CHAPTER 5

Home range, ranging pattern and habitat preference of greater one-horned rhinoceros in Chitwan National Park, Nepal

Photo: A snap of rhino capture for radio-collaring.

Introduction

Mega-herbivores like Rhinos and elephants serve as umbrella species in the ecosystem they operate. In general, they need a larger space and ample resources to maintain their daily needs compared to small herbivores (Owen-Smith 1988). More importantly, large herbivores are ecosystem drivers as they have a major impact on the physical structure of habitats, rates of ecosystem processes and the diversity of communities (Gordon *et al.* 2004, Sinclair 2003). It is in this context that their space use and intensity are important aspects to study. The area traversed during routine activities is generally termed as home range (Jewell 1966). The most cited definition of home range of an animal is that of Burt (1943): 'that area traversed by the individual in its normal activities of food gathering, mating and caring for young. Occasional excursion outside the area, perhaps exploratory in nature, should not be considered as in part of the home range.' Studies on African and Asian rhinos have revealed that the size of their home range is determined by combination of multiple factors including size of the protected area, food supply, availability of water resources, seasonal changes in resources, and population density (Owen-Smith 1988, Dinerstein 2003, White *et al.* 2007). In case of large mammals, extensive areas are often needed to hold a viable population and this can be a limitation for conservation of these species. How animal use space has important consequences for feeding ecology, social organization, mating strategies and conservation management (White *et al.* 2007).

Rhinos in Nepal and elsewhere have got greater attention because of their charismatic nature, increased endangerment due to pressure from poaching, increased public awareness in conservation and contribution of rhinos to wildlife tourism. Therefore, it is imperative to understand how the rhinos are performing with respect to the massive habitat loss outside the protected areas, changing habitat structure due to plant succession and habitat degradation in some key protected areas by invasive alien plant species (DNPWC 2009). Although good scientific information regarding habitat and space use by the greater one-horned rhinoceros in Chitwan and Bardia are available (Dinerstein 2003, Jnawali 1995, Laurie 1978) recent scientific information in this regards is lacking. As a result, a long-term study was designed to understand the demography, feeding ecology and spacing behavior of rhinos in Chitwan with respect to changing habitat. In this chapter attempt has been made to explore and discuss on the following questions:

a) How big are the seasonal and annual home ranges of rhinos?

b) Do the home ranges vary with seasons?

c) Are the home range size and habitat use pattern same as previous studies in the present context of low population density and observed habitat quality degradation?

d) What are the available habitats for rhinos?

e) Is there a habitat choice in selecting i) home ranges within the landscape, ii) core areas within home ranges, and iii) foraging areas within home ranges?

This study is also intended to inform conservation management. The restriction of many species, particularly large mammals, almost exclusively to protected areas has been instrumental for their survival (White *et al.* 2007). Knowledge of seasonal home range size, ranging patterns and other aspects of spatial ecology are crucial for effective protected area design and reintroductions, for example, to estimate the needed area to contain a target number of individuals or home ranges. Knowledge of home range ecology figures prominently in the conservation of many species (e.g. Price *et al.* 1994, Wong *et al.* 2004).

Field Methods

Rhino capture

Radiotelemetry has been used to study greater one-horned rhinoceros in Nepal for over 25 years. This technology has provided significant insight into the life-history strategies of these rhinos (Dinerstein 2003). Six adult females and two adult males were immobilized between 2010 and 2011 in Chitwan National Park and fixed with GPS radiocollars. Fifteen captive elephants were used to circle the rhino and to prevent any fatalities. Firstly, the capture team can be attacked by rhinos, bear or tiger in the tall grassland and secondly, to avoid drowning of darted rhinos in the water bodies. The elephants are very useful to keep the rhinos in desired grassland within a circle. The rhinos were darted by a dart gun (Harrington and Richardson.Inc, Georgia, USA) from the elephant back within a distance of 25 m powered by medium-speed charges. I used 2-3 mg etorphine hydrochloride (M99) mixed with 10-20 mg acepromazine to immobilize the rhinos. It took 10-18 minutes to get rhinos sedated after the drug administration. Antidote Diprenorphine (M50-50) 6-12 mg was given intravenously in an ear vein for total reversal of the effect of etorphine hydrochloride. The animals recovered within 3 – 5 minutes after the antagonist was administered. The capture operation was completed within 30 - 45 minutes to minimize the stress to animals. Detailed protocol for rhino capture and chemical immobilization is available in Dinertsien *et al.* (1990).

GPS radiocollars

This was the first time GPS telemetry used on greater one-horned rhinoceros. I used VECTRONIC Aerospace GmbH GPS collars (Berlin, Germany) for 6 animals and Afro Track GPS radiocollars (Africa Wildlife Tracking, Inc, Pretoria, South Africa) for 2 animals. The collars consisted of a GPS device, an internal antenna, a transmitter, and a battery. The GPS unit inbuilt in the collar records GPS locations at the desired time interval as programmed by the researchers. The GPS schedule could be remotely changed via a UHF signal link. The GPS locations are saved in the collar and can be downloaded with the help of UHF transmission to a hand held receiver. Each GPS collar contained a conventional Very High Frequency (VHF) transmitter that was used to track the rhinos from elephant back with the aid of 3 elements Yagi antenna and a receiver. The radio frequency of the collars was between 150 – 151 MHZ. The average weight of the GPS collars was 1.6 ± 0.32 kg including belting. Figure 5.1 gives a glimpse of rhino capture, GPS data downloading, and landscape of study area.

Figure 5.1. a) A snap of capturing and radio-collaring of rhino; b) researcher, on the elephant back, downloading GPS locations from the GPS collars that have been fitted to the rhinos; c) Rapti river and floodplain tall grasslands dominated by *Saccharum spontaneum* (white flowering) of Chitwan during monsoon season. It is the principal habitat of rhinos in Chitwan.

Regular monitoring of radio collared animals

The GPS collars were programmed to record position at every 5 to 6 hours interval. The animals were tracked by the VFH, hand held Yagi antenna and a receiver from the elephant back. Once the rhino was detected data could be downloaded at anytime. I downloaded GPS data from the collars every week. The downloaded data was then stored in a computer at the field research centre. The performance of GPS collars varied from 1 to 25 months. The Afro Trek collars failed within a month. The VECTRONIC collars varied in their performance. The first batch of VECTRONIC collars lasted for 6 months. After incorporating modifications the second batch of the VECTRONIC collars performed well and continued to provide GPS fixes even after two years. Amongst collars that failed the VHF transmission continued to work thereby allowing me to track these rhinos via traditional radiotelemetry using a 3 elements Yagi antenna and a radio receiver. For the working collars (n =6) I remotely reprogrammed the collars to record a GPS coordinate every 30 minutes for 5 continuous days in each season so as to enable me to plot the movement paths of each rhinos accurately for habitat use analysis.

Continuous monitoring

In addition to the data from the GPS radiocollars all individual rhinos were continuously monitored for 24 hours from the elephant back for minimum of 3 days in each season. For detail of the methodology please see Chapter 3 and 4. Rhino locations for every half-hour interval were recorded that allowed me to plot the foraging and movement path of rhinos for habitat use analysis even for those rhinos that did not have a functional GPS radiocollars.

Home range estimation

All the data downloaded from the GPS collars and manually obtained through VHF tracking system were arranged in excel spreadsheets. I used 4 locations in a day (24 h) from the dataset directly downloaded from the GPS collars and one to two locations in a day for dataset that were obtained from the manual VHF tracking for home range computation to ensure that location data were not auto-correlated. I used ArcGIS 9.3 version with Hawth tool extension (Environmental Systems Research Institute, Redlands, CA, USA) to calculate home ranges. Two non parametric methods, the minimum convex polygon (MCP) (Mohr 1947) and the fixed Kernel (Worton 1989) were used to estimate the seasonal and annual home range sizes. I computed 95% MCP and 95% fixed kernel that removes the effects of exploratory movements and outlier fixes (Kernohan *et al.* 2001, White and Garrot 1990) and provides opportunity to compare with previous studies. Kernel method is popular even with the large dataset collected through satellite collars for home range estimate because of its ease to use (Kie *et al.* 2010). Smoothing factor (band width) 0.6 was selected by visualizing the best proportion fit from 0.2 to 1 in the fixed kernel density estimate. I calculated 99, 95, 90, 85, 80, 75, 70, 65, 60, 55, 50, 45, 40, 35, 30 and 25 percentages fixed Kernel home ranges for each rhino and average value for each contour was obtained. The average area for each contour was plotted against percentage kernel to determine the point of inflection of the curve. This inflection point defines the core area of the home range (Powell 2000, Wal and Rodgers 2012). Adequacy of location samples required to estimate home ranges for each rhino was examined using area accumulation plot. The fixes were randomized and added 10 locations at every increment (Harris *et al.* 1990, Kernohan *et al.* 2001) for home range estimates using HRT tools in ArcGIS 9.3. Home ranges (95% MCP) were plotted against number of fixes used to determine if the home range reached asymptote. Data were tested for normality and subsequently one-way ANOVA was used to check for variation in seasonal home ranges (Zar 2010).

Movement rate

Seasonal daily movement rates of rhinos were calculated from the GPS collar data or VHF telemetry data recorded during continuous monitoring at every half hour interval for 3 to 5 days in a season from all individual rhinos. Daily tracks were generated in ArcGIS 9.3 and average distance moved every hour was calculated. Two-way ANOVA was used to check whether there were differences on movement between sex, seasons and day or night (Zar 2010).

Habitat map preparation and habitat classification

I used 5m resolution satellite images (http://www.rapideye.com/products/ortho.htm, RapidEye, Germany, March, 2011) for habitat map preparation. For ground truthing 135 random ground control points (GCPs) were assessed for each vegetation community. These GCPs were used to identify the signature of particular habitat and vegetation community for unsupervised classification followed by supervised classification (Lillesand *et al.* 2004). Six different habitat types were classified based on these signatures. The main features of the habitat types are described below:

Riverine forest

The dominant trees in the riverine forests are *Trewia nudiflora* and *Bombax ceiba* contributing over 60% of all individual trees. It is very mixed in composition. Other associated species are

Myrsine chisia, Murraya Koenigii, Litsea monopetala, Ehretia laevis, Ficus racemosa, *Syzigium cumini, Syzigium operculata, Albizzia lucida* and *Dalbergia sissoo*. The understory layer is dominated by *Coffea bengalensis, Callicarpa macrophylla, Colebrokia oppositifolia* and various types of grasses and forbs. Riverine forests cover the moist part of the study area and it rarely gets burnt by the annual fire.

Sal forest

Shorea robusta (Sal) is the dominant tree species and forms the upper canopy. Other species associated species of the Sal forest are *Terminalia tomentosa*, *Terminalia chebula, Terminalia belerica, Lagerstromia parviflora, Dillenia pentagyna, Buchanania latifolia* and *Adina cordifolia*. Seedlings of different tree species and grasses form the ground layer in Sal forest. More than 85% of the Sal forest gets burnt annually as it covers the drier part of the park.

Tall grassland

Tall grasslands are formed along the river and stream beds and along the formerly cultivated lands or human settlements. About 75% of the tall grasslands in the study area are dominated by *Saccharum spontaneum*. Other associated species with the *Saccharum spontaneum* are *Sacchcharum bengalensis, Eragrostris tenella, Phragmites karka, Narenga porphyrocoma* and *Imperata cylindrica*. The remaining 25% of the tall grasslands are mixed type and dominated by *Sacchcharum bengalensis, Eragrostris tenella, Phragmites karka* and *Narenga porphyrocoma*. However, *Saccharum spontaneum* always remains associated with these species. In the drier bed of the riverine floodplain *Saccharum bengalessis* is dominant in small pockets. The moist waterlogged areas are dominated by *Phragmites karka*. Since these grasslands were quite small in size and were intermingled with each other in a fine scale we did not separate them as different habitat and classified as tall grasslands. About 75% of the tall grasslands are burnt annually.

Short grassland and meadows

Imperata cylindrica and *Saccharum spontaneum* form the dominant cover in this type of grasslands and height is less than one meter. *Cynodon dactylon*, C*hrysopogon aciculatus* are associated species. Short grasslands are formed as a result of human and cattle uses and repeated grazing by herbivores across all seasons. Short grasslands are intermingled with tall grasslands and riverine forests in the study area. Pure *Imperata cylindrica* dominated short grasslands now hardly exist in the study area as a result of plant succession after the removal of people and livestock in 1980s. Short grasslands are very important pockets for rhinos and other herbivores for grazing that are created by human actions (cultivation, grazing, fire) and are often maintained as grazing lawns by high intensity use by ungulates (Karki *et al.* 2000)

Wooded grassland

Short grasslands or tall grasslands in the riverine flood plain can turn into the pure forest patch within few years if some disturbances or management interventions are not done. Wooded grasslands refer to the areas where saplings of woody species like *Trewia nudiflora, Bombax ceiba,* and *Wendlandia exserta* have established in the grasslands and covered about 20% of the canopy. Major Grass species are *Saccharum spontaneum, Narenga porphyrocoma, Imperata cylindrica, Saccharum bengalensis,* and *Themeda* species.

Rivers and wetland

The areas covered by river and riverbed, and big water bodies are classified under this category. Rapti and Dhungre are the major rivers in the study area. Patna tal, Garud tal, Marchauli Ghol, Jayamangala Ghol and other small depressions form wetlands in the study area.

Habitat use and preference

Compositional analysis (Aebischer *et al.* 1993) was used to investigate habitat selection with a modification that assigns value based on the utilization distribution (Millspaugh *et al.* 2006). In this, habitat use by an individual animal is defined by the proportion of utilization distribution (UD) volume in each habitat type within its 95% kernel home range (Millspaugh *et al.* 2006). The primary output of fixed kernel was the UD which consist of pixels containing probabilities of space use across the home range. The UD of the entire kernel contour sums to one unit. Pixels with high probability values indicated locations where a rhino was most likely to occur and pixels with low probability values indicated locations less likely to be used by rhinos. This is new approach to investigate habitat use and modeling resource selection proposed by Marzluff *et al.* (2004). Rather than a simple binary characterization of resource units, the approach of Marzluff *et al.* (2004) considers use as a continuous variable summarized by a UD. Ninety five percent

UD was clipped using Hwath tools in ArcGIS 9.3 (Environmental Systems Research Institute, Redlands, CA, USA) to reduce potential bias in home range estimates resulting from extremely low-use areas on the tails of the UD (Vanak and Gompper 2010). I used Program Resource Selection for Windows to conduct a compositional analysis (Leban 1999). Habitat preference was investigated at three levels: (i) selection of home range within study area, (ii) selection of core area within home range, and (iii) selection of foraging paths within home range. Ivlev's index (Ivlev 1961) was also used to see the habitat preference.

Results

Sample size adequacy for home range analysis

Data for home range analysis was obtained from 8 radio-collared adult rhinos. Out of which six (F1 to F6) were females and two (M1 and M2) were dominant male. The radio-collared animals were monitored for a total of 3,576 days (Table 5.1). Over 19,896 GPS locations were obtained including 24 h continuous monitoring out of which 8,491 locations were used for the home range analysis.

Table 5.1. Number of days tracked for GPS collared 8 rhinos in Chitwan National Park between 2010 and 2012; number of locations in night, day and in different seasons used for home range estimation.

Rhino ID	Duration Tracked (Days)	Total locations used	Distribution of locations				
			Night	Day	Monsoon	Hot dry	Cool dry
Saili (F1)	619	352	88	264	103	144	105
Dalli (F2)	592	358	97	261	151	133	74
Poke (F3)	584	2470	1266	1204	251	1150	1069
Gadwal (F4)	288	406	127	279	-	406	-
Gleanse (F5)	291	823	253	570	116	426	281
Chanchali (F6)	541	2224	878	1346	1035	638	551
Gardhane (M1)	313	504	139	365	94	288	122
Jakhu (M2)	348	1354	558	796	504	605	245
Total	**3576**	**8491**	**3406**	**5085**	**2254**	**3790**	**2447**

Minimum number of locations required to estimate the annual and seasonal home ranges for VHF data was over 90 and for GPS collar downloaded data asymptote was obtained only after 350 fixes (Figure 5.2).

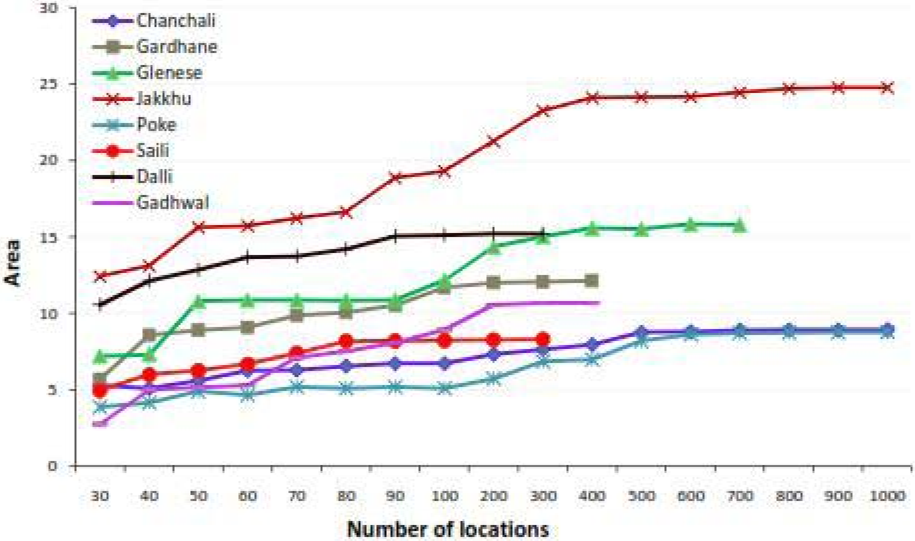


Figure 5.2. Plot of 95% MCP home ranges of rhinos versus number of radio locations to determine adequacy of sample size in Chitwan National Park.

Seasonal and annual home range estimates

Average annual 95% Kernel home range was 20.54 ± 6.06 km^2 for male and 10.58 ± 1.34 km^2 for female (Table 5.2). The female home range during cool dry season was 10.06 ± 1.48 km^2, 9.08 ± 1.25 km^2 in hot dry season and 9.81 ± 1.19 km^2 in the monsoon. The male home range was 16.52 ± 4.02 km^2 for cool dry season, 17.760 ± 4.94 km^2 for hot dry season and 18.63 ± 4.53 km^2 for monsoon. There was a significant difference between male and female home ranges (One-way ANOVA, $F_{1, 29} = 21.21$, $p < 0.001$). However, there was no seasonal variation in the home ranges for both sexes (One-way ANOVA, $F_{3, 29} = 0.07$, $p= 0.975$). Figures in the following pages show distribution of radio locations (Figure 5.3), 95% kernel home ranges of rhinos (Figure 5.4) and 95% MCP home ranges of rhinos (Figure 5.5) within the study area.

Table 5.2. Annual and seasonal (95% MCP and 95% kernel) home ranges (km^2) of individual rhinos in Chitwan National Park, Nepal.

