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Research article

The effects of agricultural fields and human settlements on the use of rivers by wildlife in the mid-Zambezi valley, Zimbabwe

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Abstract

After the eradication of the Tse-Tse fly in the Mid-Zambezi valley, human settlements and fields extended mainly along the main rivers. In order to investigate the consequences of this human development on wildlife diversity we monitored three rivers of the Mid-Zambezi valley in Zimbabwe: Angwa, Manyame and Kadzi. The rivers were divided in segments of 200 m which were checked for spoors in order to assess the number of species and the number of individuals that used the segments. Human settlements were also recorded. We used a GIS to define the spatial characteristics of the fields present along the rivers, and related them to the distribution and abundance of wild species spoors in the river beds and banks. Our results show that the number of species in one segment of the river decreased with the increasing size of the field area bordering the segment. For all the major ungulate species, the numbers of individuals recorded per segment decreased with increasing field area. A similar trend was observed for small and medium-sized carnivores, though they were in lower numbers when present. Our analyses thus confirm that the extension of human agriculture in wildlife areas has an impact on most wild species, but we also define some threshold value of field size above which there seem to be an acceleration of the decrease in wildlife density and diversity: 3.2 ha for medium and small herbivores and carnivores; only the elephant seem to tolerate larger field area with a threshold value of 32 ha.

Introduction

Savanna ecosystems in Africa are an important biological and economic resource, but are currently at risk and, as everywhere else on the planet, human activities are the main causes for the loss of biodiversity, chiefly through habitat change and/or destruction (Erhlich 1988). The total savanna area has been reduced dramatically over recent decades, mainly due to conversion to arable fields and rangelands grazed by livestock, a consequence of the ever increasing human demand for resources, and the widespread replacement of nomadic pastoral systems with sedentary agro-pastoral systems (Young and Solbrig 1993). These land uses, particularly the presence of settlements and of intensive or semi-intensive crop farming, have a major effect on the distribution and abundance of wild ungulates, both at the population level (Serneels and Lambin 2001) or at the community level (Prins 1992; Verlinden 1997), mostly causing wildlife populations to decline. The reduction of grazing areas and of access to water sources, and the modification of migratory routes, sometimes to the extent of ending them, are often cited as the most dramatic causes for these declines (Knight et al. 1988; Williamson et al.

1988; Prins 1992; Verlinden 1997; Serneels and Lambin 2001), and today wild ungulates represent only 10% of the total large herbivore biomass on the continent (Owen-Smith and Cumming 1993). The increase in human densities also appear to be the driving factor for the distribution of large predators, either because of direct persecution or reduced suitable habitats and prey numbers (Woodroffe 2000).

In this context, non protected lands are therefore of prime importance for wildlife conservation actions, since they have a crucial place within the ecological network by the importance of the area they cover and their role in the connectivity between protected areas (Bennett 1998). The sustainable management of these areas is therefore considered as a central aspect for wildlife conservation policies (Western 1989; Child and Child 1991; Halladay and Gilmour 1995). These policies require to be built on the understanding of the relationships between wild species and human activities, in space and time; both in terms of human-animal conflict, such as crop raiding or livestock predation, wildlife utilisation by local communities and competition for space and key habitat resources (Newmark et al. 1994; Naugton-Treves 1998; Muchaal and Ngandjui 1999).

The mid-Zambezi valley (Zimbabwe, Zambia and Mozambique) is one of the last remaining wildernesses of southern Africa, with a large proportion of the ecosystems set aside in protected areas (Chenje 2000). Several community-based natural resources management programmes were implemented in order to combine rural development with biodiversity conservation (Chenje 2000). However, after the eradication of the Tse-Tse fly (*Glossina sp*), some areas of the Zambezi valley were opened for resettlement, and the increase in human population was accompanied by an increase in livestock number and agricultural fields (Chenje 2000; Biodiversity Project 2000), as often in similar situations (Stephen et al. 2001). This dynamic of human settlement was questioned in terms of its impact on biodiversity, as human demography is often related to wildlife extinction (Brashares et al. 2001).

