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Tracking snares to mitigate the threat to wildlife: Quantification of hunting methods along the fringes of Valmiki Tiger Reserve, India

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ABSTRACT

Traditional hunting methods, despite their simple design pose a serious hazard to wild animals. Keeping in view, the negative impacts of traditional hunting methods including wire snares on the survival of wildlife, especially tigers that are endangered, anti-snare walks were carried out in Valmiki Tiger Reserve (VTR). We used a stratified random sampling method to walk a total of 142.71 km on 23 tracks along the forest fringes of eight forest ranges in the VTR. A total of 132 hunting incidences were encountered out of which 44 were wire snares, followed by 35 bird snares, 27 other hunting tools (axe, bow, arrows, sickles, and knife), 14 nets for mammals, 6 spears, 4 jaw traps, and only 2 electric wires. The detection rate of hunting incidences was 0.92 ± 0.32 per kilometre. The majority of snares were made of clutch wire (89 %), and the rest were made of galvanised iron wire (11 %). The average diameter of a snare loop was 37.75 ± 6.79 cm, while the average length was 219.52 ± 20.99 cm. The result showed that the snare loop and anchor plant girth have a linear relationship (i.e., positive correlation) with the number of snares. The detection rate of snares increased in the VTR boundary zones, with the highest density (66 %) found at the international border (Nepal) and interstate (Uttar Pradesh), India. We developed a kernel density estimation map to show hunting hotspots in the VTR, with the darker the red, the more the dense the event locations of the hunting incidences. We involved 268 people in the anti-snare walk, including representatives from various law enforcement agencies and local volunteers, in order to build capacity by providing participants with direct field-based practice. Our findings are expected to add valuable ground-based data to fill current knowledge gaps on the deleterious impact of hunting methods including snares on wildlife in VTR.

1. Introduction

Human activities are now endangering more species than ever before in history (Sattar et al., 2021). Anthropogenic pressures continue to place immense strains on natural habitats, putting nearly one million plant and animal species at risk of extinction (Figel et al., 2021). Terrestrial mammalian megafauna (e.g., large herbivores and apex predators) are particularly vulnerable to space constraints, and susceptibility to overexploitation (Ripple et al., 2015). Hunting has surpassed habitat loss as the primary cause of megafauna extinction in and around protected areas around the world (Diamond, 1989; Harrison et al., 2016; Ibbett et al., 2020), and wire snares are one of the most commonly utilized hunting methods (Gray et al., 2018). When hunting is carried out using firearms, shots may be heard which increases the potential of law enforcers to detect incidences. Snares and traps on the other hand are silent killers, hidden among the understory of the forests, and remaining active until they are either detected or an unfortunate victim falls prey to them (Corlett, 2007; Fa and Brown, 2009; Matungwa and Wawa, 2021). They are typically made of readily available materials such as clutch wires, fencing wires, nylon, irrigation pipes, or plant material (vines, creepers, and climbers) which are capable of trapping a wide range of aerial, arboreal, and terrestrial species, whether diurnal or nocturnal (Mudumba et al., 2021).

Snares generally result in the death or serious injury of the animal due to asphyxia as the snare tightens and causes serious harm to the animal's limbs or throat (Linkie et al., 2003; Sarkar et al., 2021). The duration of restraint in the trap has a significant impact on the severity of injuries and distress endured by a captured animal (Lossa et al., 2007). Long periods of restraint can cause myopathy, starvation, and dehydration (Descovich et al., 2015). It can also lead to stress by interfering with motivational and natural behavior systems (Joca et al., 2007). Animals left in traps for prolonged periods suffer, run the risk of

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infection, or become prey (Broom, 2022). Poachers and hunting tribes in India have evolved over millennia, employing snaring as a simple but highly effective strategy for catching wildlife (Sethi, 2022). Despite the fact that snares are usually designed to hunt wild herbivores or birds, they catch both targeted and untargeted species, leading to wildlife mortality or in cases the animal survives, significant injuries, permanent disability, and stress. Many of the by-catch species would be threatened in the IUCN red list classification (Gubbi and Linkie, 2012; Becker et al., 2013; Aziz et al., 2017). Snaring is also a serious animal welfare issue because some animals escape with serious injuries, putting the individual animals' long-term survival at risk (Gubbi et al., 2021). Detection effort is likely to be influenced by a number of factors, including habitat, season, cropping pattern, local communities, terrain and topography, and snare type (Braga-Pereira et al., 2020; Harmsen, 2021). Snares that are physically connected and set in lines may be more detectable than individual snares. This is because snares share many features with the species they target: they are habitat specialized, and occur in remote and inaccessible regions (O'Kelly et al., 2018). Observers' training also has an impact on snare detection (van Doormaal et al., 2021; Harmsen et al., 2021a). Although observers' proficiency in snare detection and removal is essential to lessening poaching pressure, and their performance has received far less attention. This may be related to the difficulty of surveying snares, which makes it impossible to comprehend the true scope of the wire-snaring problem in the field, as well as the perceptions of snare poaching and its effects, by law enforcement agencies (Rija and Kideghesho, 2020).

In India, although the Wildlife Protection Act (WPA, 1972) makes it illegal to kill all listed wildlife species, wire snares continue to be a popular method for capturing animals. This occurs because conservation law enforcement agencies traditionally are not trained to look for wire snares. Added to this they are typically under-resourced, with staff often inadequately trained, poorly remunerated, and insufficiently equipped to work in challenging conditions. Patrolling by ranger teams is a primary method available to park managers for dealing with anthropogenic threats to wildlife. Few empirical studies have been conducted to investigate the impact of snares on wildlife in India (Gubbi et al., 2021; Sethi, 2022), despite the fact that media reports indicate that it is common and pervasive. In 2011, the death of a Tiger due to a snare along the Karnataka – Kerala border (Bandipur Tiger Reserve and Wayanad Wildlife Sanctuary) was observed by forest department and created an urgent need to address the snaring problem (Aziz et al., 2017; Gubbi et al., 2017).

Following this incident, the Wildlife Trust of India (WTI) was one of the first organizations to step forward and identify wire snares as a serious threat to the survival of wildlife, especially tigers, in the tiger reserves of South India (Menon, 2016). The WTI team conceptualized and pioneered Anti-Snare Walks (ASW)—joint patrolling with the forest authorities to identify and remove snares, mostly along vulnerable regions like park boundaries adjacent to human-inhabited areas (Matseketsa et al., 2019). Over the years, the combing activities continued showing positive results. This method was then adapted to the Valmiki Tiger Reserve, the only tiger reserve in Bihar. According to Maurya et al. (2021), the presence of tigers was reported at 248 locations (56 %) in 2019–20 and 264 locations (60 %) in 2020–21, and the report specified a minimum figure of 48 tigers in VTR with a density of 2.71/100 km^2. With the increasing evidence of a tiger population, removing traditional hunting methods, such as wire snares, which are silent wildlife killers, from the VTR's forest fringes becomes more urgent as the weak, injured or older wild animals, as well as younger males are pushed to the periphery. In recent years, cases of snaring and hunting with wire snares have been reported in local media, and secondary evidence points to these as an emerging problem in the landscape. However, no systematic scientific study and analysis of information on hunting methods so far carried in the landscape. We hypothesised that proximity to farmland, human infrastructures such as machan (watch towers), and permanent water sources have spatial influences on the presence of hunting incidences. The objectives of our study were, (1) identify different hunting methods used by poachers in the landscape, (2), to calculate the detection rate and spatial patterns of the hunting incidences, (3) and finally we provided participants with direct field-based training for future detecting hunting incidences in the landscape. As a result, performing anti-snare walks in the forest fringes is critical for removing threats and strengthening the forest department's ability to detect and control wildlife crime in the future in this landscape.

2. Material and methods

2.1. Study area

The Terai Arc Landscape (TAL) is one of the most important landscapes in the Indian subcontinent because of its assemblage of threatened wildlife species, and it is one of the world's top 200 ecoregions for wildlife protection (Olson and Dinerstein, 2002). The VTR is the state's only tiger reserve, occupying 901.13 km^2 of the northernmost part of West Champaran district in Bettiah, Bihar (Fig. 1). Administratively, this tiger reserve is divided into two forest divisions and managed under eight ranges i.e., Manguraha, Gobardhana, Raghia (Division-1) and Chiutaha, Harnatand, Ganuali, Valmiki Nagar, and Madanpur (Division-2).

The terrain of VTR is characterized by rocky hills and valleys, which are drained by numerous rivers and streams and join with flat alluvial plains in the south. There are three distinct seasons in the year. In the month of January, the winters are accompanied by fog and light winter rains. In the reserve, the minimum temperature drops to 5 °C. Due to the hot westerly winds, the summer season begins in mid-March and ends in early May. The monsoon season begins in late June and lasts through September. The highest temperature reaches 43 °C (Singh, 2013).