Rhino ID	Annual		Cold dry		Hot dry		Monsoon	
	MCP	Kernel	MCP	Kernel	MCP	Kernel	MCP	Kernel
Saili (F1)	8.67	10.67	6.56	9.32	8.06	10.64	5.38	9.56
Dalli (F2)	11.75	14.34	11.75	14.34	10.33	11.78	10.33	12.97
Poke (F3)	10.52	8.95	10.05	7.52	8.05	7.02	6.40	9.52
Chanchali (F6)	9.86	8.37	8.40	9.04	8.37	6.88	8.07	7.21
Gleanse (F4)	15.78	15.32	4.30	5.62	14.68	14.77	11.32	13.13
Gadwal (F4)	-	-	-	-	10.68	18.81	-	-
Female average	10.20	10.58	9.19	10.06	8.71	9.08	7.55	9.81
Standard error	0.64	1.34	1.11	1.48	0.55	1.25	1.08	1.19
Gardhane (M1)	12.10	14.48	9.03	12.49	10.76	12.82	9.35	14.08
Jakhu (M2)	26.45	26.59	22.75	20.54	20.43	22.71	20.51	23.14
Male Average	19.27	20.54	15.89	16.52	15.60	17.76	14.93	18.61
Standard error	7.17	6.06	6.86	4.02	4.84	4.94	5.58	4.53

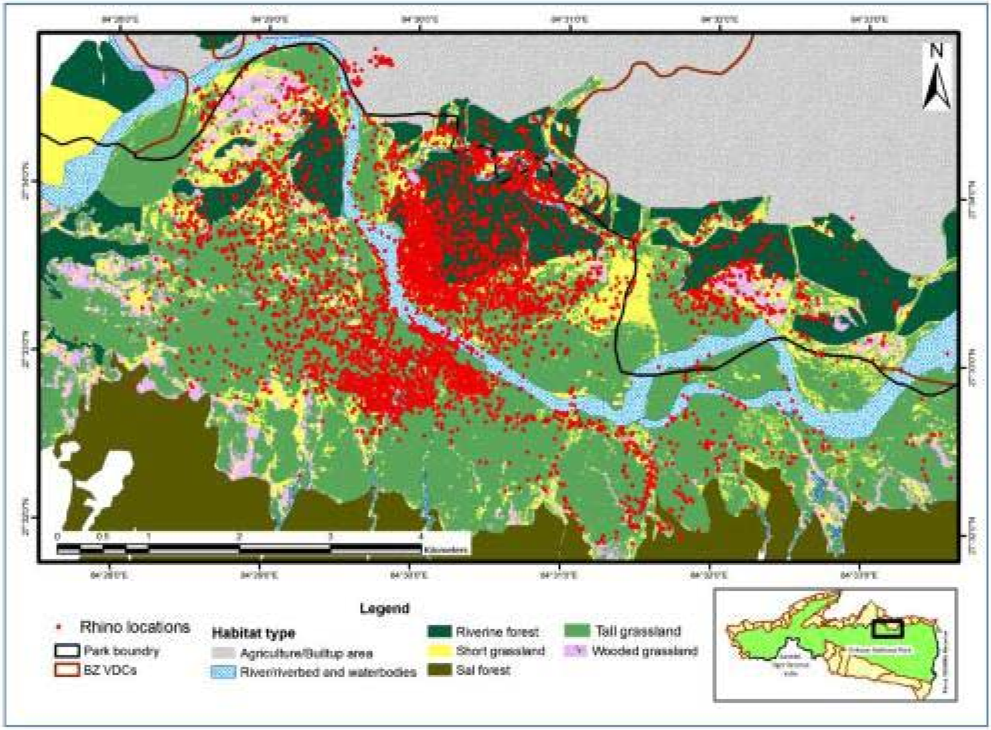


Figure 5.3. Map of intensive study area showing habitat types and radio locations of collared rhinos (n = 8). The map inset shows the location of the study area within Chitwan National Park.

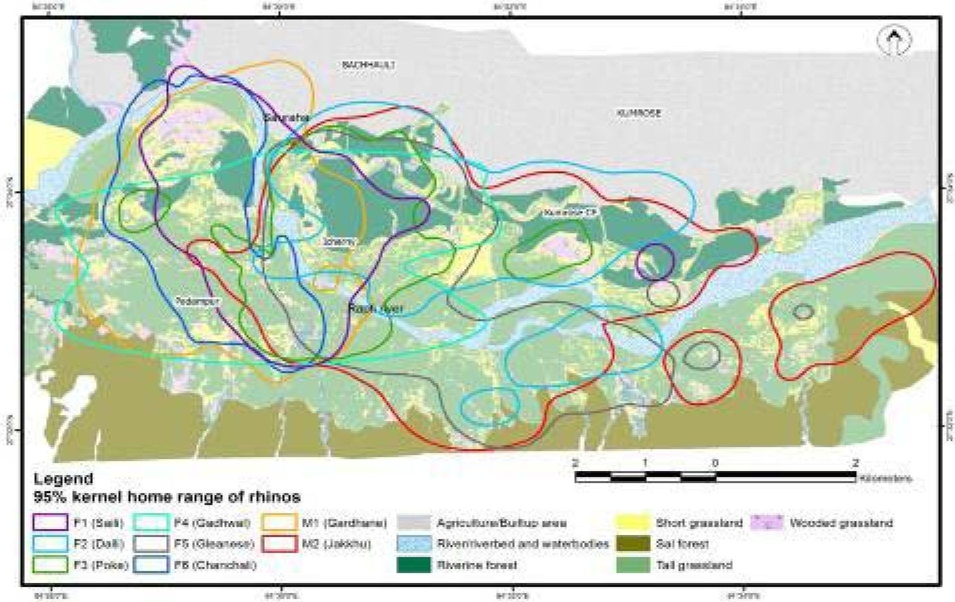


Figure 5.4. Annual 95% Kernel home range of eight radio-collared rhinos superimposed on the habitat map of intensive study area.

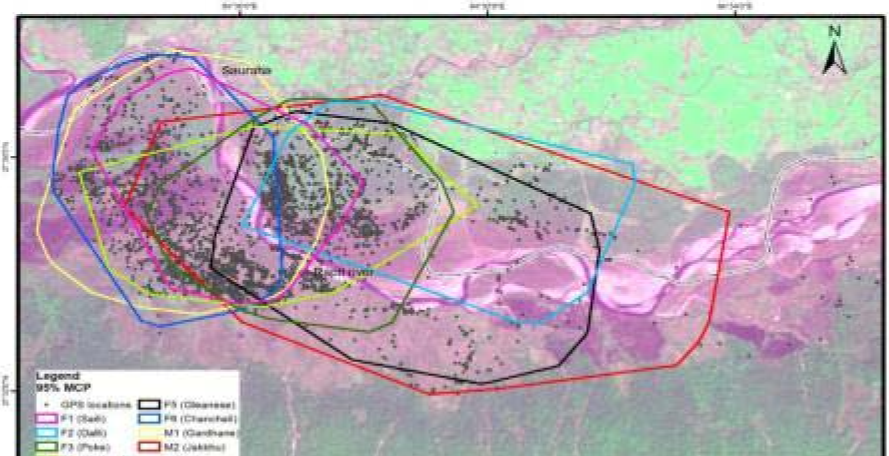


Figure 5.5. Radio locations and annual 95% MCP home ranges of 8 collared rhinos in Chitwan.

Home range overlap

There was 47% overlap of home range between two males. Home range overlap among females was also significant (Figure 5.6). Out of six females 3 females had their home ranges within the territory of male M2. Similarly, 2 other female home ranges were within the territory of male M1. In fact, there was also third dominant male (ID 1) and other 5 adult females but not radio-collared using the same area that all radio-collared rhinos were using. This fact suggests that the greater one-horned rhinos are not territorial. However, my observation and data suggest that males were slightly territorial than females.

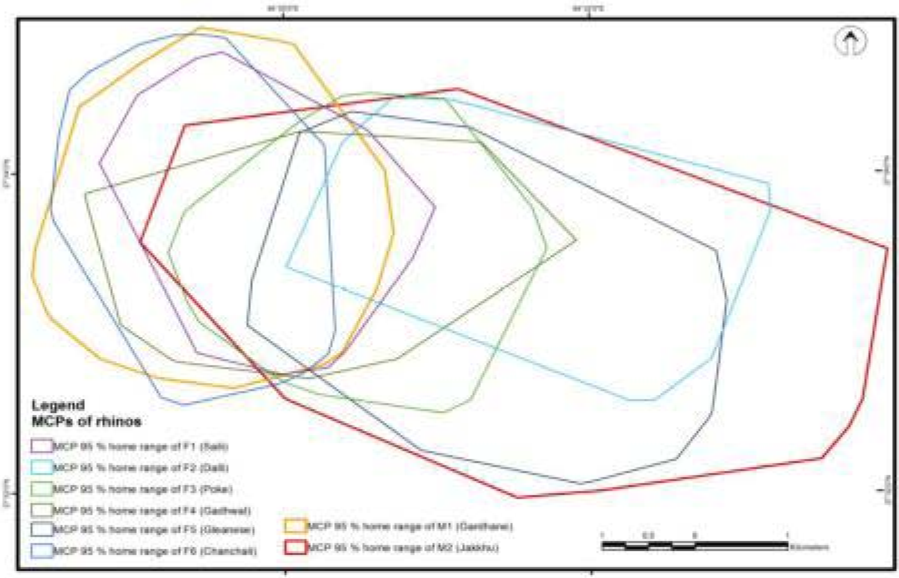


Figure 5.6. 95% MCP home ranges overlap among radio-collared males and females rhinos in Chitwan National Park.

Core area estimates

Core areas were assessed using fixed kernel home ranges with area/probability curve. The point of inflection in the graph suggesting uniform distribution of radio locations ranged from 75% to 85% isopleths values. Hence, 80% fixed kernel was selected to represent core areas of the study animals (Figure 5.7). Annual and seasonal average 95% kernel home ranges and 80% kernel home ranges (core area) of male and female are given in the table 5.3. There was no differences between the seasonal core home ranges of rhinos (One-way ANOVA, $F_{3, 29} = 0.1$, $p = 0.960$). However, the seasonal core differed between male and female (One-way ANOVA, $F_{1, 29} = 30$, $p < 0.001$).

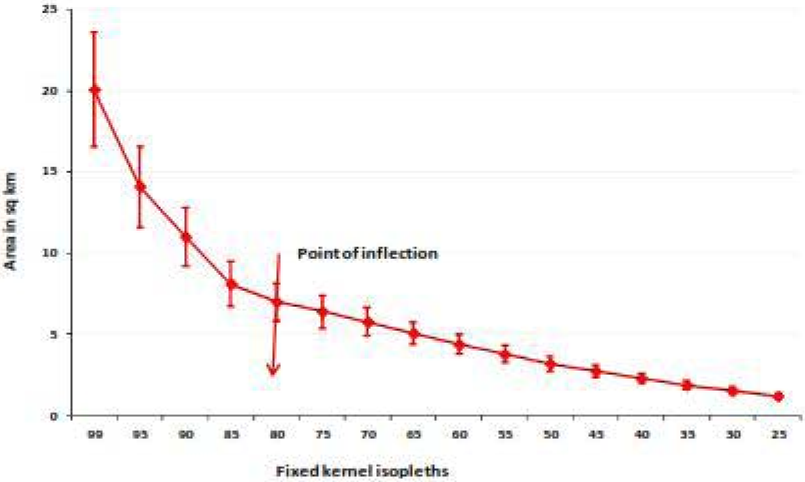


Figure 5.7. Plot of average home range area versus incremental fixed kernel isopleths to determine the point of inflection that defines the core area contour of the fixed kernel home range obtained from different rhinos. Error bars are standard errors.

Table 5.3. Seasonal and annual average 95% kernel and 80% kernel (core) home ranges of rhinos. The values in the parentheses are SE.

	Annual		Cold dry		Hot dry		Monsoon	
Sex	95% Kernel	80% kernel	95% Kernel	80% kernel	95% Kernel	80% kernel	95% Kernel	80% kernel
Male	20.54 (6.06)	11.11 (1.93)	21.51 (9.02)	12.42 (4.70)	17.76 (4.94)	9.81 (1.74)	18.61 (4.53)	10.36 (1.52)
Female	12.02 (1.25)	6.89 (0.75)	9.72 (1.31)	5.54 (0.78)	10.65 (1.29)	5.87 (0.82)	11.08 (1.10)	6.48 (0.70)

Habitat composition and preference

Intensive study area was 63 km^2 (Figure 5.8). Of which 17% was covered by Sal forest, 41% by tall grassland, 13% by short grassland and meadows, 7% by wooded grassland, 8% by river and riverbed and 14% by mixed riverine forest.

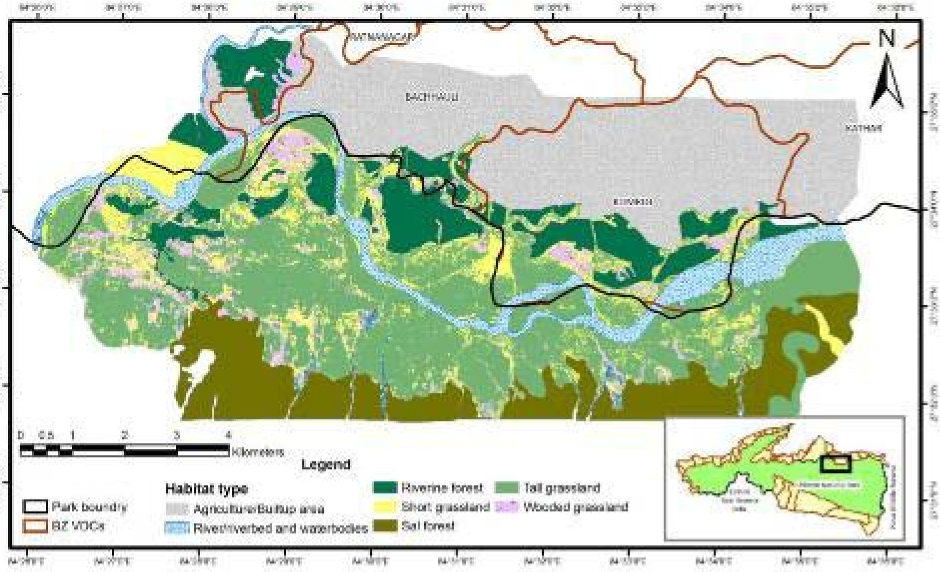


Figure 5.8. Habitat map of intensive study area showing different vegetation communities. The map inset shows the location of Sauraha (intensive study area) within Chitwan National Park.

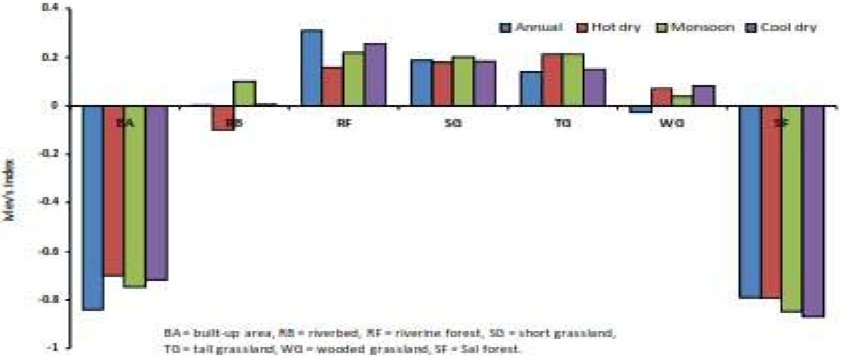
Habitat preference in study area level

The results of compositional analysis for annual habitat use and availability in study area level showed that the rhinos preferred certain habitats over others ($\chi^2_{(6\ df)} = 18.63$, $p < 0.001$).

1. The order of annual habitat preference at study area level was riverine forest > short grassland > tall grassland > wooded grassland > river and river bed > Sal forest > built-up area.

2. Habitat preference order for cool dry season ($\chi^2_{(6\ df)} = 16.543$, $p < 0.001$) was riverine forest > short grassland > tall grassland > wooded grassland > river and riverbed > built–up area > Sal forest.
3. The preference order for hot dry season ($\chi^2_{(5\ df)} = 24.29$, $p < 0.001$) was tall grassland > short grassland > riverine forest > wooded grassland > river and riverbed > built-up area > Sal forest.
4. During monsoon the preference ($\chi^2_{(5\ df)} = 15.154$, $p < 0.05$) order was Tall grassland > riverine forest > short grassland > river and riverbed > wooded grassland > built-up area > Sal forest.

Ivlev's index gave identical result as compositional analysis for all seasons (Figure 5.9).



BA = built-up area, RB = riverbed, RF = riverine forest, SG = short grassland, TG = tall grassland, WG = wooded grassland, SF = Sal forest.

Figure 5.9. Ivlev's index of overall habitat preference by radio-collared greater one-horned rhinoceros in study area.

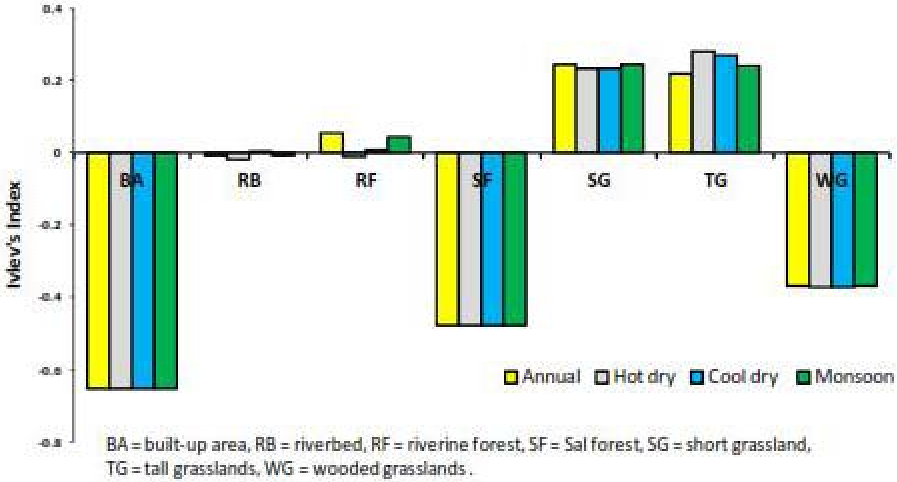
Habitat preference in core area

i) Annual habitat preference within core area (95% kernel as availability and core area as use) ($\chi^2_{(5\ df)} = 19.32$, $p < 0.05$) was short grassland > tall grassland > riverine forest > river and riverbed > wooded grassland > Sal forest.

ii) The hot dry season preference ($\chi^2_{(5\ df)} = 17.71$, $p < 0.05$) within core habitat was tall grassland > short grassland > riverine forest > river and riverbed > wooded grassland > Sal forest.

iii) Cool dry season preference (($\chi^2_{(5\ df)} = 18.78$, $p < 0.05$) was same as of hot dry season.

iv) Monsoon season preference ($\chi^2_{(5\ df)} = 18.36$, $p < 0.05$) was short grassland > tall grassland> riverine forest > river and river bed > wooded grassland > Sal forest. Ivlev's index of habitat preference gave the identical result (Figure 5.10).



BA = built-up area, RB = riverbed, RF = riverine forest, SF = Sal forest, SG = short grassland, TG = tall grasslands, WG = wooded grasslands.

Figure 5.10. Ivlev's index of annual and seasonal core area habitat preferences by radio-collared rhinos within 95% Kernel home ranges in Chitwan National Park.

Habitat preference during foraging

a) Annual habitat preference order within home range for foraging ($\chi^2_{(6\ df)} = 325.24$, $p < 0.001$) was short grassland > tall grassland > wooded grassland > riverine forest > river and riverbed > Sal forest > built-up area.

b) The preference order for cool dry season ($\chi^2_{(5\ df)} = 168.98$, $p < 0.001$) was short grassland > tall grassland > wooded grassland > riverine forest > river and river bed.

c) The foraging preference order for hot dry season ($\chi^2_{(5\ df)} = 181.65$, $p < 0.001$) was tall grassland > short grassland > wooded grassland > riverine forest > river and riverbed > Sal forest.

d) The preference order for monsoon ($\chi^2_{(5\ df)} = 97.\ 97$, $p < 0.001$) was tall grassland > short grassland > wooded grassland > river and riverbed > riverine forest > Sal forest.

The Ivlev's index gave a preference of short and tall grassland in all season except cool dry season for tall grassland (Figure 5.11).

