Wiley
International Journal of Zoology
Volume 2025, Article ID 8884833, 14 pages
https://doi.org/10.1155/ijz/8884833

WILEY

Research Article

The Rhinoceros Relocation Mystery: Unraveling the Determinants of Habitat Use and Conservation Threats of Translocated Population in Nepal

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Received 10 May 2024; Accepted 29 March 2025

Academic Editor: Lipi Buch

Due to the rapid decline of the *Rhinoceros unicornis* population during the 1960s, the Government of Nepal implemented several conservation measures, including translocation programs to various protected areas within the country. The program's primary goal was to establish a founder population and lessen the risk of local extinction due to natural catastrophic events, disease, and poaching. However, there is a lack of comprehensive information regarding the relationships between the translocated *R. unicornis* population and their habitats, which is instrumental in planning and implementing conservation plans and policies. Thus, this study aimed to understand the factors affecting the habitat use of the translocated population of *R. unicornis* and the major existing conservation threats in Shuklaphanta National Park of Nepal. During the summer of 2022, we undertook a transect-based habitat assessment over 15 sampling grids of size 4×4 km, encompassing a 246 km^2 area. Conservation threats were assessed through the combined approach of direct field visit, systematic literature reviews, and focus group discussions. Model-averaged estimates of significant variables ($p < 0.05$) indicate that *R. unicornis* detection is more likely in grasslands (low canopy cover) and in the proximity of water source and farther from roads. At the same time, the detection probability decreases with the presence of invasive species. In addition to this, our study ranked habitat loss, fragmentation, land degradation, and small population size as the severe threats to *R. unicornis.* These findings suggest that conservation efforts should prioritize preserving and restoring suitable grassland habitats and effective control measures to reduce invasive species. Additionally, population monitoring and management efforts should be strengthened to address the challenges posed by small population size and to support the long-term persistence of *R. unicornis* in the region. We also recommend a similar study in a larger geographical setting, considering multiple seasons and assessing possible corridors and connectivity to link the local population with the Indian population to maintain genetic diversity.

Keywords: grassland; *Rhinoceros unicornis*; Shuklaphanta National Park; threats; wildlife translocation

1. Introduction

Globally, many animal species have faced significant population declines, with some driven to extinction and others nearing it due to a combination of natural and anthropogenic factors [1, 2]. Mammal populations are in critical condition as historical trends indicate the majority of them have declined in population and range, with major victims being the large ones [3]. One of the highly threatened large mammal species is the greater one-horned rhinoceros (*Rhinoceros unicornis*), hereafter referred to as rhinoceros. It is one of the five living species of the family Rhinocerotidae [4, 5] and is listed as vulnerable under the IUCN Red List of Threatened Species [6] as well as by CITES. The species has been extirpated from its historical distribution range and is currently restricted to a small area of less than 20,000 km^2 [6, 7]. Currently, almost 4034 individuals of rhinoceros inhibit in the restricted fragments of protected areas in Southern Nepal and Northern India [8–11]. These restricted populations are also facing threats such as poaching, habitat loss, and other natural and anthropogenic disturbances [6, 12].

In Nepal, rhinoceroses were almost extinct due to anthropogenic pressure, with only 100 individuals remaining in 1966 [13, 14]. Poaching, fragmentation, infrastructure development, habitat degradation, invasion of alien species, and climate change have jeopardized the conservation success of the species [15–19]. The Government of Nepal has also protected this species under the National Parks and Wildlife Conservation Act 1973 AD [20]. Since then, valiant conservation efforts have succeeded in increasing the rhinoceros population in Nepal to 752 (in 2021) with a 16% increment since the 2000s [21, 22]. However, the annual growth rate has dropped to 3%, which was 5% (between 2011 and 2015) [21]. Furthermore, the major rhinoceros population is highly restricted to Bardia National Park (hereinafter BNP) and Chitwan National Park (hereinafter CNP) in Nepal [15, 23]. While the increasing rhinoceros population is a positive sign, their restriction to a small habitat range poses significant challenges. Recently, reports of rising rhinoceros mortality have highlighted threats from anthropogenic factors (e.g., poaching and poisoning), natural disasters (e.g., flooding), and an increasing number of carnivore attacks [22, 24]. The carnivore attacks specifically are a growing concern as large carnivores such as tiger have increased in recent times. According to a study conducted by Bhandari et al. [13], it was found that the presence of larger carnivores, such as tigers, within protected areas can lead to a rise in direct mortality among rhinoceros calves.

Reintroducing endangered species to their historical habitat ranges, particularly for mega herbivores like rhinoceros, is crucial for reducing the threat of extinction [7]. Over the past four decades, conservation translocation has been a significant management tool in Nepal for restoring animal species [25]. Since the late 1980s, the Government of Nepal has translocated rhinoceroses from the source population in CNP to BNP and Shuklaphanta National Park (ShNP) [22]. Between 1986 and 2023, a total of 102 rhinoceroses were translocated to BNP, ShNP, and Koshi Tappu Wildlife Reserve (KTWR); however, the most recent national survey recorded only 38 individuals in BNP and 17 in ShNP [21]. Small populations (< 50) are particularly vulnerable to demographic fluctuations, climatic and non-climatic disasters, disease outbreaks, and stochastic genetic events, all of which threaten long-term survival and increase extinction risks [7, 22]. These challenges underscore the need for targeted conservation strategies to enhance the viability of translocated rhinoceros populations.

Understanding habitat use by mammals is essential for assessing their biological needs, survival strategies, and conservation management [26]. Additionally, evaluating the threat status of ecological communities is critical for effective conservation planning and implementation [27]. However, information on habitat use and threats to translocated populations remains scarce in Nepal [25]. Despite the rhinoceros being a flagship species and one of Nepal's most studied large mammals, research on the habitat use and conservation challenges of translocated populations is limited. Most studies have focused on climate change–induced habitat impacts in Nepal [28] or densely populated areas such as CNP [29, 30]. Among the limited literature, Thapa et al. [31] analyzed habitat preference in ShNP and BNP but provided only broad habitat-type observations. Given that habitat conditions continuously change due to climate change, human activities, invasive species, and natural events [15, 32], a more detailed, up-to-date study is necessary.

