Assessing the Spatial Patterns of Crop Damage by Wildlife using GIS

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Introduction

Damage caused by wildlife to human economic activities is a serious problem to wildlife conservation efforts. In Africa, most of the people whose farming activities are often impacted by the presence and abundance of ‘problem’ wild animal species are the resource poor local subsistence farming communities, and in some cases, commercial farms adjacent to wildlife habitats. Reports of crop damage caused by wildlife on crop farms are associated with interactions between humans and wildlife, mainly through the alteration of the wilderness landscape resulting from expansion of human activities which encroaches on wildlife habitats or the establishment of conservation areas in close proximity to human livelihood activities such as crop farming. This alteration of the wilderness landscape has a direct or indirect influence on wildlife foraging preference and patterns of foraging (Hoare & Mackie 1993). Wild animal damage to farming activities, including crop raiding requires an understanding of the spatial dynamics of the damage, how this damage impacts on individual farm activity, and the implications on wildlife management. This understanding can be in form of socio-economic concerns of crop damage caused by ‘problem’ wildlife species, temporal patterns and spatial patterns of crop damage. An understanding of the spatial aspects of wildlife-crop damage assessment is very crucial for wildlife conservation planning, and human-wildlife conflict management in and around the protected areas (Fielding & Bell 1997).

Documented studies on wildlife crop raiding provide relatively high assessment of the socio-economic concerns, the temporal patterns of wildlife visitation in crop farms and the consequences, such as crop damage (Nevo & Garcia 1996:1-2; Ferraz *et al.* 2003). However, the actual amount or area of crop damage and the spatial variations in crop raiding incidences are infrequently studied. Although GIS spatial capabilities undoubtedly offer valuable potential for wildlife management, the application of GIS in wildlife crop raiding assessment is also rare (Smith & Kasiki 1999). This deficiency is inherently evidenced in the academic literature as geographers who studied environmental hazards in the past emphasise modelling the geophysical environment of wildlife habitats (Barnes *et al.* 1995).

In the recent few decades, advances in computer information technology and developments in the spatial sciences, Geographical Information Systems (GIS) have provided enormous opportunity for spatially explicit modelling of the environment. The capability to assess attribute data linked with geographic information is now a predominantly easy task to perform (Sitati *et al.* 2003:1).

In few recent academic publications, there has been a significant increase in interest in the incorporation of spatial analysis in human-wildlife conflict assessment to predict the spatial patterns and the extent of damage caused by wildlife in crop farms using spatial analytical capabilities afforded by GIS and Remote Sensing (RS) (Dolbeer *et al.* 1996; Sitati *et al.* 2003; Ferraz *et al.* 2003; Tatsuya *et al.* 2007). This increase can be attributed to the increasing social and economic importance of the human-wildlife conflicts which is a prominent feature of wildlife management.

The spatial analytical capabilities, data manipulation and data storage characteristics of GIS provides an effective and efficient means to manage the kind of information required to understand spatial patterns of wildlife damage (Davis 2001:157-187). The involvement of communities through participatory GIS enhances a better understanding of the nature of conflicts as well as improving mapping accuracies.

This study provides a brief history of the human-wildlife conflicts as a result of crop raiding and highlights the importance of GIS in assessing spatial patterns of crop damage. An illustration of the application of GIS in combination with participatory mapping on eland damage in commercial agricultural farms adjacent to Kamberg Nature Reserve (KNR) in KwaZulu-

Natal Province of South Africa is provided. Implications of the study for management purposes are discussed.

Crop Damage by Wildlife in Retrospect

For several centuries agriculturalists in Africa shared the landscape with wild animals (Naughton-Treves 1998:156-159). Traditionally, farmers were balancing crop loss to wildlife with bush-meat gains by trapping animals in and around their fields. Other strategies included planting widely dispersed fields, guarding, and rotational planting (Naughton-Treves 1996). Nonetheless, crop damage by wildlife, particularly larger mammals, such as elephants prevented cultivation of some arable lands (Vansina 1990:71-99).

The linked strategies of farming and other traditional controls were decoupled across the African continent when colonial authorities prohibited certain local control measures such as hunting and use of poisonous substance to deter animals, and declared most wild animals as protected species (Graham 1973 cited in Naughton-Treves 1996). A colonial game management department in most African states protected wildlife in national parks and natures reserves.

