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:

Likelihood of HEC = exp [(116.72 - 0.209 x Distance to settlement
+ 0.822 x Distance to roads
- 0.366 x Forest fragmentation
- 0.473 x Forest cover
+ 0.138 x Agricultural suitability index
- 0.090 x Soil type)]

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.

References

AGRECO (2008) *National census of wildlife in Mozambique*. Final Report. Ministério da Agricultura. Maputo, Mozambique.

ANE (Administração Nacional de Estradas) (2006) Roads network in Mozambique. ANE, Maputo, Mozambique.

ARA (Autoridade Regional de Água) (2007) *Water source distribution in Mozambique*. ARA. Ministry of Infrastructure and Water. Maputo, Mozambique.

ARAUJO, M. (1988). *O Sistema das Aldeias Comunais em Moçambique: transformação na organização do espaço residencial e produtivo*. PhD thesis, Universidade de Lisboa, Lisboa. Portugal.

AWF (African Wildlife Foundation) (2005, 2008) *Aerial Survey of the Marromeu Complex Reserve*. Unpublished Report to Direcção Nacional das Áreas de Conservação, Maputo, Mozambique.

BEGNTSSON, J., ANGELSTAM, P., ELMQVIST, T. & EMANUELSSON, U. (2003) Reservse, Resilience and Dynamic Landscapes. *Ambio*, **32**, 389-396.

BOYCE, M. S. & MCDONALD, L. L. (1999) Relating populations to habitats using resource selection functions. *Trends in Ecology & Evolution,* **14**, 268-272.

BRAND, L. A., NOON, B. R. & SISK, T. D. (2006) Predicting abundance of desert riparian birds: validation and calibration of the effective area model. *Ecological Applications*, **16**, 1090-1102.

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

References

AGRECO (2008) *National census of wildlife in Mozambique*. Final Report. Ministério da Agricultura. Maputo, Mozambique.

ANE (Administração Nacional de Estradas) (2006) Roads network in Mozambique. ANE, Maputo, Mozambique.

ARA (Autoridade Regional de Água) (2007) *Water source distribution in Mozambique*. ARA. Ministry of Infrastructure and Water. Maputo, Mozambique.

ARAUJO, M. (1988). *O Sistema das Aldeias Comunais em Moçambique: transformação na organização do espaço residencial e produtivo*. PhD thesis, Universidade de Lisboa, Lisboa. Portugal.

AWF (African Wildlife Foundation) (2005, 2008) *Aerial Survey of the Marromeu Complex Reserve*. Unpublished Report to Direcção Nacional das Áreas de Conservação, Maputo, Mozambique.

BEGNTSSON, J., ANGELSTAM, P., ELMQVIST, T. & EMANUELSSON, U. (2003) Reservse, Resilience and Dynamic Landscapes. *Ambio*, **32**, 389-396.

BOYCE, M. S. & MCDONALD, L. L. (1999) Relating populations to habitats using resource selection functions. *Trends in Ecology & Evolution,* **14**, 268-272.

BRAND, L. A., NOON, B. R. & SISK, T. D. (2006) Predicting abundance of desert riparian birds: validation and calibration of the effective area model. *Ecological Applications*, **16**, 1090-1102.

COELHO, J. P. B. (1998) State Resettlement Policies in Post-Colonial Rural Mozambique: The Impact of the Communal Village Programme on Tete Province, 1977-1982. *Journal of Southern African Studies*, **24,** 61-91.

EVANS, T. P. & KELLY, H. (2004) Multi-scale analysis of a household level agent-based model of landcover change. *Journal of Environmental Management*, **75**, 57-72.

GM (Governo de Moçambique) (2009) *Proposta de Política de Conservação e Estratégia de Sua Implementação*. Ministerio para a Coordenaccão da accão ambietal. República de Moçambique. Maputo, Moçambique.

HARRIS, G. M., RUSSELL, G. J., VAN AARDE, R. J. & PIMM, S. L. (2008) Rules of habitat use by elephants *Loxodonta africana* in southern Africa: insights for regional management. *Oryx*, **42**, 66-75.

HOARE, R. E. & DU TOIT, J. T. (1999) Coexistence between people and elephants in African savannas. *Conservation Biology,* **13,** 633-639.

