

Investigating Geospatial Patterns of Elephant Crop Damage Adjacent to the Serengeti National Park and Grumeti Game Reserve, Tanzania

A. A. Mamboleo^{1*}, C. Doscher², and A. Paterson³

¹ *Department of Tourism and Hospitality Management, St. Augustine University of Tanzania, P. O. Box 307, Mwanza, Tanzania*

² *Department of Environmental Management, Lincoln University, Lincoln 7647, New Zealand*

³ *Department of Pest-management and Conservation, Lincoln University, Lincoln 7647, New Zealand*

Received 25 August 2020; revised 10 September; accepted 26 September 2020; published online 30 September 2020

ABSTRACT. We investigated a spatial configuration of human-elephant interactions in communities bordering the Serengeti National Park and Grumeti Game Reserve. Elephant crop damage was the most common adverse impact of the interactions. Geographic information systems were used to assess the distribution, hot and coldspots and relationships of elephant crop damage and environmental features in the Bunda District, Tanzania. Six hotspots and three coldspots were identified. Of all elephant crop damage incidents, 66% occurred in the wider village areas bordering Grumeti Game Reserve, 28% in the wider village areas bordering the Serengeti National Park and 6% in village areas that did not border the protected areas. There was a high concentration of elephant crop damage near rivers and protected areas, which decreased with increased geographical distance from the edge of these features.

Keywords: Bunda district, elephant crop damage, Grumeti Game Reserve, hot spots, human-elephant conflict, Serengeti National Park

1. Introduction

Human-elephant interactions (HEI) cause various types of adverse impacts including human and elephant deaths, crop and house damage, and indirect impacts. Like other types of human-herbivores interactions, crop damage is the most common adverse impact that elephants (*Loxodonta africana*) inflict on communities bordering protected areas (Desai and Riddle, 2015). At the local level, African elephants cause substantial and severe impacts to farmers (Parker et al., 2007) by raiding crops, damaging property, and, in some cases, causing death and injury. African elephants damage different types of crops, which makes them, locally, the most destructive vertebrate pest (Nelson et al., 2003; Osborn, 2004). Elephants have large appetites and lengthy feeding hours and may remain active for up to 18 hours in a day (Osborn, 2004). Crop damage is a common occurrence in communities surrounding protected areas, which elephants routinely visit for food and water (Lamarque et al., 2009). Other vertebrate species, such as eland, black rhino, baboon, wild boars, redbilled quelea, rodents, and hippos, also cause similar types of crop damage (Meerburg et al., 2008; Peterson et al., 2010).

A GIS approach is useful for assessing the spatial distribution and concentration of patterns of elephant crop damage

However, technological and financial constraints marginalise some parts of the world from adopting geographic information technology. Knowledge of the geographical configurations of crop damage is essential for decision-making and strategic planning for mitigation measures. Understanding the spatial pattern of elephant crop damage is important during planning, policy devising, and decision making because many decisions have spatial components (Mutanga and Adjorlolo, 2008). GIS tracks events and entities (Longley et al., 2005). Two important ingredients of geographical data are spatial data and attributes (Einstein, 2001).

Advancement and flexibility of GIS have enhanced spatiotemporal analysis of patterns for wildlife management (Wilson et al., 2013). GIS enhances the understanding of causal mechanisms and processes of geographically referenced phenomena (Vanleeuwe, 2010). Consequently, GIS provides important tools for solving wildlife management problems (Longley et al., 2005) and in understanding species conservation status, interactions, and movements (Rahman et al., 2010). Ecologists use GIS to solve complex and dynamic geographical problems relating to wildlife management. For example, Kyale et al. (2011) deployed GIS to understand spatial patterns of elephant poaching incidents in Tsavo East National Park in Kenya. Conservationists deployed a GIS approach to address different wildlife conservation issues. Mutanga and Adjorlolo (2008) assessed eland crop damage by deploying GIS in Kwa-Zulu Natal, South Africa. In a similar study, the prediction of spatial aspects of HEI occurrences was made in an unprotected range of Maasai Mara National Reserve, Kenya (Sitati et al., 2003). However, pre-

* Corresponding author. Tel.: +255-763-688-765; fax: +255-28-2550-167. E-mail address: abel.mamboleo@saut.ac.tz (A. A. Mamboleo).