This study was part of the Biodiversity Project (Biodiversity conservation with sustainable development in the Zambezi valley after eradication of the Tse-Tse fly), which was implemented in 1996 in the Dande communal area, Zimbabwe, to develop the sustainable use of natural resources for the benefit of local communities (Biodiversity Project 2000), and to assess the consequences of the extension of human activities on the large mammalian diversity of the valley. This project was, and still is, locally integrated through its support to the Zimbabwean CAMPFIRE programme (Communal Area Management Programme For Indigenous Resources), one of the early programme to have promoted the actual involvement and empowerment of rural communities in the management of wildlife resources (Martin 1986; Murindagomo 1989).

After the eradication of the Tse-Tse fly, the major axes of human colonisation of the Mid-Zambezi valley have been the large rivers that provided better alluvial soils and easy access to water. River banks maize, tobacco and vegetable garden constitute perched water table irrigation used in the dry season (Chenje 2000). Areas of cotton fields are also increasing through extensive bush clearing (Biodiversity Project 2001). Consequently, the area covered by human settlements and fields has been multiplied by four within 10 years, mainly along the three main rivers of the area, the Angwa, The Manyame and the Kadzi, and around the village of Gonono (Figure 1). The Manyame is by far the most populated, followed by the Angwa and the Kadzi. The field around the Kadzi seem to be more related to people living in the Gonono area, and mainly used for cattle herding. In this paper, we report the results of the analyses of the consequences of this human development along river beds on the use of these key habitats by wild mammalian species, hence on their diversity and abundance.

Study site

The study area is located in the middle Zambezi valley, in Zimbabwe, between 30° and 31° long. East and 15°30 and 16°20 lat. South (Figure 1). It is a communal land, constituted by three Wards (2, 3 and 4) of the rural Guruve District, in the Dande communal area. The area is characterised mainly by the former floodplains of the Zambezi river basin, at an altitude of c. 400 meters, and drained by three main rivers. The climate is dry tropical, with low and very variable annual rainfalls (on average 450 to 650 mm/year), and mean annual temperature of 25 °C. Two seasons are clearly defined: a rainy season from December to March, and a long dry season from April to November. People and wildlife coexist in this communal land of 2044 km^2, which is characterised by two contrasted habitats: a dense human settlement with crop lands, and a wooded savannah. A total of 13 000 inhabitants live in this area, mainly settled along main rivers,

