

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 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 km² 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 km² 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 km² (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 LTFCA 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/km² 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 were 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 km²), 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 are 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) (Pontauiller *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 where 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):

$$w = \exp [\beta_0 + \beta_1(A) + \beta_2 (B) + \beta_3 (C) + \dots\beta_n (N)]$$

where:

w = is the probability of use, $\beta_0, \beta_1, \beta_2, \beta_3, \dots, \beta_n$ = 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 assess 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 (25km²) is much greater than the 1 to 5 km² 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 \pm 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 \pm 8.488	2.633 \pm 3.943	5.564 \pm 8.488	3.333 \pm 4.834	13.564 \pm 25.033	11.954 \pm 21.875	13.564 \pm 25.033	11.954 \pm		
Distance to settlement	3.420 \pm 1.941	4.449 \pm 2.069	3.420 \pm 1.941	4.100 \pm 2.047	0.000	0.724 \pm 1.302	0.000	11.954 \pm 21.875		
Distance to water	3.647 \pm 1.729	3.479 \pm 1.526	3.647 \pm 1.729	3.501 \pm 1.638	0.000	1.150 \pm 2.036	0.000	0.724 \pm 1.302	3.464 \pm 2.912	0.000
Distance to roads	2.384 \pm 1.231	2.132 \pm 0.900	2.384 \pm 1.231	2.058 \pm 0.881	0.000	0.847 \pm 1.535	0.000	1.150 \pm 2.036	1.439 \pm 1.219	0.000
Topography	43.811 \pm 20.388	33.701 \pm 13.612	43.811 \pm 20.388	34.720 \pm 14.020	2.295 \pm 7.392	18.464 \pm 28.124	2.295 \pm 7.392	0.847 \pm 1.535	44.061 \pm 20.490	0.000
Forest cover	5.322 \pm 1.446	5.700 \pm 1.055	5.322 \pm 1.446	5.417 \pm 1.481	4.230 \pm 1.802	4.517 \pm 1.744	4.230 \pm 1.802	18.464 \pm 28.124	14.102 \pm 5.208	8.583 \pm 6.382
Forest fragmentation	0.968 \pm 0.281	0.400 \pm 0.270	0.968 \pm 0.281	0.917 \pm 0.266	0.656 \pm 0.560	0.770 \pm 0.524	0.656 \pm 0.560	4.517 \pm 1.744	0.948 \pm 0.429	0.522 \pm 0.413
NDVI			9.000 \pm 3.000	10.000 \pm 2.000			8.000 \pm 3.000	8.000 \pm 4.000	9.000 \pm 3.000	8.000 \pm 4.000
Biomass of food species of elephants	62.339 \pm 71.114	85.767 \pm 70.859	62.339 \pm 71.114	79.442 \pm 71.671	47.027 \pm 67.340	44.526 \pm 66.206	47.027 \pm 67.340	28.988 \pm 28.452		
Number of elephant locations									38.976 \pm 76.123	99.077 \pm 171.841
Agricultural suitability									Moderate to suitable	low to moderate
Soil type									clay and alluvial	sandy
Frequency of exploited species									159.059 \pm 144.703	60.355 \pm 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 \pm 0.530	0.057 \pm 0.048	0.333 \pm 0.646	0.133 \pm 0.320	0.291 \pm 0.987	0.313 \pm 1.014	0.291 \pm 0.987	0.313 \pm 1.014		
Distance to settlement	9.842 \pm 5.760	15.207 \pm 7.640	10.275 \pm 6.569	10.948 \pm 6.858	2.361 \pm 6.563	1.793 \pm 5.652	2.361 \pm 6.563	1.793 \pm 5.652		
Distance to water	3.397 \pm 2.139	4.167 \pm 3.838	2.932 \pm 2.475	3.339 \pm 2.924	0.607 \pm 1.784	0.519 \pm 1.487	0.607 \pm 1.784	0.519 \pm 1.487	4.270 \pm 2.669	0.000
Distance to roads	30.919 \pm 11.324	56.996 \pm 10.548	32.428 \pm 13.259	63.768 \pm 11.670	8.105 \pm 19.566	5.638 \pm 14.543	8.105 \pm 19.566	5.638 \pm 14.543	13.346 \pm 12.566	0.000
Topography	220.351 \pm 113.457	356.023 \pm 110.320	235.921 \pm 109.251	373.660 \pm 106.674	51.860 \pm 125.055	38.374 \pm 97.064	51.860 \pm 125.055	38.374 \pm 97.064	175.719 \pm 112.419	0.000
Forest cover	39.123 \pm 20.326	29.753 \pm 16.911	41.242 \pm 19.994	32.944 \pm 18.681	24.709 \pm 22.903	25.299 \pm 23.328	24.709 \pm 22.903	25.299 \pm 23.328	21.739 \pm 10.895	17.480 \pm 11.300
Forest fragmentation	0.022 \pm 0.013	0.029 \pm 0.012	0.024 \pm 0.011	0.033 \pm 0.011	0.020 \pm 0.013	0.019 \pm 0.013	0.020 \pm 0.013	0.019 \pm 0.013	0.224 \pm 0.013	0.020 \pm 0.030
NDVI			9.000 \pm 3.000	10.000 \pm 2.000			8.000 \pm 3.000	8.000 \pm 3.000	7.000 \pm 3.000	9.000 \pm 3.000
Biomass of food species of elephants	1.445 \pm 0.559	0.903 \pm 0.732	1.938 \pm 0.628	0.825 \pm 0.660	1.101 \pm 0.752	1.142 \pm 0.755	1.101 \pm 0.752	1.142 \pm 0.755		
Number of elephant locations									4.258 \pm 21.347	6.235 \pm 18.205
Agricultural suitability									Moderate to suitable	suitable
Soil type									grey and clay	clay and alluvial
Frequency of exploited species									47.091 \pm 34.890	48.221 \pm 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
<i>Elephants (Dry+Wet)</i>							
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
<i>Human (Dry+Wet)</i>							
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)

