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Research Article

Mapping of Human-Wildlife Conflict Hotspots in Silowana Complex of Western Province in Zambia

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Abstract

This paper is about a study conducted on mapping HWC hotspots in the silowana complex of Western Province in Zambia. Spatially identifying HWC (hotspots) and possible mitigation measures is necessary to inform HWC management to facilitate a nonviolent coexistence of humans and wildlife. This study used earth observation techniques, Geographic information systems and spatial modelling to identify areas at risk of HWC and possible mitigation measures to address the conflict, based on the Silowana Complex (SC) as a case study area. The study achieved three (3) specific objectives: It analyzed forms of HWC; modelled HWC hotspots and established possible HWC mitigation measures in the case study area.

Keywords: Wildlife conservation, Spatial Modelling, Earth observation, Integrated land use planning, Coexistence, Maximum entropy

INTRODUCTION

Human-Wildlife Conflict (HWC) also interpreted as wildlife-human conflict, is one of the global problems faced by conservationists and decision-makers worldwide. It occurs when people compete with wildlife for food and resources. Often HWC is driven by habitat loss, due to anthropogenic factors, such as the construction of transport networks, human encroachment, and the conversion of forests to arable land (Acharya et al., 2017). Other drivers of HWC include increasing human and wildlife populations, and climate variability/change (Bargali et al., 2018). Climatic changes affect wildlife's habitat composition, availability of forage, and water accessibility, triggering conflict beyond protected areas (Barnes, 1982). It, therefore, becomes imperative to map areas at risk of HWC and analyze the drivers, and possible mitigation measures, to better inform conservation efforts (Barua et al., 2013). HWC has contributed to the extinction of numerous species and caused immeasurable loss of human life, crops, livestock, and property. Further, HWC has indirect consequences for the livelihoods of communities, their psychological and economic well-being, and food security (Brennan et al., 2020). On the other hand, the retaliatory killing of wildlife by humans contributes to the loss of biodiversity and changes in ecosystem structures as a whole (Chibeya et al., 2021).

The study area, Sioma Ngwezi National Park (SNNP), and Lower West Zambezi Game Management Area (LWZ GMA) are collectively called Silowana Complex (SC) (Chomba et al., 2012). The SC presents a unique case for this study because the SNNP has since 1971 when it was gazetted incorporated human settlements inside the park (Cushman et al., 2018). The villages that are inside the park include Dihele, Imusho, Ngweze, Mbao, and Mbala. These villages are spatially distributed within the national park, hosting sub-villages and communities (Chamaille-Jammes et al., 2008). It was estimated that about 5,000 people live in the national park

(Dasgupta et al., 2015). Despite this, the SNNP also has a GMA around it, with some communities living in the GMA. It could be expected that HWC would be more in the national park than in the GMA (demotts et al., 2012).

Several challenges exist in mapping and quantifying the extent of HWC in SC, mostly because existing data and information hardly indicate how widespread HWC is spatially (Dunkin et al., 2013). In addition, Hanks indicated that community members tend to exaggerate the extent of their losses because they see reporting damage as an opportunity to express frustration or anger about their helplessness in dealing with conflicts with wildlife (Dyar et al., 2003). In some areas, HWC is underestimated because each incident may not be reported and/or reports may lack pertinent information vital for the geospatial analysis of HWC (Gastineau et al., 2019). Therefore, this study used a geospatial approach to better understand the dynamics of the conflicts in the area, as communities continue to reside in the national park. The use of earth observation, geographical information systems, and spatial modelling systems in this study helped fill up these gaps in knowledge and overcome the above challenge (Graham et al., 2008). Further, regarding the severity of HWC effects on both humans and wildlife, Muyoma, noted that several studies on HWC are reactive largely focusing on understanding the drivers of HWC, mitigation measures, perceptions and attitudes of community members towards wildlife and the visible direct and hidden costs of HWC (Hoare, 1999). However, few or no studies are taking a geo-spatial approach to delineate areas at risk of HWC (hotspots) and identify possible mitigation measures (Hoare, 1999).

The causes, and consequences of HWC in Zambia are well documented (Hoare, 2001). However, geographical patterns of HWC are not documented in most parts of Africa. The SC is no exception to this trend, due to the lack of comprehensive and uniform HWC data collection methods and systems (Jadhav et al., 2012). This presents difficulties in defining science-led management decisions and developing sound and smart land-use-led HWC mitigation programs since mitigating HWC requires an understanding of how HWC varies in space and time. Previous studies in SC have focused on ecological connectivity (Kerley et al., 2006).

The central location of SC within KAZA TFCA makes it a critical connectivity landscape for elephants and other large carnivores. The transboundary flow of wildlife traversing the ecosystem from Namibia and Angola increases the risk of HWC and has tremendous impacts on the local community. Despite SC's transboundary geographical nature, there are no studies in SC that have focused on quantifying the damage of HWC, analyzing geographical patterns, examining its relationship with habitat use, and mapping HWC.

Therefore, knowledge about HWC geographical patterns inside Sioma Ngwezi National Park (SNNP) and Lower West Zambezi Game Management Area (LWZ GMA) is limited and undocumented. The inadequate information and spatial data on HWC, calls for efforts towards a better understanding of geographical patterns of HWC in SC. Spatially identifying areas at risk of HWC (hotspots) and possible mitigation measures are necessary to inform HWC management and facilitate a nonviolent coexistence of humans and wildlife.

This paper aims to identify areas at risk of HWC and possible mitigation measures to address the conflict, based on the Silowana Complex (SC) as a case study area. The paper will achieve three (3) specific objectives: It will analyze forms of HWC; model HWC hotspots and establish possible HWC mitigation measures in the case study area.

MATERIALS AND METHODS

Research method and design

This section describes the methods used for data collection, the sources of data, and how data were analyzed.

