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RESEARCH ARTICLE

Trophy Hunting of Elephants Close to the Park Boundary of Gonarezhou National Park, Zimbabwe, Deters Elephants From Using Adjacent Hunting Areas

L. Nzombane[1] | O. L. Kupika[2] | T. Tarakini[1] | T. G. O'Connor[3]

[1]School of Wildlife and Environmental Sciences, Chinhoyi University of Technology, Chinhoyi, Zimbabwe | [2]Okavango Research Institute, University of Botswana, Maun, Botswana | [3]Centre for African Ecology, School of Animal, Plant and Environmental Sciences, University of the Witwatersrand, Johannesburg, South Africa

Correspondence: L. Nzombane (lloyd@gonarezhou.org)

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ABSTRACT

Trophy hunting of elephants may influence their habitat utilisation, which might have cascading impacts on resource availability and their dynamics. The effects of elephant trophy hunting were investigated in hunting areas in the proximity of Gonarezhou National Park between 2017 and 2023. It was investigated whether elephants were being hunted close to the park boundary and, if so, whether such 'periphery hunting' had created a barrier of fear which restricted elephants' movement into, and use of, hunting areas. Utilisation of hunting areas was studied by tracking the movements of 11 bull elephants fitted with GPS collars, and by counting elephant dung along 20 belt transects and in 60 plots distributed across a non-hunting area and an adjacent hunting area. A total of 70 bull elephants were hunted, with more elephants killed in 2021 than in 2020, most likely owing to the effects of the COVID pandemic on international travel. Elephants were hunted at distances from the park boundary of between 0.02 and 7.50 km, with 51% of the kills occurring within less than 1 km. Movement of bull elephants suggested that a 'barrier of fear' along the park boundary reduced their movement into, and use of the hunting areas. Dung distribution further indicated that elephants used the non-hunting area more than the hunting area. Periphery hunting was confirmed as an appropriate descriptor of the spatial pattern of hunting.

1 | Introduction

Protected Areas (PAs) are the mainstay of biodiversity conservation at local, regional and global levels (Borowik et al. 2018). However, due to their limited size or unfavourable shape, PAs often do not provide sufficient protection (Muswete and Brijesh 2018) of large mammals such as the African savannah elephant *Loxodonta africana* (hereafter 'elephant') that need large areas (Borowik et al. 2018). PAs may serve as core areas for animal populations, but owing to their high perimeter–area ratio and spatial isolation, protection of target species or animal communities may be difficult to achieve (Woodroffe and Ginsberg 1998). The long-term viability of many wildlife populations and migrations in Africa is threatened by the increasing isolation of PAs driven by habitat loss, fences and roads, over-hunting and disease (Newmark 2008). The problem of reserve isolation must therefore be addressed with a multi-pronged conservation strategy. To this end, hunting areas located adjacent to national parks can play a significant role in ensuring the preservation and protection of wildlife (Muswete and Brijesh 2018).

The elephant is listed by the International Union for Conservation of Nature (IUCN) as Endangered (Gobush et al. 2021), and is listed in appendix I of the Convention on International Trade for Endangered Species (CITES), except for the populations of Botswana, Namibia, South Africa and Zimbabwe, which are included in appendix II (CITES 2023), meaning that commercial international trade through trophy hunting of up to 500 elephants per year is allowed in Zimbabwe. Historically, elephants were widely distributed throughout Africa, reflecting their adaptability to a wide range of environments (Laws 1970; Poche 1980). The estimated elephant population in Africa in 2014 was between 419,000 and 650,000 individuals (Simon et al. 2016), of which Southern Africa held 42%, Eastern Africa 28%, Central Africa 25% and West Africa 5% (Gebrehiwet and Weldeabzgi 2024). Zimbabwe has the second largest population of between 90,000 and 100,000 elephants (Zimparks 2024), of which Gonarezhou National Park (GNP) was home to an estimated 10,812 elephants in 2022 (K. Dunham 2022). Culling between 1960 and 1988 kept the elephant population in GNP between 4000 and 5000 elephants (Booth 1989). From 1980 to 1991, this elephant population increased from 4704 elephants (0.96 elephant/km^2) to 6406 elephants (Coulson 1980; Jones 1991). The density of >2 elephants per km^2 recorded in 2022 in GNP is one of the highest for a protected area in a semi-arid region, and exceeds the recommended density of 0.5 elephants/km^2 (Kukura 2019). In the absence of any corresponding increase in the size of the national park, it is imperative to consider how elephants from GNP can make use of the conservation landscape adjacent to the national park. The Communal Area Management Programme for Indigenous Resources (CAMPFIRE) provided access for communities to wildlife resources, including elephants, through trophy hunting. The Zimbabwe Parks and Wildlife Management Authority (Zimparks) allocates hunting quotas to each of the CAMPFIRE districts through a participatory and science-based process without exceeding the number prescribed by CITES (Vernon et al. 2022). The CAMPFIRE areas act as a buffer between the park and human settlement, and hunting takes place within these buffer areas. GNP is the main source of elephants for the CAMPFIRE hunting areas surrounding the park (Jeke et al. 2019).

Trophy hunting uses a quota system that promotes sustainable off-takes by removing a fraction of a natural population's growth rate, which arguably falls within the compensatory mortality range and has a negligible impact on the overall ecology of wildlife species (Morrill 1993). Trophy hunting in Zimbabwe is closely regulated and monitored by Zimparks. In respect of elephants, usually only mature bulls with good-quality tusks are targeted (Mbaiwa 2018). Although some studies exist on trophy quality trends, understanding is poor of how trophy hunting influences wildlife movement and habitat use.