<i>Elephants (Dry+Wet)</i>							
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
<i>Human (Dry+Wet)</i>							
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	Human density	0,149	0,114	0,132	0,082	0,129	Not applicable
Libombo	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
Limpopo	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

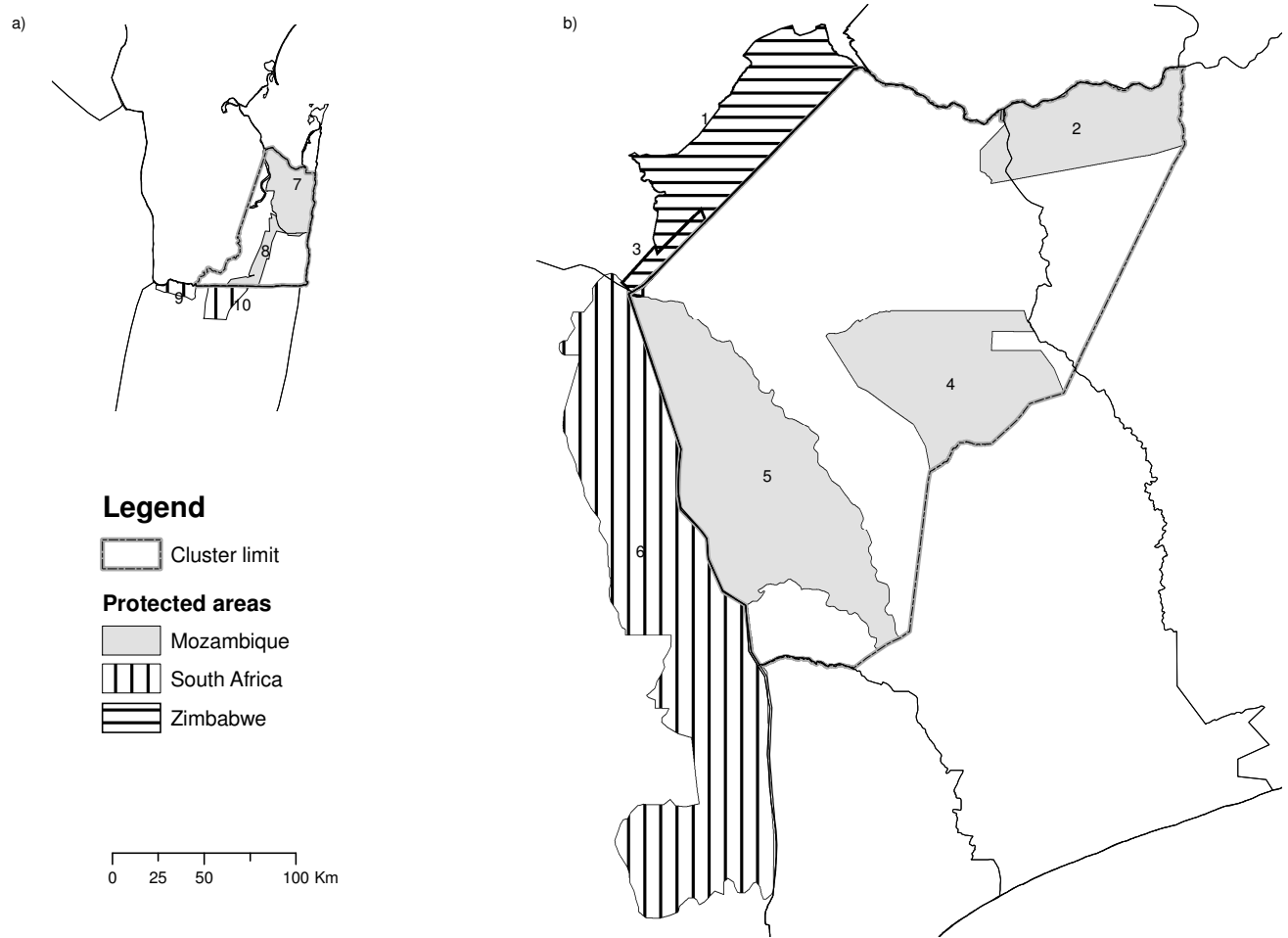


Fig. 1 The Location of the Lubombo Transfrontier Conservation Area (LTFCA) (a) and the Great Limpopo Transfrontier Conservation Area (GLTFCA) (b) clusters, with the protected areas associated. 