Study area

The study area is bounded by two perennial rivers, the Kwando river and the Zambezi river. Further, ecosystems are transboundary dispersal areas in KAZA for megafaunal species such as African Elephant (*Loxodonta africana*), Lion (*Panthera leo*), African Wild dogs (*Lycaon pictus*) and Hippopotamus (*Hippopotamus amphibius*), Common Zebras (*Equus quagga* or *E. burchellii*) and African buffalo (*Syncerus caffer*). The vegetation in the study area is characterized by diverse types such as Zambezi teak *Baikiaea plurijuga* forests, grasslands, termitary associated bushland, and woodlands classified as 'Kalahari' *Brachystegia* sp., *Julbernardia* sp., *Isoberlinia* sp., 'munga' *Acacia* sp., *Combretum* sp., *Terminalia* sp., 'mopane' *Colophospermum mopane*, that are intermingled with flood plains and seasonal water pans on generally flat terrain and porous soils associated with kalahari sand deposits. Generally, soils in the study area can be described as Orthi-Ferrallic Arenosols. Implying that they are excessively drained, very deep, very pale brown to yellowish brown, and loose to very friable sandy soils. Climate in the study area is characterized by two seasons, the rainy season (November to April) and the dry season (May to October). The dry season could further be subdivided into the cool dry season (May to August), and the hot dry season (September to October). The rainy season is rather unreliable. Annual rainfall is less than 750 mm, erratic, and of high intensity such that drought and moisture stresses are frequent. Further, it is characterized by very high temperatures (up to 40°C) in September-October. Reference should be made to Figure 1 with the map of the study area (Figure 1).

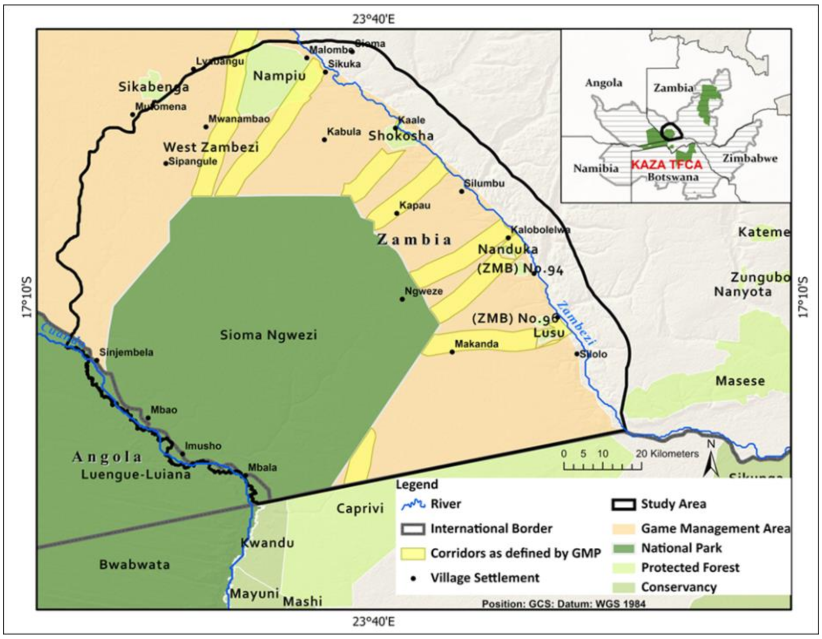

Figure 1. Study area.

The study area is inhabited by around 15,000 people (10, 000 in the GMA and 5000 in NP) in a cluster of villages that are spatially distributed, hosting sub-villages and communities. The economy in the study area is based on natural resources exploitation, subsistence agriculture and livestock rearing as well as small-scale trading in groceries.

Data collection

Primary sources of data: The study achieved its objectives through a total of 200 HWC incident records covering 2020 to 2021 acquired from the Department of National Parks and Wildlife (DNPW). To supplement this dataset, a semi-structured questionnaire was administered to 100 respondents.

Secondary sources of data: The study modelled HWC occurrences together with environmental predictor variables extracted from the land cover map. The land cover map was classified from sentinel 2 Level 1C satellite images using the Supported Vector Machine (SVM) algorithm in ArcGIS Pro (Version 2.4.1). Maximum Entropy (MaxEnt) software (Version 3.4.1) was used to model HWCs. The outputs were analyzed and mapped using ArcGIS Pro (Version 2.4.1).

Data analysis and processing

HWC incidence data analysis and processing: The study treated all HWC incidents reported from 2020 to 2021 as the population of the study. HWC incident reports were subjected to further cleaning by confirming the conflicts using place names. The researcher worked with key informants and HWC victims to confirm incidents recorded and geo-located the incidents to known places. HWC incidents recorded by DNPW were assigned a unique identity and considered once as a single observation and assigned to only one category of damage (crop, livestock, and property damage) in a data schema that was developed by the researcher. The study used proportions to describe common conflict species and forms of HWC. Descriptive statistics were used to show the distribution of HWC incidents according to seasons, using Microsoft data analysis toolpak. In addition, responses from the household surveys and key informant interviews informed HWC mitigation measures. Responses from respondents were analyzed using a thematic approach and presented by tables and charts.

HWC hotspot data analysis and processing

The study modelled HWC occurrences obtained from DNPW together with three environmental predictors extracted from the land cover map (classified sentinel 2 imagery). Maximum Entropy MaxEnt software (Version 3.4.1) was used to model the probability of HWC. Hotspots were then extracted from the probability of HWC model output. It was imported into ArcGIS Pro (Version 2.4.1) in ASCII format, where the probability values were classified into ten classes based on equal intervals. The range 0.6 to 1 probability of HWC was considered as 'Human-Wildlife Conflict hotspot areas' and extracted as HWC hotspots then mapped using Geographical Information System platforms ArcGIS Pro (Version 2.4.1) and ArcMap (Version 10.7) creating two classes of Non- HWC Hotspot area for probability values below 0.6 and HWC Hotspot area for values above 0.6 using the Natural Breaks (Jenks) classifier its outputs informed the results which were then analyzed. The flow chart below in Figure 3 depicts the process and a detailed exposition of how predictor and response variables were obtained.

Environmental/predictor variables data: Three environmental variables considered important for predicting HWC were selected. The major factors considered were anthropogenic pressure (settlements and cropland/farms), land cover (vegetation), and availability of water. These were derived from the satellite imagery through land use and land cover mapping as described below.

Land use and land cover classification: The study used both supervised and unsupervised classification to classify a mosaicked, atmospheric and geometric corrected Sentinel imagery from ArcGIS Pro (Version 2.4.1) image classification wizard. The mosaic was then segmented using the inbuilt maximum likelihood unsupervised classification algorithm to classify the spectral data into a thematic map using the segmentation tool with the spectral detail set at 15.50, spatial detail set at 15, and the minimum segment in pixel size set at 20.

Segmentation provided a methodological framework for the machine-based interpretation of complex classes, using both spectral and spatial information, and generated better classification results with a higher degree of accuracy than pixel-based methods. The algorithm helped to merge pixels with their neighbours having relative homogeneity criteria based on defined minimum mapping threshold units. Information about the spectral values of image layers, slope, and texture was used in the land cover mapping. Additional data relating to vegetation indices, for example, the Normalized Difference Vegetation Index (NDVI), and a land-water mask were also used for the mapping procedure. These indexes were calculated from the mosaicked image using the indices tool from ArcGIS Pro (Version 2.4.1).