This research fills a critical gap by specifically examining the habitat use, distribution, and conservation threats of translocated rhinoceros in ShNP—one of Nepal's less studied regions for this species. Unlike previous studies, it incorporates natural and anthropogenic factors to assess recent habitat changes, adaptation challenges, and long-term sustainability. Moreover, the high mortality risk in translocated rhinoceros populations underscores the urgency of site-specific threat assessments. By providing crucial insights into habitat suitability, conservation threats, and management strategies, this study will directly inform policymakers and conservation authorities, aiding in the long-term survival of translocated rhinoceros in ShNP and similar protected areas.

2. Materials and Methods

2.1. Study Area. The study was conducted in the ShNP (latitude—28°50′45″ N and longitude—80°13′44″ E) [32], a protected area in the Terai of the Sudurpashchim Province, covering an area of 305 km^2 at an altitude of 174 to 1386 m (Figure 1). In 2004, the buffer zone of the park was expanded to include an additional 243.5 km^2 [33]. The park has a tropical to subtropical climate, with an average maximum temperature of 37°C and an average lowest temperature of 7°C. Over 2016 mm of rain may fall per year [34]. The park is connected to the Pilibhit Tiger Reserve in India, the Dudhwa Tiger Reserve to the southeast via the Laljhadi forest corridor, and the Nandhaur Wildlife Sanctuary to the northwest via the Brahmadev forest corridor and Mahakali River. The protected area is one of the best-preserved instances of floodplain grassland and is an example of the Terai–Duar savanna and grassland ecoregion.

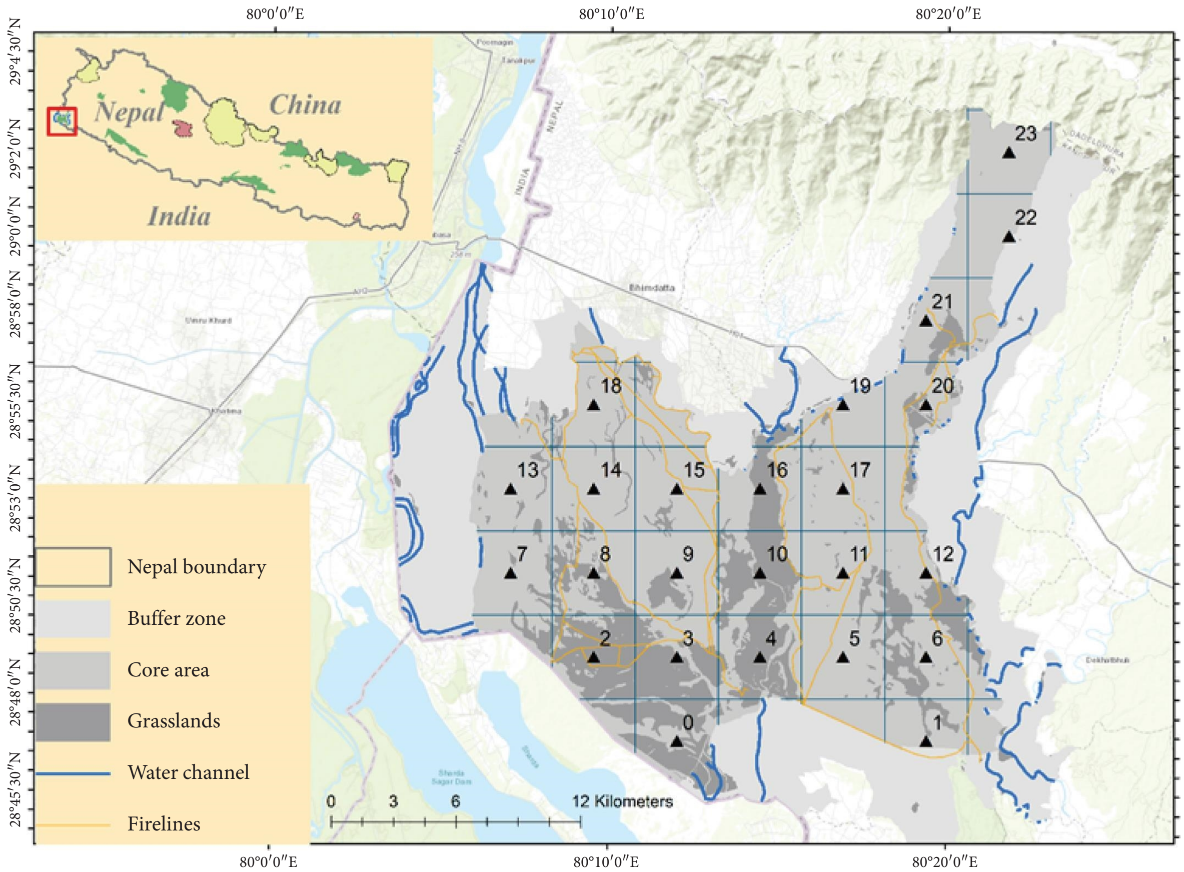


Figure 1: Map of ShNP showing buffer zone and core area with a grid of 4 × 4 km.

Shuklaphanta National Park supports a wide range of biodiversity, which is naturally and globally important. The park comprises the Terai, Bhabar, and Chure, and its vegetation can be broadly classified into forests, grasslands, and aquatic habitats (wetlands). More than 665 plant species from 438 genera and 118 families can be found in the aquatic and terrestrial ecosystems of ShNP, making it one of the most diverse protected areas in Terai [34]. Similarly, 459 species of birds, 57 species of mammals, and 71 species of herpetofauna have been identified thus far [34]. Although several variations in species association may lead to the formation of many forest types, they are primarily grouped into sal forest (*Shorea robusta*) and deciduous riverine forest. *Shorea robusta* predominates the vegetation, which also contains *Lagerstroemia parviflora, Terminalia tomentosa,* and *T. bellirica*. The park is home to the greatest population of swamp deer (*Rucervus duvaucelii*) in the entire world, as well as a number of endangered species such as the hispid hare *(Caprolagus hispidus)*, Royal Bengal tiger (*Panthera tigris tigris*), greater one-horned rhinoceros (*Rhinoceros unicornis*), and Asian elephant (*Elephas maximus*) [34].

2.2. Data Collection. This study was conducted in two phases. In the first phase, in May 2022, a focus group discussion was held with representatives from ShNP, the buffer zone management committee, the nature guide association, and local biologists. The discussion aimed to gather information about the potential locations, field settings, and conservation challenges faced by the rhinoceros in the park. Additionally, a preliminary field visit was conducted to identify areas of rhinoceros activity, assess the habitats they use, and document existing threats to their population. During the field visit, GPS points of potential rhinoceros' habitats were recorded, which helped to plan and select sample grids for further study.