For many decades the combined impact of colonial wildlife resources exploitation, the ivory trade, deforestation, and civil war removed or displaced large animals from their natural dwellings. Surviving wildlife is therefore isolated in patches of protected areas (Howard 1991). Few farmers today have contact with large wild animals unless they farm near the human-made islands of so-called protected areas.

Human-wildlife conflicts around protected areas continue to be a growing challenge in contemporary conservation, especially when attempts are made to balance global environmental goals with local residents' livelihood activities. As a result, integrating wildlife conservation with other land-use options is difficult, particularly where densely settled agricultural land are adjacent to a protected area. Large or potential damage-causing 'problem' animals impact on agriculture in several parks and reserves in Africa (Dolbeer *et al.* 1996). This loss has an immense social significance which may best be understood in terms of vulnerability, which is broadly defined as the potential for loss (Matzke & Nabane 1996; Liverman 1990).

Despite the growing attention to human-wildlife conflicts around protected areas, uncertainty persists about the actual magnitude of the problem especially in terms of understanding the spatial patterns of the damage (Dudley *et al.* 1992:118). Most published research on crop damage by wildlife around protected areas is based on interviews with farmers with deficiency in the spatial quantification of crop damage by the suspected wildlife species (Hill 1993). Social research studies thus offer valuable insight, particularly into the human perceptions of crop loss but lacks the spatial context.

In some cases, attempted spatial investigations have revealed a disparity between reported and observed damages, with farmers most often overestimating the amount of crops lost to wildlife (Hill 1997). Other studies introduce error when researchers try to extrapolate verbally observations from a single site to an entire park or reserve because the areas of crop damage within the crop fields are either inaccurately mapped or are poorly predicted without any clear environmental considerations in the affected fields.

As a result of paucity of accurate information, some technical experts from conservation departments claim that local farmers exaggerate crop damage in hopes of compensation (Bell 1984), and claim that mega-fauna, such as elands, elephants or rhinoceroses, are unjustly blamed for crop raiding (Hawkes 1991).

Although surrounding crop farms may confine wildlife to meagre patches of protected natural habitat, local farmers are unlikely to bear crop loss without complaint. At sites where the risk of damage is perceived to be significant, farmers may be hostile to wildlife. The complaints of neighbouring farmers have led park managers to invest large sums of money to prevent wild animal crop raiding and livestock predation (Hoare & Mackie 1993).

Whereas the bitter complaints of farmers capture the attention of protected-area managers, only rarely is the actual impact spatially assessed, or the prevailing environmental factors tested in order to predict such damages. The absence of this information hinders effective management and accurate comparisons between farms which results in deficiency of appropriate policy formulation.

Hoare and Mackie (1993) assessed ‘problem’ animal control and management of wildlife populations in the communal lands of Zimbabwe, and found out that generally crop damage incidences occur on farms that are in close proximity to wildlife habitats or located mainly in wildlife migration corridors more than on crop farms located further from wildlife habitats. This suggests that there is a spatial variation between the location of crop fields and the susceptibility of farms to crop raiding incidences. An understanding of the geographical patterns of human-wildlife interaction is crucial for conservation planning, which forms an integral part of formulation of conservation policies and decision-making. In this regard, an assessment of human-wildlife interaction, such as information on crop raiding caused by wild animal species, requires acquisition and analyses of both spatial and attributes data. The role of GIS and RS methodologies as an approach to assess the spatial aspects of crop damage provides valuable tools to study the spatial variations of human-wildlife interactions.

Measuring the Extent of Wildlife Damage on Crop Fields

People often perceive that wildlife can damage up to 100% of agricultural production (Perez & Pacheco 2005), especially where there are no adequate buffer zones and/or absolute barriers. It is vital to gain a thorough understanding of the spatial patterns of animal damage in order to develop and direct mitigation strategies. Most studies evaluating wildlife damage in crop fields are based on surveys that gather information from the affected people and/or point estimates in the damaged crop fields (Perez & Pacheco 2005).