INE (Instituto Nacional de Estatística) (1999) Moçambique em Números 1998. Instituto Nacional de Estatística, Maputo, Moçambique.

INGC (Instituto Nacional de Gestão de Calamidades Naturais) (2009) *Synthesis report. INGC Climate Change Report: Study on the impact of climate change on disaster risk in Mozambique* (eds B. van Logchem & R. Brito). INGC, Maputo, Mozambique.

INIA (Instituto Nacional de Investigação Agronómica) (1995) *Legenda da carta nacional de solos*. INIA - DTA, Série Terra e àgua. Comunicação no. 73. Maputo, Moçambique.

JOHNSON, C. N. (2002) Determinants of loss of mammal species during the Late Quaternary 'megafauna' extinctions: life history and ecology, but not body size. *Proceedings of Royal Society of London B*, **269**, 2221-2227.

LANDIS, J. R. & KOCH, G. G. (1977) The measurement of observer agreement for categorical data. *Biometrics*, **33**, 159-174.

MA (Ministério da Agricultura) (2009) *Shapefiles de mapeamento de uso e cobertura de terra*. Direcção Nacional de Terras e Florestas. Maputo, Moçambique.

MACHEMER, P. L., SIMMONS, C. & WALKER, R. T. (2006) Refining Landscape Change Models through Outlier Analysis in the Muskegon Watershed of Michigan. *Landscape Research*, **31**, 277-294.

MANLY, B. F. J., MCDONALD, L. L., THOMAS, D. L., MCDONALD, T. L. & ERICKSON, W. P. (2002) *Resource selection by animals: statistical design and analysis for field studies.* 2nd edition. Kluwer Academic Publishers, Boston.

MEENTEMEYER, V. & BOX, E. O. (1987) Scale effects in landscape studies. In *Landscape Heterogeneity and Disturbance* (ed. M.G. Turner), pp. 15-34. Springer-Verlag, New York, New York, USA.

MITUR (Ministério de Turismo) (2010) *Elephant Management Plan*. MITUR. Maputo, Mozambique.

NAUGHTON-TREVES, L. (1997) Farming the Forest Edge: Vulnerable Places and People around Kibale National Park, Uganda. *Geographical Review*, **87**, 27-46.

NAVEH, Z. (2000) What is holistic landscape ecology? A conceptual introduction. *Landscape and Urban Planning*, **50**, 7-26.

NEWMARK, W. D., MANYANZA, D. N., GAMASSA, D. M. & SARIKO, H. I. (1994) The Conflict between Wildlife and Local People Living Adjacent to Protected Areas in Tanzania: Human Density as a Predictor. *Conservation Biology*, **8**, 249-255.

PARKER, I. S. C. & GRAHAM, A. D. (1989) Elephant decline Part I. Downward trends in African elephant distribution and numbers. *International Journal of Environmental Studies,* **34**, 287-305.

SANDERSON, E. W., REDFORD, K. H., VEDDER, A., COPPOLILLO, P. B. & WARD, S. E. (2002) A Conceptual model for conservation planning based on landscape species requirements. *Landscape and Urban Planning*, **58**, 41-56.

SUROVELL, T., WAGUESPACK, N. & BRANTINGHAM, P. J. (2005) Global archaeological evidence for proboscidean overkill. *Proceedings of Natural Academy of Sciences of United States of America*, **102**, 6231-6236.

TIA (Trabalho de *Inquérito Agrícola)* (2002) *Trabalho de Inquérito Agrícola 2002. Resultados Definitivos*. Departamentos de Economia e Estatística, Ministério da Agricultura e Desenvolvimento Rural. Maputo.

TWINE, W. & MAGOME, H. (2008) Interactions between elephants and people. In *Elephant Management: A Scientific Assessment for South Africa* (eds R. J. Scholes, & K. G.Mennell), pp. 206-240. Wits University Press, South Africa.

UIF (Unidade de Inventário Florestal) (2007) *Avaliação Integrada das Florestas de Moçambique: Inventário Florestal Nacional*. Direcção Nacional de Terras e Florestas. Maputo, Mozambique.

WEAR, N. & BOLSTAD, P. (1998) Land-use changes in Southern Appalachian Landscapes: Spatial Analysis and Forecast Evaluation. *Ecosystems*, **1**, 575-594.