To enhance the accuracy of the segmented classes, supervised classification was conducted using researcher-generated training samples based on the segmented image. A total of about 1.1 million pixels were trained based on five broad themes, Water, Forest cover, Wetlands, Settled/cultivated, and Shrub/grassland. The segmented image was classified using the Support Vector Machines (SVM) classifier. Support Vector Machines (SVM) are one of the most robust and accurate methods of well-known machine learning algorithms. SVM Machine learning tool was applied because it aims to find separating hyperplanes and separate pixels as reliably as possible into the distinct data classes. It has also been found reliable for predictive modelling in ecology and spatial data modelling. In addition, the land use/cover classification accuracy was assessed using a confusion matrix based on the independent dataset generated from the Google Earth observations. The overall accuracy was 94% with Kappa statistics of 0.9. The user's accuracy ranged from 92% to 100% while the producer's accuracy ranged from 83% to 100%.

Spatial prediction/response variables data

Spatial modeling of human-wildlife conflict probability: MaxEnt software (version 3.4.1) was used for risk modelling of the HWC risk area. Data points regarding the incidence of conflicts were extracted from 20 HWC reports obtained from DNPW based on their coordinates (latitude and longitude) and saved in the CSV format. The derived land cover map (section 4.3.3.1) was clipped to the study area and converted into an ASCII format as an input into MaxEnt. The MaxEnt model was run for 1000 iterations. A default setting of 10,000 maximum background points was accepted for the model run. The model's output was generated using the default format of Cloglog. This format provides an estimate of the probability of presence between 0 and 1, which is from the lowest to the highest probability of distribution.

Predictive accuracy and validation of the model: The predictive accuracy of the model was accessed based on the area using the Receiver Operating Characteristics (ROC) curve and the Area Under the Curve (AUC). The Area Under the Curve (AUC) was considered for both training and actual data, plotted against sensitivity (correctly classified presences in the y-axis) and specificity (correctly classified absences in the x-axis) for all possible thresholds. The AUC value ranks between 0 and 1, in which <0.5 means no discrimination, 0.5 to 0.69 is poor, 0.7 to 0.79 is reasonable, 0.8 to 0.89 excellent, and >0.9 exceptional predictions. HWC hotspot areas were then extracted from the probability ranges and analyzed concerning protected areas in the study area. The model was trained on using 40% of the actual HWC occurrence data from the study area.

RESULTS AND DISCUSSION

This section presents the results and discusses forms of HWC, hotspots and community-led mitigation measures in SC.

Forms of human-wildlife conflict in the silowana complex

Population characteristics: This section focuses on describing the population characteristics of the respondents interviewed, these could as well be referred to as HWC victims. Regarding gender and age, the results indicated that 58% of the respondents were males and 42% were females. This corresponds, with Munyao et al., who concluded that in Africa, most of those killed in HWC are men and that many of these incidents occur during the night. Further, 58% of the respondents were between the age of 36-50 years, followed by 30% representing 18-35 years, then 10% represented 51-65 years and 2% represented those that were above 65 years and 0% for those that were below the age of 18 years. Concerning the geographical distribution of respondents, the results show that 82% of the respondents were in LWZ GMA, 12% were in the SNNP, and 6% were in the OA. The results are not surprising because it is expected that you would find more HWC incidents in LWZ GMA and not in SNNP based on human density variations within these protected areas.

Common conflict wildlife species: The results indicated that the common conflict wildlife species in order of magnitude were; African elephants (*Loxodonta Africana*) at 47%, common hippopotamus (*Hippopotamus amphibius*) at 24%, Nile crocodile (*Crocodylus niloticus*) at 21%, blue wildebeest (*Connochaetes taurinus*), African buffalo (*Syncerus caffer*) and Spotted Hyena (*Crocuta crocuta*) at 2% each, Lions (*Panthera Leo*) at 1% and common duiker (*Sylvicapra grimmia*) at 1%. These results indicated that elephants are the major conflict species within the study area. These results suggest that large herbivores and carnivores are highly involved in HWC and this could be attributed to the fact that, they require a large home range, and due to their high energy requirements, they need to consume large quantities of food each day. Therefore, based on the foregoing needs and range it can be inferred that large-bodied terrestrial mammal species are likely to navigate far, beyond protected areas borders onto human-inhabited lands in their quest to satisfy daily dietary requirements thus making them important contributors to HWC.

Forms of HWC by conflict species and type

During the period 2020 to 2021, a total of 200 HWC incidents were recorded by DNPW. Of the incidences, 59% were for crop damage, 24% for loss of human life or injury, 16% for livestock depredation and 1% for property damage. Based on these results four forms of HWC emerged in the following order of magnitude crop damage, loss of human life or injury, livestock depredation, and property damage. These results are consistent with similar studies suggesting that crop damage is the most common form of HWC. This potentially threatens the household income and food security of the affected communities.

Crop damage: The study found that African elephants (*Loxodonta africana*) were largely responsible for crop damage. Respondents indicated that when elephants come in a large group, they destroy large areas of crops in a single night. The results based on HWC incident reports obtained from DNPW further indicated that crops were raided by the following species in their order of magnitude 66% African elephants (*Loxodonta africana*), 28% common hippopotamus (*Hippopotamus amphibius*), 3% blue wildebeest (*Connochaetes taurinus*), 2% common duiker (*Sylvicapra grimmia*) and 1% African buffalo (*Syncerus caffer*). The most raided crops were Maize at 82%, 1% Millet with 2% Sorghum other crops such as vegetables accounted for 15%. These findings show that large mammals are the most damaging species to crops targeting especially the maize crop. Given that maize is the most raided crop in the study area. These results are consistent with suggested that crop damage by wildlife is a widely reported form of HWC. However, crop damage effects on people's livelihoods are insufficiently measured.

