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An investigation into the environmental factors influencing elephant poaching and poaching hotspots in RIFA, Hurungwe Safari Area, Mid- Zambezi Region, Mashonaland West, Zimbabwe.

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Abstract

This study investigates the environmental factors influencing elephant (Loxodonta Africana) poaching and poaching hotspots in RIFA, Hurungwe Safari Area, Mid- Zambezi Region, Mashonaland West, Zimbabwe. Using data collected during ranger patrols (local, extended, strategic and aerial patrols) and secondary data sources (reports) were also used from 2018 to 2022 for poaching statistics while elephant collar data was obtained from 09 collared matriarchs that were being monitored over the same period. The research also examines the elephant poaching hotspot, the relationship between elephant poaching and seasonal distribution, boundary, rivers, boreholes, roads and vegetation cover using Arcgis 10.3 tools. The results show a significant relationship between dry season elephant distribution and poaching of elephants, also a strong relationship between boundary, rivers and poaching of elephants and no relationship between roads, boreholes and poaching of elephants. The results also showed that the elephant poaching hotspots is in the north western of RIFA which is near to the mighty Zambezi River and also the boundary between Zambia and Zimbabwe. This study concludes that boundary, rivers and dry season as main drivers of elephant poaching in RIFA area. These finding highly recommends the wildlife managers to increase patrol in the North western area of Rifa and also increase the border patrols.

Keywords: elephant poaching; vegetation cover; hotspot; collared; monitored; boundary

Introduction

The poaching of African elephants (*Loxodonta Africana*) for ivory is a major concern throughout Africa with poaching contributing to the major declines in the populations of the species in most African countries (Kyando et al., 2017). African elephants are among approximately 30,000 species of animals and plants that are listed by the Convention on International Trade in Endangered Species (CITES) list as endangered (Sibanda et al., 2016) and the African elephants are listed under Appendix I of the CITES (Maingi et al., 2012). Despite a ban on the international ivory trade, African elephants are still being poached in large numbers. Tens of thousands of elephants are being killed every year for their ivory tusks. The ivory is often carved into ornaments and jewellery, with China being the destination and the biggest consumer market for such products (WWF, 2020). While the highest driver for elephant poaching has been ivory, there has been a lot of change with some now targeting the elephant for meat and others for both meat and ivory (Sibanda et al., 2016).

An estimated 22,000 African elephants were illegally killed across Africa in 2012 with the most serious threats to the species' survival across the continent being habitat loss, human-elephant conflict, and illegal killing for meat which have been compounded by an explosion of organized ivory poaching syndicates, especially in Zimbabwe (Sibanda et al., 2016). Monitoring of Illegal Killing of Elephants (MIKE) covers 60 sites across Africa, within which more than 19,000 elephant carcasses have been detected by rangers to date (Kuiper et al., 2020). An understanding of the spatial distribution or pattern of poaching activities is fundamental for purpose of reducing these poaching activities. However, the conservation efforts to protect elephants are challenging due to their vast habitat range, and as such conservation efforts focused on high-risk areas provide a more efficient management method than randomly patrolling entire habitat areas (Shaffer and Bishop, 2016).

Several studies have explored relationships among elephant abundance, environmental variables, and human factors. Several of these studies identified distance to water as the primary environmental factor influencing the density of the elephant population at the local level (Verlinden and Gavor 1998; Redfern et al. 2003). In the Congo Basin, found that the abundance of many mammal species increased with distance from roads because of hunting pressure. Other studies have looked at the relationships between elephants and vegetation has successfully utilized satellite-derived vegetation indices such as the normalized difference vegetation index (NDVI) and the enhanced vegetation index (EVI) as proxies for vegetation productivity (e.g., Chamaillé-Jammes et al. 2007; Hien et al. 2007; Loarie et al. 2009).

At the global scale, a major perspective used to explain crime is based on factors that increase the motivation to commit a crime and those that enhance the opportunity for criminal activity (Van Dijk 1994). Cohen and Felson (1979) came up with the concept of distance decay, which suggests that most offences occur relatively close to the domicile of a local offender. The distance-decay concept implies that crimes will tend to cluster where opportunities and motivated offenders are plentiful, and guardianship is missing or weak. In the case of elephant poaching, we can expect poaching activity to be intense where elephants are most abundant and where transportation of the poached ivory directly to the ivory traders or through middlemen is easiest because this provides the poacher with the highest return on effort. Likewise, we can expect poaching activity to be tempered by the poacher's fear of detection by game rangers and law enforcement. Indeed, Milner-Gulland and Leader-Williams (1992) found that the probability of capture was a highly significant factor in the poacher's decision to hunt black rhinos and elephants in the Luangwa Valley in Zambia. Several studies have explored relationships among elephant abundance, environmental variables, and human factors. Several of these studies identified distance to water as the primary environmental factor influencing the density of the elephant population at the local level (Verlinden and Gavor 1998; Redfern et al. 2003). In the Congo Basin, Blake et al. (2008) found that the abundance of many mammal species increased with distance from roads because of hunting pressure.

