# Assessment of Grassland Communities, its Use by Mammals, and Mapping the Potential Habitat of *Rhinoceros unicornis* in Valmiki Tiger Reserve, Bihar

**Dissertation Submitted to Saurashtra University, Rajkot, in Partial Fulfilment of the Master's of Science Degree in Wildlife Science**


**By**

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## Certificate

This is to certify that Mr. Krishna Murari has carried out an original piece of research in partial fulfillment of Master's Degree in Wildlife Science of the Saurashtra University, Rajkot. The topic of his dissertation is "**Assessment of grassland communities, its use by mammals, and mapping the potential habitat of *Rhinoceros unicornis* in Valmiki Tiger Reserve, Bihar**". The study was carried out under our supervision from December 2016 to June 2017. We hereby certify that this work has not been submitted for any degree of any university.

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## Abstract

1. The fast diminishing tall alluvial grasslands of Terai is home to some of the endangered fauna of the world, obligate to these grasslands, preferring specific grassland vegetation communities. *Rhinoceros unicornis,* a megaherbivore once inhabited the alluvial floodplain of Valmiki Tiger Reserve (VTR), Bihar. Its reintroduction may rejuvenate the ecosystem. Therefore, this study was conducted to identify grassland vegetation communities, associated mammals and to find out the potential habitat of *Rhinoceros unicornis* (hereafter, referred as rhino) in VTR. Additionally, study assessed the status of ungulates in the intensive study area.

2. A multi scale approach of species distribution modeling (using MaxEnt) for whole reserve followed by extensive ground sampling in predicted area was done. Vegetation sampling (circular for grassland, n=304 and quadrate for forest, n=451) along transect lines was used to describe grassland association and availability of food plants of rhino. Belt transect was laid for identifying the association of mammals with grassland vegetation communities. Twenty transects with four replicates each was walked to assess the ungulate abundance.

3. The study identified seven grassland vegetation communities (associations), different from associations present in other Terai regions due to absence of two dominant grass- *Narenga porphyrocoma* and *Arundo donax* – found in other regions. Chital (*Axis axis*), hog deer (*Axis porcinus*) and domestic cattle were associated *Typha angustifolia-Saccharum spontaneum–Imperata cylindrica-Vetiveria zizanoides* association. Nilgai (*Boselaphus tragocamelus*) was associated with grassland association of disturbed site- *Sclerostachya fusca-Saccharum ravennae-Saccharum spontaneum-Carex vesicaria* association. Rufous tailed hare (*Lepus nigricollis ruficaudatus*) was associated with dry upland *Saccharum munja* association. Wild pig (*Sus scrofa*) was associated with Tall moist association of *Typha anguistifolia-Saccharum arundinaceum-Saccharum spontaneum.* One hundred two species of food plants of Rhino belonging to 87 genera classified into 49 families were found. Major food plants (assessed from their prominence

values) identified are- *Saccharum spontaneum, Saccharum munja, Imperata cylindrica, Vetiveria zizanoides, Mallotus phillipensis, and Callicarpa macrophylla.* Ungulate estimation revealed individual density of chital, hog deer, nilgai, wild pig and domestic cattle as 14.96 (SE ± 5.17), 8.07 (SE ± 5.9), 8.29 (SE ± 3.46), 7.59 (SE ± 3.11) and 40.65 (SE ± 24.26) individuals per square kilometer.

4. **Synthesis and applications** – Conservation of the identified grassland vegetation communities is key to conservation of associated mammal. VTR has potential to support a small rhino population, which may not be viable but the potential habitat can be used for conservation breeding of rhino or other similar conservation programs. Ungulate abundance data may be used as baseline data for future prey population monitoring.

# 1. Introduction

## 1.1. Background of the study

The Terai is composed of the alluvial floodplains that roll out along with rivers from the rugged hills and provide uniqueness in terms of diversity. Zooming from micro to macro, one would realize everything in nature is finely knitted in one thread of equilibrium giving sustenance to all forms of life. Fertile floodplains give rise to some of the tallest grasslands of the world. However, the problem is, it is not just the wild grasses, but also the artificially grown food grasses that occupy the same productive floodplains. Thus, these wild tall grasslands facing extinction due to human intervention have shrunk to just few protected areas and merits conservation because of their global importance (Bell and Oliver 1992). Again, it is not only terai grasses but also the wild fauna that are dependent on them. Some fauna like hog deer, rhino, swamp deer, hispid hare are very specific to particular grassland vegetation communities and hence, conservation of these specific communities becomes a key to conservation oftheir associated fauna. Therefore, identification of grassland communities becomes a necessary task for ecologist and wildlife managers (Peet et al. 1999). Valmiki Tiger Reserve (VTR), Bihar has also such small patch of alluvial grassland and rhinos from adjoining Chitwan ventures in and out (Sinha 2011). It is very interesting case of visit of a mammal in its historic range distribution. Grassland communities have not been studied in this alluvial grassland patch and its study may infer the present status of grasslands left and open the mystery of rhino visit. Therefore, a multiscale study was done in response to this situation wherein species distribution modeling was done for whole study area and availability of food plants was checked in intensive study area. Additionally, ungulate abundance estimation using line transect distance sampling method in intensive study area was done.

## 1.2. Literature review

### 1.2.1. Grassland vegetation communities and its use by mammals

Terai is the low land region that lies at the foothills of Himalayas and is characterized by mosaic of tall grasslands, swamps, savannah and tropical moist deciduous forests (Champion and Seth 1968). The grassland area of the Terai is organized into a number of assemblages, called communities. These communities are dominated by few species, which exhibit unique physiognomy in the vegetation (Chaturvedi et al. 1985). Tall grasslands of Terai are diverse and among the most productive in world (Dinerstein 1979,Lehmkuhl 1994). These grasslands are now limited to a small number of protected areas and are of global importance for biodiversity conservation (Bell and Oliver 1992). Grassland species assemblages are dynamic, site specific and prone to change in structure and composition due to fluvial processes, fire, thatch collection, and grazing.

Initial classification of Terai grasslands was done by Dabadghao and Shankarnarayan in 1973 but they broadly covered whole north India under *Saccharum-Pharagmites-Imperata* type of grassland (Yadava and Singh 1977) which is a very general classification (Lehmkuhl 1994). Further species assemblage in Royal Chitwan National Park was studied by Lehmkuhl and he came with classification giving floristic and successional relationship among associations and provide an ecological basis for grassland management (Lehmkuhl 1994). Later, Peet et al. in 1997 sampled the four protected areas of Nepal – Royal Chitwan National Park, Royal Bardia National Park, Royal Suklaphanta Wildlife Reserve and Koshi Tapu Wildlife Reserve and identified nine grassland species assemblages with eight phases. Most of the plant species richness in the tall grasslands of Nepal results from a large number of low abundance, low frequency species (Lehmkuhl 1994,Peet et al., 1999). Further, Kumar (2002) in Terai conservation area did species assemblage study and he identified nine grassland species assemblages. Apart from grassland species assemblages in TAL, study has been done on other grassland areas. Like, Khatri and Barua found out three assemblages in tall and short grasslands of Kaziranga (Khatri and Barua 2011) and Chauhan identified six assemblages in Daun grasslands of Kutch (Chauhan 2002). Diversity of grasses in VTR has been studied on exploratory basis by Haines (1925), Banerjee et al. (1969) and Singh (2007). Sinha et al. did scientific study in terms of diversity, productivity, classification in 2016. They categorized three kinds of grasslands based on habitat features – grasslands on dry alluvial banks, riverine grasslands in seasonally inundated banks and hillside grasslands. Their study identified 113 species of grasses in VTR (Sinha et al. 2016). However, the alluvial grassland of VTR has not been studied from community point of view.

Selection of vegetation community by herbivores is apparent, their use may differ season wise (Gordon 1989). While studying terai grassland Nicholas Peet identified grassland communities and its use by associated ungulates. Association and use reflects use for these communities for food or shelter or both or escape cover or all. Some associations are- like hog deer and rhino prefer *Phragmites karka-Saccharum spontaneum*, swamp deer prefer *Imperata cylindrica-Narenga porphyrocoma*, chital prefer *Imperata cylindrica*, wild pig use all communities but have slight preference for *Narenga porphyrocoma* (Peet et al. 1999).

### 1.2.2. History and status of *Rhinoceros unicornis*

Rhinoceros belong to order Perissodactyla, along with other mammal like horses and tapirs. Evolutionary history of rhinoceros are marked by three features- the antiquity of lineage, diversity and variety of ungulate feeding niches occupied and numerical abundance. However, sadly, climate change probably caused decline of many groups of Rhinoceros at the end of Miocene and thus we are left with only five living species of Rhinoceros - Black Rhinoceros (*Diceros bicornis*), White Rhinoceros (*Ceratotherum simum*), Greater One Horned Rhinoceros (*Rhinoceros unicornis*), Javan Rhinoceros (*Rhinoceros sondaicus*) and Sumatran Rhinoceros (*Dicerorhinus sumatrensis*). Among them, Greater One Horned Rhinoceros, Sumatran Rhinoceros and Javan Rhinoceros are flood plain specialists and thus their declining number is caused by loss of this habitat due to human encroachment for cultivation in fertile floodplain and poaching against the case of other two rhinos of Africa where relentless poaching is only major declining factor (Dinerstein 2003). Both species of African rhinos are inhabitors of savannahs and woodlands, while Javan and Sumatran rhinos live in lowland tropical forests and Greater One Horned Rhinoceros is specialist to floodplain using mosaic of tall grasslands and riverine forest mostly (Dinerstein 2003, Laurie 1978).

Greater One Horned Rhinoceros has been kept under "Vulnerable" category in IUCN Red List of Threatened species. It is also listed in "Appendix I" of CITES (Convention on International Trade in Endangered Species of wild flora and fauna).

Greater One Horned Rhinoceros is an obligate grazer, and thus grasses constitutes major portion of the diet in all seasons. Three categories of food items are required by rhino - i) tall grasses, ii) browse plants and iii) aquatic and semi aquatic herbs (Rawat 2005). It is associated with *Saccharum spontaneum* and *Phragmites karka-Saccharum spontaneum-Saccharum arundinaceum* grassland communities. In winter, grasses become unpalatable thus browsing is highest for which riverine patch is favored. Inferring from previous studies done on food plants of rhino (See **Appendix 1**), on an average grass constitutes 67.95 % of its diet. On an annual basis, major activities of rhino include foraging (40-55 %) followed by resting (25-35 %) and wallowing (12-16 %). Wallowing is highest in monsoon, during which temporary wallows develop all around tall grasslands. In hot season wallowing is infrequent than monsoon and little bit of wallowing need is fulfilled by dipping in streams and nalas. Rhino density and home range are variable with season, vegetation of area and management intervention. Density might range from 0.3 individuals per sq.km to 13.3 individuals per sq.km. Similarly, annual home range of dominant male rhino may range from 3.26 sq.km to 20.54 sq.km (See **Appendix2**). Considerable overlap of 40 % in home range of male rhinoceros had been reported. Daily movement rate range from 3.4 to 6 km (Laurie 1978, Jnawali 1995, Dinerstein 2003, Kandel 2003, Subedi 2012, Adhikari 2015).

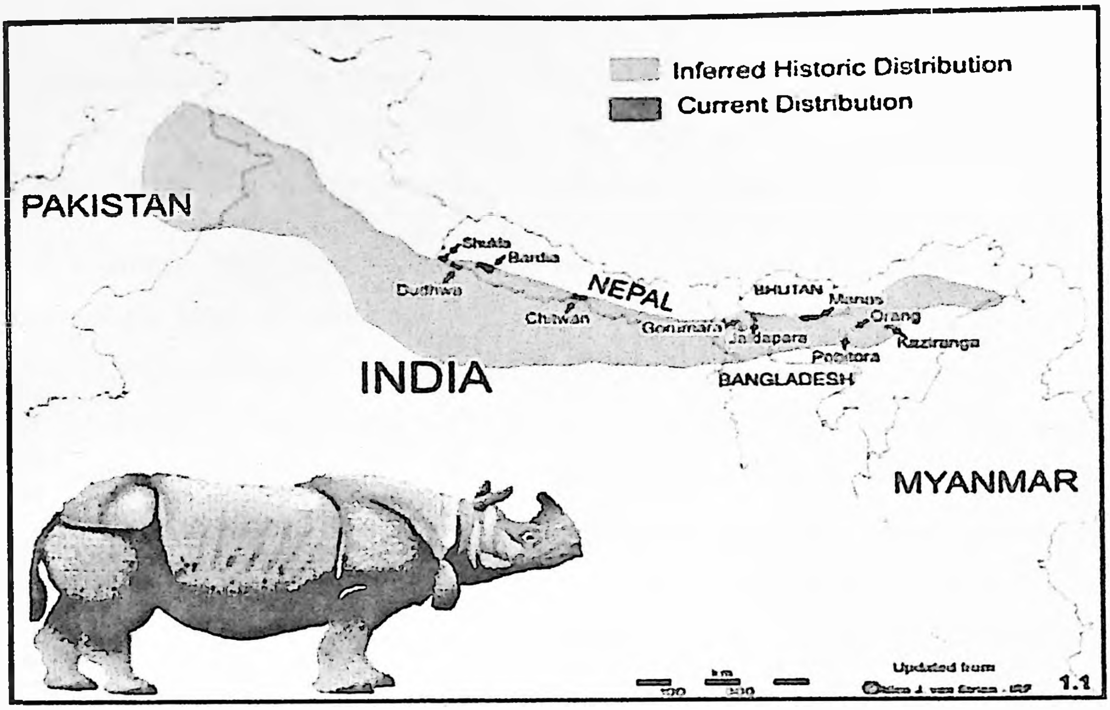


**Figure 1**: Historic and present range distribution of *Rhinoceros unicornis* (Modified from Subedi 2012)

Historically, the Indian rhinoceros once existed across the entire northern part of the Indian subcontinent, along the Indus, Ganges and Brahmaputra River basins, from Pakistan to the Indian-Burmese border, including parts of Nepal, Bangladesh and Bhutan (Foose and van Strien 1997) – (**Figure 1**). The area of historic prime habitat was approximately a 4 km wide band along major rivers, resulting in 35,800 sq.km., a conservative estimate of the area, which multiplied by the densities of Chitwan in prime habitat, gave a minimum total population estimation of 476,140 individuals (Dinerstein 2003). Currently, the population of wild *Rhinoceros unicornis* has shrunk around 3,553 individuals in which Kaziranga has the largest population of 2,401 individuals (2015 census) comprising 67.57 % of total, followed by Royal Chitwan National Park having 605 individuals (2015 census) comprising 17.02 % . The immense decline in population of rhino is due to relentless poaching and loss of productive floodplain grasslands. At present, no more than 2% of alluvial grasslands of Indo-Gangetic plain remain intact (Dinerstein 2003). Now, there are only 12 existing population of *Rhinoceros unicornis* in protected areas, which can be categorized into (i) naturally occurring population in

Kaziranga, Orang, Pabitora in Assam; Gorumara, Jaldapara in West Bengal, and Chitwan in Nepal; (ii) reintroduced population in Dudhwa, UP; Manas, Burhachapori in Assam and Bardia, Suklaphanta, in Nepal and transient migratory population in Katarnia Ghat Wildlife Sanctuary, UP and Valmiki National Park, Bihar (Sinha 2011).

VTR is historic range of rhino. Last rhino shot in Champaran was in 1939 and 1960 (Rookmakker 2002). Possibly, they may have wandered from Chitwan (See **Figure 2**). Now, it has become sink for rhinos, where in rhinos from adjoining source population in Chitwan frequently visits portions of VTR. Alluvial floodplain grassland of Champaran, now confined to Madanpur range of VTR was chosen as one of the possible reintroduction sites of rhino in 1971 by IUCN Rhino specialist group (Sale 1981). Many a time rhino have been frequented in reserve. In 1982, one rhino that came from Chiwan was caught and sent to Patna zoo. In 2001-2002 few rhinos came through floodgates of Indo-Nepal barrage and took permanent refuge in floodplain of Madanpur range left of river Gandak. Their number was reported to be three. One birth of rhino calf was reported in 2003 (Sinha 2011). This hinted Madanpur range as good habitat for rhino. However, sadly one female Rhino died due to rail accident at Bagaha-Chhitauni railway line in 2007 (See **Figure 3**) and another, a male rhino drowned in adjacent canal of Uttar Pradesh in 2008. After that, few rhinos again came from Chitwan and now their number increased to four. Sadly, one more female rhino was hit by train on March 2013 while crossing the same Bagha-Chittauni Railway line and died. (Source - Forest department, TCP of VTR 2013-14). Following the incident rhinos possibly went back from Madanpur after September 2013, as no evidence was seen. Again, one male rhino calf from Chitwan came to Chunbhatta area of Valmikinagar Range and took residence for 4 months, after which it got injury and was sent to Patna Zoo where it succumbed to injuries in 2015. One or two thino keep coming to grassy patches of western and eastern portion of Valmiki possibly following the channels of river Sonha, Pachnad and Pandai. Currently, there are no rhinos in Valmiki.

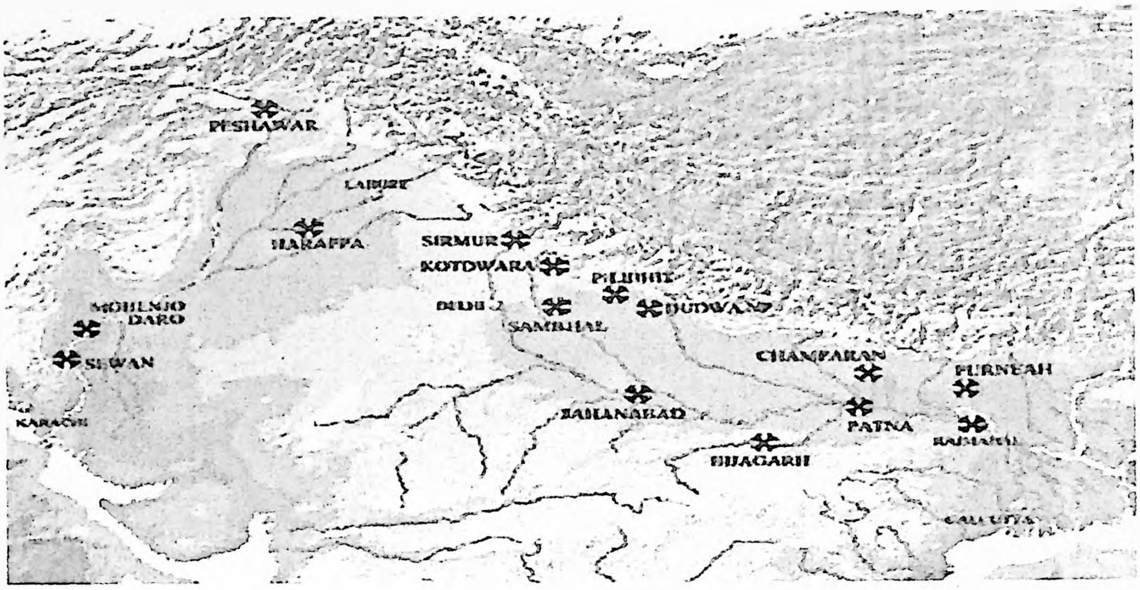


**Figure 2:** Historic range of *Rhinoceros unicornis* in Northern Indian Subcontinent (mentioning Champaran) - (Adapted from Rookmakker 2002)

**Figure 3:** Train accident of rhino at Bagaha-Chhitauni railway track. (Source - Forest department)

### 1.2.3. Studies on different aspects of Rhino including habitat evaluation

First scientific study on Greater One Horned Rhinoceros was done by Andrew Laurie in Chitwan in 1978 (Laurie 1978). But, the major contribution came from conservational study by Eric Dinerstein since 1984 (Dinerstein and Price 1991). Thereafter many short and long term studies (including habitat suitability studies) have been done on the same rhino population of Chitwan by various researchers- (Jnawali 1995, Kandel 2003, Subedi 2012, Adhikari 2015). Apart from Chitwan, study has been done on the rhino population of Orang (Hazarika and Saikia 2012, Hazarika and Saikia 2010), Pobitora (Bhatta 2011), Kaziranga (Banerjee 2001). Similar studies on reintroduced population of rhino was done in Dudhwa (Sale and Singh 1987, Sinha 1987, Sinha and Sawarkar 1990, Tripathi 2012).

Habitat evaluation for conservation of wild flora and fauna need a complete knowledge of parameters pertaining to food, water and shelter (Kushwaha et al. 2000). Habitat evaluation is the assessment of the suitability of land or water as habitat for specific wildlife species that need a model to predict the suitability of land in a given particular set of land conditions. Such model is called a habitat suitability model (Leeuw et al. 1996). Use of remote sensing coupled with ground truthing and GIS domain has increasingly become an important tool of habitat analysis and modeling (Kamat 1986, Porwal et al. 1996). Habitat / Vegetation cover mapping and water body assessment studies(Kushwaha 1990) is an important component of wildlife habitat analysis. Various habitat suitability studies in India have been done on many herbivores like gaur (Imam and Kushwaha 2012), swamp deer (Nandy et al. 2012), sambar (Pant et al. 1999, Porwal et al. 1996), muntjak (Singh and Kushwaha 2011)and carnivore like tiger (Singh et al. 2009, Imam et al. 2009, Kanagaraj et al. 2011).

Out of 12 existing populations of *Rhinoceros unicornis*, similar habitat suitability analysis studies have been done in 5 places - Kaziranga National Park (Kushwaha et al. 2000), Royal Chitwan National Park (Thapa 2005, Kafley 2008), Orang National Park (Sarma et al. 2011), Pobitora (Bhatta 2011), Laokhowa-Burhachapori Wildlife Sanctuary complex (Ojah et al. 2015). Kushwaha et al. 2000, Sarma et al. 2011 and Bhatta 2011 first prepared habitat / vegetation / landcover map of study area and then using it as one parameter with other parameters like proximity to water body, proximity to road/settlement, elevation etc, generated the suitability map. Kafley (2008) used the presence only point in MaxEnt to determine the habitat suitability. While, Ojah et al. (2011) in Laokhowa-Burhachapori collected 15 field parameters (fodder quality, fodder availability, drinking water availability, wallowing space, perinneality of wetlands, highland presence, land cover distribution, high flood inundation, ungulate presence, pre 1980's rhino presence, soil / bank erosion, human presence, thatch collection, fishing, livestock grazing), scored it on 1 -10 scale and put up the cumulative score for each grid and prepared map using Arc GIS. Subedi (2012) classified Chitwan into most suitable and moderately suitable based on water availability and availability of forage plants (*Saccharum spontaneum, Imperata cylindrica* together with browse species). While, (Thapa et al. 2014) determined the spatial distribution of suitable habitat area for rhino using fragmentation metrics. He used presence of grass, and forest as input variables to calculate the habitat suitability index. Combining the habitat suitability analysis (Kushwaha et al. 2000) on broad scale and forage availability (Laurie 1978, Dinerstein and Price 1991, Jnawali 1995, Subedi 2012, Adhikari 2015) on fine scale, may be the best method to figure out the suitable area for threatened species like *Rhinoceros unicornis* in case of any translocation, introduction or reintroduction program.

### 1.2.4. Ungulate estimation

Ungulates being the crucial link between the primary and tertiary trophic levels in food chain, affects the structure and function of ecosystem (McNaughton 1979). Ungulate densities and abundances have been used to compare estimate of carrying capacity for different habitats (Eisenberg and Seidneisticker 1976). Carrying capacity represents the equilibrium between animals and vegetation and is usually measured in units of animal densities (Caughley 1979). Ungulate abundance is required for time series analysis to know the effect of any event like fodder enrichment, catastrophes, or reintroduction of species. Distance sampling is commonly used method to estimate density and abundance of biological populations. Line transect sampling and point transect sampling are the methods of distance sampling (Buckland et al. 2001). Other methods that have been used are vehicle transects, belt transects, block counts etc.

## 1.3. Objectives

**i)** To assess the suitable habitat for *Rhinoceros unicornis* in study area

**ii)** To study the grassland plant communities and its usage by associated mammals

**iii)** To estimate ungulate densities in intensive study area

### 1.3.1. Research questions

**i)** Which are the areas that have suitable habitat for *Rhinoceros unicornis*?

**ii)** What are the grassland plant communities and their structure present in the intensive study area?

**iii)** What are the ungulate preferences for different grassland community?

**iv)** What is the availability of forage plants of *Rhinoceros unicornis* in the intensive study area?

**v)** What are the densities of ungulates in the intensive study area?

## 2. Study area

### 2.1. Location

Valmiki Tiger Reserve is situated along the Indo-Nepal border at the foothills of Himalayan terai in West Champaran district of Bihar with an area covering from 27° 10' to 27° 03' N latitude and 83° 50' and 84° 10' E longitude. VTR covers an area of 899.38 sq.km. with 880.78 sq.km. notified as Valmiki Wildlife Sanctuary which includes 335.64 sq.km. declared as Valmiki National Park (See **Figure 4**). VTR along with adjoining Chitwan National Park and Parsa wildlife Reserve of Nepal covering an area of 3500 sq.km. form the level 1 Tiger Conservation Unit. It is the only tiger reserve in the state of Bihar and represents one of the last patches of forests having the unique combination of Terai-Bhabar vegetation (Johnsingh *et al.* 2004). It has also interrupted connectivity with Sohagi Barwa wildlife sanctuary from west.The reserve has also been designated as Important Bird Area (IBA) by the Indian Bird Conservation Network. For administrative purpose, VTR has been divided into eight ranges namely: Manguraha, Gobardhana, Raghia under division-1 and Chiutaha, Harnatand, Ganuali, Valmiki Nagar and Madanpur under division-2. VTR is divided into six blocks- Madanpur, Triveni, Naurangia, Kosil, Raghia and Someshwar.

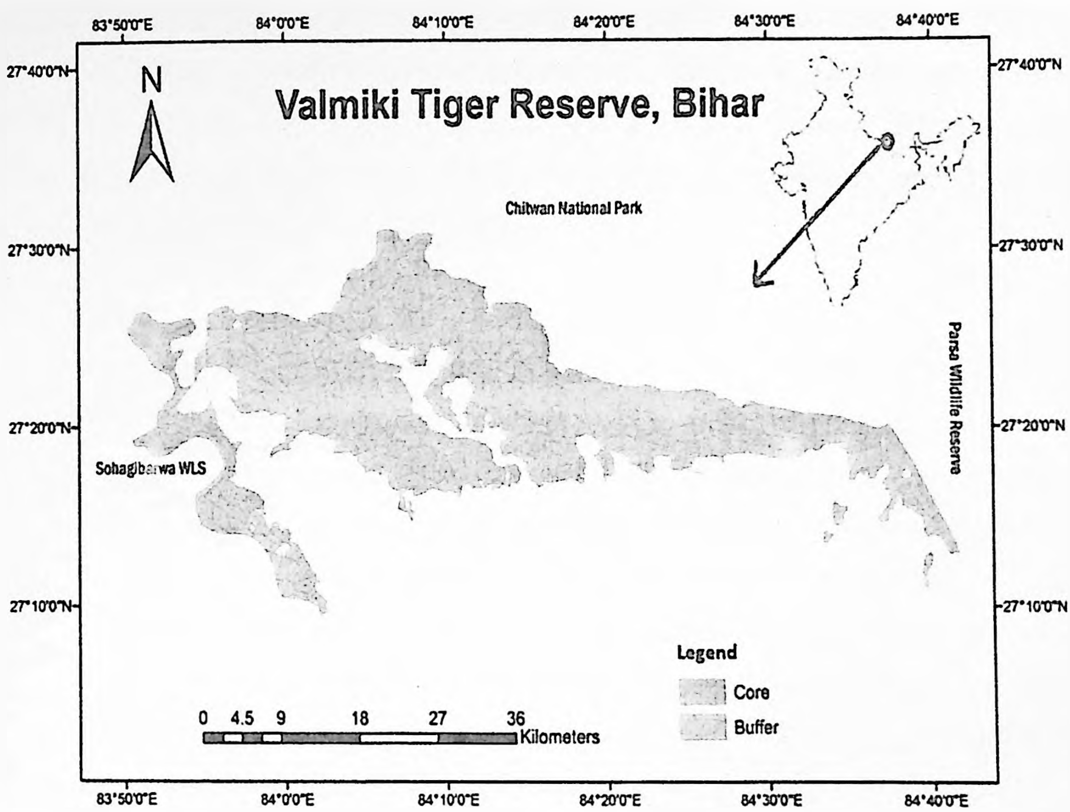


**Figure 4:** Map of Study area.

## 2.2. Physical features

Being located at the foothills of Himalayas, terrain of the area is characterizedby rocky hills, dun valleys in north to alluvial flood plain in south-west along river Gandak. The main geo-morphological formation is Siwaliks, Bhabhar and Terai. Bhabhar portion of the area extends fom Triveni Ghat in north-eastern portion to Raghia in western portion.The entire Madanpur is on alluvial floodplain. Soils of reserve has been distinguished on the basis of parent material and is classified into six categories- Bhangar hard clay soil, Babhani reddish loam soil, Lateritic soil, Baldhus loose sandy soil, Kankar and saline soil and Alluvial soil (TCP 2013-14). The altitude variesfrom 140 m above msl to the highest point being about 874 m above msl (Someshwar Temple) in the Gobardhana Range of Division-1(WWF 2014).

