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)

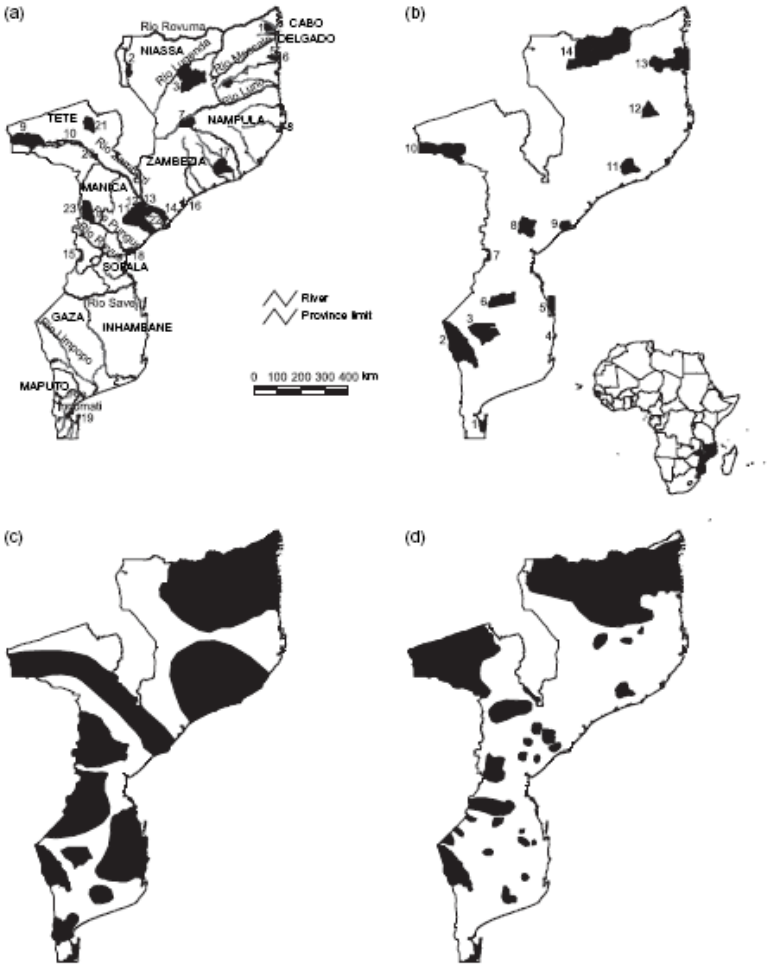

FIG. 1 (a) Mozambique, showing the most relevant historical locations mentioned in the text. 1, Mocimboa da Praia; 2, Metangula; 3, Marrupa; 4, Balama; 5, Quissanga; 6, Quirimbas; 7, Mutuali; 8, Ilha de Moçambique; 9, Zumbo; 10, Songo; 11, Inhaminga; 12, Inhamitanga; 13, Shupanga; 14, Luabo; 15, Chimanimani; 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.