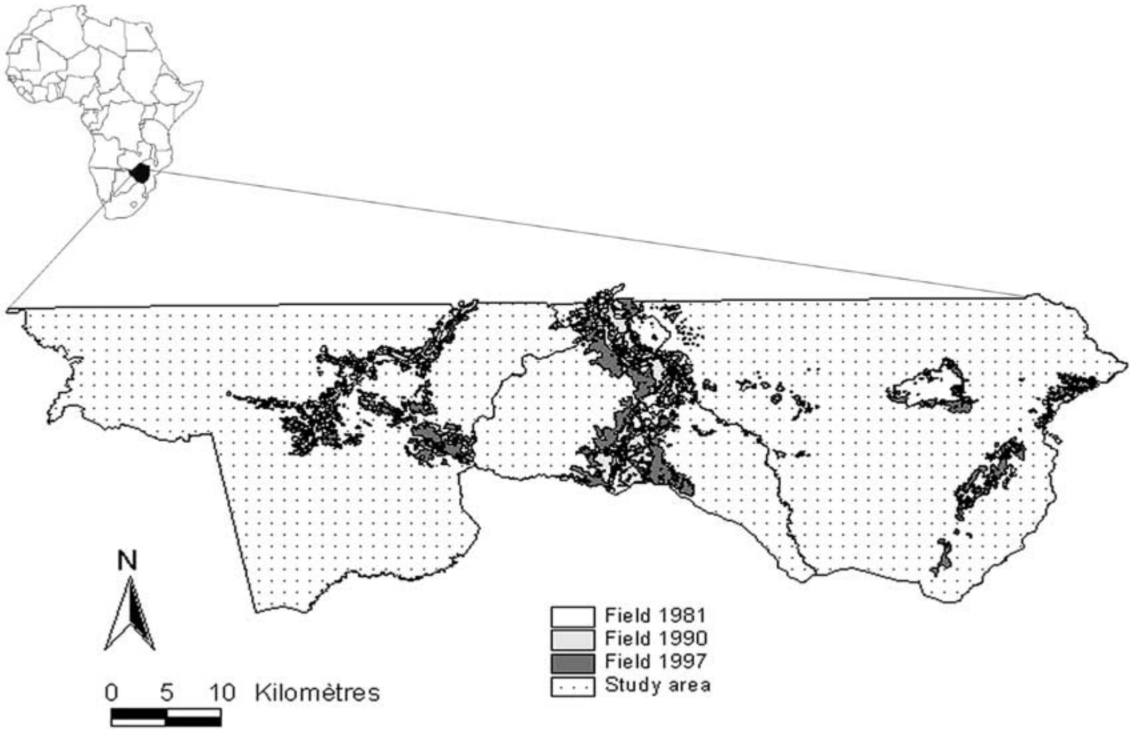

Figure 1. Study area and location of segments per rivers, with map showing the Zimbabwe area in the South–East African.

where farming is their dominant activity (mainly cotton and maize) (Biodiversity Project 2001). Livestock populations are relatively low and localised around settlements, and although cattle numbers have been increasing recently, overgrazing does not appear as a problem yet. The uninhabited areas still cover a large proportion of the valley (83% of the study area), and contain a remarkable species richness, with more than 40 large mammals, 200 birds and 700 plants species (Biodiversity Project 2001). The natural land cover is a deciduous dry savannahs, dominated by Mopane trees (*Colophospermum mopane*) mainly associated with *Combretum apiculatum, C. mossambicense, Commiphora spp., Dalbergia melandoxylon, Diospyros kirkii, Kirkia accuminata, Sclerocarya birrea, Terminalia brachystemma, T. stuhlmannii, T. stenostachya*, and *T. sericea*. The composition and structure of each vegetation type vary with the types of soils, and form a mosaic of woodland and shrubland varying from 4 to 18 meters in height.

Methods

Data collection

The data were collected during the dry season 1996, from July to September. The three main rivers, the Angwa, the Manyame and the Kadzi where divided in segments of 200 m, and in each segments the banks and the river bed were inspected for spoors in order to assess the number of species, the number of individuals per species that used the segments. The total number of segments was 166 for the Angwa, 140 for the Manyame and 157 for the Kadzi. Human settlements and signs of activities (traps, nets, fire places. . .) were also recorded. Four persons, including three professional trackers, took part in this monitoring. To make sure that the number of groups per species, and the number of individuals per group, were assessed as accurately as possible, individual spoor trajectories were reconstituted. The spoor was qualified as fresh ($\leq$ 48 h), intermediate ($\leq$ 7 days) and old ($>$ 7 days). Only the two first categories were used in the analysis. All spoors were identified at the species level, except for mongooses. However, because of the small sample size, and in some instance difficulties in identification, African wild cat, genet cat, mongooses were grouped as small carnivores, and jackals, serval cat, caracal, civet cat and honey-badger were classified as medium carnivores. The species concerned ranged from mongooses to elephants, including large carnivores such as lions or leopards (Table 1). This methodological approach using tracks and spoor has proven very efficient in studying rare and shy animals (Stander et al. 1997; Stander 1998), and we are confident that with our experienced team, the information collected were reliable.