WU, J. & HOBBS, R. (2002) Key issues and research priorities in landscape ecology: An idiosyncratic synthesis. *Landscape Ecology*, **17**, 355-365.

YIN, R. S., XIANG, Q., XU, J. T. & DENG, X. Z. (2010) Modelling the Driving Forces of the Land Use and Land Cover Changes along the Upper Yangtzer River of China. *Environmental Management*, **45**, 454-465.

ZEILER, M. (2001) *Exploring ArcObjects*. Redlands, CA, USA: ESRI Press.

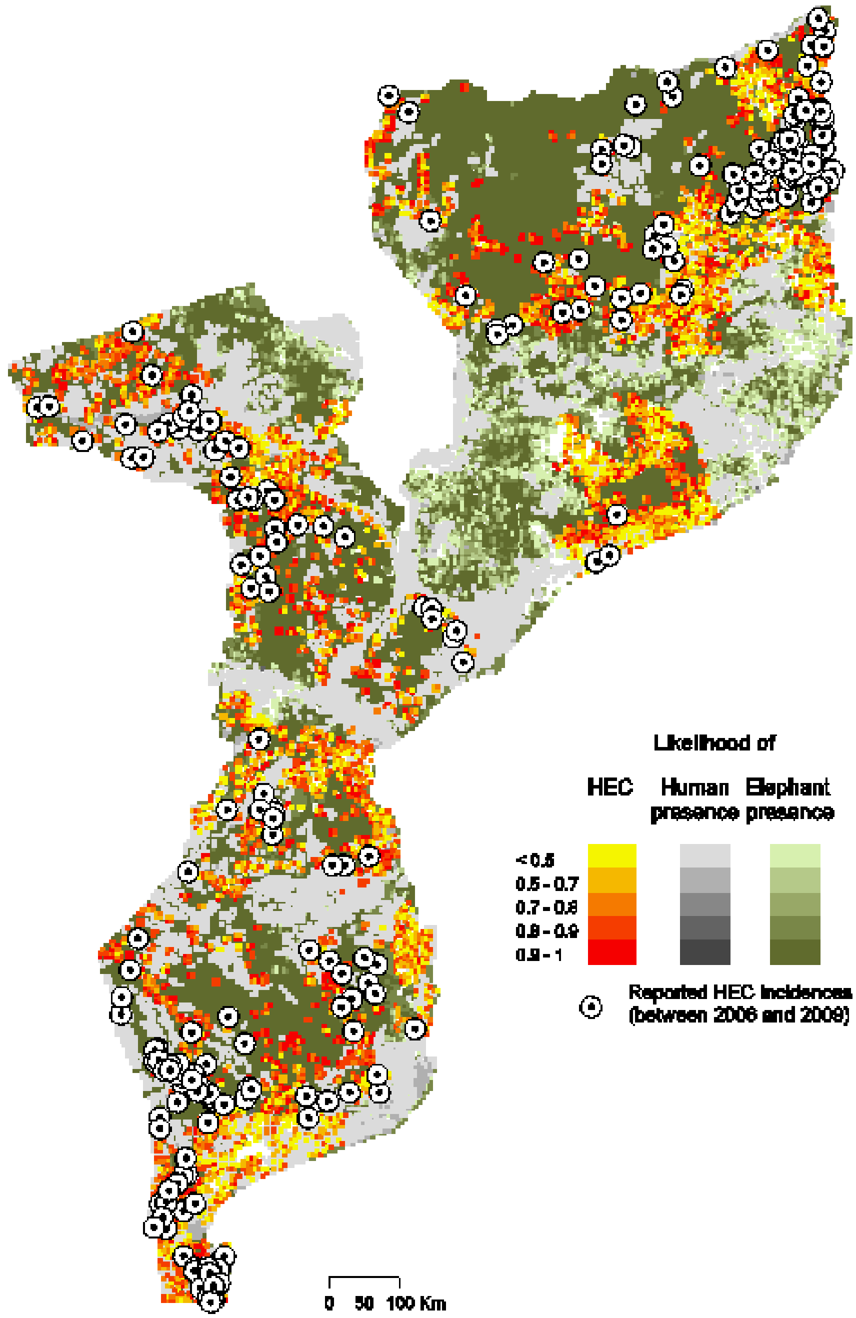

Fig. 1 Predicted distribution of people, elephant and HEC, and independent occurrence records for HEC across Mozambique. Both models were built with ArcGIS 3.2 by extrapolating RSF models designed for Lubombo and Great Limpopo TFCAs in southern Mozambique and calibrated with some additional variables 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.

