoods in the Maputaland and Limpopo clusters differ. Small scale subsistence farming is typical for people in the former and here few people keep livestock. To the contrary, in the Limpopo cluster people in the central areas herd cattle while those living along the Limpopo River practice both subsistence and commercial agriculture with relatively large swatches of land having been cleared for apparent communal farming activities (Witter, 2010). These lifestyle differences may at least in part explained differences in RSF and in the Limpopo cluster proximity to roads and agricultural suitability appeared important, while in the Maputaland the absence of elephants and forest fragmentation cluster entered the RSF model as important explanatory variables. Agricultural suitability is much a function of distance from water and soil type and these variables can thus not be ignored as of importance to people. The absence of elephants may be due to elephants avoiding people and not vice versa, also the fragmentation of forest might have been caused by people, this then explaining the spurious importance of these variables in the modelled RSF for settlements.

Using RSF to predict HEC

I succeeded to illustrate the usefulness of RSF modelling to identify the variables that can predict the presence of elephants and people. I consequently also could predict the regions where people and elephants have a high likelihood of co-occurring and where conflict may occur. However, predicted regions with a likelihood of conflict did not agree with that recorded during independent surveys, suggesting that the maps I generated need further refinement to successfully predict HEC and to pinpoint regions that should be avoided by people to ameliorate HEC. This, however, is not supported by the relatively high K statistic of validation, which imply that the models performed relatively well in predicting the locations of potential HEC.

The lack of land use planning may result in an increase in HEC, simply because people increasingly settle in areas sought after by elephants, such as the Futi Corridor, which according to my RSF exercise is important for elephants. Here increased recent settlement in areas where conflict is likely may explain why conflict occurred more frequently than predicted by the model.This corridor has been earmarked as a protected area. Here relatively high incidences of HEC may occur as RSF identified resource overlap to be relatively high. This has some practical implication in the management of HEC in Mozambique.

Management implications

The knowledge of the drivers of elephant and human use of the landscape may have important management and conservation implications. Despite relative incomplete data and the course scale thereof RSF provide a way through which to predict HEC. I illustrated a quantitative link between human and elephant distribution and a set of predictable landscape features of the landscape. My findings are similar to those of others and suggest that conflict may occur in the proximity of water and on land suitable for agriculture.

The government of Mozambique embraced the TFCA philosophy (Hanks, 2001) which goes beyond political boundaries to link protected areas. In southern Mozambique, the TFCA approach is applied to link the Maputo National Reserve (MNR) through the Futi Corridor (FC) to Tembe Elephant Park (TEP) (the LTFCA) as well as to link the Limpopo National Park, Banhine National Park and Zinave National Park together with the area in between as a whole to the Kruger National Park and Gonarezhou National Park (Spenceley, 2006). Although the motivation for the establishment of these two TFCAs was politically acceptable, no appropriate ecological assessment has been done to support species distribution (elephants in this case) with minimum impact on rural people livelihoods. The TFCA concept reinstates the ecological principles (Lee & Graham, 2006) needed to ensure elephant persistence with the political and economic goals, which can alter the politically driven process of land use tenure and land use change.

Ntumi *et al*. (2009) hypothesized that changes in the landscape through human activities have decreased elephant numbers and range in Mozambique during the last four decades. Conservation initiatives supported by the Mozambican government call for the recovery of elephant numbers and range and RSF may be used to earmark areas for such recovery. Suitable habitat that links core elephant population ranges suggested by other workers for elsewhere (Mwalyosi, 1991; Osborn & Parker, 2003; Cheryl-Lesley *et al*., 2006), may best help to improve the land use planning under persistent habitat fragmentation typical of my study areas. Here, ecological processes (see Cheryl-Lesley *et al*., 2006 for details in concepts), the outcomes of which I described by using RSF models may prove to be essential to elephant conservation and HEC mitigation. I would like to argue that landscape solutions based on the needs of species (Coppolillo *et al*., 2004) as here demonstrated for people and elephants, offer a realistic approach to develop megaparks as suggested by others (van Aarde *et al*., 2006; van Aarde & Jackson, 2007).

The area predicted by RSF models in the LTFCA as a potential corridor, which coincide with the proposed FC by the government of Mozambique (see Ostrosky & Matthews, 1995), well support the notion that the FC still exists and elephants do use quite frequently even opportunistically. Unfortunately, this impacts on people living along the Futi River. This result supports my prediction that the escalated HEC is a matter of resource use rather than elephant numbers *per se*. Also, this may denote a lack of land use planning, since most of the communities experiencing HEC live where elephants are expected to occur. However, the predictability of my models may change, most due to the known political and environmental uncertainty of Mozambique. If so, these RSF models will have to be updated periodically if they were to be used to implement conservation development initiatives as proposed by transfrontier conservation initiatives.

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Table 1 Number of locations of settlements and elephants in the two TFCAs (here, Maputaland cluster = LTFCA and Limpopo cluster = GLTFCA) used in this study. Locations from six male elephants and ten female elephants were also segregated into two seasons (dry and wet).

Elephant ID	Sex	Dry season								Total	Wet season								Total	Dry + Wet
		1999	2000	2001	2002	2004	2005	2006	2007		1999	2000	2001	2002	2004	2005	2006	2007		
Maputaland cluster																				
Futi 13	Male		14	205	143					362		40	255	160					455	817
Futi 18	Male		17	190	191					398		38	229	147					414	812
Maputo 19	Female		17	187	200					404		31	231	141					403	807
Maputo 20	Female		11	217	204					432		48	273	183					504	936
Maputo 21	Male		15	171	190					376		31	217	159					407	783
Maputo 54	Female	189								189	188								188	377
Maputo 55	Female	52								52	155								155	207
Maputo 56	Female	77								77	62								62	139
Maputo 57	Female	123								123	125								125	248
Maputo 58	Male	76								76	38								38	114
Total	Male	76	46	566	524					1212	38	109	701	466					1314	2526
Total	Female	441	28	404	404					1277	530	79	504	324					1437	2714
Total	Male+Female	517	74	970	928					2489	568	188	1205	790					2751	5240
Settlements										812									812	812
Limpopo cluster																				
KNP 1	Female														56				56	379
KNP 2	Female					108	93	122		323					72	91	83		246	263
KNP 3	Female					17				17					58				58	277
KNP 4	Female					114	105			219					71	84	14		169	597
KNP 5	Male					225	92	111		428					73	97	112	49	331	676
KNP 6	Male					118	105	122		345					76	111	83		270	939
Total	Male					239	197	233		669					149	208	195	49	601	1164
Total	Female					243	198	122		563					257	175	97	0	529	1761
Total	Male+Female					482	395	355		1232					406	383	292	49	1130	1536
Settlements										1800									1800	1800
Maputo + Limpopo																				
Male+Female		517	74	970	928	482	395	355		3721	568	188	1205	790	406	383	292	49	3881	6776
Settlements										2612									2612	2612

Table 2 Resource variables included in the study and data description and processing procedures.

Model variable (Units)	Source	Year	Description	Analysis	Number of classes
Settlements data (points)	INE	1997 & 2007	Excel spreadsheet (villages per cell) joined to elephant locations and study area files.	Number of locations per cell or distance to some predictors	Continuous
Elephants data (points)	CERU and UEM elephant satellite tracking data	1999 - 2002	Excel spreadsheet (locations per cell) joined to all shape files designed for the study area	Number of locations per cell or distance to some predictors	Continuous
Human density (classes)	INE	1997 & 2007	Excel spreadsheet (villages with respective households and inhabitants per cell) to study area grid cell. A new field calculates people per sq km	Density per cell	Continuous
Distance to settlement (kilometres)	INE	1997 & 2007	Excel spreadsheet (village per cell) joined to elephant locations and study area files. A new field calculates Distance to village	Distance to	Continuous
Distance to roads (kilometres)	ANE	1999	Either buffered or used "Distance to" spatial analysis tool	Distance to	Continuous
Distance to water (kilometres)	ARA	2000	Either buffered or used "Distance to" spatial analysis tool	Distance to	Continuous
Topography (meters)	CENACARTA	1999	Was rastered to be used in spatial analysis	Number of locations per cell	Continuous
Habitat type (classes)	Ministry of Agriculture, CERU, MITUR	2005 - 2007	Was rastered to be used in spatial analysis	Number of locations per class	1 = forest 2 = thicket 3 = woodland 4 = grassland 5 = swamp 6 = anthropogenic landscapes

Table 2 (Continued)

Model variable (Units)	Source	Year	Description	Analysis	Number of classes
Forest cover (hectares)	Ministry of Agriculture , CERU, MITUR	2005 - 2007	Was rastered to be used in spatial analysis	Hectares per cell	Continuous
Forest fragmentation (ratio)	Ministry of Agriculture , CERU, MITUR	2005 - 2007	Was rastered to be used in spatial analysis	Mean ratio Perimeter/ Area per cell	Continuous
NDVI (classes)	CENACARTA	2004	Was rastered to be used in spatial analysis	Range of greenness	1 = very low 2 = low 3…6 = moderate 7…10 = high 11…12 = very high
Frequency of species (number of species)	Field work	2005 - 2008	Excel spreadsheet (species per cell) joined to grid cell and elephant and settlement locations in the study area	Number of species per cell	Continuous
Frequency of elephants (number of locations)	CERU and UEM elephant satellite tracking data	1999 - 2002	Excel spreadsheet (locations per cell) joined to all shape files designed for the study area	Number of locations per cell	Continuous
Soil type (classes)	INIA	1995	Was rastered to be used in spatial analysis	Number of locations per soil classes	1 = alluvial 2 = clay 3 = mananga 4 = rhyolite 5 = calcrete 6 = sand
Agricultural suitability index (classes)	INIA	1995	Was rastered to be used in spatial analysis	Range of suitability	1 = unsuitable 2 = low suitability 3 = moderately suitable 4 = suitable

Table 3 Mean ± SD of environmental variables and other characteristics of cells that were used and avoided by elephants and people at the Maputaland (a) and Limpopo (b) clusters.

a)