Prescribed burning, a widely employed technique for managing habitats, has been a long-standing practice in Nepal's protected areas [34]. It has been carried out by park authorities annually since their establishment, primarily during the period spanning from November to April [32]. The primary objective of this practice is to boost the quality of forage available for herbivores, which is critical for their survival and well-being [35]. The detailed field study (second phase) was conducted post-burning season (between May and June 2022) when there was sparse vegetation cover in the park. Sparse vegetation cover increases species detectability, thereby minimizing the potential for bias due to undetectability [32, 36].

To assess rhinoceros habitat selection, we employed a Resource Selection Function (RSF) approach based on a transect-based sampling framework. Using the Fishnet tool in ArcGIS 10.8.1, we overlaid a uniform grid of 4 × 4 km (16 km^2) grids across the study area [37]. Out of 23 sampling grids, only 15 were selected, encompassing a 240 km^2 area for this study based on the recommendation of focus group discussion and observation made during the preliminary field in the first phase. The number of grids was reduced to maintain survey precision while minimizing survey costs and logistical complexity. Inside each selected sampling grids, single transects of 4 km [38] were laid resulting in 60 km of total transect distance. We used straight transects in this study instead of walking routes to avoid bias. Walking routes are often chosen for ease of access, which could lead to overrepresentation of certain habitat types and underrepresentation of others. Additionally, human activity on trails open to visitors can negatively affect species behavior and distribution, resulting in biased data [39]. Altogether we determined 15 transects representing all five habitat types in the park, namely, wetland, grassland, mixed forest, riverine forest, and *S. robusta* forest [32, 33, 40], accounting for three transects in each habitat type.

Four team members—two field technicians and two field biologists—investigated each transect for direct and fresh indirect signs of rhinoceroses (a week old (dung and footprints)) to detect their presence or absence during the study period. All individuals seen within a 50 m distance and any evidence of its indirect presence observed within a 5 m distance at either side of the transect were recorded [41–44]. The survey was carried out in the morning (06:00–10:00 hr) and evening (15:00–19:00 hr) of the day when the activity of rhinoceros is maximum [6]. Whenever the direct/indirect sign of the rhinoceros was identified, a circular plot of a 5 m radius was established [45, 46] with the observation point as the center. For each of those circular plots established, one additional circular plot of the same size was established 150 m away in a randomly selected direction from the center of the former circular plot, following the previous research suggestions from [42, 47]. In all plots of both types, we measured 10 habitat characteristics that included canopy cover, ground cover, habitat type, presence or absence of invasive species, grass species, and tree species, height of grass species, nearest distance to road (state roads/path or forest firelines), settlements, and water source [48] (Table 1). Further, we used ArcGIS 10.8.1 [49] to create a distribution map by recording GPS coordinates of all rhinoceros individuals spotted (direct sightings) and indirect signs. The canopy cover was measured using a spherical crown densiometer. Ground cover, habitat type, and presence or absence of invasive species, grass species, and tree species were determined based on visual observations by the team members possessing similar field experiences in the past [36]. Similarly, the height of grass species was measured with a linear tape. Furthermore, the road/path/firelines and settlement shapefiles were extracted from an Open Street Map [50]. Moreover, the shapefiles of the water source were extracted using Digital Elevation Model (DEM)of 12.5 m resolution [51] and Landsat 8 image [52]. Finally, the nearest distance to roads, settlements, and water sources from the species location was calculated through the nearest analysis tool in ArcGIS 10.8.1 [49].

We utilized three approaches to assess the conservation threats to rhinoceros: direct field visit, systematic literature review [13, 19, 24, 27, 40, 53–55], and Focus Group Discussion (FGD). The methodology has been used in previous studies for various other threatened species such as *Bubalus arnee* [41], *Catreus wallichii* [56], and *Caprolagus hispidus* [32]. During the direct field visit, we identified and listed possible conservation threats for rhinoceros population in the national park. Additionally, the lead author conducted a systematic literature review of research about conservation threats to rhinoceros throughout national parks of Nepal, utilizing a methodology similar to that employed in [57, 58]. The first FGD comprised five participants, including the representatives from the national park ($n = 2$), buffer zone management committee ($n = 1$), nature guide association ($n = 1$), and local biologists ($n = 1$). The FGD participants were selected based on their extensive experience with rhinoceros in the region. The primary objective of the first phase of FGD was to identify and list the major conservation threats to rhinoceros in ShNP, utilizing the participants' field-based knowledge and experience. By utilizing this approach, a comprehensive list of eleven major conservation threats was identified and recorded (as shown in Figure 2).

During the second phase of the FGD involving the same group as the first one, these threats were then ranked using the relative threat ranking method, which has been previously employed in studies conducted in [41, 56, 59]. In the next step, we distributed a printed list of the eleven major conservation threats identified during the first phase of the FGD to each of the five participants and requested them to rate the severity of each threat in terms of its impact on the survival of rhinoceros in ShNP on a scale of 1 to 10. Subsequently, we calculated the mean score for each threat by averaging the individual scores provided by all the participants [32]. Out of eleven threats identified, eight threats (top rated) including small population size; invasive species; livestock pressure; habitat loss, fragmentation, and degradation; wildlife disease and parasites; climate change and natural disaster; competition with other herbivores; and human-rhinoceros conflict were selected for further relative threat ranking considering the criterion in [59].

2.3. Data Analysis

2.3.1. Factors Influencing Habitat Selection by *Rhinoceros unicornis*.

Binary logistic regression (with logit link function) was used to investigate the variables affecting the occurrence of rhinoceros at the selected location. We used rhinoceros's presence or absence (1 = presence and 0 = absence) at the observed location as the dependent variable. We selected 10 predetermined predictor variables (see Table 1) as independent variables. Prior to performing the regression analysis, the variance inflation factor (VIF) in the R package "Faraway" [60] was used to examine the multicollinearity issue in R × 64 4.0.3 [61]. All independent variables had VIF values less than 10, indicating that there was no multicollinearity [62]. Afterward, we conducted a full model logistic regression analysis using the logit link function under the binomial family, which included all of the independent variables. Using the "MuMIn" R package [63], we constructed models with all conceivable subsets of possible predictors. All the models were constructed and ranked using the Akaike information criterion (AIC), adjusted for small

Table 1: Habitat features associated with rhinoceros sign detections, including the number and percentage of signs recorded for each category.

