Chapter 4

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

Abstract

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

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

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

Introduction

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

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

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

From studies elsewhere in Africa, we know that elephants tend to move away from highly settled and developed areas (Parker & Graham, 1989; Hoare & du Toit, 1999; Lee & Graham, 2006; Harris *et al*., 2008) and may concentrate in refuge area (Osborn & Parker, 2003). In Mozambique protected areas may provide such refuge as some 16 percent of the country has been set aside for formal protection (MICOA, 2003). Most of these protected areas are inhabited by elephants and people (see Ntumi *et al*. 2009), but elephants also live in unprotected areas and on communal land that makes up some 50 percent of the area of the country (UIF, 2007). The density (mean±SD) of people inside protected areas (2.69±2.60 people/km^2 ;MITUR, 2010) far exceeded that in rural aereas beyond protected areas (17,86±9,08 people/km^2 ;INE,2007). In Mozambique communal land often surrounds protected areas and human activities may disrupt and isolate populations. Consequently, apart from attempts to reduce HEC in areas that could link fragments of a former more extended elephant population, the design of a network of land use options that can provide for the co-existence of people and elephants may also be considered a priority. In this chapter, I develop a conceptual framework to identify the

ecological and sociological factors that may drive HEC. The objective of the chapter is to evaluate the relationship between human presence, human activities, elephant presence and reported incidences of human-elephant conflict. In terms of ecological factors, I asked i) if the presence or absence of elephants is a function of human density, ii) if HEC is a function of distance from protected area, iii) if the likelihood of HEC can be explained by elephant density, and iv) if HEC is a function of landscape transformation. I furthermore used a GLM to determine the abilities of selected variables to explain variability in the incidences of HEC. Here I used a poverty index, human population growth, human density, human dispersion and landscape transformation as predictor variables. I predicted that i) human density determines the presence and absence of elephants, ii) incidences of HEC would be higher in the proximity of protected areas than further afield, iii) incidences of HEC would be a function of elephant density, but iv) be explained by landscape transformation.

A conceptual HEC framework

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

environmental, social and economic variables. Variables dictating spatial use (Sitati *et al*., 2005) thus have consequences for plans to mitigate HEC effectively.

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

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

Spatial use by humans may reflect a compromise of resource demand, environmental conditions, social structure and cultural factors (Hamilton *et al*., 2007). However, proximity to infrastructure may also be important and in rural areas of Mozambique where people live close to roads, water sources and alluvial soils suitable for agriculture (MPF, 2002). Elephants do also select landscapes based on the

productivity of the environment, environment correlates and population biology (Western & Lindsay, 1984; Wittemyer *et al*., 2007; Young *et al.,* 2009a; Young & van Aarde, 2010).

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

Study area

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

The human population is increasing at ~2.2% per year (INE, 2007). People live in all nationally protected areas in Mozambique. Threats to conservation inside and outside protected areas include the uncontrolled establishment of settlements, the clearing of

vegetation for agriculture, logging, poaching, cattle and goat farming, non-forestry products extraction, informal mining and fire (ARD, 2002; AGRECO, 2008). Cattle numbers are relatively high in southern and central Mozambique, but low in northern Mozambique (AGRECO, 2008). Land transformation induced by cultivation, clearing of vegetation, logging, charcoal production and firewood collection often follow on the establishment of settlements.

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

Data & Methods

Elephant and HEC distribution

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

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

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

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

Correlates of HEC in Mozambique

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

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

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

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

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

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

Statistical analyses

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

variables are useless in prediction of dependent variable) and 1 (independent variables in model predict the dependent variable perfectly).

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

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

Furthermore, I used a generalized linear model (GLM) (see Boyce & Waller, 2003) to evaluate the best subsets of human dispersion index, percent of forest cover, percent of cultivated area, human population growth rate and poverty incidence index to

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

Results

Human-Elephant Conflict in Mozambique

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

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

Presence and absence of elephants in rural districts of Mozambique

Elephants apparently were absent from districts with high human densities and where much of the land had been transformed to cultivated areas. For instance, a logistic regression confirmed that the presence of elephants was strongly affected by human density (logistic regression, $z = -0.171$, $df = 109$, $p = 0.001$). The R^2L value of 0.57 for

this regression suggests a moderately strong association between human density and the presence/absence of elephants in given rural district of Mozambique (Fig. 3a).