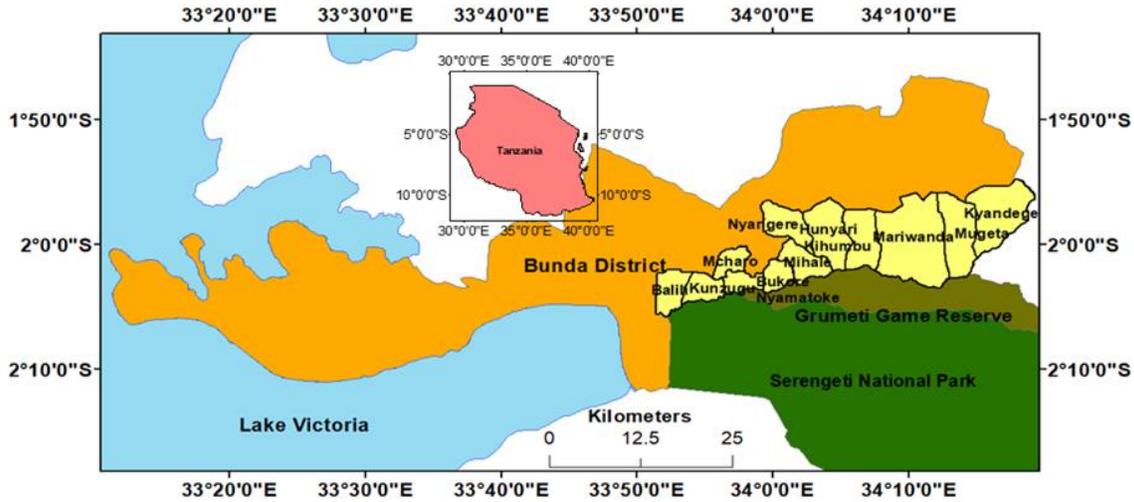


Figure 1. Map of the Bunda District, the Serengeti National Park and Grumeti Game Reserve.

vious spatial examination of elephant crop damage takes place with inadequate or no consideration of the density of crop damage occurrences (hotspots and coldspots). Because each elephant crop damage incident has spatial characteristics (Goodchild, 2006), a better understanding of its spatial configuration may provide elephant stakeholders with the necessary information required for developing proactive mitigation measures.

The study aimed at understanding the location, distribution and concentration of elephant crop damage incidents, in the villages near the Serengeti National Park (SENAPA) and Grumeti Game Reserve (GGR) in the Bunda District, Tanzania. Previous studies have only analyzed the location of elephant crop damage incidents (*X, Y* coordinates) in the district (Prasad et al., 2011). Knowledge on location, distribution and concentration of elephant crop damage is essential as it highlights to elephant conservation stakeholders on the geographical understanding of HEI. The spatial understanding of elephant crop raiding is lacking, particularly in the communities bordering SENAPA and GGR. The district was conducted in the district because of the high incidents of elephant crop damage, amounting more than 500 annual incidents in the district (Mduma et al., 2010). We collected the data from twelve villages adjacent to the Serengeti National Park and Grumeti Game Reserve in Bunda District.

2. Materials and Methods

2.1. Description of the Study Area

Bunda district is in the northern part of Tanzania, lying between latitudes 1°30" and 2°45" S, and between longitudes 33°39" and 34°05" E (Kideghesho and Mtoni, 2008). It covers about 3088 km², where Lake Victoria occupies 200 km² of the district and Serengeti National Park occupies 480 square kilometers (Figure 1). Tanzania hosts the second largest elephant population in the world after Botswana (Blanc et al., 2007). Despite the ongoing ivory poaching, the number of elephants is increasing and will keep on growing in Serengeti ecosystem

(TAWIRI and KWS, 2014). Bunda is the home of more than 25 human ethnic groups. The primary economic activity in the region is agriculture, which accounts for about 80% of the people's annual income (Walpole et al., 2004). The population of elephants in the district is about 126 individuals. The current human population is 365034 people (URT, 2013).

2.2. Data Collection

In Tanzania, a village is a small community in a rural area made up of inhabitants, infrastructure, forests, farms and geographical features, governed by a legally established local authority (URT, 1982, 1999). Collection of spatial data took place in Bukore, Balili, Hunyari, Kihumbu, Kyandegge, Kunzugu, Mihale, Mcharo, Mugeta, Mariwanda, Nyamatoke and Nyangere villages (Figure 1). Proximity to protected areas and the high number of incidents of crop damage were the main criteria for the selection of the villages. The study adopted an adaptive purposive sampling technique to identify and record the farms and households that experienced elephant crop damage. Farms with elephant crop damage were visited for identification and documentation of crop damage patterns. Formal village meetings were also used to identify household representatives whose farms had suffered elephant crop damage. Historical patterns, elephant crop damage occurred over a previous year, were identified and collected. The scale or extent of crop damage was not considered in this study.

Household representatives, elephant dung, distinctive feeding characteristics of elephants and elephant tracks were the main identification and verification criteria for the presence or absence of elephant crop damage. In this study, elephant crop damage was considered as the destruction of at least a portion of a crop by elephants. Due to the complex nature of crop damage, experts were consulted for clarification and confirmation of the damage. Experts consisted of wildlife officers, agricultural officers, and community development officers from the Bunda District Council. Additionally, villagers and their leaders were consulted in the identification and description of ele-

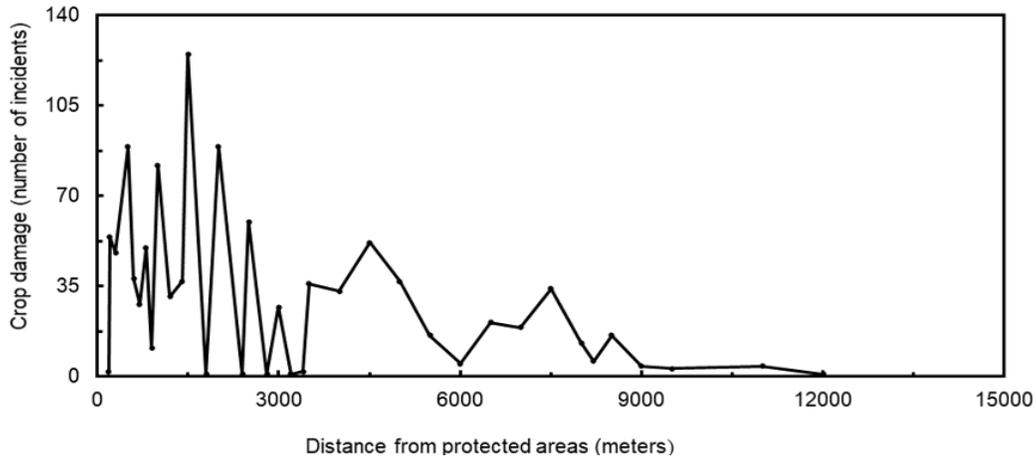


Figure 2. Crop damage incidents with increasing distance from SENAPA and GGR.