The project area is a transboundary landscape surrounded by 140 revenue villages on the periphery of the buffer and 26 revenue villages within VTR, all of which exert significant pressure on the Tiger Reserve, including the core area (Maurya and Borah, 2014). The sociocultural diversity of the Valmiki landscape is evident. The scheduled tribe known as the Tharu is the dominant community on the landscape. Agriculture is the main economic activity in this valley, although there is also poaching, illegal hunting, and fuel wood harvesting (Maurya and Borah, 2013). *Shorea robusta, Terminalia tomentosa, Terminalia belerica, Adina cordifolia, Miliusa velutina, Trewia nudiflora, Mallotus philippensis, Lagerstroemia parviflora, Salmalia malabarica*, and *Acacia catechu* are some of the most common tree species in the area (Maurya and Borah, 2013).

2.2. Methods of data collection (Anti-snare walk)

Before the start of fieldwork, the Field Officers from the WTI team provided a proper orientation to the target group {forest department, paramilitary posted at the site which is the Sashastra Seema Bal (SSB), and local village volunteers (V3)} regarding how to carry, identify and remove the wire snares/other traditional hunting tools from the forest fringes as well as the safety precautions that should be observed during the anti-snare walk. The target groups were informed on the different types of traditional hunting tools they might come across during an anti-snare walk, which typically include wire snares, jaw traps, bird snares, electric wires, mammalian nets, and spears (Photo Plate 1). Sensitive forest fringe villages were selected based on previous wildlife crime data available with the forest department. The stratified random sampling method was used to collect the data (Watson et al., 2013). Anti-snare walks (ASWs) are best undertaken in the early morning hours from (7 am–9 am). The chance of detecting the hunting incidences is entirely dependent on visual investigation and the anticipation created on the trail. Although the snare can be set at night and removed in the morning, the snare binding marks on the tree trunk are usually visible. However, we do not include these marks in data analysis during data collection. The fringe width varied from 250 to 500 m depending on the

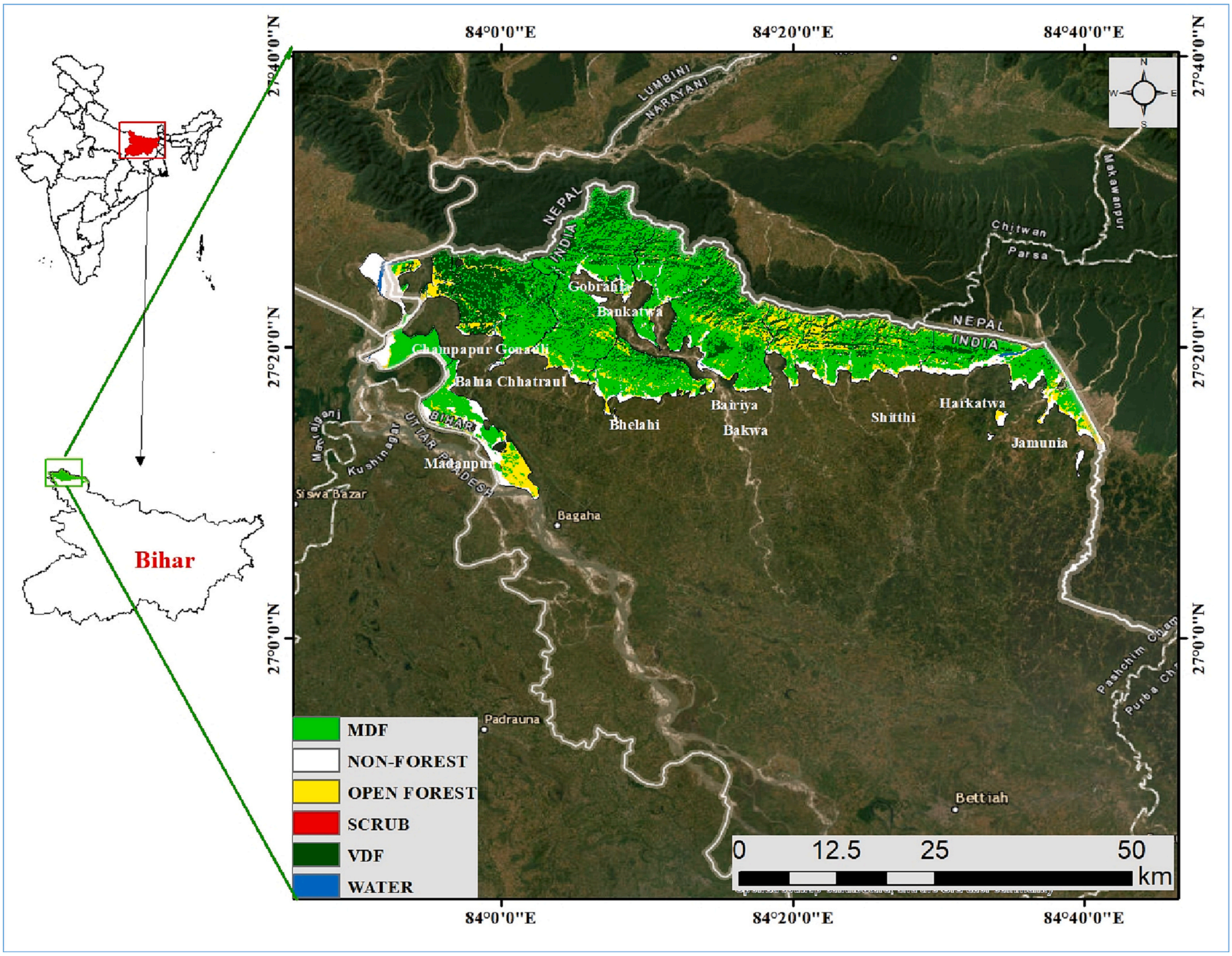

Fig. 1. Map of the study area showing forest type, surrounding villages, water bodies in the Valmiki Tiger Reserve, Bihar India. MDF- moderate dense forest; VDF- very dense forest (Map generated using ArcGIS version10.8.2).

topography, and we did an anti-snare walk throughout the entire width, covering all potential trails within the width. The starting point of the ASW is geotagged, using either a handheld GPS (e-trex) or a mobile app with high accuracy. Simultaneously the track recorder is also activated on the device. The walk's length is then determined by the terrain and accessibility to roads. The WTI Field Officer leads the team, follows the route that runs parallel to the forest boundaries as well as farmlands, and machan (watchtowers) adjacent to forest fringes. Along the trials, permanent water sources were also investigated. The team is divided into two small groups that follow each other at a distance of approximately 100 m in order to maximize the detectability of the hunting tools using the double observation method. Each team comprises of at least seven (7) individuals who walk parallel to one another across the width of the forest fringe. A regular ASW is approximately 6 km long per day.

When a wire snare or hunting tool was found, the location was noted and labelled with the type and quantity of the items detected. The snare or hunting tool's GPS position was marked with adhesive tape and tagging paper. After being geotagged, the snare was deactivated and placed into an envelope or zip-lock bag. Other hunting tools found were removed from the locations in the same systematic manner. We classified snare into two main types wire (clutch/ galvanised iron) snare for mammals and bird snares. In addition, snare loop size, length, and anchored tree/ fencing pole girth were measured in the field for the wire snares. Once the decided endpoint was reached, it was marked and the track stopped. After completing the track, the walk was mapped using GIS software (ArcGIS) and the snares found were recorded. The information on specific tracks (anti-snare walk), snare type, seizure, and geographical location was shared with the concerned forest range. Finally, the geo-tagged hunting tools were then handed over to the forest official of the respective ranges for future motoring. It will be easier for patrolling staff to keep an eye on these hotspots on a regular basis as a result, reducing threat in the long run. We sum all the snare/traditional hunting tools that we found per track. To estimate the detection rate in each range, we divided the number of hunting incidences by distance walked on foot along the forest fringe. All the above data was collected during the study period 2021–2022 in the VTR, Bihar in India.

2.3. Data analysis

The data was analysed using Principal Component Analysis (PCA) and a Kernel density estimation (KDE). KDE is a non-parametric technique, which calculates the probability density function of a random variable. In order to comprehend and possibly predict event patterns, KDE techniques are frequently used in spatial data visualisation and analysis (Silverman, 2018). In our case, the hunting incidences distribution indication was displayed around each output raster cell on the map by the KDE, which calculates the density of event locations (Zhang and Xu, 2023). PCA analysis was used to explore relationships between

Photo Plate 1. Representative hunting methods that were detected from Valmiki Tiger Reserve, Bihar, India.

dependent variables and display the relative positions of data points in fewer dimensions while retaining as much information as possible. We used PCA to determine how each hunting methods, or set of hunting methods, was related to each forest range studied. PCA was performed with Software R Studio 4.0.1(R Core Team, 2020). To quantify the effect of snare attributes like snare loop (cm), snare length (cm), anchor plant GBH (cm), anchor-fencing pole GBH (cm) on the total number of snares removed, a Generalized Linear Model (GLM) was performed considering the total number of snares as a covariate and the independent variables were snare attributes. The hypothesis proximity to farmland, human infrastructures such as machan (watch towers), and permanent water sources have spatial influences on the presence of hunting incidences was tested using one-way analysis of variance (ANOVA) with repeated measures followed by post hoc least significant difference test through the software Origin Pro version 9.8.