Although elephant population in Zimbabwe is increasing, poaching of elephants in protected areas which are proximity to country's boarder has changed and the factors causing this has not been yet established. This has caused poaching mitigatory measures to be insufficient to end or reduce the poaching incidences, thereby requires immediate attention to ensure enhanced elephant conservation in these protected areas and in the country at large. According to the studies done in the past six years poaching incident were mainly located in the north eastern side of Hurungwe Safari Area, but there has been an increase of poaching incidences on the south western side of Hurungwe safari Area mainly RIFA concession. The escalating crisis of elephant poaching in the Hurungwe Safari Area, Zimbabwe, demands urgent attention and action. Previous research highlighted that poaching activities were primarily concentrated in the Nyakasanga region of the Hurungwe Safari Area. However, recent data has revealed a concerning shift, with poaching incidents increasingly clustering in the Rifa section over the past few years. This study aims to uncover the underlying factors driving this change. This includes assessing whether the movement patterns of elephants have made them more vulnerable in certain areas or if poaching tactics have evolved in response to anti-poaching efforts in Nyakasanga. This study also aims to unfold when and where the shifts occurred, offering insights into the timing and potential triggers of increased poaching activity. The previous study done by Sibanda et al 2015 was basing on the location of carcass rather than movement of elephants in Hurungwe safari Area, this study will therefore correlate the movement of elephants and poaching incidence. Since the collaring of elephant in Rifa no studies were done to reveal the factors causing the shift of poaching incidence from north east to the south western of Hurungwe Safari Area, the present study will therefore work as a baseline data for the seasonal movement of elephant in Rifa. Elephant poaching mitigation are determined by the behavior and occurrence of the poaching incidence and factors influencing poaching, the present study aims to unfold the relationship between environmental factors the movement of collared elephant. Moreover, the study will come up with scientific based information which will guide Park manager and policy makers to come up with informed decision in elephant conservation. The aim of the paper is to investigate the environmental factors influencing elephant *(Loxodonta Africana)* poaching and poaching hotspots in RIFA, Hurungwe Safari Area, Mid- Zambezi Region, Mashonaland West, Zimbabwe

Materials and Methods

Study Area

The study was conducted in the HSA–RIFA section of the Zambezi Valley within the Hurungwe Safari Area in northern Zimbabwe. The study area covers approximately 619 km² and is located between 16°6′59.76″S and 29°9′47.52″E. Elevation ranges from 350 m above sea level in the Zambezi floodplain to 1050 m along the Zambezi Escarpment. The terrain consists of a sparse dendritic river network draining into the Zambezi River.

The area has an average annual rainfall of 650 mm, falling mainly between November and April. However, the rainfall is very erratic, and droughts are a regular occurrence. The average minimum temperatures range from 9 °C in July to 22 °C in December, while the average maximum temperatures range from 15 °C in July to 30 °C in December. The relative humidity is highest during the rainy season, especially between November and January, and frost has never been recorded below the escarpment. The vegetation types below the escarpment are characterized by mopane woodland with scattered baobab trees, while the higher ground is dominated by Brachystegia species. The area supports a wide range of wildlife, including elephants, fish, birds, and a variety of insects.