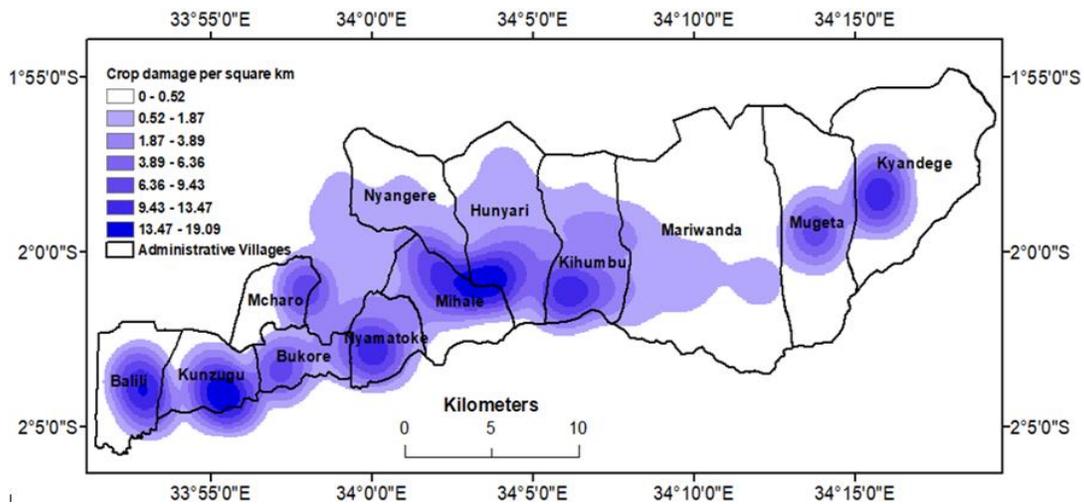


Figure 3. Crop damage incidents per square kilometers (Kernel Density).

phant crop damage from each village before entering an incident into the geodatabase (Wilson et al., 2013). A handheld Garmin GPS receiver was used to record the locations (X, Y coordinate) of verified current and previous signs (over the previous year) of elephant crop damage. The collected incidents were used to create an elephant crop damage layer in Arc-GIS 10.6. The incidents were carefully reviewed and confirmed before entering them into geodatabase. This study investigated about type and location of elephant crop damage incident, not the extent and history of the damage. Researchers are confident that the data collected were representative because the principal researcher participated throughout the survey, all the participants were appropriately informed in advance about the aims and objectives of the study before engaging in the survey, the villagers were asked to participate voluntarily in the survey. Moreover, the survey was carried out in the languages which most participants understood. This helped break communication barriers between researcher and participants. However, misconception, geographical challenges and reluctant political leaders were some of the notable difficulties in this study.

2.3. Data Analysis

ESRI GIS layers of the Serengeti National Park, Grumeti Game Reserve, rivers and administrative villages, were obtained from the Lincoln University GIS Server and Serengeti National Park office. The village GIS layers consisted of a set of contiguous polygons representing the areas over which villages had responsibility rather than just the spatial extent of each individual village. A kernel density analysis identified the clusters of elephant crop damage in the district (Gibin et al., 2008). This study used a 5000 m buffer zone around Serengeti National Park and Grumeti Game Reserve as the bandwidth (Biodiversity a-z, 2015). The Spatial Joint tool combined each village's map and the locations (X, Y coordinate) of crop damage in ArcMap. The resulting map contained a new field with the number of crop damage incidents for each village. The hotspot analysis used the new map to identify villages with a significant concentration of crop damage incidents. In this study, 'hotspots' were significantly high concentrations of elephant crop damage, and 'coldspots' was a significantly low concentration of crop damage (Harris et al., 2017). The Gedi-Ord G^* algorithm was used to

identify crop damage hot and cold spots (Getis, 1992). A high z -score and small p -value indicated significant hotspots. A high negative z -score and small p -value indicated cold spots. Hotspot analysis scrutinises whether high or low values of crop damage incidents were spatially clustered. In addition, proximity analysis assessed the geographical distance for each elephant crop incident to the edge of SENAPA and GGR.

Also, Moran's Index was calculated to measure spatial autocorrelation. The following formula is used to calculate the Moran's I statistic:

$$I = \frac{N \sum_{i=1}^n \sum_{j=1}^n w_{ij} (x_i - \bar{x})(x_j - \bar{x})}{\left(\sum_{i=1}^n \sum_{j=1}^n w_{ij} \right) \sum_{i=1}^n (x_i - \bar{x})^2} \quad (1)$$

where N is the number of observations (elephant crop damage), \bar{x} is the mean of the variable, x_i is the variable value at a particular location, x_j is the variable value at another location, w_{ij} is a weight indexing location of i relative to j .