Environmental variable	Elephants								Settlements	
	Used				Unused				Used	Unused
	Wet		Dry		Wet		Dry			
	Bull	Cow	Bull	Cow	Bull	Cow	Bull	Cow		
Human density	5.564±8.488	2.633±3.943	5.564±8.488	3.333±4.834	13.564±25.033	11.954±21.875	13.564±25.033	11.954±		
Distance to settlement	3.420±1.941	4.449±2.069	3.420±1.941	4.100±2.047	0.000	0.724±1.302	0.000	11.954±21.875		
Distance to water	3.647±1.729	3.479±1.526	3.647±1.729	3.501±1.638	0.000	1.150±2.036	0.000	0.724±1.302	3.464±2.912	0.000
Distance to roads	2.384±1.231	2.132±0.900	2.384±1.231	2.058±0.881	0.000	0.847±1.535	0.000	1.150±2.036	1.439±1.219	0.000
Topography	43.811±20.388	33.701±13.612	43.811±20.388	34.720±14.020	2.295±7.392	18.464±28.124	2.295±7.392	0.847±1.535	44.061±20.490	0.000
Forest cover	5.322±1.446	5.700±1.055	5.322±1.446	5.417±1.481	4.230±1.802	4.517±1.744	4.230±1.802	18.464±28.124	14.102±5.208	8.583±6.382
Forest fragmentation	0.968±0.281	0.400±0.270	0.968±0.281	0.917±0.266	0.656±0.560	0.770±0.524	0.656±0.560	4.517±1.744	0.948±0.429	0.522±0.413
NDVI			9.00±3.000	10.00±2.000			8.000±3.000	8.000±4.000	9.000±3.00	8.000±4.000
Biomass of food species of elephants	62.339±71.114	85.767±70.859	62.339±71.114	79.442±71.671	47.027±67.340	44.526±66.206	47.027±67.340	28.988±28.452		
Number of elephant locations									38.976±76.123	99.077±171.841
Agricultural suitability									Moderate to suitable	low to moderate
Soil type									clay and alluvial	sandy
Frequency of exploited species									159.059±144.703	60.355±108.271

b)

Environmental variable	Elephants								Settlements	
	Used				Unused				Used	Unused
	Wet		Dry		Wet		Dry			
	Bull	Cow	Bull	Cow	Bull	Cow	Bull	Cow		
Human density	0.303±0.530	0.057±0.048	0.333±0.646	0.133±0.320	0.291±0.987	0.313±1.014	0.291±0.987	0.313±1.014		
Distance to settlement	9.842±5.760	15.207±7.640	10.275±6.569	10.948±6.858	2.361±6.563	1.793±5.652	2.361±6.563	1.793±5.652		
Distance to water	3.397±2.139	4.167±3.838	2.932±2.475	3.339±2.924	0.607±1.784	0.519±1.487	0.607±1.784	0.519±1.487	4.270±2.669	0.000
Distance to roads	30.919±11.324	56.996±10.548	32.428±13.259	63.768±11.670	8.105±19.566	5.638±14.543	8.105±19.566	5.638±14.543	13.346±12.566	0.000
Topography	220.351±113.457	356.023±110.320	235.921±109.251	373.660±106.674	51.860±125.055	38.374±97.064	51.860±125.055	38.374±97.064	175.719±112.419	0.000
Forest cover	39.123±20.326	29.753±16.911	41.242±19.994	32.944±18.681	24.709±22.903	25.299±23.328	24.709±22.903	25.299±23.328	21.739±10.895	17.480±11.300
Forest fragmentation	0.022±0.013	0.029±0.012	0.024±0.011	0.033±0.011	0.020±0.013	0.019±0.013	0.020±0.013	0.019±0.013	0.224±0.013	0.020±0.030
NDVI			9.000±3.000	10.000±2.000			8.000±3.000	8.000±3.000	7.000±3.000	9.000±3.000
Biomass of food species of elephants	1.445±0.559	0.903±0.732	1.938±0.628	0.825±0.660	1.101±0.752	1.142±0.755	1.101±0.752	1.142±0.755		
Number of elephant locations									4.258±21.347	6.235±18.205
Agricultural suitability									Moderate to suitable	suitable
Soil type									grey and clay	clay and alluvial
Frequency of exploited species									47.091±34.890	48.221±37.277

Table 4a Number of variables included in the model (K); Akaike's Information Criterion (AIC); Differences in Akaike's Information Criterion scores (ΔAIC), Log likelihood (-2LL); LRatio X^2; p and Model rank for candidate best RSF models developed for cows and bulls elephants in the dry and wet seasons as well as the best RSF model for human in the LTFCA, southern Mozambique.

Candidate models	K	AIC	ΔAIC	AIC_{wi}	LRatio X^2	p	Model rank
Bull							
Distance to settlement +Biomass of preferred species	**2**	**192,54**	**0.00**	**649.86**	**24,78**	**0,001**	**1**
Distance to settlement)	1	206,48	13.94	0.00	8,84	0,003	2
Biomass of preferred species	1	207,38	14.84	0.00	7,94	0,005	3
Cow							
Distance to settlement + Distance to roads + NDVI	**3**	**405,85**	**0.00**	**5.39**	**53,52**	**0,001**	**1**
Distance to settlement + Normalized Difference Vegetation Index	**2**	**409,22**	**3.37**	**0.19**	**48,15**	**0,001**	**2**
Distance to settlement + Distance to roads	2	429,19	19.97	0.00	28,18	0,001	3
Distance to settlement)	1	432,33	26.48	0.00	23,05	0,001	4
Normalized Difference Vegetation Index	1	449,19	43.34	0.00	6,18	0,013	5
Distance to roads + NDVI	2	449,31	43.46	0.00	8,06	0,018	6
Distance to roads	1	452,74	46.89	0.00	2,64	0,105	7
Dry							
Distance to settlement + NDVI + Biomass of preferred species	**3**	**421,71**	**0.00**	**66.05**	**27,08**	**0,001**	**1**
Distance to settlement + NDVI	2	430,40	8.69	0.01	16,40	0,002	2
Distance to settlement + Biomass of food species	2	434,98	13.27	0.00	11,82	0,003	3
Distance to settlement)	1	435,90	14.19	0.00	8,89	0,003	4
Biomass of preferred species	1	444,58	22.87	0.00	0,21	0,651	5
Normalized Difference Vegetation Index	1	444,73	23.02	0.00	0,06	0,799	6
Normalized Difference Vegetation Index I+ Biomass of food species	2	446,46	24.75	0.00	0,34	0,844	7
Wet							
Distance to settlement	**1**	**417,80**	**0.00**	**0.83**	**16,70**	**0,001**	**1**
Distance to settlement + Biomass of food species	**2**	**418,84**	**1.04**	**0.37**	**17,65**	**0,001**	**2**
Distance to settlement + Topography	**2**	**419,77**	**1.97**	**0.20**	**16,73**	**0,001**	**3**

Table 4a (Continued)

Distance to settlement + Topography + Biomass of food species	3	420,84	3.04	0.11	17,66	0,001	4
Topography	1	427,51	9.71	0.00	6,99	0,008	5
Topography + Biomass of preferred species	2	429,10	11.30	0.00	7,39	0,025	6
Biomass of preferred species	1	433,70	15.90	0.00	0,80	0,370	7
Elephants (Dry+Wet)							
Distance to settlement + Distance to roads + NDVI+ Biomass of food species	**4**	**741,90**	**0.00**	**56.58**	**60,59**	**0,001**	**1**
Distance to settlement + Distance to roads + Biomass of preferred species	3	749,99	8.09	0.02	50,51	0,001	2
Distance to settlement + Distance to roads + NDVI	3	760,50	18.60	0.00	40,00	0,001	3
Distance to settlement + Distance to roads	2	761,68	19.78	0.00	36,82	0,001	4
Distance to settlement + NDVI+ Biomass of food species	3	763,82	21.92	0.00	36,69	0,001	5
Distance to settlement + Biomass of food species	2	766,78	24.88	0.00	31,72	0,001	6
Distance to settlement	1	769,99	28.09	0.00	26,51	0,001	7
Distance to settlement + NDVI	2	770,72	28.82	0.00	27,78	0,001	8
Distance to roads	1	790,43	48.53	0.00	6,07	0,014	9
Distance to roads + NDVI	2	791,48	49.58	0.00	7,02	0,030	10
Distance to roads + Biomass of food species	2	791,97	50.07	0.00	6,53	0,038	11
Human (Dry+Wet)							
Frequency of elephants +Forest fragmentation	**2**	**69.60**	**0.00**	**1.45**	**16,27**	**0,001**	**1**
Frequency of elephants	**1**	**71.47**	**1.87**	**0.30**	**7,82**	**0,005**	**2**
Forest fragmentation	1	72.02	2.42	0.21	4,43	0,035	3

NDVI = Normalized vegetation index derived as explained on page 148

Table 4b Number of variables included in the model (K); Akaike's Information Criterion (AIC); Differences in Akaike's Information Criterion scores (ΔAIC), Log likelihood (-2LL); LRatio X^2; p and Model rank for candidate best RSF models developed for cows and bulls elephants in the dry and wet seasons as well as the best RSF model for human in the GLTFCA, southern Mozambique.