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

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

HEC in landscapes beyond protected areas

Land cover and HEC profiles for districts with elephants and protected areas differed from those with elephants but without protected areas. For instance, percent forest cover (35.9±21.2) and cultivated area (6.03±6.1) in the districts without protected areas were significantly higher ($t_{76} = 2.15$, $p = 0.03$ & $t_{76} = 2.59$, $p = 0.01$ respectively) than those

with protected areas (25.3±14.97 & 2.57±2.07 respectively). However, human density (t_{76} = 1.88, p = 0.06), human dispersion index (t_{76} = 1.69, p = 0.09), poverty incidence index (t_{76} = -0.61, p = 0.54) and human population growth rate (t_{76} = 0.23, p = 0.82) for these two categories of districts were similar. Significantly more HEC incidences (16.8 ± 28.1) and higher RIHEC values (5.0 ± 9.9) were recorded in the districts with protected areas than those without protected areas (6.8 ± 7.9; 0.90 ± 2.08, respectively; HEC incidences: t_{76} = -2.78, p = 0.007: RIHEC: t_{76} = -2.98, p = 0.004).

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

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

rate, percent cultivated and percent forest cover) returned the best fit for the latter (Table 2).

HEC in the protected areas

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

Discussion

Human-Elephant Conflict in Mozambique

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

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

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

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

but provide a first approximation that may explain the widespread incidences of HEC across Mozambique, albeit mainly occurring in zones adjacent to protected areas.

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

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

associated with human density and the associated transformation of land may therefore be responsible for high incidences of HEC.

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

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

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

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

Nearly 60% of the landscapes of most of the provinces of Mozambique were intact. These large swatches of natural vegetation provide habitat for elephant, but for a variety of reasons very few elephants occurred there and most of Mozambique's elephants were limited to protected areas (see Chapter 2). People also live in protected areas and much of the conflict between people and elephants occurred within and around

these areas. The relatively high incidence of conflict in the immediate vicinity of protected areas may be a function of the uneven distribution of people across Mozambique, especially if more people live in the proximity of protected areas then further afield. I do not know if this is the case and the resolution of data at my disposal did not allow for such an analysis. This lack of fine scale data introduces other complications, many of these at the conceptual level that often rules political decision taking. For instance, apparent idiosyncratic patterns at the district level persisted, possibly due to the presence of protected areas that provided matrices of natural landscapes in which people also lived. In other districts, where there were no protected areas, matrices of unnatural landscapes dominated by humans still comprised sufficient habitat for elephants. In the former, the presence of elephants may be considered 'natural', but in the latter, they may be considered 'an invader'. Actions to resolve conflict will thus also be idiosyncratic.

The presence or absence of elephants and of protected areas was obvious drivers of HEC. This may be due to differences in human density and percent cultivated areas between these. However, the presence of elephants may be driven by human densities (see above), which in turn were higher in provinces without protected areas than those with protected areas. Nevertheless, within protected areas the incidence of HEC was not a function of elephant or human density. This notion is also mooted by Hoare (1999) and Warner (2008). However, the increased reports on HEC incidences from districts with protected areas, may also highlight the proximity to protected area effect (Newmark *et al*., 1994; Naughton-Treves, 1997; Twine & Magome, 2008), which also was observed in this study. Living close to protected areas which harbours elephants, particularly those

surrounded by densely settled agricultural areas, as appears to be the case of Mozambique, may represent a risk for HEC due to the higher probability of human-elephant encounters at the edge of protected areas (also see Twine & Magome, 2008; Warner, 2008). Protected areas alone are inadequate for sustaining elephants (Warner, 2008) and frequently, elephants move beyond refuges to feed and may destroy fields (Graham *et al*., 2010). Proximity to protected areas may be an added plausible explanation of HEC incidences in the rural districts of Mozambique. An effective land-use plan should thus accommodate distance from protected areas to enable the co-existence of humans and elephants in human dominated landscapes.

Correlates of human and elephant conflict in Mozambique

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

Human population density, human population growth rate and the extent of cultivation best predicted the likelihood of incidences of HEC as well as RIHEC across rural districts in Mozambique. These variables, however, were not linearly related due to elephants not being present once a threshold density of 60 people/km^2 has been exceeded – very few incidences of HEC then occurred. Below the threshold density, the incidence

of HEC may best be explained by a combination of demographic and spatial variables. These variables, however, were closely linked and landscape transformation increased with increased density and population growth rate. Where elephants persisted despite landscape transformation, the incidence of HEC increased with increased human density, population growth rate and habitat transformation until the threshold density is reached. Human dispersion index may then also be important to predict incidences of HEC.