Loss of human life or injury: The results of incidences related to loss of human life or injury were analyzed it was discovered that 57% of the cases were injury related and 43% were related to humans losing their lives. Four species were responsible for this form of conflict in the following order of magnitude 38% common hippopotamus (*Hippopotamus amphibius*), 30% Nile crocodile (*Crocodylus niloticus*), 27% African elephants (*Loxodonta africana*), and 5% African buffalo (*Syncerus caffer*). The results indicated that community members were attacked when performing the following activities; 25% were attacked while crossing the river going to school and walking at night between neighboring villages. 38% were attacked while fishing in the Zambezi and Kwando rivers, 13% were attacked while protecting their crops and herding cattle, 12% were attacked while drinking water and washing from the river and others were attacked when disrupting African elephants from drinking water from the river. These results contribute to addressing the future research areas highlighted by Chomba, where it was indicated that, future research should determine the gender and age group of people killed, time of the day and activity conducted by the victims at the time of the fatality incidence. This study investigated victim activities during attacks by human life-threatening conflict species.

Livestock depredation: The results indicate that cattle are the most attacked livestock in the study area followed by goats. The results showed that they are three common apex and predator species in the ecosystem in the following order of magnitude, Nile crocodile (*Crocodylus niloticus*) at 67%, 10% Spotted hyena (*Crocuta crocuta*) 10% Lion (*Panthera leo*) and 14% other species. In addition, property damage cases were very rare. Only one isolated incident was recorded in the period under study. Reference should be made to Table 1.

Table 1. showing forms of HWC, conflict species and conflict type.

Form	Conflict species	Conflict type
Crop damage	66% African elephants (*Loxodonta africana*), 28% common hippopotamus (*Hippopotamus amphibius*), 3% blue wildebeest (*Connochaetes taurinus*), 2% common duiker (*Sylvicapra grimmia*) and 1% African buffalo (*Syncerus caffer*)	Crops raided represented 82% maize, 1% millet and 2% Sorghum other crops 15%
Livestock depredation	67% Nile crocodile (*Crocodylus niloticus*), 10% spotted hyena (*Crocuta crocuta*) 10% lion (*Panthera leo*) and 14% other species	Livestock depredated included; 67% cattle, 19% goats and 14% other species
Human life loss/Injury	38% common hippopotamus (*Hippopotamus amphibius*), 30% Nile crocodile (*Crocodylus niloticus*), 27% African elephants (*Loxodonta Africana*) and 5% African buffalo (*Syncerus caffer*)	Humans Injured 57% and 43% loss of human life

Temporal patterns of human wildlife conflict hotspots in SC

Knowing when HWC occurs during the year is key to enhancing the awareness and preparedness of community members for conflict. The results from this study showed that HWC occurred throughout the year. However, two seasonal hotspots emerged, seasonal splits were based on two main seasons, the rainy season (November to April) and the dry season (May to October). The dry season was further subdivided into the cool dry season (May to August), and the hot dry season (September to October). Based on these splits the study found that the rainy season accounted for 52% of HWC incidents, 36% of HWC incidents occurred in the hot dry season and 12% occurred in the cool dry season.

Monthly, the study observed that the highest HWC incidences occurred in October at 31%, followed by March at

18% and January at 13%. The months of August and May had the lowest proportions of incidents. The highest proportions of incidents happened during harvesting periods with 39 % of incidents taking place from January to March. These results align with other studies which concluded that crop-raiding usually peaks when crops are mature because of a lessening in the nutritive quality of grasses.

The other peak takes place during the driest period of the year in October representing 31% of HWC incidents. This situation could be explained by the fact that the study area is in a water-stressed ecosystem that experiences early dry-ups of water pans forcing wildlife out of the National Park in search of food and water. The scarcity of resources brought by seasonality may result in high levels of animal aggregation and interference competition can occur in such a scenario and play a role in resource acquisition for both wildlife and people.

Spatial patterns of human-wildlife conflict hotspots in SC

Probability of human-wildlife conflict in the study area: This section presents the modelled HWC probability based on the maximum entropy software. The study obtained an AUC value of 0.908 from the training data, with a regularized training gain of 1.398 and an unregularized training gain of 1.666. When the maximum achievable AUC is less than 1. If the actual data is drawn from the same as the training distribution itself, then the maximum possible test AUC would be 0.871 rather than 1; in practice, the test AUC may exceed this bound.

The study obtained an AUC value of 0.840 when the model was run on the actual sample data (HWC Occurrence data), representing the high accuracy of the model as predicted by the training data. The AUC value indicates the model's predictive power. In this case, a value of 0.84 for the AUC means that 84% of the time, a random selection from the positive group (sensitivity) will have a score greater than a random selection from the negative class (specificity). Hence, the results from this model can accurately predict the probability of HWC incidents in the study area.

The model showed that HWC is linearly distributed in the landscape, following the river network systems. The Kwando River on the southwest and the Zambezi River on the northeast river line areas showed higher probability values for HWC compared to the central region of the study area. This indicated that river line areas should be prioritized for HWC management due to the higher risk of conflicts that prevails in these areas within a buffer of 2 to 5 kilometres from the rivers running through the study area. These results align with Dunkin who suggested that the movement of wildlife is affected by the availability of water. Further, Kerley & Landman, added that elephants, for instance, tend to congregate in areas with sufficient water to drink and in which to bathe and play, especially in coastal lowlands and along river valleys. Reference should be made to Figure 2; showing the spatial probability of HWC in the study area.

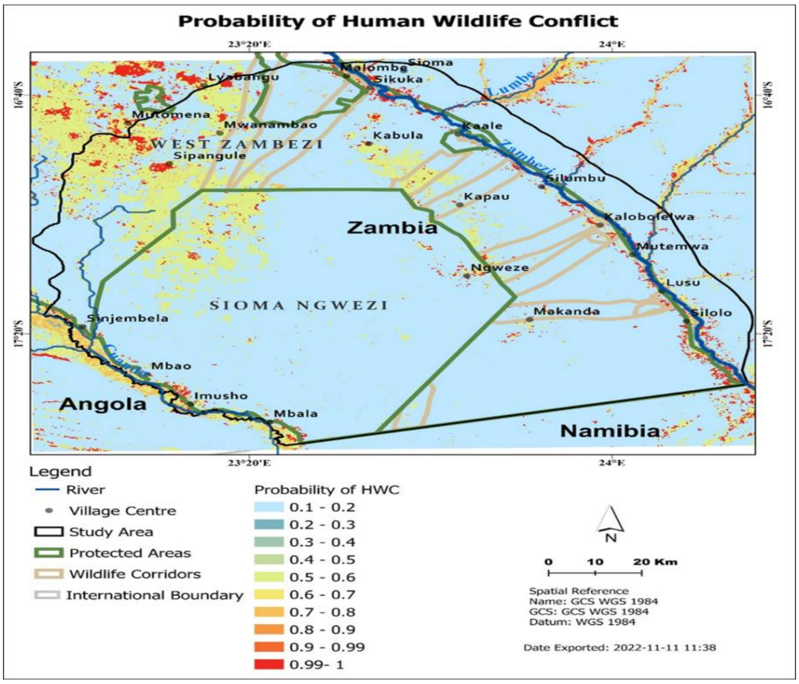

Figure 2. Spatial probability of HWC in the study area.