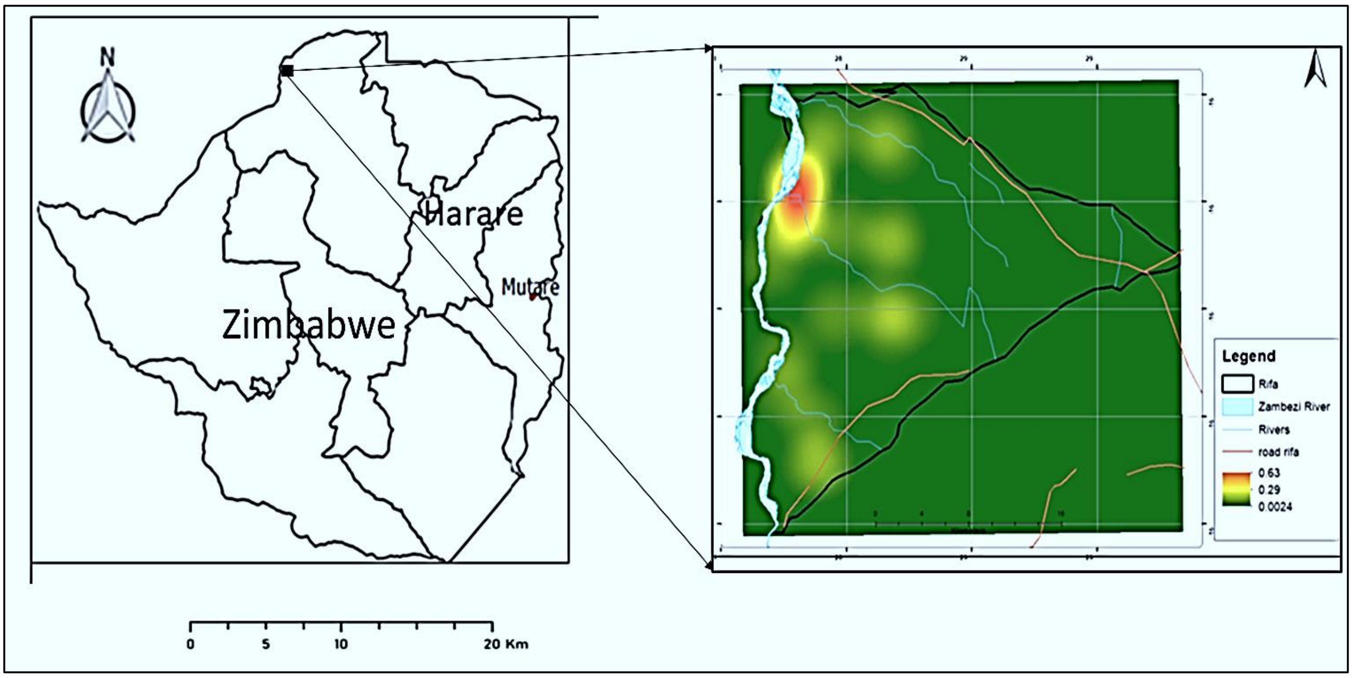

Figure 1: Map of Zimbabwe showing the location of RIFA

Data Collection

The data for this research was collected between 2018 and 2022 using both primary and secondary sources. The primary data was collected using ranger patrols (local, extended, strategic, and aerial), where the locations of elephant carcasses were recorded using handheld GPS devices. The data was recorded in decimal degrees and later used to create Microsoft Excel spreadsheets with corresponding dates and location information. In addition, movement information was collected from nine collared elephant matriarchs who were being tracked during the same period.

The secondary data was collected from patrol reports and mortality reports that were filed at the station to confirm the information collected from the field. This information is part of a protected area law enforcement data management system and was deemed accurate for the purpose of this study.

Variables that were thought to affect the risk of poaching, such as vegetation cover, distance to water sources, distance to the park boundary, and seasonality, were used in a logistic regression model in ArcGIS. This helped to determine the strength of the relationship between the variables and the risk of poaching, as well as the variables that had the greatest influence on the risk of poaching.

Lastly, the spatial distribution of the elephants during the different seasons was overlaid with the spatial distribution of the poaching incidents during the different seasons using GIS. Regression analysis was used to determine the relationship between the spatial distribution of the elephants and the poaching incidents.

Data Analysis

Spatial and statistical data analysis was performed using ArcGIS 10.3. To analyze the multi-temporal distribution of poaching hotspots between 2018 and 2022, Kernel Density Estimation (KDE) was applied to the georeferenced poaching incident data obtained from ranger records, ground observations, and aerial surveys. This approach allowed the creation of a continuous surface layer to represent the density and aggregation of poaching incidents in the study area, facilitating the detection of spatial hotspots over time.

Spatio-temporal distribution of elephants was identified using GPS collar data from the nine monitored matriarchal elephants. Seasonal movement patterns were analyzed through home range estimation by KDE, while spatio-temporal clustering analysis was employed to examine changes in elephant distribution over time. Seasons were divided into wet (November to April), dry (May to October), and a transitional autumn phase (April to May).

Presentation of Results

Quantifying Multi-Temporal (2018–2022) Distribution of Poaching Hotspots in RIFA

The map(Figure 2) shows the spatial distribution and level of elephant poaching incidents in the RIFA section of the Hurungwe Safari Area using Kernel Density Estimation (KDE). The map color gradient indicates the level of poaching, with red areas indicating very high-density hotspots, yellow areas indicating moderate-density hotspots, and green areas indicating low-density or negligible poaching activity. The park boundary is shown by a black line, rivers are shown in blue, roads are shown in red, and the Zambezi River marks the western boundary of the study area.

The results show a very prominent primary hotspot in the north-western corner of the park, right along the boundary of the Zambezi River. This region has the highest kernel density values (close to 0.63), which indicate a high level of spatial aggregation of poaching incidents.

The high level of poaching incidents along the river boundary indicates that access to water sources and international routes may play a significant role in poaching incidents.