It is inevitable to estimate the extent of crop raiding incidences without incorporating the spatial aspects. Spatially explicit assessment of crop raiding incidences is pivotal to the quantification of crop losses to wildlife and the related management implications. Sitati *et al.* (2003) studied wildlife impact on adjacent crop farms (predicting spatial aspects of human-elephant conflict) and indicated that although temporal patterns of crop raiding by wildlife is relatively predictable, mapping the spatial variations exhibits specific trends, indicating where such damages will take place, and at predicted severity. Furthermore, affected people whose farms and/or properties are raided by wildlife may provide imprecise and biased information because of lack of direct experience in measuring the damage, or their personal feelings towards wildlife. Damage caused by wildlife to crops in many developing countries in sub-Saharan Africa is not only poorly assessed, but the spatial configuration of crop damage is not well understood. Conflicts usually take place close to protected areas and they also occur between dusk and dawn, and for crop raiding in particular, it is usually seasonal (Sitati *et al.* 2003). Systematic spatial and temporal studies of the human-wildlife conflict have scarcely been studied.

Recent technologies such as Geographical Information Systems (GIS), and Global Positioning Systems (GPS) and Remote Sensing (RS) are being used in combination for the input, storage, manipulation, analysis, and display of geographic information and its associated attribute data (Coulson 1992). These spatial techniques provide an effective and efficient means of generating habitat spatial information as well as more accurate measures of damage caused by wildlife (Anderson 1996).

GIS is increasingly being used in combination with habitat models as a source of environmental variable predictor and as a method of displaying model results. With advances in computer technology and an increasing interest to understand spatial relationships within wildlife habitat ecology, GIS technology has become increasingly useful in wildlife management and research. Recently, further advances in the acquisition of digital remotely sensed image data such as hyperspectral remote sensing provides a valuable source of data for the modelling of wildlife-crop raiding incidences (Austin *et al.* 1996).

Using GIS and RS, it is possible to accurately locate and map planted fields and crop damage sites. The use of these technologies offers advantages in conservation research and implementation of damage control strategies. Identifying and categorising patterns of damage, assessing the severity and refining the application of control tactics can all benefit from GIS/GPS, and RS technology (Goodchild *et al.* 1993; Adams & McShane 1992. The involvement of communities, through participatory GIS helps a great deal in tapping the socio-economic knowledge of conflicts and this can then be represented it in a spatially explicit context.

In Piracicaba, Brazil, GIS have been used to describe and quantify the actual damage caused by *Capybaras* in a corn field. The aim of that study was to get basic information on how much damage, and where the damage occurred. The GIS allowed for mapping of individual patches where crop damage occurred to be plotted into an aerial topography map. Crop damage percentages were interpolated by the linear krigging method to obtain a map of spatial distribution and the predicted pattern of crop damage for the study area (Ferraz *et al.* 2003).

In the Masai Mara National Park of Kenya, spatial aspects of human-elephant conflicts were spatially predicted using GIS. A grid-based GIS was built with a 25 km^2 resolution utilising cost-effective data sources, combined with simple statistical tools (Sitati *et al.* 2003). The model could successfully predict the spatial aspects of crop raiding in local communities adjacent to the Masai Mara National Reserve (Sitati *et al.* 2003). Tatsuya *et al.* (2007) modelled the conflict between agricultural production and white-fronted geese using a behaviour-based model. The spatially explicit model could track the day-to-day spatial distribution of geese and their physiological dynamics.

In other studies, birds have exhibited considerable spatial and temporal patterns in their crop raiding (Tourenq *et al.* 2001). This has enabled appropriate management and mitigation measures to be strategically applied.

Mapping Crop Damage in the Kamberg Nature Reserve

We illustrate the utility of participatory GIS to map areas damaged by elands (*Taurotragus Oryx*) in farms adjacent (Allendael, Reekie Lynn & Riverside farms) to the Kamberg Nature Reserve (KNR) of KwaZulu-Natal (Figure 1).

It has been noted that the movement of elands into farms and crop raiding incidence report continues although eland fencing has been erected to prevent the ‘problem’ animals from crossing the KNR boundary. Crop damage caused by elands in farms adjacent to the KNR impacts on the economic activities of the farmers, and elands themselves are endangered to poaching when found outside the boundaries of the KNR.

This study is based on an Eland Crop Raiding (ECR) data collected in the field, and the use of aerial photography. The data was analysed in two main approaches, with the first set of analyses comprising data pre-processing tasks involving data preparation and digitising of polygons describing the relevant cultivated fields adjacent to the KNR. This was done in order to collect the necessary information on which specific crop fields were affected by ECR incidences.