Bull							
Topography + Normalized Difference Vegetation Index	**2**	432,75	**0.00**	**0.70**	4,40	0,111	**1**
Topography	1	433,40	0.65	0.42	1,75	0,186	2
Normalized Difference Vegetation Index	1	433,46	0.71	0.41	1,69	0,194	3
Cow							
Distance to settlement + Distance to roads	**2**	**151,40**	**0.00**	**0.96**	**8,29**	**0,004**	**1**
Distance to settlement + Biomass of preferred species	**2**	**152,98**	**1.58**	**0.29**	**8,71**	**0,013**	**2**
Distance to settlement + Topography	**2**	**153,40**	**2.00**	**0.22**	**8,29**	**0,016**	**3**
Distance to settlement + Topography + Biomass of preferred species	3	154,89	3.49	0.09	8,80	0,032	4
Biomass of preferred species	1	159,12	7.72	0.01	0,57	0,452	5
Topography	1	159,55	8.15	0.01	0,14	0,707	6
Topography + Biomass of preferred species	2	160,48	9.08	0.01	1,21	0,545	7
Dry							
Distance to water + Distance to roads	**2**	**747,65**	**0.00**	**1.23**	**10,62**	**0,005**	**1**
Distance to water	**1**	**748,12**	**0.47**	**0.77**	**8,15**	**0,004**	**2**
Distance to roads	1	755,43	7.78	0.01	0,85	0,358	3
Wet							
Distance to settlement + Topography	**2**	**803,18**	**0.00**	**0.39**	**7,38**	**0,025**	**1**
Distance to settlement + Distance to roads	**2**	**803,78**	**0.60**	**0.26**	**6,78**	**0,034**	**2**
Topography	**1**	**803,95**	**0.77**	**0.24**	**4,61**	**0,032**	**3**
Distance to settlement + Distance to roads + Topography	**3**	**804,75**	**1.57**	**0.15**	**7,81**	**0,050**	**4**
Distance to settlement + Topography	2	805,93	2.75	0.08	4,62	0,010	5
Distance to settlement	1	806,06	2.88	0.07	2,49	0,114	6
Distance to roads	1	806,71	3.53	0.05	1,85	0,174	7

Table 4b (Continued)

Elephants (Dry+Wet)							
Distance to settlement + Distance to water + Distance to roads	**3**	**1394,61**	**0.00**	**0.67**	**9,78**	**0,021**	**1**
Distance to water	**1**	**1396,10**	**1.49**	**0.23**	**4,29**	**0,038**	**2**
Distance to water+ Distance to roads	2	1396,76	2.15	0.16	5,63	0,060	3
Distance to settlement + Distance to water	2	1396,88	2.27	0.15	5,51	0,064	4
Distance to settlement + Distance to roads	2	1398,32	3.71	0.07	4,07	0,131	5
Distance to roads	1	1398,85	4.24	0.05	1,54	0,214	6
Distance to settlement	1	1399,62	5.01	0.03	0,77	0,381	7
Human (Dry+Wet)							
Distance to roads+ Agricultural suitability	**2**	**31,10**	**0.00**	**0.89**	**3,60**	**0,165**	**1**
Distance to roads	**1**	32,24	**1.14**	**0.36**	0,46	0,498	**2**
Agricultural suitability	1	32,25	1.15	0.36	0,46	0,499	3

NDVI = Normalized vegetation index derived as explained on page 148

Table 5: Parameter estimates generated from GLIM models in the resource selection functions for ten adult female elephants and six male elephants during dry and wet seasons between 1999 and 2000 (Libombo TFCA) and 2000 and 2004 (Great Limpopo TFCA) in southern Mozambique.

Study area	Predictor variable	Sex		Season		Overall	
		Cow	Bull	Dry	Wet	Elephant	Human
TFCA Libombo	Human density	0,149	0,114	0,132	0,082	0.129	Not applicable
	Distance from settlement	**0,753****	**0,509****	**0,761*****	**0,906*****	**0.758*****	Not applicable
	Distance from water	0,145	0,075	-0,207	-0,100	-0.006	-0.023
	Distance from roads	**-0,365*****	-0,049	-0,144	0,002	**-0.345*****	-0.141
	Topography	-0,162	-0,065	-0,075	0,114	-0.063	-0.093
	Forest	0,223	0,287	0,105	-0,049	**0.250****	**0.313****
	Forest fragmentation	0,151	0,156	0,100	-0,092	-0.045	**0.482*****
	Normalized Difference Vegetation Index	-0,401**	0,128	**-0,398****	**-0,510*****	**-0.260****	Not applicable
	Biomass of preferred species	0.117	**0.390****	**0.403****	**0.400****	**0.290****	Not applicable
	Frequency of elephants	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	**-0.337*****
	Agricultural suitability	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	-0.158
	Soil type	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	0.187
TFCA Great Limpopo	Human density	0.195	-0.011	-0.078	-0.045	0.019	Not applicable
	Distance from settlement	**-0.344****	0.300	-0.034	**-0.257****	**-0.236****	Not applicable
	Distance from water	-0.004	-0.033	**-0.272****	-0.049	**-0.243****	-0.005
	Distance from roads	0.003	0.038	**0.312****	0.168	**0.294****	**-0.207****
	Topography	0.162	0.169	**-0.299****	0.153	-0.020	0.068
	Forest	-0.067	-0.091	-0.065	-0.075	-0.183	0.018
	Forest fragmentation	0.050	-0.032	**-0.251****	-0.081	-0.174	**0.251****
	Normalized Difference Vegetation Index	0.002	-0.165	0.035	-0.053	0.036	Not applicable
	Biomass of preferred species	0.009	0.043	0.005	0.007	0.176	No applicable
	Frequency of elephants	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	0.046
	Agricultural suitability	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	**-0.240****
	Soil type	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	0.078

Table 6 Variables significant in the spatial models predicting the occurrence of elephants (elephant range areas) and the probability of incidences of Human Elephant Conflict (HEC) in both Maputaland and Limpopo clusters (all data combined). In the table, (+) and (−) indicate whether the significant association was positive or negative, respectively.

Predictor variable	HEC	p	Elephant range areas	p
Distance to settlement	- 0.209	0.006	0.263	0.017
Distance to water	0.055	0.142	- 0.129	0.189
Distance to roads	0.822	0.000	0.549	0.000
Forest fragmentation	- 0.366	0.000	- 0.401	0.000
Forest cover	- 0.473	0.000	0.697	0.000
Agricultural suitability index	0.138	0.000	- 0.129	0.022
Soil type	0.090	0.004	- 0.033	0.547

Fig. 1 The Location of the Lubombo Transfrontier Conservation Area (LTFCA) (a) and the Great Limpopo Transfrontier Conservation Area (GLTFCA) (b) clusters, with the protected areas associated. 1, Gonarezhou National Park; 2, Zinave National Park; 3, Sengwa Corridor; 4, Banhine National Park; 5, Limpopo National Park; 6, Kruger National Park; 7, Maputo National Reserve; 8, Futi Corridor; 9, Ndumo Game Reserve and 10, Tembe Elephant Park. Protected areas in Mozambique, Zimbabwe and South Arica are filled in differently.

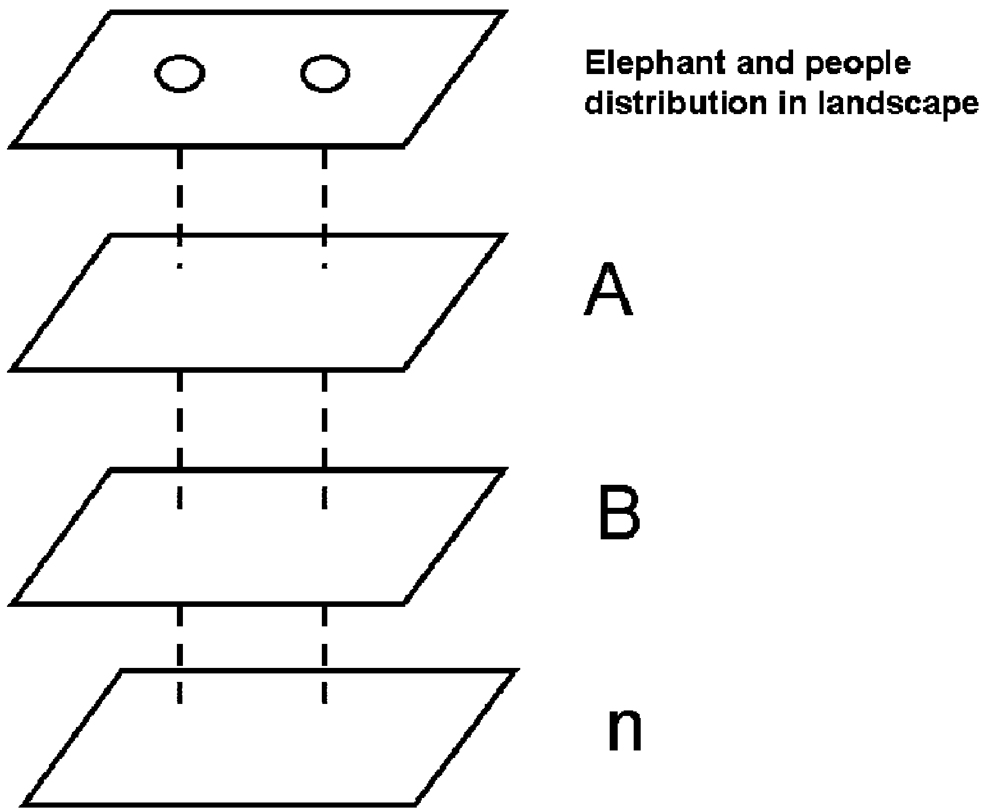


Fig. 2 Schematic presentation of the distribution of elephant and people as a function of resources in the landscape. Elephant and people do not occur randomly in the landscape. There are **A**, **B** and **n** resources layers that may explain the location of both species in the landscape.