## 2.3. Climate

Area comes under sub tropical monsoonal climate and has three clearly defined seasons. Summer season commences from mid march to early may reaching highest temperature of 43° C and more. Rainy season begins from mid- June to September with pre-monsoon showers in April. Winter season commences from November and end in February. Minimum temperature goes down to 5° C. Annual precipitation is 1106.23 mm of which major contribution comes from monsoon. Maximum rainfall reaches to 407.36 mm in month of July, which remain highest humid month. Months have been divide into three seasons – Cool dry season (CDS) from October to January, Hot dry season (HDS) from February to May and Monsoon season (MS) from June to September.

## 2.4. Flora

According to "revised survey of forest types of India" by Champion and Seth (1968), the forest of VTR has been classified into seven forest types. These forest types are (i) Bhabar Dun Sal Forest, (ii) Dry Siwalik Sal Forest, (iii) West Gangetic Moist Mixed Deciduous Forest, (iv) Khair-Sissoo Forest , (v) Cane Brakes , (vi) Eastern Wet Alluvial Grassland and (vii) Barringtonia Swamp Forest. Some of dominating tree species forming top canopy layer are- *Shorea robusta, Terminalia alata, Albizzia procera, Anogeissus latifolia, Lagerstroemia parviflora, and Adina cordifolia* in sal dominated forest *and Syzygium cumini, Bombax ceiba, Trewia nudiflora, Acacia catechu, Dalbergia sissoo* in alluvial floodplain riverine forest. Some of common shrubs include *Clerodendron infortunatum, Coolebrokia oppositifolia*. Common weeds are *Lantana camara, Ageratum conizoides, Mikania micrantha* and *Phoenix humilis*.

## 2.5. Fauna

Among vertebrates, VTR is home to 58 species of mammals. Some of the large mammals are*Panthera tigris, Panthera pardus, Melursus ursinus, Bos gaurus, Vulpes bengalensis, Canis aureus, Cuon alpinus, Axis axis, Axis porcinus, Cervus unicolor, Muntiacus muntjak, Boselaphus tragocamelus, Sus scrofa, Platanista gangetica* etc. Newly discovered mammals are- Crab eating Mongoose (*Herpestes urva*), Himalayan Serow (*Capricornis thar*), Yellow throated Marten (*Martes flavigula*) (WWF 2014), Himalayan Brown Goral (*Naemorhedus goral)* and Clouded leopard (*Neofelis nebulosa*) (source-Forest Department). Greater one Horned Rhinoceros (*Rhinoceros unicornis*) frequently visits VTR from adjoining Chitwan National Park. Four mammals got locally extinct from Valmiki are- Elephant (*Elephus maxuimus*), Black buck (*Antilope cervicapra*), Barasingha (*Rucervus duvauceli duvauceli*) and *Caprolagus hispidus*, the Hispid Hare (TCP of VTR 2013-14, Sawarkar and Hussain 1995). Apart from mammals, VTR is also home to around 250 species of birds, 37 species of reptiles. 50 species of fishes. Among invertebrates 100 species of butterfly, 100 species of moth and other invertebrates has been reported.

## 2.6. Human dimension

There are 26 revenue villages surrounding VTR with an estimated population of 22,000. Their occupation is agriculture and is heavily dependent on forest for fuel wood, firewood, NTFP, Grass collection for thatch making etc. Cattles graze in and around reserve. Madanpur block is most disturbed because villages and their agriculture fields from all sides surround its linear stretch, cut off from larger land of VTR.

## 2.7. Intensive study area

Based on probaility distribution of rhino and its presence before local extinction from Madanpur block of VTR, compartments from M1 to M26 (See **Figure 5**) were chosen as intensive study area covering an approximate legal forest area of 89.6 sq.km including encroachment by public. The area has unique ecosystem compared to rest blocks of reserve owing to its location in fertile alluvial floodplain of Gandak River and presence of following five forest types- West Gangetic Moist Mixed Deciduous Forest, Eastern Wet Alluviial Grassland, Khair-Sissoo Forest, Canebrakes and Barringtonia Swamp Forest. Hog deer and rhinoceros are obligate mammal of this unique ecosystem. This area has high human pressure due to presence of revenue villages from all four sides. Heavy extraction of fuel wood, fodder, grass collection, human induced burning in grasslands, illicit felling, poaching and uncontrolled grazing by domestic cattle are the main problems. Intensive study area was further divided into three sub-study area, for ease of work, into Madanpur, Naurangia and Bhedihari. Madanpur comprise of compartment M1 to M10 with an approximate area of 29.5 sq.km, Naurangia from M11 to part of M17-18-19 until Dhobha bridge with an approximate area of 24 sq.km. and Bhedihari comprises part of M17-18-19 upto M26 with an approximate area of 27.8 sq.km. (Area given in above line does not include present encroached area of forest and the area cut off due to action of river Gandak)– (See **Figure 6**).

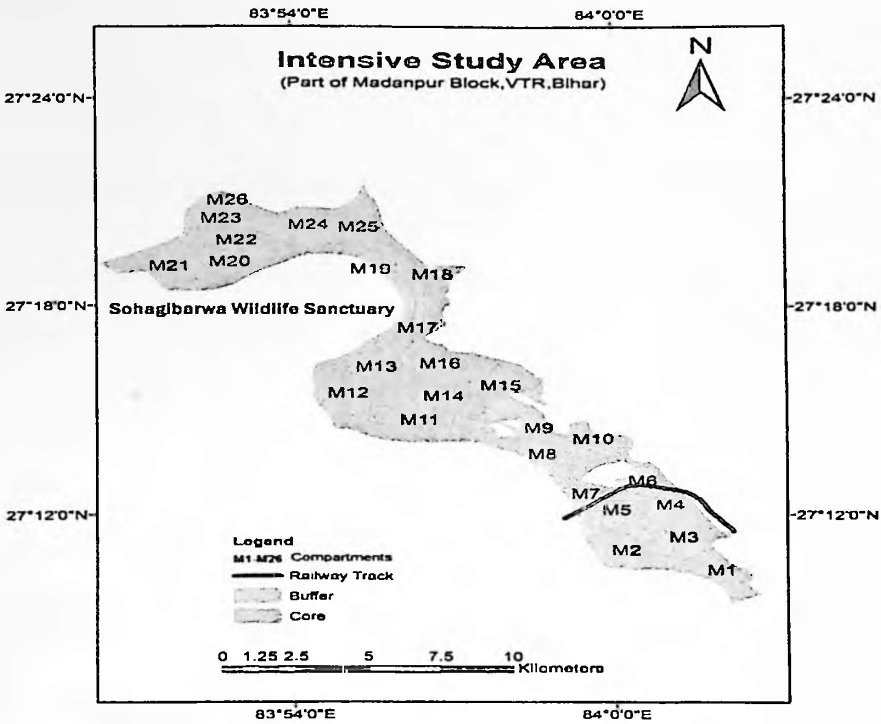


**Figure 5:** Map of Intensive study area with compartment boundary and number

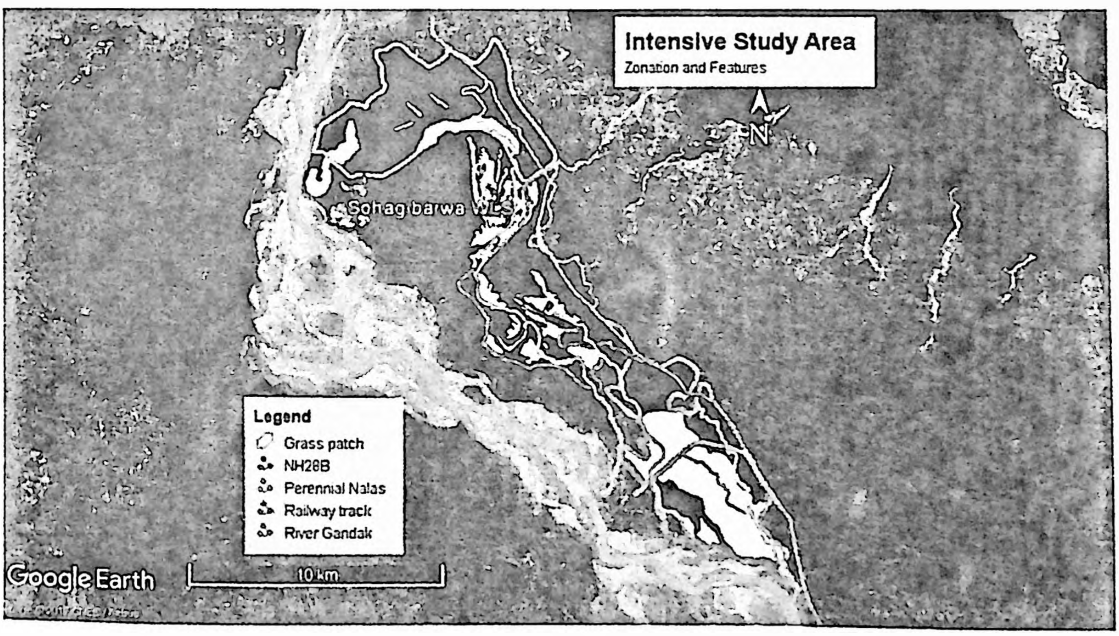


**Figure 6:** Zonation of Intensive study area (area bounded by green line is Madanpur, area bounded by red is Naurangia, area bounded by yellow is Bhedihari, and area bounded by dark blue line is Madanpur-RRA)

# 3. Methods

## 3.1. Field methods

### 3.1.1. Grassland vegetation communities

Intensive study area was divided into three zones based on division by settlements and forest boundaries. These three zones are- Madanpur, Naurangiya and Bhedihari. All three zones were first sampled for grassland vegetation in order to not miss the inflorescence of grasses. Then they were sampled for browse species in forest.

Grassland vegetation plots were laidin intensive study area between December and January. Ideally, it should have been from October to December when inflorescences are fresh and thus easy to distinguish between morphological similar grass species. Therefore, in initial stages of sampling, local names of plants were written down and subsequently herbarium was prepared to be identified at Herbarium section of Wildlife Institute of India, Dehradun. Two meter radius circular plots were laid to ensure visibility would not impair ocular estimation of percent cover contribution of tall and short grasses in the plot. The distance between two circular plots on transect was 200 m and two transects were laid about 450 m apart. This design of vegetation sampling along transect lines ensured the systematic sampling of study area (Jnawali 1995). Three hundred four plots were laid in almost all patches of small and large sized grasslands.

The minimum number of circular vegetation plots required to describe the floristic feature of study area was determined by constructing species area curve for all three zones of study area (See **Figure 8**). The total number of circular plots (after pooling plots of three zones) needed to describe and compare my study area floristic feature with other studies was determined by species area curve, when it reached an asymptote (i.e. 90% of species covered). This was done in R using Vegan package by the use of function "specaccum". To get biomass contribution of each species to the community, I clipped plots from entire range of cover values for each species separately.

### 3.1.2. Use of grassland vegetation communities by mammals

For checking use of community by mammals, pellet groups and dung were counted (Peet et al. 1999) on belt transects of 2 × 20 m keeping the circular plot at center of belt transect so that ungulate pellets confirm to that grassland vegetation community. Besides, a visual community structure was noted down for the area of belt transect.

### 3.1.3. Availability of food plants

Food plants of Rhino include both grass and browse. Grass sampling has already been explained above. For browse sampling within study area, quadrate plots of size 10m × 10m was laid on transect lines at an interval of 200m. The distance between two transects were about 450 m. The minimum number of vegetation plots required to describe the floristic feature of study area was determined by constructing species area curve for all three zones of study area (See **Figure 9**). The number of quadrates (after pooling quadrates of three zones) needed to describe and compare my study area floristic feature with other studies was determined by species area curve, when it reached an asymptote (i.e. 90% of species covered). This was done in R using Vegan package by the use of function "specaccum". In each quadrate plant species was estimated occularly for their percent cover contribution.

### 3.1.4. Species distribution modeling

For preparation of species distribution modeling, GPS point locations were collected from all the locations where rhino was present in Valmiki before their local extinction. GPS point locations were also taken from entire intensive study area for different vegetation class, water bodies, and settlements.

### 3.1.5. Ungulate density estimation

Distance sampling is commonly used method to estimate density and abundance of biological populations and is superior because of two issues, whichit solves- spatial sampling and observability (Buckland et al. 2001). Line transect sampling and point transect sampling are the methods of distance sampling. Line transect method was used to estimate the ungulate densities within study area (Anderson et al. 1979). Twenty transects of variable length were laid in such a way to ensure uniform coverage of the area. Each transect was walked morning and evening to ensure 4 temporal replicates except two transects which were having 5 temporal replicates covering a total effort length of 167.9 km. Following parameters were noted down when an animal was encountered – animal species, cluster size, gender, number of adult and young animals in the cluster, transect bearing, animal bearing, GPS point of the sighting location and habitat type.

### 3.1.6. Human Dimension

Circular plot of 15 m radius was laid on each transect at an interval of 200 m. Within the plot number of stumps, fuelwood collection intensity (no, low, high), grass and cane cutting (yes, no), number of trails, forest fire (yes, no) and number of cattle seen nearby were noted down.

## 3.2. Analytical methods

### 3.2.1. Biomass contribution of dominant grass species

A species specific regression (with intercept set at zero to avoid negative values of biomass in processed data) was used for dominant grass species for estimating biomass from their percent cover using data of all the plots.

### 3.2.2. Grassland vegetation communities

Among several clustering techniques, TWINSPAN was usedin software package PC-ORD, because of the way former forms the cluster. It partitions the dissimilarity space determined by main gradients in data against the partioning of natural groups of similar sites done by many other clustering techniques. Besides, being a very popular technique, it classifies in a way that reflects main gradients in species composition which follow key ecological factors (Roleček et al. 2009).

TWINSPAN (Two Way INdicator SPecies ANalysis) is a FORTRAN program developed to analyze communities from a set of sample plots having species occurrences. It is a hierarchical divisive classification technique. It is designed to construct two-way ordered table, by identification of differential species. A differential species is one with clear ecological preferences whose presence defines unique environmental conditions. There are three ordinations involved in making two-way ordered table - primary ordination, refined ordination and indicator ordination i.e. it first constructs a classification of the samples, and then uses this classification to obtain a classification of the species according to their ecological preferences. The two classifications are then used together to obtain an ordered two-way table that expresses the species synecological relations as succinctly as possible (Hill 1979).

The levels of abundance that are used in TWINSPAN to define the crude scale are termed as Pseudospecies cut levels. These levels were chosen such that they reflect typical values of abundance. Cut values were - 0, 3, 5, 10, 20, 30, 50, 70, and 100. Maximum numbers of indicators per division and maximum levels of divisions were chosen as three.

### 3.2.3. Use of grassland vegetation community by mammals

Ivlev's Electivity Indices (IEI) described by Lechowich (1982) and percent intensity of use were computed to identify use and preference of grassland vegetation community by mammals, using the collected data on their indirect signs – pellet groups. Former is better approach of identifying uses of habitat because it considers the use with availability of habitat and indicates selection in true sense (Strauss 1979) while latter accounts only usage and ignores the relative abundance / availability. Following assumptions were considered regarding pellet groups as index of use of habitat – (i) ungulates defecate in proportion to the time spent in the habitat and (ii) there is no preference for certain habitats for defecation unless territorial as in case of nilgai. For dealing with territoriality issue of nilgai, midden sites were to be noted separately.

Ivlev's Electivity Indices-

$$IEI = (Ri-Pi)/(Ri+Pi)$$

Where, IEI is degree of selection or measure of electivity

Ri is relative uses of the habitat

Pi is relative availability/abundance of the habitat

IEI range from -1 to +1 indicating complete avoidance to complete selection.0 indicates random selection.

Percent Intensity of use is total number of pellet groups or dung of a species in that community divided by total number of pellets or dung in all the community multiplied by 100.

### 3.2.4. Availability of food plants

For availability of food plants, prominence value was calculated for each species of grass and browse (Dinerstein 1979a, Jnawali 1995).

$PV_x = M_x \times (\sqrt{F_x})$

Where, $PV_x$ is prominence value of species $_x$

$M_x$ is mean percent cover of species $_x$

$F_x$ is the frequency of occurrence of species $_x$

### 3.2.5. Species distribution modeling (SDM)

Among many presence only SDM methods, MaxEnt (Elith et al. 2011) was inferred to give better results (Hernandez et al. 2006, Baldwin 2009) and thus was used.

Rhino locations were acquired from rhino survey done in Chitwan in march 2008 (Jnawali et al. 2009, Subedi 2012) and were rarefied to 2 km, representing the average home range of a dominant male rhino (Dinerstein 2003) using SDM toolbox in Arc GIS to remove auto-correlation. Environmental covariates that were chosen to test in model are- digital elevation map (DEM), land use land cover map (LULC), Nov Normalised difference vegetation index (NDVI) for post monsoon, April NDVI as pre monsoon. Supervised classification was done for Chitwan -Valmiki landscape using FCC (false composite color) of April 2017, which in turn was made by stacking bands from Landsat 8 data of the April month over the study area. Among them, LULC is a categorical variable. LULC was categorized into following seven land cover classes - riverbed, river, degraded grassland, riverine forest, tall grassland, sal and mixed forest, built up with agriculture. Nov NDVI was removed from model owing to its very less contribution to model assessed from Jackknifing test (Baldwin 2009). Out of 47 rarefied presence points, twenty-five percent of data was used to test the projected model while rest was used in training the model. Chitwan area having uniformly spread rhino presence points was used to train the model. The model was projected on Chitwan-Valmiki landscape (since both fall in same landscape) and to visualize possible corridors through which rhino comes to Valmiki from Chitwan.

### 3.2.6. Ungulate density estimation

Program DISTANCE (Laake et al. 1979) was used to come up with an estimate of abundance and densities. Depending on the average detection probability of the species, different models are chosen among uniform, half-normal, hazard rate, negative exponential detection functions to come up with best fit model. The goodness of fit is judged by likelihood measure AIC (Akaike Information Criteria). Lower the AIC better the model is fit. Sambar was not analyzed because of too low sample size.

### 3.2.7. Human dimension

One square kilometer grid was overlaid on intensive study area. Using the tool Spatial Join in Software Arc-map, average value of each category of human disturbance data was assignedto each grid and final map was created. Additionally, secondary data on mortality of wild animals on Chhitauni-Bagaha railway track was analysed to find out the impact of this permanent barrier on movement of wild animals.

## 4. Results

### 4.1. Grassland

Three hundred four plots were laid in almost all patches of small sized and large sized grasslands and all these plots were was used in analysis as determined from species accumulation curve (See **Figure 7**).

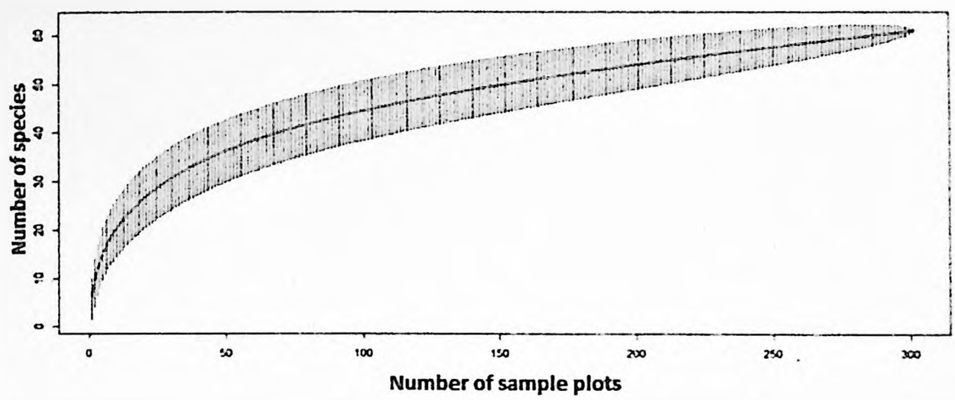


**Figure 7:** Species accumulation curve for Grassland in Madanpur block

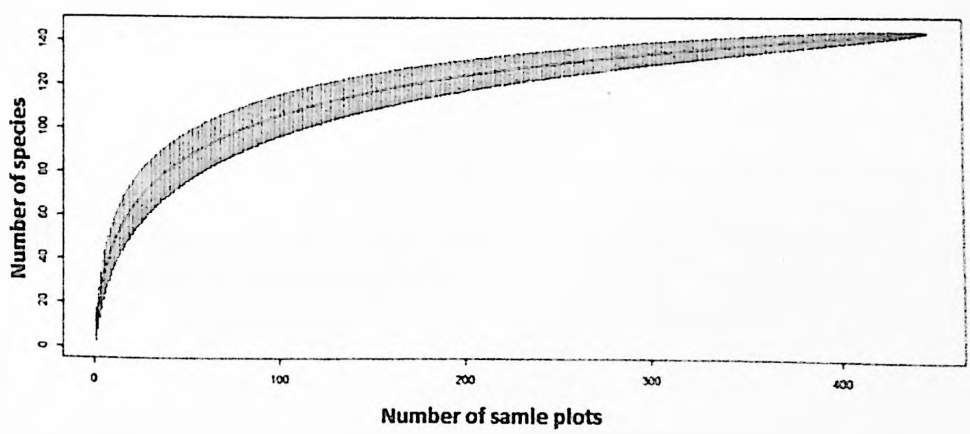


**Figure 8:** Species accumulation curve for browse in Madanpur block.

Four hundred fifty three quadrates were laid in forest for browse which resulted 757 plots after combining all circular (304 plots) and quadrate plots and all these plots were was used in analysis as determined from species accumulation curve (See **Figure 8**).

Regression analysis gave following equations for computing fresh weight from their percent cover for different species (See **Figure 9-18**).

***Imperata cylindrica***

Fresh weight = 0.164 × percent cover ($R^2$= 0.60)

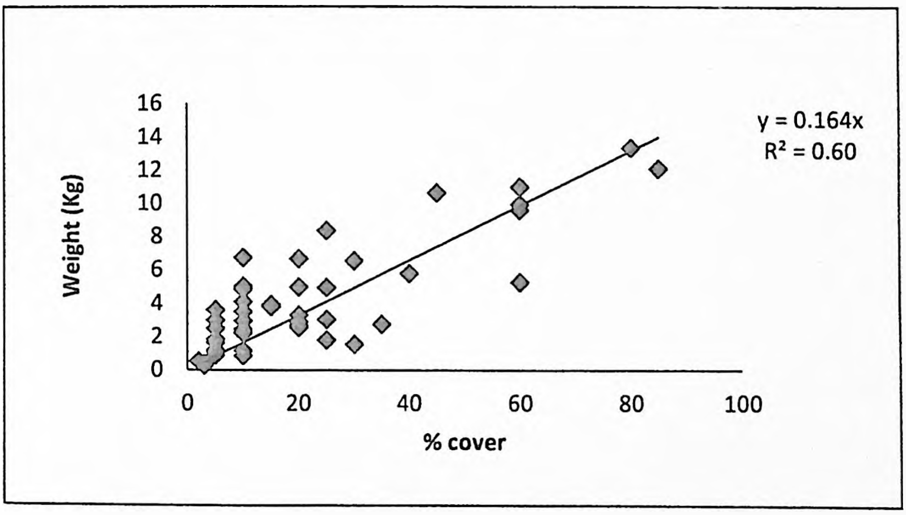


**Figure 9**: Regression analysis between percent cover and fresh weight of *Imperata cylindrica* using data of 47 plots.

*Saccharum ravennae*

Fresh weight = 0.412 × percent cover (R²= 0.86)

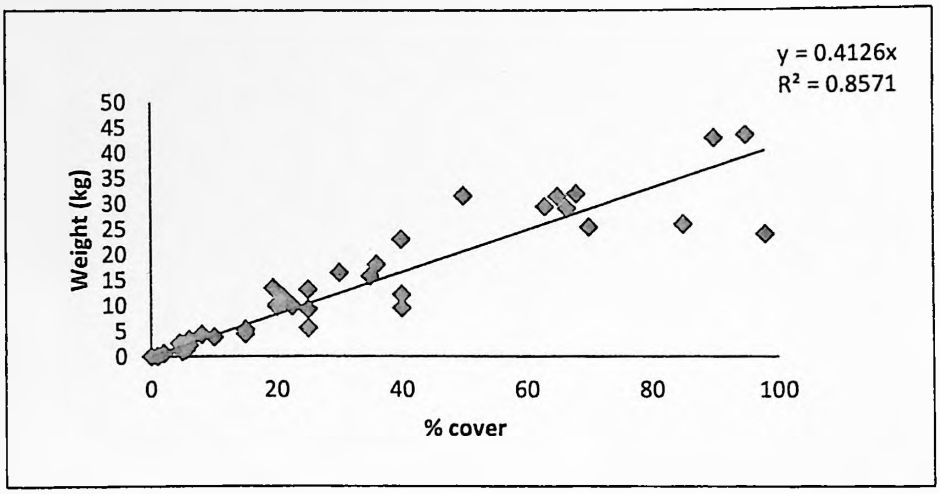


**Figure 10:** Regression analysis between percent cover and fresh weight of *Saccharum ravennae*using data of 38 plots

*Sclerostachya fusca*

Fresh weight = 0.419 × percent cover (R²= 0.67)

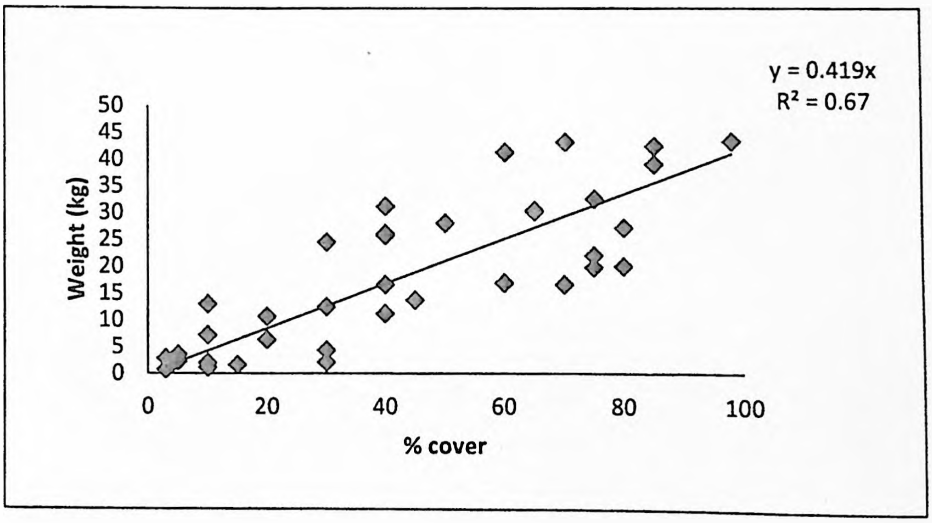


**Figure 11:** Regression analysis between percent cover and fresh weight of *Sclerostachya fusca* using data of 36 plots

*Vetiveria zizanoides*

Fresh weight = 0.218 × percent cover ($R^2$= 0.70)

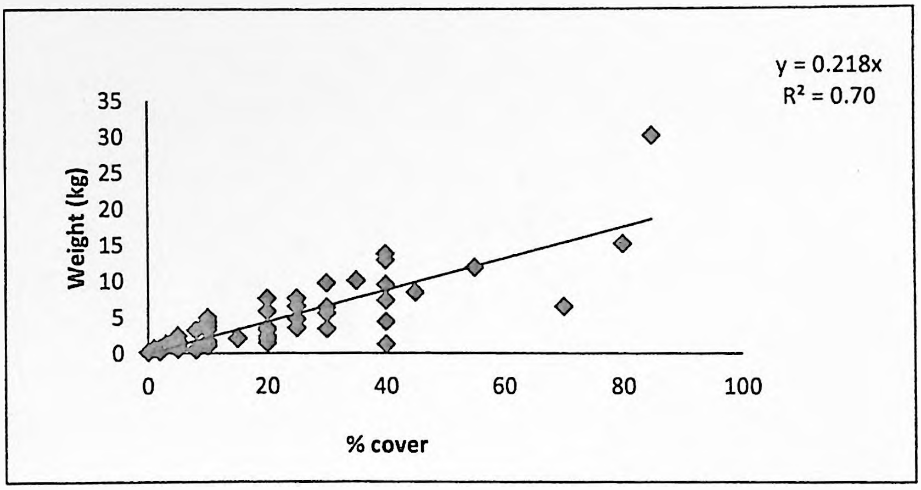


**Figure 12:** Regression analysis between percent cover and fresh weight of *Vetiveria zizanoides* using data of 59 plots

*Carex vesicaria*

Fresh weight = 0.258 × percent cover ($R^2$= 0.89)