Habitat features	Number of signs	Percentage
Habitat types (HT)		
Grassland (GL)	80	**47.34**
Mixed forest (MF)	14	8.28
Riverine forest (RF)	25	14.79
S. robusta forest (SF)	20	11.83
Wetland (WL)	30	17.75
Canopy cover (CC)		
0%–25%	74	**43.79**
26%–50%	34	20.12
51%–75%	21	12.43
76%–100%	40	23.69
Ground cover (GC)		
0%–25%	56	33.14
26%–50%	29	17.16
51%–75%	20	11.83
76%–100%	64	**37.87**
Distance to water sources (m) (WD)		
0–200	152	**89.94**
201–400	9	5.33
401–600	8	4.73
Distance to settlement (m) (SD)		
0–2000	6	3.55
2001–4000	7	4.14
4001–6000	28	16.57
6001–8000	55	32.54
8001–10000	73	**43.19**
Distance to road (state roads/path or forest firelines) (m) (RD)		
0–2000	134	**79.29**
2001–4000	12	7.10
4001–6000	1	0.59
6001–8000	15	8.88
8001–10000	7	4.14
Presence or absence of invasive species (P.A inv)		
Yes	64	37.87
No	105	**62.13**
Presence or absence of grass species (P.A. gra)		
Yes	108	**63.91**
No	61	36.09
Presence or absence of tree species (P.A. tree)		
Yes	113	**66.86**
No	56	33.14
Height of grass species (cm) (Ht. gra)		
0–200	104	**61.54**
201–400	14	8.28
401–600	50	29.59
601–800	1	0.59

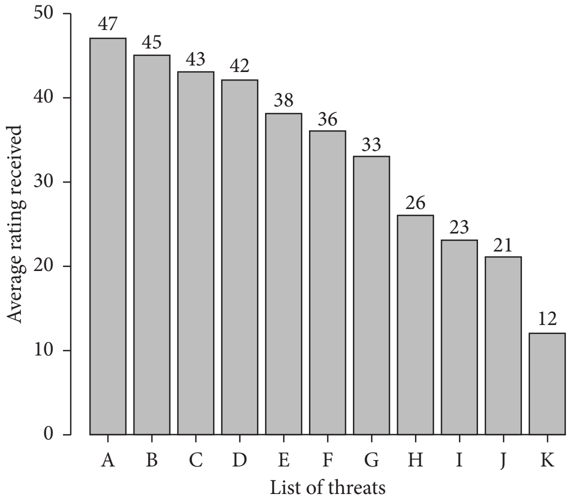
Note: The bold numerical values represent the highest percentage of signs detected.

sample sizes using AICc, as suggested in [63]. The AIC methodology selects the best model by prioritizing simplicity while balancing data fit and penalizing overfitting. To achieve this, three components are calculated: AIC, adjusted AIC (AICc), and delta AIC (ΔAIC) using equations (1)–(3). The model with the least value of AIC, AICc, or ΔAIC is regarded as the best-fit model for the data.

$$\mathrm{AIC} = 2\mathrm{K} - 2\log(\mathrm{L}), \tag{1}$$

$$\mathrm{AICc} = \mathrm{AIC} + \frac{2K(K+1)}{n-K-1}, \tag{2}$$

$$\Delta\mathrm{AIC} = \mathrm{AICc}(i) - \mathrm{AICc}(\mathrm{m}), \tag{3}$$



A: small population size
B: invasive species
C: livestock pressure
D: habitat loss, fragmentation, and degradation
E: wildlife disease and parasites
F: climate change and natural disaster
G: competition with other herbivores
H: human rhinoceros conflict
I: forest fire
J: accidents
K: poaching and illegal trade

FIGURE 2: Figure showing the average rating received by each threat category. The top eight threats were selected for the final threat ranking, considering the criterion of WWF [59].

where K is the number of independent variables used, L represents the maximized values of the likelihood function, n is the sample size, AICc(i) is the individual AICc score of each model, and AICc(m) is the minimum AICc score of the model being tested.

The leading candidate models were averaged (models with $\Delta AIC \leq 2$) [64] to generate model-averaged coefficients (Estimate, Std. Error, z value, and $(\Pr(>|z|))$) for each independent variable using the package "AICmodavg" [65]. Among them, the Estimate represents the effect size and direction of the relationship between each independent variable and rhinoceros presence. A positive Estimate indicates a positive association, suggesting that an increase in the variable is linked to a higher likelihood of rhinoceros detection. Conversely, a negative Estimate implies a negative association, indicating that an increase in the variable reduces the probability of rhinoceros detection. The statistical significance of each variable was assessed using the p value $(\Pr(>|z|))$. A p value less than 0.05 was considered statistically significant, suggesting that the observed relationship is unlikely to have occurred by chance.

Finally, the predictive ability of best-fit model was quantified based on the area under curve (AUC) of the Receiver Operator Characteristics (value range 1 to 0) by using the R package "ROCR" [66]. The values between 0.7–0.8 were considered acceptable discrimination, 0.8–0.9 as excellent, and more than 0.9 as superior [67]. $p(\Pr(>|z|))$.

2.3.2. Threat Assessment Analysis. A relative whole-site threat ranking method [59] was used to rank the existing conservation threats that were listed from FGD, literature review, and field observations. This threat ranking approach uses four criteria for threat classification: scope, severity, urgency, and irreversibility [41, 56, 68] (see Table 2). For each of the threat classification, threat ranking (1–8) was done for each selected eight threat in the FGD. The largest ranking value (8) implies threats with the highest effect, and the lowest ranking value (1) implies threats with minor consequences for all four criteria. Later, the ranking values of scope, severity, urgency, and irreversibility criteria were summed up for each threat to classify threats into four categories: very high (24.1 $-\leq 32$), high (16.1 $-\leq 24$), medium (8.1 $-\leq 16$), and low (≤ 8) [69]. The overall conceptual framework for the data collection and analysis process is given in Figure 3.