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

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

Management implications

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

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

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

Given that the Mozambique government is committed to "…. *maintain and, where possible, increase numbers and range of elephant populations*……"(MITUR, 2010), conflict mitigation can no longer continue to focus on elephants *per se*, but need to

address the demographically associated spatial utilization activities of people. From my analysis it follows that elephants avoid densely populated and intensely transformed rural areas. People settling in new areas where elephants live will experience conflict. The obvious option then is to forbid such settlement or any other form of settlement in areas demarcated or earmarked as elephant habitat (see Chapter 5). Law enforcement and improved knowledge through dedicated education programs thus may assist in dealing with the causes rather than symptoms of the conflict.

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

I fully appreciate that conflict profiles may be site specific and for instance differ between protected and non-protected areas. Site specific solutions for the conflict

therefore may also differ but in principle should focus on demographic and spatial variables of humans. For instance, encouraging low levels of dispersion onto natural or semi-natural landscapes may provide the means to reduce the likelihood of conflict.

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

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

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

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

a)

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

b)

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

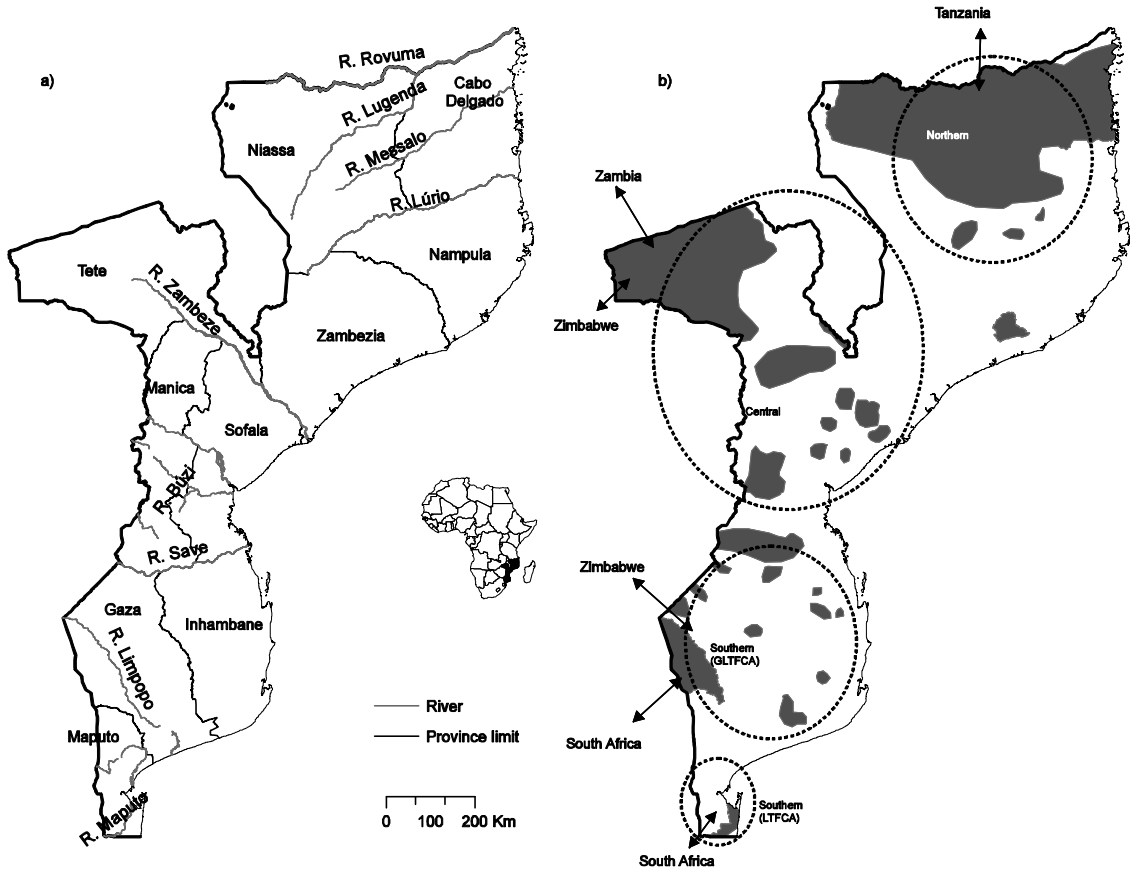

Fig. 1 Line diagrams of Mozambique, with (a) showing the most relevant rivers and provinces; (b) illustrating present elephant range, structured in the four main clusters (dashed lines) with links to Tanzania, Zambia, Zimbabwe and South Africa (modified from Ntumi *et al*., 2009).