It usually calculates the Moran's I Index value and both a z -score and p -value to evaluate the significance of that Index. Moran's Index usually classifies patterns as clustered, dispersed, or random. However, in this study the autocorrelation was automatically calculated from ArcGIS 10.6 software.

3. Results

3.1. Impacts of Environmental Features on Elephant Crop Damage

We recorded 1033 incidents of elephant crop damage from 12 villages over one year. The highest number, 147 (14.23%), of incidents occurred in Mihale village, and the lowest number, 18 (1.74%), of incidents occurred in Nyangere village. Based on proximity analysis, the majority of crop damage events (554 or 51.5%) occurred within 2000 meters of rivers and streams. There were no incidents of crop damage beyond 10000 meters from the rivers and streams. The majority of incidents 574 (53.3%) occurred between 0 and 2000 meters from the boundary of protected areas (SENAPA and GGR), while, the lowest number of incidents happened between 10000 and 12000 meters from the boundaries of the protected areas (Figure 2). In comparison, the numbers and proximity of crop damage incidents to rivers and protected areas were similar. The number of incidents recorded at a certain distance from rivers resembled the number of incidents recorded at a similar distance from the boundary of SENAPA and GGR, probably because, SENAPA and GGR used rivers, such as Ruwana River, in some parts, as their physical boundaries. The chi-square test at a 0.05 significance level, showed no significant differences between the number of incidents recorded at similar distances from rivers and the boundary of SENAPA and GGR ($n = 6$, Value = 30, $p = 0.224$).

3.2. Kernel Density Estimation

Kernel Density estimated six major concentrations of crop

damage in Kunzugu, Mihale, Kyandegge, Balili, Kihumbu and Hunyari villages (Figure 3) (Gibin et al., 2008). The largest concentration of crop damage incidents was between Hunyari and Mihale.

3.3. Hotspot Analysis

A hotspot analysis identified statistically significant hotspots and coldspots of elephant crop damage in the study area. There were significant hotspots of elephant crop damage in Hunyari and Kihumbu villages and a cold spot in Nyangere village. The hotspots bordered Grumeti Game Reserve and SENAPA. The coldspots occurred near GGR, particularly in Mariwanda, and in the villages that have no borders onto any of the protected areas, Mcharo and Nyangere villages (Figure 4). Six villages, Balili, Hunyari, Mihale, Nyamatoke, Kihumbu and Kunzugu, had a statistically significant concentration of crop damage incidents (Figure 4). Bukore, Mugeta and Kyandegge had an insignificant concentration of crop damage incidents.

3.4. Spatial Autocorrelation

According to ArcGIS 10.6, Moran's Index was 0.46, z -score was 1.29 and p -value was 0.19. The results show positive spatial autocorrelation because the Moran's I is close to +1. This means that there is really no statistical evidence of negative autocorrelation in the study area. In other words, there is clustering of elephant crop damage in the map (Figure 5).

4. Discussion

The degree and frequency of crop damage incidents varied between and within the villages bordering protected areas. For instance, all villages had varying rates of crop damage incidents throughout their administrative areas. Kihumbu, Mihale and Hunyari villages had the highest concentration of elephant crop damage compared to other villages. Crop damage incidents were clustered and more common in the villages near protected areas than villages that are more distant (Figure 5). For example, the low crop damage incidents in Nyangere village indicates that crop damage is unlikely to occur in communities disconnected from protected areas. Crop damage was more common in farms near rivers and SENAPA and GGR than farms that were distant from these features. In that context, the findings agree that the boundaries of the protected areas are the focal points of elephant crop damage, certainly for unfenced and unprotected farms (Raihan Sarker and Røskoft, 2014). Likewise, Nyirenda et al. (2012) asserted that protected areas, rivers, human presence and densities, and quality forage might influence the extent of elephant crop damage.

The proximity to water and certain species of forest trees increases the probability of elephant crop damage (Hazarika and Saikia, 2013). Water quality and quantity inside the Serengeti National Park and Grumeti Game Reserve are unreliable. The elevated pH of greater than 10 and high fluctuations of dissolved oxygen (between 1% and 200%) make most of the water in the protected areas undrinkable to elephants (Gereta and Wolanski, 1998). Under these circumstances, elephants and other migra-