Spatial analysis

A Geographical Information Systems (GIS) program, ArcView 3.2 (Mitchell 1999), including both vector and raster modules was used in this research. A primary coverage was developed which contained the study area (3 wards) as defined by latitude and longitude, the Zambezi valley, and the limits of the different arable fields (1981, 1990 and 1997) (Figure 1). An additional coverage, in point format, was created for the 200 m segments of the river and contained the information about animal species. The perimeter and area of each field was measured using ArcView 3.2, as well as the distance between each river segment and the nearest field.

Statistical analysis

We first used a GIS to define field characteristics such as surface and perimeter and then investigated their influence on the diversity of species present in each segment. Then we determined the probability of presence of the species in a segment in relation to field characteristics, using logistic models (Austin et al. 1984; Ter Braak 1985; Ter Braak and Looman; 1986, Huisman et al. 1993; Woodroffe 2000). The model used supposes a sigmoid response of the species, and is written:

$$\text{pr (j presence/x,y)} = PE_j(x,y) = \exp(a + b.x_i)/(1 + \exp(a + b.x_i))$$

Where $PE_j(x,y)$ is probability of occurrence of each species as function of a quantitative variable avoiding any assumption about the form of the species sigmoid response, a is a constant, b values of parameter equation, x_i, values of significant explanatory variables (Austin et al. 1984;Ter Braak 1985; Ter Braak and Looman 1986; Huisman et al. 1993; Oldland et al., 1995).

Finally, we investigated whether the number of individuals per species was influenced by field characteristics. The effect of field characteristics on the number of species and the abundance of individuals per species were analysed using regression analyses on STATVIEW F-5.0 software. Graphical analyses included non-parametric techniques such as species richness and locally weighted sequential smoothing (LOWESS; Cleveland 1979; Trexler and Travis 1993). LOWESS is non-parametric local least squares graphical procedure that was developed to be a robust means of finding patterns in refractory data (Cleveland and McGill 1985). In this study, LOWESS is used to help determine the unbiased form of the relationship between human agriculture and wildlife density or diversity.

Some species, such as large carnivore species, where only used in the analysis on species richness, as the number of contact was to low to allow for any specific statistical analysis. Our statistical unit was the segment, however the number of species and the type of species may not be independent from one adjacent segment to the other. To account for this potential bias, we ensured that all tracks that were crossing several segment were only counted once, in the segment where it first entered the river bed. Further, we performed a control random draw of a set of 80% of segments per rivers, taking care not to over-represent the segment without wildlife records. Over-representation of zero values are known to cause difficulties in analysing habitat or resource use or preference (Manly et al. 1993; Elston et al. 1996). In some of the analyses, the sample size may vary due to the absence of some information related to some species. When the distribution of values differed from normality, variables were $\log_{10}$-transformed.

Results

At first, it appears that the more heavily populated river, the Manyame has less species, 15, than the two others 22 and 18 for the Angwa and the Kadzi respectively. This is consistent with the fact that the number of wild species recorded per cluster was mainly affected by the presence of settlements, the number being higher in cluster with or without indices of human activities than in cluster with activities and settlements (Figure 2)

Of all field characteristics, only the area had an effect on wild species distribution and abundance. The

Table 1. Species and categories recorded during the river survey.