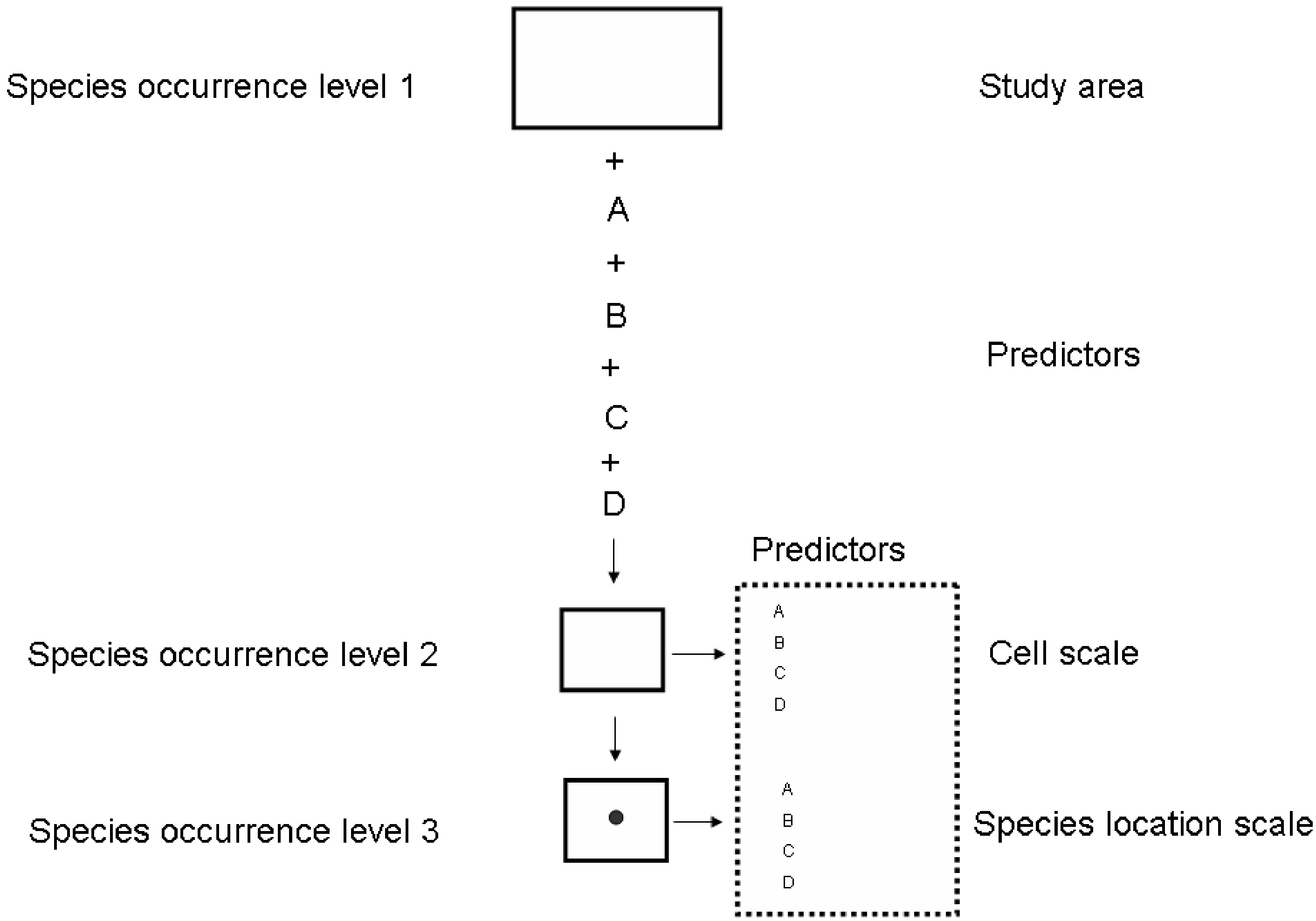


Fig. 3 A conceptual flow diagram of the methodological approach to RSF modelling to predict human-elephant conflict in southern Mozambique at the landscape, cell and location scale.

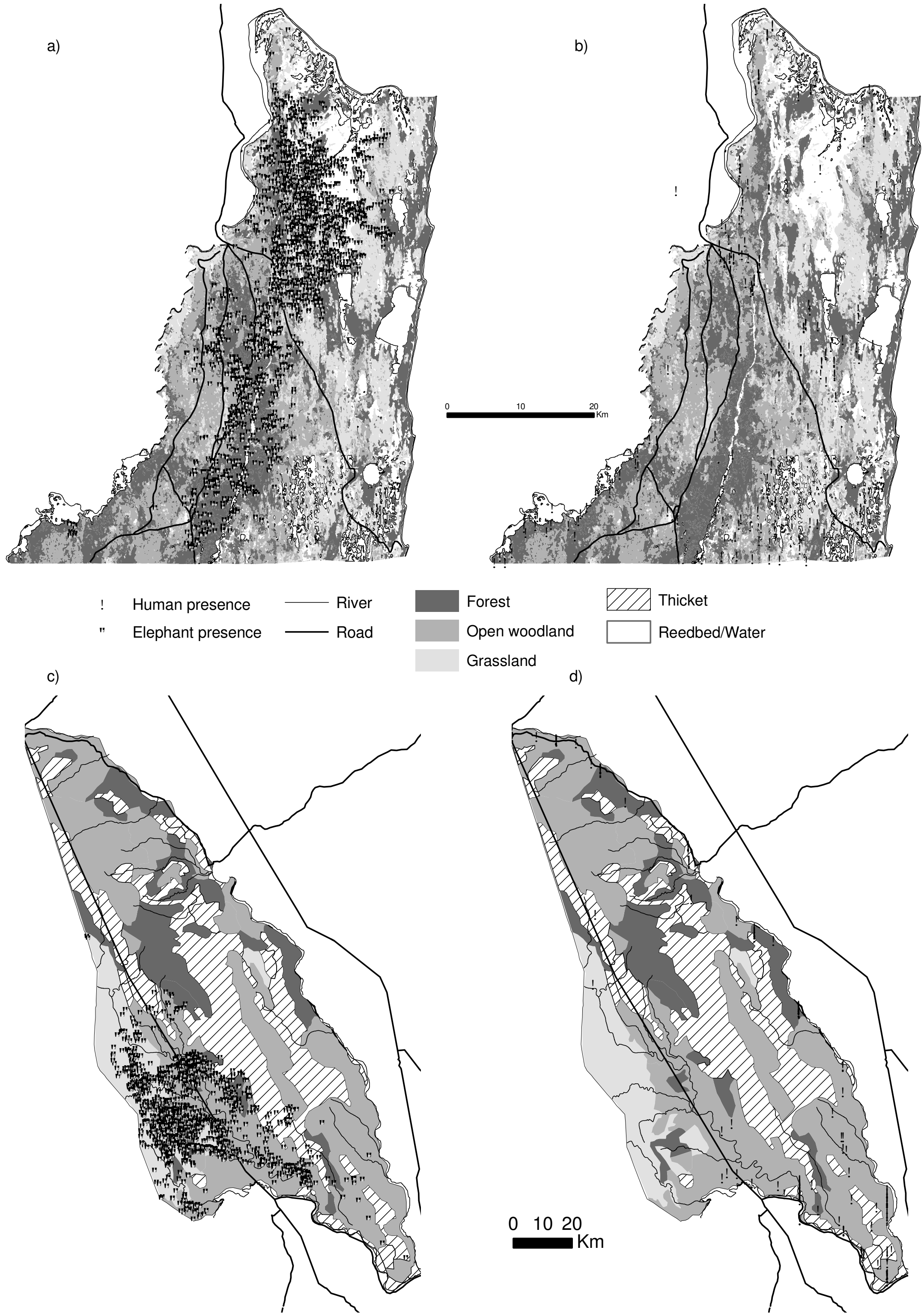
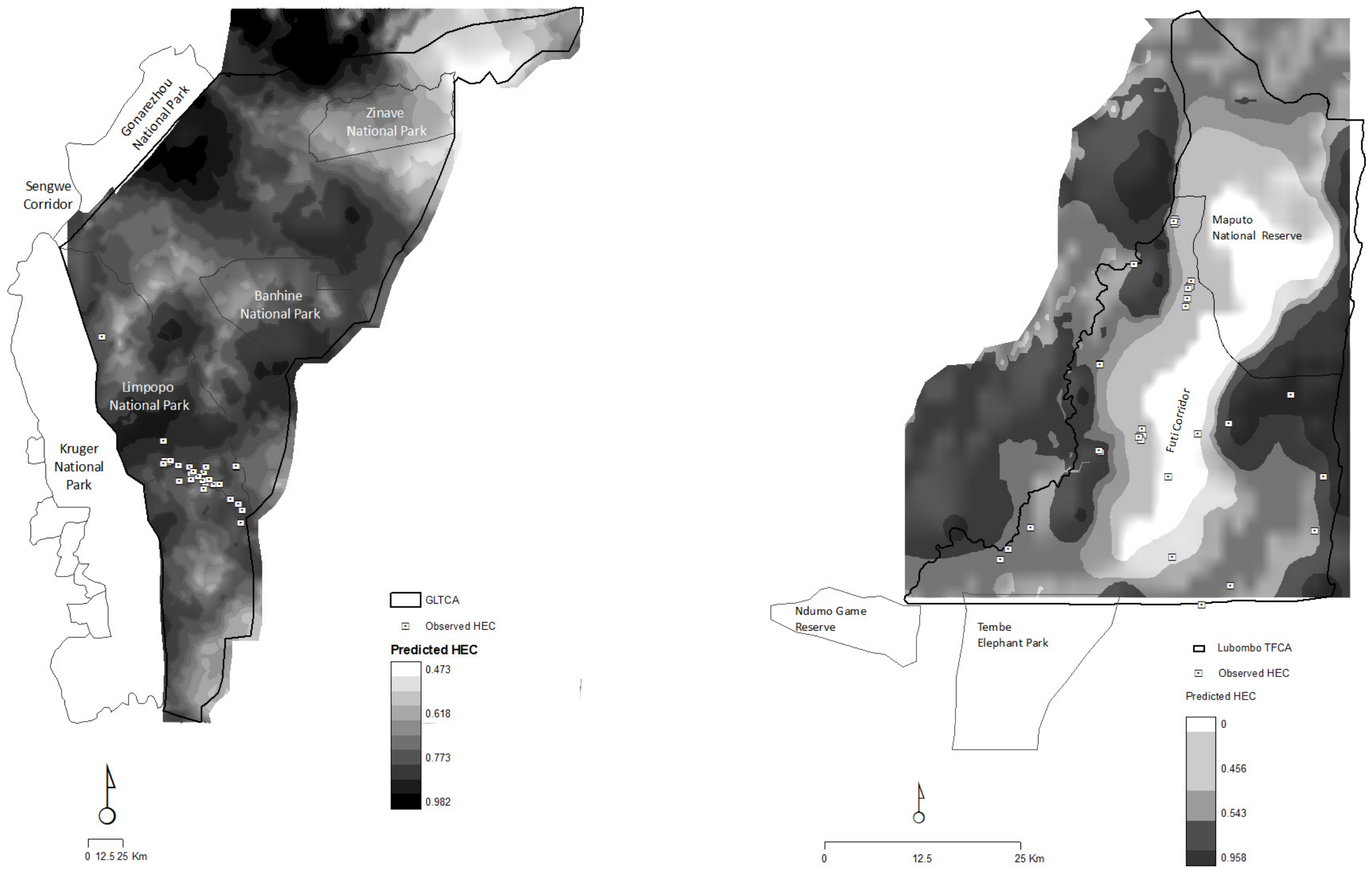
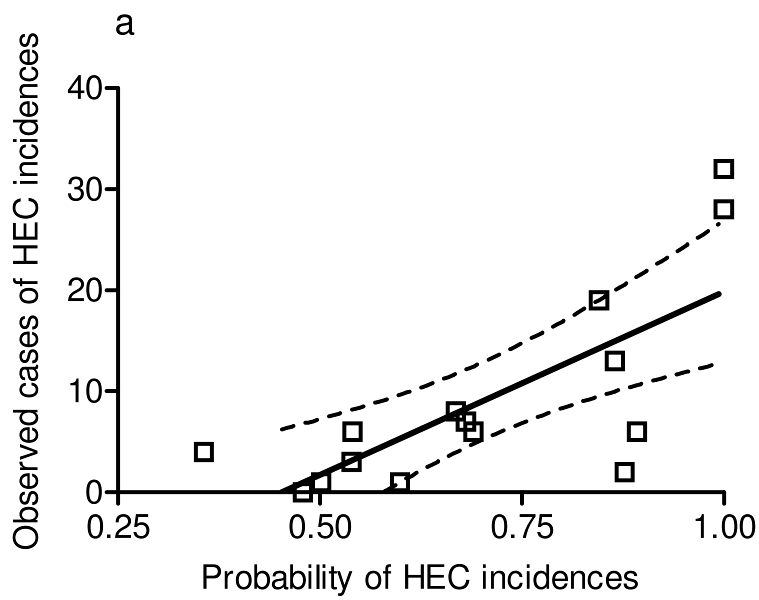