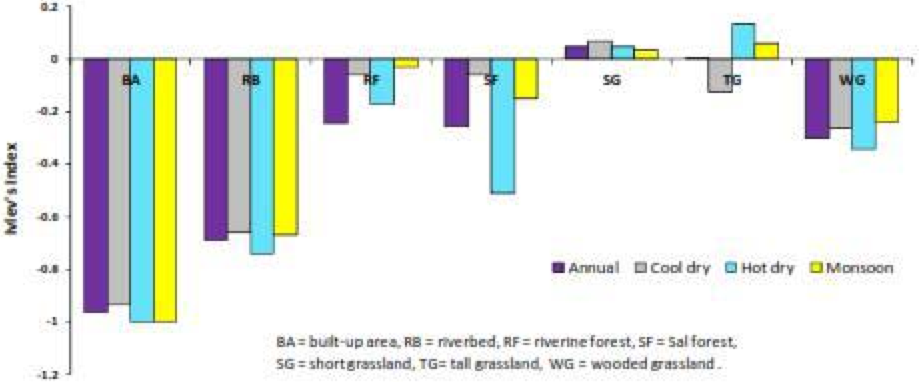


Figure 5.11. Ivlev's index showing annual and seasonal habitat preferences of radio-collared rhinos during peak foraging hours within 95% kernel home ranges in Chitwan National Park.

Seasonal daily movement pattern

Male rhinos moved average 6.45 ± 0.73 km/day (24 hours) with 269 ± 70 m average hourly displacement in the cool dry season and 6.47 ± 0.62 km/day with 270 ± 73 m/hour displacement during the hot dry season (Figure 5.11 and 5.12). The male rhinos moved more in the evening and before midnight compared to other periods of the day in all seasons (Figure 5.12 & 5.13).

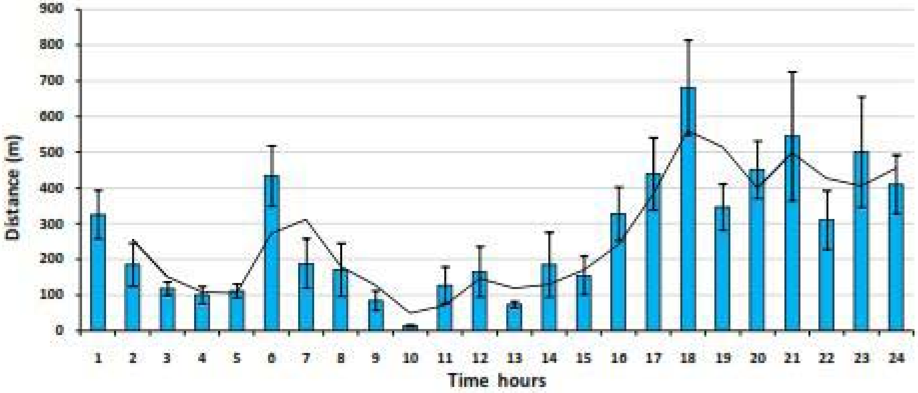


Figure 5.12. Average hourly distance moved by male rhinos during cool dry season. Error bars are SE.

Female rhinos moved 4.06 ± 0.24 km/day in cool dry season, 3.19 ± 0.18 km/day in hot dry season and 3.71 ± 0.51 km/day in monsoon. The average hourly displacement was 169 ± 10.12 m/h in cool dry season, 133.26 ± 7.74 m in hot dry season and 154.67 ± 39.77 m in monsoon (Figure 13, 14 & 15). Female movement was high in the morning (6:00 – 7:00 hrs) and evening (19:00 – 20:00 hrs) in the monsoon (Figure 5.13). In all seasons, movement was relatively higher in the night compared to day time (Figure 5.14, 5.15 & 5.16).

Distance moved by male rhinos in 24 hours was higher than female (Two-way ANOVA, $F_{1, 120} = 28.34$, $p < 0.0001$). There was a higher movement in night (18:00 – 06:00) than in day (06:00 – 18:00) for both sexes (Two-way ANOVA, $F_{1, 120} = 6.53$, $p = 0.019$). But the movement did not differ with seasons for both sexes (Two-way ANOVA, $F_{2, 81} = 1.39$, $p = 0.256$).

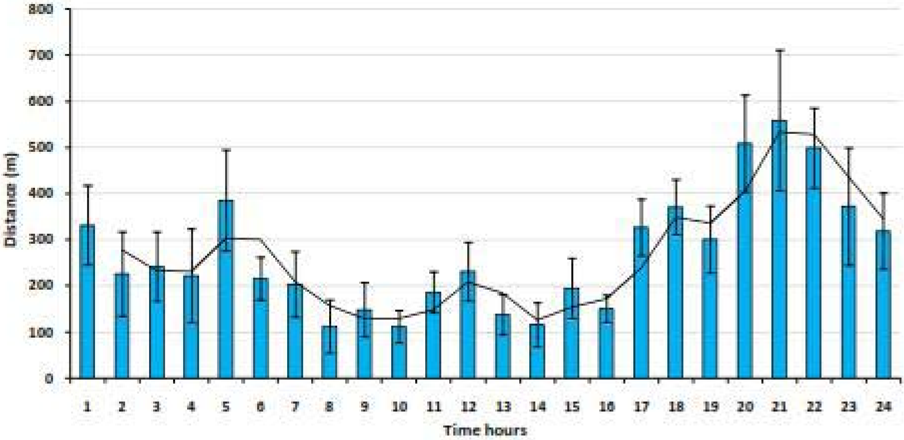


Figure 5.13. Average hourly distance moved by male rhinos during hot dry season. Error bars are SE.

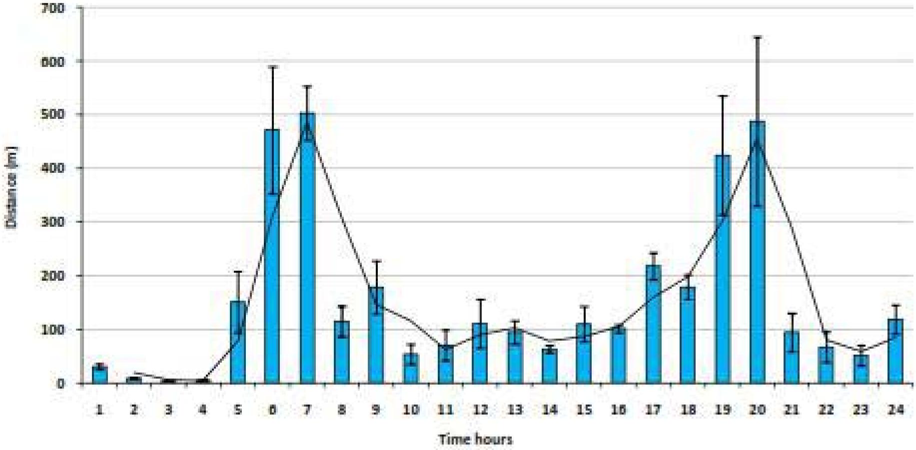


Figure 5.14. Average hourly movement rate of female rhinos during monsoon with standard errors.

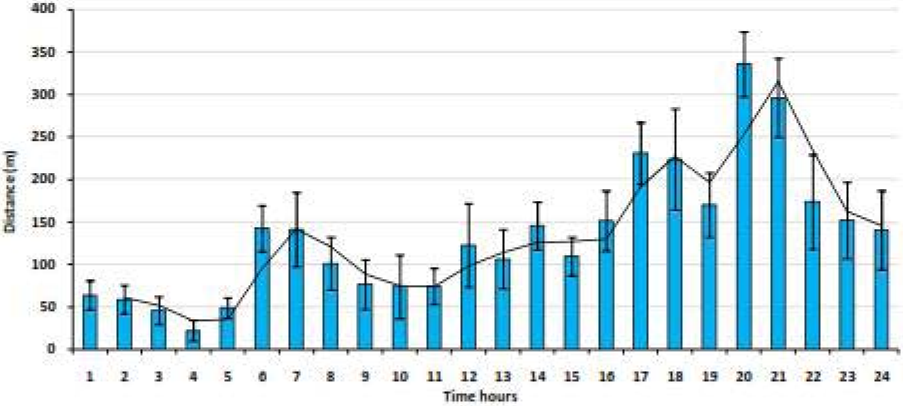


Figure 5.15. Average hourly movement rate of female rhinos during hot dry season with standard errors.

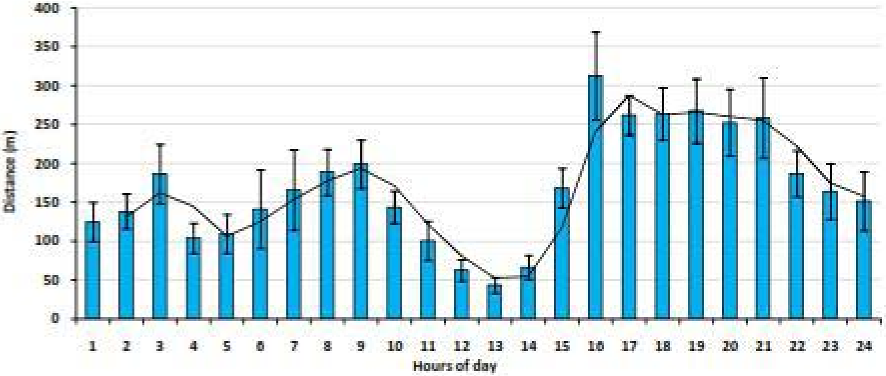


Figure 5.16. Average hourly movement rate of female rhinos during cool dry season with standard errors.

Discussion

Home range

Study on home range size and spatial distribution are fundamental to understand the distribution and abundance of animals, and ultimately their population regulation (Wang and Grimm 2007), habitat selection, community structure (Fagan *et al.* 2007), and for conservation management (Woodroffe and Ginsberg 2000). The current study gives an idea about rhino home range sizes in the context of habitat degradation due to *Mikania micrantha* infestation based on data collected by GPS radio telemetry method. Estimates for individual home ranges reach asymptotes at different values and with a variety of curves, depending on the pattern of home range utilization and range size for that particular individual (Harris *et al.* 1990). Sample size adequacy results showed that over 90 locations for 95% MCP were needed with the VHF data set while about 350 locations were needed for GPS downloaded dataset to model rhino space use area (Figure 5.2). This figure was higher than that (28 fixes) reported in an earlier study on the greater one-horned rhinos (Jnawali 1995, Dinerstein 2003). I have used 4 locations in 24 hours for home range analysis which is justifiable given that average movement rate of 4 - 6 km/day for rhinos so that between locations rhinos have sufficient time to be anywhere within their home range. Since not all regions of an animal‘s distribution are necessarily characterized by the same degree of spatial autocorrelation (Osborne and Sua´rez-Seoane 2002) using a single smoothing parameter may over-smooth in some regions and undersmooth in others (Hemson *et al.* 2005). For the present study the appropriate reduced reference bandwidth was fixed to 0.60 proportions, by reducing the reference bandwidth just prior to the point where that estimate starts to fragment in an unrealistic manner.

No significant variation on the home ranges of both sexes is an indicator of less seasonality on the availability of food plant resources and mates throughout the year. The home range estimates in my study were substantially bigger than the home ranges reported by Jnawali (1995) and Dinerstein (2003) based on the study carried out during early 1990s in the same study area. However, the present home ranges were not bigger than that reported for newly reintroduced rhinos (Jnawali 1995) to Bardia National Park in Nepal (Table 5.4). Jnawali (1995) argued that the low population density and low availability of prime habitats dominated by *Saccharum spontaneum* for the bigger home ranges in Bardia.

Table 5.4. Comparison of MCP home ranges (mean ± SE, km^2) estimated in the present study with previous studies conducted on rhinos in Chitwan NP and Bardia NP in Nepal during 1990s.

Home range	Present study		Dinerstein (2003) (Chitwan)		Jnawali (1995) (Chitwan)		Jnawali (1995) (Bardia)	
	Male	Female	Male	Female	Male	Female	Male	Female
Annual	19.2±7.1	10.2±0.6	3.3±0	2.9±0.9	3.3±0.9	2.9±0.9	41.8±4.4	25.1±9.3
Hot dry	15.6±4.8	8.71±0.5	2.7±0.8	2.7±1.7	2.0±0.6	1.1±0.4	21.2± 11.1	13.3±4.9
Cool dry	15.9±6.8	9.19±1.1	2.9±1.8	2.4±0.7	1.1±0.1	1.2±0.4	20.7±10.3	15.6± 4.5
Monsoon	14.9±5.5	7.55±1.1	3.7±2.0	2.4±0.7	1.4±0.4	1.3±0.5	14.4±7.1	14.4±7.1

The significant increment in the home range of rhinos could be due to combined effects of following causes: i) The population density of rhinos has declined in the study area from 13 individuals/km^2 (Dinerstein and Price 1991, Dinerstein 2003) to ca. 2 individuals/km^2 at present for overall intensive study area (see Chapter one). With the decreased population density the rhinos expand their ranges to access more resources *i.e.* food, water and mates (Kiwia 1989, Rachlow *et al.* 1999, Jnawali 1995). ii) The study area has undergone deteriorative changes in habitat quality due to drying up of important water bodies and wallows in the core habitat in recent years (Naresh Subedi, unpublished data); changes in grassland composition due to plant succession (NTNC, unpublished data), and low availability of preferred food plants because of *Mikania micrantha* invasion in the prime rhino habitats (Sapkota 2007, DNPWC 2009, Murphy *et al.* 2012). Rhinos would therefore need to increase home ranges to have sufficient resources within their area of use for maintaining body condition for life history stages (e.g. Emslie 1999, Reid *et al.* 2007, Julian II *et al.* 2012). iii) Rhinos used to obtain 5% to 13% of their diet from the agricultural crops (Jnawali 1995). This opportunity of obtaining highly nutritious foods has been lost by the installation of rhino proof power fence on the Park border since 2005 (NTNC unpublished data) and that may have compelled rhinos to move further for better foraging areas. iv) Padampur village, which was inside the core area of the park, was evacuated in 2004 (Dhakal *et al.* 2011) that has provided an extra 18 km^2 of grasslands and wetlands to rhinos of the study area. This availability of new habitat dominated by early successional vegetation communities could have attracted them for foraging and hence increased home ranges. These rhinos in the past were squeezed by the two villages (Padampur in the south and Sauraha in the north) and may have checked their dispersal. v) I suspect that Jnawali (1995) and Dinerstein (2003) used low number of locations mostly based on the day time observations through VHF radiotelemetry for home range estimates. They have not included the agricultural areas used by the rhinos in the home range analysis. Therefore, their home range estimates may have been smaller than reality. In the current study the use of GPS collars as well as continuous monitoring data in each season for all rhinos embarked that the location data captured information on the entire home range.

Similar increment on the home ranges of African black and white rhinos with respect to habitat quality and population density has been reported elsewhere across Africa. For example: In the good habitats, Conway and Goodman (1989) reported home range size of 4.3 – 14.3 km^2 in Ndumu, South Africa for black rhinos. Similarly, in moderate desert habitats Gottert *et al.* (2010) reported 220 – 234 km^2 home ranges for black rhinos in Etosha National Park, Namibia. Moreover, in the desert habitats of Damaraland, Namibia, black rhino home ranges were reported to be >500 km^2 (Loutit 1984). Similar type of variation on the home range size of the white rhinoceros (*Ceratotherium simum*) owing to habitat quality and population density are available in the literature: Umfolozi, South Africa: 9 – 15 km^2 (Owen-Smith 1988), Govi Game Park, Zimbabew: 4 – 33 km^2 (Rachlow *et al.* 1999), Umfolozi, South Africa: 6 – 66 km2 (White *et al.* 2007). Therefore, I conclude with my extensive dataset and field observations that the increment of the home ranges of rhinos in Chitwan was influenced by multiple factors but higher contribution was of habitat degradation and decreased population density than other factors.

The significant home range overlap among males and females suggested that greater one-horned rhinos were not territorial. But there was a slight tendency of territorial behavior among the males. Dinerstein (2003), Jnawali (1995) and Laurie (1978) have also reported the non territorial behavior on rhinos in Chitwan. This finding also has implications on finding out the carrying capacity in Chitwan. For rhinos, it has been already been observed that if food resources and water are ample in supply they can confine themselves in less than 2 km^2 core area (Dinerstein 2003, Jnawali 1995).

The lack of significant variation in the seasonal home ranges of both sexes further suggests that the resources availability across seasons were more or less stable in the study area.

Habitat preference

At the study area level, annual preference for habitat was riverine forest, short grassland and tall grassland. Riverine forest was preferred during cool dry season. The annual and cool dry season preference for riverine forest could be due to: i) rhinos switch on browse species for foraging in winter and availability of browses was higher in the riverine forest (Jnawali 1995), and ii) during winter nights, rhinos commonly take a refuge into the riverine forests where the cold blowing winds and fog were less compared to open grasslands and providing favorable environment to rhinos. Tall grassland and short grassland were preferred during hot dry and monsoon season. The reasons for this preference could be: i) during hot dry season the tall grassland of Chitwan was were full of green flush after the annual burning and quality forage for grazers were bountiful in supply. Similar was the situation during the monsoon because of ample rainfall, ii) rhinos are water dependent species and need sufficient waterholes and rivers for wallowing especially during hot dry and monsoon season (Dinerstein 2003). My data also confirm this as over 90% of the rhino locations were within 1.8 km distance of permanent water resources (Figure 3). In the study area, most favored waterholes were in tall grasslands of Padampur; and Rapti river was dissecting the study area from the midpoint creating ample alluvial floodplain grasslands.

At the core area selection within home range, rhinos preferred short and tall grasslands across all seasons. The availability of ample forage and water resources for wallowing in these habitats across all seasons could be the main reason for their preference. Rhinos prefer early successional habitats dominated by *Saccharum spontaneum* that are intermingled with mosaics of riverine forests (Laurie 1978, Jnawali 1995, Dinerstein 2003).

Similarly, foraging paths of rhinos showed preference of short or tall grassland throughout the year. For example: rhinos foraged aptly in the tall grasslands during hot dry season and monsoon as there was substantial supply of nutritious food plants due to annual burning and rainfall. While short grasslands were preferred during cool dry season as the grasses in tall grassland flower and become senescent and were thus less palatable. The short grasslands were maintained by the herbivores through rigorous grazing throughout the year (McNaughton 1984, Karki *et al.* 2000). Some of the tall grasslands were maintained as short grasslands as a result of human and livestock use in the study area. Such short grasslands were preferred for foraging in cool dry season because of availability of new sprouts that are nutritious and palatable herbaceous layer created by continuous disturbances (grazing).

This finding highlights the importance of short and tall grasslands in the alluvial floodplain of Chitwan to maintain the rhinos and other dependent herbivores (Odden *et al.* 2005). However, the grasslands in Chitwan are rapidly converting to wood-land and are also infested by invasive weeds like *Mikania micrantha* (DNPWC 2009, see chapter 5 also). On the other hand, fire management in Chitwan is haphazard and late burning (April/May) of grassland is common. Late burnings are deleterious as it burns everything because of high temperatures and also may change the soil microbial activities because of intense fire. Thus, vegetation succession, invasive weeds, and indiscriminate burning may have lead to the reduction and degradation of these precious grassland habitats in the study area and elsewhere in Nepal Terai. Scientific management based on applied research (e.g. Karki *et al.* 2000, Peet *et al.* 1999, Lehmkuhl 1989 and 1994) would help to improve the management of grasslands in the study area and hence conservation of rhinos and other ungulates as well.