Species	Category (if needed)	Number of segments where present*
Cane rat (*Thryonomys swinderianus*)		101
Baboon (*Papio ursinus*)		225
Bushbuck (*Tragelaphus scriptus*)		226
Buffalo (*Syncerus caffer*)		206
Duiker (*Cephalophus grimmia*)	Small antelopes	287
Sharpe's Grysbok (*Raphicerus sharpei*)	Small antelopes	–
Steenbuck (*Raphicerus campestris*)	Small antelopes	–
Impala (*Aepyceros melampus*)		129
Kudu (*Tragelaphus strepsiceros*)		154
Elephant (*Loxodonta africana*)		359
Eland (*Taurotragus oryx*)		48
Porcupine (*Hystrix spp.*)		98
Roan antelope (*Hippotragus equinus*)		7
Sable antelope (*Hippotragus niger*)		27
Vervet monkey (*Cercopithecus aethiops*)		140
Warthog (*Phacochoerus africanus*)	Wild pigs	127
Bushpig (*Potamochoerus porcus*)	Wild pigs	–
Zebra (*Equus burchelli*)		5
Leopard (*Panthera pardus*)		4
Lion (*Panthera leo*)		4
Lycaon (*Lycaon pictus*)		8
Spotted Hyena (*Crocuta crocuta*)		33
Serval cat (*Felix serval*)	Medium carnivores	311
Caracal cat (*Felix caracal*)	Medium carnivores	–
Civet cat (*Viverra civetta*)	Medium carnivores	–
Black-backed Jackal (*Canis mesomelas*)	Medium carnivores	–
Side-stripped Jackal (*Canis adustus*)	Medium carnivores	–
Honey badger (*Mellivora capensis*)	Medium carnivores	–
African wild cat (*Felis libyca*)	Small carnivores	269
Genet cat (*Genetta trigrina*)	Small carnivores	–
Mongooses	Small carnivores	–

species richness, log(biodiversity), decreased with increasing field area in the three rivers (Manyame: n = 60; $R^2 = 0.72$; p < 0.0001; F = 97.585, Angwa: n = 144; $R^2 = 0.88$; p < 0.0001; F = 1220.237 and Kadzi: n = 96; $R^2 = 0.91$; p < 0.0001; F = 605.421) (Figure 3).

The relationship between log(biodiversity) and log(area) differed between rivers (ANCOVA F = 367.137, P < 0.0001) with the Kadzi river markedly different from the two others (Kadzi vs Angwa, F = 260.928, P < 0.0001; Kadzi vs Manyame, F = 61.076, P < 0.0001). The slope from Angwa did not differ from that of Manyame (F = 0.195, P = 0.66), but the y-intercepts did (F = 123.549, P < 0.0001): for a given field area the segments of the Angwa have a greater number of wildlife species (Figure 3).

Consistently with the pattern found for species richness, the probability of presence of species (herbivores and carnivores) declined with patch (area) size (Table 2). Small and medium carnivores had a similar probability function but there were some differences between the main five herbivores species (Figures 4 and 5). The probability of presence of elephants tended to decline slower than for the other species. For impala, the probability remained high longer than for kudu and small antelopes, but dropped very quickly

Table 2. Results of the logistic regressions describing the probability of presence of wild species in relation to log(area). We only calculated the regression for species with large enough sample size.

	b	a	Chi 2	Maximum likelihood ratio	p
Babouin	4.562	−1.02	23.128	−4.809	<0.0001
Buffalo	1.434	−0.196	1.329	−1.153	0.2491
Bushbuck	2.698	−0.45	6.639	−2.577	0.01
Eland	5.541	−1.767	14.319	−3.784	0.0002
Elephant	5.39	−0.926	28.707	−4.646	<0.0001
Impala	9.468	−2.319	40.695	−6.379	<0.0001
Kudu	4.144	−1.046	20.226	−4.497	<0.0001
Medium carnivore	6.292	−1.223	32.071	−5.663	<.00001
Small antelope	4.631	−0.972	22.924	−4.788	<.00001
Small carnivore	4.103	−0.796	17.695	−4.207	<.00001
Vervet monkey	5.357	−1.386	25.203	−5.02	<.00001
Wild pig	4.231	−1.136	19.67	−4.435	<.00001

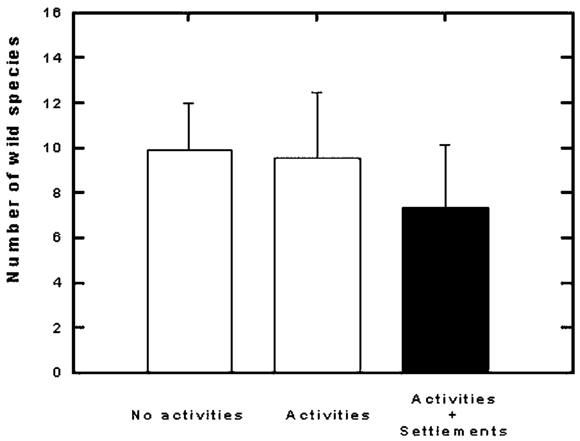

Figure 2. Average number of species per river segment differing in human activities and presence.