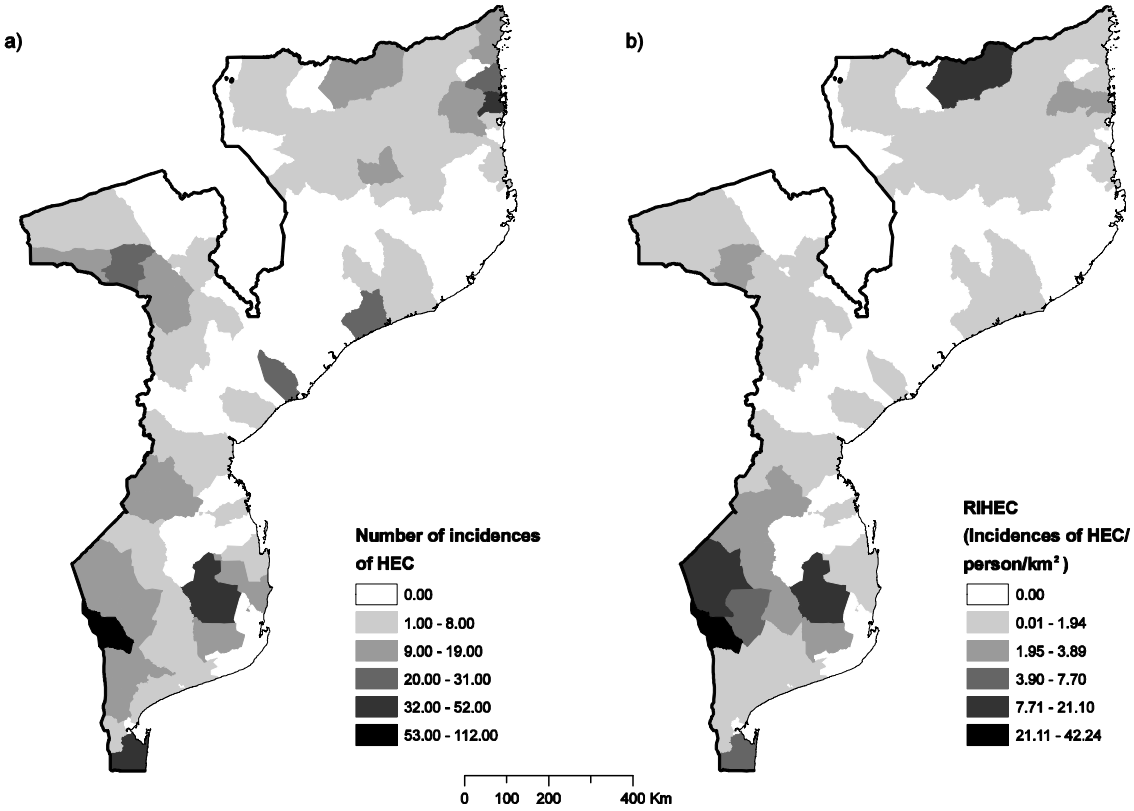

Fig. 2 Line drawings of Mozambique illustrating (a) the number of HEC incidences per district reported from 2006 to 2009, and (b) RIHEC as an index of conflict that corrects for district area and human density.