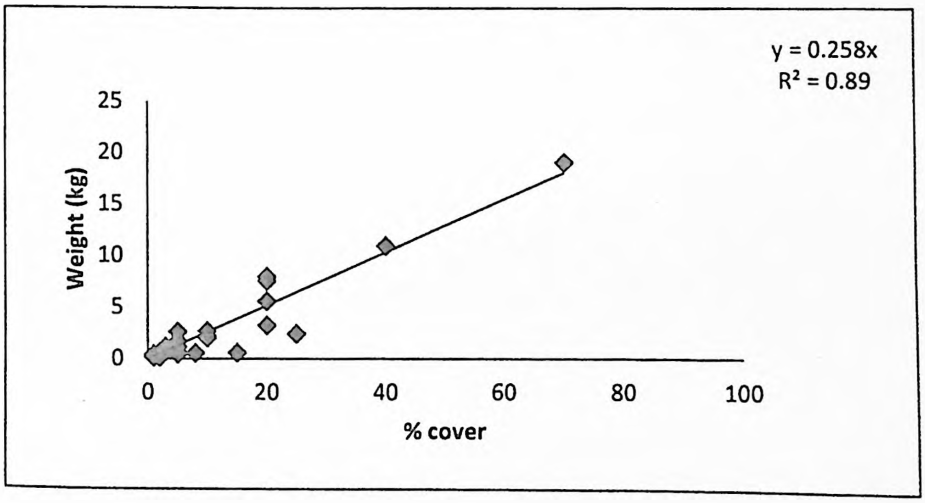


**Figure 13:** Regression analysis between percent cover and fresh weight of *Carex vesicaria* using 27 plots

***Saccharum spontaneum***

Fresh weight = 0.374 × percent cover ($R^2$= 0.65)

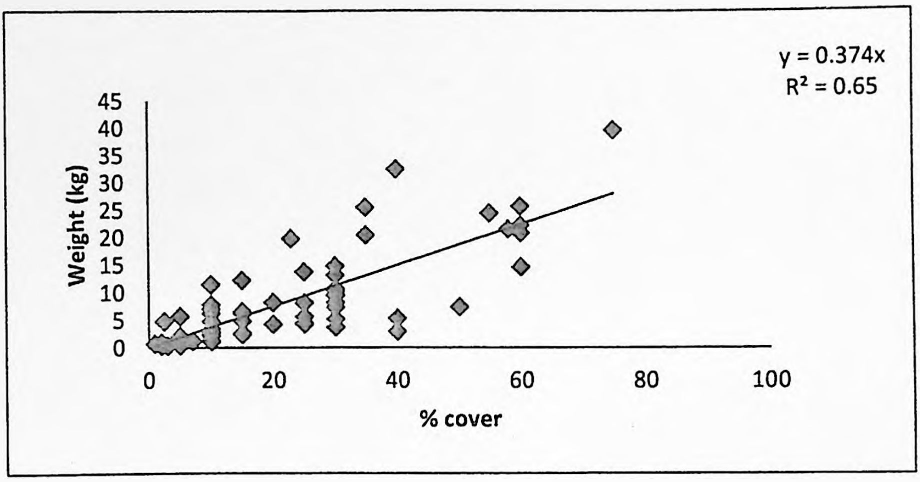


**Figure 14:** Regression analysis between percent cover and fresh weight of *S. spontaneum* using data of 71 plots

***Saccharum munja***

Fresh weight = 0.311 × percent cover ($R^2$= 0.68)

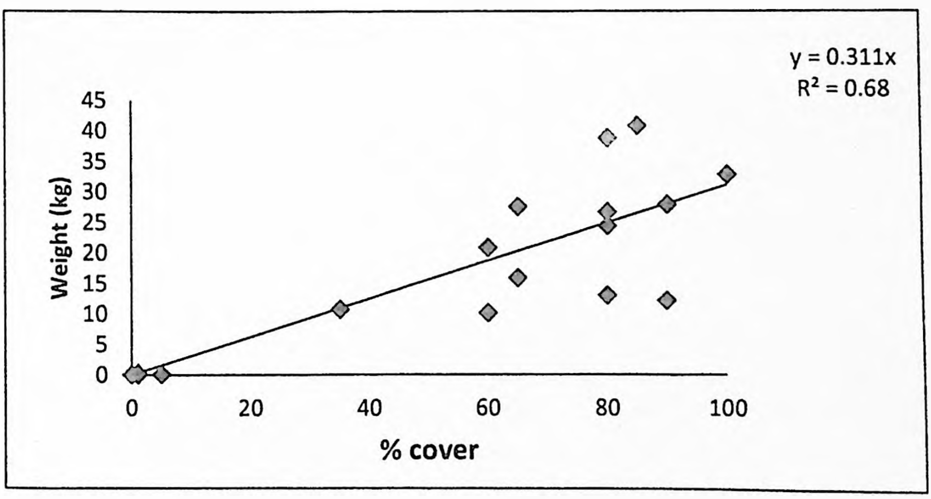


**Figure 15:** Regression analysis between percent cover and fresh weight of *S.munja* using 17 plots

*Phragmites karka*

Fresh weight = 0.426 × percent cover (R²= 0.73)

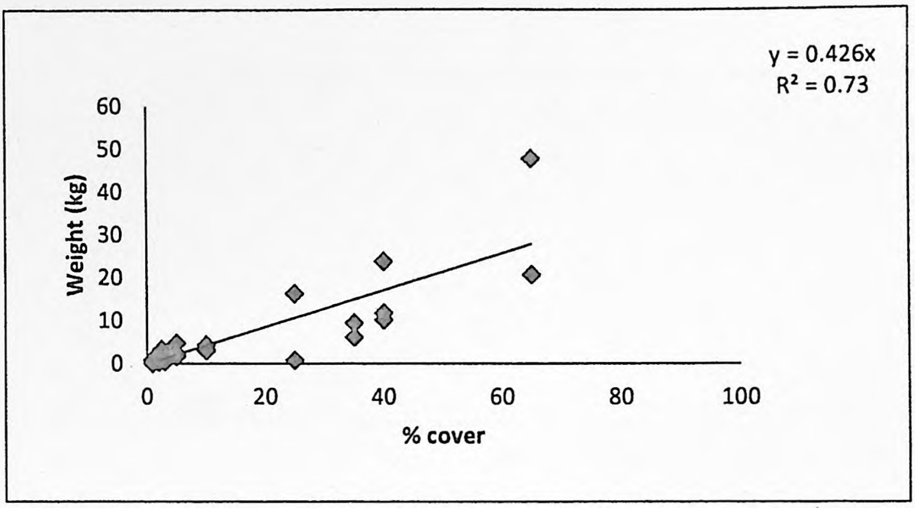


**Figure 16:** Regression analysis between percent cover and fresh weight of *Phragmites karka* using data of 33 plots

*Typha anguistifolia*

Fresh weight = 0.393 × percent cover (R²= 0.71)

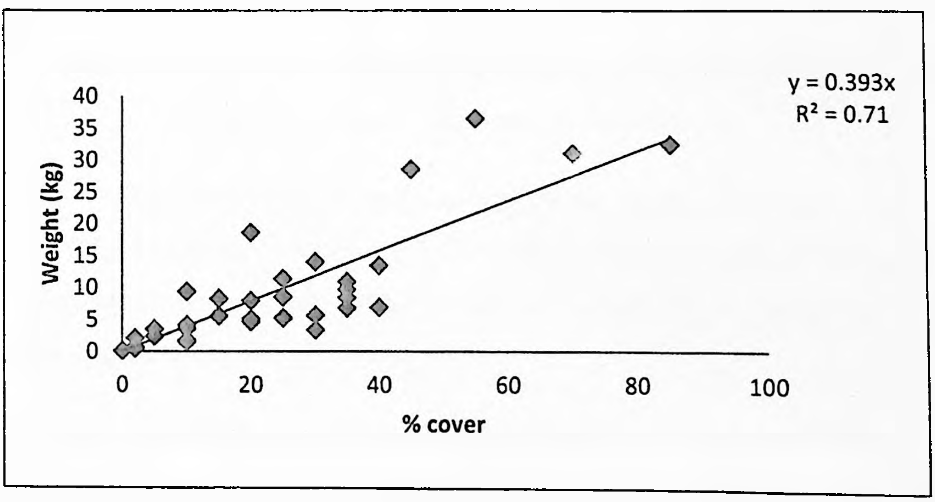


**Figure 17:** Regression analysis between percent cover and fresh weight of *Typha anguistifolia* using data of 33 plots

***Saccharum arundinaceum***

Fresh weight = 0.455 × percent cover (R²= 0.76)

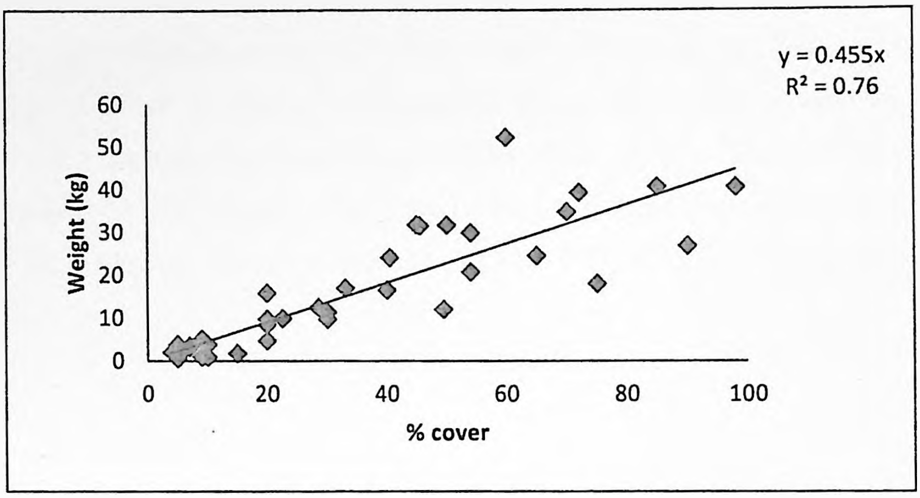


**Figure 18:** Regression analysis between percent cover and fresh weight of *S.arundinaceum* using data of 39 plots

## 4.1.1. Dominance and above ground biomass in grassland

Grassland vegetation sampling in intensive study area resulted a total presence of 60 herbaceous species, out of which 18 belonged to grass and grass like species. Among them, three belonged to Cyperacea, one Typhaceae and rest Poaceae.

Mean percent cover in total sampled area was highest for *Typha angustifolia* (12.40 ± SE 1.22) followed by *Vetiveria zizanoides* (10.46 ± SE 1.53), *Imperata cylindrica* (10.05 ± SE 1.14), *Saccharum arundinaceum* (9.34 ± SE 1.15), *Saccharum spontaneum* (8.39 ± SE 0.86) (See **Figure 19**).

However, percent fresh biomass was highest for *Phragmites karka* (19.28 %) followed by *Typha angustifolia* (16.32 %), *Saccharum arundinaceum* (14.25 %), *Saccharum spontaneum* (10.52 %), *Sclerostachya fusca* (8.27 %), *Saccharum ravennae* (7.65%), *Vetiveria zizanoides* (7.64%) (See **Figure 20**). Mean percent cover was higher for

*Imperata* and *Vetiveria* than relative fresh biomass because they were medium length grass with low weight, but for tall grass like *S.munja*, biomass was lower than cover because of its spreading top canopy.

The total above ground biomass for most dominant grass species in intensive study area are as follows *Phragmites karka* ($1.39\times10^6$ ± SE $5.96\times10^2$ kg/ha ) followed by *Typha angustifolia* ($1.18\times10^6$ ± SE $3.82\times10^2$ kg/ha), *Saccharum arundinaceum* ($1.03\times10^6$ ± SE $4.18\times10^2$ kg/ha), *Saccharum spontaneum* ($7.60\times10^5$ ± SE $2.58\times10^2$ kg/ha), *Sclerostachya fusca* ($5.97\times10^5$ ± SE $3.39\times10^2$ kg/ha), *Saccharum ravennae* ($5.53\times10^5$ ± SE $3.07\times10^2$ kg/ha), *Vetiveria zizanoides* ($5.52\times10^5$ ± SE $2.67\times10^2$ kg/ha).

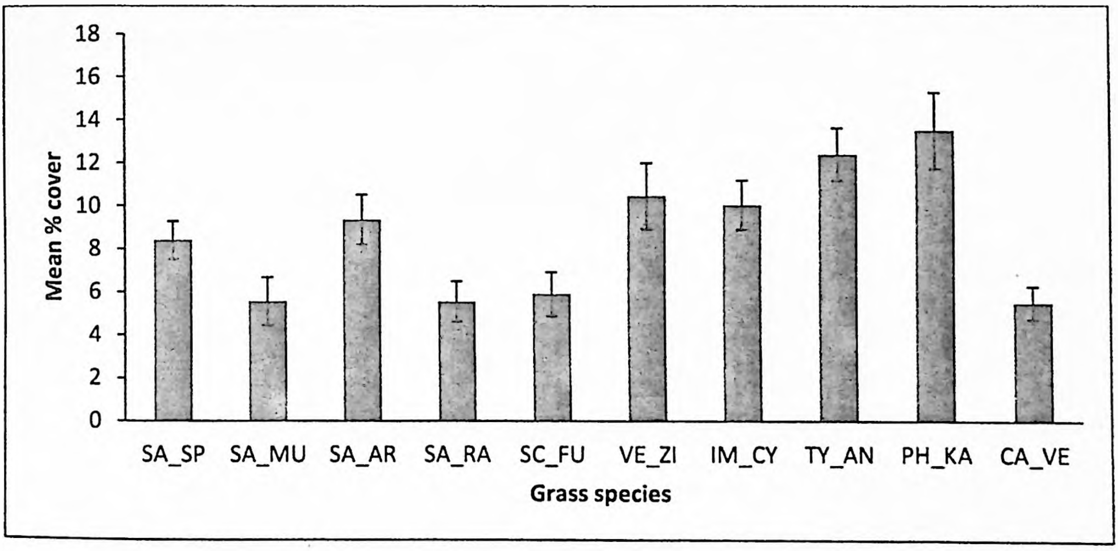


**Figure 19:** Mean percent cover of 10 most dominant grasses in Intensive study area

**Abbreviations used in Figure 19** (SA_SP is *Saccharum spontaneum*, SA_MU is *Saccharum munja*, SA_AR is *Saccharum arundinaceum*, SA_RA is *Saccharum ravennae*, SC_FU is *Sclerostachya fusca*, VE_ZI is *Vetiveria zizanoides*, IM_CY is *Imperata cylindrica*, TY_AN is *Typha anguistifolia*, PH_KA is *Phragmites karka* and CA_VE is *Carex vesicaria*)

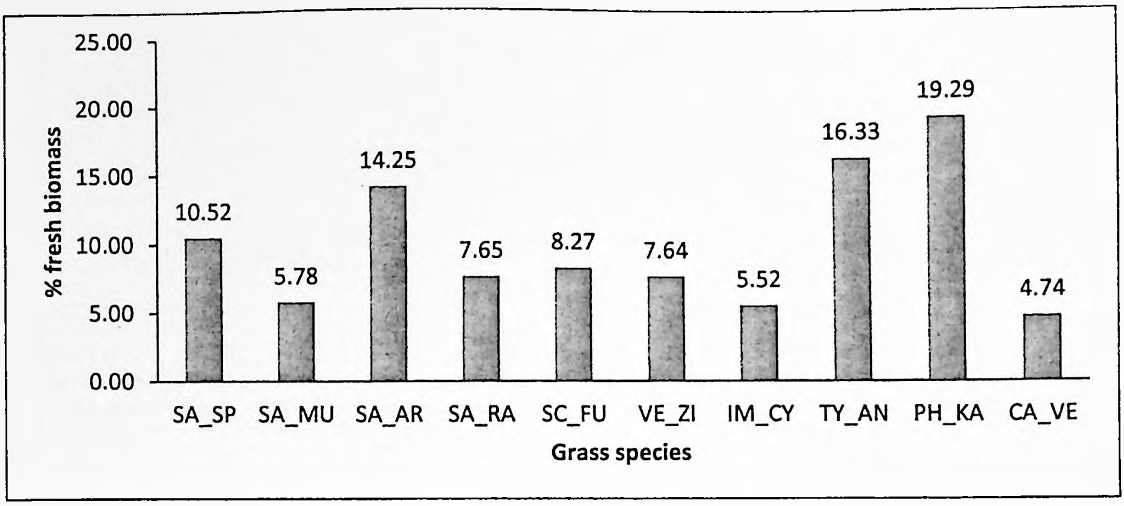


**Figure 20:** Percent fresh biomass of 10 most dominant grasses in intensive study area

**Abbreviations used in Figure 20** (SA_SP is *Saccharum spontaneum*, SA_MU is *Saccharum munja*, SA_AR is *Saccharum arundinaceum*, SA_RA is *Saccharum ravennae*, SC_FU is *Sclerostachya fusca*, VE_ZI is *Vetiveria zizanoides*, IM_CY is *Imperata cylindrica*, TY_AN is *Typha anguistifolia*, PH_KA is *Phragmites karka* and CA_VE is *Carex vesicaria*)

### 4.1.2. Grassland vegetation communities

TWINSPAN analysis classified 304 plots into seven different Grassland vegetation communities based on plant species association (See **Figure 21**). Dendrogram developed on the basis of results of TWINSPAN analysis, clearly explained the identified communities based on the similar habitat they shared. First division of 304 plots occurred at eigen value 0.6636 and separated wet communities from dry communities. Second division occurred at eigen value 0.4551 which further separated the dry communities into upland dry communities and lowland moist communities. Third division occurred at eigen value 0.6971 which further divided wet communities into high wet community and low wet community. Fourth division occurred at eigen value 0.5872 which separated relatively dry communities into upland dry community and lowland moist community. Fifth division occurred at eigen value 0.4735 which separated two different relatively moist communities. Sixth division occurred at eigen value 0.3737 which differentiated mono dominant wet community and poly dominant wet community. Seventh division occurred at eigen value 0.4365 which differentiated wet non-grass species.

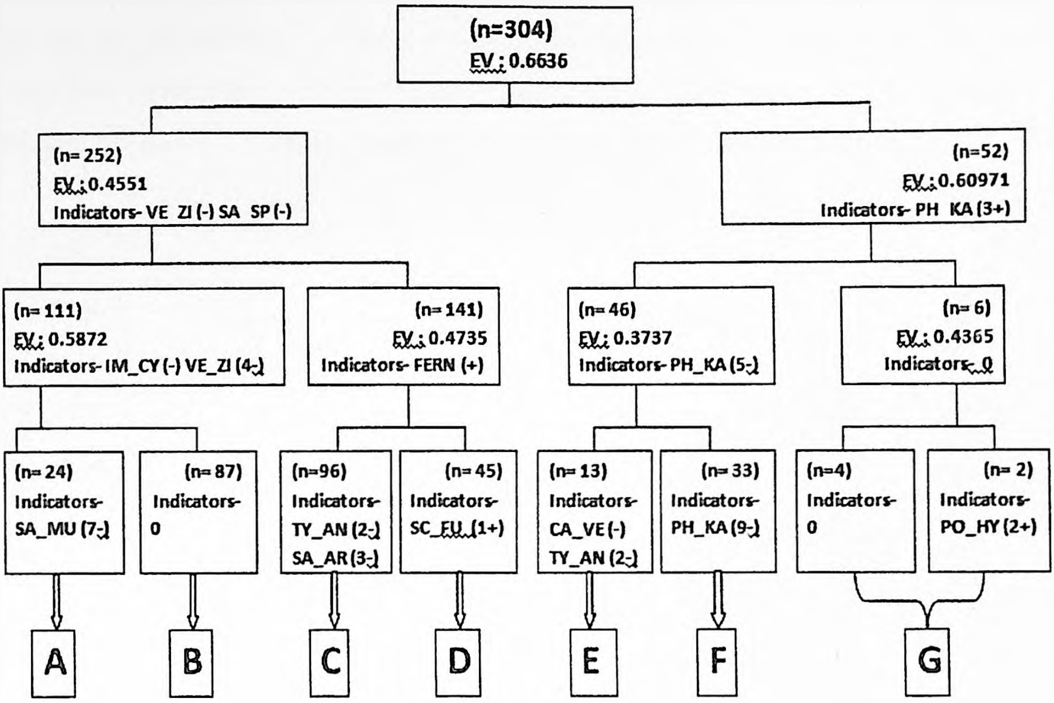


**Figure 21:** Dendrogram developed based on results of TWINSPAN analysis on all 304 plots within Grassland habitat

**Abbreviations used in Figure 21** (EV is eigen value, n is number of sample plots. VE_ZI is *Vetiveria zizanoides*, SA_SP is *Saccharum spontaneum*, PH_KA is *Phragmites karka*, IM_CY is *Imperata cylindrica*, SA_MU is *Saccharum munja*, TY_AN is *Typha anguistifolia*, SA_AR is *Saccharum arundinaceum*, SC_FU is *Sclerostachya fusca*, CA_VE is *Carex vesicaria*, PO_HY is *Polygonum hydropiper*)

Following are the seven identified grassland communities-

**A:** *Saccharum munja* association

**B:** *Typha angustifolia- Saccharum spontaneum –Imperata cylindrica-Vetiveria zizanoides* association

**C:** *Typha anguistifolia-Saccharum arundinaceum-Saccharum spontaneum* association

**D:** *Sclerostachya fusca-Saccharum ravennae-Saccharum spontaneum-Carex vesicaria* association

**E:** *Phragmites Karka-Saccharum arundinaceum-Typha anguistifolia-Carex vesicaria* association

**F:** *Phragmites karka* association

**G:** *Phyllanthus sp. – Carex vesicaria-Ficus heterophylla* association

In alluvial floodplains of VTR, following two grassland communities was having higher frequency of occurrence – *Typha anguistifolia-Saccharum arundinaceum-Saccharum spontaneum* association (31.58 %) and *Typha anguistifolia-Saccharum spontaneum-Imperata cylindrica-Vetiveria zizanoides* association (28.62 %) (See **Figure 22**).

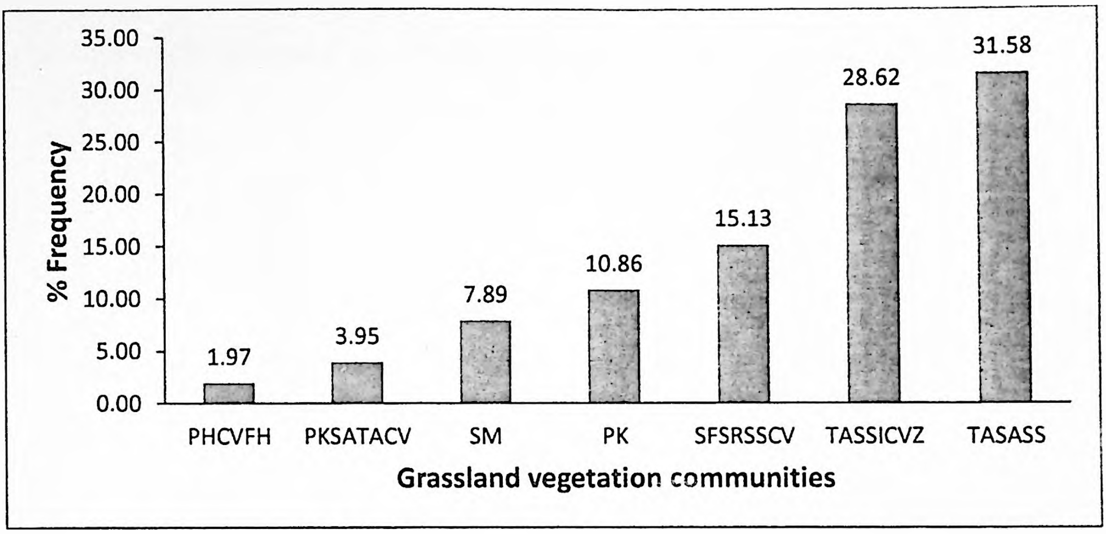


**Figure 22:** Percentage frequency of occurrence of all the associations in Intensive study area.

**Abbreviations used in Figure 22** (PHCVFH is *Phyllanthus sp.-Carex vesicaria-Ficus heterophylla* association, SM is *Saccharum munja* association,PKSATACV is *Phragmites karka-Saccharum arundinaceum-Typha anguistifolia-Caresx vesicaria*, PK is *Phragmites karka*, SFSRSSCV is *Sclerostachya fusca-Saccharum ravennae-Saccharum spontaneum-Carex vesicaria* association, TASSICVZ is *Typha anguistifolia,-Saccharum spontaneum,-Imperata cylindrica-Vetiveria zizanoides* association and TASASS is *Typha anguistifolia-Saccharum ravennae-Saccharum spontaneum* association)

Community A- ***Saccharum munja* association**

This community was separated at division 4 with eigen value 0.5872 having 24 plots in it. *Saccharum munja* is the sole indicator species of this community. Mean percent cover is highest for *Saccharum munja* (67.5 ± SE 4.79 %) followed by *Imperata cylindrica* (5.4 ± SE 1.4 %), *Ziziphus sp.* (4.3 ± SE 1.69 %) and *Saccharum ravenne* (4.06 ± SE 1.90 %) **(Figure 23).**

Percent fresh biomass of dominant species are as follows – *Saccharum munja* (81.74 %), *Saccharum ravennae* (6.5 %), *Sacchaarum arundinaceum* (4.24 %), *Imperata cylindrica* (3.45 %) **(Figure 24).**

The total fresh biomass of all grass species in the community was 4.90×10^5 ± SE 3.92×10^4 kg/ha. *Saccharum munja* (4.01×10^5 ± SE 1.188×10^2 kg/ha) contributed highest to the above ground fresh biomass followed by *Saccharum ravennae* (3.2×10^4 ± SE 6.26×10^2 kg/ha), *Saccharum arundinaceum* (2.08×10^4 ± SE 2.75×10^2 kg/ha), *Imperata cylindrica* (1.70×10^4 ± SE 1.84×10^2 kg/ha).

This community is found at dry upland areas and is the late succesional community.

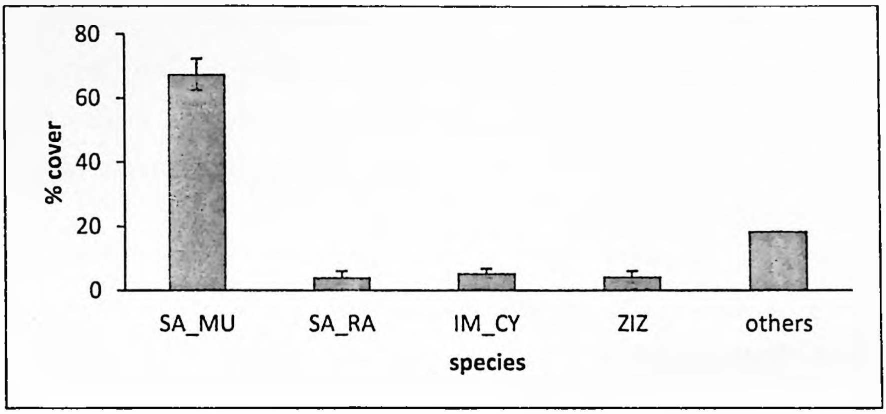


**Figure 23:** Percent cover of dominant plant species in *Saccharum munja* association

**Abbreviations used in Figure 23** (SA_MU is *Saccharum munja*, SA_RA is *Saccharum ravennae*, IM_CY is *Imperata cylindrica*, ZIZ is *Ziziphus* sp.)

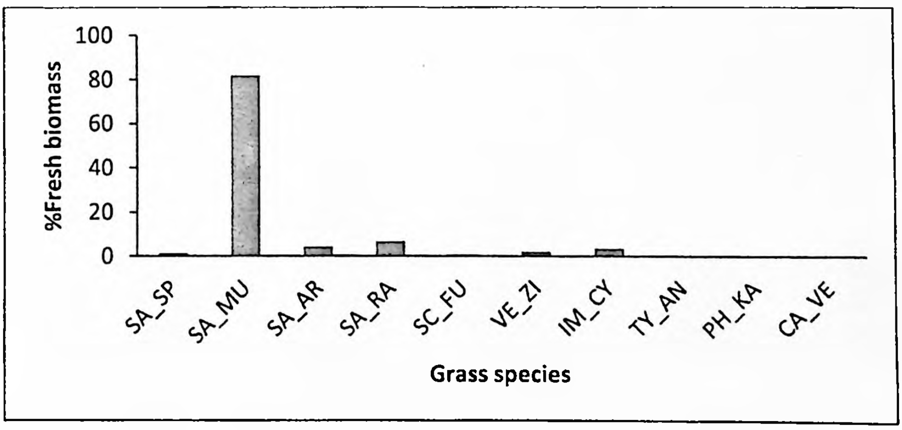


**Figure 24:** Percent fresh biomass of dominant plant species in *Saccharum munja* association

**Abbreviations used in Figure 24** (SA_SP is *Saccharum spontaneum*, SA_MU is *Saccharum munja*, SA_AR is *Saccharum arundinaceum*, SA_RA is *Saccharum ravennae*, VE_ZI is *Vetiveria zizanoides*, IM_CY is *Imperata cylindrica*, TY_AN is *Typha anguistifolia*, PH_KA is *Phragmites karka*, CA_VE is *Carex vesicaria*)

Community B- ***Typhaangustifolia- Saccharum spontaneum –Imperata cylindrica- Vetiveria zizanoides* association**

This community was separated from community A at fourth division with eigen value 0.5872 having 87 plots in it. TWINSPAN has not given any indicator species for this community, but most dominant species occurring together with mean percent cover are as follows – *Imperata cylindrica* (30.49 ± SE 2.91) % , *Vetiveria zizanoides* (29 ± SE 4.6)%, *Typha anguistifolia* (13.38 ± SE 1.91)%, *Saccharum spontaneum* (9.6 ± SE 1.3) (See **Figure 25**).