after 1000 m^2, i.e. 0.1 ha (Log(Area) = 3.2). Kudu and small antelope appeared to cope better with the increase in field size (Figure 4).

For the main herbivores species, the number of individuals recorded for the different species decreased quickly with an increase in field area (Figure 6), to reach their minimum value (close to 0 in some instances) after a field size threshold of 3.2 ha (Log(Area) = 4.5). Only elephant numbers remained reasonably high above this threshold, although they also decreased, until they reached a second threshold value of 32 ha (Log(Area) = 5.5).

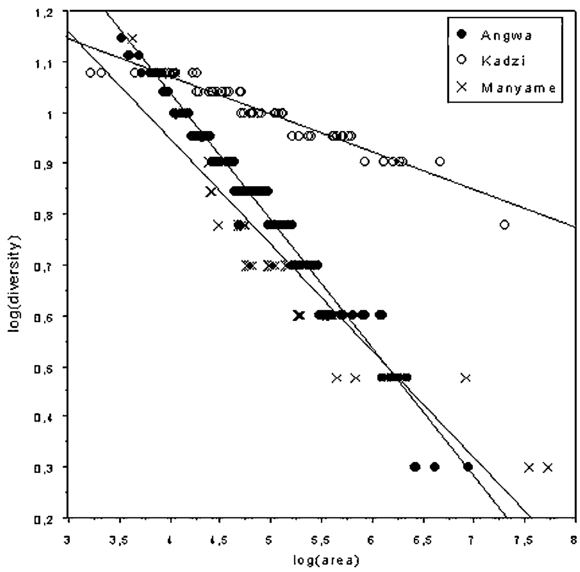

Figure 3. Relationship between species richness (biodiversity) and log (area) per rivers. The equations for the three rivers are: log(diversity) = 2.044 – 0.252* log(area); R^2 = 0.968 (Angwa); log(diversity) = 1.365 – 0.074* log(area); R^2 = 0.937 (Kadzi); log(diversity) = 1.787 – 0.21* log(area); R^2 = 0.856 (Manyame).

Discussion

Our analyses shows that the extension of human agriculture in wildlife areas has an impact on most wild species, but we also define some threshold value of field size above which there seem to be an acceleration of the decrease in wildlife density and diversity.

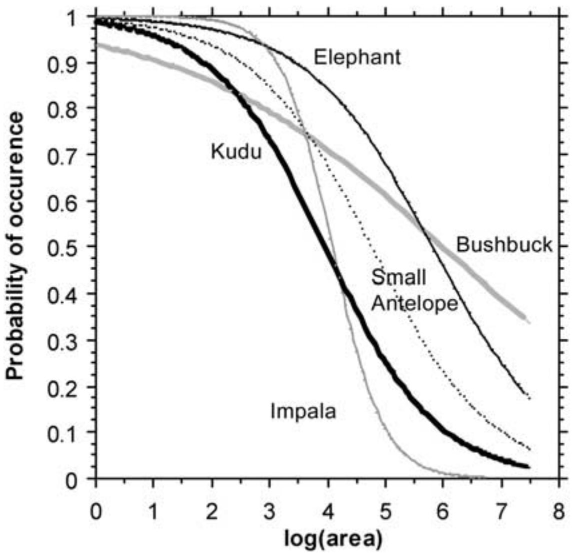

Figure 4. Response curves for Impala, Kudu, Elephant, Bushbuck and Small antelope as a function of the log(area).