3. Results

A total of 268 people participated in anti-snare walks along 23 tracks on the forest fringes of eight forest ranges in VTR, Bihar, covering a total distance of 142.71 km with an average distance of 17.84 ± 9.12 (ranges from 6.6 to 32.54 km) per range. Supplementary Table 1 provides a detailed summary of forest ranges, distance walked on foot, number of people who participated, and hunting tools removed per range. Most participants (maximum of 56 %, N = 147) belonged to the forest patrolling staff followed by Beat incharge (20 %, N = 53), SSB staff (17 %, N = 46), and Local volunteers (7 %, N = 18) (Supplementary Table 1).

A total of 132 hunting incidences of 7 major types were encountered along with the fringe areas of the VTR, out of which 35 % (N = 44) were wire snares, followed by bird snares (27 %, N = 35), other hunting equipment (20, (N = 27), and nets for mammals (11 %, N = 14), spears (5 %, N = 6), jaw traps (3 %, N = 4) and electric wires (1 %, N = 2) (Fig. 2). Out of the 132 incidences detected, the maximum 89 % (N = 117) of them were found during the AWS, the reminder 10 % (N = 12) were found by the forest department during the regular patrolling and local village volunteers (V3) who had been trained during the anti-snare walk 2 % (N = 3) (Supplementary Table 1).

The detection rate for wire snare was 0.32 ± 0.23 per km. According to the spatial distribution of snare detection, political boundaries were found to increase the detection of wire snares across the study terrain (Supplementary Fig. 1). The majority (66 %) of wire snares were removed at a detection rate of 1.28 per km along the international border (Nepal) and interstate (Uttar Pradesh), with the remainder (34 %) removed from other forest edges at a detection rate of 0.15 per km (Supplementary Fig. 1). Wire (clutch/ galvanised iron) was used to make the entire snare for mammals that we dismantled. The majority of the snares are made of clutch wire (89 %) while the remaining 11 % were made of GI wire. A snare loop's average diameter was 37.75 ± 6.79 (ranges from 20.32 to 71.2 cm) and its average length was 219.52 ± 20.99 (ranges from 167.64 to 304.81 cm). Most (57 %) of the snares were anchored with tree species (commonly *Tectona grandis* & *Shorea robusta*) and the rest with fencing poles (43 %). The anchor tree species GBH (girth at breast height) was with an average value of 55.98 ± 17.53 (ranges from 30.4 to 101.6 cm), and the average GBH of the fencing poles was 43.21 ± 15.19 (ranges from 20.32 to 73.66 cm). The linear regression model result showed that the snare loop and anchor plant have a linear relationship (i.e., positive correlation) with the number of snares. While the relationship between the numbers of snares represents a negative correlation with snare, length and anchor fencing pole GBH (Table 1; Fig. 3). Of the total number of snares detected, 57 % have been anchored to trees and 43 % to fencing poles. The linear regression model interpretation relieved that the local poachers believe the snares anchored to the tree were more effective than those were placed in other fencing pools may be the cause of this. The positive correlation emphasizes the importance of certain snaring parameters like snare loop, anchor plant GBH, on the snare installation.

The detection rate for all hunting incidences was 0.92 ± 0.32 per km. The maximum rate 2.22 per km was observed in Harnatand range followed by Manguraha 1.57 per km and lowest 0.31 per km in the Valmiki Nagar range (Supplementary Table 1). We found significant positive relationship of hunting incidences with that farmland (t value = 3.5843, $p < 0.001$), watch towers (t value = 2.4171, $p < 0.01$), and permanent water sources (t value = 3.3491, $p < 0.001$) across the study terrain. The majority of hunting incidences were reported from farmland fringes (65 %) followed by watchtowers (30 %), and water sources (5 %). The pattern of distribution map of hunting incidences in the VTR is shown in Fig. 4.

Based on the event location of the reported hunting incidence in the landscape, we extrapolated the data to an estimated detected incidences using kernel density. The density map (Fig. 5) reveals density variations at smaller spatial scales. The kernel density map highlights hotspots in the landscape where hunting incidences detected most frequently, further illustrates the threat by darkening the red color. When a point is closest to the red color, the density value is highest; as the point gets farther away, the density value decreases (Fig. 5). When compared to the core ranges (Harnatand and Ganuali) on the map, the outer and far-flung forest ranges (Manguraha, Chiutaha, Madanpur) were expected to have a high density of hunting incidences/wire snares, whereas the Valmiki Nagar range has a low density.

The maximum number ($N = 31$) of hunting incidences were reported from the Manguraha range (sharing the border with Nepal) and the

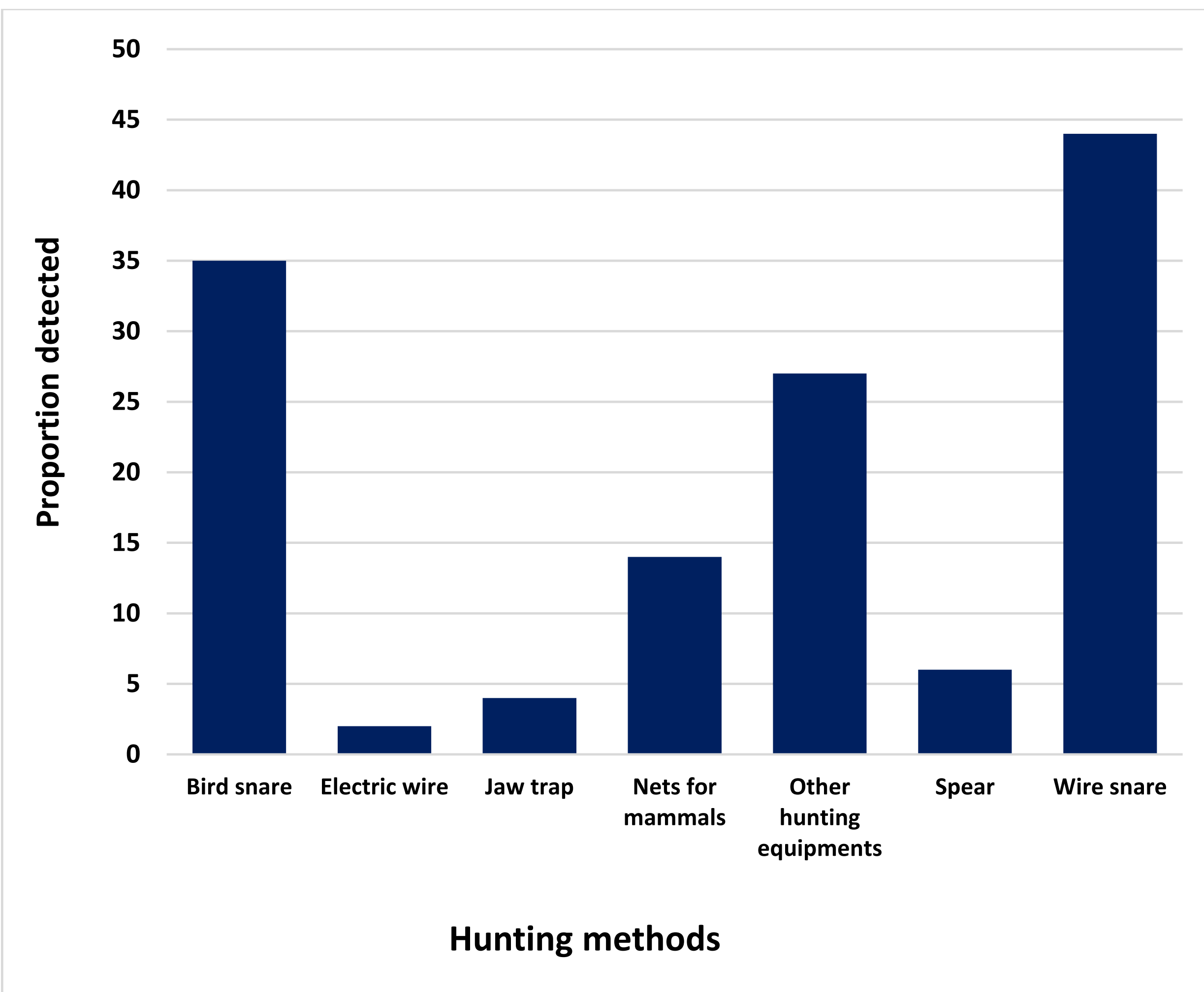

Fig. 2. The proportion of different hunting methods detected from Valmiki Tiger Reserve, Bihar, India.