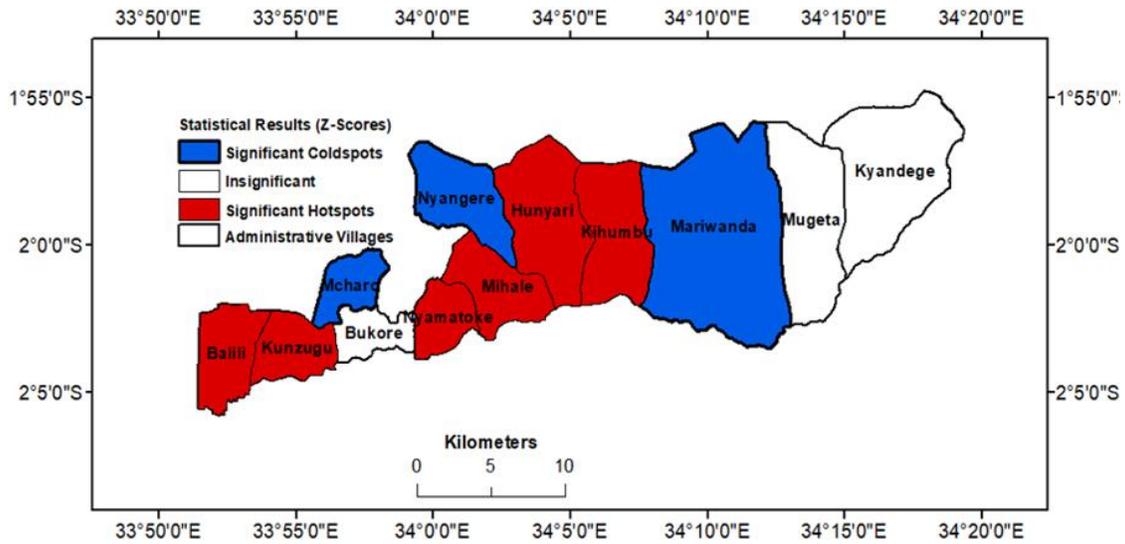


Figure 4. Statistical test for hotspots and coldspots of elephant crop damage.

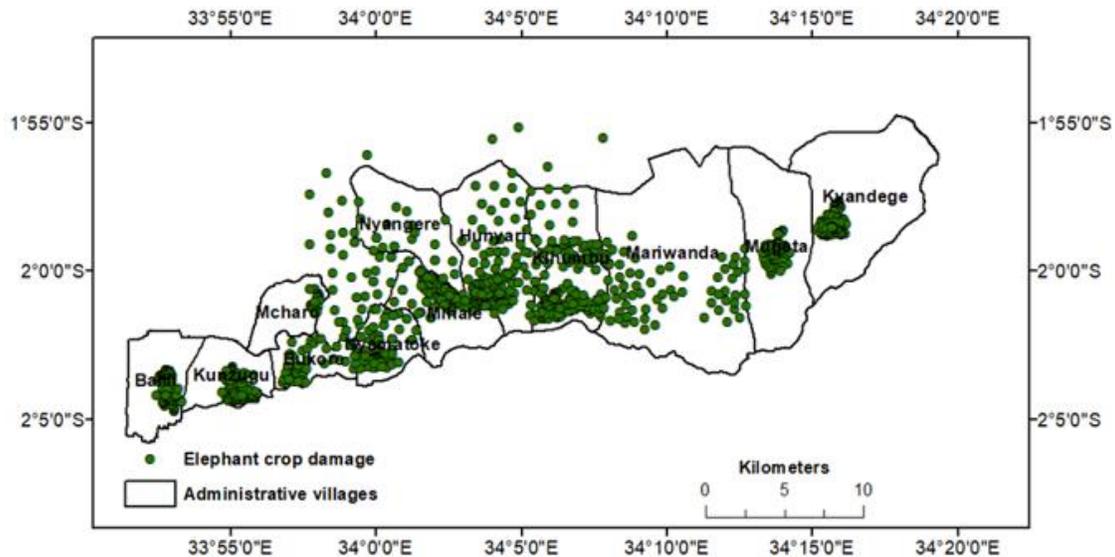


Figure 5. Distribution map of elephant crop damage in the study area.

tory species will move to unprotected habitats searching for water with satisfactory quality and quantity. The process of migration escalates the probability of elephant encroachment into crop farms and water infrastructure. According to Nyirenda et al. (2012), elephant crop damage near rivers is more intensive in dry seasons compared to the rainy seasons.

Human population densities and settlements may have caused a clumped spatial distribution of crop damage in certain areas of the district. Bunda District has a human density of nearly 200 people per km² (URT, 2013a). Despite the high population density, some areas have remained untouched by agricultural and settlement encroachments as populations tend to grow in areas with a suitable level of soil nutrients, moisture content, social services and development infrastructures (Linard et al., 2012; Ahmed and Taha, 2016). In that respect, crop farming

becomes possible in the human-dominated landscape. The distribution of the human population coincides positively with the spatial distribution of elephant crop damage in the district. In the district, many residents usually have households surrounded by crop farms. Regardless of human presence, farmlands near conservation areas tend to attract elephant damage because the natural food of elephants usually decreases beyond the boundaries of protected areas (Chen et al., 2015).

Environmental parameters influenced the distribution and concentration of elephant crop damage in the villages. Most of the crop damage occurred between 0 and 2000 meters from the edge of rivers, Grumeti Game Reserve and Serengeti National Park, and there was no elephant damage recorded beyond 10000 meters. The elephant is a water-dependent species, spending most of its time near streams and rivers (Nyirenda et al., 2012).

In that respect, crop farms that are closer to rivers and borders of conservation areas are more vulnerable to elephant crop damage than those at a distance. Harris et al. (2008) asserted that elephants choose foraging near conservation areas and rivers because they prefer moving less, eating well, drinking easily and avoiding human encounters. Water availability in the savannah landscape affects the foraging patterns of elephants because animals travel long distances searching for water and food when resource scarcity prevails in the protected landscape (Sitati et al., 2005). In those situations, the proximity of planted crops to rivers and streams is one of the important factors influencing the concentration of elephant crop damage adjacent to rivers and streams.