1, Gonarezhou National Park; 2, Zinave National Park; 3, Sengwa Corridor; 4, Banhine National Park; 5, Limpopo 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.

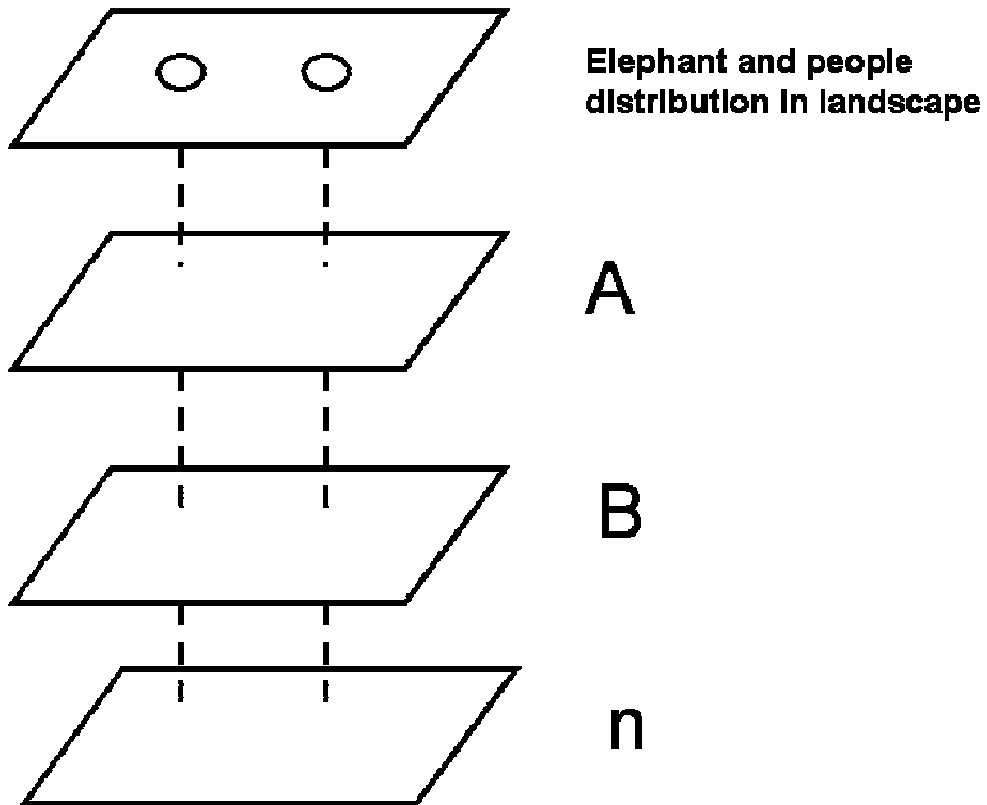


Fig. 2 Schematic presentation of the distribution of elephant and people as a function of resources in the landscape. Elephant and people do not occur randomly in the landscape. There are **A**, **B** and **n** resources layers that may explain the location of both species in the landscape.