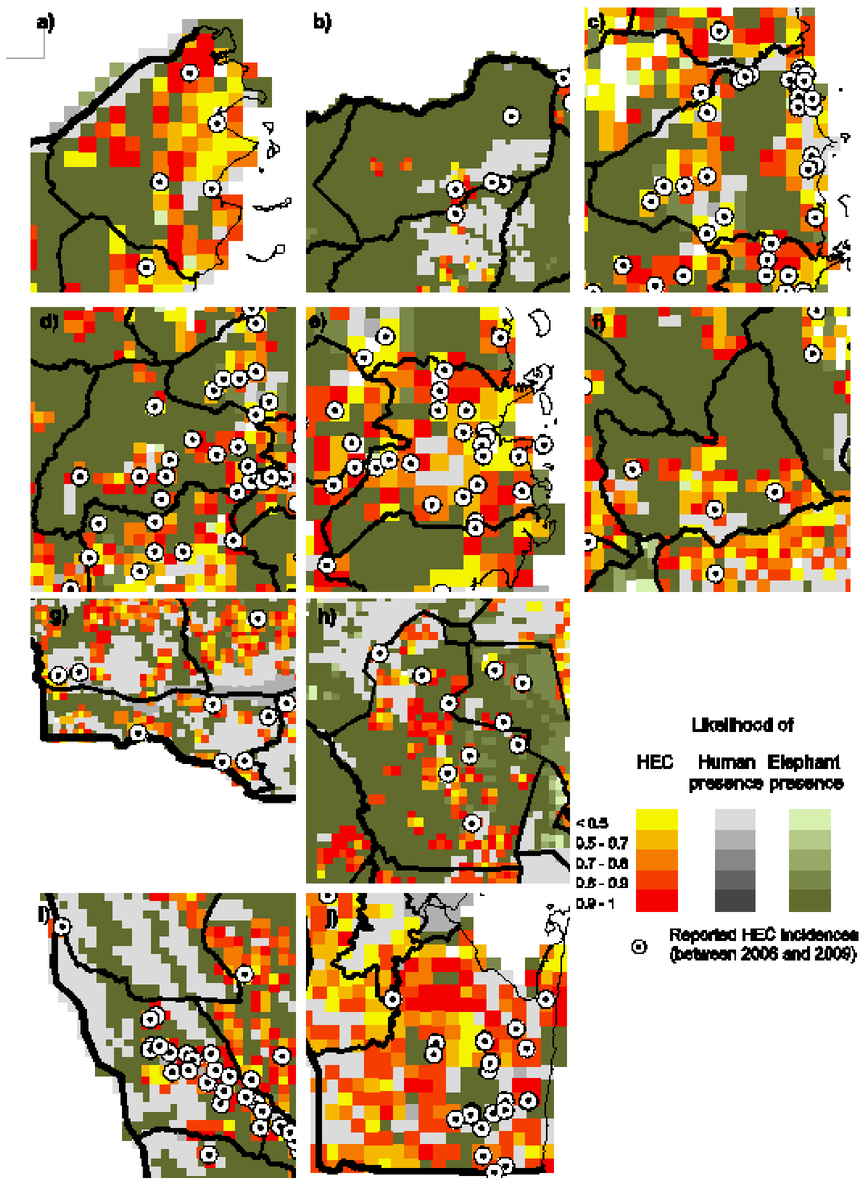

Fig. 2 Evaluation of the HEC model in the HEC hotspots districts: (a) Palma, (b) Mecula, (c) Macomia, (d) Meluco, (e) Quissanga, (f) Nipepe, (g) Mágoè, (h) Funhalouro, (i) Massingir and j) Matutuine. These districts, but Palma and Funhalouro harbours protected areas.