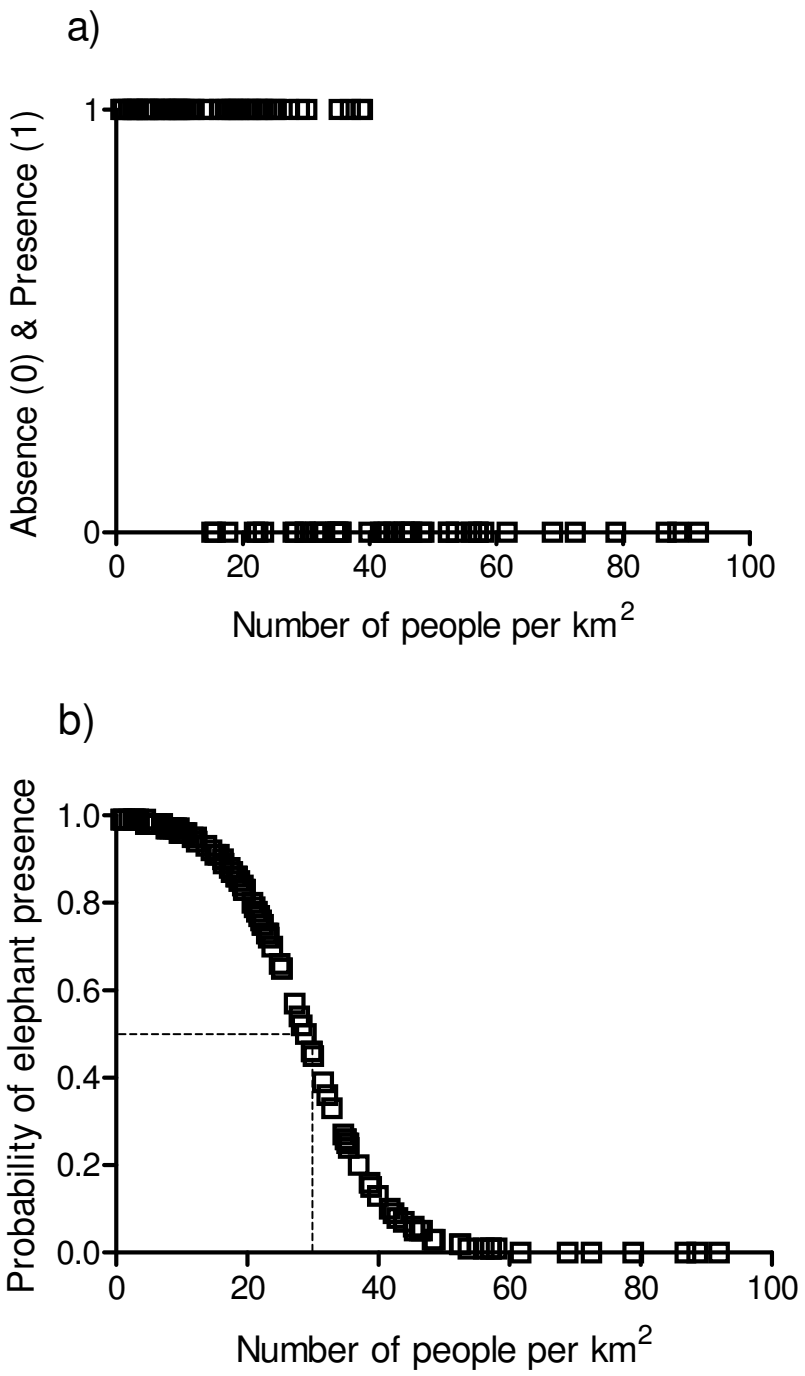

Fig. 3 The presence and absence (a) and the likelihood of presence of elephants (b) as a function of human density (people per km^2) across the rural districts of Mozambique. Likelihood estimates were based on logistic regression analysis.