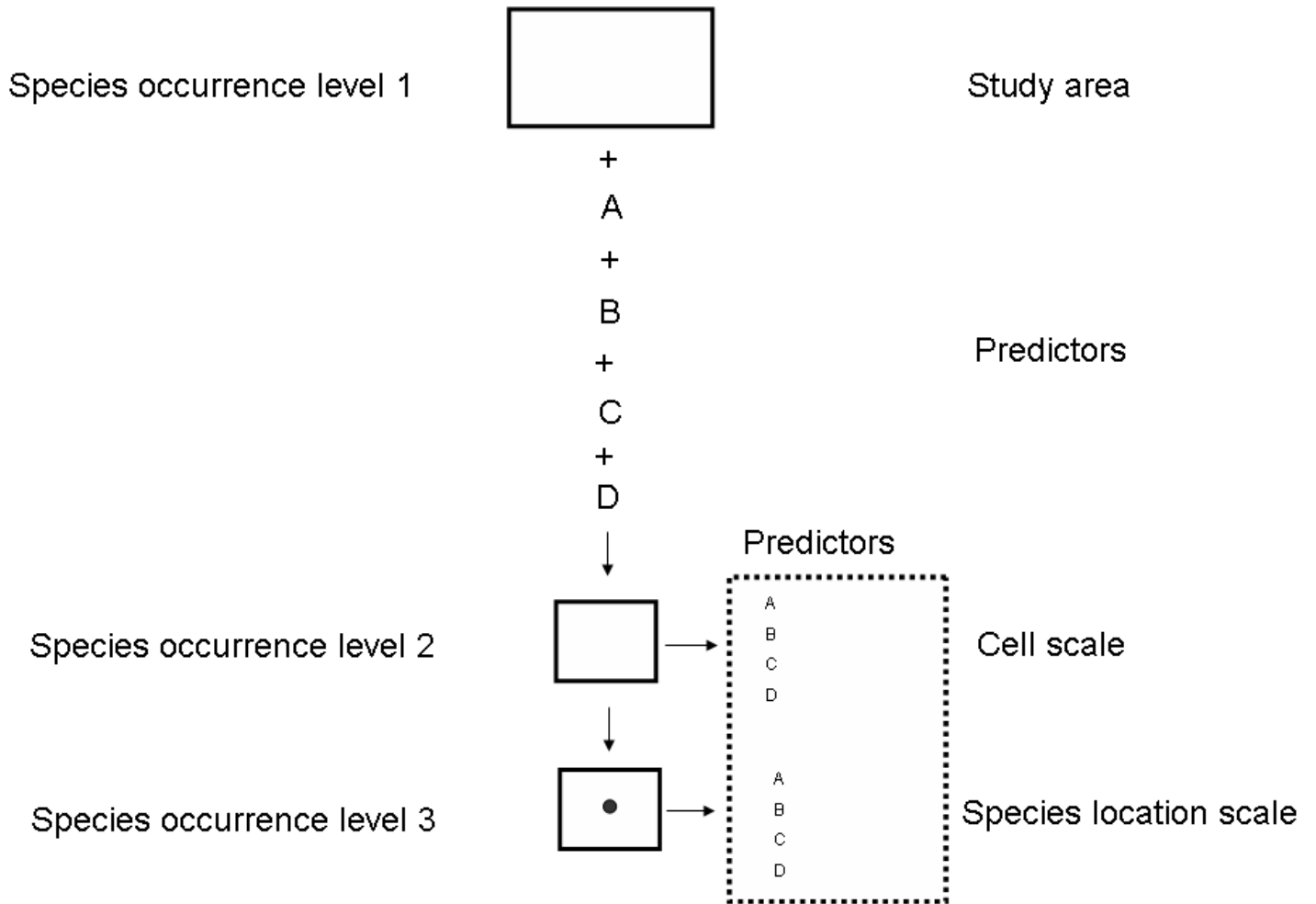


Fig. 3 A conceptual flow diagram of the methodological approach to RSF modelling to predict human-elephant conflict in southern Mozambique at the landscape, cell and location scale.