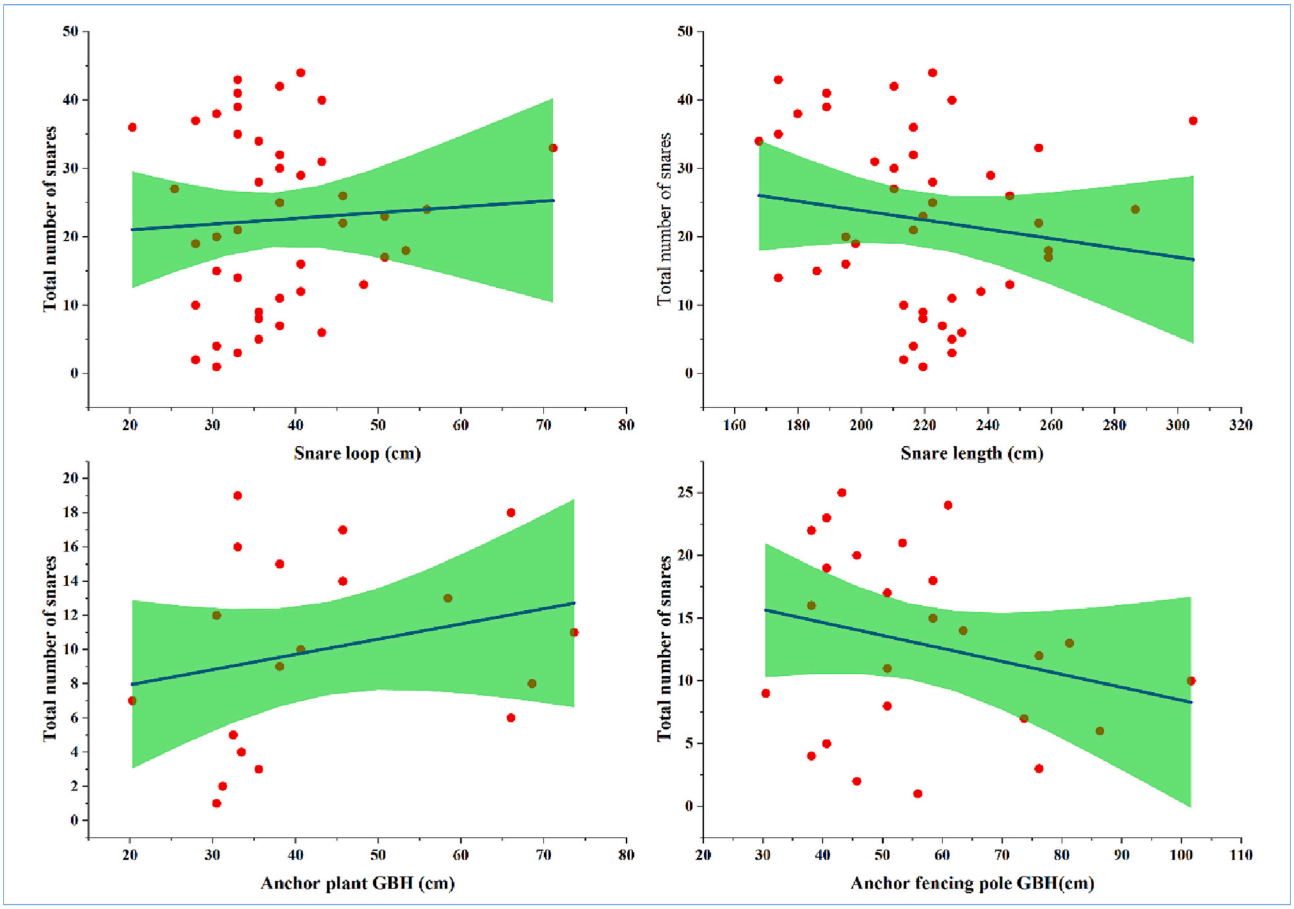

Fig. 3. Linear regression between number of snares and (a) snare loop; (b) snare length (c) anchor plant and (d) anchor fencing pole Valmiki Tiger Reserve, Bihar, India.

minimum (N = 3) from the Chiutaha range (sharing its boundary with other VTR ranges). A maximum of other hunting tools like bow, arrows, catapult, wire bundles, sickles, axes, knife, and ropes were found in the forest fringes of Harnatand and Madanpur ranges. However, jaw traps were found in the core forest ranges (Raghia range). Overall, Division 1 was more vulnerable with (57 %) of the hunting incidences compared to Division 2 with (43 %). The decreasing order of hunting incidences density is shown in Fig. 6.

The proportion of variance in the data was explained by Principal Component Analysis (PCA) in which the specific hunting tools were linked to a particular range based on differences in preference levels with PC1 (35.6 %) and PC2 (31.9 %) of distribution in the biplot (Fig. 7 **a, b**). The percentage of explained variables is graphically represented in the bar plot (Fig. 7b). PC1 has significant positive loadings from bird traps, nets, spears, jaw traps, electric wire, and snares, so it measures the long-term impact to wildlife. PC2 has significant negative loadings from other hunting equipment, so this component measure strong negative associations in the landscape. Furthermore, we determine the level of correlation of hunting methods with the targeted ranges. The snare and other hunting equipment, for example, were found linked to the Manguraha forest range and the Gobardhana, Harnatad, and Chiutaha ranges, respectively. Electric wire was the prevalent method in Valmiki Nagar. PCA analyses elucidated different groups clearly separated from one another, whereas ranges were classified based on similarities in combed hunting methods (Fig. 7).

4. Discussion

Here we provide a detailed study on the quantification of hunting methods as a threat to wildlife in Valmiki Tiger Reserve, Bihar India. The results revealed (i): snaring was the common hunting method used by local poachers in the landscape, (ii): the detection rate for all hunting incidences was 0.92 ± 0.32 per km (iii): we observed that hotspots in the landscape sharing the forest fringes with international border (Nepal) and interstate (Uttar Pradesh), India (iv): we provided participants with direct field-based training for future detecting hunting incidences along forest fringes. We observed that the local poachers prefer the snaring methods since they are less expensive, easier to conceal, and transport for poachers. The explanation for this could be that the residents of the area are poverty-stricken and cannot purchase modern hunting tools (firearms). In addition, the local poachers believe that the snares, unlike guns, pose a threat even after the hunter has left the forest, and they routinely elude discovery by even the most experienced anti-poaching teams in forest fringe areas where poachers leave traps and snare unattended for weeks or even months. Our results are supported by findings of Gubbi and Linkie (2012) who reported wire snares are frequently (85 %) used by poachers of hunting in other tiger reserve (Periyar tiger reserve) in India.

In the current study, a total of 132 hunting incidences were encountered from the periphery of VTR, with wire snares accounting for up to 35 % of the total. This means that, as in other parts of India, snaring is the most common method for encircling farmland as a primary means of crop protection. Similar findings were reported by Gubbi et al. (2021) from Karnataka, India. During cropping, when farmers went to considerable measures to secure their crops, including installing snares to dissuade crop-raiding herbivores, snaring instances were prevalent. The results confirm our hypothesis and offer a potential explanation for why snares were found more frequently near agricultural farmlands and