Daily movement

This is a first comprehensive GPS radio-collar based study on greater one-horned rhinoceros that easily allowed me to calculate hourly movement pattern of rhinos in all seasons with good accuracy. The male moved longer distance (>6km/day) than female (ca.4km/day). Dinerstein (2003) also reported daily movement of rhinos in Chitwan that is in line with this finding. This daily movement pattern of greater one-horned rhinoceros was also similar to the white rhinos (*Ceratotherium simum*) in South Africa which moved 4 - 5 km/day (Owen-Smith 1988). There was no seasonal variation in daily movement of rhinos in Chitwan which also suggests less variability on the availability of forage resources and mates across seasons. Male rhinos generally keep moving to find mates and maintain its dominance in the area. In the greater one-horned rhinos male mating strategy is to occupy the most resourceful prime habitat and keep more females within its home range so as to maximize mating success. Mating with most familiar male has been reported in white rhinos (White *et al.* 2007) and anecdotal evidences in my study area also supports this finding as the females were found mating with the most familiar dominant male of the area in most instances. Most probably the male rhinos were travelling more to exploit the resource rich patches, scent marking within the home ranges and searching for females that were in heat. Mostly male rhinos were more active during nights than females as dominant male does not have any predators and night movement was not restricted. But females with small calves moved less during the nights and favored park border areas which could be a predator avoidance strategy of females. But the question remains to answer why the rhinos moved more in night than in day? It is most probably related with less fear of predation, less human-caused disturbances, and mild temperatures especially during hot dry and monsoon seasons for foraging in the night. Day time temperatures in Chitwan during hot and monsoon season reach over 35^0C that hinders foraging on the open grasslands. Similar type of night active behavior has been reported in black and white rhinos in Africa in response to thermal stress (Owen-smith 1988).

CHAPTER 6

Demography of greater one-horned rhinoceros in Chitwan National Park, Nepal

Newly born male calf and radiocollared female (F1).

Introduction

Information on the demographic parameters of megaherbivores and other endangered species are crucial for conservation management and therefore are of interest of wildlife biologists, park managers and decision makers. Population growth rates of megaherbivores (> 1000 kg body weight) are slow compared to large carnivores or medium sized herbivores (Moss 2001). Similarly, delayed first age of calving, long interbirth interval and one offspring at a time hinders rapid population growths of these species (Owen-Smith 1988, Moss 2001). Moreover, localized distribution of megaherbivores on heavily fragmented human-dominated landscapes with low numbers, continuous poaching pressures and habitat degradation due to invasive species in the recent decades have further lowered the population performance of these species in most habitats. In an isolated population, growth rate and age structure are determined by age specific survival and birth rates. These variables change over time with respect to habitat dynamics, competition, predation intensity, diseases and human induced mortalities (Sibly and Hone 2002). Megaherbivores being "K-selected" their demographic parameters are influenced by population density (Owen-Smith 1988). Density dependent reproduction, mortality and dispersal are conspicuous in large mammals (Fowler 1981). Declining resources have also been related to reduction in reproduction rate, reduction in juvenile and adult survival (Trimble *et al.* 2009). Therefore, demographic parameters are important components to be closely monitored to sustain the long term conservation and management of these species.

Since the rhinos in Chitwan had undergone a population bottle neck during 1960s (ca. 100 individuals in 1966; Laurie 1978), there is always a chance of manifestation of low population growth, increased interbirth interval and first age of calving. Although rhinos in Chitwan were reported to have high heterozygosity (Dinerstein and McCracken 1990, Zschokke *et al.* 2011), this may have been reduced since historic time. Recently, observed habitat degradations through rapid invasion of *Mikania micrantha*, and vegetation successions in the prime rhino habitats has been suspected to have negative impacts on rhino population in Chitwan (DNPWC 2009, Murphy *et al.* 2012). Therefore, there was a pertinent need of long term monitoring of rhinos to gain an understanding of their demographic parameters for adaptive conservation management.

To achieve this objective, an Individual identity based (ID-based) intensive rhino monitoring system was initiated by the end of 2008 in Sauraha subpopulation and other low population density areas of Chitwan. This monitoring system together with long term data on rhino census and record of mortality allowed me to analyze the demographic parameters of rhinos with reasonable accuracy. In this chapter, demographic parameters of rhinos have been discussed and are further compared with previous studies. The findings of this chapter are of enormous importance for Nepal and elsewhere to further enhance rhino conservation and management especially since rhinos are facing ever looming threats from poaching and alien invasive species.

Methods

Field method for individual identification of rhinos

In the beginning of 2008, wildlife technicians and game-scouts were trained on ID-based rhino monitoring using the IUCN Asian Rhino Specialist Group accredited course (IUCN AsRSG 2009). Concurrently, a system of intensive rhino monitoring in the poaching prone and low density population sites was set up. The rhino monitoring teams were equipped with digital camera, binocular, field bag, standardized field data sheet (Figure 6.2) and captive elephants for jungle cruise. Centralized data screening, quality control and entry into the standard computer software (SightingBase, Figure 6.3) were also set up at Sauraha research station where I was leading the research program. Six monitoring blocks were set up within 200 km^2 intensive study area of Sauraha. Most rhinos are identified individually from well recognized features such as horn shapes, folds and body marks (Laurie 1978, Dinerstein and Price 1991, Figure 6.1). I have been monitoring rhinos by individual identification on a monthly basis in the study area for past 5 years (2008 - 2012). *Mahuts* and senior wildlife technicians from National Trust for Nature Conservation (NTNC) and trained park game-scouts routinely search and record individual rhinos in a given blocks whose profile protocol includes full body photographs highlighting distinguishing characteristics, sex, age and information about locations and associated rhinos (Amin *et al.* 2006). Few rhinos, mainly subadults, do not have readily recognizable features. However, these constitute only 2 - 5% of all sightings and such individuals were distinguished from others by their location and range use, as well as from associated identified rhinos. This intensive and extensive monitoring allowed knowing individual rhino, typical group size, sex and age composition, number of births, number of deaths, reproductive activities, age at first calving, interbirth interval and so forth. Additionally, 8 adult rhinos were radio-collared in the same area which made monitoring further easy.

Figure 6.1. Rhinos can be identified with certainity by body and horn features; for example a) ear cut and feature of horn, b) upper lip cut and horn features. Similarly, other body features help to identify rhinos.

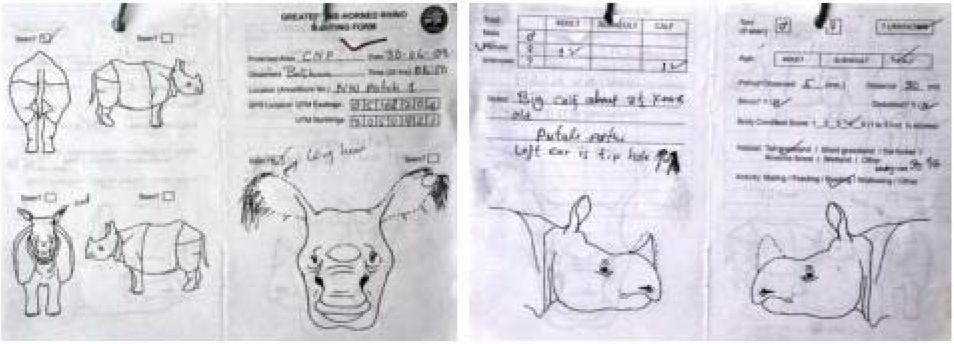


Figure 6.2. A complete sighting form filled in by wildlife technicians in the field. The field teams take photos and fill in sighting forms that are submitted to central database management team for data entry in the rhino SightingBase computer program. Individual rhinos are identified/confirmed by photos and then entered into the database system.

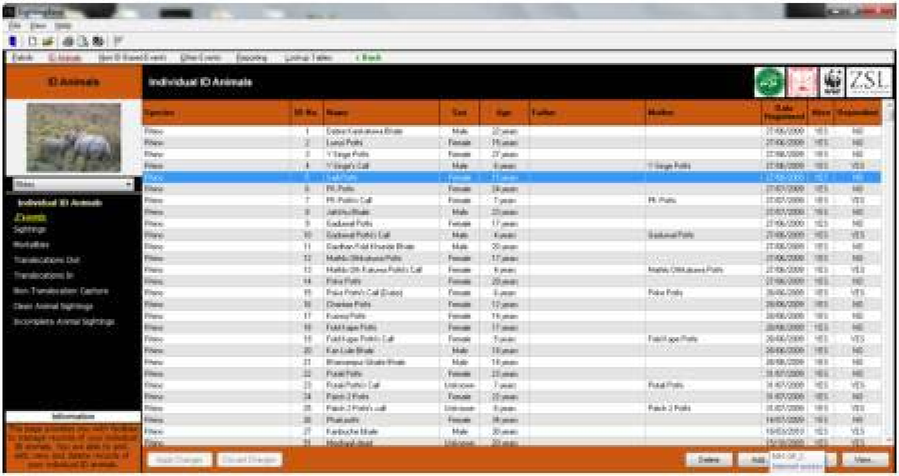


Figure 6.3. A screen shot of SightingBase software and rhino database management system showing ID database of rhinos in Chitwan.

Survival analysis

Stage specific annual and span survival probability of rhinos was estimated through a known-fate model (Skalski *et al.* 2005) in Program MARK (White and Burnham 1999) using the staggered entry design (Pollock *et al.* 1989; Hayward *et al.* 2005). The fate of each rhino was known in the study area through intensive monitoring and therefore this technique can be used with certainty and independently. I grouped encounter histories of the rhinos into time intervals of 4 months each and created a live-dead matrix where '10' meant the individual lived through the interval, '11' meant the individual died during the interval and '00' meant censoring the individual (when unaware about the fate; Cooch and White 2009). Rhinos monitored before adulthood, and that lived long enough to enter the next stage class, were included in all appropriate stage classes with the assumption that survival rates in different age classes of an animal were independent. I estimated adult rhino survival by monitoring 53 adult (>7 years age) rhinos (8 radio-collared and 45 non-collared but individually known), juvenile and subadult (1 – 7 years) survival by monitoring 23 rhinos and young calves (<1 year age) survival by monitoring 12 rhinos. Because of small sample size and not much difference on the survival after age of one year, I classified only three age categories for the analysis.

I also estimated cause-specific mortality using program MICROMORT (Heisey and Fuller 1985) according to the total number of monitoring days and death of monitored rhinos occurring in the interval covered (Trent and Rongstad 1974). Mortality was distinguished as either natural or poaching in case of adults and subadults while in calves it was either due to tiger predation or due to infanticide. I generated 95% confidence intervals on survival rates (Zar 2010); non-overlapping confidence intervals on survival estimates were considered significantly different.

Group composition and sex ratio

I used 553 opportunistic rhino sightings across Chitwan National Park and 331 sightings in Sauraha subpopulation to deduce group composition and sex ratio. There was a possibility of sampling individuals more than once and therefore a single sample survey with replacement model was used to compute the adult sex ratio and cow calf ratio (Skalski *et al.* 2005).

Age of first calving and interbirth interval

I closely monitored 6 subadult female rhinos for about 5 years whose age was known to find out the first age of calving in the Sauraha subpopulation. Similarly, I monitored 11 known adult female (4 radio-collared) rhinos to detect the interbirth interval for the same period. Mating date and events (n = 11) were also recorded and followed until new birth. I recorded month wise records of every new birth encountered in Chitwan National Park (n = 44; 16 in Sauraha subpopulation, and 28 in other parts) to deduce seasonality of calving.

Mortality analysis

Due to extensive patrolling, ongoing research and monitoring activities combined with the large body size of rhinos most rhino mortalities were recorded. Every rhino carcass discovered was examined by a veterinarian and a post-mortem report submitted. The official records at park headquarters of Chitwan and records kept at the research station of NTNC in Sauraha between 1998 and 2012 were compiled and analyzed to understand the causes of mortality.

In the intensive study area I am quite sure that I picked up every birth and mortality of rhinos because of intensive search in each patch on a weekly basis. Also, in the intensive study area there were over 60 captive elephants that along with their keepers visit different patches for grazing. Trained nature guides with their guests also visit most of the patches regularly as jungle walk within the national Park is allowed for guides and visitors. Any interesting observation like a new birth or death was reported by elephant keepers and tourist guides to the Park authorities or NTNC office. Therefore, there was a very less probability of not picking up the any mortality or births of rhinos in the area.

Population trend analysis

I used published data from the rhino counts to compute the realized rate of increase (r) between 1966 and 2000 (growing phase), 2001 and 2005 (decreasing phase), 2005 and 2011 (increasing phase). Natural log transformed population estimates were regressed against years to compute r (Caughley 1977, Skalski *et al.* 2005). Since rhino counts in Nepal are done with a large effort covering entire rhino habitats using the same methodology *i.e.* total block count from the elephant back (for detail methodology see chapter 2), I believe that use of the data from the previous counts as a reliable index of population trend is justified.

Comparison of demographic parameters with previous studies

All the demographic parameters I recorded and analyzed were compared with the previous studies carried out by Dinerstein (2003) and Laurie (1978).

Results

Age and sex ratio

Across Chitwan National Park, sex ratio (female : male) in all age class was 1.22 ± 0.09, adult sex (female : male) ratio was 1.24 ± 0.14, and calf : cow ratio was 0.60 ± 0.05.

In the intensively studied Sauraha subpopulation, sex ratio (female : male) in all age class was 1.13 ± 0.20, adult sex ratio (female : male) was 1.12 ± 0.24 and calf : cow ratio was 0.68 ± 0.17.

Survival of different age class

Annual survival rate for young calf (< 1 year) was 0.69 ± 0.14, while it was 0.98 ± 0.01 for juvenile and subadults (1 – 7 years) and 0.977 ± 0.01 for adults (> 7 years). Span survival for juvenile and subadults was 0.91 ± 0.03, and it was 0.52 ± 0.03 for adults. I assumed total life span of rhinos as 35 years in the wild for span survival analysis based on the records of observations made in Chitwan. Calf survival rate was found significantly less than previously reported by Dinerstein and Price (1991) and Laurie (1978). However, the survival of adults and subadults were comparable.

Cause specific mortality in the calves was 5.46 (SE 0.19)% by tiger predation and 8.9 (SE 0.36)% by infanticidal male. Similarly, mortality on subadults by poaching was 1.4 (SE 0.0002)%. Annual mortality on adults was 2.74 (0.0004)% by poaching and 2.74 (0.0004)% by old age.

Age of first calving, interbirth interval and birth season

The age of first calving ranged from 7.1 to 9.4 years giving average age of first calving (n = 8) at 8.06 ± 0.31 years.

Average interbirth interval (n = 11) was found 44.82 ± 3.64 months. The longest interbirth interval period recorded was 58 months and shortest was 22 months. The short duration were observed when mothers lost their calves to tiger predation, and infanticidal male. In such case, females were observed to mate within 5 months of the calves death and interbith interval were 22 to 24 months (N =2).

I recorded 44 new births of rhino calves across all months. There was no defined seasonality for the birth ($\chi^2 = 2$, df =2, p = 0.367; Kruskal Wallis one-way ANOVA). However, there was slight tendency of more births during the monsoon (July –August) and the cool dry season (January – February) than other months (Figure 6.4).

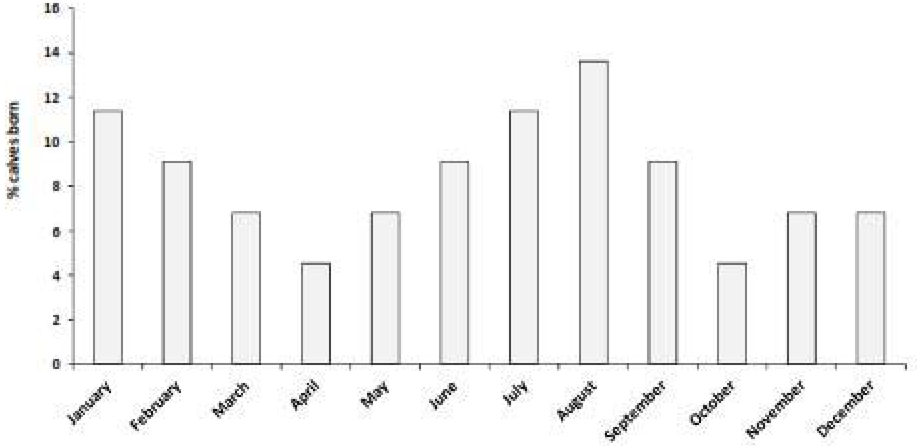


Figure 6.4. Monthly pattern of calving by rhino in Chitwan National Park as recorded (n = 44) between 2008 and 2012.

Population trend

The rhino population in Chitwan has fluctuated markedly with respect to time (Figure 6.5). The realize rate of increase (r) was 0.05 ($p = 0.06$, $R^2 = 0.92$) between 1966 and 2000 in Chitwan. The realized rate of decrease (r) was 0.076 between 2000 and 2005. However, the overall population has again increased gradually to near its former peak level with $r = 0.051$ ($p = 0.15$, $R^2 = 0.94$) after 2005.

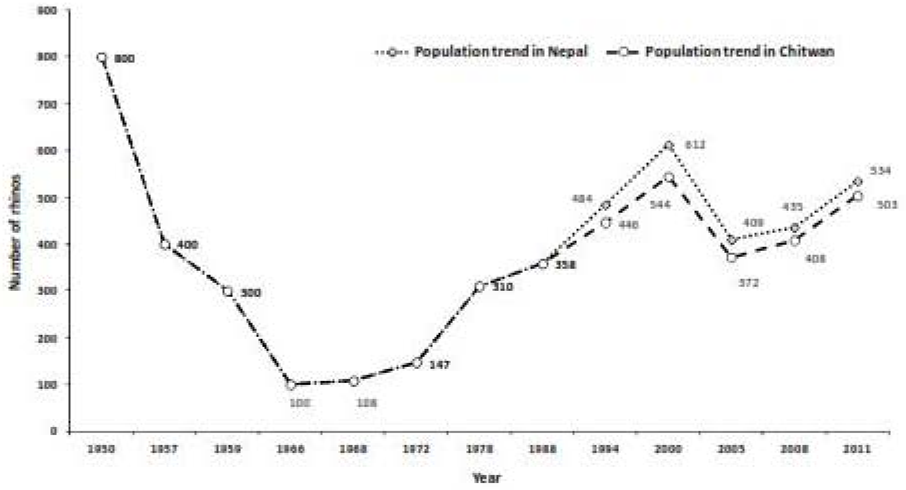


Figure 6.5. Rhino (*Rhinoceros unicornis*) population trend in Chitwan and Nepal between 1950 and 2011.

Mortality

Between 1998 and 2012, 365 rhino mortalities were registered in Chitwan. Of these, 48% were male, 35% female and 17% unsexed. Similarly, 85% were adult, 2% subadult and 13% calf. Poaching was the main causes of rhino mortality in Chitwan (47%) and other causes were old age (22%), natural calamities (7%), tiger predation (5%), trampling by adult rhinos (4%), disease (2%) and unidentified (6%) causes (Figure 6.6). Natural calamities included floods, exhaustion and drowning in muddy swamps and death by tree fall. Poaching related mortalities fluctuated between different years (Figure 6.7) but mortalities caused by other causes were more or less consistent across different years. In the past 15 years, average recorded annual mortality was 24.33 ± 0.65 individuals; of which poaching caused mortalities were 11.53 ± 0.76 individuals and natural and other factors caused mortalities were 12.52 ± 0.65 individuals per year in Chitwan National Park.

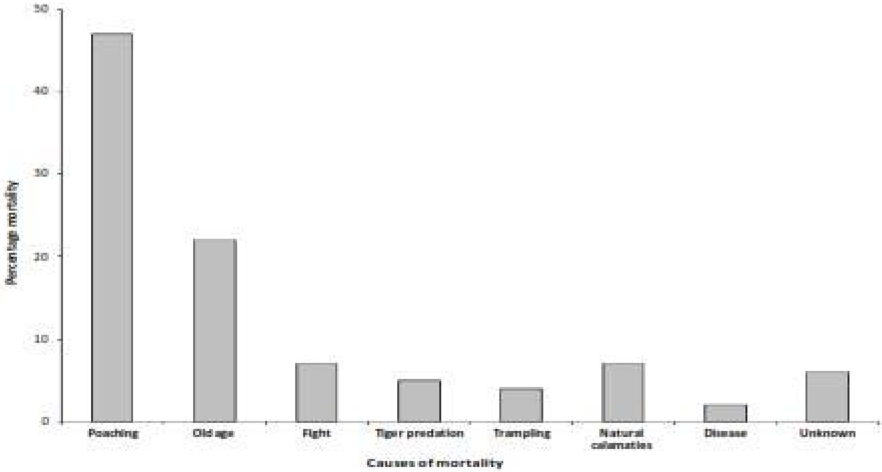


Figure 6.6. Causes of rhino (*Rhinoceros unicornis*) mortality (N = 365) in Chitwan, based on field records and as depicted in post-mortem reports (1998 -2012).