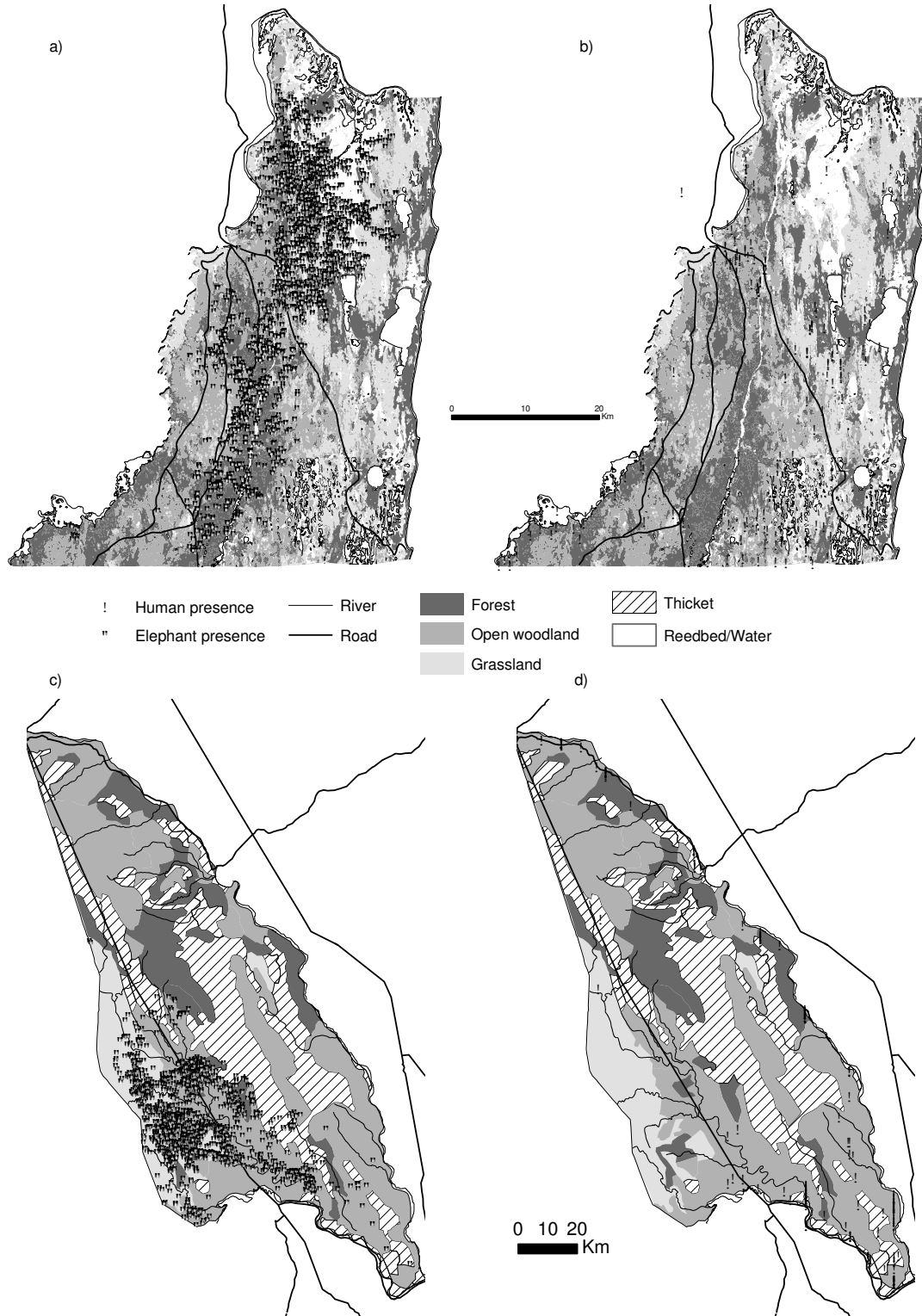
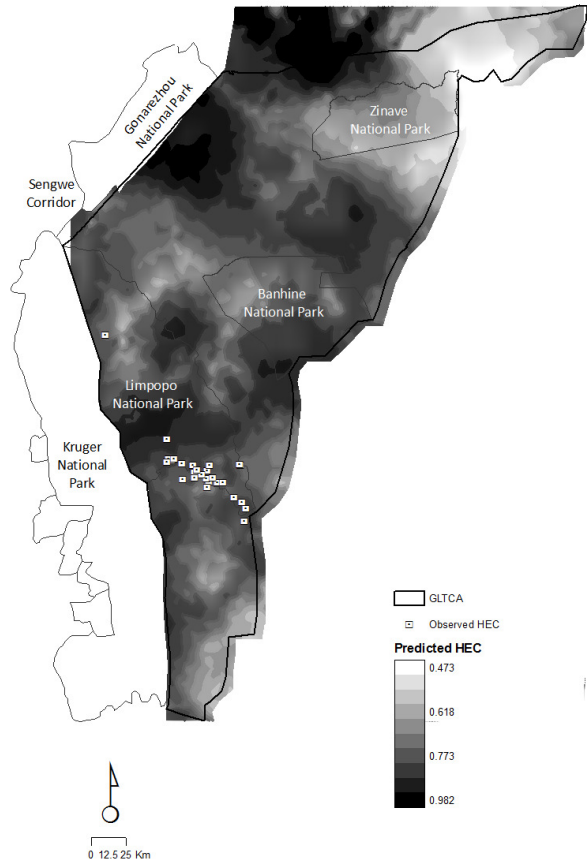
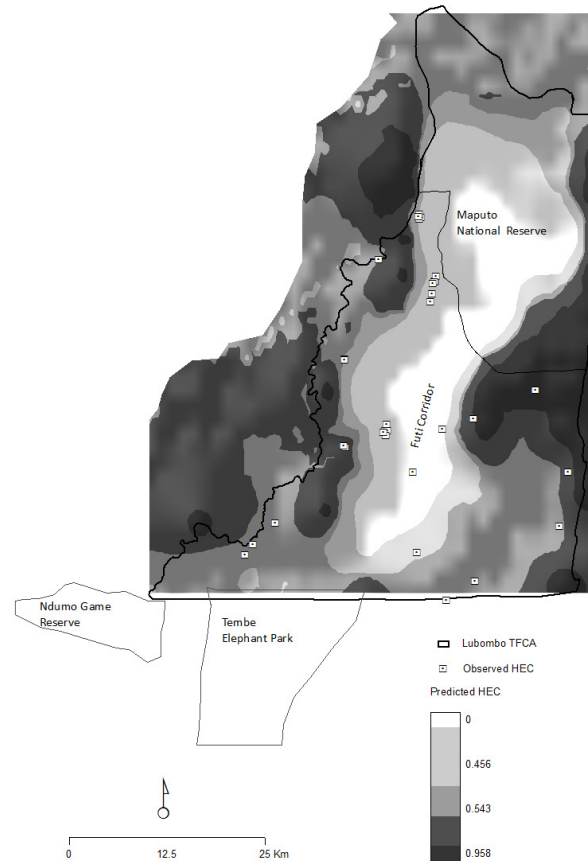