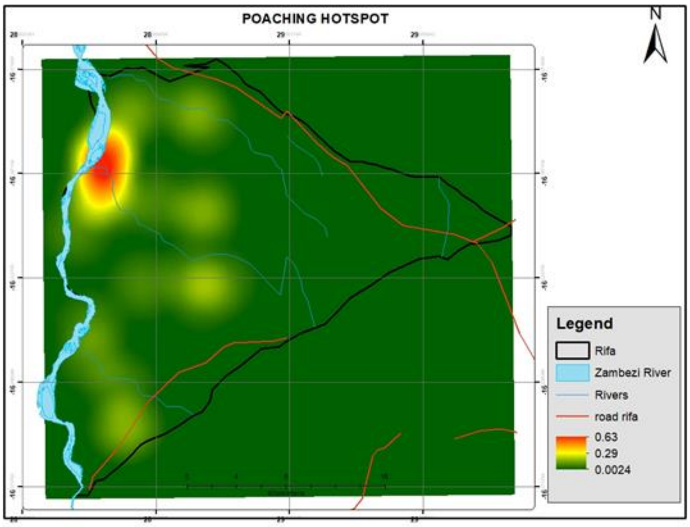

Figure 2 Poaching hotspots in RIFA

Assessing Environmental Factors Influencing Poaching Hotspots in RIFA

The map Figure 3 shows the spatial distribution of vegetation cover in the RIFA section of the Hurungwe Safari Area using the Normalized Difference Vegetation Index (NDVI). The NDVI index is shown using a color gradient, where green represents dense vegetation, yellow represents moderate vegetation cover, and orange to reddish colors represent low vegetation density. The park boundary is shown in black, the Zambezi River along the western boundary, and seasonal rivers in the park are also shown. Black spots show the recorded cases of poaching.

The dense vegetation cover is shown along the western boundary of the park, especially around the Zambezi River, where dense green patches are shown. The central and eastern parts of the park show moderate vegetation cover (yellow color), while low vegetation density is shown in some parts of the escarpment and the interior. This trend indicates a positive spatial relationship between vegetation density and poaching incidence. Dense vegetation around permanent water sources, especially along the Zambezi River, could offer opportunities for concealment and ambush points for poachers to attack elephants. On the other hand, regions with low vegetation density appear to have relatively lower levels of poaching incidence, possibly because of the lack of cover. In general, the NDVI map indicates that vegetation spatial structure is a significant environmental variable that affects the spatial distribution of poaching incidents in the study area.

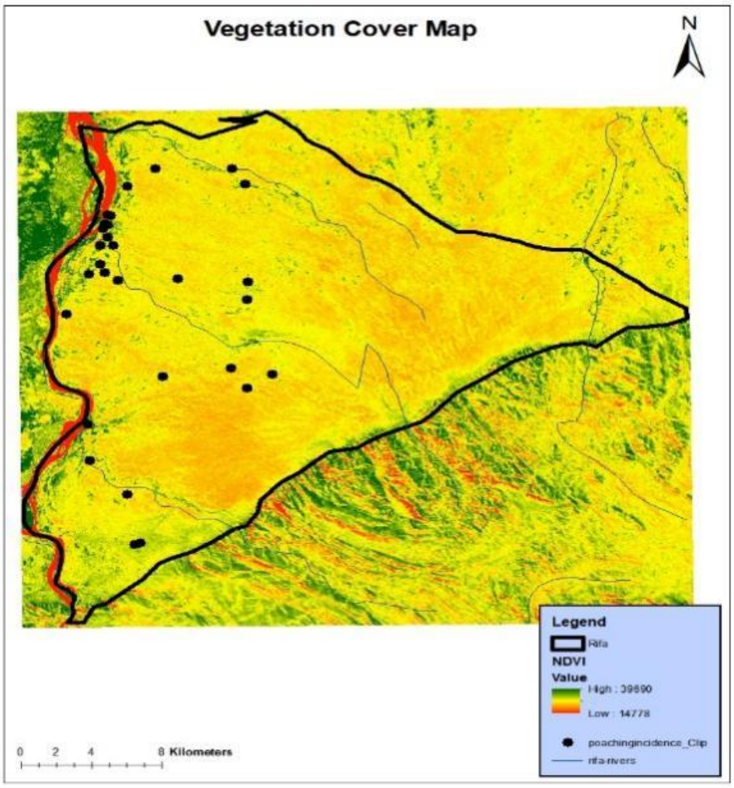

Figure 3: Poaching incidences and vegetation cover.

Relationship between poaching incidents and roads

From the scatter plot, it can be observed that there is a strong positive relationship between the presence of roads and the predicted elephant poaching incidents in the RIFA/Hurungwe Safari Area, as indicated by the high value of R^2 at 0.71. This value indicates that 71% of the variation in the level of poaching can be explained by the presence of roads or road density, which can be considered as an important conduit for poaching activities in the Mid-Zambezi Region. Although the regression line indicates a steady increase in the level of poaching, there is considerable clustering of data points, especially in the higher range, which helps to identify "hotspots" where the risk of poaching is at its highest. This indicates that although roads are the most important environmental factor, the level of poaching may be further fueled by the convergence of transport infrastructure with other local factors such as water points or patrol gaps.