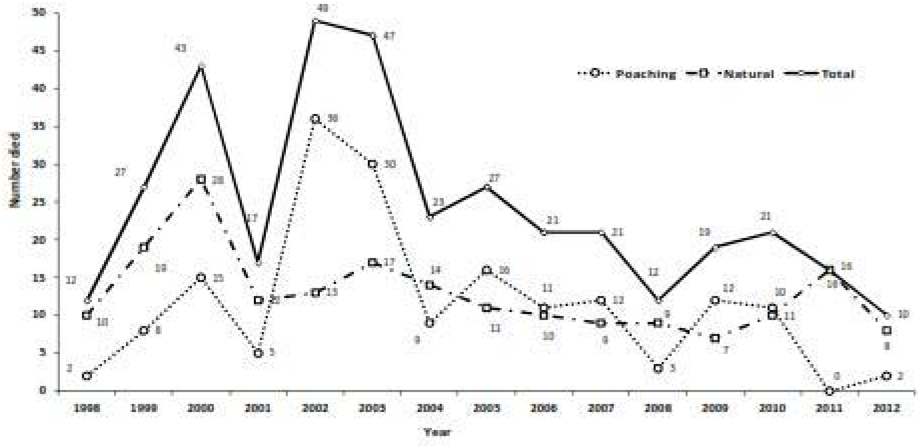


Figure 6.7. Mortality trends of rhinos (*Rhinoceros unicornis*) caused by poaching and natural death in Chitwan between 1998 and 2012. Mortalities other than poaching are presented as natural death in this figure.

Discussion

Adult sex ratio in Chitwan was found female biased which was also reported in previous studies (Laurie 1978, Dinerstein and Price 1991). Some of the demographic parameters were similar with these studies in the Sauraha subpopulation but there were some noticeable differences (Table 6.1). Observed differences were: i) Increment in the male proportion in the adult section of population, ii) Slight increment in interbirth interval and age of first calving, iii) High mortality of calves compared to previous studies, and iv) The Sauraha subpopulation had negative growth between 2008 and 2010 but after complete control on poaching in 2011 and 2012 the increment rate has changed into positive which was slightly less than previous studies (Table 6.1).

Table 6.1. Comparison of demographic parameters of greater one horned rhinoceros in Chitwan in different years.

Demographic parameters*	Present study (2012)	Dinerstein & Price (1991)	Laurie (1978)
In Sauraha Subpopulation			
Calf : cow ratio	0.68 ± 0.17	0.62	0.78
Sex ratio (f : m)	1.13 ± 0.20	1.28	1.22
Adult female : adult male ratio	1.12 ± 0.24	1.51	1.93
First age of calving	8.06 ± 0.31	7.25	7.1
Interbirth interval (months)	49.7 ± 2.14	48	42
Annual calf mortality %	30 ± 14	2.8	8.5
Annual subadult mortality %	1.7 ± 0.02	2.2	1.2
Annual adult mortality %	2.3 ± 0.2	2.9	3.4
Population growth rate (r) %	3.2	4.8	2 to 6
In overall Chitwan NP			
Sex ratio (f : m)	1.22 ± 0.09	1.17	1.12
Calf : cow ratio	0.6 ± 0.05	0.61	0.82
Population growth rate (r) %	5.1	4.8	6.1

* Present study was done between 2008 & 2012; Dinerstein & Price (1991) was done between 1984 & 1988, Laurie (1978) was done between 1974 & 1978.

Questions arise, why these differences were observed in the Sauraha subpopulation; while the overall population in Chitwan has increased in the recent years. The differences observed were may be due to: i) Sauraha subpopulation went through an indiscriminate poaching pressure between 2001 and 2005 in which may be more adult females were poached that resulted in an increased male proportion in the adult section. ii) Increased tiger population, 50 individuals in 1998 (Smith *et al.* 1998) to 125 in 2010 (Karki *et al.* 2009), in Chitwan National Park may have exerted increased predation on the rhino calves. On the other hand, increased adult male proportion may have contributed to more trampling of new born calves. In case of Sauraha subpopulation, both causes were equally important as out of 4 recorded (between 2010 & 12) calf mortalities (all were < 4months old) 2 were predated by tigers and 2 were trampled by males. Therefore, there was high mortality of calves than subadults and adults. The reason for low survival of adults than subadults could be because of poaching pressure. Because of their bigger horn sizes adults were more prone to poaching than subadults. Similarly, because of low population density intraspecific fight related mortalities were also less on the subadults in the study area. In contrast, Ferriera *et al.* (2011) reported higher mortality on the subadults than claves and adults in black rhinos at Kruger National Park, South Africa. Subadults had lowest survival, which most likely result through social interactions as young dispersing individuals may encounter older individuals more often (Ferriera *et al.* 2011). But in Sauraha subpopulation the subadults were found dispersing maximum of 20 km (east or west) from their mother's core home range areas.

However, in the overall rhino population of Chitwan National Park the proportion of female is comparatively better than previously reported (Table 6.1) and also the calf : cow ratio (0.60) was satisfactory. Similar pattern on the demographic patterns have been reported in the growing populations of white and black rhinos in Africa. For example, age of first calving 7.4 years, interbirth interval of 2 to 6 years in white rhinos (Rachlow and Burger 1998) and age of first calving 6.5 years, interbirth interval of 2.7 years in black rhinos (Hitchens and Anderson 1983) have been recorded.

There was no specific temporal pattern in the distribution of births. Mostly seasonality of birth occurs in highly seasonal environments. Aseasonality as observed in Chitwan is primarily due to high resource availability throughout the year in highly productive alluvial floodplains. The small peak observed during monsoon and late cool dry season could be due to marginally better nutritional advantages for lactating mothers.

Poaching has been the major cause of rhino mortality in Chitwan (Poudyal *et al.* 2009) causing nearly about 50% of the mortalities. Other causes were old age, intraspecific fight among males, male trampling, floods and so forth. It is obvious that poaching has become always limiting factor for the population growth and the rate of increase or decrease are heavily driven by the intensity of poaching rather than density dependent factors or other factors. Density dependent factors (eg. Rachlow and Burger 1998, Okita-Ouma 2010) and poaching (*eg.* Leader-William 1988, Emslie and Brooks 1999, Brodie *et al.* 2011) have been reported as limiting factors in black and white rhinos in African well protected rhino sanctuaries. In spite of heavy poaching pressures in different time periods Chitwan rhinos are still exhibiting rapid recovery with different rate of increase (Laurie 1982, Dinerstein 2003). Therefore, in highly productive environment of Chitwan where the rhino population is below the carrying capacity (Rothley *et al.* 2004), over 5% annual growth rate can be easily achieved if sufficient protection is maintained against poaching. The female skewed sex ratio and ample food supply in Chitwan are good indicators (Owen-Smith 1988, Emslie and Brooks 1999) of growing population. About 5 to 10% population growth rates of black and white rhinos have been reported elsewhere in well guarded protected areas in Africa (*eg.* Owen-Smith 1988, Rachlow and Burger 1998, Walpole *et al.* 2001, Okita-Ouma *et al.* 2010, Ferriera *et al.* 2011).

But recent *Mikania micrantha* invasions in the prime rhino habitats together with vegetation succession has resulted on decline in population density locally in previously known prime rhino habitats. For example: Icherny Island (ca. 5 km^2) where Dinerstein (2003) reported 10.5 rhinos/km^2 in 1986, I found only 5.7 rhinos/km^2 in 2011 and 2012 (during the peak season *i.e.* early monsoon). Similar pattern of decline was recorded in Baghmara community forest. In Baghmara there used to be 15 rhinos in 2000 (NTNC unpublished data) and only 9 rhinos were recorded in 2011 (present study). Both of these pocket areas (Icherny & Baghmara) were heavily invaded by *Mikania micrantha* after 2000. Decreased population densities on black and white rhinos caused by habitat degradations have also been reported elsewhere in Africa (eg. Foose *et al.* 1991, Adcock *et al.* 2007, Okita-Ouma *et al.* 2010). Therefore, I suspect that increased *Mikania micrantha* invasion in the rhino habitat exerted negative effect on the demographic parameters of rhinos and the first effect was manifested as decreased local population density. This indicates that if actions to control and manage *Mikania micrantha* are not taken in a meaningful way it may adversely affect other demographic parameters of rhinos as well. Therefore, continuous monitoring of the demographic parameters of rhinos and actions to control and manage *Mikania micrantha* invasions are of immense importance for long-term conservation management of rhinos in Chitwan concurrently with poaching control.

CHAPTER 7

Effect of invasive *Mikania micrantha* on greater one-horned rhinoceros conservation in Chitwan National Park

Nepal

My PhD Supervisor Dr. Y.V. Jhala and Co-supervisors Dr. S.R. Jnawali and Dr. Rajan Amin inspecting *Mikania micrantha* affetced habitats in Chitwan during study design.

Introduction

Invasive species are defined as those non-native species that threaten ecosystems, habitat or species (CBD 2008) and are key drivers of human-induced global environmental change (Vitousek *et al.* 1997). Invasive species are the second greatest agent of species endangerment and extinction after habitat destruction (Wilcove *et al.* 1998). Globally, almost 20% of vertebrates thought to be in danger of extinction are threatened in some way by invasive species (Macdonald *et al.* 1989). Invasive species have also posed serious impacts on ecosystem functioning and ecosystem services provisioning (Higgins *et al.* 1996, Pejchar and Mooney 2009). Invasive species can carry a heavy economic loss, in terms of reduced crop and livestock production, reduced native biodiversity, increased production costs and so forth. Pimentel *et al.* (2005) estimated annual costs within USA attributed to invasive species to be almost $120 billion. With the increasing global trade and climate change the problem of invasive is becoming further complicated. Realizing the threat of biological invasion more attention has been given on research, monitoring, control and management of invasive species in the recent years by global communities (Meiners *et al.* 2001, Zhang *et al.* 2004, Mangla *et al.* 2008, Hejda *et al.* 2009, Hovic *et al.* 2011, Inderjit *et al.* 2011).

Mikania micrantha H.B.K (henceforth termed as *Mikania*) is a multi-branched scrambling perennial vine belonging to family Asteraceae and is native to Central and South America (Holm *et al.* 1977). *Mikania* has been called "Mile-a-minute" and "plant-killer" (Waterhouse 1994; Ye and Zhou 2001). The species is widespread throughout tropical Asia, including China, India, Malaysia, Thailand, Indonesia and Nepal, and recently in Australia and USA. It can reproduce easily through both sexual and vegetative reproduction. It can produce a large number of seeds (170,000/m^2) (Kuo *et al.* 2002), that are small and light (8.92 x 10^{-5} g) (Hu and But 1994). Seed dispersal takes place mainly by wind and is the main source of invasion into disturbed environments. *Mikania* can also reproduce from stem fragments which root easily at the nodes. Most local spread results from vegetative propagation (Swamy and Ramakrishnan 1987, Wen *et al.* 2000). The seed has pappuses that facilitate dispersal by wind. The pappus enables seeds to cling to the clothing of humans, the skin of animals and other surfaces. When the seeds fall on the surface of water, the pappus helps prevent them from sinking and thus facilitates dispersing the seeds by runoff water (Yang *et al.* 2005).

Research, monitoring and management of biological invasions has not yet a priority in Nepal. In fact, very limited information is available regarding invasive species, their distribution and effect on the native species and ecosystems. Over 165 invasive plants have been identified in Nepal (Tiwari *et al.* 2005) and information regarding the invasive fauna is almost lacking. *Mikania* was first reported in early 1960s from district of Ilam in Nepal (Tiwari *et al.* 2005). *Mikania* has been reported spreading aggressively in Koshi Tappu Wildlife Reserve, Chitwan National Park and other parts of eastern and central Terai of Nepal especially along the moist riverine forests and alluvial floodplain grasslands. *Mikania* is the principal invasive species in Chitwan National Park (DNPWC 2009). Once established, *Mikania* smothers other plant species nearby. It then kills the smothered plants by cutting out the light (Huang *et al.*, 2000). *Mikania* also exerts allelochemical effects to the neighbouring plants and thereby inhibiting their growths (Chen *et al.* 2009). *Mikania* increases soil organic matter, total organic nitrogen and water soluble phenolics, but it reduces total plant species richness and the soil microbial activities in the invaded ecosystem (Kaur *et al.* 2012). The *Mikania* invasion has profound effects on soil chemical properties and soil microbial activities mostly negatively affecting to the native plants and favoring to the *Mikania* itself (Li *et al.* 2006).

In Chitwan, *Mikania* has smothered and killed various types of native plants (Sapkota 2007). It has invaded 45% of the prime rhino habitats along the moist riverine forests and alluvial floodplain habitats at various levels (DNPWC 2009, Murphy *et al.* 2012). The potential for the invasive alien plant to destroy prime rhino habitat is very high (Murphy *et al.* 2012). Failure to control this invasive species is likely to significantly reduce the rhino and other herbivores carrying capacity of this prime area in the next few years. The most immediate impact of this invasion on rhino is likely reduction in variety, quantity and quality of food plants. This could ultimately retard the growth rate and increase rhino-human conflicts due to rhinos invading buffer areas and crop fields, which will jeopardize the conservation of this charismatic species in Nepal. Realizing the immediate need of research on how the *Mikania* invasion has affected rhinos and their habitats this study was initiated in 2009. The following hypotheses have been tested and discussed in this chapter.

1. *Mikania* invasion decreases the availability of rhino food plants.

   Prediction: cover and biomass of preferred food plants should decrease in *Mikania* invaded habitats.

2. Rhinos prefer habitats that do not have *Mikania* or the habitats having low level of *Mikania* invasion.

   Prediction: foraging by rhinos should show avoidance of *Mikania* invaded areas.

Since the aim of the research is to provide scientific input for the conservation management of rhinos this chapter also synthesizes how the demography, time budget, activities and home ranges of rhinos have been affected by the *Mikania* based on the results of chapters 2 - 6 of this thesis.

Methods

Rhino capture and radiocollaring

Eight adult rhinos were radio-collared in the Sauraha area of Chitwan National park between 2010 and 2011 to study how the rhinos are responding to *Mikania* invasion in their habitats. By sampling these individuals I studied seasonal nutritional ecology of rhinos and focused to understand how invasive species have affected food and nutrition of rhinos (please see chapter 3). Similarly, seasonal time budget, activities, space use and ranging behavior have been investigated in chapter 4 and 5 and these were compared with previous studies and discussed with respect to habitat degradation by invasive *Mikania*. In this chapter, based on the findings of previous chapters (Chapter 2, 3, 4, 5 & 6) I have discussed how the *Mikania* has affected rhinos in Chitwan National Park. Some inferences have also been made.

Mikania distribution assessment and mapping

I tried to capture the signature of *Mikania* in a 5 m resolution multi spectral satellite image (Rapideye, Germany, March 2011, http://www.rapideye.com/products/ortho.htm). However, it was not successful because of intermingling nature of *Mikania* with the other species. Therefore, ground survey and mapping method was applied to assess *Mikania* distribution and coverage. In 2011, the intensive study area was divided in 500 m x 200 m grids. Each grid was visited on the elephant back and 50 m X 50 m plot within the grid centre was assessed for percentage coverage of *Mikania* and three dominant plant species in the plot. The percentage coverage by *Mikania* was estimated by an ocular estimation basis on 10% interval scale using RelevĖ method (Barbour *et al.* 1987). In addition to this systematic survey, locations obtained during regular rhino monitoring in 2011 were also used for distribution and mapping of *Mikania*. A total of 2,696 plots were used to evaluate the distribution and abundance and mapping of *Mikania* across the intensive study area. This information was analyzed in ArcGIS 9.3. A *Mikania* distribution map was then prepared by using interpolation method (Kriging, spherical considering 12 peripheral points with maximum distance 500m) (Oliver and Webster 1990).

Evaluating effects of *Mikania* on habitat use

Mikania was hypothesized to impact the foraging of rhinos since other activities of rhinos would less likely to be altered by *Mikania* invasion on the habitat. Overall habitat use and preference by rhinos would add noise to pin point the specific impact on foraging. I therefore, used only the peak foraging paths to test the hypothesis. The continuous dataset generated for every season from the GPS radio-collar and continuous monitoring of individual rhinos was used to prepare the daily movement tracks of rhinos in ArcGis 9.3. The daily tracks during the peak foraging hours (14:30 - 20:30 h and 4:30 – 8:30 h; for detail see chapter 4 on time budget and activity pattern) were selected so as to determine how rhinos were responding to *Mikania* invaded habitats during their peak foraging hours. The peak foraging routes were buffered 15 m in both side to represent the real habitat and area that the rhinos used during their foraging time. The habitat type and percentage cover of the *Mikania* on the buffer strip was calculated through the aid of ArcGIS 9.3. Annual and seasonal compositional analysis (Aebischer *et al.* 1993) was performed (% *Mikania* coverage area under 95% Kernel vs. % *Mikania* area under peak foraging routes) to analyze the preference of rhinos to different *Mikania* invaded and non-invaded habitats during the peak foraging hours. Resource selection function window based program (Leban 1999) was used for compositional analysis.

Effect of *Mikania* on biomass and cover of native species

In 2010, ten herbivore proof exclosures of 10m x 10m x 1.75m, size were installed in different categories of *Mikania* invaded (eg. no *Mikania*, <25% *Mikania*, 25 -50% *Mikania*, >50%

Mikania) prime rhino habitats (Figure 7.1). Five random quadrates of 1m x 1m sizes were clipped for every season both inside and outside the exclosures. To avoid edge effects 1m distance was left from the fence line while laying the quadrates for clipping (Mullen and Rongstad 1979, Jhala 1991). Average height of the grass, average coverage by each species and biomass of each species were measured in the quadrates. In this chapter, I have used these data to show how the species richness, cover and biomass production of native food plants of rhinos decreases with the increment of *Mikania* in the plots. I categorized % *Mikania* cover into 5 categories (0, 1-20, 20-40, 40-60 and > 60% *Mikania* invasion) post facto. These categories were considered as main effects for an ANOVA test after testing for normality. I also considered the effects of herbivores as another main effect i.e. plots clipped inside the exclosures were ungrazed and those outside grazed. I used two-way ANOVA to assess the impact of *Mikania* and ungulate grazing on a) native species biomass, b) native species cover, c) rhino food plant cover, d) rhino food plant biomass. Interaction between herbivore grazing and *Mikania* was statistically tested. If interactions and main effects were insignificant the test design was collapsed (data pooled) to a one-way ANOVA to gain statistical power. I used Tukeys and Duncans post hoc tests to test for differences between different *Mikania* abundance categories and the response variables.

Figure 7.1. A herbivore proof grazing exclosure set up in burnt tall grassland of Chitwan National Park to study the effects of *Mikania* on biomass production and plant biomass off-take by ungulates.

Results

Mikania distribution

Intensive study area was 63 km^2. Of which 17% was covered by Sal forest, 41% by tall grassland, 13% by short grassland, 7% by wooded grassland, 8% by river and riverbed and 14% by mixed riverine forest. Out of 2,696 plots assessed 29% plots did not have *Mikania*, 34% had <20% *Mikania*, 26% had 20 - 40% *Mikania* and 11% had > 40% *Mikania* coverage. The *Mikania* distribution map produced through kriging in ArcGIS 9.3 revealed that 21% of the study area was free of *Mikania* invasion, 49% of the habitat had mild level of invasion (<20%), 23% had intermediate level of invasion (20 - 40%) and 7% of the habitat had severe invasion (>40%) of *Mikania* (Figure 7.2).