The adaptive behavior of elephants reflects a cost-benefit analysis approach. Elephants prefer maximising the benefit from food and water and reproduction while minimising time and energy required to obtain them. Monney et al. (2010) suggested that elephants take into consideration the cost of energy before deciding where to graze and drink and that animals will avoid raiding farms located too far from park boundaries because they are expensive to visit in terms of energy. In respect to external factors, the absence of crop field guards, unfenced protected areas, and the presence of the most preferable natural plants at the edge of the parks, together with an increase in the susceptibility of neighbouring farms to elephant raiding (Sitati et al., 2005; Desai and Riddle, 2015). The clustering of elephant damage at a particular distance from the edges of conservation areas was similar to the distribution around rivers. The protected area authorities regard rivers, including the Rubana River, as geographical boundaries for SENAPA and GGR. In that respect, the same river is also the physical boundary dividing the anthropogenic and protected landscape into two parts.

Kernel density analysis estimated elephant crop damage occurrence in the study area to produce a continuous map for establishing the actual concentration of the damage. The largest concentration of crop damage incidents was between Mihale and Hunyari villages. The villages are next to Grumeti Game Reserve. In addition, there were many concentrations of incidents in villages near GGR compared to SENAPA (Figure 3). Of all crop damage incidents, 66% occurred in the village bordering GGR, 28% in the villages bordering SENAPA and 6% in the village the bordered none of the protected areas. The geographical setting of the study might have contributed to the presence of many concentrations of crop damage incidents near GGR as the majority, nine (75%) villages involved in the study are next to Grumeti Game Reserve and three (25%) villages border SENAPA.

Concession hunting may be linked to crop damage. The largest concentration of crop damage incidents occurred in the villages next to Grumeti Game Reserve. Protected areas in eastern Africa allow trophy hunting for eradicating problem elephants (Burke et al., 2008). In Tanzania, the Wildlife Conservation Act of 2009 allows trophy hunting in game reserves, while prohibiting any hunting activity in the Serengeti National Park (URT, 2009). Hunting usually affects the movement and foraging behaviours of certain species (Burke et al., 2008; Conover, 2010). As an example, frequently hunted agricultural pests that escape con-

cession hunting usually intensify the extent of crop damage (Thurjell et al., 2012). The Tanzania Wildlife Authority (TAWA) and the District Game Office (DGO) has inadequate resources for managing problem elephants in the district (URT, 2013b). Tanzania National Parks (TANAPA) that manages the SENAPA has more human and logistical resources than TAWA, which may account for the lower incidence outside SENAPA. In that context, geographical challenges and inadequate resources overwhelm the competencies of TAWA to control problem animals outside all national parks.

Understanding the significant crop-raiding hotspots and the influencing factors enhances the ability of conservationists to identify and map the areas with substantial clustering of elephant crop damage events for proactive mitigation measures. Graphical display of hotspots on maps allows policymakers to identify where damage occurs and potential reasons for their clustering. The presence of many significant hotspots identifies Kihumbu, Mihale, Nyamatoke, Kunzugu, Balili and Hunyari villages as highly predisposed areas to elephant crop raiding and at higher HEI risk for crop farming in the district. In addition, the presence of significant coldspots in Mariwanda and Nyangere suggests that the villages are safer for farming. There were some issues with collecting and identifying evidence of elephant crop damage in the coldspots areas, such as reluctance to participate in the study and inadequate corporation from village governments. More importantly, the geographical setup of some villages, such as Mariwanda and Mugeta were difficult for data collection, the nature of the terrain made some farms in the villages inaccessible for data collection. Such challenges may have influenced the identification of hotspots and coldspots in this study.

Our findings likely apply to other regions with active ranges of African elephants. The elephant stakeholders may use the findings to identify and document elephant distribution outside protected areas. Understanding the habitat utilisation and distribution outside protected areas is one of the major aspects of elephant management. Moreover, conservation authorities may use the findings to identify areas that are vulnerable to elephant crop damage when developing intervention measures. For example, it is likely that the distance from rivers and protected areas will be relevant to other areas in Africa.

5. Conclusions

A spatial approach advances understanding of the geographical configuration of direct and indirect adverse impacts of HEI. The findings of this study are critical for understanding a current situation of elephant crop damage in the district. A proper understanding of spatial configuration of crop damage helps conservation stakeholders envisage the context of spatial relationships between African elephants and crop damage in the Bunda District. The study revealed the spatial characteristics underpinning HEI, such as frequency and the magnitude of elephant crop damage near protected areas and rivers. In particular, the study found that, there are many incidences of elephant crop damage near rivers and protected areas. It provided insightful information, such as where humans live and cultivate, where HEI occurs and how elephants use the areas outside the protect-

ed areas. As a result, conservationists may use the resultant maps to identify the elephant distribution and habitat utilization in the district. It is also possible to use the maps to identify, design and delimit elephant migratory routes. The government may use the maps for the identification of safe areas for relocating human settlements and agricultural farms. In short, this geospatial study serves as a powerful communication tool and activates discussions about HEI, elephant management plans, conservation policies and socio-economic development.

Like many spatial studies, this one was influenced by data quality, quantity and geographical errors. The collection and analysis of spatial data were carried out in 12 administrative villages. The selection of participating villages in this thesis based on their proximity to SENAPA and GGR not on either frequency or magnitude of HEI. Such selection introduced some geographical issues. The Tanzania government defines village boundaries for administrative not conservation purposes. It was crucial to consider both geographical location and the magnitude of elephant crop damage for each participating village. In addition, time constraints, the willingness of participants to participate in the study, expertise on identifying elephant crop damage patterns and geographical challenges of the study area may have affected the quality and quantity of the geospatial data used for conclusion. As an example, elephant crop damage rectification experts on crop damage patterns. Moreover, some villagers needed incentives to participate in the surveys. Such challenges hindered the availability of reliable data used for spatial analysis. It is important to acknowledge that elephant crop damage happened in the margins of protected areas. Therefore, regional and landscape planning is essential to eradicate HEI incidents near protected areas. Prior to the comprehensive regional planning, the assessment of the spatial configuration of elephant crop damage is important, as it may disclose the spatial characteristics of the incidents in the human and elephant landscape. There are myriads of ways to analyze the expressions of elephant crop damage in the landscape. GIS efficiently connects the damage patterns directly to the regional landscape, but computational modelling and simulation technique provides the dynamic nature of the incidents.