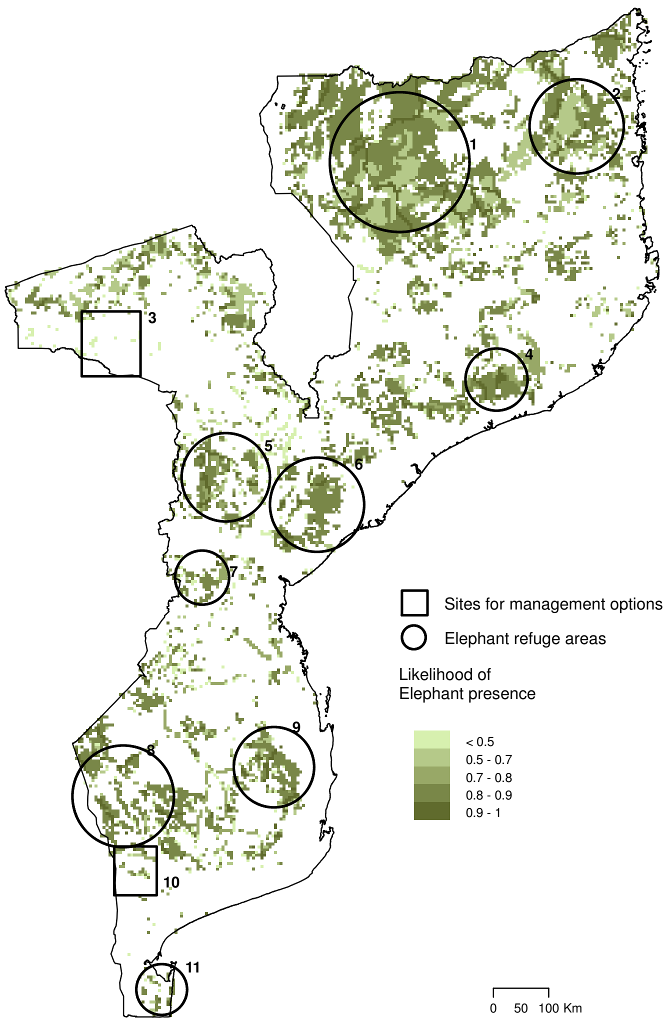

Fig. 3 Likelihood of elephant distribution in Mozambique, showing some probable relevant elephant refuges. 1, Selous- Niassa; 2, Quirimbas National Park; 3, Mágoè district; 4, Gilé National Reserve; 5, Gorongosa National Park and surroundings; 6, Marromeu; 7, Chimanimani National Reserve; 8, Limpopo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

References

BATH, A. J. & ENCK, J. W. (2003) Wildlife human interactions in national parks in Canada and the USA. *Social Science Research Review*, **4**, 1-32.

CHAMAILLE-JAMMES, S., VALEIX, M. & FRITZ, H. (2007a) Elephant management: why can't we throw out the babies with the artificial bathwater? *Diversity and Distributions*, **13**, 663-665.

CHAMAILLÉ-JAMMES, S., VALEIX, M. & FRITZ, H. (2007b) Managing heterogeneity in elephant distribution: interactions between elephant population density and surface-water availability. *Journal of Applied Ecology,* **44**, 625-633.

CHERYL-LESLEY, B. C., St. CLAIR, C. C. & BOYCE, M. S. (2006) Corridors for Conservation: Integrating Pattern and Process. *Annual Review of Ecology, Evolution and Systematics*, **37**, 317-342.

DE BEER, Y. & VAN AARDE, R. J. (2008) Do landscape heterogeneity and water distribution explain aspects of elephant home range in southern Africa's arid savannas? *Journal of Arid Environments,* **72**, 2017-2025.

DEFRIES, R., KARANTH, K. K. & PAREETH, S. (2010) Interactions between protected areas and their surroundings in human-dominated tropical landscapes. *Biological Conservation*, **143**, 2870-2880.

DE KNEGT, H. J., VAN LANGEVELDE, F., SKIDMORE, A. K., DELSINK, A., SLOTOW, R., HENLEY, S., BUCINI, G., DE BOER, W. F., COUGHENOUR, M. B., GRANT, C.C., HEITKONIG, I. M. A., HENLEY, M., KNOX, N. M., KOHI, E. M., MWAKIWA, E., PAGE, B. R., PEEL, M., PRETORIUS, Y., VAN WIEREN, S. E. & PRINS, H. H. T. (2011) The spatial scaling of habitat selection by African Elephants. *Journal of Animal Ecology*, **80**, 270–281

DICKMAN, A. J. (2008) *Key determinants of conflict between people and wildlife, particularly large carnivores, around Ruaha National Park, Tanzania*. PhD thesis, University College London, London, UK.