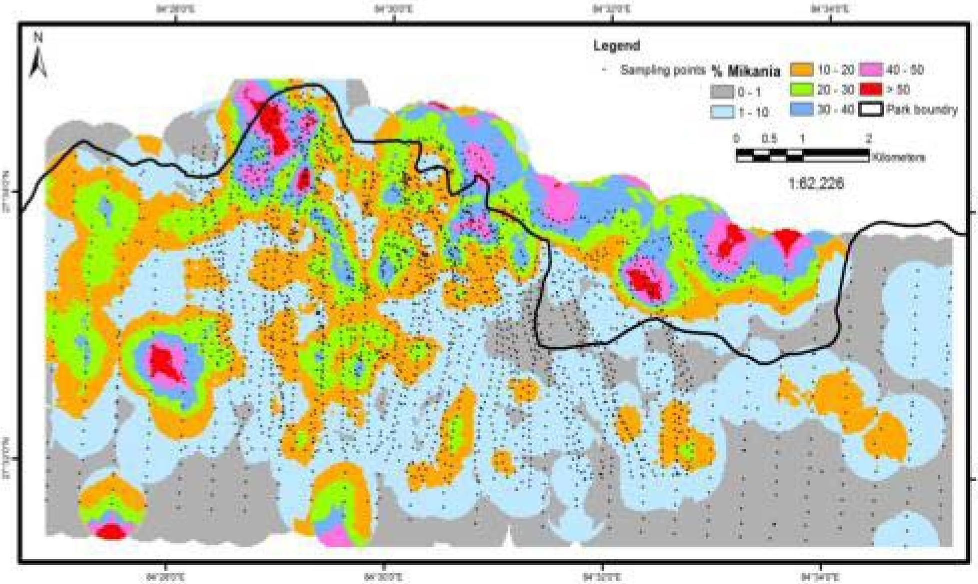


Figure 7.2. Distribution of *Mikania* in the intensive study area. The map shows different categories of *Mikania* invasion with 10% increments and points sampled for *Mikania*.

Mikania invasion was prominent on moist part of riverine forests, tall grasslands and short grasslands which were also preferred habitats of rhinos. Sal forest that covers drier part of study area and had intact canopy cover was found to be less invaded. The habitats that were next to the human settlements had higher *Mikania* coverage than in the core habitats (Figure 7.2).

Effect of *Mikania* on native forage plants

There was a negative effect of *Mikania* especially on grasses, herbs, shrubs and forbs. Simple linear regression equation depicted that with the increment in the % cover of *Mikania*, the biomass and % cover of native forage plants of rhinos decreased significantly (Figure 7.3, 7.4 & 7.5). The effects were more adverse in the areas having over 60% *Mikania* coverage.

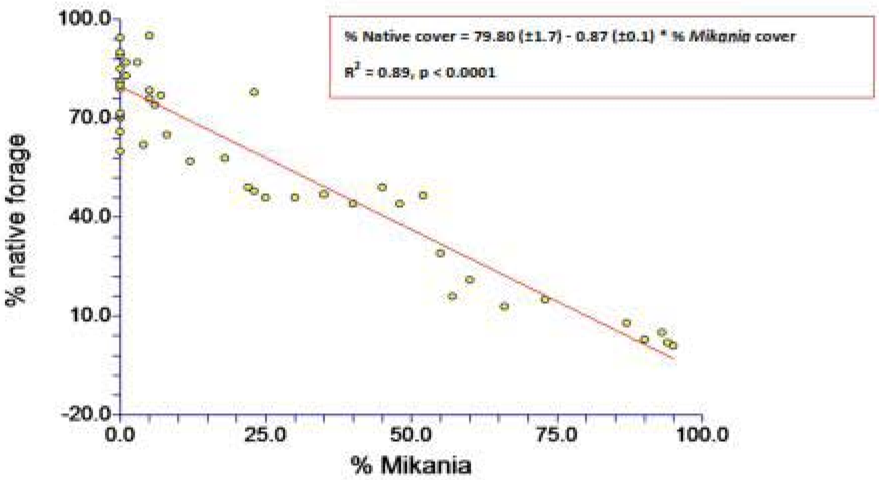


Figure 7.3. A scatter plot of native plant species cover versus % *Mikania* cover. The regression shows a significant declining trend in native species coverage as *Mikania* cover increases.

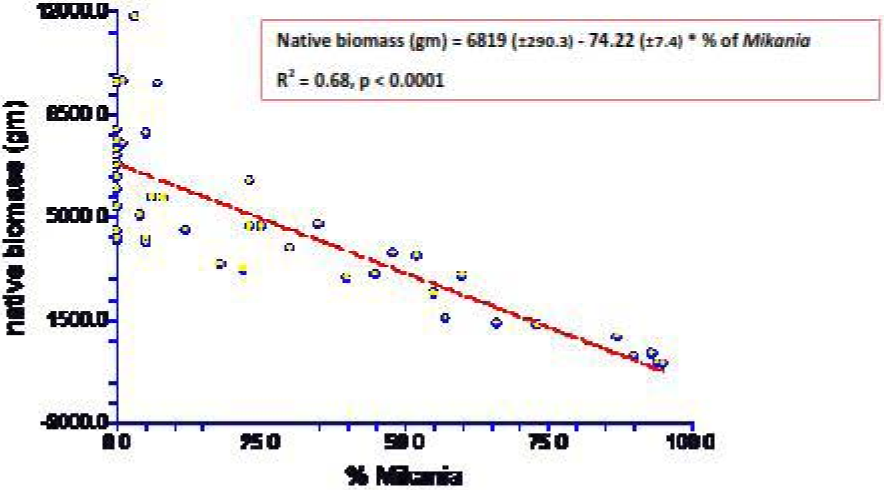


Figure 7.4. A scatter plot of native plant species biomass versus % *Mikania* cover. The regression shows a significant declining trend in native species biomass as *Mikania* cover increases.

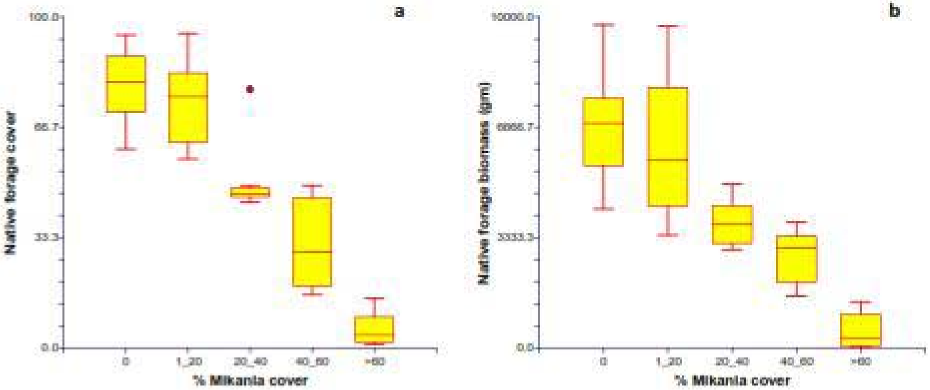


Figure 7.5. Box and whisker plot of a) native forage species cover and b) native forage biomass of rhinos plotted for various % cover values of *Mikania* in tall grassland habitat of Chitwan National Park, Nepal.

A significant effect of % *Mikania* cover was found to reduce the % cover of native forage plants (Two-way ANOVA, $F_{4,\,98} = 91.80$, $p < 0.0001$). However, there was no difference in % native cover inside or outside the exclosures (Two-way ANOVA, $F_{1, 98} = 0.015$, $p = 0.7015$) and there was no interaction between % cover of *Mikania* and ungulate grazing on cover % of native forage species of rhinos (Two-way ANOVA, $F_{4, 98} = 1.04$, $p = 0.3899$). Similarly, the effect of *Mikania* was significant on the biomass production of native forage species (Two-way ANOVA, $F_{4, 98} = 31.66$, $p < 0.0001$). The biomass production of native forage species differed inside and outside (Two-way ANOVA, $F_{1, 98} = 14.75$, $p = 0.0002$) the exclosures but there was no interaction effect (Two-way ANOVA, $F_{4, 98} = 1.65$, $p = 0.1678$) of grazing and % *Mikania* cover on forage biomass.

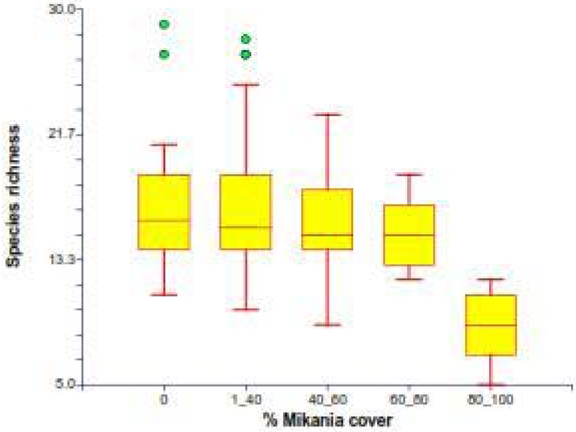


Figure 7.6. The box and whisker plot depicting number of species with level of *Mikania* invasion in the habitat.

Species richness reduced significantly as *Mikania* cover increased (One-way ANOVA; $F_{4, 22} = 10.10$, $p < 0.0001$) and the effect was severe after 80% invasion (Figure 7.6). In the moderately invaded (<40% *Mikania*) habitats species richness was not altered but species composition changed in favor of other invasive species like *Ageratum conyzoides*, *Ageratina adenophora*, *Parthenium hysterophorus* and some native *Dryopteris* species and shade tolerant herbs. Strikingly, the biomass production of major food plant species like *Saccharum spontaneum* decreased with increased *Mikania* invasion while the biomass of *Eragrotris tenella* was highest in 20-40% *Mikania* invasion and sharply reduced then after (Figure 7.7). However, most of the other food plant species showed same trend like of *Saccharum spontaneum*.

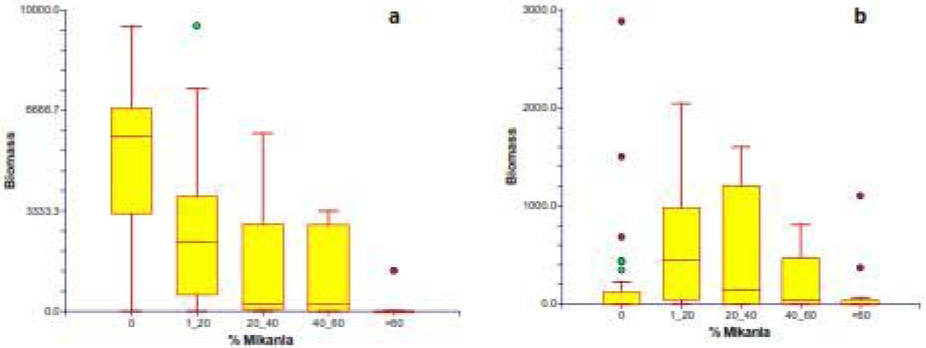


Figure 7.7. Box and whisker plot of a) above ground biomass of *Saccharum spontaneum* and b) *Eragrostris tenella* both preferred grass species of rhinos plotted for various % cover values of *Mikania* in tall grassland habitat of Chitwan National Park, Nepal.

Effect of *Mikania* on habitat preference during peak foraging

Rhinos preferred short grassland, tall grassland and riverine forests for foraging in all seasons (see chapter 5 for details). Habitat preference during foraging peaks (Figure 7.8) was decisively for lower percentage cover *Mikania* across all seasons.

I. Annual preference ($\chi^2_{(6\ df)} = 115.27$, $P < 0.0001$) was 10 - 20% > 20 - 30% > 1 - 10% > 0% > 40 - 50% > above 50%.

II. The cool dry season preference ($\chi^2_{(6\ df)} = 64.55$, $P < 0.0001$) was 10 - 20% > 20 - 30% > 30 - 40% > 1 - 10% > 0% > above 50% > 40 – 50%.

III. The hot dry season preference ($\chi^2_{(6\ df)} = 67.39$, $P < 0.0001$) was 10 - 20% > 1 - 10% > 20 - 30% > 0% > 30 - 40% > above 50%.

IV. The order of preference for the monsoon season was same ($\chi^2_{(6\ df)} = 75.56$, $P < 0.0001$) as of hot dry season.

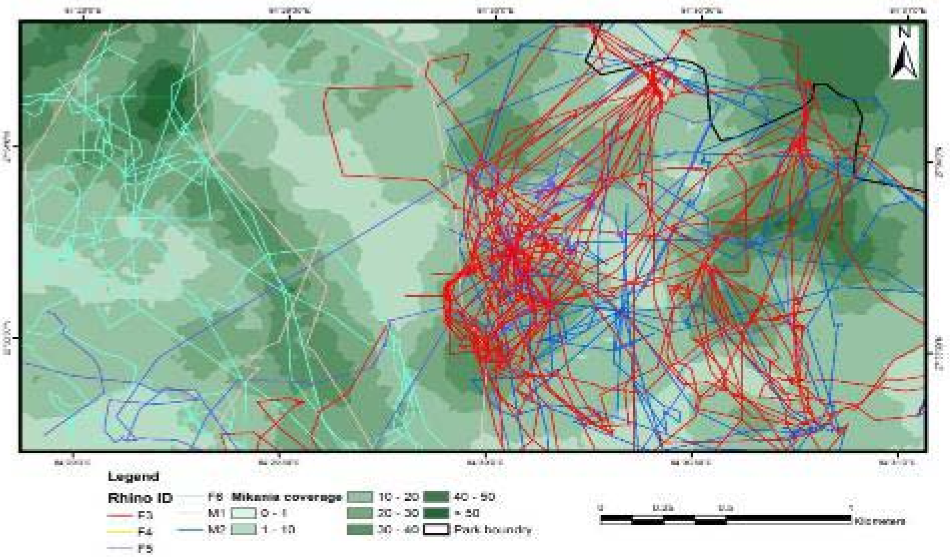


Figure 7.8. Some peak foraging routes of rhinos in different seasons overlaid on the *Mikania* distribution map.

Effect of *Mikania* on home range and time budget

Compared to previous radio-collar studies in the same study area the home ranges in present studies were 3 to 6 times bigger in females and males (For details please see chapter 5). Similarly, there was a slight increment (> 7%) in the time investment on feeding as well (For details please see chapter 3 & 4). I suspect that the increment of the home range and feeding time of rhinos may have been caused by various confounding factors such as habitat degradation, installation of power fence and low population density of rhinos and so forth (See chapter 3, 4 and 5 for details). However, data suggests that *Mikania* was one of the major factors. It can be predicted that increment on the *Mikania* invasion percentage (over 40%) and coverage in the rhino habitat will reduce availability of food plants and lead to habitat degradation resulting in detrimental cascading effects within the ecosystem.

Effect of *Mikania* on demography

There was no significant change on the overall demographic parameters of rhinos within Chitwan National Park since last 15 years. However, there was a continuous population decline in the sauraha subpopulation (49% since 1988) (See chapter 2 for details). This decline was suspected to be a cumulative effect of multiple factors like poaching, removal for translocation, and habitat degradation. Therefore, *Mikania* alone cannot be claimed as a factor leading to this change. However, my data suggest that the local population density of rhinos has been declined in *Mikania* dominated habitat patches. For example, principal rhino habitat patches like Icherny and Baghmara, where *Mikania* invasion was severe (Figure 2) compared to other parts, rhino density was lower than previously reported. Dinerstein (2003) reported about 10.5 rhinos/ km^2 in the Icherny island of sauraha during 1986 but I found only 5.7 rhinos/km^2 in 2011 and 2012 indicating a sharp decline in rhino density. Similar pattern of decline (maximum 15 rhinos in 2000) (NTNC unpublished data) vs. 9 rhinos in 2011 (present study) in rhino numbers within the Baghmara community forest was observed in a decade (NTNC, unpublished data on rhino monitoring). Other demographic parameters were not detected affected due to *Mikania*. Therefore, I suspect that the increased *Mikania* invasion in the rhino habitat has initiated to negatively affect the demographic parameters of rhinos and the first manifestation was noticed as decreased local density in previously favored habitats.

Discussion

Mikania invasion in the study area initiated in early 2000 and therefore it was still in the dispersal and establishment phase. During this period, *Mikania* has become a principal invasive species and has invaded two third of the study area at various level. The patches that were invaded in early 2000 have turned into severe invasion (>50% *Mikania)* and intermediate invaded patches will turn into *Mikania* dominated assemblage within few years. The level and intensity of invasion is exacerbated by disturbance factors like fire, annual flood and human-mediated dispersal (Swamy and Ramakrishnan 1988). The high level of *Mikania* invasion in the habitats that were close to human settlement could be due to the high level of human-mediated disturbances (Murphy *et al.* 2012). *Mikania* has also been reported affecting the local livelihoods in Chitwan (Rai *et al. 2012*). Annual fire and grass cutting by local communities in Chitwan are traditional practices (Mishra 1982, Lehmkuhl 1989) and about 45% of the study area gets burnt annually. *Mikania* is a fire adapted species and is very efficient in nutrients utilization compared to native plants (Swamy and Ramakrishnan 1988). The nutrients are bountiful in supply immediately after the burning of tall grasslands in Chitwan. Any sort of disturbances can help invasive species for their dispersal, and successful establishment in the new habitats (Swamy and Ramakrishnan 1988). Therefore, the extent of invasion in remaining habitats that are less invaded or have not yet been invaded will depend on the intensity of disturbance (driving) factors that are exacerbating the invasive *Mikania* and application of any control measures.

As reported in previous studies (*e.g.* Huang *et al.* 2000, Wang *et al.* 2004, Kaur *et al.* 2012) adverse effects of *Mikania* on the native plants were confirmed in Chitwan National Park as well. As the percentage cover of *Mikania* increased the species richness, biomass and percentage coverage of native forage plants of rhinos decreased. *Saccharum spontaneum, Saccharum bengalense, Narenga porphyrocoma, Imperata cylindrica, Phragmites karka,* and *Cynodon dactylon* were the main forage grasses of rhinos. While *Coffea bengalensis, Callicarpa macrophylla, Dalbergia sissoo, Acacia catechu, Bombax ceiba* and *Trewia nudiflora* (fruits) were major browse species. All of these grasses and browse species were killed by *Mikania* (Figure 7.9). The reason for the low species richness, low cover percentage and low biomass production of native forage species in the *Mikania* dominated habitats could be attributed to smothering and cutting out of light by *Mikania* (Huang *et al.* 2000), allelochemical effects to neighboring plants by *Mikania* (Chen *et al.* 2009) and profound effects on soil chemical properties and soil microbial activities mostly negatively affecting the native plants and favoring *Mikania* itself (Li *et al.* 2006). Good species richness in intermediate *Mikania* invasion (<40%) level could be due to edge effects and favorable conditions created by *Mikania* invasion to certain opportunistic plants. In the intermediate *Mikania* invaded habitats other invasive species like *Ageratum conyzoides*, *Ageratina adenophora*, *Parthenium hysterophorus* and some native *Dryopteris* species were common whereas they were less or absent in the non-invaded sites. But in some sites production of *Eragrostris tenella*, preferred forage grass of rhinos, was good in intermediate *Mikania* invasion. It may be due to suppression of dominant grass *Saccharum spontaneum* by *Mikania* and the associated species like *Erasgrostis tenella* got opportunities to outcompete other native species in the low *Mikania* level.

Figure 7.9. Radio-collared female rhino and calf in *Mikania* invaded *Saccharum spontaneum* and *Saccharum bengalensis* dominated tall grassland. In the picture, *Mikania* has killed the native forage species substantially (>80%) in the invaded site while the non-invaded site (background) still has very good native forage in flowering stage.