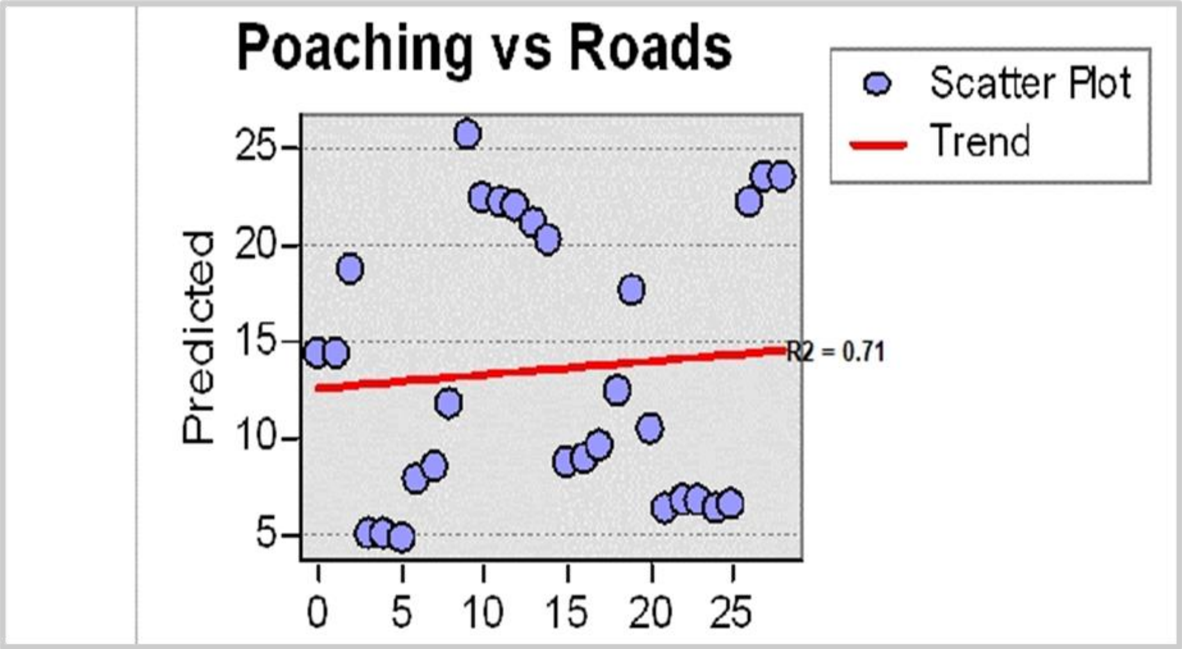

Figure 4 Poaching Vs roads

Relationship between poaching incidents and boreholes

Analysis of the results shows a clear negative correlation between borehole distribution and the predicted number of elephant poaching incidents in the RIFA area of the Hurungwe Safari Area. The scatter diagram shows that areas with low borehole distribution have high levels of predicted poaching, while areas with high borehole distribution have low levels of poaching. The regression analysis shows a high coefficient of determination ($R^2 = 0.81$), which means that about 81% of the variation in poaching levels can be explained by the distribution of boreholes. The strong statistical relationship between the two variables underscores the importance of water as a key environmental factor that shapes the dynamics of elephant poaching. The negative trend line confirms that as artificial water sources increase, the number of predicted poaching incidents declines, which means that boreholes can be a critical factor in reducing elephant concentration around scarce natural water sources and, in turn, reducing the risk of being attacked by poachers.

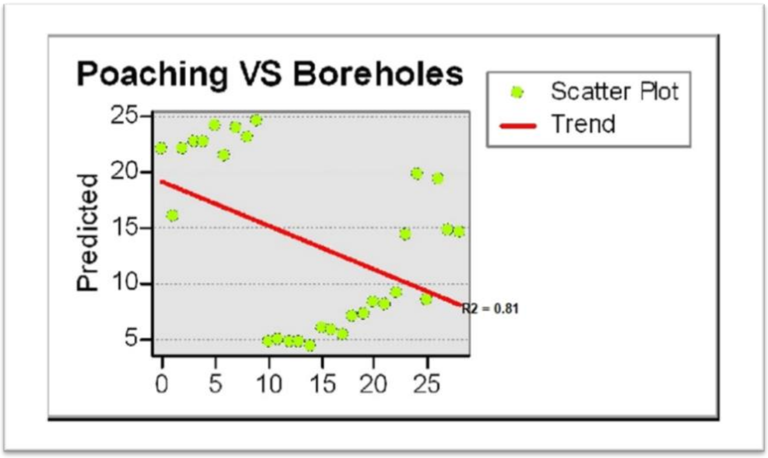

Figure 6 Poaching Vs Borehores

Poaching Vs Rivers

The scatter diagram illustrating the correlation between Rivers and Predicted Poaching incidents in the RIFA/Hurungwe Safari Area indicates a strong positive linear relationship, as indicated by the high $\mathbf{R^2}$ value of 0.66. The value of this coefficient indicates that 66% of the variability in poaching incidents can be explained by the distance or density of riverine systems, thereby establishing them as a key environmental determinant of poaching hotspots. The sharp upward trend of the red trend line in the scatter diagram also indicates a strong positive correlation between the riverine variable and the predicted poaching rate, which can be attributed to the fact that these water sources are known to harbor animals in predictable numbers, making them high-risk areas for poaching elephants. The points in the scatter diagram are also seen to be concentrated in the higher range of the spectrum, thereby establishing that riverine areas in the Mid-Zambezi Region are key determinants of illegal poaching activities.