Given the social polarity of trophy hunting in modern-day conservation, more research is needed to inform policy at the park, local, regional and international levels (Muposhi, Gandiwa, Bartels, and Makuza 2016; Muposhi, Gandiwa, Bartels, Makuza, and Madiri 2016). Most international policies are implemented by member countries, and research on the sustainability of trophy hunting as a conservation tool would aid in adaptive management processes (Muposhi, Gandiwa, Bartels, and Makuza 2016; Muposhi, Gandiwa, Bartels, Makuza, and Madiri 2016). In particular, many countries endowed with diverse wildlife resources find themselves financially constrained to protect and conserve their vast wildlife habitats (Muposhi, Gandiwa, Bartels, and Makuza 2016; Muposhi, Gandiwa, Bartels, Makuza, and Madiri 2016). Trophy hunting creates source-sink dynamics between national parks and hunting areas (Jeke et al. 2019). Source-sink dynamics between GNP and Malipati Safari Area were perceived to result in more individuals with desirable trophy sizes occurring in the hunting area due to the vacuum effect created by trophy hunting (Jeke et al. 2019). Source-sink dynamics are possible only if elephants can access and utilise the sink areas; hence the need to understand if hunting on the park boundary restricts elephant movement into those areas.

The term '*periphery hunting*' has been proposed to describe a pattern of hunting along the boundary of a protected area that eventually creates a boundary of fear, which is attributed to the ability of elephants to remember gunshots and their witnessing of individuals being killed (Joshua 2023). Elephants may consequently avoid utilising such areas. Hunting along the boundary between a park and a hunting area has emerged as a problem in limiting the free-ranging movement of elephants (Joshua 2023). A broader context for this concern is the creation of the Greater Limpopo Transfrontier Park (GLTP) that was intended, in part, to promote a shared population of elephants among the Limpopo National Park (LNP) in Mozambique, Kruger National Park (KNP) in South Africa and GNP in Zimbabwe (Chirozva et al. 2017). The GLTP was developed further to become the Greater Limpopo Transfrontier Conservation Area (GLTFCA), an area of approximately 90,000 km^2. The rationale of the GLTFCA was to promote the dispersal of elephants out of the GLTP into other conservation areas and specifically into Mozambique, where elephant density is very low compared to GNP and KNP (Huang et al. 2022). This would connect the Zinave and Banhine National Parks of Mozambique into the GLTP.

Whereas there has been no direct study of the effect of hunting elephants near national park boundaries on their movements, studies on other taxa have demonstrated that such hunting results in a 'landscape of fear' (Ripple et al. 2015). In combination with the demonstrated behaviour of elephants showing spatial avoidance of human activity (Graham et al. 2009), it is hypothesised that hunting elephant bulls near the boundary of the park will deter their movement into and use of the hunting area beyond the park. The following key questions were investigated. (1) Is the distribution of distance of hunting from the park boundary consistent with the hypothesis of 'periphery hunting? (2) Are elephant bull movements affected by hunting along the boundary of GNP? (3) If so, does periphery hunting limit the use of designated community hunting areas (hereafter 'hunting areas') immediately adjacent to the park by elephants? (4) What is the number of hunted elephants in each year and area? This study therefore, aimed to examine how trophy hunting of elephants influences the movement behaviour and habitat use of elephants, particularly regarding their distance of movement outside of the park boundary.

2 | Materials and Methods

2.1 | Study Area

This study was conducted in GNP, Malipati Safari Area (MSA) and the surrounding hunting areas (Naivasha Conservancy, Sengwe 1 and 2 and the hunting portion of the Malipati communal land), which all fall under the Chiredzi district in the southeast lowveld of Zimbabwe (Figure 1). There are two portions of the Malipati communal hunting area; one is a fenced hunting area and the other is an area occupied by human communities.

GNP was proclaimed a national park in 1975, and the GLTP treaty was signed into force in 2002 (Mombeshora et al. 2009). The Sengwe-Tshipise Corridor (STC), conceived under the auspices of the GLTP treaty, was gazetted in 2009, and provides a corridor between the GNP and KNP (Chirozva et al. 2017). The GNP, 5053 km^2, borders Mozambique on its eastern boundary, and is connected to KNP through the STC. Trophy hunting is not permitted in GNP; it was stopped in MSA in 2017. Trophy hunting is, however, permitted in the other hunting areas, whose combined area of 1078 km^2 is approximately 20% of the area of GNP.

The study area has three climatic seasons: the hot wet season (November to March) when 90% of annual rain falls; the cool dry season (April to August); and the hot dry season (September to October) (Mandinyenya et al. 2024). The mean annual rainfall is between 500–600 mm. Woodland savannah and scrubland, respectively, cover 59% and 40% of GNP (Martini et al. 2016). Woodland savanna comprises dry deciduous vegetation, with characteristic types being *Colophospermum mopane* or miombo woodlands (Mandinyenya et al. 2024). No vegetation map exists for the hunting areas.

This study assessed the impact of hunting on individual elephant movement patterns, habitat use, and avoidance behaviour of adult bulls. The extent to which hunting areas were used by bull elephants was investigated using two complementary approaches. The first was the movement of collared animals (telemetry data); the second was by dung counts. Archived office records of Hunting Return forms were searched to extract the locations of kill sites.

2.2 | Elephant Movement

Location data were derived from tracking GPS collars (model SM 2000E; https://awt.co.za) fitted on 11 adult bull elephants in GNP between 2016 and 2022 (Mandinyenya et al. 2024). Bulls were prioritised because they are the primary targets of trophy hunting (Joshua 2023), and their movements and behaviour are likely to be most affected by hunting activity. The collars were programmed to send a GPS position of an elephant every 6 h, a frequency of recording expected to capture elephant movements. All data points of elephants which moved out of the park into a hunting area were used to assess the extent to which elephants used the hunting areas, which we assumed was independent of hunting activities.