While, percent fresh biomass wise *Vetiveria zizanoides* was dominant with 27.10 %, followed by *Typha anguistifolia* (22.54 %), *Imperata cylindrica* (21.44 %), *Saccharum spontaneum* (15.40 %) (See **Figure 26**).

The total fresh biomass of all grass species in the community was 1.62×10^6 ± SE 5.39×10^4 kg/ha. Fresh biomass of *Vetiveria zizanoides* was 4.38×10^5 ± SE 8.03×10^2 kg/ha, followed by *Typha anguistifolia* 3.64×10^5 ± SE 5.9×10^2 kg/ha, *Imperata cylindrica* 3.46×10^5 ± SE 3.80×10^2 kg/ha, *Saccharum spontaneum* 2.49×10^5 ± SE 3.97×10^2 kg/ha.

This community is found in lowland areas where water inundates it for few months and moisture is present throughout the year.

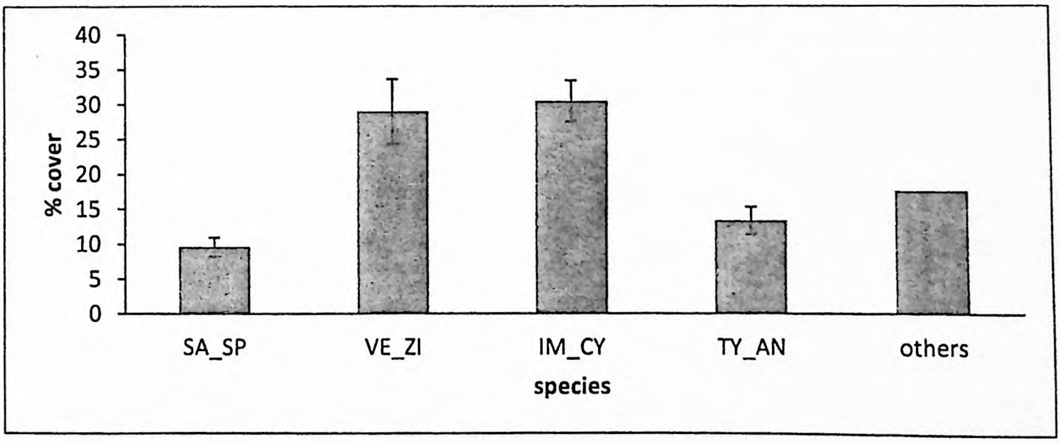


**Figure 25:** Percent cover of dominant plant species in *Typha-anguistifolia-Saccharum spontaneum-Imperata cylindrica-Vetiveria zizanoides* association

**Abbreviations used in Figure 25** (SA_SP is *Saccharum spontaneum*, VE_ZI is *Vetiveria zizanoides*, IM_CY is *Imperata cylindrica*, TY_AN is *Typha anguistifolia*)

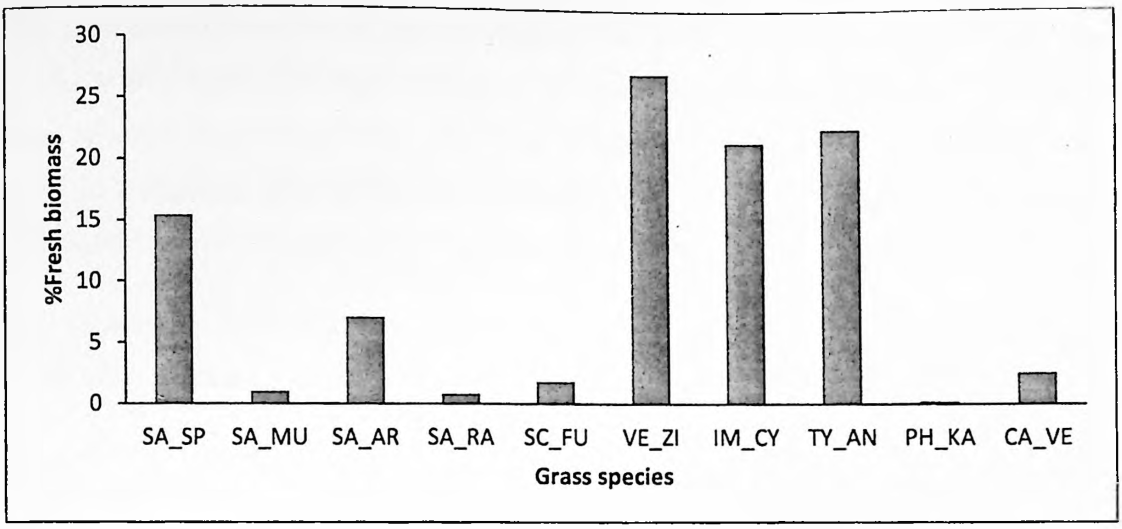


**Figure 26:** Percent fresh biomass of dominant plant species in *Typha anguistifolia-Saccharum spontneum-Imperata cylindrica-Vetiveria zizanoides* association

**Abbreviations of Figure 26** (SA_SP is *Saccharum spontaneum*, SA_MU is *Saccharum munja*, SA_AR is *Saccharum arundinaceum*, SA_RA is *Saccharum ravennae*, SC_FU is *Sclerostachya fusca*, VE_ZI is *Vetiveria zizanoides*, IM_CY is *Imperata cylindrica*, TY_AN is *Typha anguistifolia*, PH_KA is *Phragmites karka*, CA_VE is *Carex vesicaria*)

Community C- ***Typha anguistifolia-Saccharum arundinaceum-Saccharum spontaneum* association**

This community was separated at fifth division with eigen value 0.4735 having 96 plots in it. *Typha angustifolia* and *Saccharum arundinaceum* are the indicators of this association with mean percent cover of 25.69 ± SE 2.86 % and 23.32 ± SE 2.85 %. Other dominant species of this association are *Saccharum spontaneum* and *Carex vesicaria* with mean percent cover of 12.06 ± SE 1.96 % and 8.55 ± SE 1.70 % respectively (See **Figure 27**).

However, *Typha angustifolia* was having highest mean percent cover in community, but it was contributing less than *Saccharum arundinaceum* in terms of fresh biomass. Percent fresh biomass of the *Saccharum arundinaceum* was 32.73 %, *Typha angustifolia* was 31.14 %, *Saccharum spontaneum* was 13.91 % and *Saccharum ravennae* 8.17 % (See **Figure 28**).

The total fresh biomass of all the the grass species in this community was $2.48 \times 10^{6} \pm$ SE $9.65 \times 10^{4}$ kg/ha. The fresh biomass of dominant species are as follows- *Saccharum arundinaceum* ($8.11 \times 10^{5} \pm$ SE $1.04 \times 10^{3}$ kg/ha), *Typha angustifolia* ($7.72 \times 10^{5} \pm$ SE $8.97 \times 10^{2}$ kg/ha), *Saccharum spontaneum* ($3.45 \times 10^{5} \pm$ SE $5.84 \times 10^{2}$ kg/ha), *Saccharum ravennae* ($2.03 \times 10^{5} \pm$ SE $5.34 \times 10^{2}$ kg/ha).

This community is found in low lying areas where water stagnates for 4-5 months (July – November). Burning for thatch stalk collection is regular phenomena.

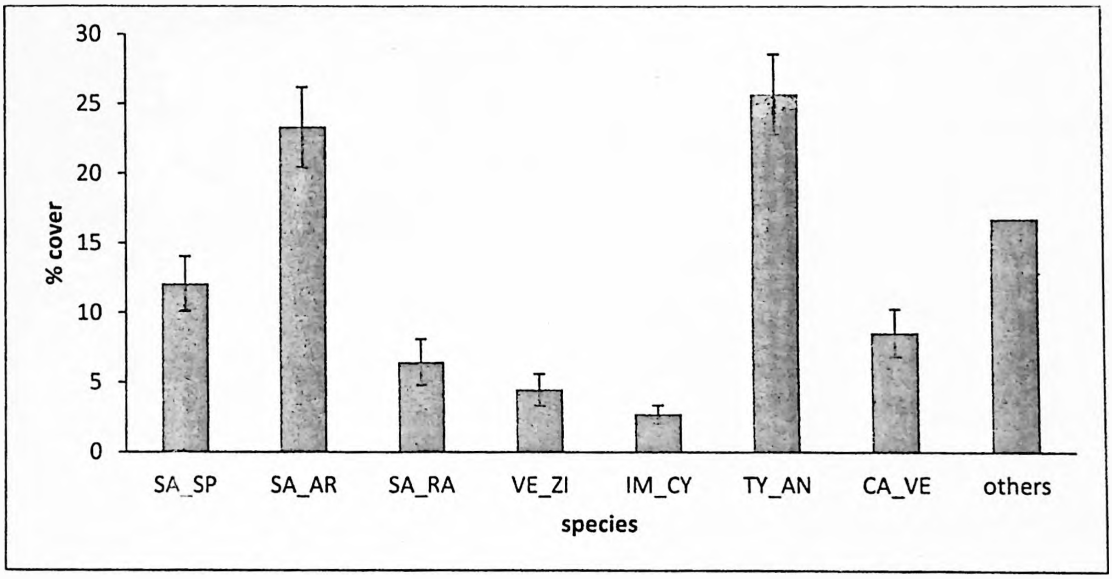


**Figure 27:** Percent cover of dominant plant species in *Typha anguistifolia-Saccharum arundinaceum-Saccharum spontaneum* association

**Abbreviation used in Figure 27** (SA_SP is *Saccharum spontaneum*, SA_AR is *Saccharum arundinaceum*, SA_RA is *Saccharum ravennae*, VE_ZI is *Vetiveria zizanoides*, IM_CY is *Imperata cylindrica*, TY_AN is *Typha anguistifolia*, CA_VE is *Carex Vesicaria*)

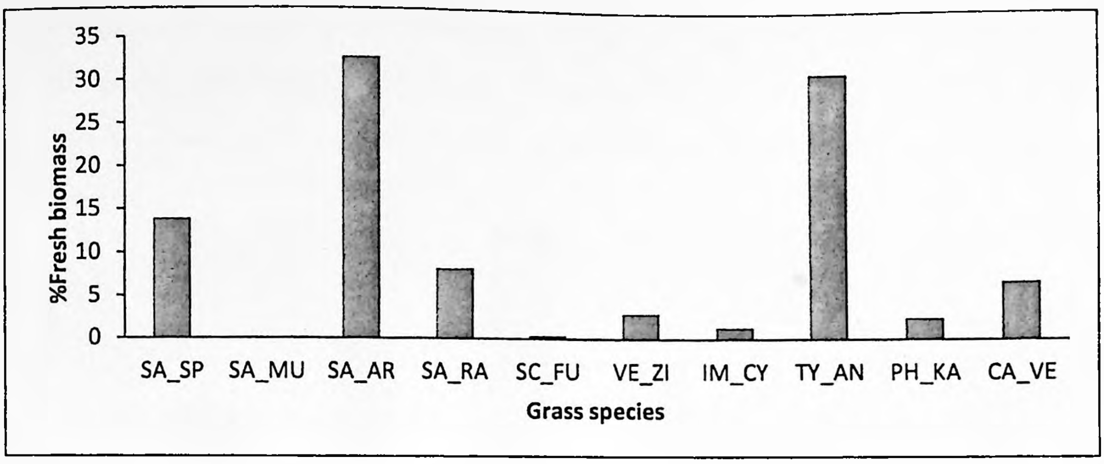


**Figure 28**: Percent fresh biomass of dominant plant species in *Typha anguistifolia-Saccharum arundinaceum-Saccharum spontaneum* association

**Abbreviations used in Figure 28** (SA_SP is *Saccharum spontaneum*, SA_MU is *Saccharum munja*, SA_AR is *Saccharum arundinaceum*, SA_RA is *Saccharum ravennae*, SC_FU is *Sclerostachya fusca*, VE_ZI is *Vetiveria zizanoides*, IM_CY is *Imperata cylindrica*, TY_AN is *Typha anguistifolia*, PH_KA is *Phragmites karka*, CA_VE is *Carex vesicaria*)

Community D- ***Sclerostachya fusca-Saccharum ravennae-Saccharum spontaneum-Carex vesicaria* association**

This community was separated at fifth division with eigen value o.4735 having 45 plots in it. *Sclerostachya fuscais* the indicator species of this community and has mean percent cover of 36.95 ± SE 4.59 %. Other dominant species of this community has following mean percent cover- *Saccharum ravennae* (19.24 ± SE 4.50 %), *Saccharum spontaneum* (10.24 ± SE 2.38 %), *Carex vesicaria* (9.44 ± SE 2.66 %) and *Calamus tenuis* (4.13 ± SE 1.57 %) (See **Figure 29**). The percent fresh biomass of dominant species is as follows- *Sclerostachya fusca* (47.70%), *Saccharum ravennae* (24.42%), *Saccharum spontaneum* (11.80%), *Carex vesicaria* (7.5%) (See **Figure 30**).

The total fresh biomass of all the grass species this community was 1.16×10^6 ± SE 5.61×10^4 kg/ha. Fresh biomass of dominant species are as follows- *Sclerostachya fusca* (5.55×10^5 ± SE 1.53×10^3 kg/ha), *Saccharum ravennae* (2.84×10^5 ± SE 1.48×10^3 kg/ha), *Saccharum spontaneum* (1.37×10^5 ± SE 7.10×10^2 kg/ha), *Carex vesicaria* (8.73×10^4 ± SE 5.47×10^2 kg/ha).

This community occurs in low lying areas where seasonal inundation happens for 5-8 months (July – December).

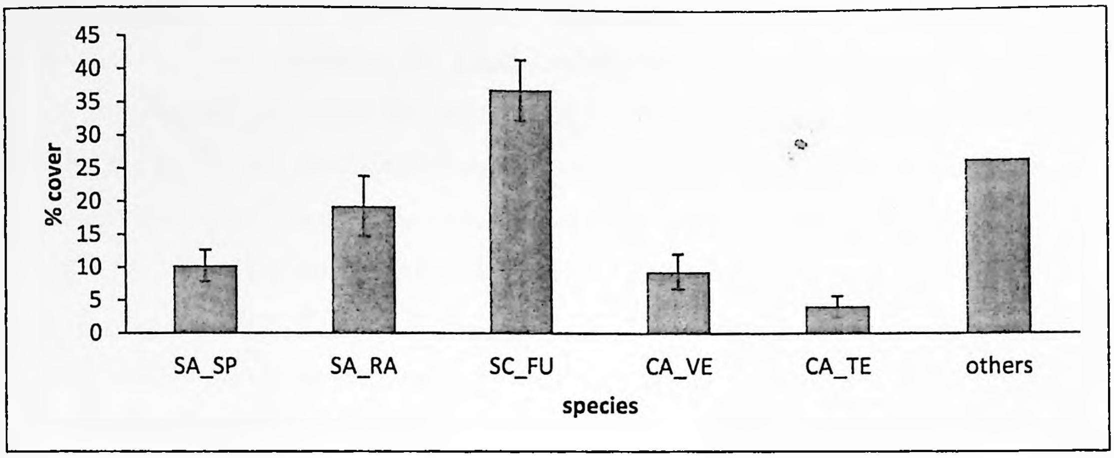


**Figure 29:** Percent cover of dominant plant species in *Sclerostachya fusca-Saccharum ravennae-Saccharum spontaneum-Carex vesicaria* association

**Abbreviations used in Figure 29** (SA_SP is *Saccharum spontaneum*, SA_RA is *Saccharum ravennae*,SC_FU is *Sclerostachya fusca*, CA_VE is *Carex vesicaria*, CA_TE is *Calamus tenuis*)

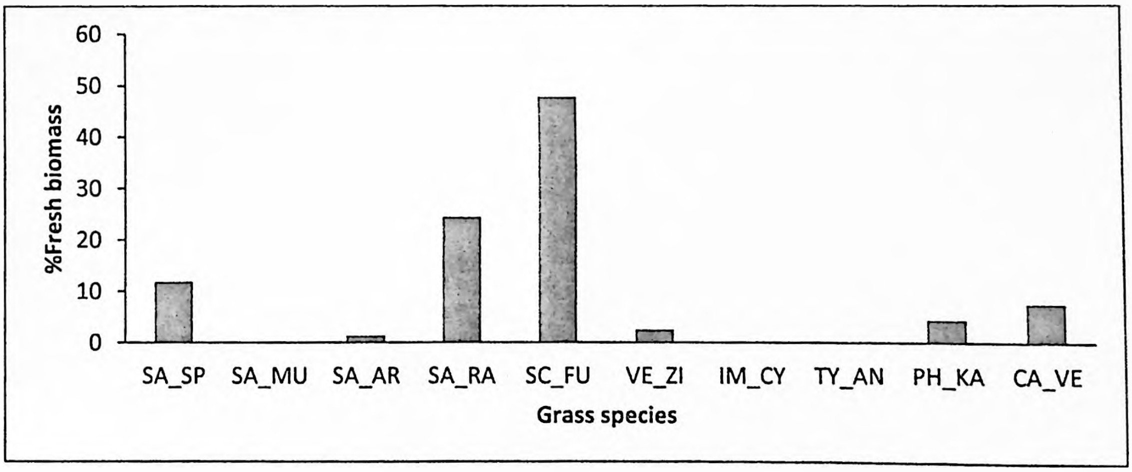


**Figure 30:** Percent fresh biomass of dominant plant species in *Sclerostachya fusca-Saccharum ravennae-Saccharum spontaneum-Carex vesicaria* association

**Abbreviations used in Figure 30** (SA_SP is *Saccharum spontaneum*, SA_MU is *Saccharum munja*, SA_AR is *Saccharum arundinaceum*, SA_RA is *Saccharum ravennae*, SC_FU is *Sclerostachya fusca*, VE_ZI is *Vetiveria zizanoides*, IM_CY is *Imperata cylindrica*, TY_AN is *Typha anguistifolia*, PH_KA is *Phragmites karka*, CA_VE is *Carex vesicaria*)

Community-E ***Phragmites karka-Saccharum arundinaceum-Typha anguistifolia-Carex vesicaria* association**

This community was separated at sixth division with eigen value 0.3737 having 13 plots in it. Though, *Carex vesicaria* and *Typha anguistifolia* were given as indicator species but their mean percent cover and percent fresh biomass was very low as compared to *Phragmites karka* and *Saccharum arundinaceum*. Mean percent cover of dominant and indicator species are- *Phragmites karka* (52.92 ± SE 5.21 %), *Saccharum arundinaceum* (14.34 ± SE 5.90 %), *Typha anguistifolia* (9.61 ± SE 2.96 %), *Carex vesicaria* (3.23 ± SE 1.18 %) (See **Figure 31**).

Percent fresh biomass of dominant and indicator species are as follows - *Phragmites karka* (64.87 %), *Saccharum arundinaceum* (18.78 %), *Typha anguistifolia* (10.87 %), *Carex vesicaria* (2.39 %) (See **Figure 32**).

The total fresh biomass of all grass species in the community was $3.6\times10^{5}$ ± SE $2.30\times10^{4}$ kg/ha. The fresh biomass of dominant and indicator species are as follows- *Phragmites karka* ($2.33\times10^{5}$ ± SE $1.77\times10^{3}$kg/ha), *Saccharum arundinaceum* ($6.76\times10^{4}$ ± SE $2.14\times10^{3}$ kg/ha), *Typha anguistifolia* ($3.91\times10^{4}$ ± SE $9.28\times10^{2}$ kg/ha), *Carex vesicaria* ($8.62\times10^{3}$ ± SE $2.43\times10^{2}$ kg/ha).

This community occurs in low lying areas near to nalas.

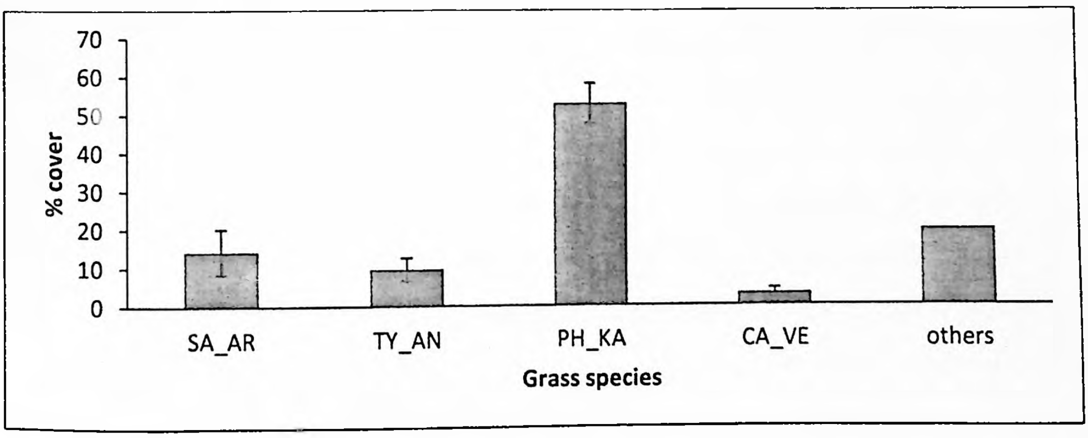


**Figure 31:** Percent cover of dominant plant species in *Phragmites karka-Saccharum ravnnae-Typha anguistifolia-Carex vesicaria* association

**Abbreviations used in Figure 31** (SA_AR is *Saccharum arundinaceum*, TY_AN is *Typha anguistifolia*, PH_KA is *Phragmites karka*, CA_VE is *Carex vesicaria*)

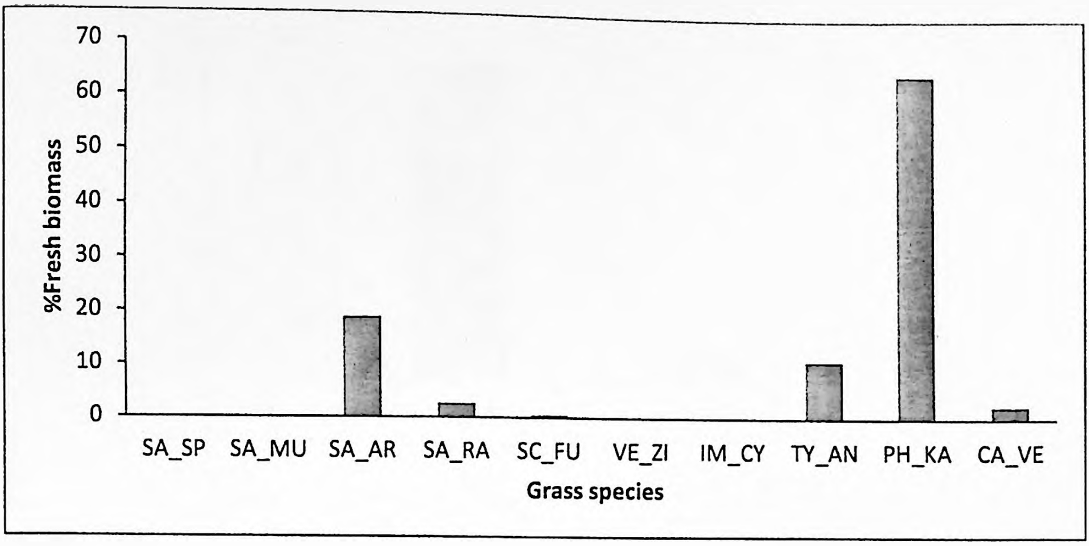


**Figure 32:** Percent fresh biomass of dominant plant species in *Phragmites karka-Saccharum ravnnae-Typha anguistifolia-Carex vesicaria* association

**Abbreviations used in Figure 32** (SA_SP is *Saccharum spontaneum*, SA_MU is *Saccharum munja*, SA_AR is *Saccharum arundinaceum*, SA_RA is *Saccharum ravennae*, SC_FU is *Sclerostachya fusca*, VE_ZI is *Vetiveria zizanoides*, IM_CY is *Imperata cylindrica*, TY_AN is *Typha anguistifolia*, PH_KA is *Phragmites karka*, CA_VE is *Carex vesicaria*)

Community F- ***Phragmites karka association***

This community was separated at sixth division with eigen value 0.3737 having 33 plots in it. *Phragmites karka* is sole indicator of this community and forms pure mono dominant patch. The mean percent cover of *Phragmites karka*was found to be 92.36 ± SE 3.01 %. The percent fresh biomass *of Phragmites karka*was found 96.66 % followed by negligible value of *Saccharum spontaneum* with 1.67 % (See **Figure 33 & 34**).

The total fresh biomass of the community was 1.07×10^6 ± SE 1.03×10^5 kg/ha. Fresh biomass of *Phragmites karka* was found out to be 1.03×10^6 ± SE 1.02×10^3 kg/ha, followed by *Saccharum spontaneum* 1.79×10^4 ± SE 5.41×10^2 kg/ha.

This community is found in water logged swampy areas.

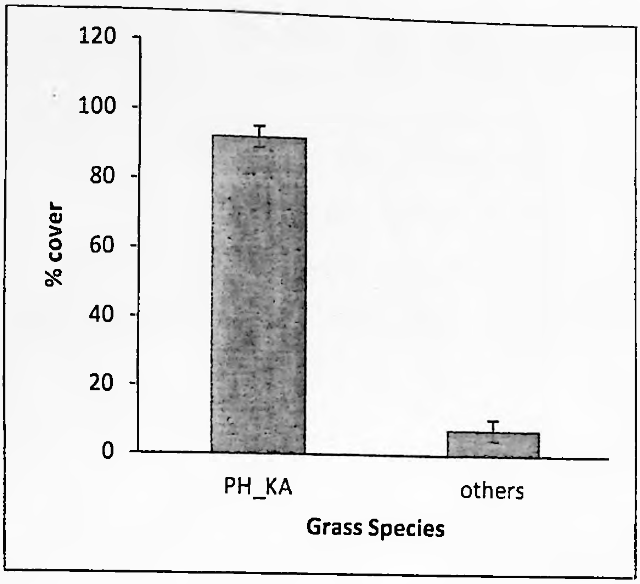


**Figure 33:** Percent cover of dominant plant species in *Phragmites karka* association

**Abbreviation used in Figure 33** (PH_KA is *Phragmites karka*)

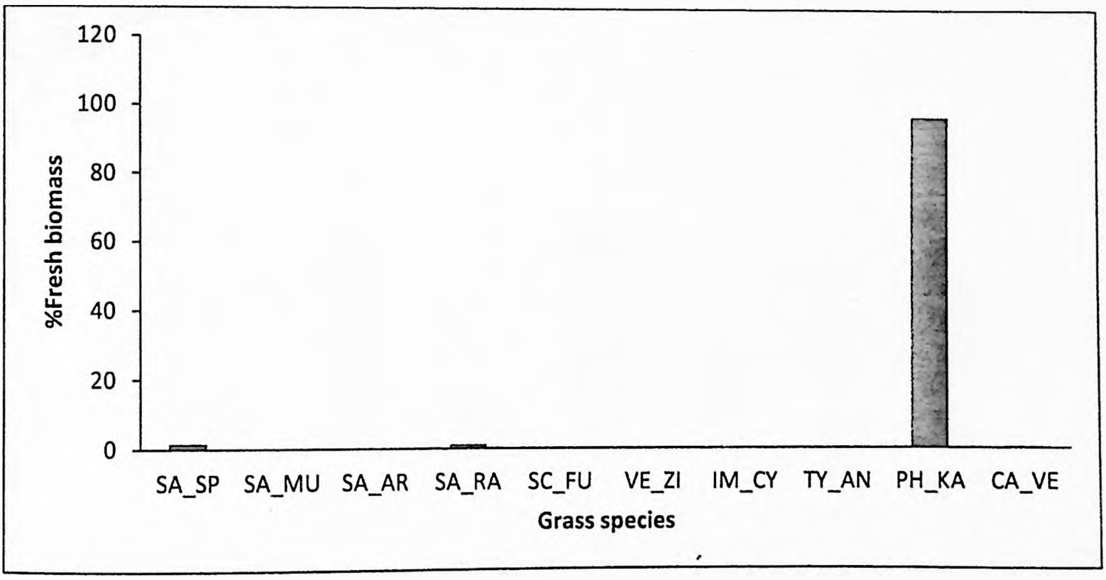


**Figure 34:** Percent fresh biomass of dominant plant species in *Phragmites karka* association

**Abbreviations used in Figure 34** (SA_SP is *Saccharum spontaneum*, SA_MU is *Saccharum munja*, SA_AR is *Saccharum arundinaceum*, SA_RA is *Saccharum ravennae*, SC_FU is *Sclerostachya fusca*, VE_ZI is *Vetiveria zizanoides*, IM_CY is *Imperata cylindrica*, TY_AN is *Typha anguistifolia*, PH_KA is *Phragmites karka*, CA_VE is *Carex vesicaria*)

Community G- ***Phyllanthus sp.* – *Carex vesicaria-Ficus heterophylla*association**

This community was separated at third division with eigen value of 0.6097 having 6 plots in it. At this division, there was no indicator species. Dominant species were non-grass species and their mean percent cover values are as follows- *Phyllanthus sp.* (28.33 ± SE 8.23 %), *Carex vesicaria* (26.33 ± SE 7.90 %), *Ficus heterophylla* (10.83 ± SE 6.81 %) (See **Figure 35**).