3. Results

3.1. Distribution of Rhinoceros unicornis in ShNP. Rhinoceros in ShNP were primarily found in the western region, which includes areas such as the Mahakali River, Pipariya, Barkaula, Shuklaphanta, Singhpur, Radhapur, Mangalsera, and the western side of the Chaudhar River. Additionally, areas such as Beldadi and Tarapur also held a significant population in the eastern sector of the ShNP (Figure 4). An average of 2.82 signs of rhinoceros per kilometer was recorded in the study area. The highest rate of encounters was found to be dung at a rate of 1.62 signs per kilometer, followed by footmarks at a rate of 1.18 signs per kilometer (Table 3).

3.2. Factors Associated With the Occurrence of Rhinoceros. Through model averaging (models with $\Delta AIC \leq 2$), three component models were generated. Among them, the model including canopy cover, habitat type, presence or absence of invasive species, nearest distance settlement, road, and water established a best fitting model with lowest AIC value of 114.08 and highest AIC weight of 0.50. The following competing component model included canopy cover, habitat type, presence or absence of grass species, presence of absence of invasive species, and nearest distance to settlement, road, and water with AIC value of 115.24 and AIC weight of 0.28 (see Table 4 for details).

Also, the area under the receiver operating curve (ROC) for the best-fit model was calculated to be 0.95 with an accuracy value of 0.91 (91%) (see Figure 5).

Model-averaged coefficients revealed that, out of the ten predefined variables, only canopy cover ([26-50%], [51-75%] and [76-100%]), grassland habitat, presence of invasive species, and proximity to roads and water sources significantly influenced rhinoceros occurrence in ShNP (see Table 5 for details). The results revealed that the probability of detecting rhinoceroses decreases with increased canopy cover, the presence of invasive species, and proximity to road. Similarly, the probability of detecting rhinoceros increases with grassland as habitat type and decreasing distance to the water source.

Table 2: Interpretations of criteria and associated rankings used to prioritize each threat, adapted from [59, 68].

Criteria and rankings	Definition
Scope	The geographical extent of the impact on the biological target can be fairly foreseen within 10 years under existing conditions.
Very high	The threat is expected to be pervasive in its scope, influencing the target over all or most (71%–100%) of its occurrence/population.
High	The threat is expected to be widespread in its scope, influencing the target over 31%–70% of its occurrence/population.
Medium	The threat is expected to be restricted in its scope, influencing the target over 11%–30% of its occurrence/population.
Low	The threat is expected to be very narrow in its scope, influencing the target over a lesser part (1%–10%) of its occurrence/population.
Severity	The degree of damage to a biological target that may be realistically predicted within 50 years under existing conditions.
Very high	The threat is expected to eliminate or degrade the target or minimize its population by 71%–100% within 10 years or three generations within the scope.
High	The threat is expected to seriously degrade the target or minimize its population by 31%–70% within 10 years or three generations within the scope.
Medium	The threat is expected to moderately degrade the target or minimize its population by 11%–30% within 10 years or three generations within the scope.
Low	The threat is expected to slightly degrade the target or minimize its population by 1%–10% within 10 years or three generations within the scope.
Urgency	This attribute measures the certainty and time frame over which the threat's effects will be seen.
Very high	The threat's impacts are already noticeable, and action to cope with the issue within a year is urgent.
High	The threat's impacts are likely to emerge, and the issue is predicted to occur during the upcoming 1–10 years.
Medium	The threat's impacts are likely to emerge, and the issue is predicted to emerge within the upcoming 10–25 years.
Low	The impacts of the threat are unlikely to occur, and the issue is predicted in about 25 years from now.
Irreversibility	The extent to which the impacts of a stressor can be reversed.
Very high	The threat's impact cannot be reverted, and it is doubtful that the target can be recovered, and/or it would take 100 years to attain this.
High	The threat's impact can technically be reverted, and the target is likely to be recovered, but it is not feasible practically and/or it may take a long period (21–100 years) to achieve this.
Medium	The threat's impact can be reverted, and the target is likely to be recovered with a sensible commitment of resources and/or within 6–20 years.
Low	The threat's impact is quickly reversible and the target may be easily recovered at a reasonable cost and/or within 0–5 years.

3.3. Conservation Threats Associated With Rhinoceros. Among the eight identified threats to rhinoceros, habitat loss, fragmentation and land degradation, and small population size were ranked as the most severe threats in the study area. Similarly, livestock pressure and the presence of invasive species were ranked as high threats (Table 6).

4. Discussion

Rhinoceros studies are often restricted to their natural habitats, with limited knowledge about translocated populations. To address this gap, we used a binary regression modeling technique to investigate the habitat use and threats to a small, translocated rhinoceros population in ShNP. The findings of our result are discussed in the following subtopic.

4.1. Distribution and Habitat Use by Translocated Rhinoceros Population. The rhinoceros population in ShNP was established by translocating nine individuals from CNP (4 in 2003 and 5 in 2017) to create an additional viable population [22]. As of the 2021 survey, this effort has resulted in 17 rhinoceros [21]. In this study, we found most of the signs of the rhinoceros were distributed in the western sector and then in the eastern sector of ShNP. The better availability of foraging locations and the higher number of water holes in the western sector for wallowing could be a possible reason. The result of our binary logistic regression model shows that the introduced rhinoceros population prefers grassland habitat to other habitat types, such as different forest types and wetlands in the ShNP. Similar results were found in CNP, where rhinoceros preferred tall and short grasslands [70]. Grassland preference is the probability due to the abundance of high-