2.3 | Dung Counts

A dung count is an indirect, cost-effective method that can serve as an indicator of elephant relative abundance and presence (Barnes et al. 2009; Jachmann 1991). In this study, the number of dung piles was used as an index of habitat use inside and outside

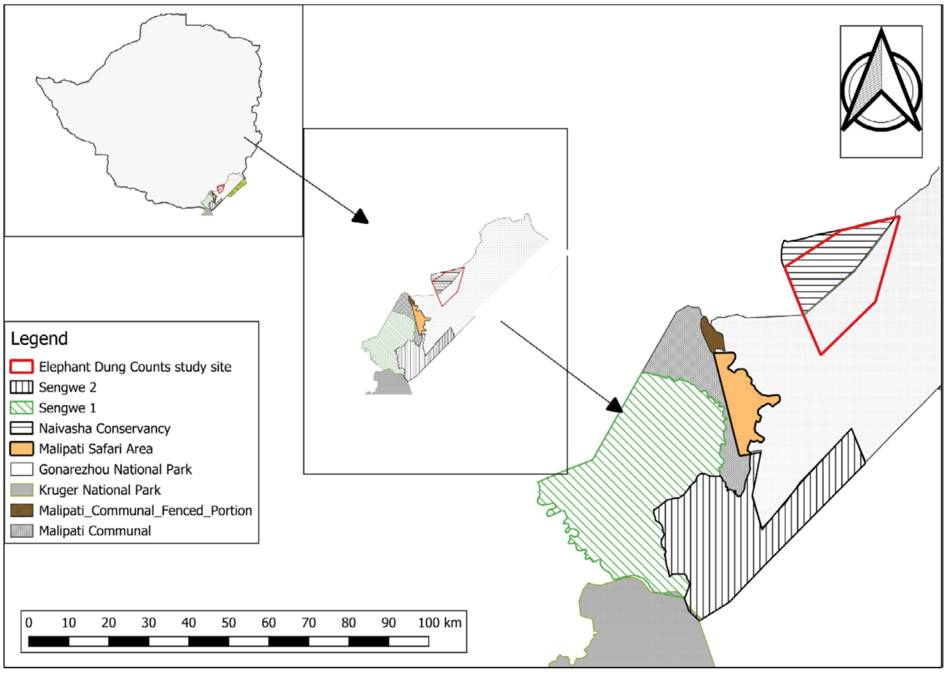

FIGURE 1 | Map of the study area showing the hunting areas around Gonarezhou National Park, and the study area for dung counts (fenced on the outer perimeter of Naivasha, and unfenced in GNP).

of the Naivasha hunting area by elephants. Hunting in Naivasha is primarily during the dry season. Therefore, dung sampling was undertaken in the dry season to reflect elephant distribution during the hunting season. Dung was counted in two ways: the first was along 20 m wide belt transects, and the second was in defined 30 m × 30 m plots along these belt transects. The area sampled in GNP, the non-hunting area, was of an equivalent size and with similar environmental conditions and vegetation types as the Naivasha hunting area (Figure 2). Ten belt transects for each area were spaced at 3 km intervals and followed the shape and size of the study area. The belt transects ran perpendicularly from the earthen track (< 3 m wide) of the Naivasha-GNP unfenced boundary to the fenced boundary of Naivasha. Belt transects also extended an equivalent distance from the earthen track in the opposite direction into GNP. Each area therefore had five belt transects of 10 km, two of 7.5 km, one of 5 km, and two of 2.5 km length. Two observers and one recorder walked along the belt transects and counted elephant dung within 10 m on either side. Along each transect, plots of 30 m × 30 m were placed every 2.5 km (the first plot being 2.5 km away from the Naivasha-GNP boundary track). Therefore, 60 plots were sampled altogether (Figure 2). Each identifiable dung pile (irrespective of state of decay) was recorded as one pile regardless of the number of dung boluses in that pile. The position of each pile was recorded using a handheld Garmin GPS Etrex 30× (software version 2.50). The dominant vegetation type of each plot was recorded.

2.4 | Hunting Kill Sites

Information about elephants hunted around GNP from 2017 to 2023 was routinely monitored by the GNP staff. For each hunt, the GPS location, date and time of the hunt were recorded in Hunt Return forms from the first day of the hunt until the elephant was killed. These forms are archived in the park office records. The distance from the park boundary where a hunted elephant was shot was calculated using the recorded GPS locations in a GIS environment.

2.5 | Data Analysis

All spatial mapping and analyses were conducted using QGIS version 3.40.1 (QGIS 2024) and statistical analyses were conducted using R version 4.3 (R Core Team 2024). QGIS was used to analyse the telemetry data from collared elephants and to generate, using Kernel Density, a heatmap of areas utilised by elephants in the proximity of the park boundary. Data on the