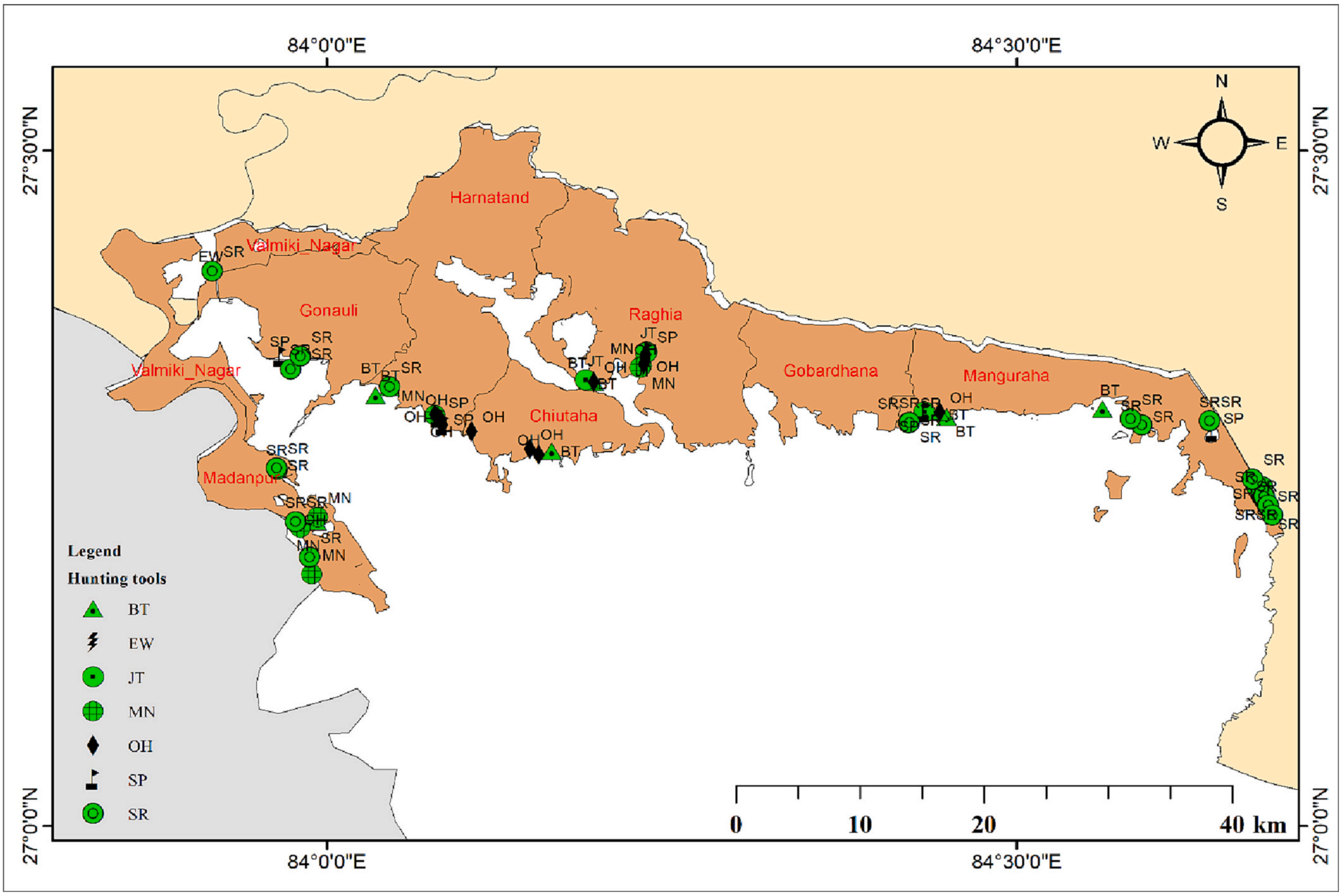

Fig. 4. Map showing the distribution pattern of hunting tools from Valmiki Tiger Reserve, Bihar, India. The yellow color area on the map represents Nepal, while the grey color area represents Uttar Pradesh, India. The abbreviation used is BT-Bird snare; EW-Electric wire; JT-Jaw trap; MN- Nets for mammals; OH- other hunting equipment; SP- Spear; SR-Snare. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 1
Linear generalized output of various study parameters from Valmiki Tiger Reserve, Bihar, India.

Parameter	F-statistic	df	*p*-Value	Estimate	SE	t value
Snare loop (cm)	0.288	39	0.258	0.288	0.251	1.147
Snare length (cm)	−0.133	39	0.109	−0.133	0.081	−1.637
Anchor plant GBH (cm)	0.008	23	0.941	0.008	0.112	0.074
Anchor fencing pole GBH(cm)	−0.089	18	0.544	−0.089	0.146	−0.611
Farmland fringes	−0.401	83	0.001	−0.337	0.111	−3.584
Watch towers	−0.467	83	0.017	−0.285	0.193	−2.417
Water sources	−1.195	83	0.001	−1.005	0.357	−3.349

forest fringes. The frequent incidence of wire snaring near agricultural land added credence to Becker et al. (2013) theory regarding the interactions between elephant crop destruction and by-catch elephants from wire-snare poaching. As a result, greater agricultural development in buffer zones is expected to worsen the conflict between people and wildlife and the mortality rate of wild animal bycatch from snares. Mudumba et al. (2021), also from Uganda, revealed similar findings. Snares are commonly made of vehicle clutch cables, binding wire, and telephone wires and are placed in areas where animals frequent, such as farm edges (O'Kelly et al., 2018). According to Maurya et al. (2021), the study area had a high prey density of 5.09 individuals/km^2, which increased the possibility of medium- to large-sized wild animals (Chital and Wild pig) being caught in snares. In the study area, snares are primarily used to hunt wild herbivores. They accidentally catch both targeted and untargeted species, causing wildlife mortality, severe injuries, permanent impairment, and stress, including wildlife species on the IUCN Red list (Gubbi et al., 2021). Our findings are consistent with those made by Li et al. (2021), who claimed that local hunters primarily use snares to capture medium- to large-sized wild animals. As a result, removing hunting tools equates to rescuing the same amount of wild animals in the area. However, due to the development of linear transmission lines around the forest fringes, the locals use electrocution as a method of hunting during the night hours in Valmiki Nagar, as this is the only forest range where electrocution wires have been removed. Therefore, we suggest that patrolling employees be trained in recognizing and combing snares/electric wires in order to avoid dangers from places where snares were present but undiscovered.

The local poachers preferred anchoring the snares with tree species (*Shorea robusta* and *Tectona grandis*). This demonstrates that the Sal vegetation type is the preferred habitat for snare installation in the landscape. Furthermore, the findings revealed that the majority of snares are anchored with medium-sized (ranges from 30.4 to 101.6 cm) tree species rather than large or small trees. This suggests that medium-sized edge tree species are preferred for snare anchoring because their strength is sufficient to hold the animal caught in the snare. Furthermore, the loop size will be sufficient to catch a medium-sized animal in it. The average size of snare loops (37.75 cm) reported in the current study falls within a suitable range set to catch wild pigs and other herbivores, but a tiger and leopard could be caught in it (Bhardwaj, 2021). This could imply that snaring is a non-selective and effective method of poaching and a silent killer of wild animals. Such data combinations on

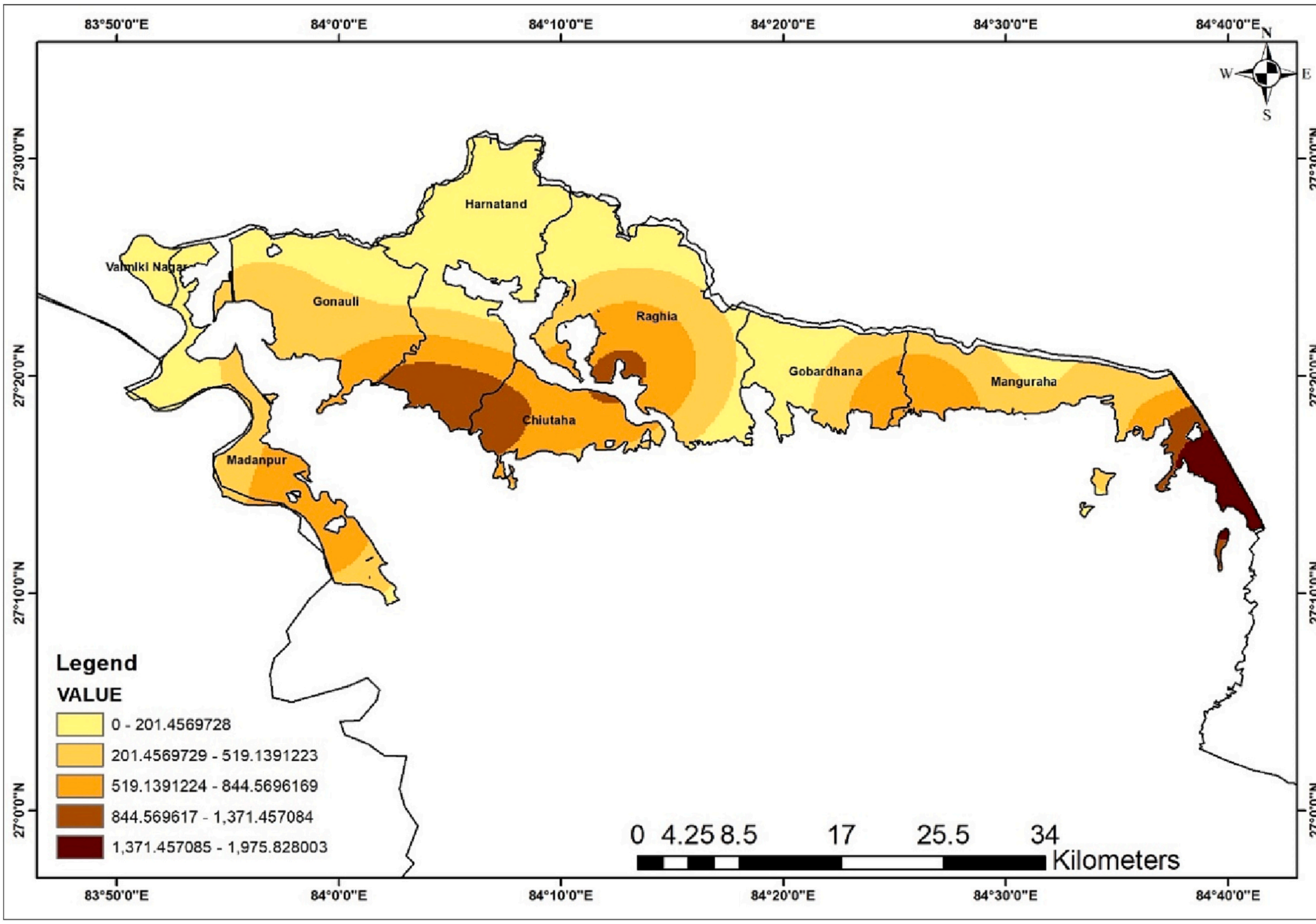

Fig. 5. The Kernel density map shows the hotspots of hunting incidences from Valmiki Tiger Reserve, Bihar, India.