In addition, the probability of HWC was found to be highest in areas with moderately dense concentrations of water, grassland, settlements, and crop fields. This is possible as communities living along rivers mostly practice livestock rearing and small-scale agriculture, mainly for subsistence.

Human-wildlife conflict hotspot extraction and validation

HWC hotspot areas were extracted from probability ranges and analyzed concerning protected areas in the study area.

The range of 0.6 to 1 probability of HWC was considered a 'Human-Wildlife Conflict hotspot area' after intense consultations and validation with key informants.

The range used for visualizing and extracting HWC hotspots was based on a conclusion from a consultative process with key informants based on their expert knowledge and experience in the landscape. Conservation-grounded institutions and staff from the study area were consulted to validate the output of the model. The range of 0.4 to 1 was proposed by the researcher based on Mallick, who treated 0.4 to 1 as HWC hotspot areas in his research. However, key informants consulted suggested that the range of 0.6 to 1 probability of HWC be considered as 'Human-Wildlife Conflict hotspot areas'.

The basis for considering the range of 0.6 to 1 is hinged on the probability theory. This theory deals with the analysis of random events. Probability is defined as a numerical assessment of likelihood on a scale from 0 (impossibility) to 1 (absolute certainty). Therefore, on the basis that the higher the probability the higher the likelihood of occurrence. Hence, the range was adopted, this range implies that all areas modelled with a probability of HWC equal to and above 0.6 or 60% were treated as hotspot areas by this study.

Further, this was also adopted based on enhancing the accuracy of results as compared to Mallick Who used the range of 0.4 to 1, His analysis was based on several ecosystems at a transboundary level. Therefore, it could be suggested that the range used in this study presents a higher distribution accuracy when extracting HWC Hotspot areas at the level of one ecosystem that was considered in this study.

The study extracted HWC hotspot areas and mapped them using geographical information system platforms such as ArcGIS Pro (Version 2.4.1) by creating two classes of Non-HWC hotspot areas for probability values below 0.6 and HWC hotspot areas for values above 0.6 using the natural breaks (Jenks) classifier. Further, HWC hotspot area outputs were then analyzed by area classification (Figure 3).

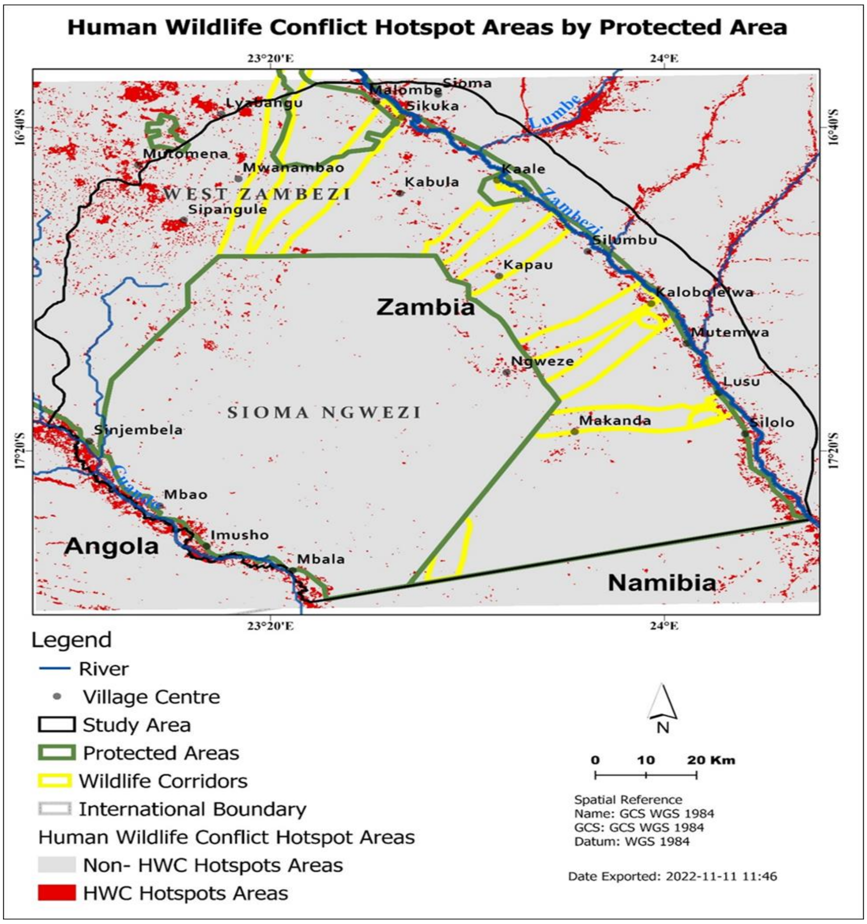

Figure 3. Distribution of HWC hotspot areas across the study area.

The results in Figure 3, show variations in the distribution of HWC hotspot areas across the study area. The emerging spatial pattern presented was that hotspots had a linear spatial pattern following river line areas along the Zambezi river and its tributaries in the north and the Kwando river in the southern portion of the study area. The linear distribution of HWC hotspots along river lines is responsive to human-wildlife interactions as theorized by the Social-Ecological Systems (SES) theory. Lischka et al., argued that, the interactions between humans and wildlife can be positive or negative and that people compete with wildlife for food and resources. Applied to these results, the SES theory explains the distribution of areas prone or at risk of HWC along the river line areas in this study due to, competition between

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wildlife and humans for resources specifically water along the river line areas from the Zambezi and Kwando rivers.

In addition, the river line areas offer refugia, forage, fertile agricultural soils and water for wildlife and the human population hence the distribution of HWC hotspots. The hydrological regimes of the study area also explain the distribution of HWC hotspots, it is observed that small water bodies in the SNNP get connected to either the Kwando or the Zambezi during periods of high floods but when the water recedes they get cut off from the channel, some dry up before another rain season starts while others retain water until the next rain season. Key informants added that, the reduced availability of water in the park during the dry season forces wildlife to alter their movement patterns and concentrate their movements and distribution along river shores for 6 months. These results are justified given that the reduced availability of water in parks enhances competition for water between humans and wildlife along river line areas.