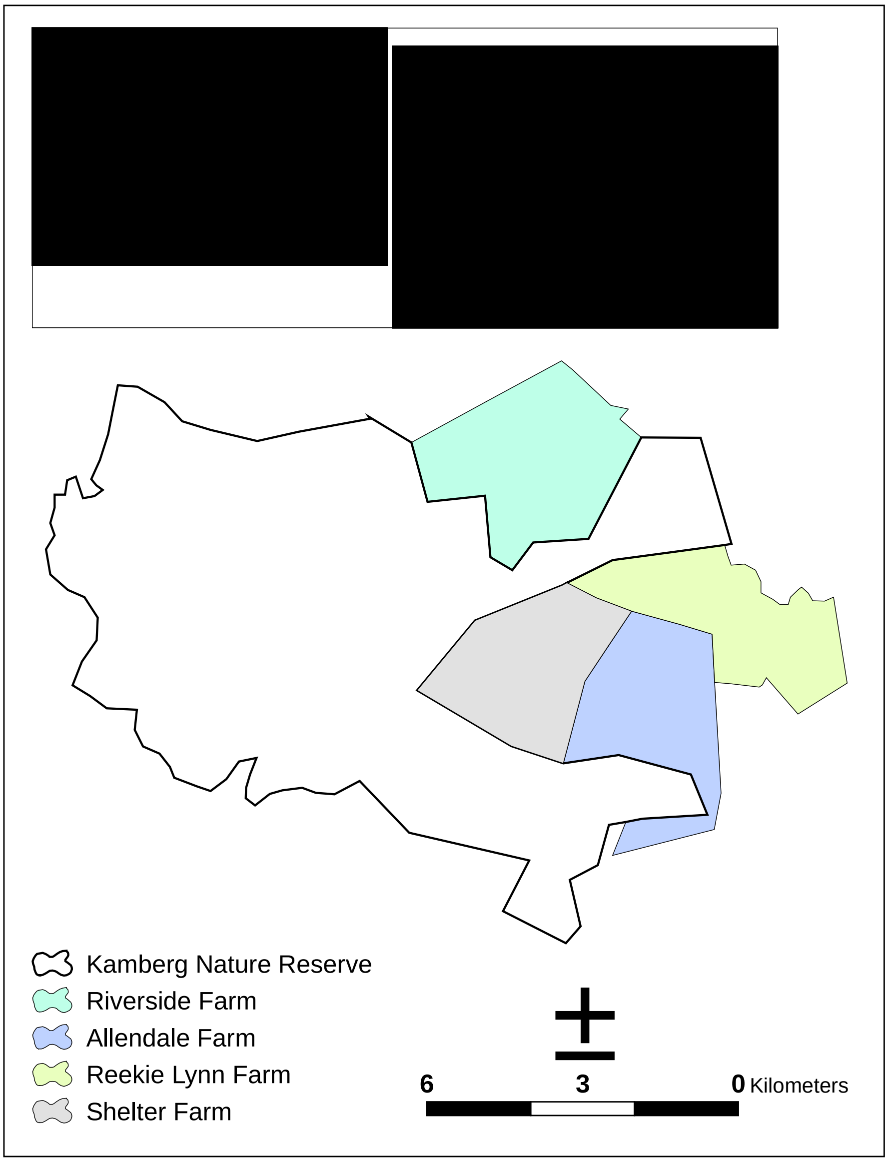
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Figure 1: Location of the study area in KwaZulu-Natal Province

The second analysis investigated the distance or proximity, and the patterns of the mapped crop damaged field polygons from different environmental features located within or outside a farm. In this section, the actual area of ECR incidence in the study area was calculated. All the analyses procedure used data that were either collected in the field or derived from the aerial photographs, and other relevant GIS coverages.

Field data collection was conducted using Garmin GPS equipment. Eland visitation in crop fields was surveyed by administering crop raid report forms to farmers, complemented with GPS recordings of the raided fields. Field visits were conducted twice a week in April through to August 2006 and polygons of damaged areas mapped with a GPS. Distinctive foraging characteristics of elands in maize crops, tracks and tooth marks descriptions were used to verify eland presence and absence in the affected fields (Perez & Pacheco 2005:2-4).