Acknowledgments. New Zealand Development Scholarship Program supported financial and logistical support. However, we wholeheartedly appreciate Saint Augustine University of Tanzania (SAUT), Lincoln University (LU), Tanzania National Parks (TANAPA), Tanzania Wildlife Authority (TAWA), Bunda District Council, Village committees, Ministry of Natural Resources and Tourism of Tanzania for making the study technically possible.

References

- Ahmed, T.R., and Taha, D.I. (2016). Influence of soil on population distribution. *International Journal of Science and Research*, 5(6), 980-982. doi:10.21275/v5i6.NOV164261.
- Biodiversity a-z (2015). Buffer zones. Retrieved from <http://biodiversitya-z.org/content/buffer-zones>. Accessed on 25th June 2015.
- Blanc, J.J., Barnes, R.F.W., Craig, G.C., Dublin, H.C., Thouless, C. R., Douglass-Hamilton, I., and Hart, J. A. (2007). African Elephant Status Report 2007: An update from the African Elephant Database. Gland, Switzerland: International Union for Conservation of Nature.
- Burke, T., Page, B., Van Dyk, G., Millsbaugh, J., and Slotow, R. (2008). Risk and ethical concerns of hunting male elephant: behavioural and physiological assays of the remaining elephants. *PLoS ONE*, 3(6), 1-9. doi:10.1371/journal.pone.0002417.
- Chen, Y., Marino, J., Chen, Y., Tao, Q., Sullivan, C. D., Shi, K., and Macdonald, D. W. (2015). Predicting hotspots of human-elephant conflict to inform mitigation strategies in Xishuangbanna, Southwest China. *PLoS ONE*, 11(9), 1-15. doi:10.1371/journal.pone.0162035.
- Conover, M. R. (2010). Effect of hunting and trapping on wildlife damage. *Wildlife Society Bulletin*, 29(2), 521-532.
- Desai, A.A., and Riddle, H.S. (2015). Human-elephant conflict in Asia. U.S. Fish and Wildlife Service Asian Elephant Support. In-donesia.
- Einstein, A. (2001). Think Spatially: GIS for beginners. Kathmandu, Nepal.
- Gereta, E., and Wolanski, E. (1998). Wildlife-water quality interactions in the Serengeti National Park, Tanzania. *African Journal of Ecology*, 36(1998), 1-14. doi: 10.1046/j.1365-2028.1998.102-89102.x.
- Getis, A. (1992). The analysis of spatial association by use of distance statistics. *Geographical Analysis*, 24(3), 190-206. doi:10.1007/978-3-642-01976-0_10.
- Gibin, M., Longley, P., and Atkinson, P. (2008). Kernel density estimation and percent volume contours in general practice catchment area analysis in urban Areas. University College London. London, UK.
- Goodchild, M. F. (2006). *GIS and Modelling Overview*. California, US: University of California.
- Harris, N. L., Goldmann, E., Gabris, C., Nordling, J., Minnmeyer, S., Ansari, S Lippmann, M., Bennet, L., Raad, M., Hanson, M., and Patapov, P. (2017). Using spatial statistics to identify emerging hot spots of forest loss. *Environmental Research. Letters*. 12, 1-14.
- Hazarika, R., and Saikia, A. (2013). The pachyderm and the pixel: an assessment of elephant habitat suitability in Sonitpur, India. *International Journal of Remote Sensing*, 34(15), 5317-5330. doi:10.1080/01431161.2013.787503.
- Kideghesho, J.R., and Mtoni, P.E. (2008). The potentials for comanagement approaches in western Serengeti, Tanzania. *Tropical Conservation Science*, 1 (4), 334-358. doi:10.1177/194008290800100404.
- Kyale, D.M., Ngene, S., and Maingi, J. (2011). Biophysical and human factors determine the distribution of poached elephants in Tsavo East National Park, Kenya. *Pachyderm*, 49, 48-60.
- Lamarque, F., Anderson, J., Fergusson, R., Lagrange, M., Osei-Owusu, Y., and Bakker, L. (2009). Human-Wildlife Conflict in Africa: Causes, Consequences and Strategies (Vol. 157). Rome, Italy: Food and Agriculture Organisation.
- Linard, C., Gilbert, M., Snow, R.W., Noor, A.M., and Tatem, A.J. (2012). Population distribution, settlement patterns and accessibility across Africa in 2010. *PLoS ONE*, 7(2): e31743. doi:10.1371/journal.pone.0031743.
- Longley, P.A., Goodchild, M.F., Maguire, D.J., and Rhind, D.W. (2005). *Geographic Information Systems and Science*. White Sussex, England: John Wiley and Sons Ltd.
- Mduma, S.R., Lobora, A.L., Foley, C., and Jones, T. (2010). Tanzania Elephant Management Plan 2010 - 2015. Arusha: TAWIRI.
- Meerburg, B.G., Singleton, G.R., and Leirsc, H. (2008). The year of the rat ends: time to fight hunger. *Pest Managanament Science*, 65 (2009), 351-352. doi:10.1002/ps.1718.
- Monney, K.A., Dakwa, K.B., and Wiafe, E.D. (2010). Assessment of crop raiding situation by elephants (*Loxodonta africana cyclotis*) in farms around Kakum conservation area, Ghana. *International Journal of Biodiversity and Conservation*, 2(9), 243-249. doi:10.5897/IJBC.9000012.
- Mutanga, O., and Adjorlolo, C. (2008). Assessing the spatial patterns of crop damage by wildlife using GIS. *Alternation* 15(1), 222-239.
- Nelson, A., Bidwell, P., and Sillero-Zubiri, C. (2003). A review of human elephant conflict management strategies. people and wildlife initiative. Oxford, UK: Wildlife Conservation Research Unit.
- Nyirenda, V.R., Myburgh, W.J., and Reilly, B.K. (2012). Predicting