Fig. 4 Locations of elephant (a) and people (b) at the Maputaland cluster and elephant (c) and people (d) at the Limpopo cluster.



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.

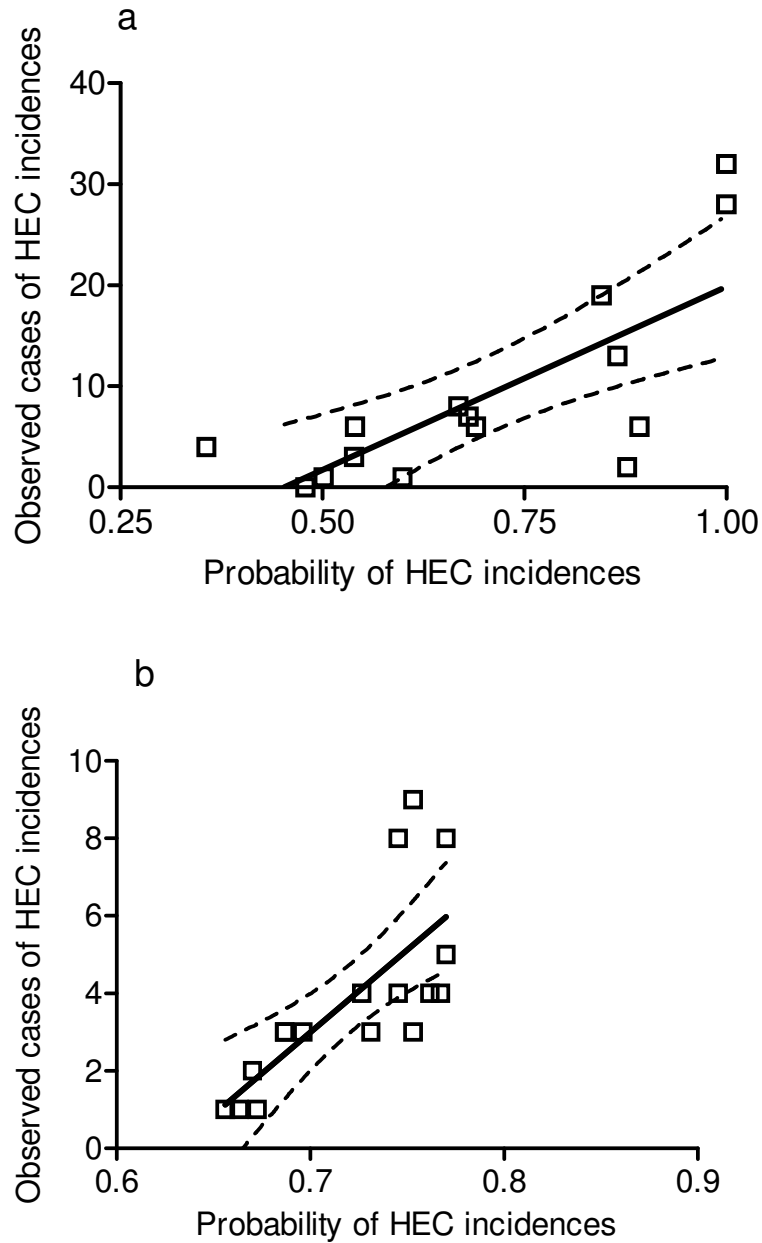


Fig. 6 Probability of incidences of HEC predicted in this study regressed with the frequency of observed incidences in the (a) Maputo NR and (b) Limpopo NP in southern