Fig. 4 Locations of elephant (a) and people (b) at the Maputaland cluster and elephant (c) and people (d) at the Limpopo cluster.



a **b**

Fig. 5 Spatial distribution of predicted Human Elephant Conflict in a) the Great Limpopo Transfrontier Conservation Area (GLTFCA) and b) the Lubombo Transfrontier Conservation Area (LTFCA). The black dots denote actual incidences of HEC based on a questionnaire.



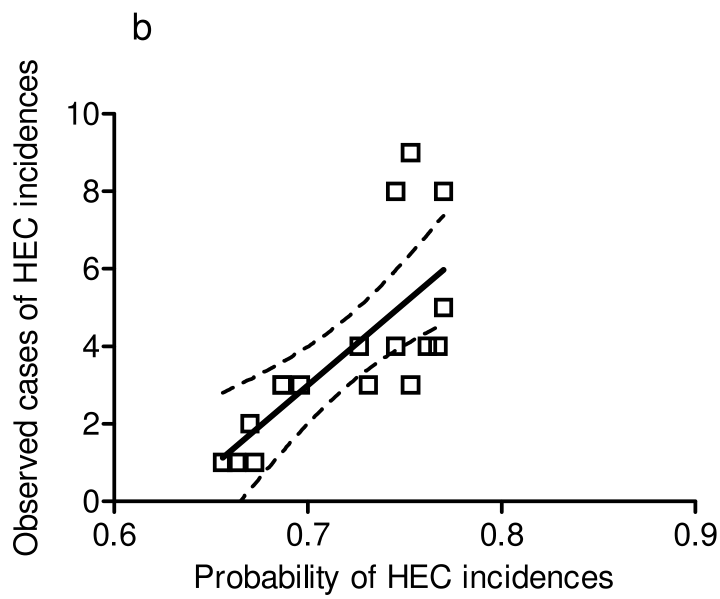


Fig. 6 Probability of incidences of HEC predicted in this study regressed with the frequency of observed incidences in the (a) Maputo NR and (b) Limpopo NP in southern Mozambique. The statistical results for the Maputo NR ($r^2 = 0.55$; $F_{13} = 15.86$; $p = 0.002$) and for the Limpopo NP ($r^2 = 0.53$; $F_{15} = 16.99$; $p = 0.001$) indicate that in both two cases, the predictive ability of the HEC model was modest.

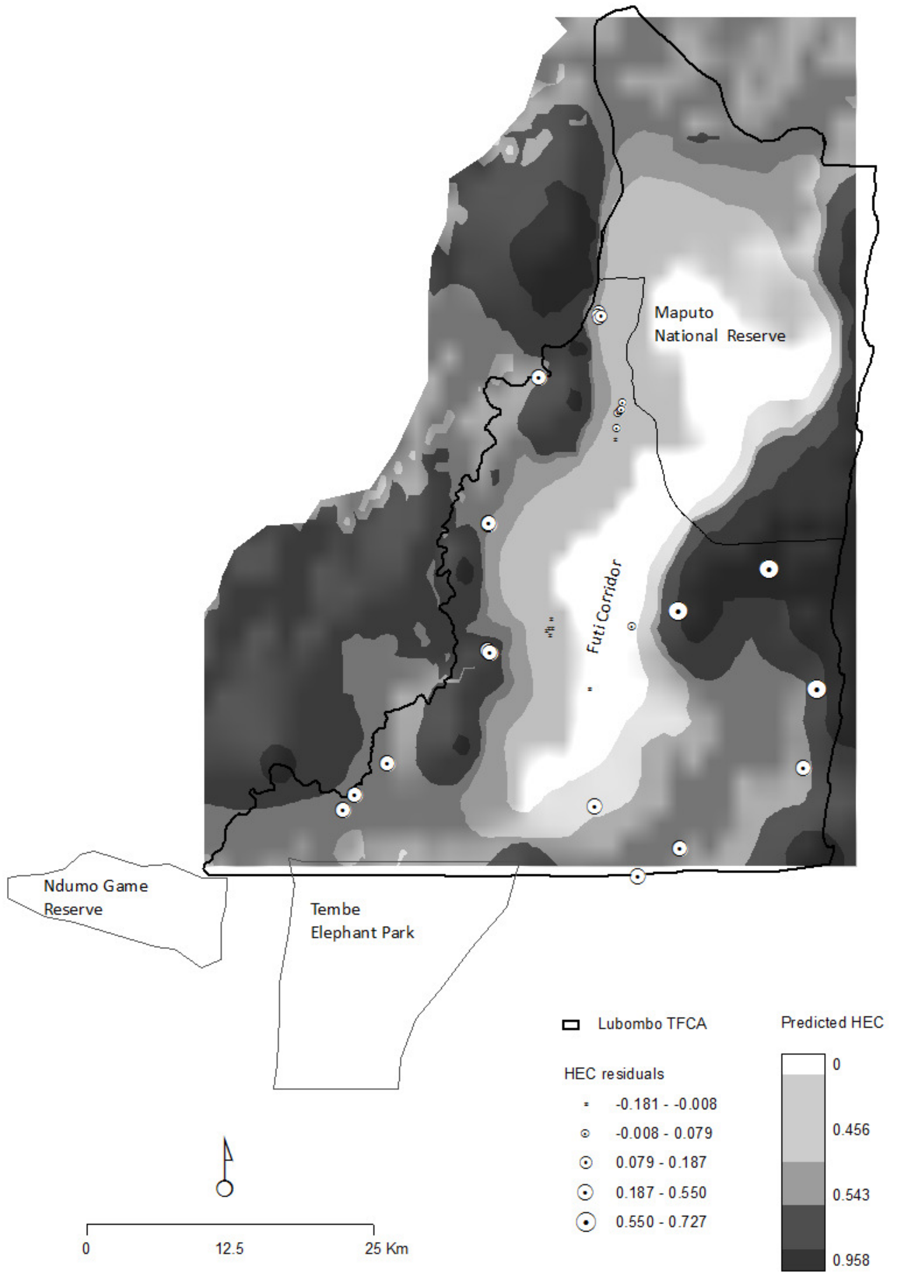


Fig. 7 Distribution of HEC residuals (difference between the predicted probability and observed frequency of HEC) across the Lubombo Transfrontier Conservation Area (LTFCA).