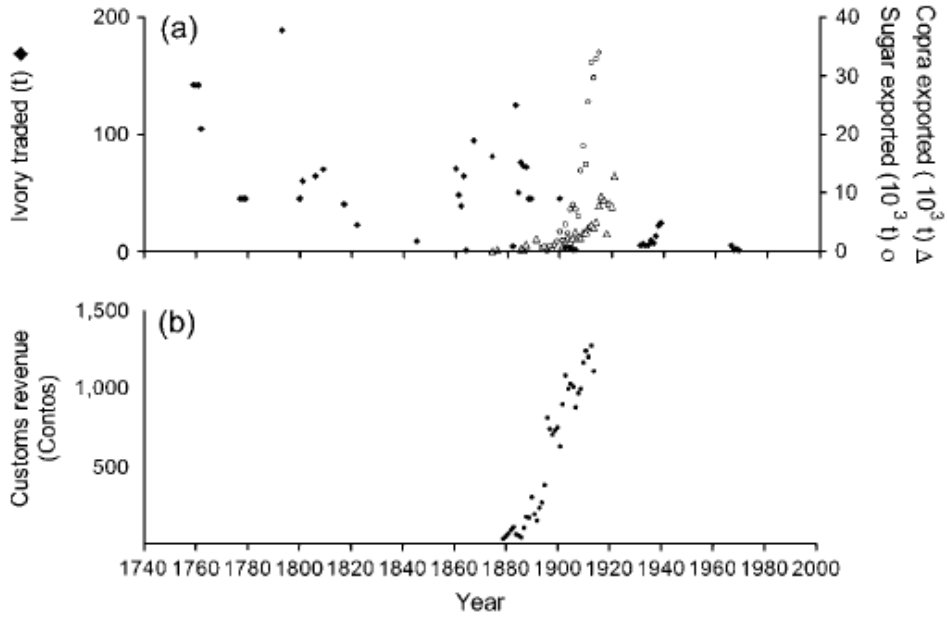

FIG. 2 (a) The amount of ivory traded in Mozambique declined from the 1700s to the late 1900s (data collated from Jordao, 1870; BEE, 1925-1970; AEC, 1926-1973; Hedges, 1978; Liesegang, 1983; Sheriff, 1983; Barbier *et al*., 1992; Spinage, 1994), whilst exports of copra and sugar increased (exports of 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).

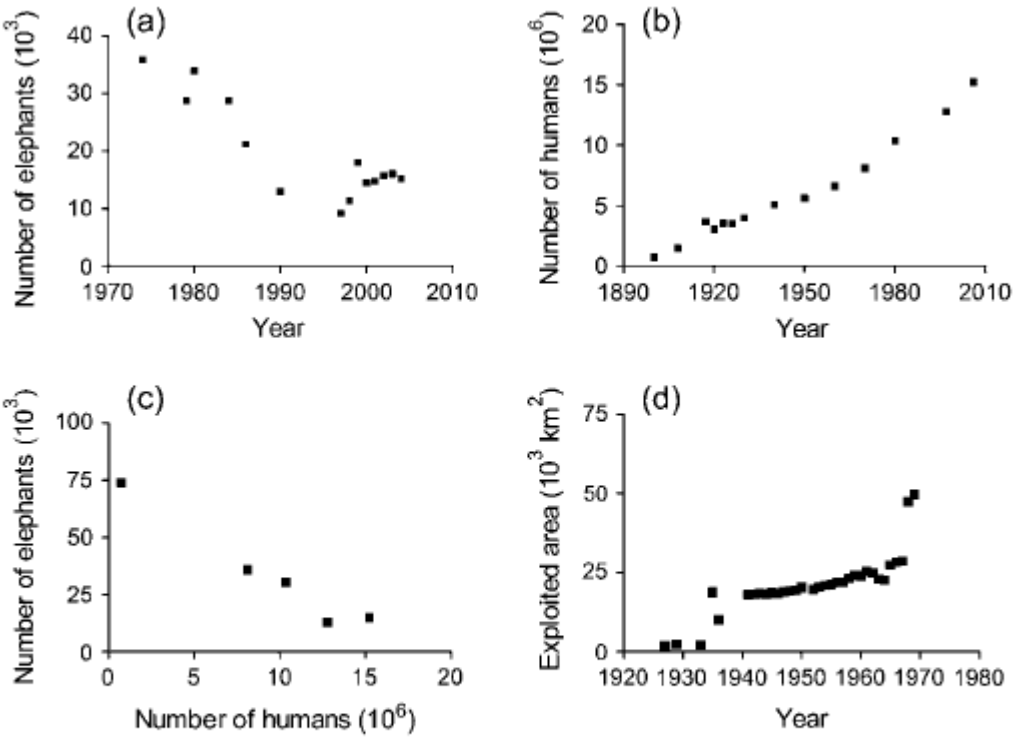

FIG. 3 Estimates of the (a) elephant (1974-2004) and (b) human population (1900-2009) in Mozambique (elephant data: DNFFB, 1999; Cumming & Jones, 2005; Table 1; human data: BEE, 1925-1970; AEC, 1926-1973; INE, 1980, 1999). (c) The elephant population declined as human numbers increased. (d) Exploited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