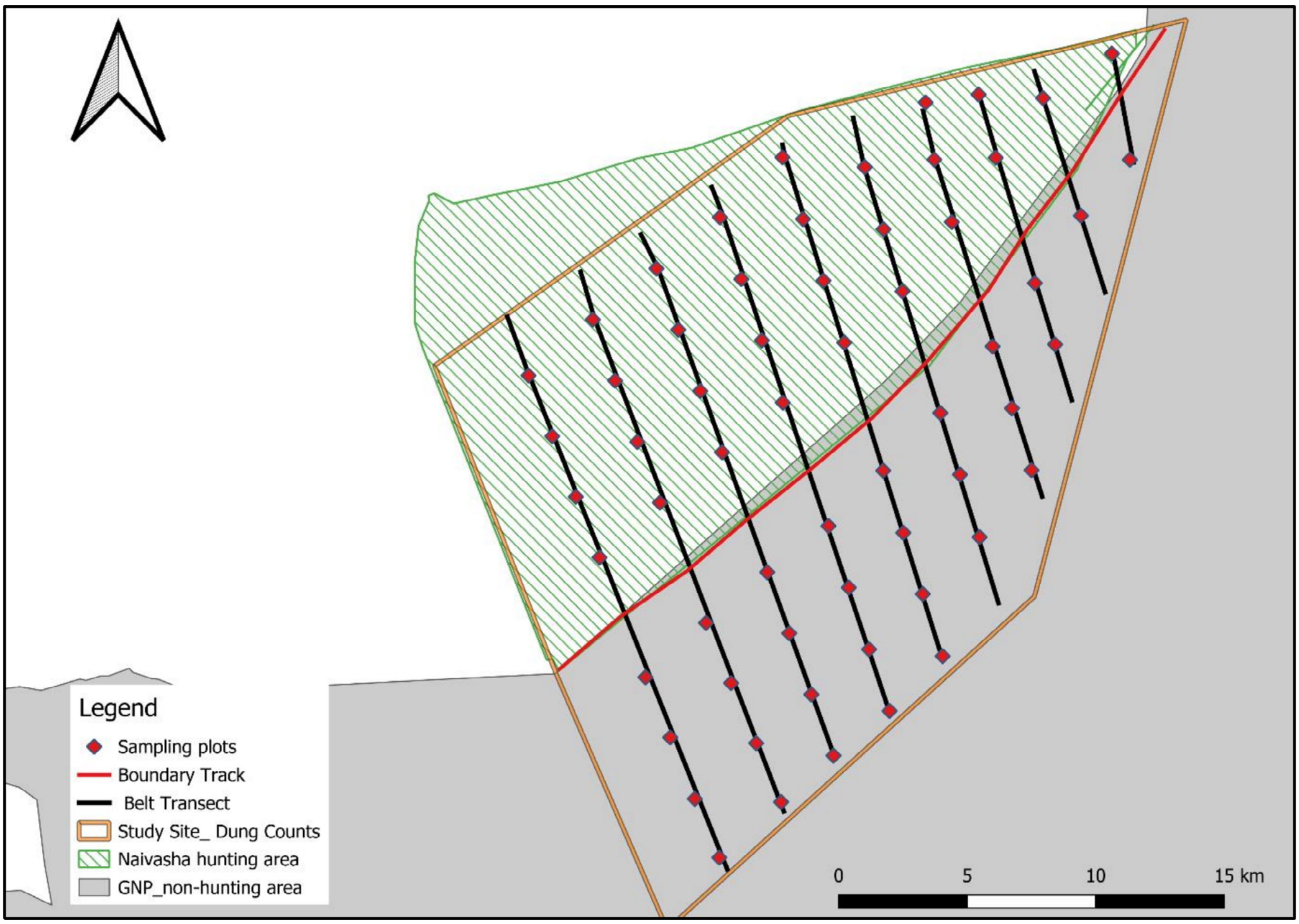

FIGURE 2 | The layout of belt transects and plots for dung counts within the Naivasha hunting area and a comparable area in the adjacent Gonarezhou National Park.

number of elephants hunted showed no dispersion; therefore, a Poisson General Linear Model with Wald z-tests and Likelihood Ratio Tests of individual coefficients were used to test if the number of elephants killed per year differed between years and across hunting areas. Data for the distance of a kill site from the park boundary failed to meet normality assumptions (Shapiro–Wilk test). The data were therefore analysed using a Kruskal–Wallis analysis of variance, with Dunn's test and Bonferroni correction applied to adjust for multiple comparisons for significant main effects. Buffer contours at 2.5 km intervals from the park boundary were created using QGIS to aid in visualising the spatial distribution of elephant kills. Differences in dung counts in belt transects and plots between hunting and non-hunting areas showed overdispersion, and the interaction between vegetation type, hunting area and non-hunting area on dung counts was modelled with a Negative Binomial Generalised Linear Model, with a Likelihood Ratio chi-squared test performed when necessary. The estimated marginal means and pairwise comparison *post hoc* tests were applied where necessary. If periphery hunting was taking place, it was predicted that dung abundance would decrease with distance from the park boundary. Accordingly, a Negative Binomial Model was fitted to estimate the slope of distance within the hunting and non-hunting areas. The difference in dung counts between the hunting area and non-hunting area, at matched distances, was tested using the Mann–Whitney test.

3 | Results

3.1 | Elephant Hunting

Seventy elephants were hunted from 2017 to 2023; 18 in Malipati Communal, 21 in Naivasha, 15 in Sengwe 1 and 16 in Sengwe 2. The numbers of elephants killed between the years 2017 to 2023 were 5, 14, 11, 4, 15, 10 and 11 respectively and showed a marginal effect across years ($\chi^2(6) = 11.52$, $p = 0.074$), Wald z-tests showed significant differences between 2017 and 2018 ($\beta = 1.03$, $p = 0.048$) and 2017 and 2021 ($\beta = 1.10$, $p = 0.033$) (Figure 3) The mean number of elephants killed did not differ across areas ($\chi^2(3) = 1.18$, $p = 0.758$).

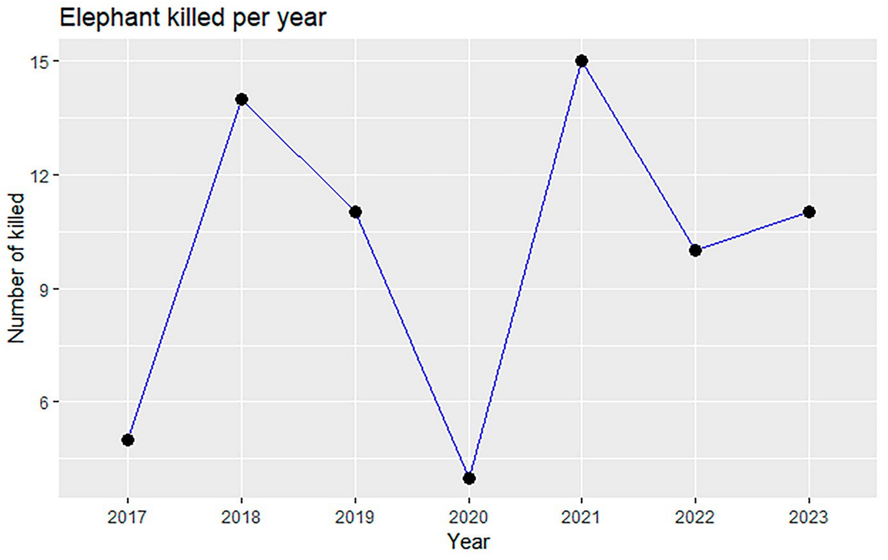

FIGURE 3 | The trend number of elephants killed each year between 2017 and 2023.