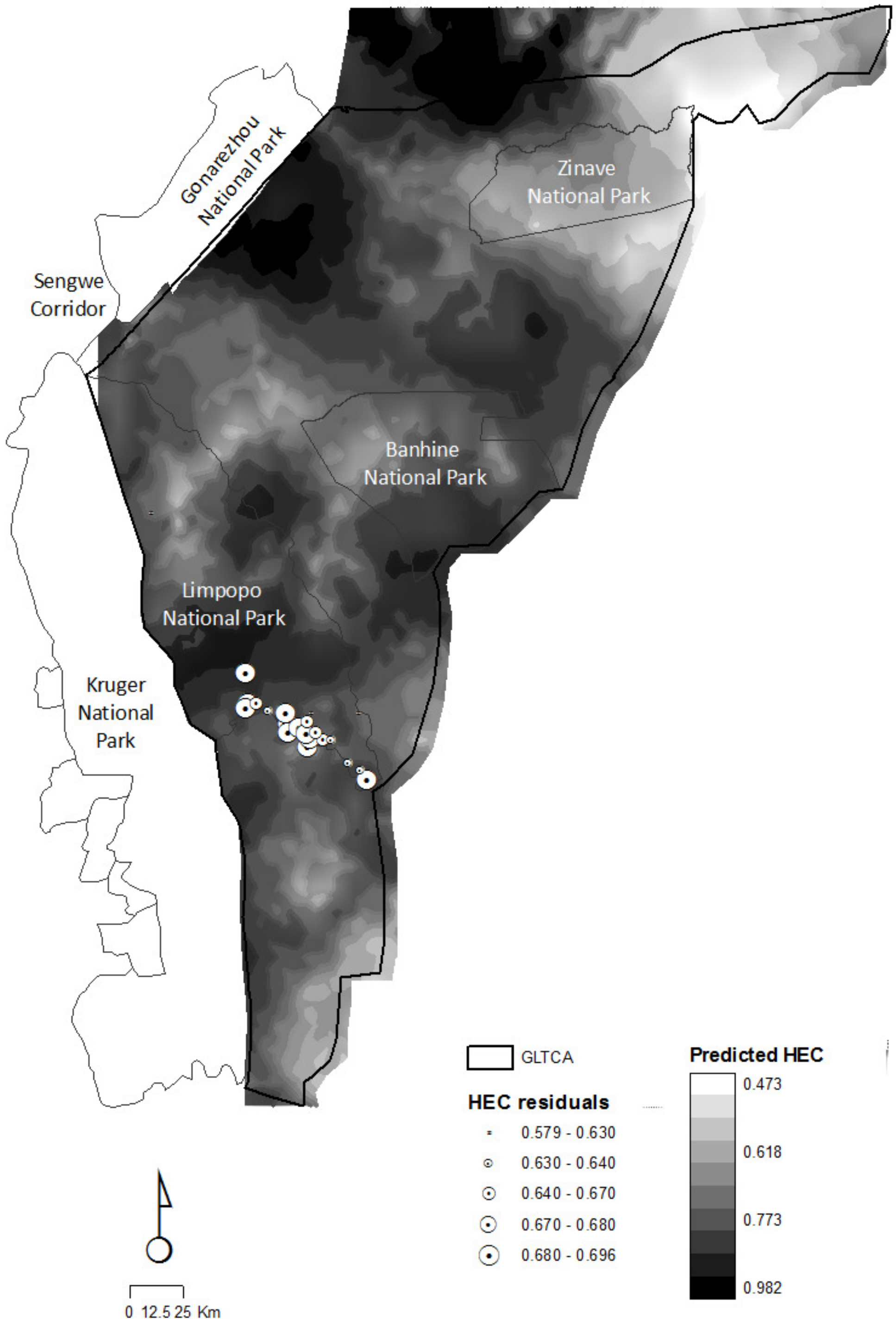


Fig. 7 Distribution of HEC residuals (difference between the predicted probability and observed frequency of HEC) across the Great Limpopo Transfrontier Conservation Area (GLTFCA)

Chapter 6

Predicting Human-Elephant Conflict (HEC) across Mozambique

Introduction

In the earlier chapters I identified explanatory variables of human elephant conflict in Mozambique. Conflict is prevalent in areas where human densities are below a threshold of 60 people per km^2 and where landscapes are relatively intact (Chapter 4). The model that I developed in Chapter 5 to predict HEC is based on two case studies in southern Mozambique and Resource Selection Function modelling. The present chapter extend this model to predict HEC across Mozambique. Specifically, I used the explanatory potential of distance to settlement, distance to roads, forest fragmentation, forest cover, agricultural suitability index and soil type to predict HEC at a grid cell level ($25km^2$) across Mozambique.

Materials and Methods

To predict HEC at a country level, I used Resource Selection Function (RSF) modelling procedures (Boyce & McDonald, 1999; Manly *et al.*, 2002) described in Chapter 5. Explanatory variables included a water source distribution (ARA, 2007), road network (ANE, 2006), settlement and villages distribution (INE, 1999; TIA, 2002), soil type and agricultural suitability (INIA, 1995), forest cover (UIF, 2007) and fragmentation index (Chapter 5) shapefiles for all of Mozambique.

I applied the best human and elephant distribution and HEC models from Chapter 5 to each cell (5X5 km), excluding those cells previously covered in the Chapter 5. I assessed the likelihood of HEC in a given cell using the following model:

$$\begin{aligned}\text{Likelihood of HEC} = \exp[(116.72 &- 0.209 \times \text{Distance to settlement} \\ &+ 0.822 \times \text{Distance to roads} \\ &- 0.366 \times \text{Forest fragmentation} \\ &- 0.473 \times \text{Forest cover} \\ &+ 0.138 \times \text{Agricultural suitability index} \\ &- 0.090 \times \text{Soil type})]\end{aligned}$$

Finally, I generated maps of the likelihood of HEC using the ArcGIS routines as described in Chapter 5 (Zeiler, 2001).

Models may fail to detect key predictor variables, and model calibration prior to their validation may reduce prediction errors (Brand *et al*., 2006). Thus, in addition to the landscape features described in Chapter 5, I included cultivation, vegetation clearance, logging, charcoal production (AGRECO, 2008) and the exposure of the cell to climate events (e.g. cell exposure to floods and drought events and erosion) (INGC, 2009) and to other land uses (MA, 2009).

I used the location dataset for elephants that were satellite tracked (see Harris *et al*., 2008 for tracking details) in the Nipepe-Marrupa area, Magude-Moamba area, Quirimbas National Park (CERU database) and data for Quiterajo kindly provided by Julie Gardner that operated under the auspices of the now defunct Maluana Ltd. Company. I also used census data for elephants in the Marromeu Complex (AWF, 2005;

2008) and from national aerial census (AGRECO, 2008), as well as settlement locations (AGRECO, 2008) and the 2006-2009 nation-wide HEC census dataset to calibrate the models.

I followed two steps to calibrate the models (e.g. Brand *et al*., 2006). Initially, I divided locations of settlement and incidences of HEC into two groups. I used the first group to train the human distribution and HEC models for calibration, and the second group to verify the predictive ability of each of the models. I used all elephant locations to calibrate the elephant distribution model. For all models, I first identified training locations fitted in the best fitting model. I then related these locations to the explaining variables at each cell by running a Generalised Linear Model (GLM) as described in Chapter 5. I subsequently mapped all new models using ArcGIS capabilities (Zeiler, 2001). Finally, I used the second dataset to calculate k statistics (Landis & Koch, 1977) as a validation procedure. I also assessed the predictive ability of the HEC model by fitting an exponential growth model relating cell-specific likelihoods of HEC and the percentage of the HEC reported incidences.

Results

Figures 1 & 2 show the predicted distribution of people, elephant and HEC, and reported HEC incidences across Mozambique. Whilst presence of settlements, intensive cultivation and roads reduced the likelihood of elephant presence, the occurrence of water increased this likelihood. Fields and settlements located close to water were likely to report HEC most often. People living or cropping close to protected areas were most likely predicted to report HEC (Fig. 2).

The best models for human, elephant and HEC (Figs 1, 2 & 3) distribution suggest that HEC may be mitigated by considering the spatial needs of people and elephants. For instance, areas with alluvial soils with high suitability for agriculture and close to water sources and protected areas were sought after by both elephants and people. The likelihood of conflict in these areas was therefore relatively high.

The relatively high k-values (0.9 & 0.92 for human and HEC distribution, respectively) suggest that predictor variables included in the models reflects well on the observed HEC incidences, but with some reservations and uncertainty.

Discussion

The Northern provinces (e.g. Niassa and Cabo Delgado) have lower human densities than provinces in southern Mozambique (e.g. Maputo, Gaza and Inhambane) (Chapter 4). As a result, the Niassa and Cabo Delgado provinces had little habitat degradation and low extent of cultivation compared to southern provinces. This may explain the predicted high probability for elephants to occur in these provinces. These results agree with those reported in Chapter 4 on the distribution of elephants in Mozambique as a function of human density, due to the expected low impact of humans on landscapes at the low human density (Parker & Graham, 1989; Hoare & du Toit, 1999).

Most areas where human densities were low served as elephant refuges that are currently protected. Districts with protected areas were most likely to experience conflict, as illustrated in Chapter 4 and the work of Newmark *et al*. (1994), Naughton-Treves (1997) and Twine & Magome (2008).

My efforts to extend local models to predict HEC at a regional scale proved to have some limitations in some areas. These limitations may be due to the data available to me not being suitable for extrapolation. For example, increasing the extent of scale may influence some quality and quantity measurements and increases the range of values for landscape variables (Meentemeyer & Box, 1987), mostly due to aggregation effects (Wear & Bolstad, 1998; Evans & Kelly, 2004). My models were powerful for explaining the observed HEC incidences over the period of 2006 and 2009, but with some unquantifiable uncertainty. This may also support the notion that limitations imposed by scale may have been minimized by the application of the integrative approach (e.g. calibration) to improve the models performance (Machemer *et al*., 2006).

Management implications

The impact of human on the persistence of species across the landscape has been noted since the birth of human civilization (Johnson, 2002). Recently, Surovell *et al*. (2005) have discussed this topic on the context of proboscidean overkill hypothesis. Recent workers on conservation have recognized the importance of considering human needs when setting areas for conservation for species with a wide distribution (Sanderson *et al*., 2002).

Although half of the area of Mozambique comprise natural vegetation (Chapter 4), the rural people living here rely on the extraction of natural resources (Chapter 3). As elsewhere (e.g. Wu & Hobbs, 2002; Yin *et al*., 2010), socioeconomic processes appear to be the primary drivers for land use and land cover change. Therefore, some of the human activities assessed in Chapters 2, 4 & 5 are likely to continue to threaten the natural vegetation of the country and cause wildlife in general and elephants in particular to live in fragmented landscapes. This is specifically true in Mozambique where some political, social and natural events may have influenced people's distribution across the landscape (see Araújo, 1998; Coelho, 1998).

Some human activities have negative impacts on elephants, and conservation must go beyond the limits of the protected area concept (Begntsson *et al*. 2003) and adopt a holistic landscape approach (Naveh, 2000) to secure land for people and for elephants, through landscape planning and zoning as I advocated here (Fig.1).

Landscape planning and zoning should set areas for agriculture, wildlife refuge, natural resources use and human development and should also secure land as corridors for wildlife in a matrix of human dominated landscapes. As a rule, cropping will be done in areas with less accessibility to wildlife and corridors may link to common resources (e.g. water). Thus, landscape planning and zoning provide additional land for the spatial needs of elephants and people and restore elephant movement patterns through the landscape with minimum human and elephant interaction.