The percent fresh biomass among dominant grasses was found to be highest for *Carex vesicaria* (68.91%) followed by *Phragmites karka* (21.60 %) (See **Figure 36**).

The fresh biomass of *Carex vesicaria* was 3.25×10^4 ± SE 1.62×10^3 kg/ha and *Phragmites karka* was 1.02×10^4 ± SE 8.75×10^2 kg/ha.

This community occurred near nalas in low lying moist areas.

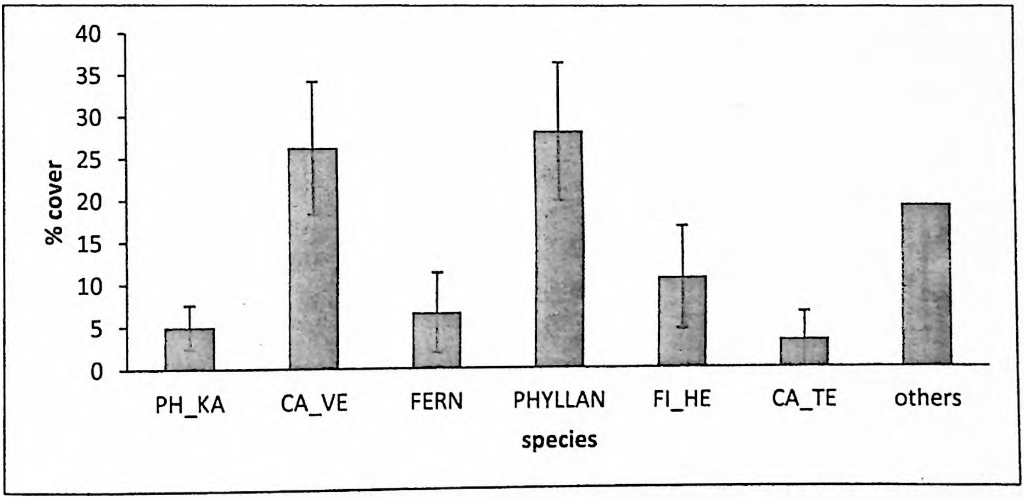


**Figure 35:** Percent cover of dominant plant species in *Phyallanthus-Carex vesicaria-Ficus heterophylla* association

**Abbreviations used in Figure 35** (PH_KA is *Phragmites karka*, CA_VE is *Carex vesicaria*, PHYLLAN is *Phyllanthus sp.*, FI_HE is *Ficus heterophylla*, CA_TE is *Calamus tenuis*)

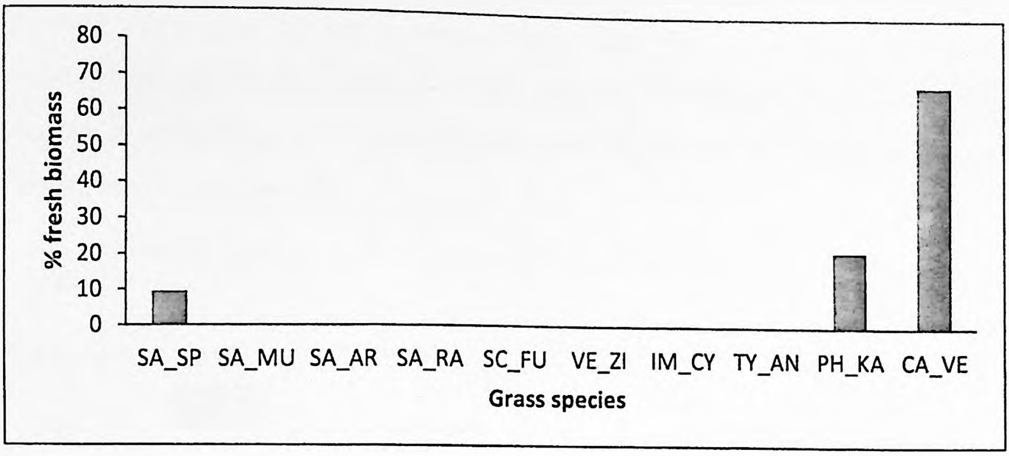


**Figure 36:** Percent fresh biomass of dominant grass species in *Phyallanthus-Carex vesicaria-Ficus heterophylla* association.

**Abbreviations used in Figure 36** (SA_SP is *Saccharum spontaneum*, SA_MU is *Saccharum munja*, SA_AR is *Saccharum arundinaceum*, SA_RA is *Saccharum ravennae*, SC_FU is *Sclerostachya fusca*, VE_ZI is *Vetiveria zizanoides*, IM_CY is *Imperata cylindrica*, TY_AN is *Typha anguistifolia*, PH_KA is *Phragmites karka*, CA_VE is *Carex vesicaria*)

### 4.1.3. Use of grassland communities by mammals

Indirect signs of following species were surveyed in belt transects- chital, hog deer, nilgai, sambar, wild pig, domestic cattle, rufous tailed hare, porcupine. Sambar and porcupine were not analyzed because of very low sample size (<5). Out of seven grassland vegetation communities found in study area, three communities were not used in analysis, just because these were found at water logged sites where pellet groups could not be searched for. Ivlev's Electivity Indices (IEI) was used to see the positive selection (preference / use more than availability) and negative selection (avoidance / use less than availability) by mammals. IEI ranged from -1 to +1.

**Chital**

Chital positively selected *Saccharum munja* association (IEI= 0.31) and marginaly *Typha anguistifolia-Saacharum spontaneum-Imperata cylindrica-Vetiveria zizanoides*association (IEI= 0.07). While it negatively selected *Typha anguistifolia-Saacharum arundinaceum-Saccharum spontaneum* association (IEI= -0.18) and*Sclerostachya fusca-Saccharum ravennae-Saccharum spontaneum-Carex vesicaria* association (IEI= -0.11) (See **Figure 37**).

Seeing only usage against the preference, *Typha anguistifolia-Saacharum spontaneum-Imperata cylindrica-Vetiveria zizanoides* association (42.88 %) and *Typha anguistifolia-Saacharum arundinaceum-Saccharum spontaneum* association (23.39%) are used more than others are (See **Figure 38**).

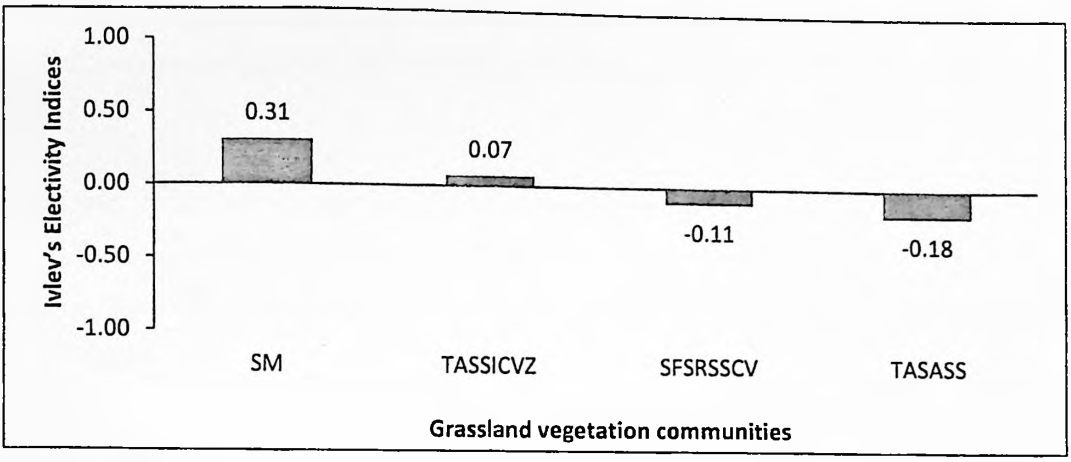


**Figure 37:** Selection of grassland vegetation community by chital based on Ivlev's Electivity indices.

**Abbreviations used in Figure 37** (SM is *Saccharum munja* association, TASSICVZ is *Typha anguistifolia,-Saccharum spontaneum,-Imperata cylindrica-Vetiveria zizanoides* association, SFSRSSCV is *Sclerostachya fusca-Saccharum ravennae-Saccharum spontaneum-Carex vesicaria* association and TASASS is *Typha anguistifolia-Saccharum ravennae-Saccharum spontaneum* association)

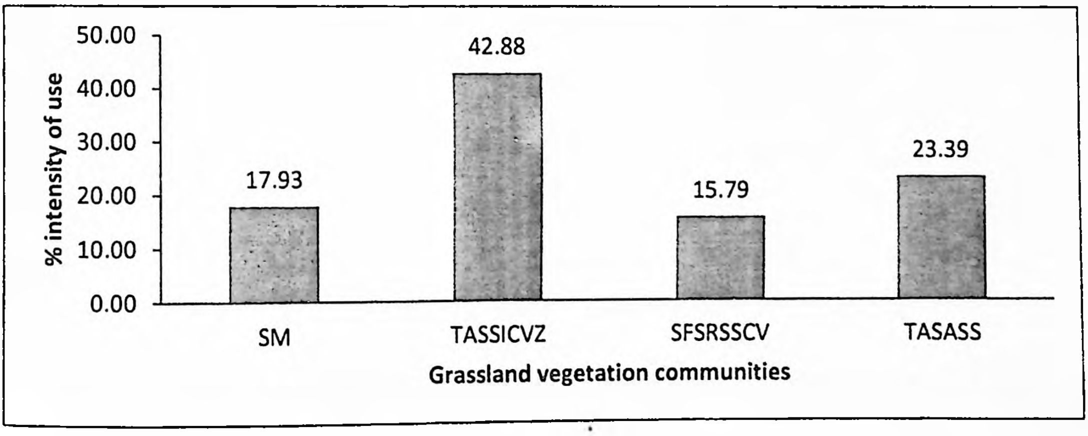


**Figure 38:** Percent intensity of use of grassland vegetation communities by chital

**Abbreviations used in Figure 38** (SM is *Saccharum munja* association, TASSICVZ is *Typha anguistifolia,-Saccharum spontaneum,-Imperata cylindrica-Vetiveria zizanoides* association, SFSRSSCV is *Sclerostachya fusca-Saccharum ravennae-Saccharum spontaneum-Carex vesicaria* association and TASASS is *Typha anguistifolia-Saccharum ravennae-Saccharum spontaneum* association)

**Hog deer**

Hog deer positively selected *Typha anguistifolia-Saacharum spontaneum-Imperata cylindrica-Vetiveria zizanoides* association (IEI= 0.10) and *Saccharum munja* association (IEI= 0.09) whereas it negatively selected *Sclerostachya fusca-Saccharum ravennae-Saccharum spontaneum-Carex vesicaria* (IEI= -0.29) and *Typha anguistifolia-Saacharum arundinaceum-Saccharum spontaneum* associations (IEI= -0.03) (See **Figure 39**).

Ignoring availability, use of *Typha anguistifolia-Saacharum spontaneum-Imperata cylindrica-Vetiveria zizanoides* (45.78 %) and *Typha anguistifolia-Saacharum arundinaceum-Saccharum spontaneum* associations (31.93 %) was highest by hog deer (See **Figure 40**).

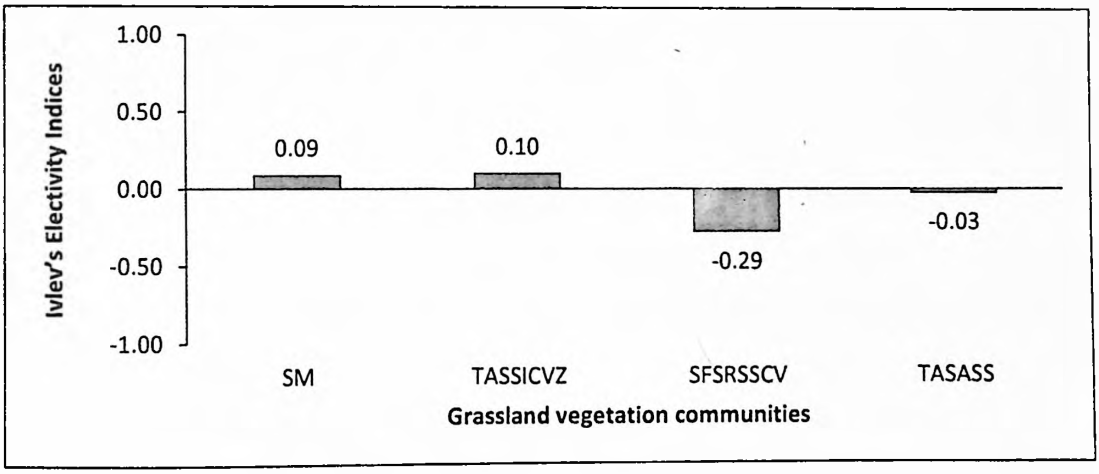


**Figure 39:** Selection of grassland vegetation community by hog deer based on Ivlev's Electivity indices.

**Abbreviations used in Figure 39** (SM is *Saccharum munja* association, TASSICVZ is *Typha anguistifolia,-Saccharum spontaneum,-Imperata cylindrica-Vetiveria zizanoides* association, SFSRSSCV is *Sclerostachya fusca-Saccharum ravennae-Saccharum spontaneum-Carex vesicaria* association and TASASS is *Typha anguistifolia-Saccharum ravennae-Saccharum spontaneum* association)

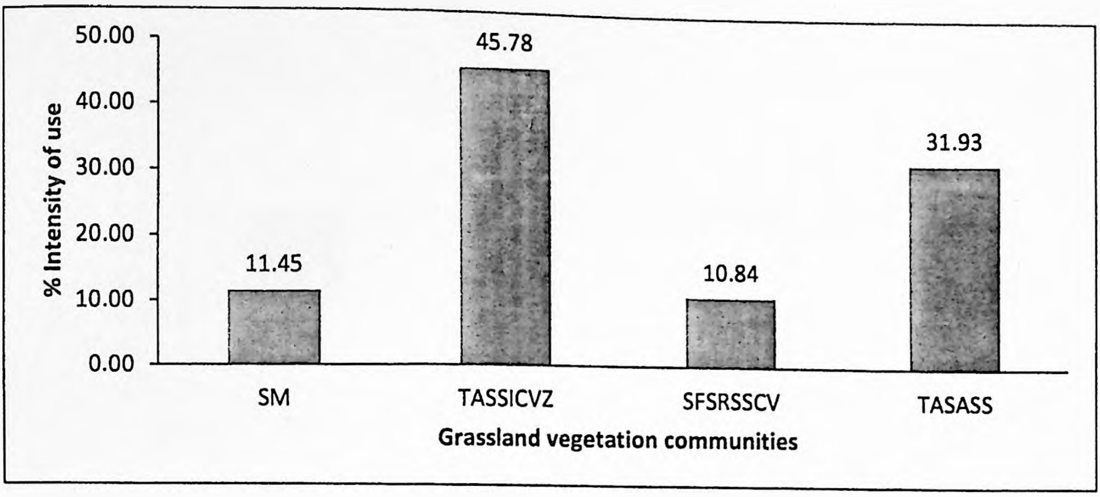


**Figure 40:** Percent intensity of use of grassland vegetation communities by hog deer

**Abbreviations used in Figure 40** (SM is *Saccharum munja* association, TASSICVZ is *Typha anguistifolia,-Saccharum spontaneum,-Imperata cylindrica-Vetiveria zizanoides* association, SFSRSSCV is *Sclerostachya fusca-Saccharum ravennae-Saccharum spontaneum-Carex vesicaria* association and TASASS is *Typha anguistifolia-Saccharum ravennae-Saccharum spontaneum* association)

## Nilgai

Nilgai positively selected *Sclerostachya fusca-Saccharum ravennae-Saccharum spontaneum-Carex vesicaria* (IEI= 0.11) and marginally *Typha anguistifolia-Saacharum spontaneum-Imperata cylindrica-Vetiveria zizanoides* associations (IEI= 0.04) and it negatively selected *Saccharum munja* (IEI= -0.45) and *Typha anguistifolia-Saacharum arundinaceum-Saccharum spontaneum* associations (IEI= -0.03) (See **Figure 41**).

While considering only use, nilgai used *Typha anguistifolia-Saacharum spontaneum-Imperata cylindrica-Vetiveria zizanoides* (40 %) and *Typha anguistifolia-Saacharum arundinaceum-Saccharum spontaneum* associations (32.14 %) more than others are (See **Figure 42**).

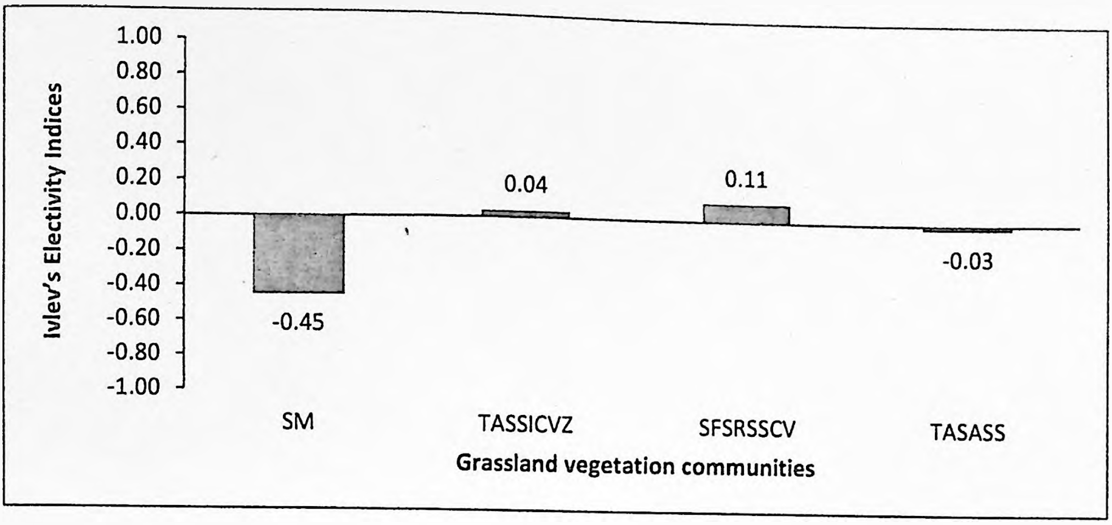


**Figure 41:** Selection of grassland vegetation community by Nilgai based on Ivlev's Electivity indices

**Abbreviations used in Figure 41** (SM is *Saccharum munja* association, TASSICVZ is *Typha anguistifolia,-Saccharum spontaneum,-Imperata cylindrica-Vetiveria zizanoides* association, SFSRSSCV is *Sclerostachya fusca-Saccharum ravennae-Saccharum spontaneum-Carex vesicaria* association and TASASS is *Typha anguistifolia-Saccharum ravennae-Saccharum spontaneum* association)

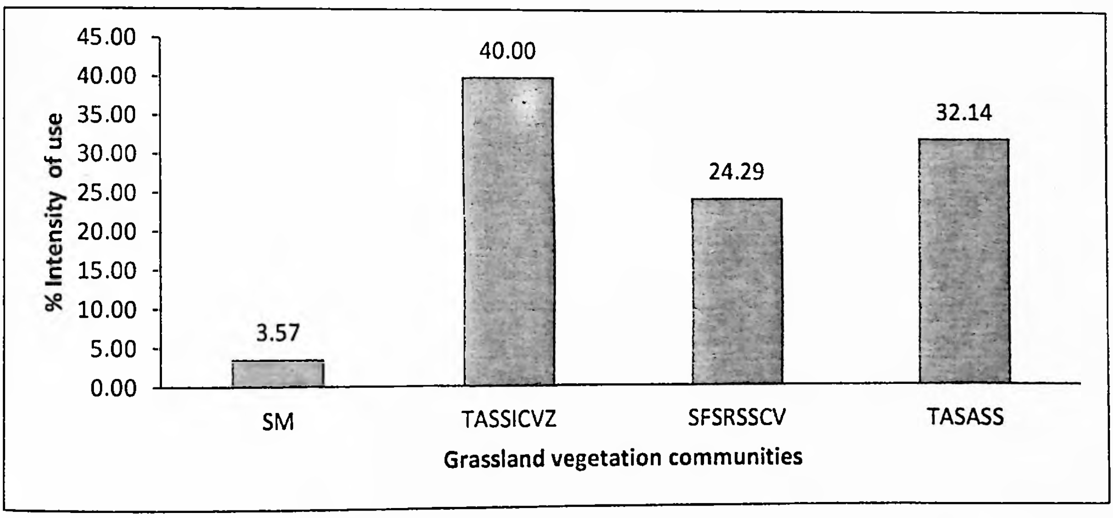


**Figure 42:** Percent intensity of use of grassland vegetation communities by nilgai

**Abbreviations used in Figure 42** (SM is *Saccharum munja* association, TASSICVZ is *Typha anguistifolia,-Saccharum spontaneum,-Imperata cylindrica-Vetiveria zizanoides* association, SFSRSSCV is *Sclerostachya fusca-Saccharum ravennae-Saccharum spontaneum-Carex vesicaria* association and TASASS is *Typha anguistifolia-Saccharum ravennae-Saccharum spontaneum* association)

**Rufous Tailed Hare**

Rufous tailed hare positively selected *Saccharum munja* association (IEI= 0.74) and negatively selected rest others (See **Figure 43**). While seeing only use, same pattern was observed i.e. highest use of *Saccharum munja* association (64.71 %) (See **Figure 44**).

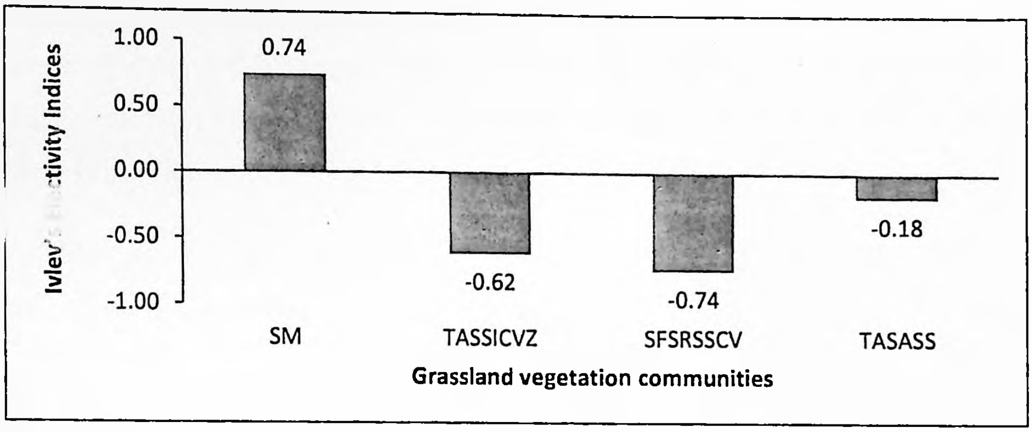


**Figure 43:** Selection of grassland vegetation community by rufous tailed hare based on Ivlev's Electivity indices

**Abbreviations used in Figure 43** (SM is *Saccharum munja* association, TASSICVZ is *Typha anguistifolia,-Saccharum spontaneum,-Imperata cylindrica-Vetiveria zizanoides* association, SFSRSSCV is *Sclerostachya fusca-Saccharum ravennae-Saccharum spontaneum-Carex vesicaria* association and TASASS is *Typha anguistifolia-Saccharum ravennae-Saccharum spontaneum* association)

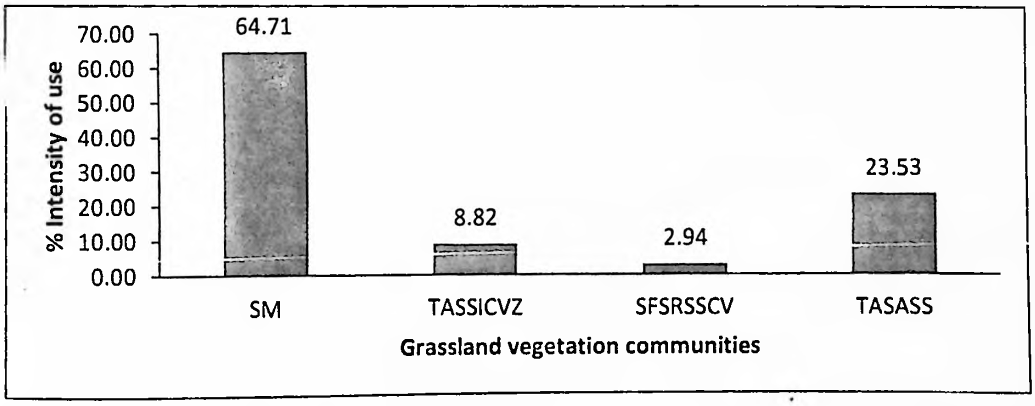


**Figure 44:** Percent intensity of use of grassland vegetation communities by rufous tailed hare

**Abbreviations used in Figure 44** (SM is *Saccharum munja* association, TASSICVZ is *Typha anguistifolia,-Saccharum spontaneum,-Imperata cylindrica-Vetiveria zizanoides* association, SFSRSSCV is *Sclerostachya fusca-Saccharum ravennae-Saccharum spontaneum-Carex vesicaria* association and TASASS is *Typha anguistifolia-Saccharum ravennae-Saccharum spontaneum* association)

### Wild Pig

Wild pig positively selected *Typha anguistifolia-Saacharum arundinaceum-Saccharum spontaneum* association (IEI= 0.13) and marginally *Typha anguistifolia-Saacharum spontaneum-Imperata cylindrica-Vetiveria zizanoides* (IEI= 0.02) association, whereas it negatively selected *Sclerostachya fusca-Saccharum ravennae-Saccharum spontaneum-Carex vesicaria* association (IEI= -0.33) and *Saccharum munja* association (IEI= -0.13) (See **Figure 45**).

Considering only use, wild pig has highest use for *Typha anguistifolia-Saacharum arundinaceum-Saccharum spontaneum* association (43.90%) than others (See **Figure 46**).