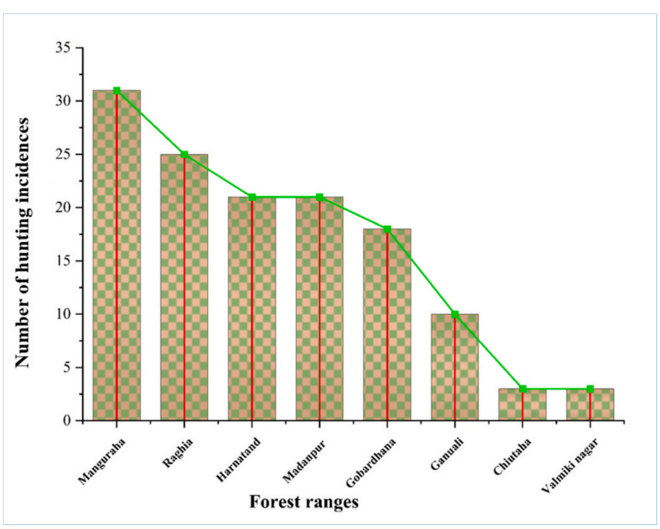

Fig. 6. Decreasing order of hunting incidences in eight ranges from Valmiki Tiger Reserve, Bihar, India.

the snare features pave the way for future applications of the study in monitoring the landscape. Our results were supported by findings of Becker et al. (2013) and Penteriani et al. (2018), who found a high level of wire snare and trap poaching, which can have a significant negative impact on large carnivores.

Hunting methods, particularly wire snaring, are one of the most urgent threats to numerous large mammal communities in the landscape, including the emerging tiger population within the study landscape. During the ASW the patrolling teams, for example, the detection probabilities was high for wire snares implying that the scale of the problem is far greater than what was observed. The success of removing snares increases with the number of patrolling staff per patrol. Mudumba et al. (2021) reported a comparable detection rate from Uganda's Karuma and Bugungu Wildlife Reserves. In tropical forests, Figel et al. (2021) discovered a virtually comparable detection rate, which validates our findings. In natural forest fringes with dense understory vegetation, snares are extremely difficult to spot, and rusty snares are even more difficult to spot because their hue is similar to that of natural soil (Ibbett et al., 2021). Similarly, van Doormaal et al. (2021) noted the difficulty in identifying snares during patrols, but few addressed the issue.

An overall detection rate of 0.32 for wire snares in this study scenario supports the assumption that detection rates for snares are low (Watson et al., 2013). Most ecological surveys cover just a small section of the entire region, and in the case of snares, a reasonable search effort may yield only a small portion of the total number of snares present. The current investigation was done along random trails, and a high detection rate was achieved when compared to previous experimental studies. Even in a controlled experiment done in the Keo Seima Wildlife Reserve in eastern Cambodia, the total detection rate was estimated to be 0.2 (O'Kelly et al., 2018a). Along the border, the detection rate was almost 8.5 times higher. This could be attributed to differences in the forest department's patrolling activity, as well as edge impact. Our findings agree with those of Gubbi et al. (2021), who identified increased anthropogenic-induced mortalities as one of the edge consequences on

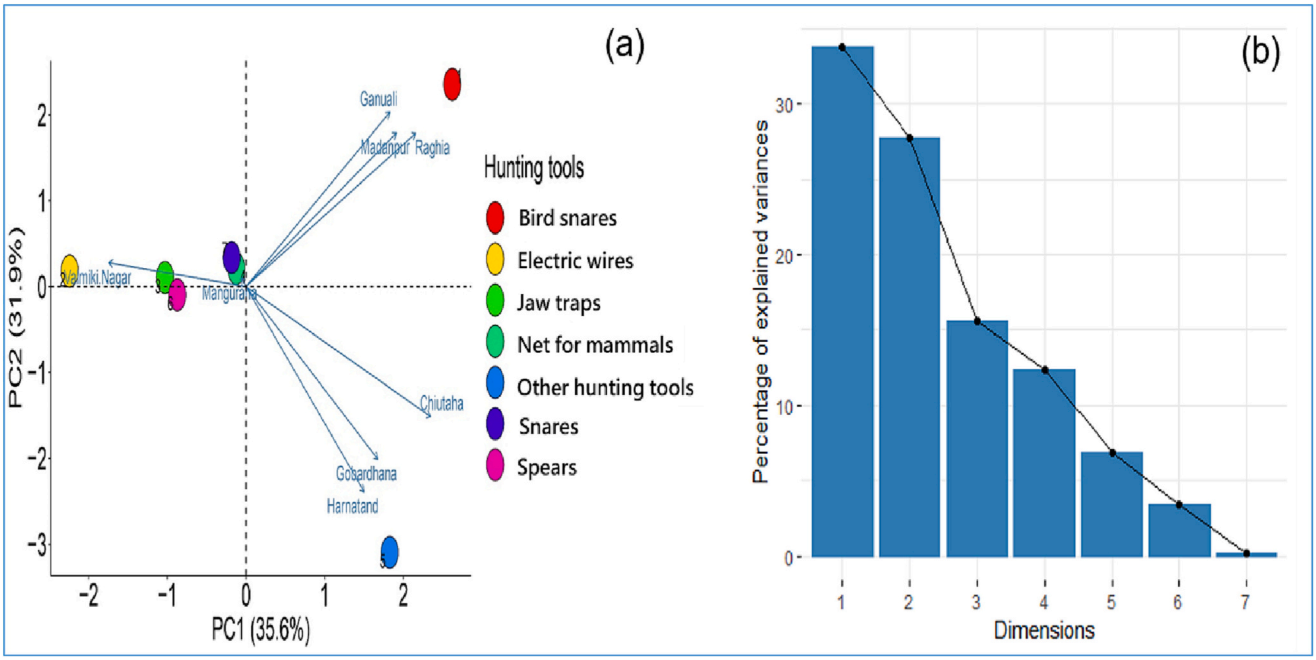

Fig. 7. (a) PCA analysis biplot of different hunting methods investigated from Valmiki Tiger Reserve, Bihar, India. (b) The bar plot shows the percentage contribution of each variable in PCA biplot.

wildlife. Additionally, it was determined that all of the snares found by the teams had been set up before the study. This emphasizes the danger that snares pose from a conservation standpoint; even snares that were set months ago continue to harm wildlife (Van Doormaal et al., 2021).

In the present study, it was observed that Division 1 was more vulnerable as compared to Division 2 of the VTR. This could be because the Manguraha range, which shares a border with Nepal, had a high density of snares. As a result, it is more vulnerable to wildlife crime. This demonstrates how effective snares are at capturing animals when compared to other hunting gear (Campbell et al., 2019). We employed a stratified random sampling strategy for identifying hotspots by hunting tools. Harmsen et al. (2021b) used a similar method in their identification of a hotspot strategy, which is effective in combating bushmeat poaching by snaring. Furthermore, it was reported that within-country state borders also have a high density of hunting incidences, particularly nets and other hunting equipment (Fig. 4). This could be attributed to a lack of enforcement coordination among neighboring states or countries. As a result, improving coordination and cooperation in combating both national and international wildlife crime is critical and a joint anti-snare walk between India and Nepal is urgently needed. The Chiutaha range has a minimal number of hunting tools because its boundaries are shared with other VTR ranges. This indicates that the locals avoided hunting inside the forest region, preferring instead to hunt on the outskirts of the forest to avoid being caught by law enforcement.