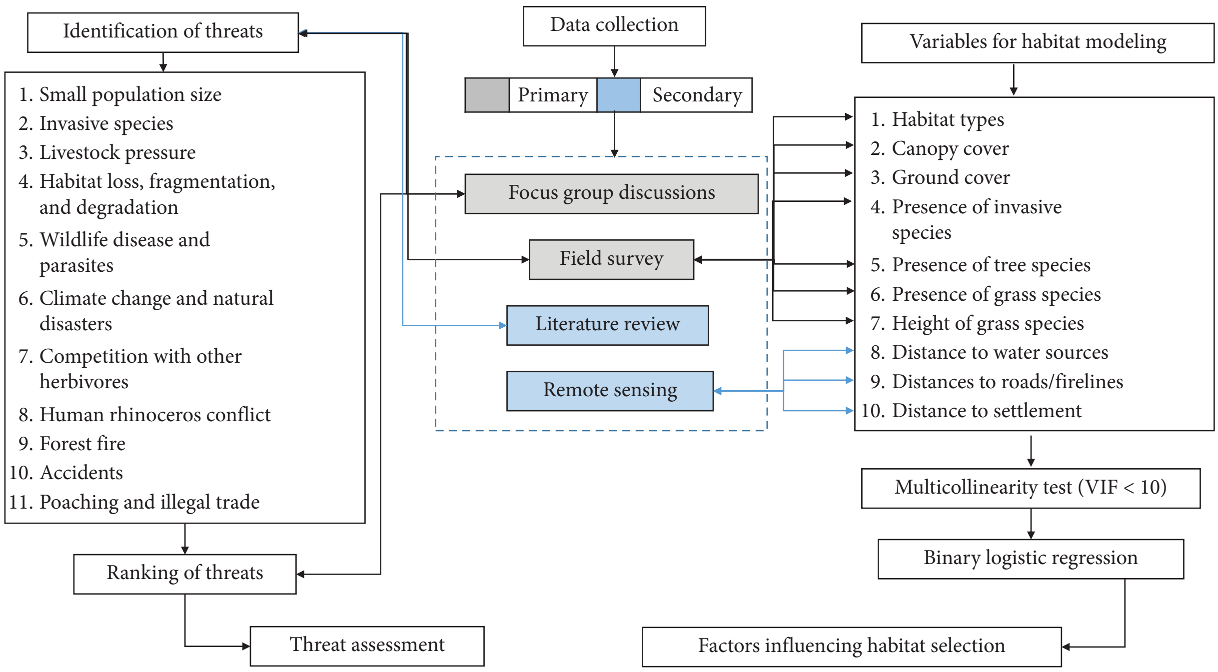


FIGURE 3: Conceptual framework for data collection and analysis in the study.

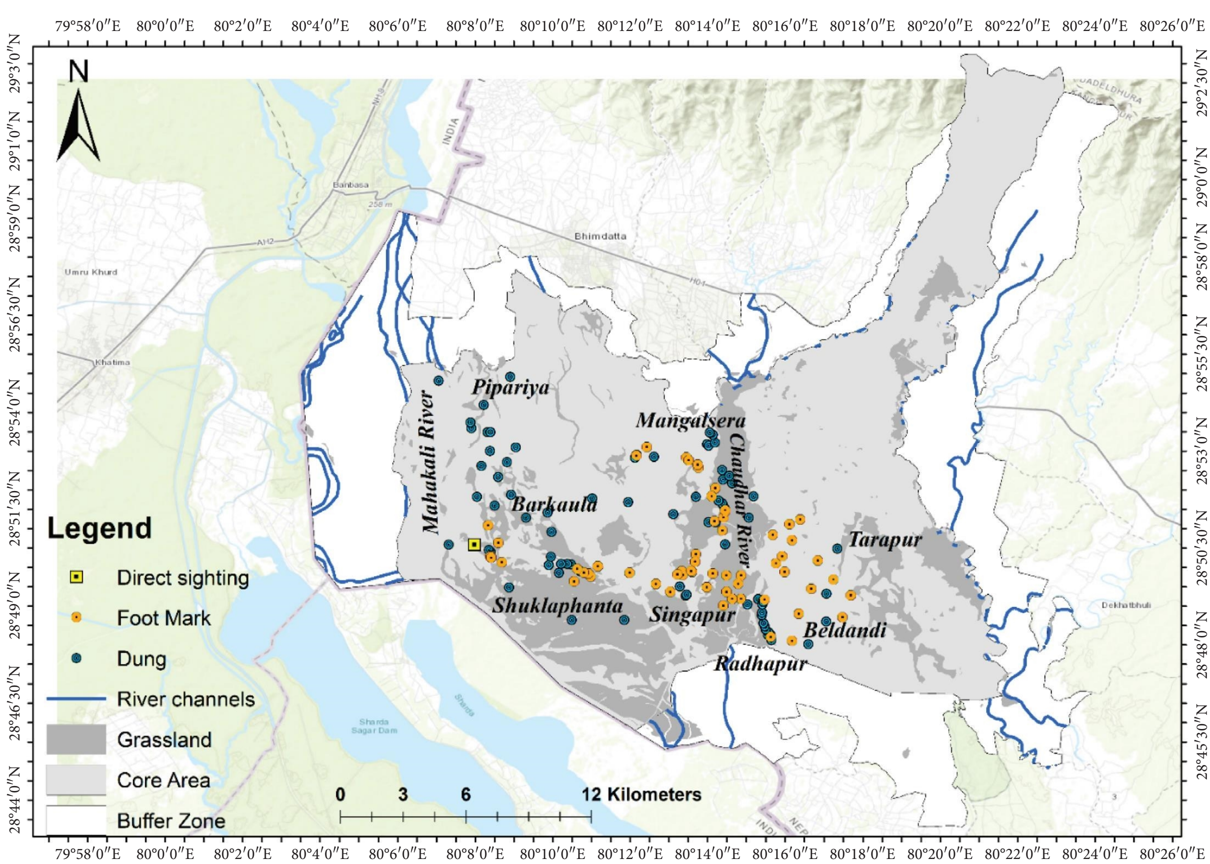


FIGURE 4: Distribution map of rhinoceros in ShNP, where the direct and indirect signs observed during the field survey are denoted with different symbols.

Table 3: Encounter rate of different sign types of rhinoceros in the study area.

Observed sign	No. of sign	Percent (%)	No. of transect surveyed	Encounter rate (no. of signs/length of transect in km)
Direct sight	1	0.59	15	0.017
Dung	97	57.39	15	1.62
Footmarks	71	42.01	15	1.18
Total	169	100	15	2.82

Note: The total length of the transect is 60 km (number of transects surveyed × each of 4 km in length).

Table 4: Component models describing the variables influencing the occurrence of rhinoceros in ShNP.

Component models	df	Loglik	AICc	ΔAIC	Weight
Detection ~ (CC + HT + P.A. inv + SD + RD + WD)	12	−44.24	114.08	0.0	0.50
Detection ~ (CC + HT + P.A. gra + P.A. inv + SD + RD + WD)	13	−43.68	115.24	1.16	0.28
Detection ~ (CC + HT + Ht. gra + P.A. inv + SD + RD + WD)	13	−43.96	115.80	1.72	0.21

Note: Refer to Table 1 for the full abbreviation.