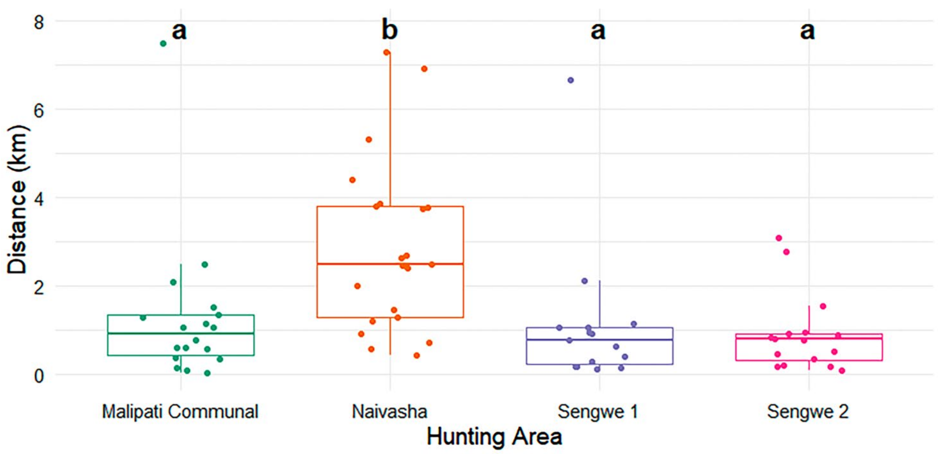

FIGURE 4 | Mean hunting distances from the park boundary across hunting areas $p = 0.00038$. Boxes with different superscripts are different at the 5% level, using Dunn's post hoc test.

TABLE 1 | Dunn's post hoc test results following a Kruskal–Wallis analysis of variance of distance from the park boundary where an elephant was killed.

Hunting area	Z	p.unadjasted	p
Malipati Communal—Naivasha	−3.050	0.002	0.013
Malipati Communal—Sengwe 1	0.526	0.598	1.000
Naivasha—Sengwe 1	3.442	0.0005	0.003
Malipati Communal—Sengwe 2	0.598	0.549	1.000
Naivasha—Sengwe 2	3.572	0.0003	0.002
Sengwe 1—Sengwe 2	0.060	0.952	1.000

The distance of elephant kills from the boundary ranged from 0.02 to 7.5 km, with 51% of kills occurring in less than 1 km and 42% occurring between 2.5 km and 5.0 km from the park boundary (Figures 4 and 7). There was no difference in the distance of hunting from the park boundary between years ($\chi^2 = 2.34$, df = 6, $p = 0.886$). In contrast, a significant difference in distance across hunting areas (Figure 4) was observed ($\chi^2 = 18.33$, df = 3, $p = 0.0003$). More specifically, elephants were killed at significantly longer distances from the park boundaries in Naivasha when compared to the rest of the areas, as summarised in Table 1.

3.2 | Dung Counts

Dung counts were influenced by both distance from the boundary and area (hunting vs. non-hunting) ($p = 0.0012$). The vegetation types with the greatest amount of dung recorded were *Colophospermum mopane* woodland, mixed *Combretum*-miombo woodland and mixed *Combretum-Terminalia* woodland (Table 2), indicating that these vegetation types supported a relatively greater number of elephants or that elephants spent a longer time in them in both hunting and non-hunting areas.

The analysis revealed a significant main effect of area type, with dung counts being significantly higher in the non-hunting area compared to the hunting area ($\beta = 1.24$, SE = 0.29, $z = 4.35$, $p < 0.001$, Figure 6). Distance from the park boundary also significantly influenced dung counts. Specifically, dung counts in hunting areas were less at 10 km than at 2.5 km from the boundary ($\beta = -1.74$, SE = 0.47, $z = -3.68$, $p < 0.001$), with an 82.5% reduction in expected dung count. The effects at 5 km ($p = 0.36$) and 7.5 km ($p = 0.079$) were not significant (Figures 5 and 6).

3.3 | Elephant Utilisation of Hunting Areas

Between 2017 and 2023, areas in which elephant kills were concentrated coincided with areas of high utilisation by collared bull elephants (Figure 7). An exception was a concentration of hunting kills along the northern boundary of the KNP.

TABLE 2 | The distribution of dung counts according to vegetation types and the number of samples for each vegetation type.

Vegetation type	Total count	Average/sample	Samples
Mixed Combretum-Miombo woodland	629	4.88	129
Mixed Combretum-Terminalia woodland	603	4.16	146
Colophospermum mopane woodland	599	6.11	99
Guibourtia coleosperma woodland	380	4.52	84
Strychnos madagascariensis woodland	182	3.87	47
Dichrostachys cinerea woodland	47	4.27	11
Ziziphus mucronate woodland	24	8	3
Mixed Combretum-Mopane woodland	9	9	1
Mixed Mopane-Miombo woodland	8	2.67	3

4 | Discussion

The interplay between elephant habitat utilisation, hunting pressure and proximity to PA boundaries is critical for understanding elephant population dynamics and conservation strategies. Trophy hunting of elephants remains a contentious issue within wildlife management and conservation efforts, particularly in regions adjacent to PAs.