We looked into general law enforcement (forest department) for ASW, which seemed insufficient. Extra enforcement and local volunteers are needed for patrols to reduce the threat posed by hunting methods. The involvement of local volunteers from Valmiki Tiger Reserve in ASWs demonstrates the level of sensitization created by the WTI team to the local youth to aid in wildlife conservation. The local volunteers assisted in the combing of hunting tools, such as snares, along with the VTR peripheral settlements/farmlands. Three snares were removed from the periphery villages by a total of ($N = 18$) local volunteers who actively engaged in the anti-snare walk. Local residents' participation will aid in the reporting of wildlife crime activities to law enforcement agencies. Thus, local volunteers' participation in anti-snare demonstrates the WTI team's efforts in capacity building by providing direct field-based training for future detecting of wildlife hunting methods, including snare, from the outskirts of forest areas, thereby assisting the forest department in wildlife conservation.

The current study encourages the participation of various agencies as well as local residents in order to increase the speed with which snaring cases are reported while also increasing societal pressure against poachers (Steinmetz et al., 2014; Viollaz et al., 2021). Indeed, when outside poachers invade community territory, reporting and selling to middlemen in remote locations, community partnerships and local informants become especially important (Twongyirwe et al., 2018). Local residents are frequently better placed to intervene in such situations than outside personnel because they have more information about on-the-ground movements (Westoby et al., 2020). Thus, the participation of multiple agencies in anti-snare walks exemplifies the ground-level cooperation and coordination developed by the WTI team in successfully combing the hunting tools around the VTR. Finally, the forest department's capacity is strengthened by direct field-based training of patrolling staff for future combing hunting tools along the forest fringes.

4.1. *Insights for wildlife conservation and policy*

The results of the current study showed that local poachers used a multiple hunting methods, but wire snares are frequently used, leading us to conclude that traditional hunting equipment is one of the greatest threats to the wildlife in the landscape. We observed that the Division 1 of the VTR was more vulnerable, therefore to reduce the threat posed by hunting methods particular wire snares, extra patrol personnel and watchtowers are required for identified hotspots. We also propose that the park mangers form an anti-snare patrolling crew to remove snares along forest fringes, which is often overlooked by regular patrolling staff. In the Valmiki Nagar range, we found that electric wire was the prevalent hunting method. Therefore, with the continued development of linear transmission lines in other parts of the VTR, we proposed the use of electric insulated cable wire around the forest fringes villages of the Tiger reserve, with proper coordination and planning with the forest department. We found that medium-sized edge tree species are preferred for snare anchoring; hence, the patrolling team should pay extra attention to examine these tree species, specifically *Shorea robusta* and

Tectona grandis. According to our findings, the majority of the hunting tools were removed along the farmland-forest boundary, which is one of the reasons farmers use snares to protect their crops from wild animals. Therefore, it is necessary to consider alternative crop damage mitigation strategies that will discourage local communities from putting up snares. The forest department should also raise the cap and make timely crop damage payments. Crop damage compensation for farmers on the fringes of the Tiger Reserve should be prioritised to better protect wildlife. Stakeholders should develop policies to compensate farmers for crop/life loss caused by wild species, which will aid in the prevention of human-wildlife conflict and thus contribute to wildlife conservation. Our study shows that the forest department combed 10 % of hunting methods after proper orientation to the target group. Therefore, we recommend that patrolling staff must receive more training in snare recognition and combing in order to prevent risks from areas where snares were present but not removed. Our study encourages the involvement of multiple law enforcement agencies to increase the legal pressure against poachers, contrary to what was previously believed that only the forest department is selected for protection. This will alter the narrative among law enforcement agencies and have a significant impact on poachers. In addition, interstate, as well as international cooperation is needed to combat wildlife crimes. Joint anti-snare walks should be conducted between interstate as well as international borders through proper plans. Furthermore, the involvement of young volunteers increases societal pressure against poachers and awareness among local communities. Local residents should be informed about zoonotic diseases transmitted by wildlife, such as covid-19, and avian influenza, this will create a reluctance in poaching. Furthermore, young schoolchildren in the landscape must be well informed about the ecological and cultural importance of wildlife from an early age in order to develop an impassionate bond with wildlife. Finally, the management action plan must involve local communities in promoting solutions that directly or indirectly strengthen the role, capacity, and rights of Indigenous peoples and include recent scientific field-based study findings for conservation mitigation.

5. Conclusion

The current study is the first to provide direct field-based quantitative data on hunting tools as a threat to wildlife in Valmiki Tiger Reserve, in India. A total of 132 hunting tools were removed along with the VTR's fringe areas, with snares accounting for the majority (35 %). Overall, Division 1 was more vulnerable with (57 %) of the hunting methods compared to Division 2 with (43 %). A high density of hunting tools were reported in forest ranges that shared boundaries with other states or international borders. Jaw traps, on the other hand, were removed from the core region. The current study encourages the participation of various enforcement agencies as well as local residents in the anti-snare walk. The participation of various law enforcement agencies in the anti-snare walk demonstrates the ground-level cooperation and coordination developed by the WTI team in successfully combing the hunting tools around the VTR. The involvement of local volunteers demonstrates the level of sensitization created by the WTI team to the local youth to aid in wildlife conservation. Without an understanding of the problem and the backing of community groups near the protected areas, conservation and anti-snaring initiatives often fail. Working with local communities can help minimize the installation of snares and reduce off the number of outsiders who snare animals in the landscape. Furthermore, training of patrolling staff demonstrates the level of capacity binding during the study by providing field-based training for dismantling traditional hunting tools including snares for future wildlife crime prevention.

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Ethics approval and consent to participate

The current research is purely based on field survey and therefore, ethical approval and consent is not applicable.

Consent for publication

Present paper does not contain any individual's person data; therefore, this section is not applicable to our study.

CRediT authorship contribution statement

Conceptualization V.M; J.L; Study Design S.K·S; D·S; S.M.H; Data collection S.M.H; Data analysis, S.M.H; Original draft writing S.M.H; review and editing V.M; J.L; D·S; S.K·S; S.M.H; All authors read and approved the final manuscript.

Declaration of competing interest

We have no conflict of interest to disclose. Moreover, the sequence of authorships mentioned in the article is based upon the contribution of the work by all authors.

Data availability

All data have been included in the manuscript.

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References

Aziz, M.A., Tollington, S., Barlow, A., Goodrich, J., Shamsuddoha, M., Islam, M.A., Groombridge, J.J., 2017. Investigating patterns of tiger and prey poaching in the Bangladesh Sundarbans: implications for improved management. GECCO. 9, 70–81.

Becker, M., McRobb, R., Watson, F., Dröge, E., Kanyembo, B., Murdoch, J., Kakumbi, C., 2013. Evaluating wire-snare poaching trends and the impacts of by-catch on elephants and large carnivores. Biol. Conserv. 158, 26–36. https://doi.org/10.1016/j.biocon.2012.08.017.

Bhardwaj, M., 2021. Leopard caught in snare for 42 hours, dies long, painful death. The New Indian Express. https://www.newindianexpress.com/states/karnataka/2021/mar/30/leopard-caught-in-snare-for-42-hours-dies-long-painful-death-2283376.html.

Braga-Pereira, F., Bogoni, J.A., Alves, R.R.N., 2020. From spears to automatic rifles: the shift in hunting techniques as a mammal depletion driver during the Angolan civil war. Biol. Conserv. 249, 108744.

Broom, D.M., 2022. Some thoughts on the impact of trapping on mammal welfare with emphasis on snares. In: Mammal Trapping.

Campbell, K., Martyr, D., Risdianto, D., Clemente, C.J., 2019. Two species, one snare: Analysing snare usage and the impacts of tiger poaching on a non-target species, the Malayan tapir. Biol. Conserv. 231, 161–166.

Corlett, R.T., 2007. The impact of hunting on the mammalian fauna of tropical Asian forests. Biotropica. 39 (3), 292–303.

Descovich, K.A., McDonald, I.J., Tribe, A., Phillips, C.J.C., 2015. A welfare assessment of methods used for harvesting, hunting and population control of kangaroos and wallabies. Anim Welf 24 (3), 255–265.

Diamond, J.M., 1989. The present, past and future of human-caused extinctions. Philosophical Transactions of the Royal Society of London. B. Biological Sciences 325 (1228), 469–477.

Fa, J.E., Brown, D., 2009. Impacts of hunting on mammals in African tropical moist forests: a review and synthesis. Mamm Rev 39 (4), 231–264.

Figel, J.J., Hambal, M., Krisna, I., Putra, R., Yansyah, D., 2021. Malignant snare traps threaten an irreplaceable megafauna community. Trop. Con. Sci. 14 p.1940082921989187.