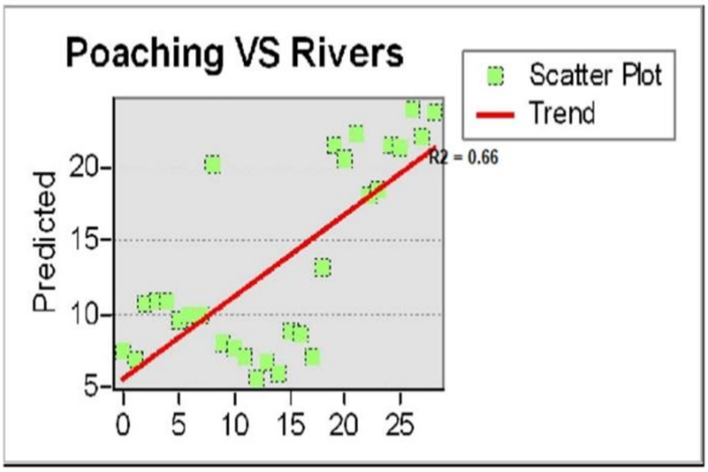

Fig 9 Relationship between poaching incidents and rivers.

Poaching Vs Boundary

The data shows a strong positive correlation between environmental proximity factors and predicted poaching activity, with boundary proximity being the most influential factor. The "Poaching VS Boundary" scatter plot shows the strongest predictive capability with an R^2 value of 0.83, indicating that about 83% of the variation in poaching activity can be accounted for by proximity to the borders of the safari area, which are often easy points of entry and exit for poachers. Likewise, the "Poaching VS Rivers" analysis reveals a strong positive trend and a strong R^2 value of 0.66, indicating that water sources are important hotspots where animals are particularly susceptible to poaching. Collectively, these findings indicate that elephant poaching in the RIFA/Hurungwe Safari Area is highly predictable and concentrated in space along administrative boundaries and water sources.

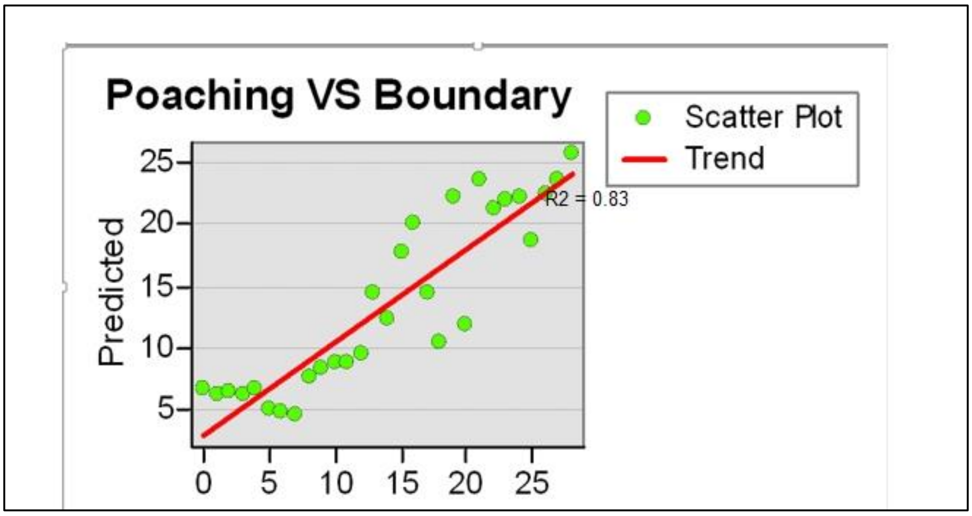

Fig 10. Relationship between poaching and the boundary.

Relationship between poaching incidents and Seasons

The overall dataset suggests that the poaching of elephants in the RIFA/Hurungwe Safari Area is mainly a function of spatial accessibility and seasonal vulnerability, with proximity to the boundary being the most significant predictor. The analysis of "Poaching VS Boundary" reveals an excellent R^2 value of 0.83, suggesting that 83% of the variation in poaching can be attributed to the boundaries of the area, followed by rivers ($R^2 = 0.66$), which are identifiable hotspots for the exploitation of wildlife resources. Moreover, the longitudinal analysis of the trends from 2018 to 2023 suggests that the Dry Season poaching cases have been steadily ahead of all other seasons, possibly because of the animals' concentration around scarce water sources, while the Autumn and Wet Season poaching cases have generally been on a downward trend.