DU TOIT, J. T., WALKER, B. H. & CAMPBELL, B. M. (2004) Conserving tropical nature: current challenges for ecologists. *Trends in Ecology and Evolution*, **19**, doi:10.1016/j.tree.2003.09.018.

DUBLIN, H. T. & HOARE, R. E. (2004) Searching for Solutions: The Evolution of an Integrated Approach to Understanding and Mitigating Human–Elephant Conflict in Africa. *Human Dimensions of Wildlife*, **9**, 71-278.

FERNANDO, P., GUNAWARDENE, M. D., HATURUSINGHE, H. S., JANAKA, H. K., JAYASINGHE, L. K. A., PERERA, R. A. R., SAMANSIRI, K. P. A., SANDANAYAKE, A., WEERAKOON, D. K. & WIKRAMANAYAKE, E. (2004) Towards a rational, scientific elephant conservation and management strategy for Sri Lanka. In *Endangered elephants, past, present & future* (ed. J. Jayewardene), pp. 288. Proceedings of the Symposium on Human elephant Relationships and Conflicts, Sri Lanka. Biodiversity & Elephant Conservation trust, Colombo.

GRAHAM, M. D. DOUGLAS-HAMILTON, I. ADAMS, W. M. & LEE, P. C. (2009) The movement of African elephants in a human-dominated land-use mosaic. *Animal Conservation*, **12,** 445-455.

GRAHAM, M. D., NOTTER, B., ADAMS, W. M., LEE, P. C. & OCHIENG, T. N. (2010) Patterns of crop-raiding by elephants, *Loxodonta africana,* in Laikipia, Kenya, and the management of human–elephant conflict. *Systematics and Biodiversity*, **8**, 435-445.

GRAINGER, M., VAN AARDE, R.J. & WHYTE, I.J. (2008) Landscape heterogeneity and the use of space by elephants in the Kruger National Park, South Africa. *African Journal of Ecology*, **43**, 369-375.

HARRIS, G. M., RUSSELL, G. J., VAN AARDE, R. J. & PIMM, S. L. (2008) Rules of habitat use by elephants *Loxodonta africana* in southern Africa: insights for regional management. *Oryx*, **42**, 66-75.

HILL, C. M. (2004) Farmers' perspectives of conflict at the wildlife–agriculture boundary: Some lessons learned from African subsistence farmers. *Human Dimensions of Wildlife*, **9**, 279-286.

HOARE, R. E. (1999) Determinants of human-elephant conflict in a land-use mosaic. *Journal of Applied Ecology*, **36**, 689-700.

HOARE, R. E. & DU TOIT, J. T. (1999) Coexistence between people and elephants in African savannas. *Conservation Biology,* **13,** 633-639.

JACKSON, T. P., MOSOJANE, S., FERREIRA, S. M. & VAN AARDE, R. J. (2008) Solutions for elephant *Loxodonta africana* crop raiding in northern Botswana: moving away from symptomatic approaches. *Oryx,* **42**, 83-91.

JOSHI, R. & SINGH, R. (2009) Gujjar Community Rehabilitation from Rajaji National Park: Moving towards an Integrated Approach for Asian Elephant *(Elephas maximus)* Conservation. *Journal of Human Ecology*, **28**, 199-206.

KUBE, R. (2005) First Experiences of a Community-Based Natural Resource Management Programme in Northern Mozambique, *Development in Practice*, **15**, 100-105.

LEE, P. C. & GRAHAM, M. D. (2006) African elephants Loxodonta Africana and human-elephant interactions: implications for conservation. *International Zoo Yearbook*, **40**, 9-19.

MANFREDO, M. J. & DAYER, A. A. (2004) Concepts for Exploring the Social Aspects of Human-Wildlife Conflict in a Global Context. *Human Dimensions of Wildlife*, **9**, 1-20.

MWALYOSI, R. B. B. (1991) Ecological Evaluation for Wildlife Corridors and Buffer Zones for Lake Manyara National Park, Tanzania, and its Immediate Environment. *Biological Conservation,* **57**, 171-186.

NAUGHTON-TREVES, L. & TREVES, A. (2005) Socio-ecological factors shaping local support for wildlife: crop-raiding by elephants and other wildlife in Africa. In: *People and wildlife: conflict or coexistence?* (eds R. Woodroffe, S. Thirgood, & A. Rabinowitz): pp. 252-277. Cambridge, Cambridge University Press.