Mikania grows very well in moist tall grasslands and riverine forests which were also preferred habitats of rhinos. Therefore, the highest intensity of *Mikania* invasion was coincided with the prime rhino habitats in Chitwan (DNPWC 2009, Murphy *et al.* 2012). *Mikania* has become an unavoidable component of Chitwan ecosystem. It is everywhere and intermingled with native forage plants and there is less choice whether the herbivores do like it or not. In response to this availability of *Mikania* in the habitats, rhinos have initiated to forage on the *Mikania,* and it contributed about 3% of the annual diet (See chapter 3 on nutrition). Nutritionally *Mikania* was as good as of native forage (See nutritional analysis, chapter 3) but because of the alkaloids present on the *Mikania* after certain level of intake rhinos cannot eat this weed as can turn into poison and reduces digestive performance.

The compositional analysis has clearly demonstrated that rhinos do not prefer high *Mikania* invaded habitats while foraging. The reason is obvious; in high invaded habitats they get less to eat in spite of large foraging efforts. Now the questions arise: why did not the rhinos prefer

Mikania non-invaded habitats for foraging? Why did they prefer low *Mikania* invaded habitats for foraging? The habitats without *Mikania* invasion in the study area were mostly Sal forest, heavily grazed (by livestock) dry meadows on the fringe of the Park, and a small portion of tall and short grasslands and were less preferred habitats by rhinos. In fact, habitats having low level of *Mikania* invasion (< 30%) were productive habitats. In such habitats there were ample shade loving herbs sprouted and native grasses emerging to compete with *Mikania* invasion. The rhinos preferred this habitat because of the availability of good forage species. On the other hand, in monotonous tall grassland mild *Mikania* invasion does play a role to mechanical breakdown of tall grassland by its smothering and choking effects and hence creates openings making it as a different type of micro-habitat. Such micro-habitats were found preferred by rhinos and other species of herbivores in Chitwan because of higher visibility and availability of nutritious food plants. But once it turned into *Mikania* dominated assemblage it was avoided or less used for foraging.

The finding of foraging habitat preference clearly demonstrated that some pockets of short and tall grasslands were very crucial for foraging. Any *Mikania* control and management program should immediately focus on these areas so as to secure the foraging grounds of rhinos. Figure 7.10 depicts that Icherny, patch 1 periphery and Padampur grasslands along the Rapti river floodplain in the study area were priority areas for *Mikania* control program.

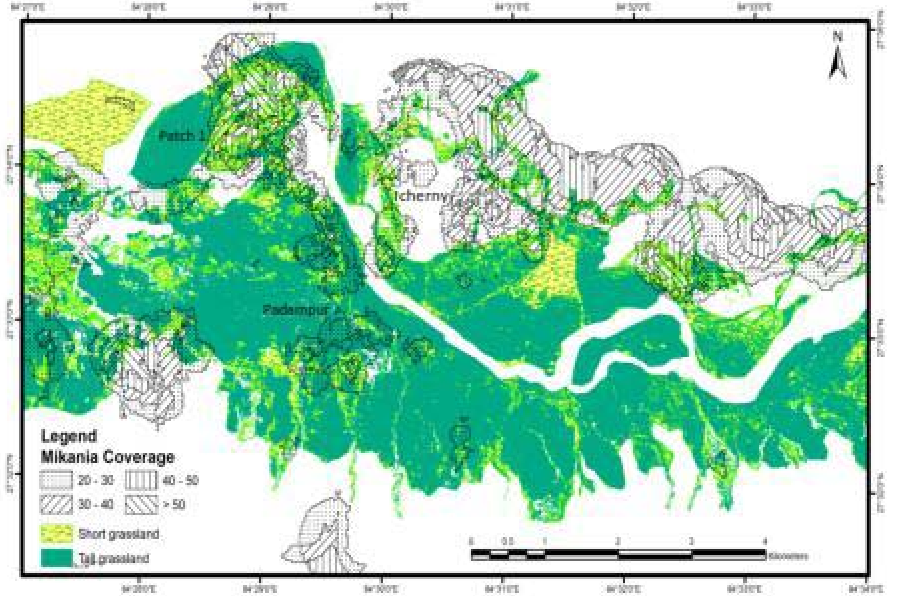


Figure 7.10. Map showing priority areas (short and tall grasslands invaded by *Mikania*) to rhinos for initiating *Mikania* control and management programs so as to secure preferred foraging grounds.

There was 3 to 6 folds increment on the annual and seasonal home ranges of rhinos in the study area compared to previous radio-collar studies done in the *Mikania* free environment during 1990s. Although the increment in the home ranges of rhinos cannot be solely argued as an impact of *Mikania*, my data suggest that the *Mikania* caused habitat degradation is one of the principal factors for home range increment. Similarly, a slight increment of the time invested on feeding has been observed compared to previous studies. This again argued that *Mikania* caused decrease in the food plants availability has major contribution on this increment. For details please see chapter 4 and 5.

The effects of density dependent factors and habitat quality degradation are manifested after a certain time period (slowly) on the demographic parameters of megaherbivores compared to small ungulates or carnivores. It is because of their long interbirth interval, birth of single calf at a time and delayed age of sexual maturity (Owen-Smith 1988). There was no significant change on the demographic parameters of rhinos in overall Chitwan National Park since a decade. However, there was a continuous population decline in the Sauraha subpopulation (See chapter 6 on demography and chapter 2 on status). But it was suspected as an effect of multiple factors like poaching, translocation harvesting, and habitat degradation. Therefore, *Mikania* alone cannot be claimed as a factor leading to this change. However, present data suggest that there was a decrease on rhino density in the *Mikania* dominated patches like in Icherny and Baghmara. But the other demographic parameters in the study area were comparable with previous studies. This suggest that rhinos may have moved to the less *Mikania* invade habitats where there was a good availability of food plants and therefore decrease in the density in some of the previously known prime rhino habitats. Therefore, I suspect that the increased *Mikania* invasion in the rhino habitat has initiated negative effects on the demographic parameters of rhinos and the first manifestation was declined rhino density within highly invaded patches. If *Mikania* infestation continued to grow in the habitats other demographic parameters of rhinos will also be affected in the future. Furthermore, the cascading effects of *Mikania* on the ecosystem will affect the population density and demographic parameters of other herbivores like chital (*Axis axis*), sambar (*Rusa uniculor*), and hog deer (*Axis porcinus*) which are major prey species of tigers in Chitwan. This suggests that the whole ecosystem of Chitwan is now threatened by this weed. Therefore, further research to understand the dynamics of the cascading effects of *Mikania* and concerted actions to control and management of *Mikania* are urgently needed.

CHAPTER 8

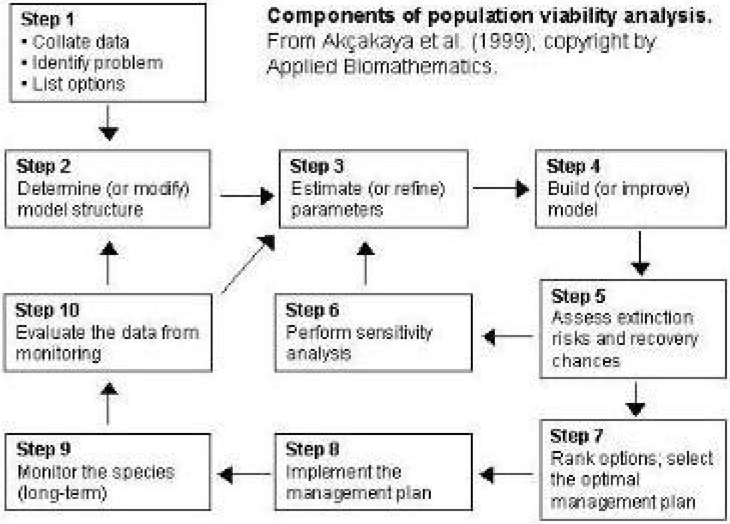
Population habitat viability analysis (PHVA) of greater one-horned rhinoceros in Chitwan National Park

Nepal

Photo: Mother and calf group of rhinos wallowing in the muddy oxbow lake at Chitwan.

Introduction

Population habitat viability analysis (PHVA) is a process of identifying the threats faced by a species and evaluating the likelihood that it will persist for a given time into the future. Population habitat viability analysis is often oriented towards the conservation and management of rare and threatened species, with the goal of applying the principles of population ecology to improve their chances of survival. Threatened species management has two broad objectives. The short term objective is to minimize the risk of extinction. The longer term objective is to promote conditions in which species retain their potential for evolutionary change without intensive management (Akçakaya et al. 1999, Boyce 1992). Steps of PHVA are presented on the following diagram (Figure 8.1).



Components of population viability analysis.
From Akçakaya et al. (1999); copyright by Applied Biomathematics.

Figure 8.1. steps and components of PHVA adopted from Akçakaya *et al.* (1999)

The VORTEX computer simulation model is a Monte Carlo simulation of the effects of deterministic forces, as well as demographic, environmental and genetic events on wildlife populations. The program was designed to model long-lived species with low fecundity, such as mammals, birds and reptiles (Lacy 1993). Since rhino population in Chitwan is isolated and has undergone many ups and downs mainly because of poaching and habitat loss there is always a chance of population crash and extinction in the long-run. Chitwan rhino population has been well studied and data on life histories, demographic parameters, poaching, frequency of natural calamities and habitat parameters are available. Therefore, extinction threat by different causes can be analyzed with reasonable accuracy by using the modern scientific tool such as population habitat viability analysis (PHVA) in program VORTEX. First PHVA of greater one-horned rhinoceros was done in India (Molur *et al.* 1995) and no PHVA for Nepal rhinos has been carried out yet. In this chapter, based on the available data from literatures and my own 5 years data on population and habitat dynamics has been used for parameterizing a PHVA analysis. The PHVA analysis was done in a manner so as to explore and prioritize threats causing negative impacts on the rhino population of Chitwa that can be utilized for long-term conservation strategy development of the species.

Methods

Rhino life history parameters were obtained either from the current study or published literature (*eg*. Dinerstein 2003, Dinerstein & Price 1991, Laurie 1978):

i) Population size estimates were carried out through block count method in 2011. A total of 503 rhinos were recorded in Chitwan. Sex ratio, number of breeding females in the population, number of calves and age structure of population was known through this total count or either from intensive long-term monitoring of Sauraha subpopulation in Chitwan. Details are available in chapter 2 and Chapter 6.

ii) Population survival and mortality data were used from the data I collected during last 5 years (2008 – 2012) in Chitwan. Current annual survival was 0.69 ± 0.14 for young calves (<1 year old), 0.98 ± 0.01 for juveniles and subadults (1 to 7 years old) and 0.977 ± 0.01 for adults (>7 years). Age of first calving of female varied between 7 and 8 years and maturity age for males was 10 years (Dinerstein 2003, present study). Sex ratio at birth was taken as 1:1 and maximum breeding age for females was modeled as 30 years. I used this maximum breeding age information based on the data available from long-term monitoring of rhinos in Chitwan that was being done by NTNC since 1980s (NTNC-BCC unpublished data). Percentage adult breeding female and male was determined as 25 (SE 2)% from the current field data. Interbirth interval was used as 4 (SE 0.25) years based on the present study and previous study of Dinterstein (2003).

iii) Dinterstein (2003) and Rothley (2004) have assumed Chitwan's carrying capacity for greater one-horned rhinos as 800. A rapid assessment method was used to assess whether the Chitwan rhino habitat can support 800 rhinos or not. Field survey data suggested that rhinos were confined within ca.500 km^2 area (including buffer zone habitats) of Chitwan (See chapter 2). Present density of rhinos in the habitats varied between 0.001 and 5.6 rhinos/km^2 (see chapter 2). Based on water availability and availability of forage plants (*Saccharum spontaneum*, *Imperata cylindrica* together with browse species) habitats were classified as most suitable and moderately suitable. Out of 500 km^2 habitat, 240 km^2 was found most suitable habitat. Based on the current rhino density in different habitats, I assumed that the best habitat can conservatively support 3 rhinos/km^2. This translates to 720 rhinos supported within the most suitable habitat. Similarly, the remaining 260 km^2 moderate habitat can conservatively support a density of 0.4 to 0.5 rhinos/km^2 translating to 100 more rhinos. Thus, I also assumed that the previously estimated conservative carrying capacity of 800 rhinos in Chitwan seems to be quite reasonable. Therefore, in PHVA models carrying capacity was used as 800 (EV 5) for Chitwan.

iv) *Mikania micrantha* (hereafter *Mikania*) has seriously impacted rhino habitat in Chitwan rhinos in the recent years. In the study area *Mikania* started invasion in year 2000 and in twelve years period it has completely (>40%) invaded 7% of the prime rhino habitat and another 70% is under various level of coverage. In totality, it has completely degraded ca. 15% of the rhino habitat in 12 years (See chapter 7). I computed the rate of conversion of rhino habitat to non rhino habitat due to severe *Mikania* infestation as 2% per year based on the survey of 2008 and 2011 in the Sauraha study area. I estimated that in 25 years period if uncontrolled *Mikania* can heavily damage upto 50% of the rhino habitat i.e 50% of the rhino carrying capacity may be reduced. *Mikania* invades moist area that are occasionally disturbed (fire, flood, grass cutting *etc.*). Such habitats that can support high cover of *Mikania* are only about 50% of the current rhino habitat. Therefore, after invading all the suitable habitat i. e. 50%, there would be a very little or no more habitat left for *Mikania* to invade. The negative effects and spread of invasive plants are likely to be decreased with time (Holmes et al. 2009, Strayer et al. 2006). Therefore, in the VORTEX modeling I have assumed that 50% of the carrying capacity of Chitwan habitat for rhinos may decrease in coming 100 years in the worst scenario if invasion is not controlled.

v) A major limiting factor for Chitwan rhino is poaching. In last 15 years (1998 -2012) average annual loss of rhinos was 12 individuals by poaching. This includes the worst poaching years of armed conflict time period in Nepal (See chapter 6 for detail). But this number can go high if Nepal faces more poaching of rhinos like South Africa is facing today. The current estimates of rhino survivorship include mortality caused by lowest level of poaching mortality that occurred during study period (2008 – 2012). Only 27 rhinos were poached during entire duration. Therefore, subsequent model wherein rhino harvest (poaching) is included amounts to additional mortality caused by poaching or translocation. Therefore, worst scenarios of poaching were built by using additional 12 rhino poaching/year and 16 rhino poaching/year. In the mild scenario additional 6 poaching/year or 8 rhino poaching per year were used to explore sensitivity of model on different poaching scenarios. Sensitivity of the model was also explored on different level of poaching to male and female adult rhinos.

vi) Till date no devastating natural catastrophes have been reported affecting the Chitwan rhinos. Forty years records of the National Park revealed no disease epidemics in Chitwan rhino population (Kamal Gaireh, Senior Veterinary Officer, pers. comm.). The worst flood in Chitwan in the recent history was reported in 1993 (Dhakal *et al.* 2011). Although actual loss of rhinos by this flood has not been documented, experienced senior wildlife technicians working in Chitwan since last 30 years suggested that the worst flood like of 1993 in Chitwan may kill 5% of the rhino population (Bishnu Lama, pers. comm.). Based on this and my own 20 years experiences in Nepal Terai, 5% loss of rhinos in every 25 years by flood catastrophe seems to be an extreme and was used to build the model by reducing survival of all age classes by 5%.

I parameterized the PHVA based on above field data and literature data to formulate 12 scenarios (Table 8.1). Each scenario was run for 1,000 times in VORTEX 9.99 (Lacy *et al.* 2009). The parameters were changed by 10% to understand the sensitivity of model outcome on the precision of parameter estimates especially age of first reproduction and calf as these two parameters differed significantly between estimates obtained by Dinerstein (2003) and present study. PHVA was carried out to identify and prioritize the sensitivity of threats faced by the Chitwan rhinos and to evaluate the likelihood that the population will persist for a next 100 years. Under the PHVA models, population persistence (probability of extinction), median time to extinction, mean final population size and stochastic rate of increase (r) were evaluated.

Table 8.1. Different scenarios modeled in program VORTEX for Chitwan rhino population.

Scenario No.	**Scenario details**
Scenario 1	Every year 12 rhinos poached, rhino carrying capacity of habitat decreases annually by 2% for 25 years. 5% rhinos killed by catastrophic flood once every 25 years.
Scenario 2	Annually 16 rhinos poached, carrying capacity of habitat decreases annually by 2% for 25 years, 5% rhinos get killed by catastrophic flood once every 25 years.
Scenario 3	Annually 8 rhinos get poached, rhino carrying capacity of habitat decreases annually by 2% for 25 years, 5% rhinos get killed by catastrophic flood once every 25 years.
Scenario 4	No catastrophes were assumed in this scenario. Annually 8 rhinos get poached, rhino carrying capacity of habitat decreases 2% annually for 25 years.
Scenario 5	No catastrophes and no loss in the current carrying capacity of the habitat was assumed in this scenario. But annually 12 rhinos get poached.
Scenario 6	Ideal situation was assumed in this scenario. No poaching, no decline in the carrying capacity and no catastrophes.
Scenario 7	No poaching, 2% carrying capacity declines/year for 25 years, 5% rhinos get killed by catastrophic flood once every 25 years.
Scenario 8	12 poached/year, no carrying capacity declines, 5% rhinos get killed by catastrophic flood once every 25 years.
Scenario 9	No poaching, no carrying capacity declines, 5% rhinos killed by catastrophic flood once every 25 years.
Scenario 10	6 rhino poaching/year, carrying capacity declines by 2%/year for 25 years, 5% rhinos get killed by catastrophic flood once every 25 years.
Scenario 11	12 rhino poaching /year, carrying capacity declines by 2%/y for 25 years, 5% population loss by catastrophe in every 25 years, age of first calving 8 instead of 7 because of habitat degradation, annual calf mortality remains 10% instead of current rate of 30%.
Scenario 12	12 poaching/year, carrying capacity declines by 2%/year for 25 year, 5% rhinos killed by catastrophic flood once every 25 years, annual calf mortality remains 10% instead of present rate of 30%, first calf in 7 years.

Results

The results of PHVA runs in the VORTEX under different scenarios were as follows:

Scenario 1: This scenario represents one of the extreme probabilistic scenarios of Chitwan. Poaching at the present level (12 rhinos poaching per year as of last 15 years) in combination with *Mikania* and flood catastrophes resulted in 38% (SE 5%) probability of population extinction in next 100 years (Figure 8.2).

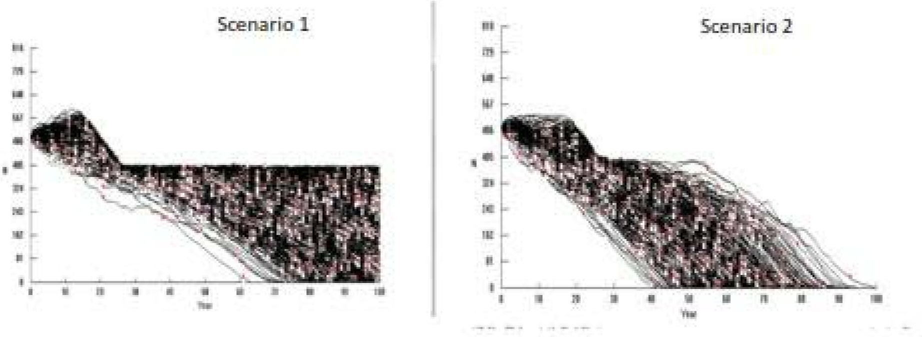


Figure 8.2 Long-term (100 years) extinction probability of Chitwan rhino population under the scenario 1 (12 poaching/year, 50% carrying capacity loss in 25 years and 5% population loss once every 25 years) and scenario 2 (16 poaching/year, 50% carrying capacity loss in 25 years and 5% population loss once every 25 years by flood catastrophe) in VORTEX.

Scenario 2: Under this worst scenario in which 16 rhinos were poached every year in combination with *Mikania* and flood catastrophes there was a 100% probability of rhino population extinction in Chitwan in next 100 years (Figure 8.2).