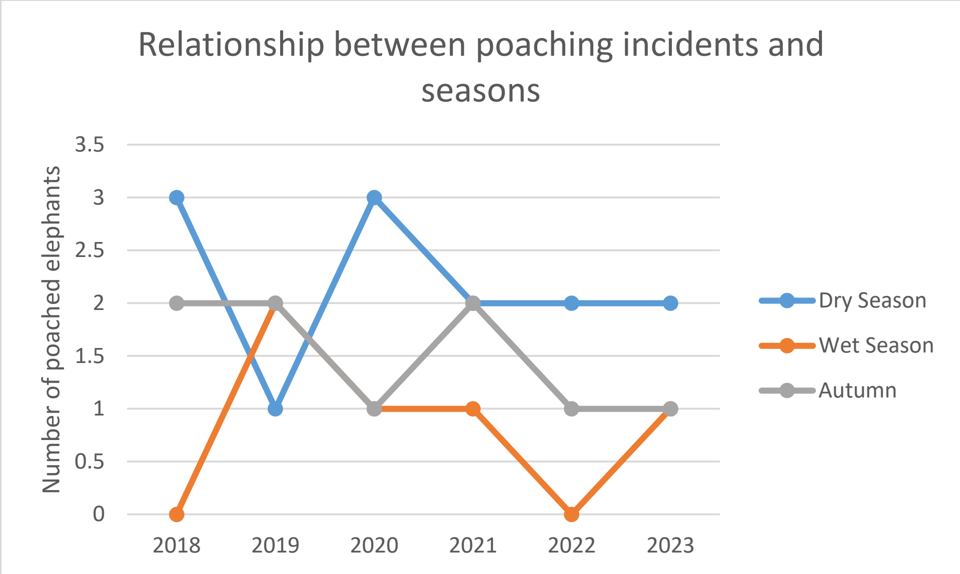

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Figure 2:graph showing the trend of poaching incidents between seasons.

Overlay Analysis of Wet, Autum and Dry Season and Poaching Hotspots

Dry Season

The Dry Season is the point of greatest poaching activity and thus greatest risk. The heatmap(Figure 12) indicates a broad, densely populated "red" hotspot in the northwest, particularly where the region intersects with large bodies of water. This is a spatial pattern that is strongly confirmed by the statistical relationship between poaching and rivers ($R^2 = 0.66$), where elephants are driven to congregate around scarce water sources during this time of year. Longitudinal data indicates that while poaching was highest in 2018 and 2020, it has been a steady level of two elephants per year since 2023.

Wet Season

In the Wet Season, the poaching events are much more evenly spread out over the landscape than in other seasons. Although there is still a major hotspot that can be seen in the northwest, this is not as intense, and the “purple” hotspots of activity are more spread out into the interior of the safari region. This is probably due to the fact that the water availability allows the elephant populations to range away from the main river systems, making them more difficult for poachers to follow. Looking at the historical data, there is a great deal of variation in this season, with a total of two incidents in 2019, but then none at all in 2022.

Autumn Season

The Autumn Season is a transitional phase and is marked by a moderate level of poaching activity distribution. The hotspots during the Autumn Season are not as extreme as those in the Dry Season but are more concentrated than those in the Wet Season. Although the northwestern boundary continues to be a hotspot, in line with the overall result that the proximity to boundaries is the most significant predictor of poaching (R^2= 0.83), the total number of incidents has been steadily declining. The number of incidents per season peaked at two incidents in 2018 and 2021 but reduced to one incident per season in both 2022 and 2023.