Gray, T.N., Hughes, A.C., Laurance, W.F., Long, B., Lynam, A.J., O'Kelly, H., Ripple, W.J., Seng, T., Scotson, L., Wilkinson, N.M., 2018. The wildlife snaring crisis: an

insidious and pervasive threat to biodiversity in Southeast Asia. Biod. Conserve. 27 (4), 1031–1037.
Gubbi, S., Linkie, M., 2012. Wildlife hunting patterns, techniques, and profile of hunters in and around Periyar tiger reserve. J. Bom. Nat. Hist. Soc. 109 (3), 165–172.
Gubbi, S., Harish, N.S., Kolekar, A., Poornesha, H.C., Reddy, V., Mumtaz, J., Madhusudan, M.D., 2017. From intent to action: a case study for the expansion of tiger conservation from southern India. GECCO. 9, 11–20.
Gubbi, S., Kolekar, A., Kumara, V., 2021. Quantifying wire snares as a threat to leopards in Karnataka. India. Trop. Con. Sci. 14, 19400829211023264.
Harmsen, H., Mbau, J.S., Muthama, J.N., Wang'ondu, V.W., 2021a. Comparing law enforcement monitoring data and research data suggests an underestimation of bushmeat poaching through snaring in a Kenyan world heritage site. Afr. J. Ecol. 59 (4), 912–923.
Harmsen, H., Wang'ondu, V.W., Mbau, J.S., Muthama, N.J., 2021b. Randomized hotspot strategy is effective in countering bushmeat poaching by snaring. Biol. Conserv. 253, 108909.
Harmsen, H.W., 2021. Effectiveness of Patrolling Protected Areas against Bushmeat Poaching through Snaring in the Soysambu Conservancy, Kenya (Doctoral dissertation,. University of Nairobi.
Harrison, R.D., Sreekar, R., Brodie, J.F., Brook, S., Luskin, M., O'Kelly, H., Rao, M., Scheffers, B., Velho, N., 2016. Impacts of hunting on tropical forests in Southeast Asia. Conserv. Biol. 30 (5), 972–981.
Ibbett, H., Milner-Gulland, E.J., Beale, C., Dobson, A.D., Griffin, O., O'Kelly, H., Keane, A., 2020. Experimentally assessing the effect of search effort on snare detectability. Biol. Conserv. 247, 108581.
Ibbett, H., Keane, A., Dobson, A.D., Griffin, O., Travers, H., Milner-Gulland, E.J., 2021. Estimating hunting prevalence and reliance on wild meat in Cambodia's Eastern Plains. Oryx. 55 (6), 878–888.
Joca, S.R.L., Ferreira, F.R., Guimarães, F.S., 2007. Modulation of stress consequences by hippocampal monoaminergic, glutamatergic and nitrergic neurotransmitter systems. Stress 10 (3), 227–249.
Li, X.Y., Bleisch, W.V., Liu, X.W., Hu, W.Q., Jiang, X.L., 2021. Human disturbance and prey occupancy as predictors of carnivore richness and biomass in a Himalayan hotspot. Anim. Conserv. 24 (1), 64–72.
Linkie, M., Martyr, D.J., Holden, J., Yanuar, A., Hartana, A.T., Sugardjito, J., Leader-Williams, N., 2003. Habitat destruction and poaching threaten the Sumatran tiger in KerinciSeblat National Park. Sumatra. Oryx. 37 (1), 41–48.
Lossa, G., Soulsbury, C.D., Harris, S., 2007. Mammal trapping: a review of animal welfare standards of killing and restraining traps. Anim Welf 16 (3), 335–352.
Matseketsa, G., Muboko, N., Gandiwa, E., Kombora, D.M., Chibememe, G., 2019. An assessment of human-wildlife conflicts in local communities bordering the western part of save valley conservancy, Zimbabwe. GECCO. 20, e00737.
Matungwa, L.M., Wawa, A.I., 2021. The effectiveness of anti-poaching techniques in combating wildebeest poaching in Serengeti National Park. Tanzania J. For. Nat. Conserv. 90 (3), 24–39.
Maurya, K., Borah, J., 2014. Status of tigers in Valmiki Tiger Reserve,Terai Arc Landscape, Bihar, India. WWF-India.
Maurya, K.K., Borah, J., 2013. Tiger Status in Valmiki Tiger Reserve, Terai Arc Landscape, Bihar. WWF, India, New Delhi, India.
Maurya, K.K., Ojha, G., Mall, A., Narayan, N., Roy, H.K., 2021. Status of Tigers and Prey in Valmiki Tiger Reserve. Terai Arc Landscape, Bihar, India.
Menon, V., 2016. Case Study 18 Wildlife Trust of India. Tropical Conservation: Perspectives on Local and Global Priorities, p. 468.
Mudumba, T., Jingo, S., Heit, D., Montgomery, R.A., 2021. The landscape configuration and lethality of snare poaching of sympatric guilds of large carnivores and ungulates. Afr. J. Ecol. 59 (1), 51–62.
O'Kelly, H.J., Rowcliffe, J.M., Durant, S., Milner-Gulland, E.J., 2018. Experimental estimation of snare detectability for robust threat monitoring. Ecol. Evol. 8 (3), 1778–1785.
O'Kelly, H.J., Rowcliffe, J.M., Durant, S.M., Milner-Gulland, E.J., 2018a. Robust estimation of snare prevalence within a tropical forest context using N-mixture models. Biol. Conserv. 217, 75–82.
Olson, D.M., Dinerstein, E., 2002. The global 200: priority ecoregions for global conservation. Ann. Mo. Bot. Gard. 89, 199–224.
Penteriani, V., Delgado, M.D.M., Krofel, M., Jerina, K., Ordiz, A., Dalerum, F., Zarzo-Arias, A., Bombieri, G., 2018. Evolutionary and ecological traps for brown bears Ursusarctos in human-modified landscapes. Mam. Rev. 48 (3), 180–193.
R Core Team, 2020. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.
Rija, A.A., Kideghesho, J.R., 2020. Poachers' strategies to surmount anti-poaching efforts in Western Serengeti, Tanzania. In: Protected areas in northern Tanzania: local communities, land use change, and management challenges, pp. 1–112.
Ripple, W.J., Newsome, T.M., Wolf, C., Dirzo, R., Everatt, K.T., Galetti, M., Hayward, M. W., Kerley, G.I., Levi, T., Lindsey, P.A., Macdonald, D.W., 2015. Collapse of the world's largest herbivores. Sci. Adv. 1 (4), 1400103.
Sarkar, M.S., Amonge, D.E., Pradhan, N., Naing, H., Huang, Z., Lodhi, M.S., 2021. A review of two decades of conservation efforts on tigers, co-predators and prey at the junction of three global biodiversity hotspots in the transboundary far-eastern Himalayan landscape. Animals 11 (8), 2365.
Sattar, Q., Maqbool, M.E., Ehsan, R., Akhtar, S., 2021. Review on climate change and its effect on wildlife and ecosystem. Ope. J. Env. Biol. 6 (1), 008–014.
Sethi, S., 2022. Insights into illegal wildlife hunting by forest guards of selected tiger reserves in Central India. Eur. J. Wildl. Res. 68 (1), 4.
Silverman, B.W., 2018. Density Estimation for Statistics and Data Analysis. Routledge.
Singh, K.J., 2013. Tiger conservation plan of Valmiki Tiger Reserve, West Champaran. Office of the Field Director, Bettiah, Bihar.
Steinmetz, R., Srirattanaporn, S., Mor-Tip, J., Seuaturien, N., 2014. Can community outreach alleviate poaching pressure and recover wildlife in south-east Asian protected areas? J. Appl. Ecol. 51 (6), 1469–1478.
Twongyirwe, R., Bithell, M., Richards, K.S., 2018. Revisiting the drivers of deforestation in the tropics: insights from local and key informant perceptions in western Uganda. J. Rur. Stud. 63, 105–119.
Van Doormaal, N., Lemieux, A.M., Ruiter, S., Allin, P.M., Spencer, C.R., 2021. Detecting wildlife poaching: a rigorous method for comparing patrol strategies using an experimental design. Oryx 1–9.
Viollaz, J., Long, B., Trung, C.T., Kempinski, J., Rawson, B.M., Quang, H.X., Hiền, N.N., Liên, N.T.B., Dũng, C.T., Huyền, H.T., McWhirter, R., 2021. Using crime script analysis to understand wildlife poaching in Vietnam. Ambio 50 (7), 1378–1393.
Watson, F., Becker, M.S., McRobb, R., Kanyembo, B., 2013. Spatial patterns of wire-snare poaching: implications for community conservation in buffer zones around National Parks. Biol. Conserv. 168, 1–9.
Westoby, R., McNamara, K.E., Kumar, R., Nunn, P.D., 2020. From community-based to locally led adaptation: evidence from Vanuatu. Ambio 49 (9), 1466–1473.
Wildlife Protection Act, 1972. A Hand Guide with Case Law and Commentaries, Natraj, ISBN 9788185019161 (with Amendments till 2022).
Zhang, G., Xu, J., 2023. Multi-GPU-parallel and tile-based kernel density estimation for large-scale spatial point pattern analysis. ISPRS Int. J. Geo Inf. 12 (2), p31.