4.1 | Number of Elephants Hunted

More elephants were shot in 2021 than in the other years. This spike in 2021 is attributed mostly to the COVID-19 outbreak in 2020 which reduced travellers (Ndlovu et al. 2021), with an increased demand for trophy hunting after the pandemic restrictions were lifted. The call for banning trophy hunting escalated in 2020 on account of negative perceptions, with many groups calling for a complete ban (Parker et al. 2020). Fluctuations in hunting pressure are often linked to changes in international demand for trophies or adjustments in national wildlife policies (Di Minin et al. 2016; Lindsey et al. 2007). The absence of differences between years other than 2017 and 2021 and 2018 indicates that hunting activity remained relatively constant across most of the years. However, the observed variability underscores the need for continuous monitoring and adaptive management to ensure that hunting practices remain sustainable (Milner et al. 2007). This is particularly important given the potential for trophy hunting to contribute to population declines if not properly regulated (Selier et al. 2014).

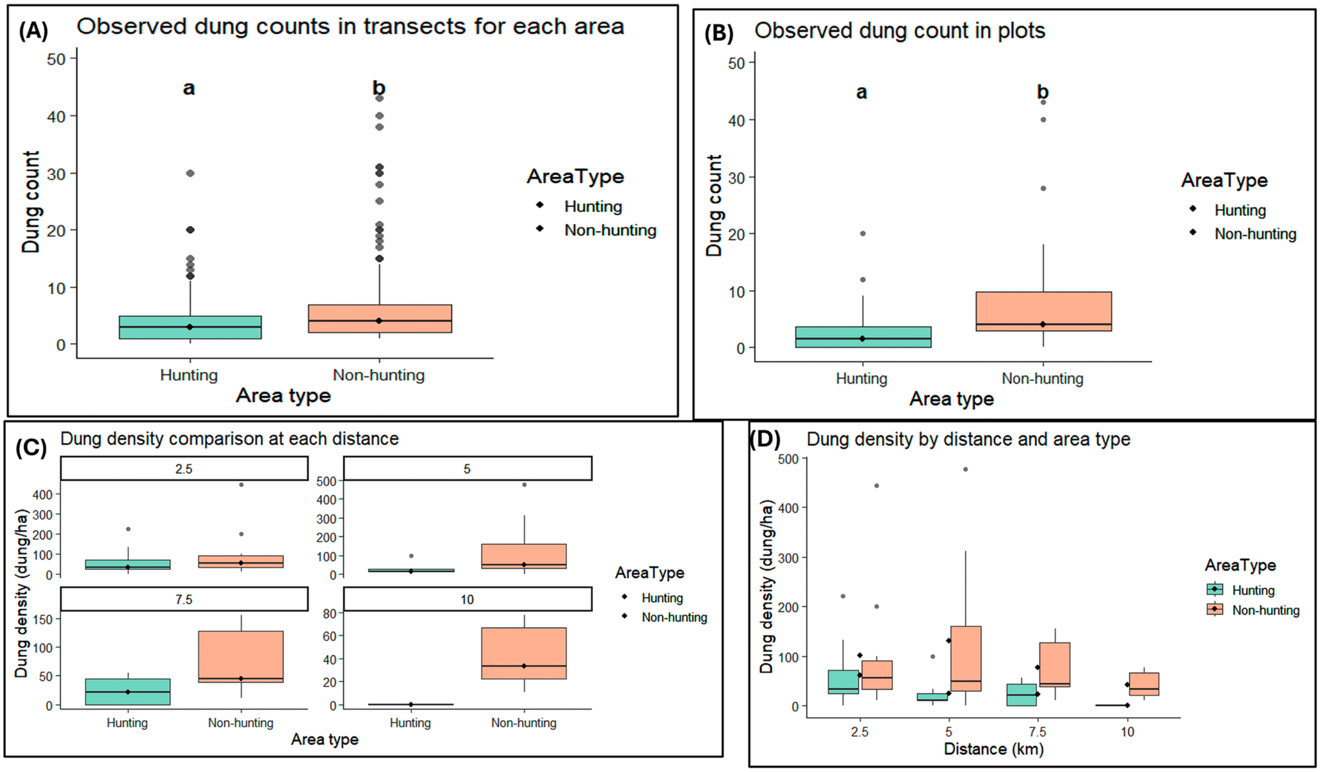

FIGURE 5 | Average number of dung balls counted for each area (A) Dung counts in transects for the hunting area ($n = 10$) and the non-hunting area ($n = 10$). (B) Dung counts for the hunting area (30 plots) and the non-hunting area (30 plots). Boxes with different superscripts are different at the 5% level. C and D comparison of dung counts between the hunting area and the non-hunting area for dung density at different plots.

Contrary to expectations, the study found no differences among the four hunting areas in the number of elephants hunted; although the highest number of elephants killed was recorded in Naivasha. This suggests that, while there are annual fluctuations, the lack of spatial variability in hunting offtake across areas could indicate consistent allocation of, and adherence to, hunting quotas as a requirement of CITES. This also highlights the importance of ensuring that hunting practices are consistently monitored and regulated to prevent reduced habitat use, particularly in areas with higher elephant hunting (Naidoo et al. 2018). This is consistent with findings from other regions, where uneven hunting pressure has led to localised declines in wildlife populations (Packer et al. 2011).

4.2 | Distance From the Park Boundary

About 51% of kills were made within 1 km into a hunting area from the park's boundary. This suggests that most hunting is taking place close to the boundary, which supports the proposal that periphery hunting is taking place. The spatial overlay of elephant kill sites onto kernel density estimates (KDE) of collared elephant movements revealed a clear pattern that elephants are being hunted in areas where they actively roam (Figure 7). This alignment between high-use zones and hunting locations suggests that trophy hunting is spatially targeted toward core elephant habitats, potentially amplifying its ecological impact and creating a landscape of fear. Similar approaches have been used to assess elephant vulnerability and habitat use in other contexts, such as mortality risk near infrastructure (Chamling and Bera 2020). The use of KDE provides a robust framework for identifying core areas of elephant activity and evaluating spatial overlap with anthropogenic pressures.