To establish a reliable and independent crop-raiding incident reporting system, information on where and when crop-raiding occurred was gathered from the farm managers, and five employees for each of the three farms were consulted for triangulation with data from the owners (Hoare & Mackie 1993). This was done to circumvent the problem of over exaggeration of crop-raiding incidents (Sitati *et al.* 2003).

The use of crop fields by elands was characterised by large amount of vestiges such as footprints and dung, and also by direct observation of the animals in crop fields. Damages observed included broken fences as well as partly eaten and completely eaten maize stands. We used farmers' expert knowledge greatly in identifying areas visited by elands through footprints and bite types.

Distinctive foraging characteristics of elands in maize crops, tracks and tooth marks descriptions were used to verify eland presence and absence in the affected fields (Perez & Pacheco 2005). Damage sites were calculated as the percentage of the total cultivated area raided for each crop field and crop type. The temporal aspects of eland visitation in farms as noted earlier was surveyed from farm managers and farm employees (N=6 in total). The frequency (rate) of visitation was calculated as the number of observed visits divided by the total number of fields sampled for crop damage incidents.

Maize and pasture damage caused by elands in the sample fields was evaluated by recording X, Y coordinates of the affected fields by applying a form of household questionnaire sampling method. The affected areas were located in Universal Transverse Mercator (UTM) coordinates system using a Garmin GPS point navigation unit. The (X, Y) coordinates of the affected areas were imported into ArcGIS v9.1 software package for manipulation prior to analysis. Separate shapefiles were created for both damaged maize and pasture fields raided by the elands. A total of 125 coordinate points were collected for analysis. Damaged maize and pasture fields were estimated by manipulating the point data into coverage polylines and this was then converted into polygons.

The Kamberg Nature Reserve boundaries and the surrounding crop farms boundary were derived from 1:50,000 scale topographic (cadastral) maps. Features such as road systems, water sources, forest cover, human settlements, transport and cultivated crop fields were derived by digitising aerial photographs of the study area. Aerial photographs obtained from the Surveyor General's Department were imported into ERDAS Imagine 8.7 for georectification and mosaicking. A scanned (georeferenced in ArcGIS v9.1) topographic map of the study was used to acquire the ground control points (GCPs) for the rectification of the aerial photographs. The georeferenced, scanned topographic map (in image format) provided quick and adequate GCPs that were easily identifiable on the aerial photographs. Georeferecing of the scanned topographic map of the study areas was easily done in ArcGIS v9.1 software because the map contained grid reference values. This values were then calculated in Microsoft excel, and saved as DBF4 (dBASE), imported into ArcGIS as X, Y data for control point.

Using the data preparation procedures and image geometric correction tools, a first order polynomial transformation was performed separately on the two aerial photographs using features that could be identified on both images and the scanned topographic map image. After rectification of the aerial photographs, the two aerial photographs were mosaicked using ERDAS Imagine software. Cutlines were created through this process and, the boundary of the cutline was then smoothed and feathered to join the two images together. Next, polygons of the cultivated fields and other features including water sources, road networks, forest cover, and human settlements within the study area were generated. Automated supervised and unsupervised image processing has been frequently used to create thematic maps from remotely sensed imagery.

However, since the main aim of this study was to determine the distribution of ECR incidences in the study area, and assess the environmental factors influencing crop raiding in the study area, it implied that the affected crop fields and the environmental features must be identified. The most convenient method to identify these was to implement onscreen digitising of all the features of interest with the aid of an aerial photograph.

Using ArcView v3.3 software, new polygon themes were created for each feature of interest by tracing the outline of the image. A theme attribute table for all features including calculating field column containing field ID/name, crop type, and field area was then done.

The resulting digitised crop fields and other features were used to build coverage polygons of the affected cultivated maize and pasture fields. The cultivated field polygons were overlayed with polygons of damaged crops using the spatial analysis tool in ArcGIS. Digital field (cadastral and 1:50,000 topographic) maps, and the GPS ground/field control points were used in order to overcome the problem of poor field boundary distinction of the aerial photograph that may have occurred due to the spatial resolution, small field size, and hilly landscape of the study area.