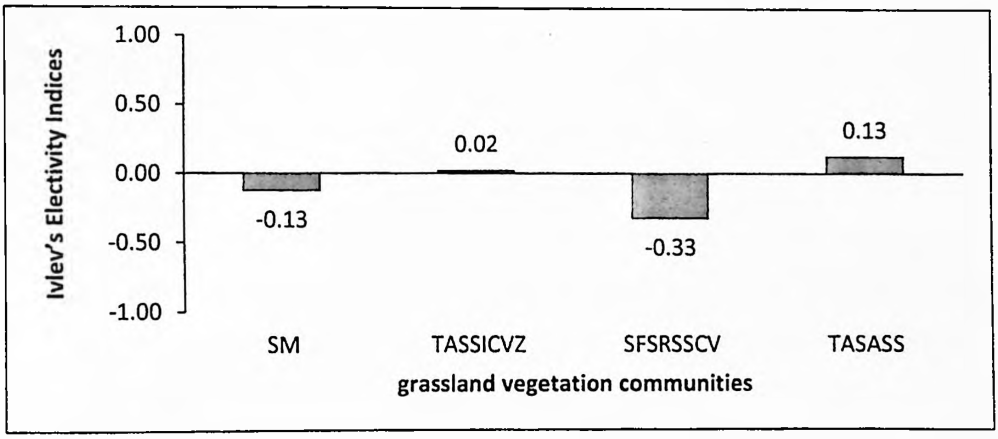


**Figure 45:** Selection of grassland vegetation community by wild pig based on Ivlev's Electivity indices

**Abbreviations used in Figure 45** (SM is *Saccharum munja* association. TASSICVZ is *Typha anguistifolia,-Saccharum spontaneum,-Imperata cylindrica-Vetiveria zizanoides* association. SFSRSSCV is *Sclerostachya fusca-Saccharum ravennae-Saccharum spontaneum-Carex vesicaria* association and TASASS is *Typha anguistifolia-Saccharum ravennae-Saccharum spontaneum* association)

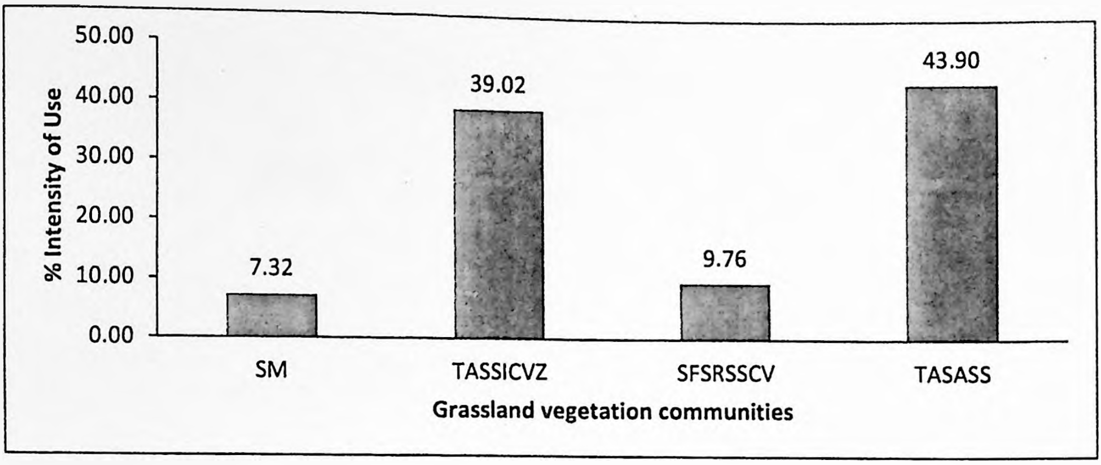


**Figure 46:** Percent intensity of use of grassland vegetation communities by wild pig

**Abbreviations used in Figure 46** (SM is *Saccharum munja* association, TASSICVZ is *Typha anguistifolia,-Saccharum spontaneum,-Imperata cylindrica-Vetiveria zizanoides* association, SFSRSSCV is *Sclerostachya fusca-Saccharum ravennae-Saccharum spontaneum-Carex vesicaria* association and TASASS is *Typha anguistifolia-Saccharum ravennae-Saccharum spontaneum* association)

## Domestic Cattle

Domestic cattle was found to have positive selection for *Saccharum munja* (IEI= 0.29), *Typha anguistifolia-Saacharum spontaneum-Imperata cylindrica-Vetiveria zizanoides* (IEI= 0.10) and marginally *Sclerostachya fusca-Saccharum ravennae-Saccharum spontaneum-Carex vesicaria* (IEI= 0.05) associations, whereas it negatively selected *Typha anguistifolia-Saacharum arundinaceum-Saccharum spontaneum* association (IEI= -0.38) (See **Figure 47**).

Considering only use, domestic cattle used *Typha anguistifolia-Saacharum spontaneum-Imperata cylindrica-Vetiveria zizanoides* (45.75 %) and *Sclerostachya fusca-Saccharum ravennae-Saccharum spontaneum-Carex vesicaria* association (21.61 %) more than others are (See **Figure 48**).

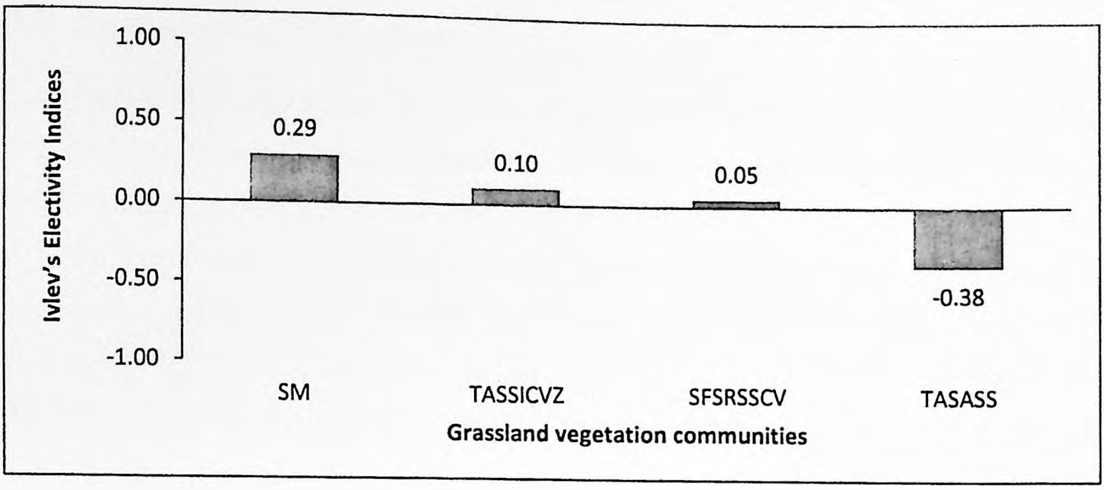


**Figure 47:** Selection of grassland vegetation community by domestic cattle based on Ivlev's Electivity indices

**Abbreviations used in Figure 47** (SM is *Saccharum munja* association, TASSICVZ is *Typha anguistifolia,-Saccharum spontaneum,-Imperata cylindrica-Vetiveria zizanoides* association, SFSRSSCV is *Sclerostachya fusca-Saccharum ravennae-Saccharum spontaneum-Carex vesicaria* association and TASASS is *Typha anguistifolia-Saccharum ravennae-Saccharum spontaneum* association)

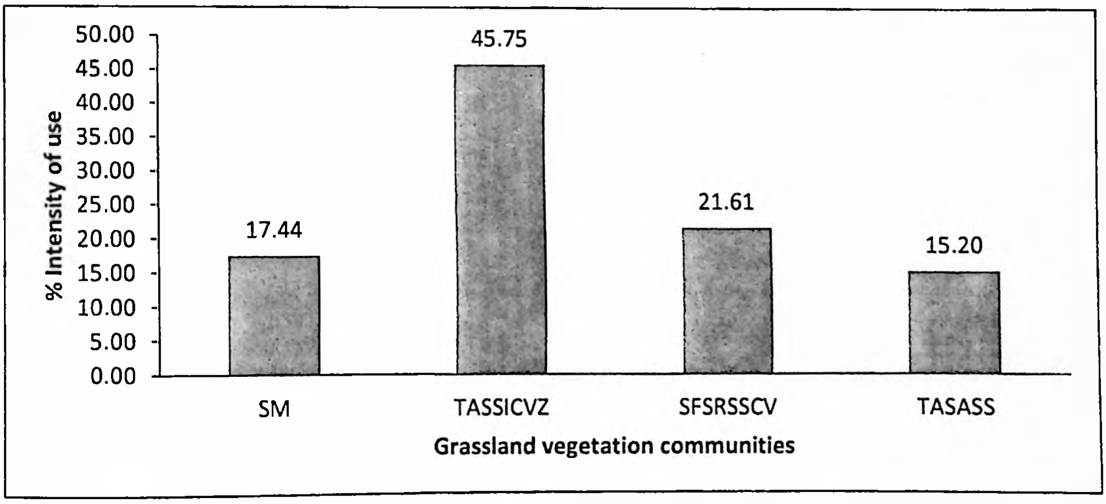


**Figure 48:** Percent intensity of use of grassland vegetation communities by domestic cattle

**Abbreviations used in Figure 48** (SM is *Saccharum munja* association, TASSICVZ is *Typha anguistifolia,-Saccharum spontaneum,-Imperata cylindrica-Vetiveria zizanoides* association, SFSRSSCV is *Sclerostachya fusca-Saccharum ravennae-Saccharum spontaneum-Carex vesicaria* association and TASASS is *Typha anguistifolia-Saccharum ravennae-Saccharum spontaneum* association)

## 4.2. Availability of food plants

Sampling of study areafound 102 species of food plantof rhino belonging to 87 genera classified into 49 families (See **Appendix 3**). Highest prominence values (PV) was found for the following food plants – *Calamus tenuis* (PV= 630.75), *Phragmites karka* (PV= 412.79), *Typha anguistifolia* (PV= 337.37), *Saccharum arundinaceum* (PV= 304.58), *Imperata cylindrica* (PV= 294.10), *Saccharum munja* (PV= 280.04), *Saccharum ravennae* (PV= 279.56), *Sclerostachya fusca* (PV= 249.30), *Vetiveria zizanoides* (PV= 244.98), *Mallotus philipensis* (PV= 240.72), *Saccharum spontaneum* (PV= 226.22) etc.

While highest percentage frequency of occurrence (% freq) was found for the following food plants – Fern (32.89%), *Mallotus phillipensis* (31.84%), *Calamus tenuis* (30.78%), *Murraya koengii* (23.78%),*Clerodendron infortunatum* (20.74%), *Imperata cylindrica* (20.21%), *Syzygium cumini* (19.82%), *Vetiveria zizanoides* (19.68%), *Saccharum spontaneum* (19.02%), *Saccharum ravennae* (18.49%) etc.

Prominence value of all the major food plants, which was present in either of the site (Valmiki or Bardia or Chitwan), was calculated and summarized in **Appendix 4.**Prominence value of top 15 dominant food species in Valmiki, Bardia and Chitwan is given in **figure 49, 50** and **51** respectively.

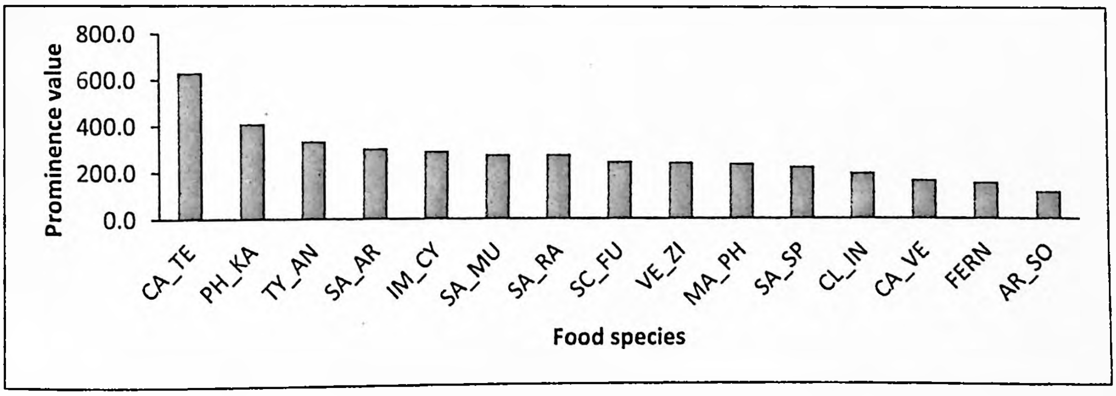


**Figure 49:** Prominence value of top 15 dominant food plants of rhino in Valmiki

**Abbrevitions used in Figure 49** (CA_TE is *Calamus tenuis*, PH_KA is *Phragmites karka*, TY_AN is *Typha anguistifolia*, SA_AR is *Saccharum arundinaceum*, IM_CY is *Imperata Cylindrica*, SA_MU is *Saccharum munja*, SA_RA is *Saccharum ravennae*, SC_FU is *Sclerostachya fusca*, VE_Z is *Vetiveria zizanoides*, MA_PH is *Mallotus phillipensis*, SA_SP is *Saccharum spontaneum*, CL_IN is *Clerodendron infortunatum*, CA_VE is *Carex vesicaria*, AR_SO is *Ardisia solanacea*).

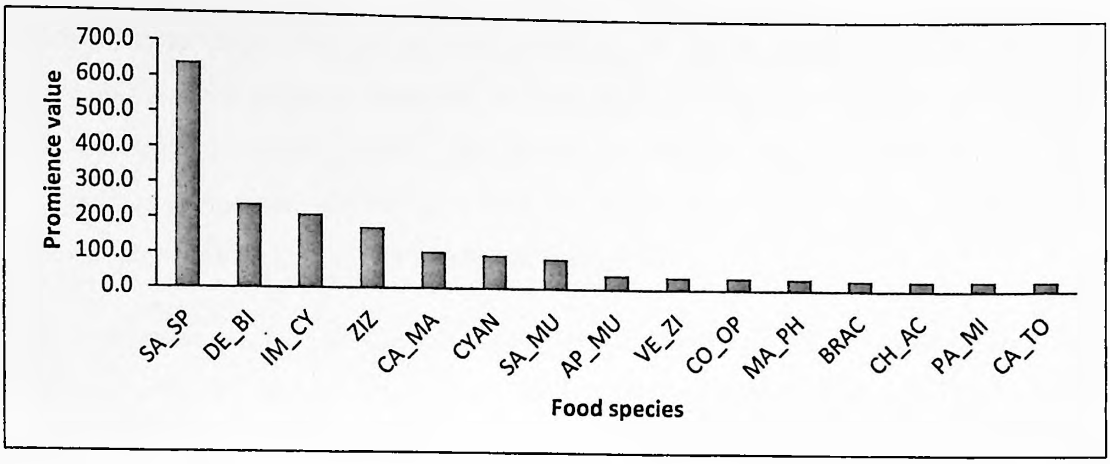


**Figure 50:** Prominence value of top 15 dominant food plants of rhino in Bardia

**Abbreviation in Figure 50** (SA_SP is *Saccharum spontaneum*, DE_BI is *Desmostachya bipinnata*, IM_CY is *Imperata cylindrica*, ZIZ is *Ziziphus* sp., CA_MA is *Callicarpa macrophylla*, CYAN is *Cyanodon* sp., SA_MU is *Saccharum munja*, AP_MU *is Apluda mutica*, VE_ZI is *Vetiveria zizanoides*, CO_OP is *Colebrookea oppositifolia*, MA_PH is *Mallotus phillipensis*, BRAC is *Bracharia* sp., CH_AC is *Chrysopogon aciculatus*, PA_MI is *Panicum miliare*, CA_TO is *Cassia tora*)

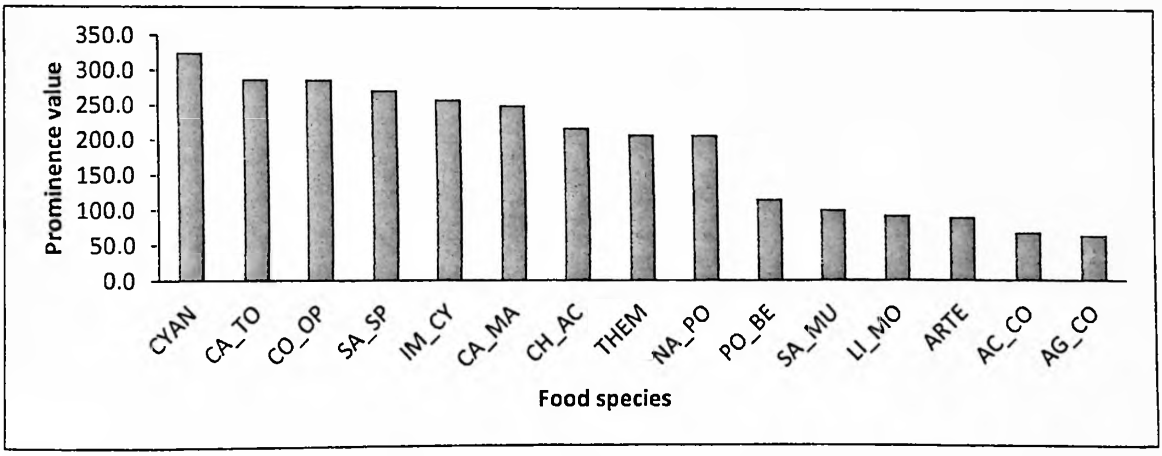


**Figure 51:** Prominence value of top 15 dominant food plants of rhino in Chitwan

**Abbreviations in Figure 51** (CYAN is *Cyanodon dactylon*, CA_TO is *Cassia tora*, CO_OP is *Colebrookea oppositifolia*, SA_SP is *Saccharum spontaneum*, IM_CY is *Imperata cylindrica*, CA_MA is*Callicarpa macrophylla*, CH_AC is *Chrysopogon aciculatus*, THEM is *Themeda sp.*, NA_PO is *Narenga porphyrocoma*, PO_BE is *Pogestimon benghalensis*, SA_MU is *Saccharum munja*, LI_MO is *Litsea monopetala*, ARTE is *Artemisia* sp., AC_CO is Acacia *concinna*, AG_CO is *Ageratum conizoides*)

A table listing major food species that constitutes 50 to 70 percent of rhino's diet has been compiled and given in **Appendix 5**. Food species, which were present in Valmiki as determined from compiled table, was then computed for their prominence value and comparison was made between this study in Valmiki and study done by Jnawali in Chitwan and Bardia (1999) (See **Table 1& Figure 52**).

The prominence value of one of major food species -*Saccharum spontaneum* was relatively less in Valmiki (PV= 226.2) than Chitwan (PV= 324.8) and Bardia (PV= 638.3), but was having highest prominence value for another important food plants – *Saccharum munja, Imperata cylindrica,Phragmites karka,Calamus tenuis, Typha anguistifolia, Vetiveria zizanoides, Mallotus phillipensis.*

Prominence value for food plants within study area was also calculated (See **Figure 53**) to compare the different zones of intensive study area and has been summarized in **Appendix 6.** Additionally, prominence value of each food plant was calculated for an area named Madanpur-RRA (Rhino Rehabilitation Area), having the largest patch of grassland but is isolated due to railway track and was compared with sub study areas. This area of 14.5 sq.km was carved out from Madanpur sub-study area and comprises compartment M1, M2, M3, M4, M5, part of M6 and M7 (area bounded by railway track and Gandak river).

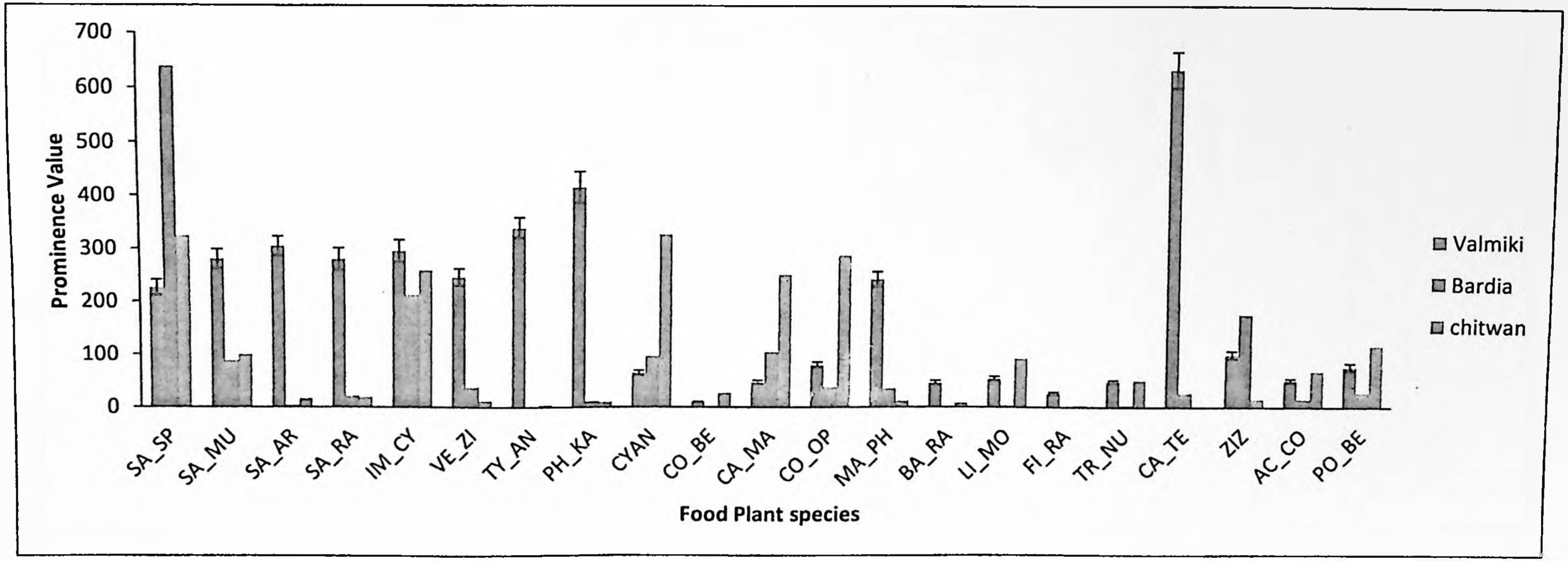


**Figure 52:** Prominence value of food plants of rhino common in Valmiki, Chitwan and Bardia

**Abbreviations in Figure 52** (SA_SP is *Saccharum spontaneum*, SA_MU is *Saccharum munja*, SA_AR is *Saccharum arundinaceum*, SA_RA is *Saccharum ravennae*, IM_CY is *Imperata cylindrica*, VE_ZI is *Vetiveria zizanoides*, TY_AN is *Typha anguistifolia*, PH_KA is *Phragmites karka*,CO_BE is *Coffea benghalensis*, CYAN is *Cyanodon dactylon*,CA_MA is *Callicarpa macrophylla*, CO_OP is *Colebrookea oppositifolia*, MA_PH is *Mallotus phillipensis*, BA_RA is *Bauhiniya racemosa*, LI_MO is *Litsea monopetala*, FI_RA is *Ficus racemosa*, TR_NU is *Trewia nudiflora*, CA_TE is *Calamus tenuis*, ZIZ is *Ziziphus* sp, AC_CO is *Acacia concinna*, PO_BE is *Pogestimon benghalensis)*

**Table 1:** Prominence value of food plants of rhinocommon in Valmiki, Bardia and Chitwan.

| **Food plant** | **Valmiki** | **Bardia** | **Chitwan** |
|---|---|---|---|
| *Saccharum spontaneum* | 226.2 | 638.3 | 324.8 |
| *Saccharum munja* | 280.0 | 88.2 | 100.9 |
| *Saccharum arundinaeum* | 304.6 | 2.6 | 16.8 |
| *Saccharum ravennae* | 279.6 | 21.1 | 19.1 |
| *Imperata cylindrica* | 294.1 | 210.6 | 257.9 |
| *Vetiveria Zizanoides* | 245.0 | 37.6 | 12 |
| *Typha anguistifolia* | 337.4 | 0.3 | 4 |
| *Phragmites karka* | 412.8 | 10.8 | 9.7 |
| *Cyanodon sp.* | 64.6 | 95.9 | 324.8 |
| *Coffea benghalensis* | 9.1 | 0 | 27.2 |
| *Callicarpa macrophylla* | 46.9 | 104.5 | 250 |
| *Colebrookea oppositifolia* | 79.8 | 37.1 | 285.7 |
| *Mallotus phillippensis* | 240.7 | 34.8 | 11.2 |
| *Bauhinia racemosa* | 45.8 | 0.2 | 8.4 |
| *Litsea monopetala* | 53.8 | 2.4 | 92.8 |
| *Ficus racemosa* | 25.8 | 0.6 | 3.1 |
| *Trewia nudiflora* | 48.1 | 2.3 | 50.6 |
| *Calamus tenuis* | 630.8 | 26.3 | 0 |
| *Ziziphus sp.* | 98.9 | 173.8 | 15.8 |
| *Acacia concinna* | 50.4 | 15.1 | 68.1 |
| *Pogestimon benghalensis* | 75.8 | 27.4 | 115.8 |

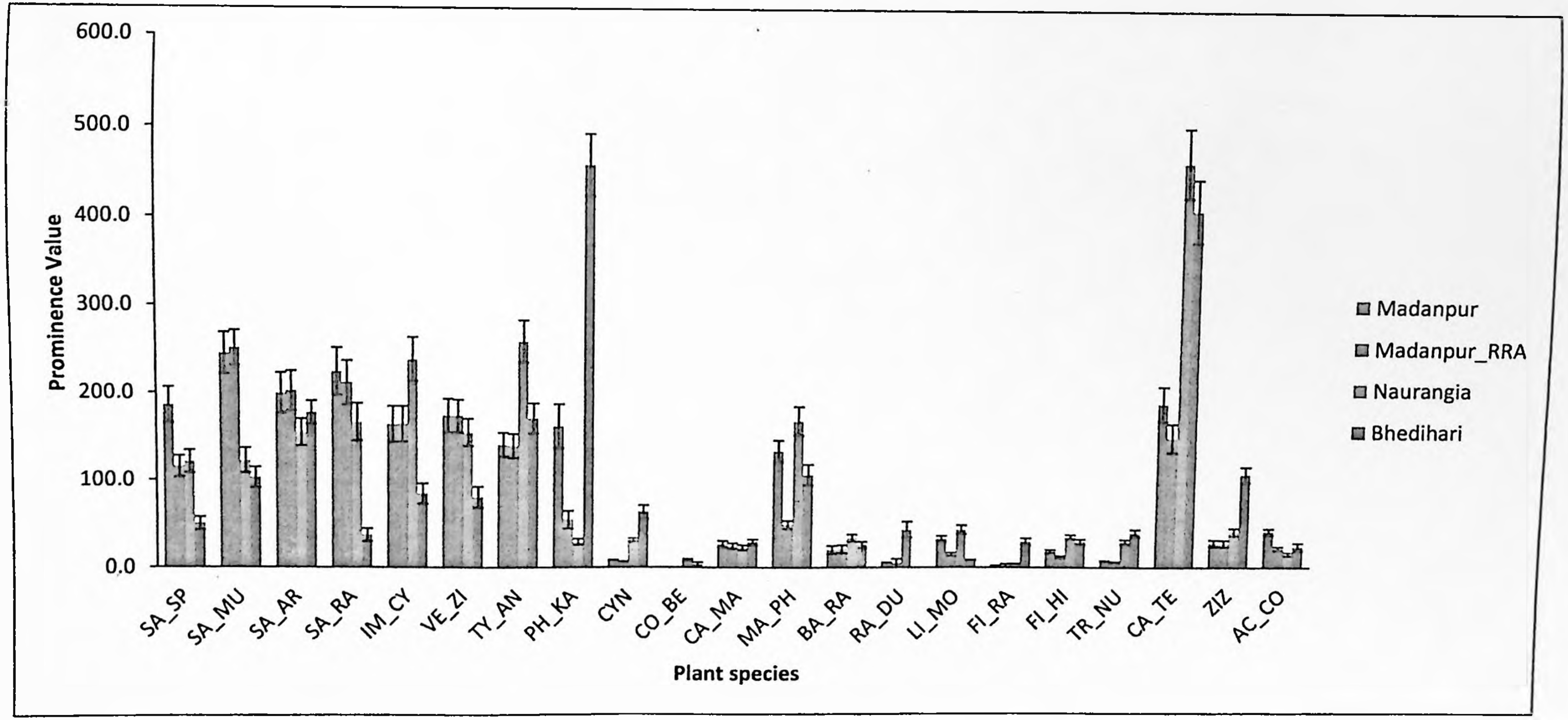


**Figure 53:** Prominence value of dominant food plants of rhino within different zones of intensive study area

**Abbreviations in Figure 53** (SA_SP is *Saccharum spontaneum*, SA_MU is *Saccharum munja*, SA_AR is *Saccharum arundinaceum*, SA_RA is *Saccharum ravennae*, IM_CY is *Imperata cylindrica*, VE_ZI is *Vetiveria zizanoides*, TY_AN is *Typha anguistifolia*, PH_KA is *Phragmites karka*,CO_BE is *Coffea benghalensis*, CYAN is *Cyanodon dactylon*,CA_MA is *Callicarpa macrophylla*, CO_OP is *Colebrookea oppositifolia*, MA_PH is *Mallotus phillipensis*, BA_RA is *Bauhiniya racemosa*, RA_DU is *Randia dumatorum*, LI_MO is *Litsea monopetala*, FI_RA is *Ficus racemosa*, FI_HI is *Ficus hispida*, TR_NU is *Trewia nudiflora*, CA_TE is *Calamus tenuis*, ZIZ is *Ziziphus* sp, AC_CO is *Acacia concinna)*

## 4.3. Species distribution modeling

MaxEnt gave the model output having AUC (Area Under Curve) of 0.785 for training data and 0.801 for test data. Model with AUC between 0.7 and 0.9 is considered good (Baldwin 2009). Model output in **figure 54** shows the probability distribution of rhino in Chitwan-Valmiki Landscape.