- environmental factors influencing crop raiding by African elephants (*Loxodonta africana*) in the Luangwa Valley, eastern Zambia. *African Journal of Environmental Science and Technology*, 6(10), 391-400. doi:10.5897/AJEST11.180.
- Osborn, F.V. (2004). Seasonal variation of feeding patterns and food selection by crop-raiding elephants in Zimbabwe. *African Journal of Ecology*, 42(2004), 322-327. doi:10.1111/j.1365-2028.2004.00531.x
- Parker, G.E., Osborn, F.V., Hoare, R.E., and Niskanen, L.S. (2007). Human-elephant conflict mitigation: a training course for community-based approaches in Africa (participants' manual). Nairobi, Kenya: IUCN.
- Peterson, M.N., Birkhead, J.L., Leong, K., Peterson, M.J., and Peterson, T.R. (2010). Rearticulating the myth of human-wildlife conflict. *Conservation Letters*, 3(2), 74-82. doi:10.1111/j.1755-263X.2010.00099.x.
- Prasad, G., Shiny, R., Reghunath, R., and Prasannakumar, V. (2011). A GIS-based spatial prediction model for human-elephant conflicts (HEC). *Wildlife Biology in Practice*, 7(2), 30-40. doi:10.2461/wbp.2011.7.14.
- Rahman, S., Rahman, S.M., Motaleb, M.A., Sobhan, I., and Khan, N.A. (2010). Geospatial techniques and route and corridor mapping of Asian elephants: a participatory initiative for conservation. International Union for Conservation of Nature. Bangladesh.
- Raihan Sarker, A.H.M., and Røskaft, E. (2014). Perceptions of farmers in Bangladesh to Asian Elephants (*Elephas maximus*). *Environment and Natural Resources Research*, 4(2), 23-38. doi:10.5539/enrr.v4n2p23.
- Sitati, N.W., Walpole, M.J., and Lwaderi-Williams, N. (2005). Factors affecting susceptibility of farms to crop raiding by African elephants: using a predictive model to mitigate conflict. *Journal of Applied Ecology*. 42, 1175-1182. doi:10.1111/j.1365-2664.2005.01091.x.
- Sitati, N.W., Walpole, N.J., Smith, R.J., and Leader-Williams, N. (2003). Predicting spatial aspects of human-elephant conflict. *Journal of Applied Ecology*, 40 (2003), 667-677. doi:10.1046/j.1365-2664.2003.00828.x.
- TAWIRI, and KWS. (2014). Aerial Total Count of Elephants and Buffaloes in the Serengeti-Mara Ecosystem. Nairobi, Kenya: TAWIRI and KWS.
- Thurfjell, H., Spong, G., and Ericsson, G. (2012). Effects of hunting on wild boar *Sus scrofa* behaviour. *Wildlife Biology*, 19(1), 87-93. doi:10.2981/12-027. doi:10.2981/12-027.
- URT (1982). The Local Government (District Authorities) Act, (1982). Government Printer, Dar-es salaam, Tanzania.
- URT (1999). The Land Act: Principal Legislation (1999). Government Printer, Dar-es salaam, Tanzania.
- URT (2009). The Wildlife Conservation Act (2009). Government Printer, Dar-es salaam, Tanzania.
- URT (2013). 2012 Population and Housing Census, Dar-es-salaam, Tanzania: National Bureau of Statistics.
- Vincent R., Nyirenda, Willem J. Myburgh, I., Brian, K., and Reilly1. (2012). Predicting environmental factors influencing crop raiding by African elephants (*Loxodonta africana*) in the Luangwa Valley, Eastern Zambia. *African Journal of Environmental Science and Technology*. 6(10), 391-400. doi:10.5897/AJEST11.180.
- Walpole, M., Ndoinyo, Y., Kibasa, R., Masanja, C., Somba, M., and Sungura, B. (2004). An Assessment of Human-Elephant Conflict in the Western Serengeti. Arusha, Tanzania: Frankfurt Zoological Society and Tanzania National Parks and Wildlife Division of Tanzania.
- Wilson, S., Davies, T.E., Hazarika, N., and Zimmermann, A. (2013). Understanding spatial and temporal patterns of human-elephant conflict in Assam, India. *Oryx*, 49(01), 140-149. doi:10.1017/s0030605313000513.