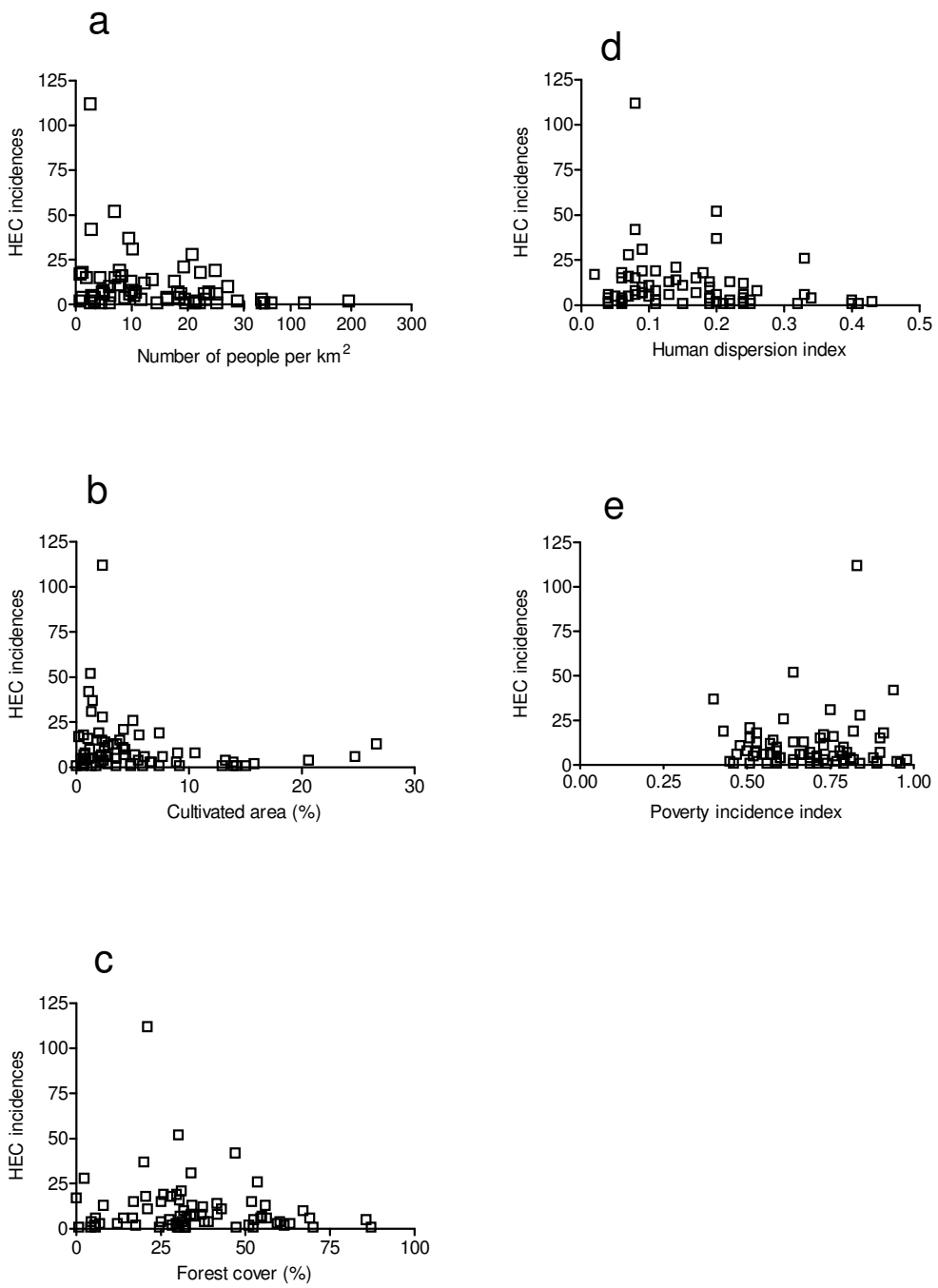

Fig. 4 District specific HEC incidences as a function of (a) human density (people/km^2), (b) cultivation (%), (c) forest cover (%), (d) human dispersion index and (e) poverty incidence index.