These findings underscore the need to consider not just the presence of hunting, but its spatial congruence with elephant movement patterns when assessing behavioural and ecological consequences. The number of killed elephants became less as the distance from the park boundary increased. Elsewhere, it was found that trophy hunting close to a boundary can restrict elephant movements and alter migration routes (Ghasemi 2021). Elephants often traverse expansive landscapes in search of food and water, and disruptions from hunting activities can induce avoidance behaviour, leading them to remain confined within protected areas (Aryal et al. 2016; Tiller et al. 2022).

4.3 | Habitat Utilisation and Dung Counts

Markedly higher dung counts in the non-hunting area than in the hunting area indicate less use of the hunted landscape by elephants. Furthermore, the coincidence of hunting hotspots with areas of high elephant utilisation indicates that hunting activities may disrupt elephant movement patterns, a finding which is consistent with other regions where hunting pressure has been shown to alter elephant distribution and habitat use (Barnes et al. 1997; Breuer et al. 2021). The presence of

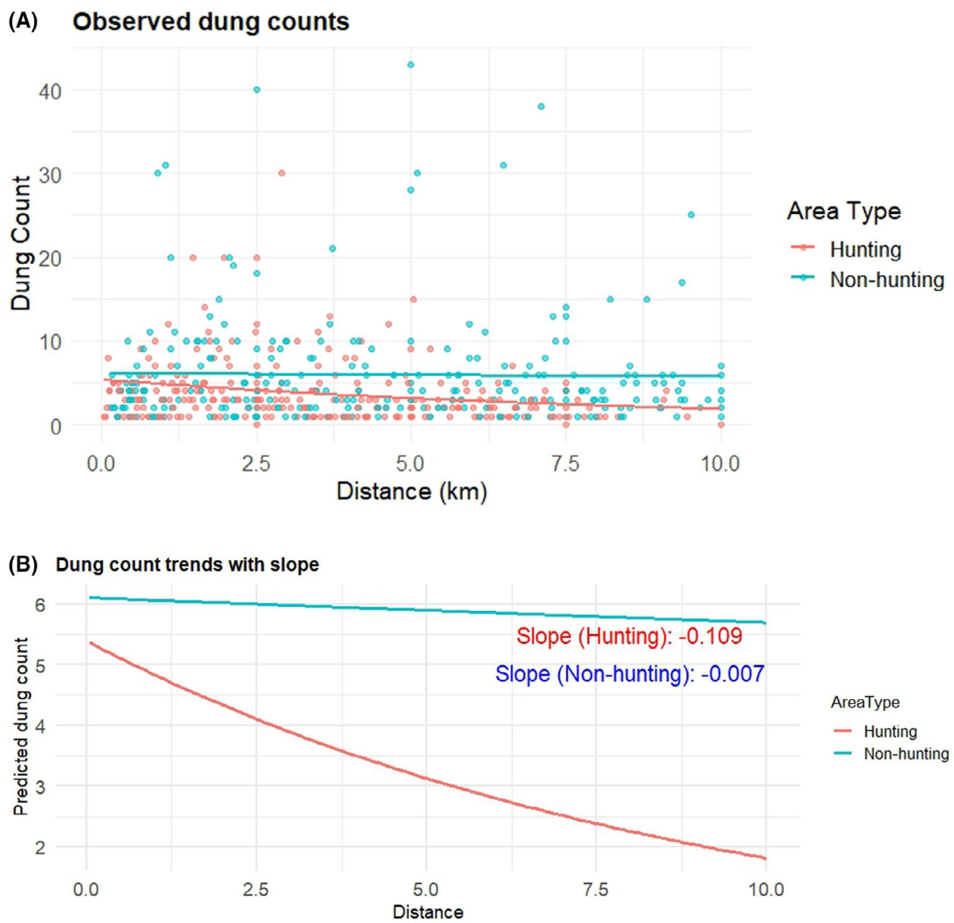

FIGURE 6 | (A) The relationship between the observed dung counts and distance from the boundary for hunting versus non-hunting areas, $p = 0.0008$. (B) The effects of distance as presented on predicted dung count with slope of distance from the park boundary.

hunting activities can also lead to altered behaviour in elephants, causing them to avoid certain areas, which may have cascading effects on their foraging efficiency and social structures (Riddle et al. 2010). The findings are consistent with previous work which showed that the proximity of hunting activities to key habitats can influence elephant distribution and movement, potentially leading to long-term ecological consequences (Selier et al. 2014).

These results underscore the spatial sensitivity of elephants to hunting pressure and edge effects, with implications for conservation zoning and buffer management. The lack of significant differences at intermediate distances (5 and 7.5 km) suggests a threshold beyond which hunting pressure substantially alters elephant distribution.

The assessment of elephant dung counts across various vegetation types provided insight into elephant distribution and habitat preferences. The high dung counts for *Colophospermum mopane* woodland and *Combretum*-Miombo woodland indicate that elephants favoured these vegetation types, as has been found elsewhere (Smallie and O'Connor 2000; Clegg 2010). The variability in dung counts across different vegetation types highlights the importance of habitat quality in supporting elephant populations, as elephants tend to congregate in areas that provide optimal resources (Murray et al. 2013). The sharp decline in elephant presence with increasing distance from the non-hunting area (Figure 5b) is considered to reflect elephants' preference for safer habitats near park boundaries, consistent with patterns observed in Ghana, where dung density decreased with proximity to roads and human activity (Danquah et al. 2004).

4.4 | Implications for Conservation and Management

The landscape of fear concept suggests that the presence of predators or human-related risks (like hunting or poaching) creates a 'fear landscape' in which animals perceive certain areas as dangerous, and their behaviour adapts accordingly (Gaynor et al. 2019). This study is consistent with this theory, as shown by predicted dung counts decreasing with distance away from the park boundary. This finding illustrates the potential for trophy hunting to contribute to fragmented populations and population declines if not properly regulated (Selier et al. 2014). The study recognises the importance of integrating ecological, socio-economic and policy data to fully understand the effects of trophy hunting in the proximity of protected areas, given that larger potential landscapes are available for elephants to roam.