NAUGHTON-TREVES, L. (1997) Farming the Forest Edge: Vulnerable Places and People around Kibale National Park, Uganda. *Geographical Review*, **87**, 27-46.

NAVEH, Z. (2000) What is holistic landscape ecology? A conceptual introduction. *Landscape and Urban Planning*, **50**, 7-26.

NELSON, A., BIDWELL, P. & SILLERO-ZUBIRI, C. (2003) *A review of humane elephant conflict management strategies*. People and Wildlife Initiative. Wildlife Conservation Research Unit, Oxford University. Oxford, UK.

NTUMI, C. P., FERREIRA, S. M. & VAN AARDE, R. J. (2009) A review of historical trends in the distribution and abundance of elephants *Loxodonta africana* in Mozambique. *Oryx*, **43**, 568-579.

O'CONNOR, T. G., GOODMAN, P. S. & CLEGG, B. (2007) A functional hypothesis of the threat of local extirpation of woody plant species by elephant in Africa. *Biological Conservation,* **136**, 329-345.

OLIVIER, P. I. VAN AARDE, R. J. & FERREIRA, S. M. (2009) Support for a metapopulation structure among mammals. *Mammal Review*, **39**, 178-192.

PARKER, I. S. C. & GRAHAM, A. D. (1989) Elephant decline Part I. Downward trends in African elephant distribution and numbers. *International Journal of Environmental Studies,* **34**, 287-305.

SANDERSON, E. W., REDFORD, K. H., VEDDER, A., COPPOLILLO, P. B. & WARD, S. E. (2002) A Conceptual model for conservation planning based on landscape species requirements. *Landscape and Urban Planning*, **58**, 41-56.

SITATI, N.W., WALPOLE, M.J., SMITH, R.J. & LEADER-WILLIAMS, N. (2003) Predicting spatial aspects of human-elephant conflict. *Journal of Applied Ecology*, **40**, 667-677.

SITATI, N. W. & WALPOLE, M. J. (2006) Assessing farm-based measures for mitigating human–elephant conflict in Transmara District, Kenya. *Oryx*, **40**, 279-286.

SMITH, E. A. (1983) Anthropological applications of optimal foraging theory: a critical review. *Current Anthropology*, **24**, 625-651.

SMITH, V. K. (1992) Environmental Costing for Agriculture: Will It Be Standard Fare in the Farm Bill of 2000? *American Journal of Agricultural Economics*, **74**, 1076-1088.

SMITH, R.J. & KASIKI, S. (1999) *A Spatial Analysis of Human-Elephant Conflict in the Tsavo Ecosystem, Kenya*. AfESG Report. IUCN/SSC, Gland, Switzerland.

STRAYER, D. L., EWING, H. A. & BIGELOW, S. (2003) What kind of spatial and temporal details are required in models of heterogeneous systems? *Oikos*, **102**, 654-662.

TREVES, A. & NAUGHTON-TREVES, L. (1999) Risk and opportunity for humans coexisting with large carnivores. *Journal of Human Evolution*, **36**, 275-282.

TWINE, W. & MAGOME, H. (2008) Interactions between elephants and people. In *Elephant Management: A Scientific Assessment for South Africa* (eds R. J. Scholes, & K. G.Mennell), pp. 206-240. Wits University Press, South Africa.

VAN AARDE, R. J. & JACKSON, T. P. (2007) Megaparks for metapopulations: addressing the causes of locally high elephant numbers in southern Africa. *Biological Conservation*, **134**, 289-297.

WARNER, M. Z. (2008) *Examining Human-Elephant Conflict in Southern Africa: Causes and Options for Coexistence*. Master of Environmental Studies thesis, University of Pennsylvania, USA.

YOUNG, K. D., FERREIRA, S. M. & VAN AARDE, R. J. (2009a) The influence of increasing population size and vegetation productivity on elephant distribution in the Kruger National Park. *Austral Ecology*, **34**, 329-342.

YOUNG, K. D., FERREIRA, S. M. & VAN AARDE, R. J. (2009b) Elephant spatial use in wet and dry savannas of southern Africa. *Journal of Zoology*, **278**, 189-205.