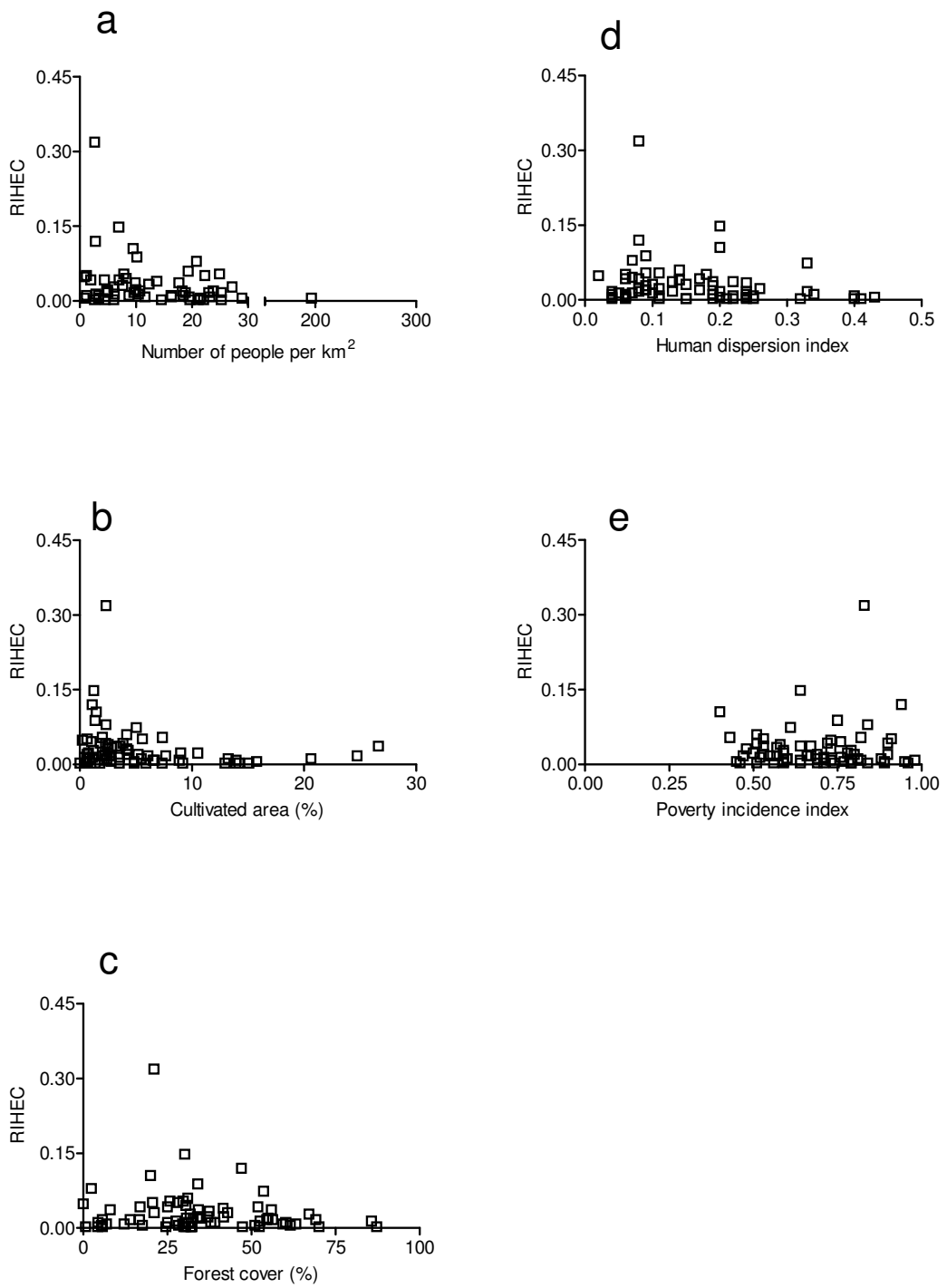

Fig. 5 District specific RIHEC as a function of (a) human density (people/km^2), (b) cultivation (%), (c) forest cover (%), (d) human dispersion index and (e) poverty incidence index.