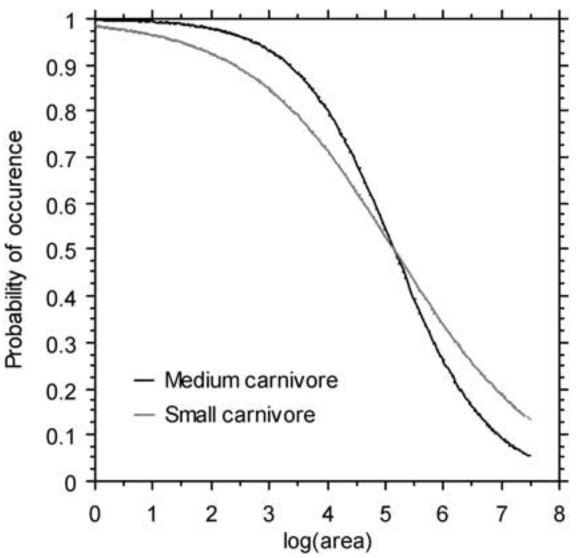

Figure 5. Response curves for Small and Medium carnivore as a function of the log(area).

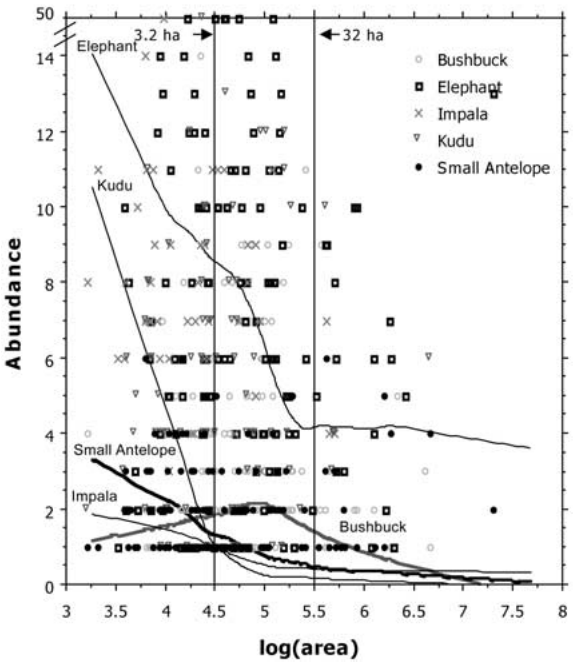

Figure 6. Relationship between the abundance of individuals and field area for the main five ungulate species. The relationship is depicted by the curved lines obtained from Locally-linear Weighted Regression Scatterplot Smoothing (LOWESS, 66% (Cleveland 1979; Trexler and Travis 1993, see method) and the points are abundance for each species.

This value appears to be around 3.2 ha. Field size appeared to be a good indicator of the expansion of human agriculture, and hence of the loss of savanna habitat, but also of the restriction in movement for animals as fragments of woodland diminish and the corridors between them disappear (Mörtberg 2001). However, the effect of human presence along the rivers certainly is a combination of processes. The increase in field area first reduces prime habitat for ungulates, such as riverine thicket. These habitats are key habitat for food in the dry season but also for cover. The fact that the human presence is concentrated along rivers also reduces the access to water points, either permanent ones, or those dug by elephants, a key resource in the dry season for most ungulates (Ayeni 1975). The increase in field areas also correspond to an increase in human population density, which can be associated with an increase in hunting pressure, especially during the dry season, and in dry years when the agriculture production is limited.

There was a marked difference between the rivers in terms of the relationship between field size and species diversity. The difference between the Kadzi and the other two rivers may be due to the fact in the Kadzi, there are fewer settlements with the fields, hence a lower density of people staying permanently along the river. Although the slopes are the same between the Manyame and the Angwa, the proportion of segments having at least one species was however much lower in the Manyame compared to the Angwa (15% vs 65%), and the number of species in any segment for a given field area was always greater in the

Angwa. These results seem to indicate that human presence (settlements) associated with fields is the major driving factor in terms of large mammal diversity in the area.