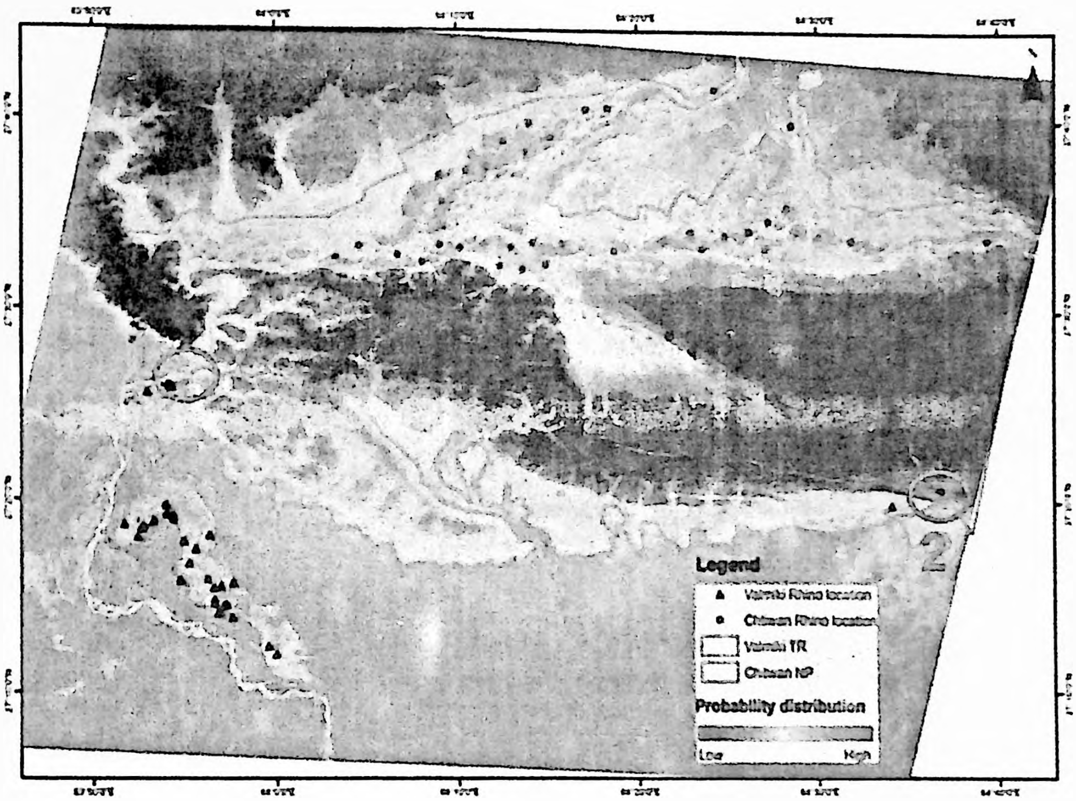


**Figure 54:** Model output (map showing probability distribution of rhino and possible corridor 1&2)

The areas having reddish colouration has highest pobability of rhino presence while area in relatively dark green colouration shows lowest probability for rhino presence. Riverine Patches, tall alluvial grasslands, some part of sal patch, and some built up with agiculture were having higher probability value of rhino presence. These high probability areas of rhino occurrence were both from VTR and adjoining Sohagibarwa Wildlife Sanctuary (compartment – UP54 and UP55). According to probability distribution map of rhino, two places seems to be possible corridor of rhino through which it comes from Chitwan to Valmiki – (1) at Triveni along confluence of river Gandak, Sonha and Pachnad, and (2) at Thori along river Pandai (See **Figure 54**). Accidental influx of rhino in Valmiki through the floodgates of Indo-Nepal barrage had been previously reported. Graph of ROC of data (See **Figure 55**) depicts that AUC of training and test data are at higher value than AUC of random prediction data. While **Figure 56** shows that probability of Rhino presence is higher with higher NDVI (greenness) in dry season, when all other variables are at their average values. **Figure 57** shows that probability of rhino presence is higher wth increase in variable 8 (riverbed) and 14 (riverine forest), when all other variables are at their average values. **Figure 58** shows that probability of rhino presence sharply declines after an elevation of 140 m, when all other variables are at their average values. **Figure 59** shows that Probability of rhino occurrence first increases with decreasing NDVI (that means near water, probability of rhino presence increases) then after a certain increase in NDVI , again probability of rhino occurrence increases (that means near greenness probability of rhino occurence increases). **Figure 60** and **Figure 61** has the similar response as in Figure 57 and 58.

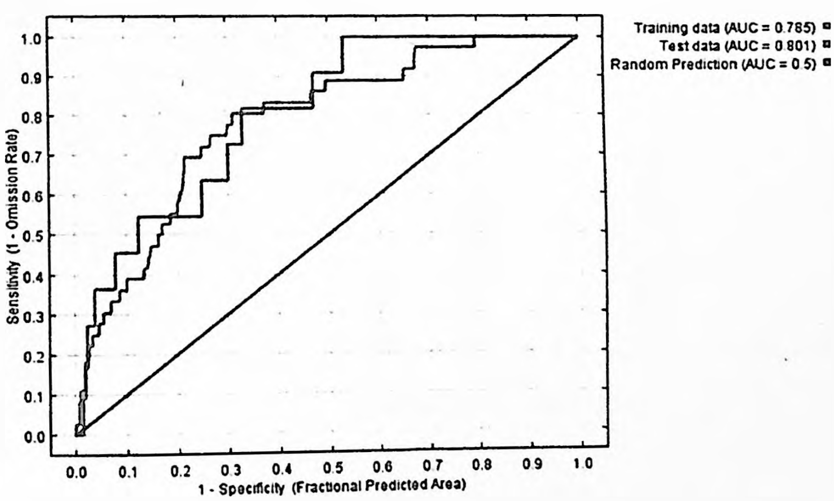


**Figure 55:** Receiver operating characteristic curve (ROC) of data

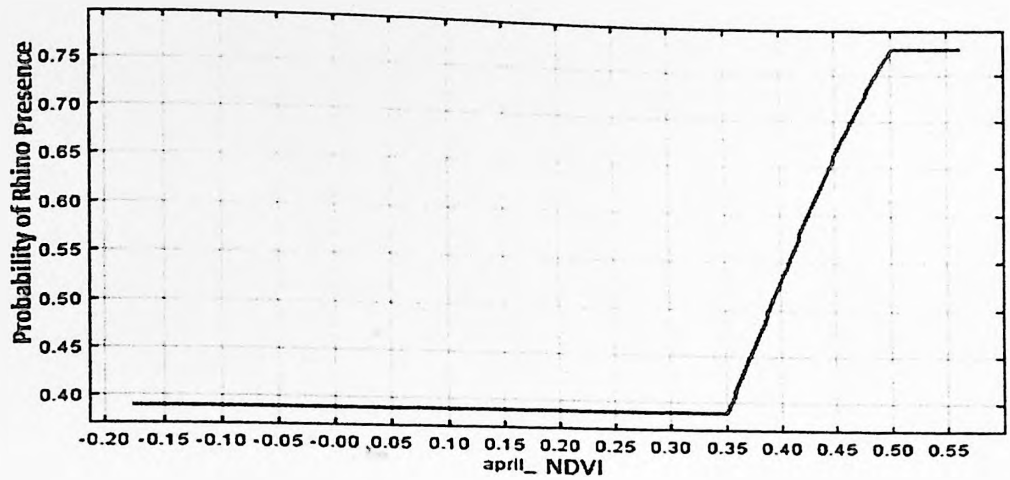


**Figure 56:** Curve showing response of probability of rhino presence with April-NDVI, keeping other variables at their average value

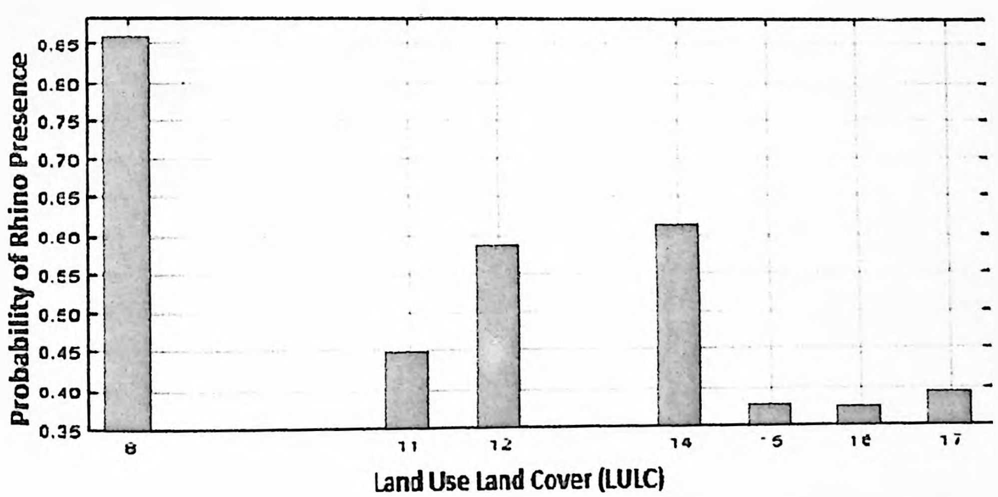


**Figure 57:** Histogram of variables within LULC showing variation in probability of rhino presence with change in it, keeping other variables at their average value

**Abbreviation used in Figure 57** (riverbed (8), river (11), degraded grassland (12), riverine forest (14), tall grassland (15), Sal and mixed forest (16) and built up with agriculture (17))

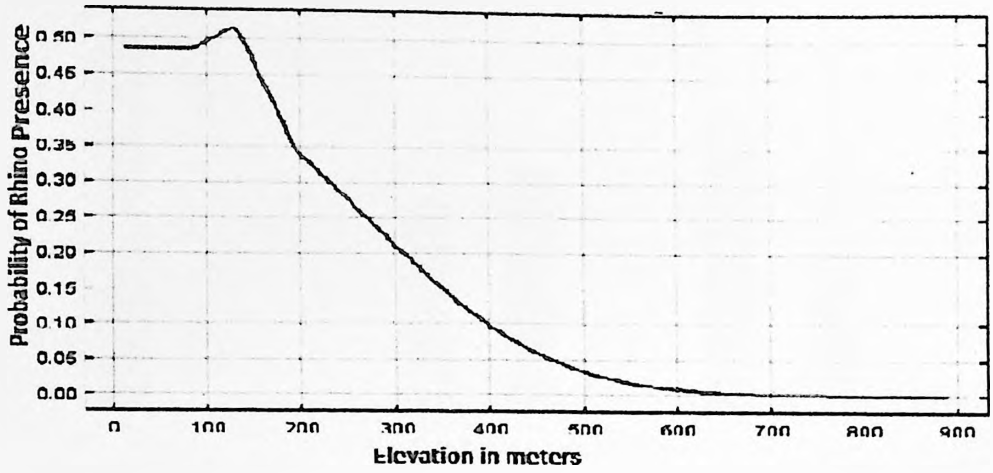


**Figure 58:** Curve showing response of probability of rhino presence with elevation, keeping other variables at their average value

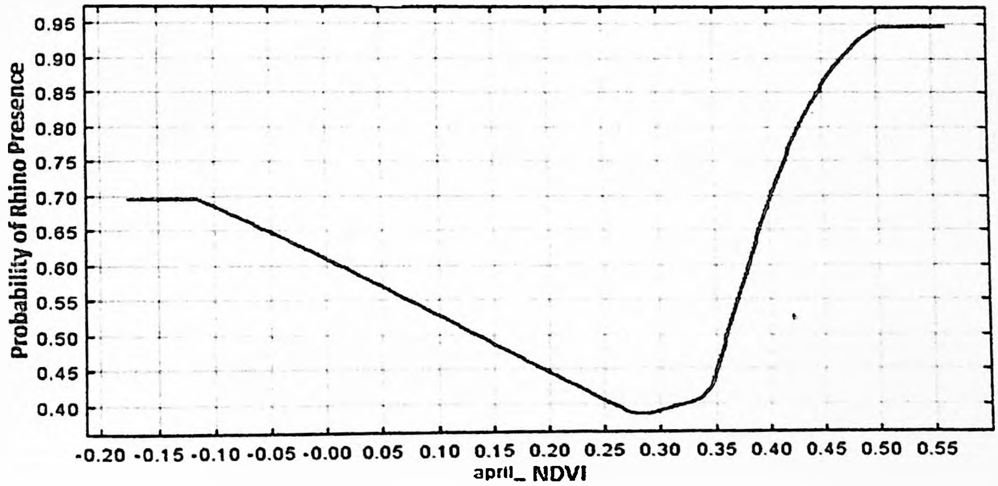


**Figure 59:** Curve showing response of probability of rhino presence with April-NDVI only.

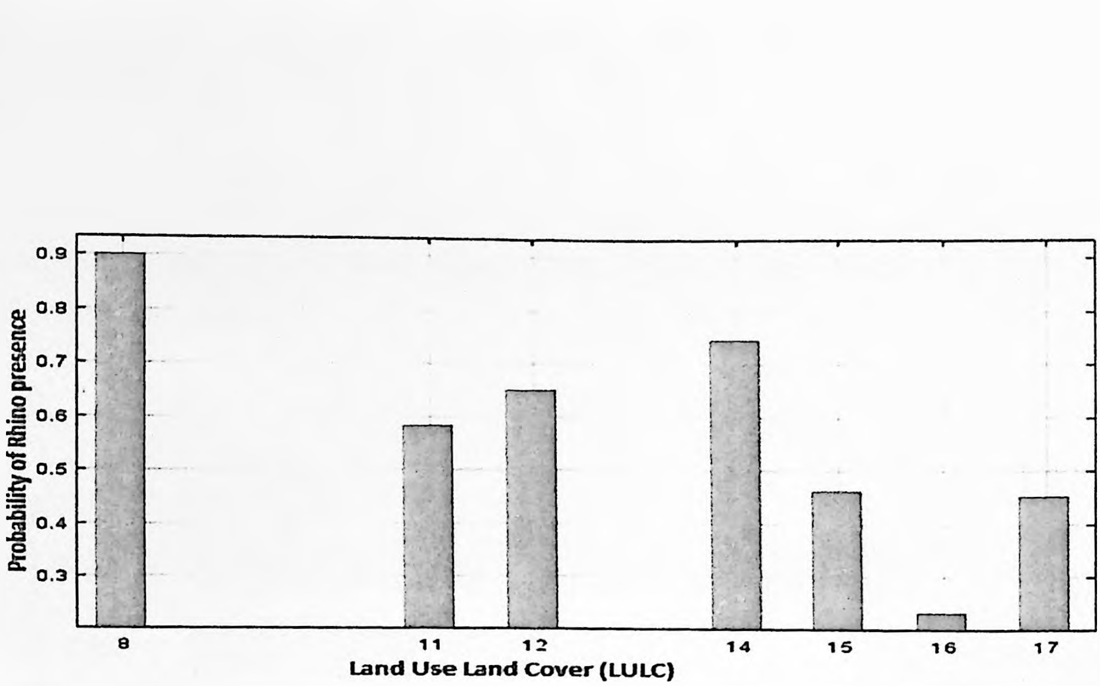


**Figure 60:** Histogram of response of probability of rhino presence with variables of LULC only

**Abbreviation in Figure 60** (riverbed (8), river (11), degraded grassland (12), riverine forest (14), tall grassland (15), Sal and mixed forest (16) and built up with agriculture (17))

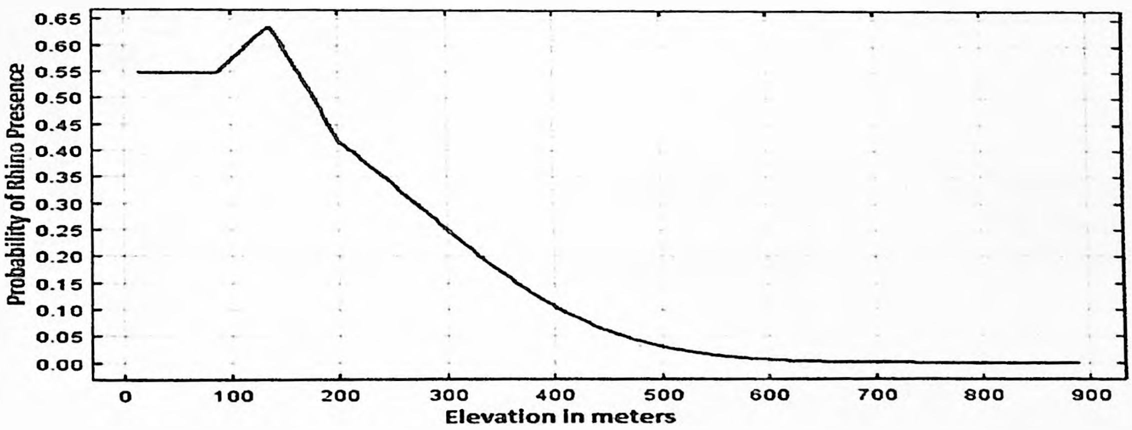


**Figure 61:** Curve showing response of probability of rhino presence with elevation only.

Jacknife test on training data and test data as depicted in **Figure 62** and **Figure 63** respectively and it shows very little contribution of variable April-NDVI. While major contribution to the model is due to rest of variables – LULC and DEM. DEM is contributing much to probability distribution than LULC. Within LULC, riverbed (number 8) and riverine forest (number 14) are major contributors to probability distribution of rhino.

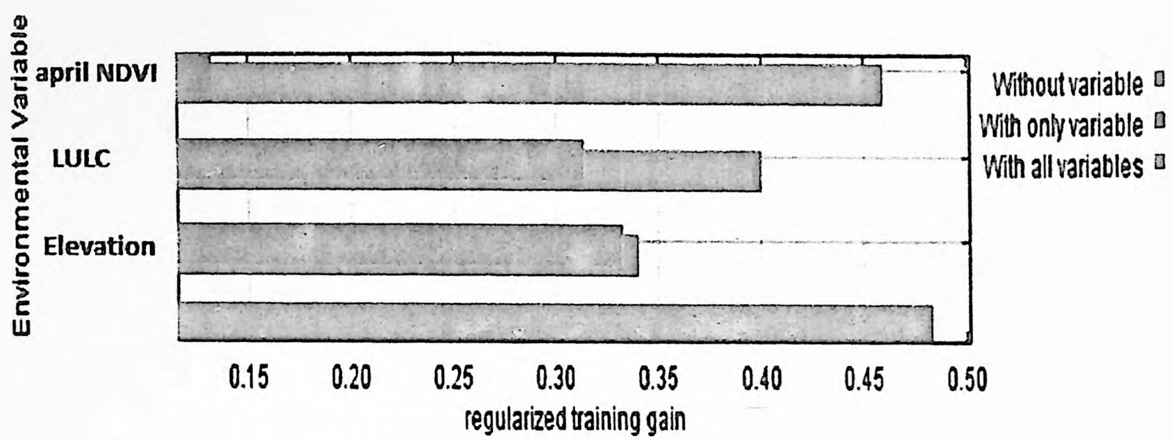


**Figure 62:** Jackknife test on training data.

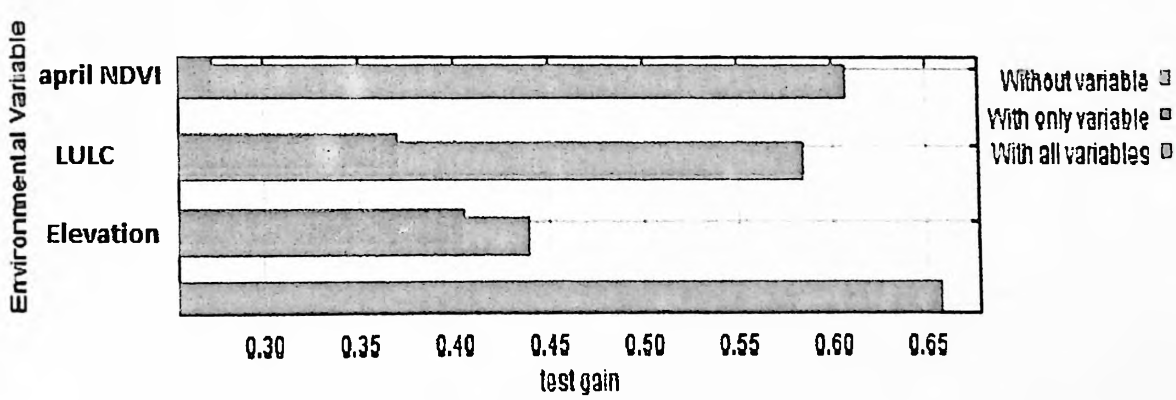


**Figure 63:** Jackknife test on test data

## 4.4. Ungulate density estimation

After surveying on 20 transect lines with a total walk effort of 166.87 km, following density estimates (See**Table 2**) were obtained for different species.Response curves of different ungulates to their detection with increasing distance are given in **Appendix** 7.

**Table2:** Model statistics and Parameter estimates of line transects in Madanpur Block. (SE is Standard error)

| **Species** | **Model** | **AIC** | **Chi square P value** | **Effective strip width (SE)** | **Number of groups detected** | **Mean Group size** | **Detection probability** | **Encounter rate (SE) per km** | **Group density (SE) per sq.km.** | **Individual density (SE) per sq.km.** |
|---|---|---|---|---|---|---|---|---|---|---|
| **Chital** | Half-normal | 221.85 | 0.89 | 40.64 (3.38) | 68 | 3.90 (0.37) | 0.26 (0.02) | 0.41 (0.09) | 4.98 (1.23) | 19.46 (5.17) |
| **Hog Deer** | Hazard rate | 58.65 | 0.95 | 14.48 (7.95) | 23 | 1.7 (0.2) | 0.95 (0.05) | 0.14 (0.07) | 4.73 (3.4) | 8.07 (5.9) |
| **Nilgai** | Half-normal | 81.47 | 0.79 | 55.89 (8.7) | 32 | 4.86 (0.87) | 0.56 (0.09) | 0.19 (0.07) | 1.70 (0.64) | 8.29 (3.46) |
| **Wild Pig** | Half-normal | 23.33 | 0.87 | 7.99 (1.98) | 12 | 1.7 (0.27) | 0.5 (0.12) | 0.07 (0.02) | 4.47 (1.69) | 7.59 (3.11) |
| **Cattle** | Hazard rate | 87.18 | 0.82 | 54.57 (23.0) | 31 | 24.03 (6.61) | 0.36 (0.16) | 0.18 (0.05) | 1.69 (0.9) | 40.65 (24.26) |

## 4.5. Human dimension

**Figure 64 to Figure 69** depicts different categories of human disturbance (See **Appendix 11**). Among the three sub sudy areas, disturbance level in terms of felled trees, trail density and fuelwood collection was highest for Naurangia followed by Madanpur whereas the human disturbance in terms of grass and cane cutting, cattle pressure and forest fire was highest for Madanpur followed by Naurangia. Among all the categories of disturbance, it was least for Bhedihari sub study area.

Data from the Tiger Conservation Plan of VTR reveals a total mortality of 51 wild animals in seven years on Bagaha-Chhitauni railway track, including mortality of one critically endangered gharial (*Gavialis gangeticus*), two vulnerable female rhino (*Rhinoceros unicornis*), two vulnerable fishing cat (*Prionailurus viverrinus*), and four vulnerable burmese python (*Python bivittatus*). Highest mortality was of nilgai (51 %) followed by chital (19.6%). Mortality data reported by forest staff was only for large charismatic animals and not of small animals like snakes, turtles etc.