Central to land use planning is a combination between regulations, community commitment and collaboration between stakeholders in designing and implementation of such an approach. Mozambique already adopted land use planning as an approach to harmonize different interests. This served as a motivation for the national wildlife census (AGRECO, 2008), national forest inventory (UIF, 2007), the elephant management plan

(MITUR, 2010), national conservation strategy (GM, 2009) and conservation act in preparation.

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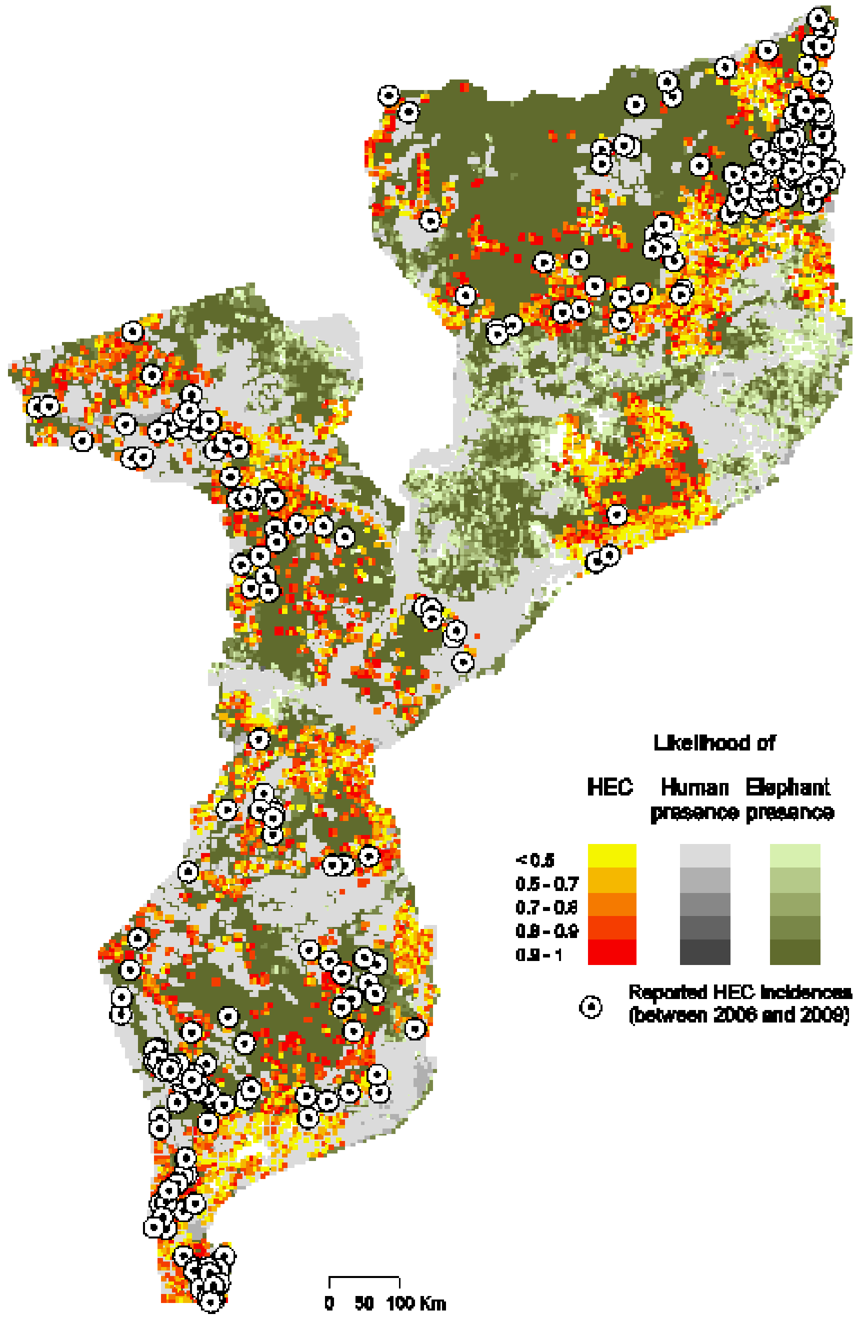

Fig. 1 Predicted distribution of people, elephant and HEC, and independent occurrence records for HEC across Mozambique. Both models were built with ArcGIS 3.2 by extrapolating RSF models designed for Lubombo and Great Limpopo TFCAs in southern Mozambique and calibrated with some additional variables describing climate and habitat throughout Mozambique. The independent HEC incidences records (the points) were collected between 2006 and 2009 by the government officials as part of a nationwide survey covering all districts.

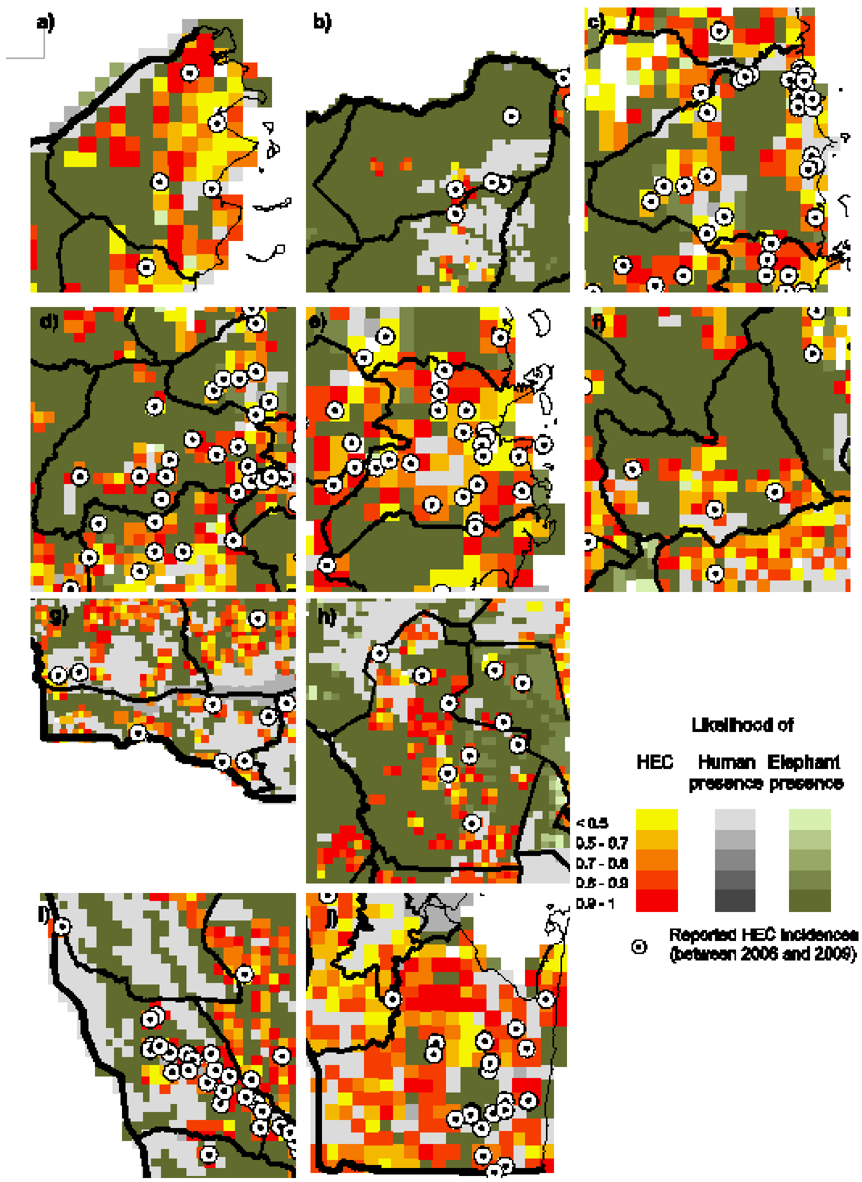

Fig. 2 Evaluation of the HEC model in the HEC hotspots districts: (a) Palma, (b) Mecula, (c) Macomia, (d) Meluco, (e) Quissanga, (f) Nipepe, (g) Mágoè, (h) Funhalouro, (i) Massingir and j) Matutuine. These districts, but Palma and Funhalouro harbours protected areas.

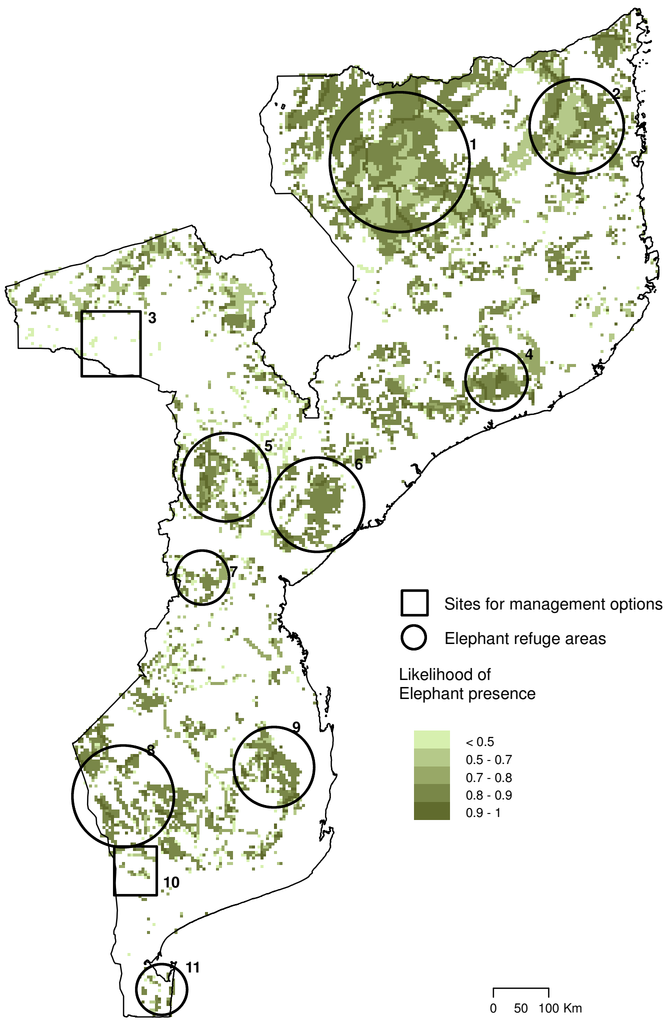

Fig. 3 Likelihood of elephant distribution in Mozambique, showing some probable relevant elephant refuges. 1, Selous- Niassa; 2, Quirimbas National Park; 3, Mágoè district; 4, Gilé National Reserve; 5, Gorongosa National Park and surroundings; 6, Marromeu; 7, Chimanimani National Reserve; 8, Limpopo National Park and surroundings; 9, Funhalouro district; 10, Moamba and Magude districts and 11, Matutuine district.