In addition, the modelled HWC hotspot areas from the results coincide with those of previous studies indicating that human-inhabited areas, highways, rivers, water plans, wetlands, plains and agricultural fields as hotspot areas. These results are supported by other studies that also found that conflict with wildlife increases in intensity with proximity to rivers and protected areas.

Analysis of human-wildlife conflict hotspot areas

This analysis was based on Zambia's protected area classification and specifically national park, game management area and open area. About 550 km^2 or 55,000 hectares of silowana complex (5% of its area) was estimated as the HWC hotspot area. The results showed that, of the total HWC hotspot areas, 60% were in the GMA, 18% were in the national park and 22% were in the Open area. It could, therefore, be concluded that the GMA would experience more HWC than the National Park (Figure 4).

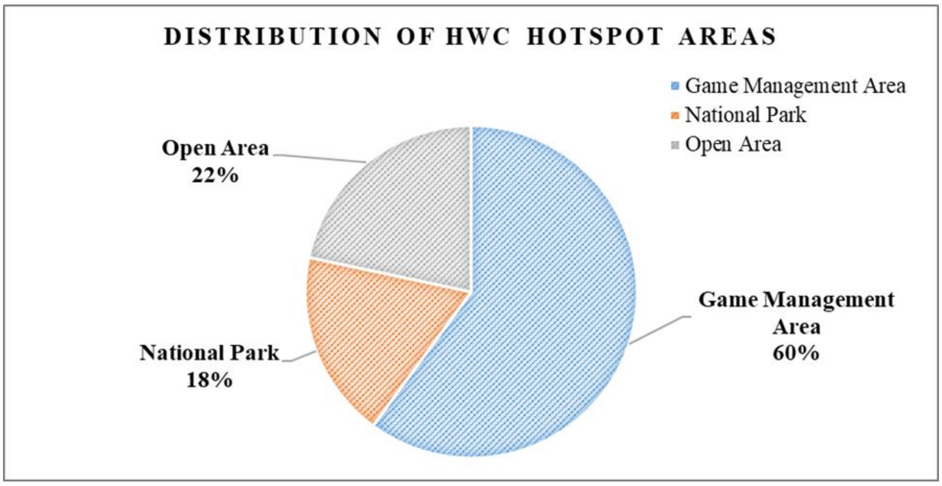

Figure 4. Analysis of human-wildlife conflict hotspot areas.

Human-wildlife conflict mitigation measures in the silowana complex

The study has documented, current and proposed community responses to HWC as presented below. This section will provide an evaluation of the community and authorities' responses to HWC. It further recommends modifications to the current responses as recommended by literature and use cases within the southern African region.

Current community-led human-wildlife conflict mitigation measures

The study found that 48% of the respondents did nothing and had no local knowledge of how to mitigate HWC. Further, 42% of the respondents responded to HWC by guarding their fields and livestock, 5% fenced their fields and property (This included, erecting predator-proof kraals, fencing houses, food storage facilities, water points, farms and gardens) and others were scared wildlife by beating drums and throwing Chilli bombs at elephants for instance (Figure 5).

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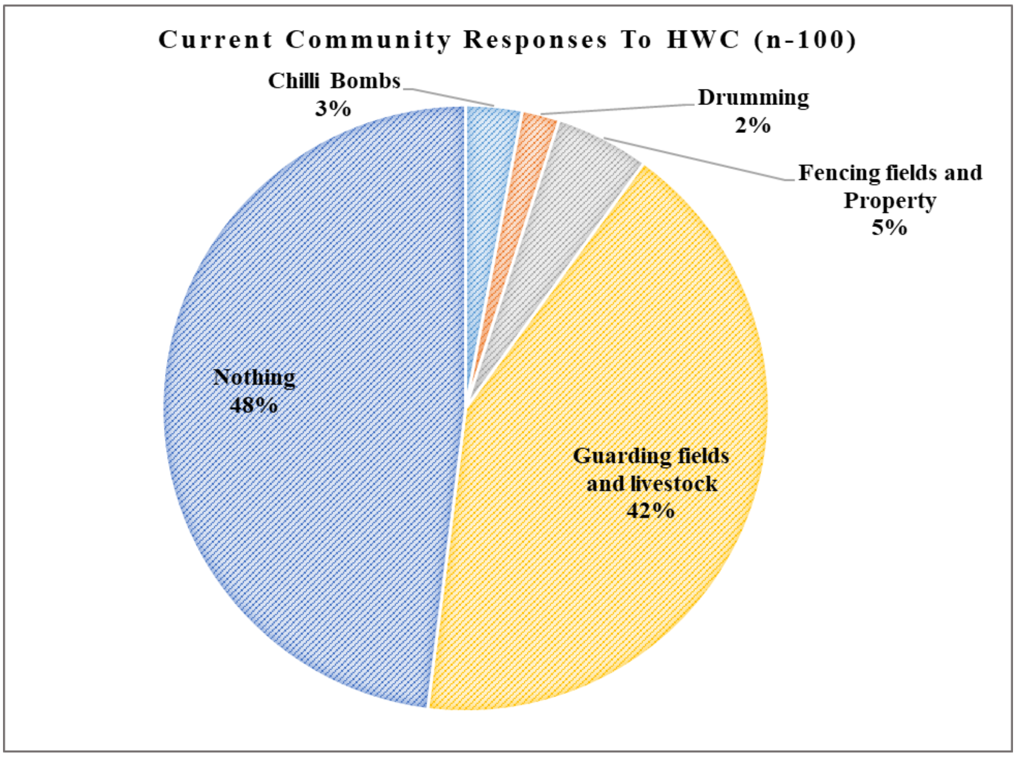

Figure 5. Community-led human-wildlife conflict mitigation measures.

It was concerning that 48% of the respondents did nothing and had no knowledge of how to mitigate HWC. At the same time, this presents an opportunity to co-create solutions with the community and pilot mitigation measures on a clean slate. This calls for capacitation and community sensitization. This situation is what may be contributing to the huge data gaps in the existing data. In that, a large number of these HWC incidents go unreported. In the case of Hwange district in Zimbabwe for instance a significant proportion of farmers do not report damage to anyone, as they just do not know whom to report to or would have to travel far to get knowledge on how to mitigate HWC.