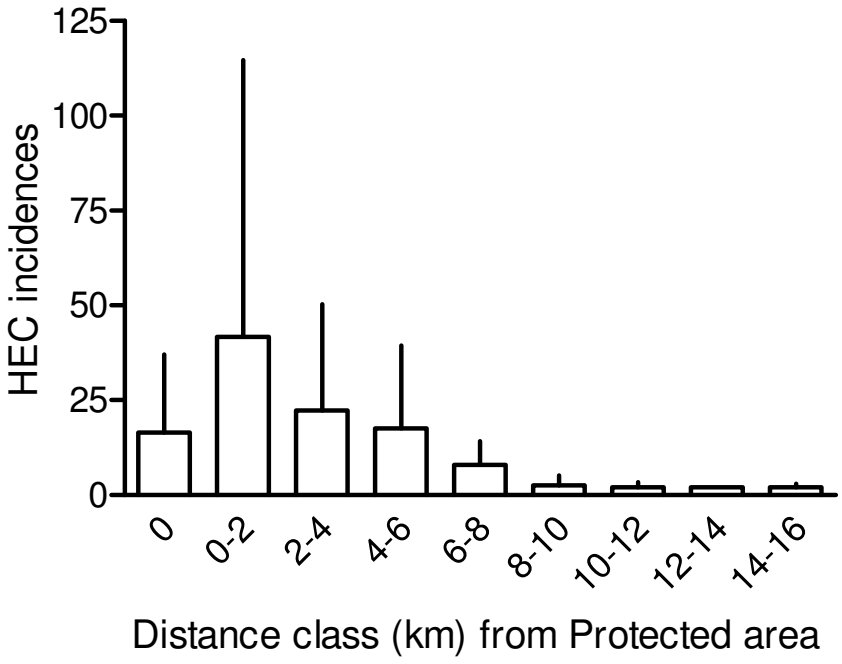

Fig. 6 Mean plus one standard deviation of the mean number of reported HEC incidences as a function of distance from protected areas where the event occurred. I retrieved 696 reports of the locations of HEC incidences from in and around Niassa NR, Quirimbas NP, Gilé NR, Mecubúri FR, Tchuma-Tchato Community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

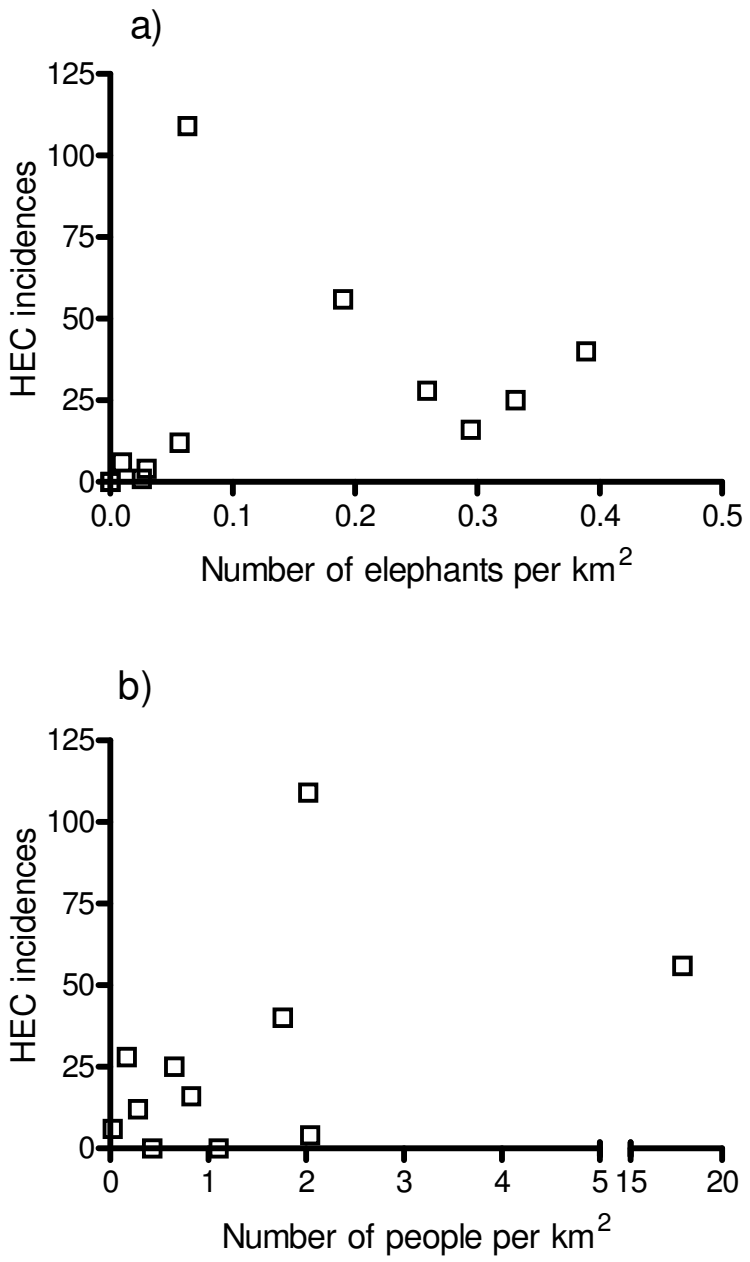

Fig. 7 HEC incidences as a function of elephant density and human density in 10 protected areas across Mozambique where elephants live. Protected areas include the Niassa NR, Quirimbas NP, Gilé NR; Mecubúri FR; Tchuma-Tchato Community Area; Marromeu NR; Gorongosa NP; Chimanimani-Moribane TFCA, Limpopo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