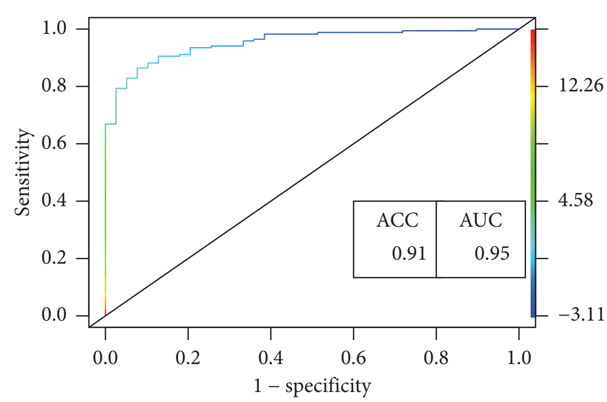


Figure 5: Receiver operating curve for best fitting modeling under binary logistic regression.

Table 5: Model averaged coefficients describing the occurrence of rhinoceros in ShNP.

S.n	Predictors	Estimate (β)	Standard error (S.E)	Z value	Pr (> |z|)
1	Intercept	14.2010812	3.5469331	4.004	6.23e-05***
2	Factor [CC (26–50)]	−3.9237458	1.1990138	3.272	0.00107**
	Factor [CC (51–75)]	−4.6805777	1.3468275	3.475	0.00051***
	Factor [CC (76–100)]	−4.0254577	1.3213029	3.047	0.00231**
3	Factor [HT (grassland)]	2.9394350	0.9733354	3.020	0.00253**
	Factor [HT (wetland)]	1.9972484	1.0987462	1.818	0.06910
	Factor [HT (*S. robusta* forest)]	0.0809052	0.9605596	0.084	0.93288
	Factor [HT (Riverine)]	−0.2060023	0.7391267	0.279	0.78047
4	Factor [(P.A. inv) 1]	−2.9321736	1.1449697	2.561	0.01044*
5	SD	0.0007561	0.0005106	1.481	0.13867
6	RD	0.0122347	0.0054978	2.225	0.02605*
7	WD	−0.0011810	0.0003825	3.088	0.00202**
8	Factor [(P.A. gra) 1]	0.2086458	0.5037784	0.414	0.67876
9	Ht. gra	0.0002658	0.0009294	0.286	0.77489

Note: Variables that significantly influence the occurrence of rhinoceros are indicated with an asterisk (∗). Significance levels are represented as follows: "∗∗∗" for p values ≤ 0.001, "∗∗" for p values ≤ 0.01, and "∗" for p values ≤ 0.05.

Table 6: Relative ranking of the most severe threats recorded from the study area.

S.n.	Threats	Scope	Severity	Urgency	Irreversibility	Total	Threat classification
1	Habitat loss, fragmentation, and degradation	8	7	7	8	30	Very high
2	Small population size	7	8	8	7	30	Very high
3	Climate change and natural disaster	3	3	4	6	16	Medium
4	Wildlife disease and parasites	4	4	3	3	14	Medium
5	Livestock pressure	5	6	6	4	21	High
6	Invasive species	6	5	5	5	21	High
7	Competition with other herbivores	2	2	2	2	8	Low
8	Human rhinoceros conflict	1	1	1	1	4	Low
	Total	36	36	36	36	144	

quality forage for rhinoceros in long and short grasslands due to habitat management interventions, including controlled burning. Rhinoceros habitats typically include early successional riverine grassland habitats dominated by *Saccharum spontaneum* that are intermixed with mosaics of riverine forests [14, 69, 72]. However, our study found no significant preference for forest habitats. This likely reflects seasonal habitat selection, as rhinoceros favor grasslands during the summer and monsoon, consistent with our data collection period. In contrast, rhinoceros prefer riverine forests over grassland during the cool dry season (winter season) due to (i) the higher availability of browse in riverine forests as grass becomes dry in grassland and (ii) the use of riverine forests as a refuge from cold blowing winds and fog [70, 72]. Similarly, we found a negative relationship between rhinoceros occurrence and canopy cover. This is probably due to the extensive use of grasslands by rhinoceros while avoiding the dense sal and mixed forests by rhinoceros [73]. In line with our results, less preference for dense sal forest by rhinoceros was also observed in CNP [70].

Large mammal's behavior patterns and individual performance may be altered as a result of disturbances [74–76] via limiting movement [77], lowering prospects for mating [78, 79], altering foraging trajectories [79], or boosting perceived predation risk [75]. There are records of both temporal and spatial shifts, for instance, large mammals avoiding roadways [80] or wildlife being proactive in the absence of humans [81]. Our results showed a positive association between the presence of rhinoceros and distance from the road. This implies that the rhinoceros preferred sites with less disturbance, and tourism activity, such as jungle safari, might have impacted the range and habitat use. Similar results were put forward by Buk and Knight [82] where they reported apparent avoidance of road by black rhinoceros in Augrabies Falls National Park, South Africa. Moreover, the exposure of the rhinoceros population to roads may threaten them to a larger extent. Subedi and Subedi [83] reported that the high risk zones for *R. unicornis* poaching are near roads in CNP, Nepal. Therefore, the planning and construction of firelines/fire breaks or roads in the rhinoceros habitat should be carefully considered to ensure sufficient suitable habitat is away from such disturbance.

Another disturbance impacting rhinoceros habitat was the presence of invasive species. Our study found a significant negative relationship between invasive species and rhinoceros presence. In line with our results, the habitat of rhinoceros is highly impacted by invasive species, among other disturbance factors in the central lowland (Chitwan-Parsa) region of Nepal [84]. Invasive species have highly invaded the grassland habitat on which rhinoceros depend [9]. Heavy invasion of exotic plant species such as *M. micrantha* leads to the decline of rhinoceros and other large herbivore populations by destroying critical habitats, posing a significant threat to several threatened species [15]. Due to their immense negative impact, timely and effective management of invasive species is crucial to protecting the already limited rhinoceros habitat in Nepal.