Further, 42% of the respondents indicated that they guarded their fields and livestock, this was concerning as well in that, it presents a range of hidden costs and implications as documented by Jadhav, Barua and Muyoma. They cited important aspects of HWC hidden costs associated with guarding crop fields and domestic animals namely, fear, psychological disturbance, giving up opportunities of schooling by children and transaction costs incurred when HWC is experienced, loss of health both psychological and physical, brought on by the stressors of guarding fields and homes. Jadhav and Barua, added that the fear of encountering wildlife is a constant stressor leading the farmers who guard their crops and livestock to suffer from a significant lack of sleep and fatigue, this often means less productivity during the day. This, therefore, justifies the accession that, the ever-increasing HWC, if not addressed will hinder the achievement of many of the Global Sustainable Development Goals (SDGs).

In addition, 5% of the respondents erected wood and grass fences around their fields and property to mitigate against herbivore-related conflicts and to mitigate carnivore-related conflicts respondents interviewed, indicated that they set up stronger kraals to prevent lions and spotted hyenas. Fences work by separating people and livestock from wildlife through a barrier to avoid negative impacts on both sides. However, barriers can also alter people's relationship with nature. Again, several respondents interviewed indicated that, they scared animals using drums and Chili bombs.

Community proposed additional HWC mitigation measures

The community members interviewed proposed additional mitigation measures, a mixture of responses is presented in Figure 6 below. Largely the responses included; relocating people from wildlife corridors, recruiting and deploying more community scouts in communities, compensation for HWC-related damages, limited hunting of common conflict species and fencing (Figure 6).

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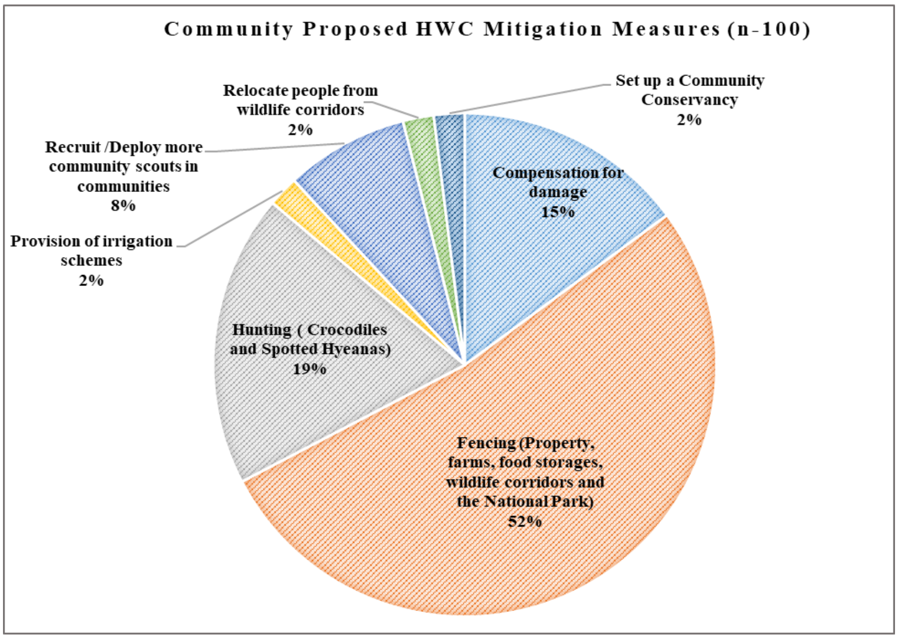

Figure 6. Community proposed additional HWC mitigation measures.

Fencing

Figure 6 shows that 52% of the respondents or community members highly recommended erecting fences around fields, property, storage facilities, wildlife corridors, water points, and the national park and erecting stronger kraals. This recommendation was highly favored and has been effective. Three types of fencing emerged from these respondents:

- Restraining fences for elephants and crocodiles.
- Predator proof kraals and
- High tension wire fences for national parks.

However, this study would not recommend some of these measures based on Graham and Ochieng, since some of these methods are exclusionary, they prevent the free movement of wildlife. Below is a detailed elaboration on each of these three types of fencing that emerged.

Restraining fences for elephants and crocodiles: Restraining fences for elephants; community members highly recommended erecting poly electric wire fences around fields and property. This recommendation was highly favoured for being effective. However, results from a comprehensive study by Thouless and Sakwa revealed a myriad of constraints ranging from design and construction to maintenance. The specifications of poly electric fences were beyond the reach of local communities unless supported by international and external agents.

In addition, Graham and Ochieng concluded that the effectiveness of electrified fences depends on their delivery of a short high-voltage, low-current, electric shock when touched and the circuit between the wires, the earth and the body of the animal touching the fence is completed. Power is generated by solar panels, and stored in lead-acid accumulators. Further, these fences are easily broken if the posts are weak, the wires are poorly attached to the post, or if voltage falls and the fences recommended are made of poly wire. The most frequent cause for low voltage is short-circuiting caused by vegetation, for example, long grass, or from badly connected wires because of poor repair. These fences therefore need to be well-built, and well-maintained, with regular clearance of growing vegetation and timely and efficient repair. Simply stated, the sustainability of this intervention is difficult for community members.

In addition, some respondents recommended the installation of crocodile restraining fences, they indicated that in some places within the study area where pilots have been done, crocodile restraining fences have proved effective in reducing human and livestock attacks by crocodiles. These fences also help in providing safe access to river lines and water. The crocodile specialist group, have documented that crocodile restraining fences work well in combination with crocodile disturbance, and more effectively, where problem sites have been identified.

The noise made by humans will continuously affect the activities of crocodiles, reducing the chances of attacks. However, ecologically this negatively affects the crocodile population, as the nesting sites are affected, and breeding rates will decrease. Further, the challenges of crocodile restraining fences come with flooding regimes of rivers. Fluctuations in water levels require that the fence be mobile for it to remain effective. In addition, river erosion and the burrowing effects of crocodiles may render them ineffective. Therefore, these fences require regular maintenance due to several factors which include rusting of the wire material usually used.

High tension wire fences for national parks: High-tension wire fences were recommended for Sioma Ngwezi national parks. However, this study would not recommend this measure based on Graham and Ochieng. Fencing a national park is exclusionary preventing the free movement of wildlife. Generally, high wildlife fences are used around national parks and other protected areas. Varying successes have been recorded in most parts of Africa. The bottom line is that this measure is difficult to maintain by the community as well as national parks authorities. Lessons in Zambia could be drawn from Mosi-Oa-Tunya and Lusaka national parks, where animals severely damage fences knocking them down or burrowing underneath, failing to keep wildlife in the park. Over time, they become so damaged that in many places it is nonexistent or is so mangled that they become a threat to wildlife as they get caught in the fence. Widespread fence damage also provides no poaching deterrent, thus providing few benefits to wildlife and people.