Scenario 3: In the mild poaching scenario (8 rhino/year) there was no probability of extinction of rhinos in Chitwan even 50% carrying capacity was reduced by *Mikania*. But the population decreased to 375 after 100 years (Figure 8.3).

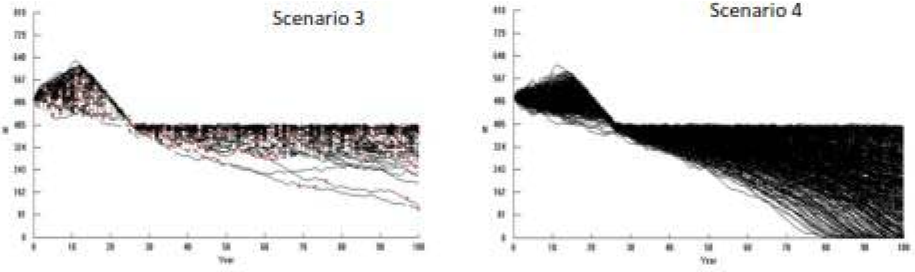


Figure 8.3. Long-term (100 years) extinction probability of Chitwan rhino population under the scenario 3 (8 poaching/year, carrying capacity decline 50% in 25 years and 5% population loss once in 25 years) and scenario 4 (8 rhinos poached/year, 50% carrying capacity decline in 25 years and no catastrophes) in VORTEX.

Scenario 4: Effect of flood for the persistence of rhinos was minimal. Even without the effect of flood there was a 16% (SE 1.6%) probability of population extinction if poaching and *Mikania* continued as of scenario 1 level (Figure 8.3).

Scenario 5: The combined effect of *Mikania* and catastrophe was significant. In the absence of both there was a very small (1%) probability of rhino extinction from Chitwan due to poaching itself. The final population in the next 100 years was about 700 (Figure 8.4).

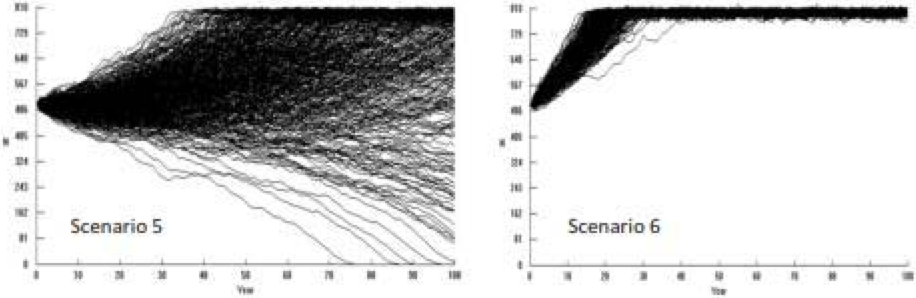


Figure 8.4. Long-term (100 years) extinction probability of Chitwan rhino population under the scenario 5 (12 rhinos poached/years and no carrying capacity decline and no catastrophes) and scenario 6 (no poaching, no carrying capacity loss and no catastrophes) in VORTEX.

Scenario 6: In ideal condition there was no probability of rhino extinction and final population after 100 years was at the carrying capacity level (Figure 8.4).

Scenario 7: Effect of poaching on the Chitwan rhinos was found significant. In the absence of poaching the effect of *Mikania* and flood were not significant to cause extinction of Chitwan rhinos. However, these factors reduced the rhino population level at about 400 after 25 years (Figure 8.5) and oscillated at that level for 100 years.

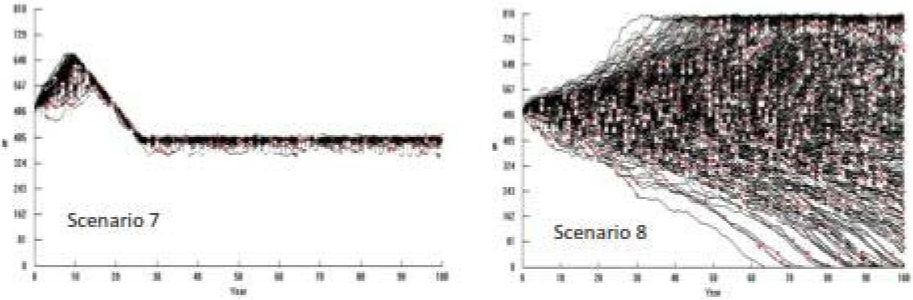


Figure 8.5. Long-term (100 years) extinction probability of Chitwan rhino population under the scenario 7 (No poaching, 50% carrying capacity decline in 25 years and 5% population loss once every 25 years) and scenario 8 (12 poaching, no carrying capacity decline and 5% population loss once every 25 years by flood) in VORTEX.

Scenario 8: The effect of *Mikania* was found significant but was having less impact compared to poaching. In the absence of *Mikania* there was still a probability (6.6%) of population extinction due to combined effect of poaching and flood (Figure 8.5). However, population remained as of present level in next 100 years.

Scenario 9: Flood had no effects on the population persistence. In the absence of *Mikania* and poaching the rhino population was oscillating at carrying capacity level in the next 100 years even where the flood was modeled as catastrophe (Figure 8.6).

Scenario 10: Mild poaching (6 animals/year) had no extinction risk in the presence of *Mikania* infestation combined with flood effects. But the population decreased to 375 in next 100 years (Figure 8.6).

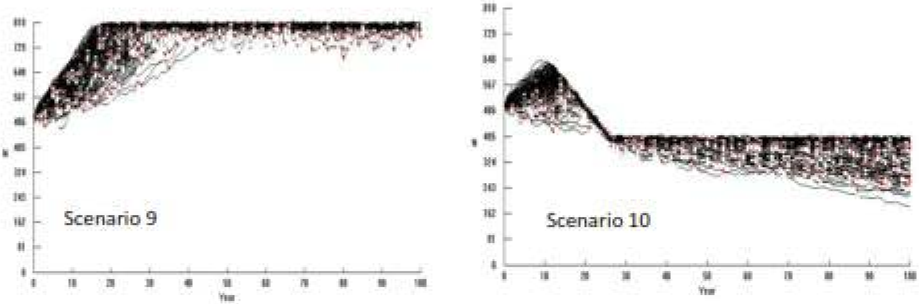


Figure 8.6. Long-term (100 years) extinction probability of Chitwan rhino population under the scenario 9 (no poaching, no carrying capacity decline but 5% population loss by flood once in every 25 years) and scenario 10 (6 poaching, 50% carrying capacity decline in 50 years, 5% rhino population loss once in every 25 years by flood) in VORTEX.

Scenario 11: The model was not very sensitive on age of first calving. But combined with poaching and *Mikania* even with the low calf mortality (10% instead of 30%) there was a 31.6% (SE 2%) probability of extinction (Figure 8.7).

Scenario 12: The age of first calving and calf mortality if combined exerted effects on persistence. In the healthy population (calf mortality 10%, age of first breeding 7 years) even with high poaching and *Mikania* together with flood there was no probability of extinction in the next 100 years (Figure 8.7).

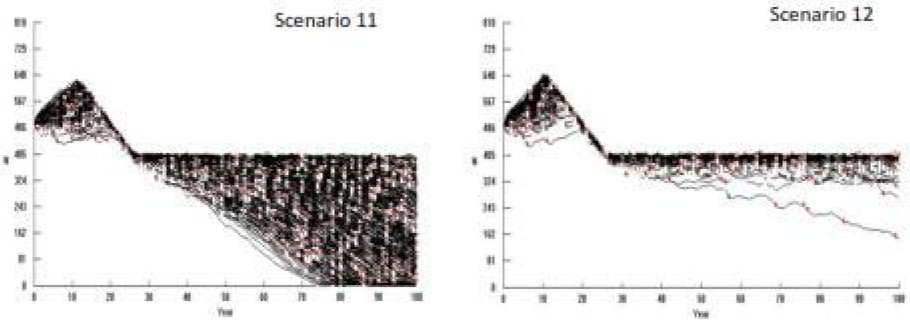


Figure 8.7. Long-term (100 years) extinction probability of Chitwan rhino population under the scenario 11(12 poaching/year, 50% carrying capacity decline in 25 years, 5% population loss once every 25 years by flood, calf mortality 10% instead of 30%, age of first calving 8) and scenario12 (as of scenario 11 but first age of calving 7) in VORTEX.

The results from the VORTEX under different scenarios are summarized in table 8.2.

Table 8. 2. Population habitat viability model predictions for Chitwan rhinos under various combinations of catastrophic events for the next 100 years.

Modeled Scenario	Extinction probabilities (SE)				Median time of extinction year	stochastic rate of increase (r)	Final population size (N)
	25 y	**50 y**	**75 y**	**100 y**			
Scenario 1: 12 rhinos poached/y, 2% carrying capacity loss/y for 25 y, 5% rhinos lost in every 25 years by flood	0	0	0.013 (0.003)	0.38 (0.053)	89 (0.61)	-0.02 (0.0003)	119 (4)
Scenario 2: 16 rhinos poached/y, 2% carrying capacity loss/y for 25 y, 5% rhinos swept in every 25 years by flood	0	0.098 (0.001)	0.89 (0.02)	1	63 (0.5)	0.059 (0.0007)	0
Scenario 3: 8 rhinos/y poached, 2% carrying capacity loss/y for 25 y, 5% rhinos swept in every 25 years by flood	0	0	0	0		0.0057 (0.0001)	375 (1.5)
Scenario 4: 12 rhinos/y poached, 2% carrying capacity loss/y for 25 y, no catastrophe	0	0	0	0.16 (0.016)	91 (0.71)	-0.0117 (0.0002)	190 (6)
Scenario 5: 12 rhinos/y poached, no carrying capacity declines, no catastrophe	0	0	0	0.01 (0.001)	88 (4)	0.005 (0.0001)	708 (7)
Scenario 6: No poached, no carrying capacity declines, no catastrophe	0	0	0	0		0.028 (0.0001)	798 (0.3)
Scenario 7: No poaching, 2% carrying capacity declines/y for 25 y, 5% loss in every 25 y by catastrophe	0	0	0	0		0.0194 (0.0001)	395 (1)
Scenario 8: 12 poached/y, no carrying capacity declines, 5% loss in every 25 y by catastrophe	0	0	0.006 (0.0001)	0.066 (0.001)	85 (2)	-0.0021 (0.0002)	522 (12)
Scenario 9: No poaching, no carrying capacity declines, 5% loss in every 25 y by flood	0	0	0	0		0.019 (0.001)	796 (0.5)
Scenario 10: 6 poaching/y, carrying capacity decline 2%/y for 25 y, 5% population loss in every 25 y by flood	0	0	0	0		0.006 (0.0002)	370 (2)
Scenario 11: 12 poaching, carrying capacity decline 2%/y for 25 y, 5% loss by catastrophe in every 25 y, age of first calving 8 instead of 7, 10% calf mortality	0	0	0.002 (0.0001)	0.316 (0.02)	91 (1)	0.0176 (0.0003)	176 (6)
Scenario 12: 12 poaching, carrying capacity decline 2%/y for 25 y, 5% loss by catastrophe in every 25 y, calf mortality 10%/y, first calf in 7 y	0	0	0	0		0.012 (0.001)	390 (1)

Discussion

The outputs of the VORTEX model substantially depend on the reliability of demographic and habitat parameters and assumptions made on the inputs. Greater one-horned rhinos of Chitwan are very well studied and reliable demographic and habitat parameters were available from the previous studies (*eg*. Laurie 1978, Dinerstein 2003). Additional data on demography and habitat parameters generated from my study provided an opportunity to evaluate the relative importance of different factors for the long-term persistence of rhino population in Chitwan. Therefore, the data used to build the model scenarios and VORTEX simulations were realistic and reliable. The assumptions made on carrying capacity decline, poaching trend and catastrophe all were based on the real field context supported by data.

The model was slightly sensitive to the age of first breeding but very sensitive to calf (< 1 year) mortality. With the one year increase on the age of first calving, the extinction probability increased by 6% due to the combined effects of poaching, *Mikania* and flood. Current rate of calf mortality (<1 year) was high (30%) and if the first year mortality can be reduced to 10% even with the high poaching and *Mikania* effects there was no chance of population extinction in the coming 100 years. However, the age of first calving and calf mortality at first year are more related to population management and in the free ranging population these factors are affected by multiple causes (*eg*. predation, habitat quality, sex ratio *etc*) and can rarely be managed.

The most important extrinsic factors affecting persistence of rhinos were poaching, carrying capacity loss because of invasive *Mikania* and subsequently to a less extent catastrophe in the form of floods. Loss of carrying capacity even up to 50% by *Mikania* was by itself not likely to cause extinctions but caused heavy decline in the population in next 100 years. However, when combined with poaching it had a synergistic effect, and under reduced carrying capacity even moderate poaching pressure of 8 - 10 rhinos per year caused extinctions. Therefore, the model was found very sensitive to annual level of poaching. The model outcomes have clearly depicted that poaching at current level (12 rhinos/year) combined with 50% carrying capacity decline in the 100 years will cause extinction of the Chitwan population. Furthermore, if poaching escalated like in South Africa (*eg*. of 2011 and 2012) and poaching of rhino reached 16/year in Chitwan there was a 100% probability of population extinction from Chitwan in coming 100 years.

Catastrophe in the form of floods every 25 years had insignificant effect on rhino populations but only in combination with *Mikania* and poaching reduced persistence probabilities. The model clearly shows poaching above 10 rhinos is a significant cause of concern and in combination with *Mikania* has disastrous impact on rhinos of Chitwan. The model was sensitive to the sex of poached animals. Model depicted that if females were not poached and only males were poached at the rate of 13 males per year there was no probability of population extinction but poaching of over 5 females per year in Chitwan could not be sustained by the population.

This PHVA output has a greater implication for the conservation management of rhinos in Nepal. This has clearly pointed out that for long-term persistence of rhinos, actions and efforts must be focused on controlling of poaching and minimizing effects of invasive species on the habitat. Therefore, control of poaching and control and management of invasive *Mikania* should be the immediate priority actions of rhino conservation strategy and action plan of Nepal. Management strategy should be focused on intensive rhino monitoring and patrolling, strengthening antipoaching efforts and community engagements. Concurrently, habitat management to increase carrying capacity is very crucial together with exploring and developing mechanisms to control and management of *Mikania* and other weeds in Chitwan National Park for long-term persistence of rhinos.

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Annexes:

Annex 1- List of plant species eaten by the greater one-horned rhinoceros in Chitwan National Park in different seasons as determined by the bite counts during different seasons. (☐) denotes to the species eaten in the particular season.

SN	Local name	Scientific name	Life form	Part eaten	Monsoon	Hot dry	Cool dry
1	Kans	*Saccharum spontaneum*	Grass	Whole plant	☐	☐	☐
2	Siru	*Imperata cylindrica*	Grass	Whole plant	☐	☐	☐
3	Baruwa	*Saccharum bengalensis*	Grass	Whole plant	☐	☐	☐
4	Banso	*Eragrostris tenella*	Grass	Whole plant	☐	☐	☐
5	Narkat	*Phragmites karka*	Grass	Whole plant	☐	☐	☐
6	Dubo	*Cynodon dactylon*	Grass	Whole plant	☐	☐	☐
7	Simghans	*Brachiaria spp*	Grass	Whole plant	☐	☐	☐
8	Kutmero	*Litsea monopetala*	Tree	Leaf/twig	☐	☐	☐
9	Coffea Jhar	*Coffea bengalensis*	Shrub	Leaf/twig	☐	☐	☐
10	Dahikamala	*Callicarpa macrophylla*	Shrub	Leaf/twig	☐	☐	☐
11	Gutel	*Trewia nudiflora*	Tree	Fruit	☐		
12	Phank	*Narenga porphyrocoma*	Grass	Whole plant	☐		☐
13	Ghodedubo	*Hemarthria compressa*	Grass	Whole plant	☐	☐	☐
14	Mikania	*Mikania micrantha*	Climber	Leaf/twig	☐	☐	☐
15	Badampate	*Desmodium spp*	Herb	Whole plant	☐		
16	Bhatmaspate	*Flemeniga spp*	Shrub	Leaf/twig	☐		☐
17	Gaindekanda	*Cersium wallichii*	Herb	Whole plant		☐	☐
18	Kuro	*Chrysopogon aciculatus*	Grass	Whole plant	☐	☐	☐
19	Phurke basno	*Digitaria spp*	Grass	Whole plant	☐		
20	Bayer	*Zizyphus mauritiana*	Shrub	Leaf/twig/fruits	☐		☐
21	Kanthkari	*Solanum surattense*	Herb	Leaf/twig/friut	☐		☐
22	Thulobihi	*Solanum torvum*	Herb	Leaf/twig/friut	☐		☐
23	Kamle	*Pilea symmeria*	Grass	Whole plant	☐		
24	Mothe	*Cyperus spp*	Grass	Whole plant	☐	☐	☐
25	Banmara	*Lantana camara*	Shrub	Leaf/twig/fruits	☐	☐	☐
26	Niuro	*Dryopteris cochleata*	Fern	Whole plant	☐	☐	☐
27	Uniu	*Pteris spp*	Fern	Twigs	☐	☐	
28	Balujhar	*Cida acuta*	Shrub	Leaf/twig/fruits	☐		
29	Simal	*Bombax ceiba*	Tree	Fruits/leaf/twig	☐	☐	
30	Pater	*Typha elephantine*	Grass	Whole plant	☐	☐	☐
31	Datrung	*Ehretia laevis*	Tree	Leaf/twig	☐		☐
32	Kharse	*Ficus hispida*	Tree	Leaf/twig/fruit	☐		
33	Gurmi	*Mukia Scabrella*	Climber	Whole plant	☐		
34	Panijhar	*Hydrilla veticillata*	Aquatic	Whole plant	☐	☐	☐
35	Panijhar	*Unknown*	Aquatic	Whole plant	☐	☐	☐
36	Mimosa	*Mimosa pudica*	Shrub	Leaf/flower	☐		
37	Bamboo	*Dendrocalamus spp*	Grass	Leaf	☐		

38	Banspate	*Curcuma zedoria*	Herb	Leaf	☐		
39	Godtapre	*Centella asiatica*	Grass	Whole plant	☐		
40	Gandhe	*Ageratum conyzoides*	Weed	Leaf	☐		☐
41	Rudilo	*Pogostemon bengalensis*	Herb	Twig	☐		☐
42	Khair	*Acacia catechu*	Tree	Twig/pod		☐	☐
43	Lunde jhar	*Amaranthus spinosa*	Herb	Whole plant		☐	
44	Sissoo	*Dalbergia sissoo*	Tree	Leaf/twig	☐	☐	☐
45	Gular	*Ficus racemosa*	Tree	Leaf/twig	☐		
46	Tapre	*Cassia tora*	Herb	Fruits			☐
47	Asare	*Murraya Koenigii*	Tree	Leaf/twig			☐
48	Dhairo	*Woodfordia fruiticosa*	Shrub	Leaf/twig		☐	☐
49	Sindure	*Mallotus philippinensis*	Tree	Leaf/twig			☐
50	Padke	*Albizzia lucida*	Tree	Leaf/twig			☐
51	Dhursil	*Colebrookia oppisitifolia*	Shrub	Leaf/twigs		☐	☐
52	Ankhle	*Equisetum debile*	Forb	Whole plant		☐	
53	Bilaune	*Myrsine chisia*	Tree	Twig		☐	
54	Ureli	*Themeda species*	Grass	Whole plant		☐	
55	Khuskhus	*Vetiveria zizanoides*	Grass	Whole plant	☐	☐	☐
56	Kagtighans	*Cymbopogon spp*	Grass	Whole plant		☐	
57	Bhede kuro	*Urena lobta*	Herb	Leaf/twig/fruits			☐
58	Tilka	*Wedlandia exserta*	Shrub	Twig		☐	☐