Our study found a significant positive relationship between rhinoceros occurrence and distance to water sources, indicating a strong preference for staying near water. Additionally, the majority of the rhinoceros were recorded in the vicinity of 0–200 m. This preference might be due to their dependence on water for wallowing to regulate body temperature, avoid ectoparasites, and consume aquatic plants during the dry season [14, 85]. Rhinoceroses also consume large amounts of water, drinking up to 72 L when thirsty, typically at night [86, 87]. This further necessitates their preference for staying near water sources. A study by Subedi [70] mentioned that more than 90% of the locations of radio-collared rhinos were within 1.8 km of a water source, which is concurrent with our study.

4.2. Threat for Translocated Population of Rhinoceros in ShNP.

Based on our threat ranking, habitat loss, fragmentation, degradation, and small population size were ranked as very high threats. Meanwhile, invasive species and livestock pressure were classified as high-risk threats, as detailed in the following subsection.

4.2.1. Habitat Destruction and Small Population Size as Major Threat for Rhinoceros in ShNP.

In the threat assessment of rhinoceros, local stakeholders considered habitat loss, degradation, and fragmentation along with small population size as the greatest threat to the survival of the introduced rhinoceros population in ShNP. In the case of habitat, this species requires floodplain grassland of the early successional stage to survive, which is maintained by meandering of the flood [14]. Due to natural succession, such grassland gets converted to woodlands [40, 70].

Obstruction to movement dynamics of flood can result in discontinuity in the formation of areas suitable for the growth of early successional grasslands dominated by *S. spontaneum*. Furthermore, certain forested areas in the buffer zones and corridors of ShNP are experiencing significant encroachment, such as the Mohana-Laljhadi corridor in the Western Terai Arc Landscape [88]. Linear infrastructure development projects, such as the Mahakali Irrigation Project's 3rd Phase, the widening of the postal highway, a proposed railway along the southern part of the Mahendra Highway, and the expansion of the Mahendra Highway from two lanes to six lanes, are causing fragmentation of the habitat of rhinoceros by traversing through it [88]. The dykes and embankments constructed in the Mahakali River control flood dynamics required for the formation of floodplain grasslands and obstruct the movement of rhinoceros [88]. Our results from the regression model also confirm the threat of such constructions and human disturbances through roads as we found a positive relation of rhinoceros occurrence with increasing distance from the road. Similarly, our results showed that the small population size of rhinoceros in ShNP is another severe threat classified as a very high threat. In line to our findings, the study by Jhala et al. [7] states rhinoceros populations under 50 have a higher risk of extinction when managed as a metapopulation. Small communities are often considered to be at risk of extinction due to inbreeding [41]. Possibly, the rhinoceros population in ShNP might have faced reduced genetic diversity due to the small population size: 17 individuals [21]. However, this hypothesis still needs validation through scientific research. A study carried out by Pathak et al. [89] in CNP also found a reduced genetic diversity among the population of rhinoceros, although the population size is larger in comparison to ShNP. Thus, to maintain higher genetic diversity, it is essential to link the population of ShNP with the population of BNP and even the Indian population through corridor and connectivity formation and also encourage further translocation programs in ShNP to enhance genetic diversity.

4.2.2. Threat of Invasive Species and Livestock Pressure. As per the threat classification, invasion of exotic plant species like *Parthenium hysterophorus* and *Lantana camara* in grasslands and forests of ShNP was another factor contributing to habitat degradation [40]. Invasive plant species alter the habitat by changing species composition and replacing native plant species, which seriously impacts ecosystem functioning and the ecosystem [70, 90]. Our assessment ranked invasive species as a high-risk threat, and output from the regression analysis also showed a negative relationship between invasive species and rhinoceros presence in ShNP, confirming the threat to their habitat. Furthermore, livestock pressure was another high-ranked threat for the translocated rhinoceros population. Although livestock grazing activities are forbidden in national parks, unregulated grazing is prevalent in most of the protected areas of Nepal [41]. Livestock grazing has increased in ShNP, which has led to competition for forage among the several herbivore populations [33]. It has also affected the habitat quality of grassland-dependent herbivores, including rhinoceros [33]. Further, livestock are also considered as the prime source of disease and parasite transfer among wild fauna [91].

5. Conclusion

This study identifies important factors affecting the habitat use and conservation challenges of translocated *Rhinoceros unicornis* in the ShNP. Our results show rhinoceroses were more likely to be found in grasslands with low canopy cover and in the proximity of water source, while their presence decreased in areas with invasive species and close to roads. Similarly, our study ranked habitat loss, fragmentation and land degradation, and small population size as the severe threats to rhinoceros. To address these issues, we recommend restoring degraded grasslands through controlled burning and grazing management, removing invasive plant species, and reducing human disturbances. Strengthening population monitoring, improving translocation programs with post-release monitoring, and enhancing habitat connectivity are also essential for long-term conservation. Since the study was limited to a single season, we recommend a similar study considering multiple seasons and assessing possible corridors and connectivity to link the local population with the Indian population to maintain genetic diversity.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest.

Author Contributions

Rashmi Bhatt: conceptualization—lead, data curation—equal, methodology—equal, formal analysis—equal, project administration—lead, and writing review and editing—equal. **Khagendra Prasad Joshi:** manuscript drafting—equal, formal analysis—equal, and writing review and editing—equal. **Jhamak Bahadur Karki:** manuscript drafting—equal and writing review and editing—equal. **Keshav Ayer:** manuscript drafting—equal and writing review and editing—equal. **Arjun Bhusal:** manuscript drafting—equal and writing review and editing—equal. **Mahamad Sayab Miya:** manuscript drafting—equal and writing review and editing—equal. **Ganesh Pant:** writing review and editing—equal. **Roshan Singh Thagunna:** manuscript drafting—equal and writing review and editing—equal. **Laxmi Raj Joshi:** manuscript drafting—equal and writing review and editing—equal. **Bijaya Dhami:** conceptualization—equal, data curation—equal, methodology—equal, formal analysis—lead, manuscript drafting—equal, and writing review and editing—equal.

Funding

This work was supported by Bhimdutta Municipality, Mahendranagar, Kanchanpur, Nepal, and the Ministry of Industry, Tourism, Forest and Environment, Sudurpaschim Province.

Acknowledgments

We are grateful to the National Trust for Nature Conservation, the Department of National Parks and Wildlife Conservation, and ShNP for providing permission and technical support for the study. Special thanks go to Mr. Kishore Kumar Meheta (Chief Conservation Officer, ShNP), Mr. Suman Malla (research assistant), and Mr. Kum Thakur (nature guide) for their support during field days in Kanchanpur.

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