Predator proof kraals: Community members also recommended the erection of stronger predator-proof kraals as a mitigation against livestock depredation. Predator-proof enclosures (called either "corrals", "pens", "paddocks", "bomas", "stockades", or "kraals") are designed to stop or reduce livestock attacks at night. However, it has to be mentioned that, livestock/predator conflict is very complex and no single solution has proven to be effective yet including predator-proof kraals. However, good results have been obtained from zero visibility predator-proof kraals, it's known that predators only attack what they can see and therefore if kraals are designed to make livestock invisible at night, then they would be effective.

Literature has shown that where predator-proof kraals have shown effectiveness they have also changed predator behavioural patterns, predators start attacking less at night and more during the day time when livestock is out of enclosures. This complexity can be addressed by applying good daytime animal husbandry practices in conflict areas such as communal herding instead of individual as observed in the study area, and adult human herders should guard livestock instead of children. Further, if the state has to use lethal control of problem predators. It could be recommended that detailed identification of individual predator animals through collaring and behavior studies be done to allow for targeted control instead of indiscriminate killing by both the state and communities.

Limited hunting of common conflict species

The results showed that 19% of the respondents advocated for wildlife cropping. Respondents suggested that the Government of Zambia through the DNPW should consider lifting the ban on hunting in Lower West Zambezi GMA where the effect of HWC was being felt the most. They recommended limited hunting of predator species for instance crocodiles and spotted hyenas. However, if this has to be considered there is a need to conduct detailed wildlife counts to justify hunting quotas. Usually, hunting is often the only or most viable solution to mitigating conflict, supporting community livelihoods, and creating conservation incentives. Further, hunting provides communities, with the resources and incentives to tolerate HWC and wildlife. Some key informants interviewed indicated that the current hunting ban in the GMA should be supplemented with alternative solutions and that coexistence initiatives are complicated.

Compensation for HWC-related damages

Further, 15% of the respondents proposed that compensation for damages caused by wildlife should be considered as a mitigation measure. Community members are interested in compensation because it mitigates HWC impacts through the provision of a financial buffer and, in turn, reduces the likelihood of victims seeking to kill wildlife in retaliation. In addition, the authorities and community members in the area have acknowledged that the situation is worsened by the fact that Zambia's legal framework does not provide for compensation arising from raiding wild animals. Respondents observed that the law provides for actions and punishing measures when the community kills or injures wildlife, while nothing is done when wildlife damages people's crops and threatens and destroys human life. Further, due to the lack of compensation, community members are discouraged from assessing, accurately reporting damaged crop fields, and participating in conservation efforts, since assessments do not lead to compensation for loss suffered.

However, this study does not recommend compensation from the authority. Since, most compensation programs reviewed by this study lack adequate incentives for communities and they encourage disregard for preventative measures. Compensation schemes for instance in Botswana, Namibia and around the globe must include a variety of factors to be effective. The most critical factors include correct and speedy confirmation of losses; timely and fair payments; clear protocols, rules, and guidelines that connect payment and appropriate conservation management practices; and an understanding of the cultural and socio-economic systems. This study underscores the importance of investigating HWC incidents as a part of compensation programs.

Recruit more community scouts in communities

Again 8% of the respondents proposed that the government should consider increasing the presence of wildlife police officers and community scouts in the area for them to have a rapid response effect to control HWC in their area. This recommendation was made on the basis that, it would translate into conservation-based long-term employment for a select few qualified community members, this in turn would benefit the community at large.

Relocating people from wildlife corridors

Further, 2% of the respondents indicated that some community members have settled in traditionally known wildlife corridors and they were of the view that if HWC has to be resolved in some hotspots there was a need to intensify wildlife corridor management and maintenance to reduce and prevent human encroachment on wildlife corridors. They suggested that people have to be relocated away from wildlife corridors and that people should not farm in wildlife corridors. This study advocates for the voluntary relocation of people from wildlife corridors as an ethical measure rather than forced relocation.

CONCLUSION

The study mapped areas at risk of HWC and documented mitigation measures in Sioma Ngwezi national park and Lower West Zambezi game management area (Silowana Complex). The study achieved three specific objectives, it analyzed forms of HWC, modelled HWC hotspots and established community-led HWC mitigation measures in SC.

The study concluded that four forms of HWC existed in the study area in the following order of magnitude crop damage, Loss of human life or injury, livestock depredation, and property damage. These forms of conflict were largely caused by caused by the following species of wildlife in their order of magnitude; African elephants (*Loxodonta africana*), common hippopotamus (*Hippopotamus amphibius*), Nile crocodile (*Crocodylus niloticus*), blue wildebeest (*Connochaetes taurinus*), African buffalo (*Syncerus caffer*) and spotted hyena (*Crocuta crocuta*), lions (*Panthera leo*) and common duiker (*Sylvicapra grimmia*).

Further, the study analysed geographical (temporal and spatial) patterns of HWC/It concluded that HWC occurred throughout the year with peaks in March and October. Further, the modelled HWC hotspot's spatial distribution showed that a total of 550 km^2 or 55,000 hectares of SC (5% of its area) was at risk of HWC. The study concluded that of the total HWC hotspot areas, 60% were in the GMA, 22% were in the open area, and 18% were in the national park. Therefore, it could be inferred that Lower West Zambezi GMA experienced more HWC than SNNP. Further, human communities in the GMA are the most affected by HWC than those in the national park. The study also established that community members practised exclusionary and deterrent methods to mitigate HWC. The practice of these methods showed that community members knew how to mitigate HWC.

The study recommended that DNPW and its conservation partners should consider prioritizing integrated land use planning in addressing HWC. Further, this study recommends HWC mitigation strategies aimed at increasing local tolerance for wildlife and reducing retaliatory killings of wildlife by implementing long-term community benefit-led HWC mitigation measures and diversified poverty-alleviating alternative livelihoods such as; creating tangible conservation-based employment opportunities, and promoting the development and community co-ownership of viable tourism based enterprises and businesses aimed exposing community members to the real value of their wildlife. Doing so will increase community member's tolerance of wildlife and move them to a situation where they consider the benefits over the consequences and costs of living with wildlife. In addition, future studies on this topic could largely replicate this model in other landscapes in Zambia. Further research is needed focused on quantifying the impacts (physiological, social and economic) of HWC on local human communities.

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