Mozambique. The statistical results for the Maputo NR ($r^2 = 0.55$; $F_{13} = 15.86$; $p = 0.002$) and for the Limpopo NP ($r^2 = 0.53$;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

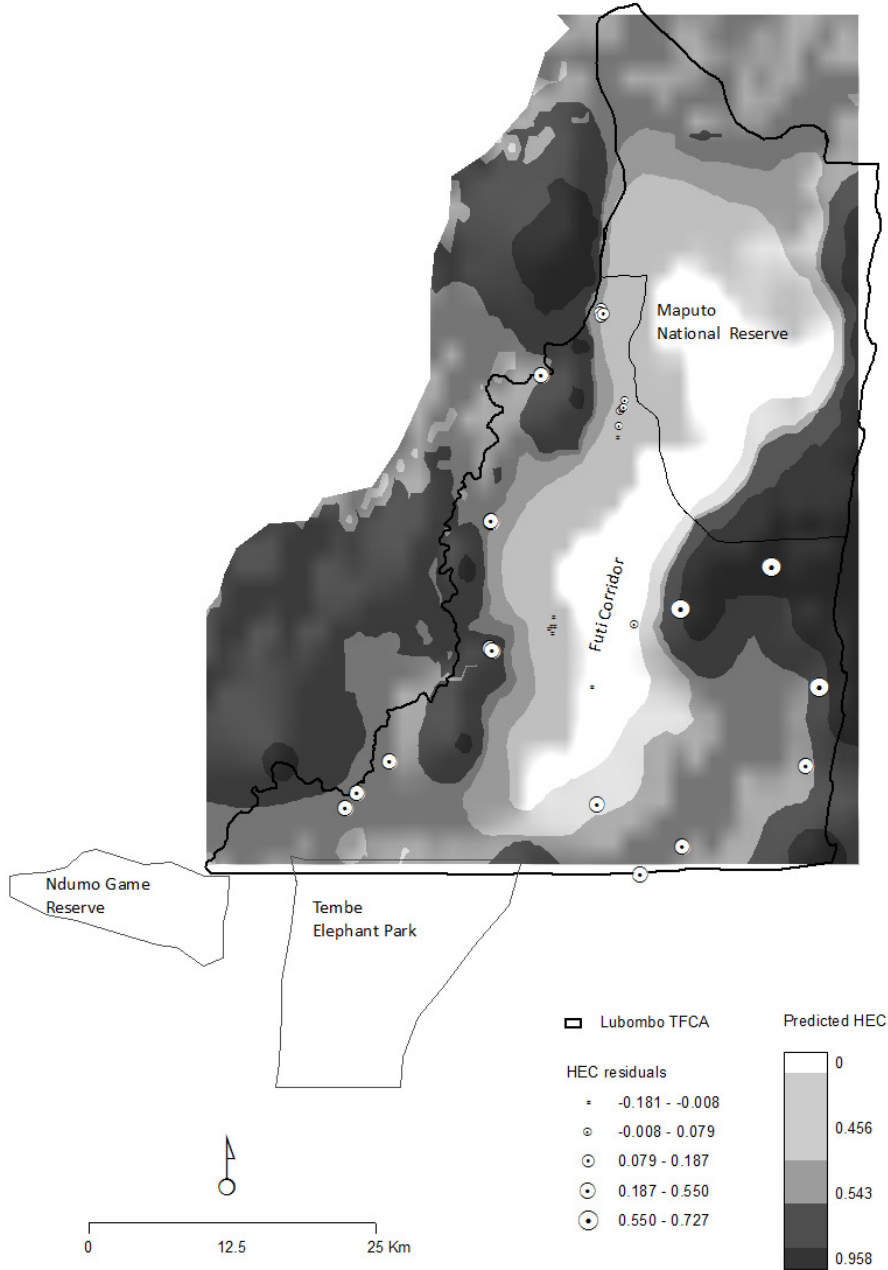


Fig. 7 Distribution of HEC residuals (difference between the predicted probability and observed frequency of HEC) across the Lubombo Transfrontier Conservation Area (LTFCA).