The consequences of human impact will depend on the requirements of species, and hence the level of habitat selectivity but also the home range and migration behaviour are likely to lead to different results. The concept of minimal critical area is now increasingly used to assess the potential impact of anthropogenic activities and habitat changes on mammalian diversity (Allen et al. 2001). Small antelopes such as duikers are known to be able to cope relatively well with human agriculture, as their elusive nocturnal habits and limited food and water requirements do not expose them to severe human persecution or competition with livestock. These species are however known to be victims of snaring in most communal area, as they may provide additional meat as in forested area (Newing 2001). The kudu, although a large ungulate, also has minimal water requirements and being mainly a browser, rarely enters in competition with livestock (Fritz et al. 1995). The bushbuck is also a browser but is largely dependent on riverine habitats, and hence suffers from the clearing up of its prime habitats. The impala seem to be the most affected of the common ungulate species. The strong water requirement of this species may explain why the animal tends to move away from human areas when these obstruct their access to water. As the area of field increase, the density of people also, and hence the pressure on wild species.

The limit of size for the absence of elephant is 32 ha whereas for the smaller ungulate it is 3.2 ha. Hence these megaherbivores do not seem to be as susceptible to human presence as the other ungulates. The small carnivores and medium carnivores were in low numbers when present, but interestingly, their threshold value of field area surface was the same for both categories of carnivores, and similar to that of medium and small ungulates, i.e. 3.2 ha.

Large carnivore, as often in communal areas, were at low densities, which did not allow any analysis, even in terms of presence absence. However, the medium and small carnivores seemed to cope well enough to allow a probability function to be calculated. As for most carnivores, there was a logistic decrease with increasing human activities and density, here represented by the increase of field area (Woodroffe 2000).

The ever increasing development of fields along the Manyame river will eventually lead to the constitution of a true barrier for wildlife species which not only will see their access to water resources reduced, but will also not be able to cross from one side to the other. In the context of the Zambezi valley, this could be detrimental for some areas, which could be completely isolated from their sources of wildlife: the protected areas at the western end of the study area. This may be the case already, as some species are already showing large difference in densities between the East and the West of the Manyame river (e.g., Biodiversity Project 2001; Gaidet et al. unpublished ms). In addition to the conservation problem, this could also be an economic one, as a large share of the revenues are generated by wildlife in these remote areas (Cumming 1993). Most of the revenues from wildlife come from safari hunting (Lewis and Albert 1997), and if the densities decrease too much, the activity may not be viable anymore, and the incentive for the maintenance of healthy animal populations amidst human agricultural field will be lost.

The understanding of the relationship between human agriculture development and wildlife is both important in terms of assessing the threat to wildlife diversity but also to define areas for potential human-animal conflict, such as crop raiding elephants (Hoare 1999). GIS approaches are increasingly used for assessing rate of land use changes and potential areas of conflict between wildlife and human development, often at the regional level (Leeuw et al. 2001), as it allows to define landscape features, such as fragment size or isolation, that may lead to dramatic diversity loss or drastic changes in ecosystem functioning (Fox and Fox 2000; Mörtberg 2001). In our study, the combination of simple monitoring methods and GIS has also proved very useful in identifying and defining a simple key feature in a rural anthropogenic landscape such as a communal area in African semi-arid savanna.

The multispecies approach is crucial in this context since the diagnosis of human impact cannot be assessed through monospecific study only, as species may have very different responses. This is the reason why methods using indicator species or guilds have been developed (Landres 1983). In African savannas, the large herbivore guild is a good indicator of the potential biodiversity, as herbivore play an essential role in the functioning of the ecosystem (Cumming 1982). Large reductions in large herbivore diversity are thought to be linked to substantial decrease in savanna diversity through long-term changes in ecosystem structure and functioning (du Toit and Cumming 1999).

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