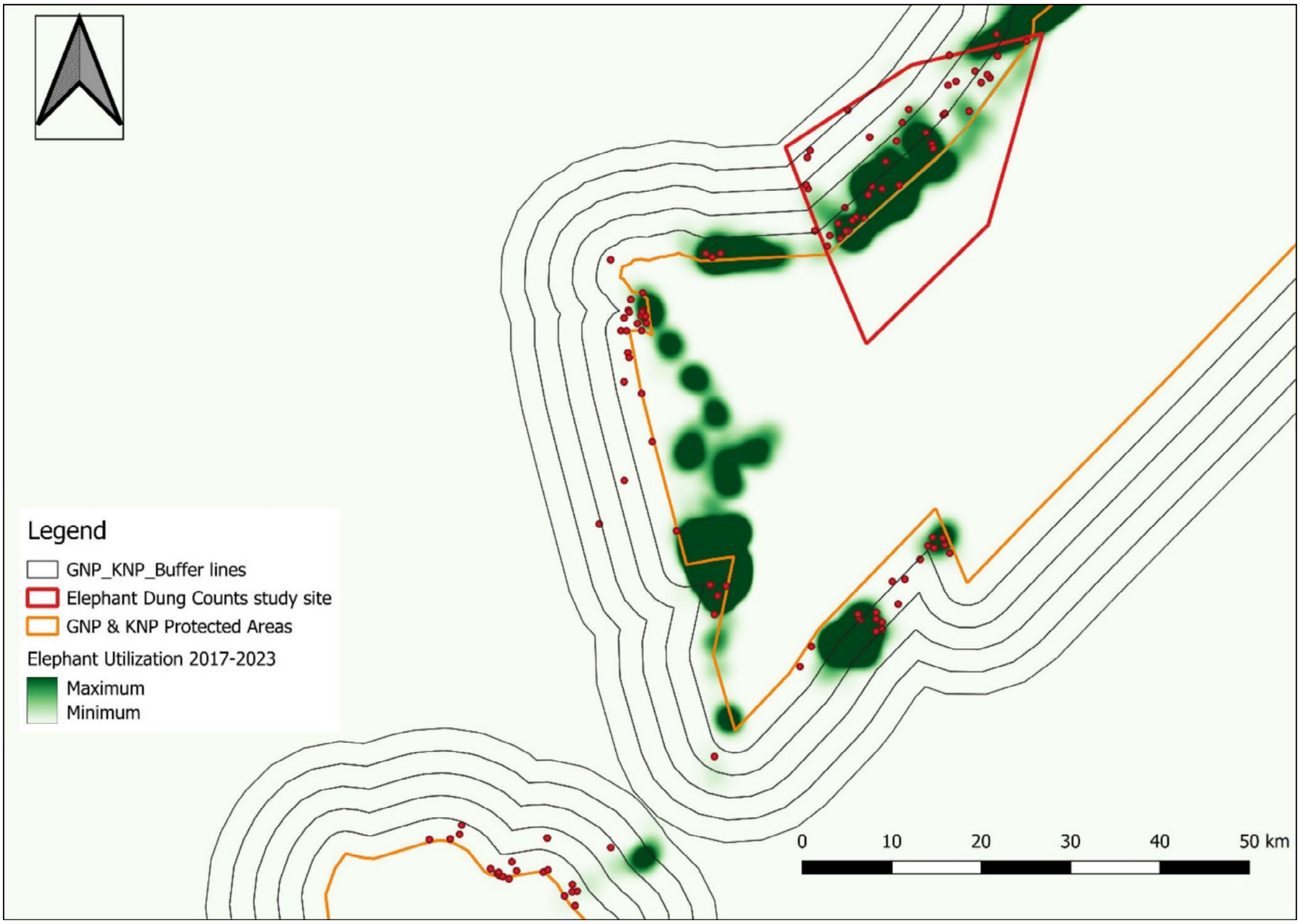

FIGURE 7 | Spatial overlap between elephant habitat use and hunting kills from 2017 to 2023. Red dots indicate individual hunting kill sites, overlaid on a heatmap of habitat utilisation by collared bull elephants. A 2.5-km buffer lines around the park boundary is also shown to highlight proximity of kills to the park edge.

5 | Conclusion

This study identified a critical need for informed policy about elephant trophy hunting that considers the broader ecological impacts, particularly regarding elephant bull movement and its relation to protected area boundaries. The findings of this study about trophy hunting of elephant bulls underscored the impact of hunting on elephant activity and habitat utilisation. The significant temporal variations in hunting activity highlight the need for adaptive management strategies (Balme et al. 2010); while the lack of spatial differences suggests that current practices in the distribution of hunting quotas have been effective to date.

These findings underscore the importance of continued monitoring and research to ensure that trophy hunting contributes to conservation goals, maintains sustainable elephant populations (Di Minin et al. 2016), balances the economic benefits against the ecological impacts on elephant populations (Bauer et al. 2019), and fosters coexistence between wildlife and local communities (Muposhi, Gandiwa, Bartels, and Makuza 2016; Muposhi, Gandiwa, Bartels, Makuza, and Madiri 2016). By integrating ecological, socio-economic and policy data, future management plans can better address the complex impacts of periphery hunting and promote the long-term conservation of elephant populations. The observed decline in elephant presence in hunting areas closer to GNP may hinder long-term population sustainability; thus, undermining conservation objectives (Treves et al. 2019). Efforts should focus on enhancing habitat connectivity between protected areas and hunting areas. This approach could facilitate safe passage for elephants and promote conservation practices that benefit both elephants and local livelihoods (Gandiwa et al. 2013).

Future research should focus on the long-term effects of hunting on elephant population behaviour and habitat use to ensure sustainable management practices that prioritise elephant conservation in the broader landscape of the GLTFCA.

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Ethics Statement

The authors have nothing to report.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

Data are available upon reasonable request.

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