Following the generation of vector data layers and their associated attributes, distance class intervals for raided fields to the selected feature factors (that is, forest cover, water sources, road network, and distance of raided fields from the KNR boundary) were then calculated. The field GPS data layer was overlayed with the polygon layer (also with the aerial photo) so that the affected fields could be selected for further analyses. The layers were manipulated to describe the distribution of polygons representing the elands' raided fields. Elsewhere, Sitati *et al.* (2003) conducted a similar analysis on crop raiding caused by elephants in subsistence farms adjacent to the Masai Mara National Reserve to assess the spatial aspects and map distribution of human-elephant conflict in the area.

Analysis of crop damaged fields and associations with assumed environmental variables (damaged field size, distance from the forest cover, road network, water sources and KNR boundary) at the field level were performed by calculating the Spearman's rank correlation (r_s). This method allowed the determination of whether there was any significance in the association between the proximity of raided fields to the variables as in the GIS plots. The analysis was completed using SPSS version 13.0 for

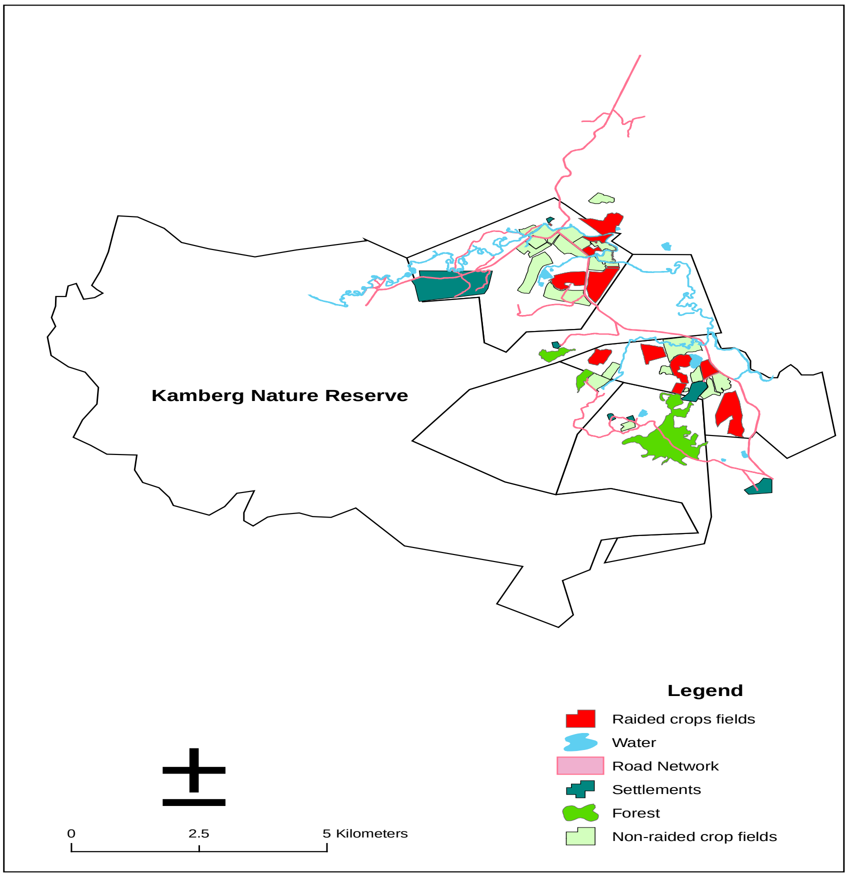

Figure 2: Location of damaged fields as mapped by GPS and local people's participation

windows. Figure 2 illustrated the location of the damaged fields as mapped by GPS and local people's participation.

Results and Discussion

Results from field observations and interviews with farmers showed that elands trespassed in maize *(Zea mays)* and ryegrass fields for foraging. Crop raiding occurred usually during early morning before 07:00 hours and late evening, after 18:00 hours. The size of the eland crop raiding herd varied between farms, but ranged from 8 to 36 animals as recorded by the farm staff. The results of calculation of the actual area of planted maize fields in Riverside farm indicated that 7.8% area of maize fields was damaged by elands. The results show the strength of GIS in characterising the quantity and spatial distribution of damage caused by elands.

To determine the severity of damage in each of the three farms mapped, we ranked the fields in terms of the intensity of crop damage. Fields were chosen for this kind of analysis because the field size (m^2), and distance from a feature factor (m) such as the KNR represent discrete units of relevance to both elands' activity patterns and farmers' guarding interests. The variation of crop raiding incidences was therefore calculated for each farm (Naughton-Treves 1998:5).