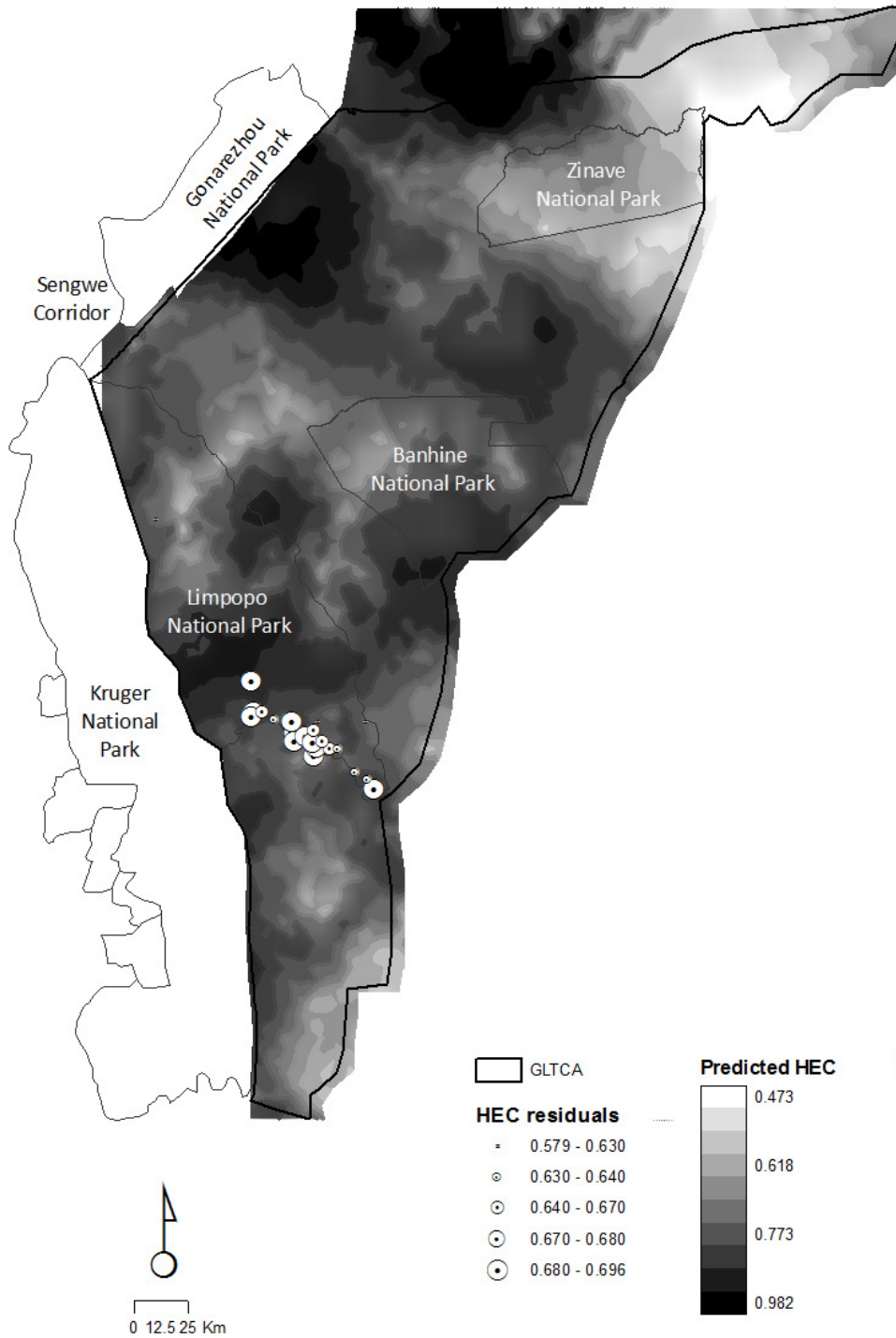


Fig. 7 Distribution of HEC residuals (difference between the predicted probability and observed frequency of HEC) across the Great Limpopo Transfrontier Conservation Area (GLTFCA)