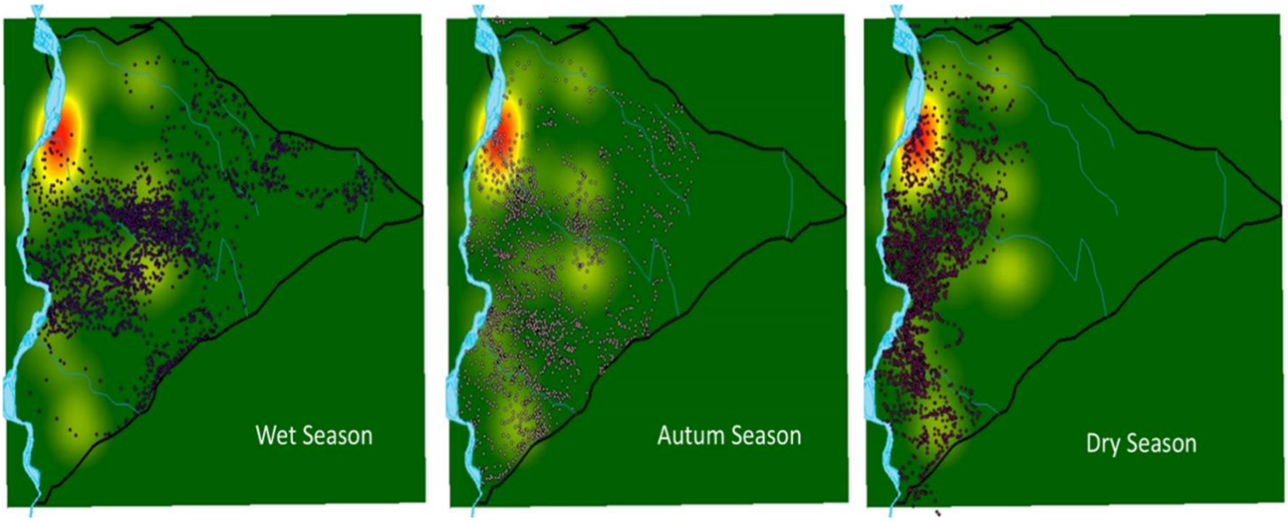

Figure 12 Overlay Analysis

Discussion of Results

The study on elephant poaching in the RIFA section of the Hurungwe Safari Area shows that poaching is not a random event but a predictable spatial and temporal process that is driven by environmental and accessibility-related factors.

Spatial Dynamics and Connectivity.

The most important result is the location of the first hotspot in the north-western corner of RIFA along the Zambezi River, which has high kernel density values (~0.63). The susceptibility of this region is largely because of its close proximity to international borders and administrative boundaries, which act as important entry and exit points for poachers. The "Poaching VS Boundary" analysis had the highest predictive ability (R^2= 0.83), which means that 83% of the variation in poaching can be explained by proximity to boundaries. Moreover, transport infrastructure is an important factor; road density enables illegal activities (R^2 = 0.71), which acts as a channel for the transportation of ivory out of the Mid-Zambezi Region. These results confirm findings in the literature that regions with high accessibility and porous boundaries are preferred targets for the illegal wildlife trade (Linkie et al., 2010; Maingi et al., 2012).

Environmental Drivers: Water and Vegetation

Water availability is found to be a clear positive driver of poaching activity. Natural water sources have a strong positive correlation with poaching events (R^2= 0.66), as the predictable animal aggregation points at water sources make elephants highly susceptible. On the other hand, the presence of boreholes has a strong negative correlation (R^2= 0.81), where more boreholes result in fewer poaching events by diffusing elephant aggregations. Vegetation density further adds to the susceptibility; high NDVI values (dense vegetation) along the Zambezi River are associated with high poaching events, probably acting as hiding and ambushing sites for poachers. The "concealment effect" of dense vegetation near water sources is a well-acknowledged factor in poaching vulnerability modeling (Ndaimani et al., 2014).

Seasonal Vulnerability

Temporal analysis shows that the Dry Season is the most vulnerable period. During this season, elephants are compelled to aggregate around natural water sources, resulting in hotspots in the northwest. Conversely, the Wet Season is characterized by a larger dispersal of both elephant and poaching incidents, as the availability of water in the interior enables herds to range away from the predictable river courses. The Autumn Season is a transition period, where a trend of reduced incidents has been observed since 2021. The changing seasons highlight the need for adaptive patrol plans based on the movement patterns of the wildlife (Wittemyer et al., 2008). The paper concludes that the poaching of elephants in the RIFA section of the Hurungwe Safari Area is a very predictable event that is influenced by the combination of spatial accessibility, environmental resource availability, and seasonality. The most important factor in the distribution of poaching is the proximity to the administrative boundaries of the park (R^2 = 0.83), which are porous entry and exit points for poachers, followed by the proximity to the roads (R^2 = 0.71), which are important transport conduits for the ivory. In terms of environmental factors, the permanent water sources and dense riverine vegetation (NDVI) are high-risk hotspots, especially in the northwestern corner of the park where the Zambezi River is located. However, the fact that the negative correlation between borehole distribution and poaching is quite strong (R^2 = 0.8) indicates that the provision of artificial water sources can be an effective measure to distribute the elephant population and make them less vulnerable. However, the fact that the intensity of the incidents is quite high during the Dry Season, as indicated by the Kernel Density Estimation, indicates that there is a substantial temporal window of opportunity where management should be focused to counter the exploitation of wildlife at water sources.

Conclusion

In summary, the research proves that elephant poaching in the RIFA section of the Hurungwe Safari Area is a non-random, spatially predictable process that is influenced by a combination of high accessibility corridors and resource dependency. The most important factor in determining poaching risk is proximity to administrative boundaries (R^2 = 0.83), followed by road density (R^2= 0.71), which are both factors that make it easy for poachers to illegally enter the area and quickly remove ivory. From an environmental perspective, the presence of permanent water sources and dense vegetation cover along the Zambezi River represents a hotspot, especially in the northwestern corner of the area where the NDVI analysis indicates that poachers take advantage of the dense foliage to hide. Nevertheless, the negative correlation between borehole distribution and poaching events (R^2= 0.81) reveals that the provision of artificial water sources is an extremely effective means of dispersing elephant populations and making them less vulnerable to attack.

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