We also tested the spatial autocorrelation of damage by calculating *Global Moran's I* value (Koenig 1999; Sitati *et al.* 2003). Results of spatial autocorrelation showed that there was a significant clustering feeding behaviour of animals. The result is critical for farmers' guarding interests. The unpacking of the spatial configuration pattern in the crop damage is important for the implementation of suitable intervention measures by farmers.

Results of the relationship between the characteristics of damaged fields and environmental variables showed that there was a strong correlation between the location, size and distance of damaged crop fields and the KNR boundary. The crop damage index between farms index varied significantly with distance to the KNR boundary as well as to water sources. In other words a negative relationship was observed between crop damage and distance from the rivers as well as distance from the KNR boundary.

The results of the correlation coefficient indicated that proximity of planted fields to permanent water sources is a significant factor influencing crop raiding in the farms. This relationship can be attributed to the distribution of the crop fields which are concentrated on river banks because most of the fields are for rotational cropping where maize crop is planted during the rainy season and rye grass, mostly on irrigated pasture, is planted during winter (Schotcher 2006). The correlation between damaged field polygons and proximity to forest cover and road network were also negative. In addition a combination of proximity of crop raiding to water source and forest cover was significantly correlated, which shows that there was strong dependency of crop raiding events in relation with both variables. The relationship between crop raiding for forest cover and road network can be explained based on the ease of access to and escape from the farms to the KNR when ‘problem’ elands wander in the crop fields for maize and pastures. In addition the forest potentially provides cover for these animals to make use of during crop raiding incidents.

In summary, this study has shown the potential of participatory GIS in unpacking the spatial distribution and configuration of damaged crop fields by elands in KwaZulu-Natal Province. The relative importance of several environmental variables in explaining the distribution and configuration of damage is critical in facilitating adaptive management strategies.

Conclusion: Implications for Management

In Africa, as indicated earlier, most of the people whose farming activities are often impacted by the presence and abundance of ‘problem’ wild animal species are the resource poor local subsistence farming communities, and in some cases, commercial farms adjacent to wildlife habitats. From a geographical perspective, it is inevitable to examine the spatial pattern of wildlife crop raiding incidences in farms located near wildlife habitats or within wild animal species foraging range. Increasingly, reports of crop damage caused by wildlife on crop farms are associated with interactions between humans and wildlife. This can mainly be attributed to the alteration of the wilderness landscape as a result of the expansion of human activities close to wildlife habitats. Additionally, the establishment of conservation areas in close proximity to human livelihood activities has also resulted in human-wildlife conflicts. The alteration of the wilderness landscape is believed to have direct or indirect influence on wildlife foraging preference and patterns of foraging. An understanding of the geographical patterns of human-wildlife interaction is therefore an important aspect of nature conservation, planning and decision-making.

Analysis of the information collected from the farm owners, management of the KNR and other spatial data on eland foraging activities in the study area revealed that elands on private lands including agricultural fields is increasingly causing human-eland conflicts. The human-eland conflicts present significant management concerns for the wildlife conservation in the southern Drakensberg ecosystem (Scotcher 2006). The results of analysis of both social concerns and the spatial dynamics of eland impacts in crop fields shows the human-eland conflicts warrant considerable strategic management in Kamberg area.

An understanding of the spatial distribution patterns and magnitude of the crop raiding incidences in Kamberg provides valuable information that is useful for strategic eland management and decision-making in terms of human-eland conflicts. Very important too is that quantifying the intensity and extent of crop raiding by elands in agricultural farms adjacent to KNR using the participatory GIS exemplified in this study is an efficient way to model the spatial aspects of crop damage incidents which will in turn help in the mitigation of human-eland conflicts in the southern Drakensberg region.

In conclusion, this study has shown that previous research has mainly concentrated on understanding only the socio-economic dynamics of human-wildlife interaction with very limited understanding of the spatial distribution of this conflict. Such an approach has caused considerable difficulties in drawing contextual conflict resolution measures, hence the need to map the extent and severity of this conflict. Participatory GIS, a tool that incorporates local expertise and knowledge with technical expertise, provides an efficient and effective way to map the extent and severity of damage caused by wild animals on agricultural land.

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