Chapter 7

Conclusions

Humans have been responsible for declines in elephant numbers (Ntumi *et al*., 2009) and their compression into protected areas (van Aarde & Jackson 2007). These effects challenge elephant conservation efforts in a milieu where socio-political efforts to reduce poverty are linked to increased availability of land for agriculture and human development. The land available for conservation may not meet the needs of expanding elephant populations and little secure habitat is available to maintain viable populations and elephant ranges.

Decades of efforts to reduce conflict has failed and methods that are applied continue to be case specific and reactive (e.g. Dublin & Hoare, 2004). The effectiveness of mitigation is clearly scale-dependent and solutions require both reactive and preventive actions (Dublin & Hoare, 2004; Fernando *et al*., 2004; Jackson *et al*., 2008), especially in areas where people and elephants co-occur. This reality, calls for a landscape approach, which encapsulates a land use planning and zonation (Naveh, 2000; Fernando *et al*., 2004) aimed to balance elephant conservation goals with people livelihoods (DeFries *et al*., 2010).

Elephants and humans are catholic in their habitat requirements. In Mozambique people do live in protected areas where elephants live. Increased occupation of these areas and the associated conversion of landscape will place pressure on elephant populations. Therefore, there is a need for additional land outside protected areas to provide for the spatial needs of elephants and to restore their movement patterns, possibly through the zonation of land use options to restrict the expansion of human activities. This may reduce people-elephant encounters and mitigate HEC.

In this thesis I examined some of the drivers of conflict along both temporal and spatial axes that may have implications on elephant conservation at landscape level. Particularly, landscape approaches caters for the needs of wildlife (e.g. elephants) and people, human threats to the persistence of other species and actions to reduce the conflict between people and wildlife (Treves & Naughton-Treves, 1999; Nelson *et al*., 2003). In short, this option seeks land use planning and zoning to accommodate conservation and human development. The development of 'megaparks for metapopulations' (van Aarde & Jackson, 2007) is one of several land use options that addresses the spatial needs of elephants and identify corridors that can link elephant populations. Spatial needs may induce local fluctuations in elephant numbers and reduce impact on other species and conflict (see Cheryl-Lesley *et al*., 2006; van Aarde & Jackson, 2007).

Findings from my thesis may contribute to understand how people and elephant's spatial needs and use may contribute to prevent HEC through a science based on landscape approach, which finally will allow populations to be spatially structured, possibly as metapopulations. By providing basis for spatial needs of people and elephants and identifying threats to the persistence of species both, landscape approach may be used to design actions to reduce HEC by preventing spatial overlap through the identification of conservation corridors and zonation. Particularly, on support for landscape approach functioning, three requirements were provided - threats to elephant conservation, people and elephant spatial needs identification, actions to reduce HEC across the landscape (Sanderson *et al*., 2002; Fernando *et al*., 2004; DeFries *et al*., 2010).

The elephant is an icon of conservation in Mozambique reflecting on successes as well as failures. Failures are mostly related to HEC, a topic that the government sees as a top priority to mitigate. A detailed toolkit, packaged within the national strategy to mitigate wildlife and human conflict exists, essentially centred on shooting a so called “problem animal”. My results provide an alternative and perhaps complementary approach.

My assessment suggests that HEC in Mozambique was a reality and predominantly occurred in and around protected areas. Considering this, HEC areas made up a relatively small proportion of rural Mozambique and may affect relatively few people. Even so, HEC may present a threat to livelihoods of rural people. Thus, mitigating HEC by advocating and planning for co-existence of humans and elephants makes sense for social, economic, conservation and political reasons. There is a need for systemic approaches to reduce the conflict between people and elephants in particular, but wildlife in general.

In this thesis, I showed that in Mozambique elephants mainly live in rural districts with protected areas and where densities were below 60 people/km^2. People living and cropping in the vicinity of protected areas (e.g. in a buffer zone of some 8 km from the borders of these protected areas), have a high likelihood of experiencing conflict with elephants. However, people living both inside and beyond protected areas rely on subsistence agricultural and the extraction of a variety of natural resources from land.

Providing for the spatial needs of both elephants and people through active zonation of land use activities may further defuse conflict. From my modelling approach, I identified three types of land use units in the landscape of Mozambique: i) areas with high suitability for elephants; ii) areas with high potentiality for human subsistence activities (>60 people/km^2) and iii) areas where both elephants and humans may co-exist. These observations may be important for conservation planning and may have implications for elephant conservation and management.

A landscape approach seeks solutions that integrate needs of both people and elephants in the context of land use planning. Here, areas with high probability for elephants to persist (e.g. Selous-Niassa-Quirimbas NP and Maiaca and Mutumar elephant-year round area, Chituculo and Chiramba (Marromeu), Mueredzi sanctuary at the Gorongosa NP, Limpopo National Park and Maputo National Reserve and Futi Corridor could potentially be maintained for elephant populations. Areas with high probability for humans (e.g. coastal zones and many of suitable areas for agriculture and urbanized areas) are recommended to be considered for human activities (e.g. settlements, infrastructures, agriculture, grazing and natural resources exploitation) due to the fact that elephant population persistence in highly settled areas is problematic (Hoare & du Toit, 1999; Lee & Graham, 2006). Areas where both elephants and humans may co-exist (e.g. Magoe, Magude and some areas of QNP) are recommended to be managed actively by involving local communities, the private sector and government (see Kube, 2005). This will treat the landscape as a common property (Mwalyosi, 1991) with an economical value to be conserved and exploited. To mitigate HEC, settlements and other human land use types should be moved from elephant ranges. This could be problematic in areas along the rivers where agriculture is the most common land use. In this case, some strong re-active actions directed at "transgressing elephants" should be established (for details see Sitati & Walpole, 2006). These different scenarios should be tested and validated as part of the land use planning process in the country. In the case that future environmental changes driven by climate changes and new socioeconomic endeavours cause certain areas to become conflict zones, then those areas may well necessitate a graded land-use planning approach.

Future research

Elephants and people in Mozambique share the land (Chapter 4), and the degree to which they conflict with each other is associated with some socioeconomic co-variates (Chapter 3) and landscape features (Chapters 4 & 5). This poses a challenge for co-existence between elephants and people.

Four main clusters of elephants may exist in Mozambique (Chapter 4), which may operate as source-sink metapopulations (Olivier *et al*., 2009). Understanding these dynamics under different vegetation structures (e.g. O'connor *et al*., 2007), water availability (Chamaillé-Jammes *et al*., 2007a&b; de Beer & van Aarde, 2008; Harris *et al*., 2008) and landscape characteristics (Grainger *et al*., 2005; Young *et al*., 2009a&b) will help to understand local and regional elephant populations' demography, which is crucial in managing elephant sub-populations in each cluster, between different clusters or together with elephant populations in the neighbouring countries.

The way that people use space reflects on the importance of land to satisfy basic resource needs. I found evidence suggesting that the socioeconomic context of households should be considered when studying HEC (Chapter 3). Given the expected socioeconomic and ecological variability of the country, more in depth cases studies at appropriate scales (Strayer *et al*., 2003; de Knegt *et al.,* 2011) are needed. These studies should be designed to cover both economic, conflict and demographic profiles of households, but also the economical value of losses incurred by wildlife. I acknowledge findings from others (e.g. Hill, 2004; Dickman, 2008) to include an attitudinal assessment due to that recognized human dimension in conservation today (Bath & Enck, 2003; Manfredo & Dayer, 2004; Naughton-Treves & Treves, 2005).

Human-elephant conflict studies have yielded some discrepancies in results they reported (see Parker & Graham, 1989; Naughton-Treves, 1997; Hoare & du Toit, 1999; Hoare, 1999; Smith & Kasiki, 1999; Sitati *et al.*, 2003; Graham *et al*., 2010; Twine & Magome, 2008 and Warner, 2008). Most of the contradicting conclusions result from the scale studies used and the specific aspects of HEC under investigation (see Graham *et al*., 2009; Graham *et al*., 2010 for details). At the finer scale, most studies tend to yield biological and behavioural drivers of HEC incidences (Hoare & du Toit, 1999; Hoare, 1999; Smith & Kasiki, 1999; Sitati *et al*., 2003) while at coarse scale some human socioeconomic drivers emerge (Parker & Graham, 1989; Naughton-Treves, 1997; Graham *et al*., 2010). Because of the permanent lack of political will to support HEC research at finer scales such as at the elephant behaviour level, there is a need to advocate multiple spatial and temporal scales that include elephant refuges and surroundings. A coarse scale may allow conservation ecologists to robustly identify key thresholds (du

Toit *et al.*, 2004) under which elephants and humans can co-exist. This will allow conservationists to formulate management strategies for implementation by police makers and local resource managers (for details, see du Toit *et al.*, 2004).

Management and conservation planning models, which take into account HEC spatial resolution and associated factors, as advocated in this thesis (see also Joshi & Singh, 2009), are needed. The impetus of the poverty alleviation and the Green Revolution advocated by the Mozambican government may increase the total amount of yield/hectare, but both with high costs on land degradation as observed elsewhere (e.g. Smith, 1992). Even under good management regimes, maintaining prime habitat for wildlife conservation in Mozambique may be difficult when people are permitted to occupy protected areas. This suggests that patterns of landscape use by both humans and elephants may bring them frequently in contact and place them at conflict. Managers should consider alternatives of land use planning scenarios which may accommodate people and elephant needs.

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