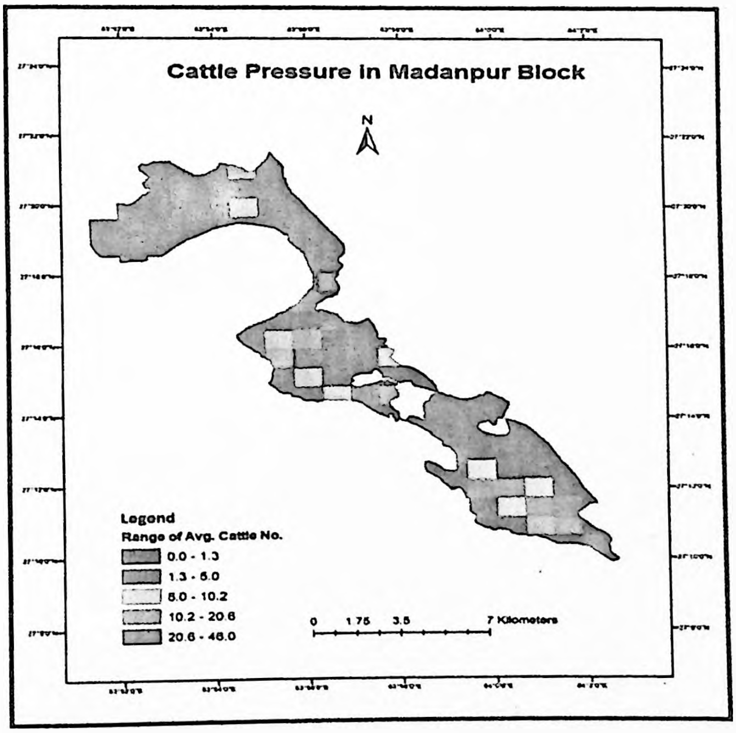


**Figure 64**: Map of cattle pressure in intensive study area

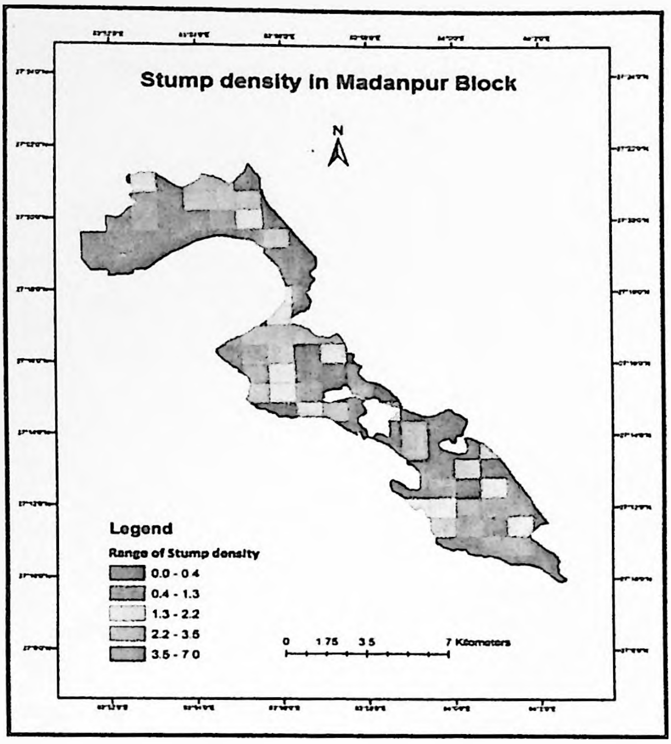


**Figure 65:** Map of stump density in intensive study area

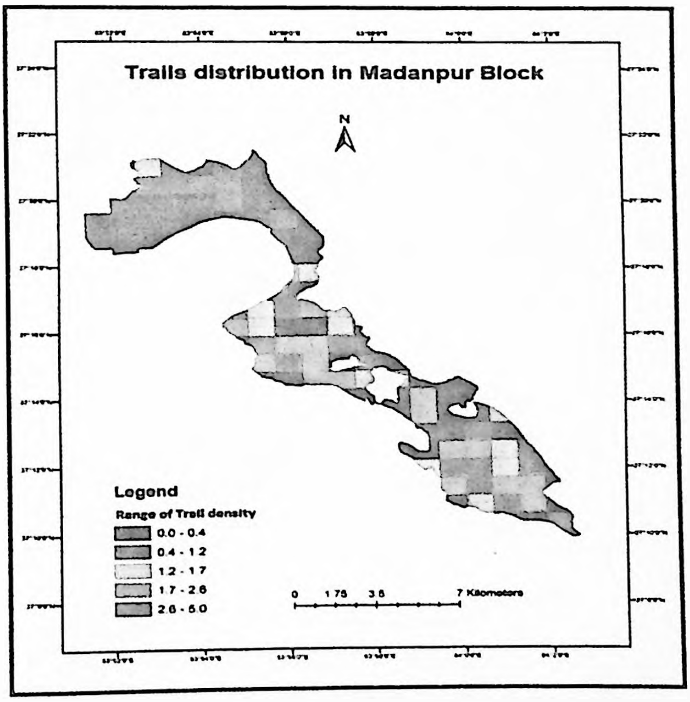


**Figure 66:** Map of trail distribution in intensive study area

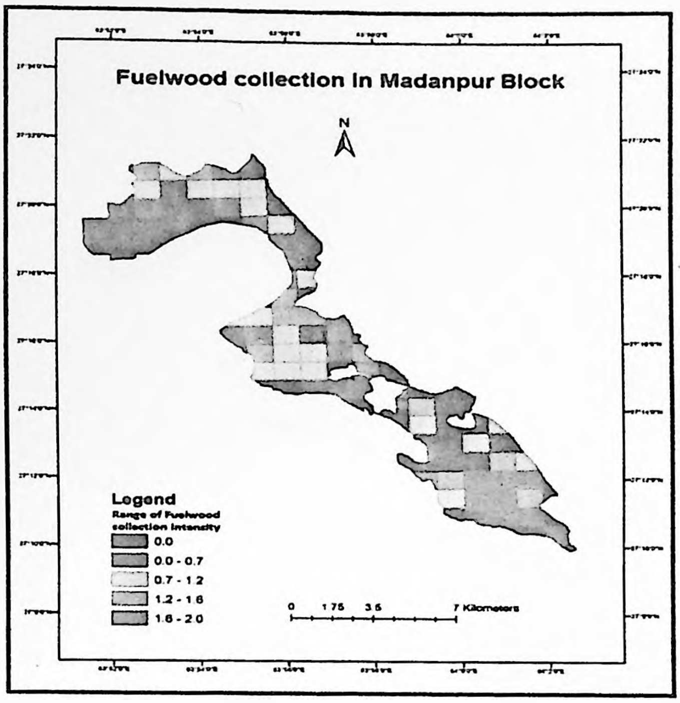


**Figure 67:** Map of fuelwood collection in intensive study area

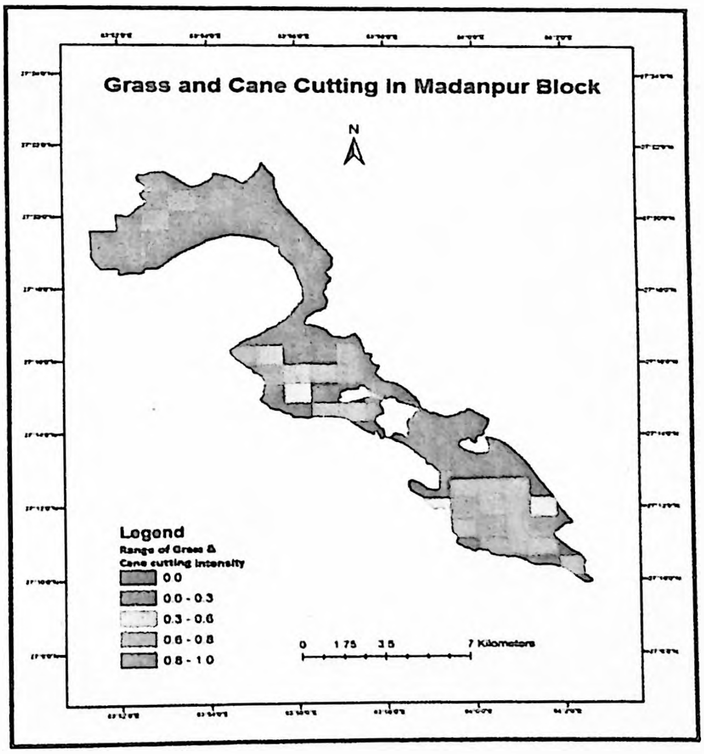


**Figure 68:** Map of grass and cane cutting in intensive study area

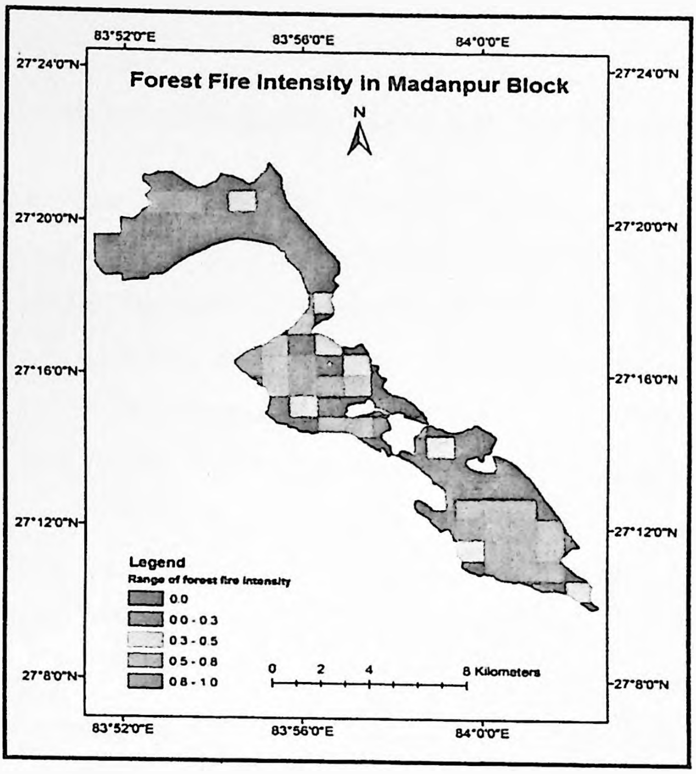


**Figure 69:** Map of forest fire intensity in intensive study area

# 5. Discussion

## 5.1. Grassland vegetation communities and its use by mammals

Habitat heterogeneity does not occur only across different landscapes, but also within the same landscape. A large, ranging animal or a generalist animal might occupy different habitat characters within the same landscape. Therefore, it is not unusual to find similar kind of niche occupied by different speciesand different kind of niche occupied by same species (Leibold 1995). This can be exemplified from the case of Valmiki. Few dominant grasses of other terai regions like *Narenga porphyrocoma* and *Arundo donax* were not found in Valmiki in this study, indicating that the communities of Valmiki were different from communities of other terai regions. High prominence value of *Phragmites karka* and *Typha anguistifolia* and high frequency of *Typha angustifolia-Saccharum arundinaceum-Saccharum spontaneum* association and *Typha anguistifolia-Saccharum spontaneum-Imperata cylindrica-Vetiveria zizanoides* association indicates the poorly drained nature of soil with high presence of low land areas in almost all grasslands of Valmiki (See **Appendix 8**).

Out of the seven grassland communities in Valmiki, two grassland communities were having maximum equivalence with the grassland communities of Chitwan studied by Lehmkuhl (1994) that is *Saccharum munja* association on uplands and *Phragmites karka-Sacharum spontaneum* in marshy lands. In the grassland study by Peet et al. (1999) on four protected areas of Nepal, the following three grasslands communities were found ecologically similar – *Saccharum munja* association, *Phragmites karka-Sacharum spontaneum* association and *Phragmites karka* association. Similarly, the following three grassland communities - *Typha anguistifolia-Saccharum spontaneum-Imperata cylindrica-Vetiveria zizanoides* association on slightly low lying areas, *Saccharum munja* association on uplands, *Sclerostachya fusca-Saacharum ravennae-Saccharum spontaneum-Carex vesicaria* association on seasonally inundated low lying areas, were found similar to grassland communities of Terai conservation area studied by Kumar in 2002.

Although, Ivlev's indices indicates chital preferring *Saccharum munja* association along with *Typha anguistifolia-Saccharum spontaneum-Imperata cylindrica-Vetiveria zizanoides* associations, but studies on ecology of chital (Mishra 1982, Peet et al. 1999) does not agree for association of chital with the tall *Saccharum munja* grassland. This result may be due to (i) relatively short height of upland *S. munja* grassland because of continuous management forest department, and (ii) due the ecotone of grassland and cover providing tall Sissam (*Dalbergia sissoo*) tree patch in M5 (iii) resting on upland area during night. The second association preferred by chital is consistent with the result of Peet et al. (1999) where chital was found to be associated with *Imperata cylindrica* and *Imperata cylindrica-Narenga porphyrocoma* assemblages. The results are supportive of the field observations and biology of species, since chital uses relatively upland areas where green glades / grazing lawns of *Imperata cylindrica* and other short grasses abundant in these grassland associations (Johnsingh 2015).

In the case of hog deer, preference was observed for the *Typha anguistifolia-Saccharum spontaneum-Imperata cylindrica-Vetiveria zizanoides* association, *Saccharum munja association* and *Typha angustifolia-Saccharum arundinaceum-Saccharum spontaneum* association. This result also supports the study of Peet et al. (1999) in which hog deer was found associated with *Phragmites karka, Phragmites karka-Saccharum spontaneum, Phragmites karka-Saccharum spontaneum-Saccharum arundinaceum* assemblages. The result also supports field observations and biology species as hog deer prefers tall grasses and food like *Saccharum spontaneum, Imperata cylindrica, Vetiveraia zizanioides* present in these grassland communities (Dhungel et al. 1991).

In the case of nilgai, *Sclerostachya fusca-Saacharum ravennae-Saccharum spontaneum-Carex vesicaria* association and *Typha anguistifolia-Saccharum spontaneum-Imperata cylindrica-Vetiveria zizanoides* association were preferred. This result has bearing with ecology of species as the former association was found at a relatively higher disturbed site, close to degraded scrub areas inhabited by nilgai (Johnsingh 2015).

In the case of rufous tailed hare, preference was found mainly for upland *Saccharum munja* association, as it needs good cover of clumps to hide and feed on the short grasses on upland areas to keep the body dry.

In the case of wild pig, high preference was noticed for tall grassland association of *Typha angustifolia-Saccharum arundinaceum-Saccharum spontaneum*. This result can be correlated by the biology of wild pig, as it prefers moist areas to dig in easily and uproot the tubers and roots of various food plants. This preferred association is foundonly in such moist areas. Besides, wild pig also uses leaves of tall grasses to make bed for littering (Prater 1948).

In the case of domestic cattle, high preference was observed for associations, which were more preferred by wild ungulates – chital, hog deer, despite the cattle being a generalist feeder. These preferred associations are *Saccharum munja* and *Typha anguistifolia-Saccharum spontaneum-Imperata cylindrica-Vetiveria zizanoides* association. This indicates high competition among domestic and wild ungulates.

## 5.2. Availability of food plants

The study could not find few perennial palatable tall grass species in Valmiki – *Arundo donax, Narenga porphyrocoma, Themeda sp*., which could have been easily detected, unless rare in study area. For example *Themeda, sp*. was found just at one place but not in sample plot. Other dominant grassy food species that were not found in study area were *Brachiaria sp*. *Setaria sp., Cymbopogon sp., Chrysopogon aciculatus*. *Eragrostis tenella* was replaced by other species of *Eragrostis* in intensive study area. Absence of these species may be because of sampling done till start of dry season in late January aiding difficulty in identification of grasses due to absence of inflorescence. Contrary, food plant like *Sclerostachya fusca* present abundantly in Valmiki has not been reported from Nepal, which was reported as food plant in Dudhwa (Tripathi 2012). Jnawali (1995) found highest prominence value of *Saccharum spontaneum* in in Bardia than Chitwan, but his results opposes the Dinerstein's statement regarding presence of high density of rhino (1.1 to 13.3 sq.km, depending on vegetation) in Chitwan compared to low density of rhino (0.3 sq.km) in Bardia due to abundant prime patch of *Saccharum spontaneum* found in Chitwan compared to Bardia (Dinerstein 2003). Among large array of food plants reported in various studies in various rhino habitats, (See **Appendix 1**) relatively good number of food plants (102) was found in Valmiki. Presence of relatively lower amount of *Saccharum spontaneum* (a grass that constitutes about 50 % of rhino's annual diet) in Valmiki compared to Chitwan, indicates possible habitat of rhino.

## 5.3. Species distribution modeling

Areas having riverine forest, alluvial grasslands, some patches of mixed sal forest, and some built up with agriculture were predicted as potential distributional areas of rhino. Projected model was validated by rhino presence locations before local extinctions in Valmiki. Over prediction of model in patches of Sal forest could be due to presence of streams as well as spectral mixing between reflectance of Sal and riverine patch. Another important reason could be few training locations used for modeling was from Sal patch and edges of Sal forest. Ideally, grasslands are relatively more suitable for Rhino than riverine forest, but opposite was predicted. Possible reason could be – (i) training locations were relatively more from riverine forest than grasslands (though rhino survey reports mentions the opposite), and (ii) because of spectral mixing between grassland and built up with agriculture thus, diluting probability of occurrence from grassland.

## 5.4. Ungulate density estimation

Among seven ungulates present in Valmiki, density estimate of three common ungulates (chital, nilgai, and wild pig) was done in this study and study done by All India Tiger Monitoring team (Maurya et al. 2014, Jhala et al. 2015) in whole reserve. The results had been compiled in **Appendix 9**.

Density of chital in Madanpur block was more than six time higher than overall density estimate for the reserve. The reason may be because (i) chital being primarily a grazer (Johnsingh 2015) finds adequate grass in Madanpur (ii) Madanpur has west Gangetic mixed moist deciduous forest which provide large array of palatable browse than sal forest (iii) chital is also considered an edge species (Johnsingh 2015) and in Madanpur due to high human pressure from all sides more edges had been created, giving way to growth of small palatable grass of chital.

Nilgai was estimated with almost double density in Madanpur compared to whole Valmiki. This could be because (i) nilgai being occupying nearly degraded scrub habiat abundantly present in Madanpur and (ii) partial liking for agricultural crops present on all sides of Madanpur block.

In case of wild pig too, high density estimate (three and half times more) was found for Madanpur block than whole reserve. Reason may be that wild pig prefers moist areas to dig out roots and tubers of food plants, present in wet alluvial flood plain of Madanpur block.

Low number of sambar is attributed to Madanpur's flat alluvial habitat. Sambar being animal of undisturbed undulating hilly terrain shuns the flat tall grasslands of Terai (Johnsingh et al. 2004).

Similarly, barking deer prefers undisturbed dense sal forest to perform its daily activities, which is not present in Madanpur (Johnsingh 2015). So it is negligibly seen in Madanpur.

Block count best estimates hog deer abundance because of its solitary and hiding nature among tall grasses (which causes very few detection during line transect sampling and thus little data to analyse), but I was able to get relatively sufficient number of observations to come up with a density estimate. The reason for relatively high detection during line transect in my survey could be due to burned grasslands facilitating high detection. The density estimate of hog deer (8.07 ± SE 5.9 individuals/sq.km) in my study area is comparable to density estimate of hog deer (4.7-10.3 individuals/sq.km) in Karnali-Bardia Wildlife Reserve (Dinerstein 1979) and to density estimate of hog deer (8.5 individuals/sq.km) in Suklaphanta Wildlife Reserve (Schaff 1978). However, it was lower than Chitwan, where density estimate of hog deer was 35 individuals per sq km (Seidensticker 1976) and 15.5 – 19.1 individuals per sq. km (Dhungel et al. 1991).

The density estimate of cattle was found to be double than density estimate of chital, five times higher than that of hog deer, nilgai, and wild pig. It indicates huge competition between wild ungulates and domestic cattle in terms of habitat use.

## 5.5. Conclusion on habitat suitability of rhino in Valmiki

Species distribution modeling and analysis of field data indicates whole Madanpur block (intensive study area) as potential habitat of rhino if afore mentioned human disturbance is eliminated including the problem of railway track as barrier to wildlife movement and cause of mortality (See **Appendix 11**).

Learnings from rhino presence in Valmiki in the past suggests free ranging rhino in Valmiki would cause high level of human-wildlife conflict owing to its crop raiding behavior especially when farmers grow sugarcane, paddy and wheat all along the boundary of Madanpur block. Therefore, the only way left out would be to put them in enclosure, a similar strategy adopted by Forest department in Dudhwa.

In case of prioritizing the area within Madanpur block, Maxent model indicates more suitable rhino habitat in Naurangia (mostly riverine patch) as opposed to Madanpur (mostly grassy patch), however food plant availability indicates the opposite. Bhedihari sub study area having three very small grassland patch (≈15-20 ha each) excluding the swampy grassland portion of M19 where enclosure is not feasible and degraded scrub mix grazing lawn in M21, owes very insignificant status for rhino reintroduction.

Major portion of grassland occurs in Madanpur area (approximately 13.24 sq.km of which grassland in Madanpur-RRA alone comprises an approximate area of 9.84 sq.km) and thus prominence value was high for dominant grass species of rhino - *Saccharum spontaneum, Saccharum munja*. The prominence value was relatively high in Naurangia for dominant browse species of rhino - *Mallotus phillipensis, Litsea monopetala, Trewia nudiflora, Calamus tenuis* but low in grasses as grassland area is just 4.57sq.km (See **Figure 6**). Since, the percent of grass in rhino's diet (67.95 %) is high, so Madanpur sub study area is probably better place for estabilishing enclosure than Naurangia. Naurangia can be second option for rhino enclosure but relatively high density of rhino can not be achieved here, as in the grassy patch of Madanpur sub study area (Dinerstein 2003).

Rhino being a megaherbivore facilitates the smaller and more selective ungulates (especially hog deer) by removing coarser grass blades through trampling and feeding which stimulates new flush of nutritious grass for consumption (Bell 1971, McMaugton 1976) and it also creates more palatable, nutritious "grazing lawns" in the tall grasslands (Dinerstein and Wemmer 1988, Karki et al 2000). But, rhino and hog deer preferring the same food plant (especially *Saccharum spontaneum*) and habitat have high competition during resource limited dry season, where they segregate it by resource portioning. Hog deer efficiently utilizes *Saccharum spontaneum* throughout the year while rhino switch to browsing in dry season (Jnawali 1995, Wegge et al. 2006). Therefore, higher availability of browse in dry season for rhino is essential to avoid high competition between rhino and hog deer.

In the above context, Madanpur-RRA alone has relatively less prominence of food plants than Naurangia so, when area of Madanpur-RRA is joined with additional 3.4 sq.km grassy patch of compartments M6, M7 and upland browse area in compartment M8, M9 and M10, promises good place for making enclosure.

However, the presence locations of locally extinct rhinos (**Appendix 10**) were mainly from Bhedihari, Naurangia, and adjoining Sohagibarwa than M[illegible] b study area. The reasons could be (a) presence of few rhinos, which can fulfill [illegible] requirement from small grassland patch and surrounding agriculture field, (b) high disturbance in Madanpur from rail (as two female rhinos got killed by train whil[illegible] ng), road and humans, (c) fidelity for Bhedihari and Nauran[illegible] m during flood and (d) low detection of rhino in tall grasses by forest staff.

Population habitat viability analysis (PHVA) for estimating via[illegible] on according to the facing threats (as pointed previously) in the available habitat is beyond the scope of this study. However, a very crude estimate of rhino population that may be supported in VTR can be rapidly assessed by applying the density of a place, which has similar annual biomass production of grasslands in its habitat besides having available forage (graze and browse) and water.

The biomass production of alluvial tall grasslands of Valmiki is 12.6 tonne per hectare (Sinha 2015) and is close to biomass production of Bardia (10.27 – 13.98 tonne per hectare) as determined from the study of Pokhrel in 1993 (Pokhrel 1993), whereas biomass production of Chitwan was quite high – 20.78 per hectare (Dinerstein 2003).

So, by applying density of Rhino from Bardia (0.34 rhinos / sq.km), Madanpur area could possibly support a minimum of seven rhino, Madanpur-RRA could possibly support a minimum of four rhino, Naurangia could possibly support minimum of five Rhino. The area considered while estimating the above crude carrying capacity in sub study areas excludes the land right of the National Highway 28B (NH 28B) passing through intensive study area (See **Figure 6**) because I assume the rhino may not be able to establish its territory in the continuous linear disturbance stretch. Therefore, estimated number of rhinos went low in sub study areas. It is worth to note that mentioned minimum density of rhino of Bardia (0.3 sq.km) is of reintroduced population well below ecological carrying capacity of the place. Besides, sampling for annual biomass production of grasses in alluvial floodplain was done in one site (Naurangia) by Sinha (2016), which may not accurately represent annual biomass production of all alluvial grassland patches in Madanpur. Therefore, Valmiki may possibly support higher density of rhino.

The reintroduction of rhino in Valmiki will not be an ideal situation for reintroduction program according to the "Guidelines of Insitu Reintroduction and Translocation of African and Asian Rhinoceros" by the IUCN Species Survival Commission, which clearly states insitu reintroduction should be done in a place which can support minimum free ranging viable population, may be in form of small populations (10 to 100) managed as one metapopulation with regular (once per generation) genetic exchange between them (Emslie et al. 2009).

Summing up the discussion, the multiscale approach of modeling with field survey reveals suitable habitat of rhino in VTR after excluding high disturbance from the study area. Projected model predicted probability of rhino presence in riverine, tall grasslands of Madanpur block. Availability of 102 food plants of rhino including the preferred palatable grass - *Saccharum spontaneum* and *Saccharum munja* also indicates the suitability of rhino. Besides, high occurrence of two preferred grassland vegetation communities of rhino - *Typha anguistifolia-Saccharum arundinaceum-Saccharum spontaneum* and *Typha anguistifolia-Sacchrum spontaneum-Imperata cylindrica-Vetiveria zizanoides* associations indicates potential habitat of rhino. Presence of two perennial nalas (Rohua and Badlua) in Naurangia and three in Madanpur (Bhul-Rohua, Rohua, and Bhapsa) can fulfill the wallowing requirement of rhinos (See **Figure 6**). Forest department can also easily create artificial wallows (Dinerstein 2003) as and when required by augmenting perennial ditches (locally called Nari). In addition, good density of sympatric hog deer preferring the same grassland community as rhino in alluvial floodplain of Madanpur also indicates the suitability of rhino habitat in VTR. However, habitat may not sustain viable population of rhino.

Therefore, the potential habitat of rhino in Madanpur block can be utilsed for conservation breeding of rhino or similar other conservation oriented programs.

Conservation of less available identified grassland vegetation communities is the key to conservation of associated threatened mammals like hog deer.

Ungulate abundance data may be used as baseline data for future prey population monitoring.

## 6. Management issues

### (i) Control on cattle grazing and check on utilization of grasses by villagers

Study indicates cattle preferring the same grassland communities (*Saccharum munja* and *Typha anguistifoia-Saccharum spontaneum-Imperata cylindrica-Vetiveria zizanoides* associations) as chital and hog deer. Therefore, huge conflict of food and space occurs among them. Rhino also prefers similar grassland community, which will additionally create high competition for food and space especially between rhino and cattle due to high diet volume. Cattle graziers also deliberately burn the grassland along with forest patches depriving animals from their palatable graze, browse and shelter. Due to cattle grazing in early morning and late evening, fire and fuel wood collection in morning and afternoon, and vigilance in night from predators, wild ungulates remain in constant stress throughout day and night affecting their physiological and reproductive fitness.

*Saccharum spontaneum* (Kharai) constitutes 50 percent of rhino's diet (Dinerstein 2003) and villagers from Bihar and Uttar Pradesh collect almost all *Saccharum spontaneum* for thatch making along with other important thatch grasses (*Imperata cylindrica*-Dabhi and *Vetiveria zizanoides*- Katra). Burning of *Saccharum arundinaceum* (Kari/Dhamsar) by villagers for rough thatch work destroys the habitat of rhino and hog deer (Peet et al. 1999).

**Ghothas** (place of cattle graziers – especially buffalo) are major source of hindrance to conservation after poaching, illegal felling in the intensive study area. They keep hundreds of buffaloes, which graze day and night in grasslands for fulfilling their complete dietary requirements. They make thatch houses for their residence and cattle shelter extensively from poles of low regenerating valuable timber trees like *Dalbergia sissoo, Acacia catechu* thus, hampering the regenerations. Many temporary Ghothas are of people from Uttar Pradesh, who have no rights of cattle grazing in the reserve.

Therefore, a check on cattle grazing and thatch grass collection is required.

### (ii) Mitigation measure on Bagha-Chhitauni railway track

Bagha-Chhitauni railway track along with road on one side is a huge barrier to the movement of fauna of Madanpur affecting their gene flow. The major fertile grassland portion has lost its link from the good grassland patch on other side of railway track. Even while considering, the placement of enclosure for rhino, inclusion of this small portion will add 3.4 sq.km of very productive grassland to rhino and can easily be maintained by adapting mitigation measures like creation of underpass at suitable sites to facilitate movement of rhino and other animals. Present placement of two underpasses are inadequate and that too placed at wrong places. Therefore, higher number of underpasses may be placed at suitable places like (i) for draining the Nalas in river Gandak, to remove water logging from M7, and (ii) in between grassy patches of M5 and M7.

### (iii) Sohagibarwa Wildlife Sanctuary as potential habitat of Rhino

Combination of personal field observation (not sampling), historical presence data of rhino and probability distribution map indicates potential habitat of rhino in Sohagibarwa Wildlife Sanctuary specially compartment UP54 and UP55 of Sheopur range (1996.90 ha) present left of river Gandak, cut off from rest other ranges. Sheopur range adjoining to Naurangia beat of Madanpur block with the same mosaic of habitat type is ecologically one structural and functional unit (See **Figure 6**) and would be better if managed as one.

### (iv) Mitigation measure on National Highway 28B

Though, survey has not been done for assessing the effect of NH 28B passing through Madanpur block (See **Figure 6**) on activity patterns and mortality of wild animals, but personal field observations and discussions from forest staff and local public reveals mortality incidents of wild animals. Therefore, it indicates NH 28B as a threat to rhino unless put in enclosure.

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# Appendices

## Appendix 1

List of major food plants of *Rhinoceros unicornis* found in various studies

| Protected Area | Area | Total no. of plant eaten | % Of grass In Diet | Dominant species constituting 50- 90 % of Diet | Study Done By |
|---|---|---|---|---|---|
| **Kaziranga NP (KNP)** | Whole (432 km²) | 47 | 75 | *Cyanodon dactylon, Eragrostis sp., Chrysopogon sp., Imperata cylindrica, I.indica, Aciculatus sp., Phragmites karka, Andropogon sp., Saccharum elephantum, Saccharum sp., Pennisetum sp., Typha elephantine, Pollinia ciliate, Arundo donax, Tamarix sp., Eichhornia crassipes, Ipomoea reptans, Nelumbo speciosum, Nymphaea lotus* | Mary et.al. (1998) |
| **Kaziranga NP (KNP)** | Short Grass-land (SG) (1.2 km²) | 47 | 77 | *Hemarthria compressa, Carex rubrobrunnea, Arundo donax, Erianthus elephantinus, Polygonum barbatum, Cyanodon dactylon, Eleochoris fistulosa, Lippia geminata* | K.C.Patar (1977) |
| **Chitwan NP (CN** | Whole (907 km²) | 183 | 70-89 | *Cyanodo dactylon, Paspalidium flavidum, Setaria pallid-fusca, Chrysopogon aciculatus, Imperata cylindrica, Saccharum spontaneum, S.munja, Narenga porphyrocoma, Phragmites karka, Themeda villosa, Cyperus digitatus, C.pilosus, Ageratum* | A.Laurie (1978) |

| | | | | | |
|---|---|---|---|---|---|
| | | | | *conizoides,Callicarpa macrophylla,Artemisia vulgaris,Trewia nudiflora,Litsaea monoptela,Premna integrifolia,Hydrilla sp., Vallisneria spiralis,Pistia sp.* | |
| **Chitwan NP (CNP)** | Whole (932 km²) | 283 | 73.4 | *Saccharum spontaneum,S.benghalensis,Cyanodon dactylon,Narenga porphyrocoma,Coffea benghalensis,Murraya paniculata,Litsea monopetala* | Jnawali (1995) |
| **Chitwan NP (CNP)** | Sauraha (SAU) (30.54 km²) | 42 | 66.58 | *Saccharum spontaneum,Imprerata cylindrica,Dryopteris cochleata,Coffea benghalensis,Phragmites karka,Callicarpa macrophylla,Sachharum benghalensis,Hemerthrea compressa,Eragrostis tennela,Narenga porphyrocoma,Litsea monopetala,Cyanodon dactylon,Equisetum debile,Desmostachya bipinnata.Tetrastigma serrulatum,Clerodendron viscosum* | R.C.Kandel (2003) |
| **Chitwan NP (CNP)** | Eastern Sector (ES) (40.25 km²) | 58 | 71.33 | *S. spontaneum,Imperata cylindrical,Eragrostis tenella,Cersium wallichii,Narenga porphyrocoma,Cyanodon dactylon,Phragmites karka,Mikania micrantha,Saccharum benghalensis,Callicarpa microphylla,Coffea benghalensis.Litsea monopetala,Lantana camara,Brachiaria sp.,Trewia nudiflora fruits,Hemarthrea compressa* | N.Subedi (2012) |

| | | | | | |
|---|---|---|---|---|---|
| **Chitwan NP (CNP)** | Sauraha | 149 | 57.74 | *Saccharum spontaneum, Narenga porphyrocoma, Imperata cylindrica, Cyanodon Dactylon, Eragrostis tennella, Saccharum benghalensis, Hemarthria compressa, Callicarpa macrophylla, Phragmites karka, Coffea benghalensis* | K. Adhikari (2015) |
| **Bardia NP (BNP)** | Whole (968 km²) | 179 | 63.3 | *Saccharum spontaneum,Arundo donax,Cyanodon dactylon,Saccharum benghalensis,Erianthus ravennae,Mallotus phillippinensis,Dalbergia sisoo,Callicarpa macrophylla,Calamus tenuis* | Jnawali (1995) |
| **Bardia NP (BNP)** | Babai valley (BV) (48 km²) | - | 63 | *Saccharum spontaneum,Phragmitis karka,Arundo donax,Imperata cylindrical,Cyanodon dactylon,Dalbergia sissoo,Mallotus phillippinensis,Litsea monopetala* | Steinheim et.al (2005) |
| **Bardia NP (BNP)** | Karnali river flood-plain (KRFP) (50km²) | 71 | 45.5 | *Saccharum spontaneum,Themeda sp.,Arundo donax,Phragmites karka,Cyanodon dactylon,Cymbopogon sp.,Mallotus phillippinensis,Dalbergia sissoo,Callicarpa macrophylla,C.oppositifolia,Bombax ceiba,Circium wallichii* | Wegge et.al (2006) |
| **Orang NP (ONP)** | Whole (78.81 km²) | 71 | 86.6 | *Hemarthria compressa, Hymenachne pseudointerrupta, Leersia hexandra, Arundo donax, Chrysopogon aciculatus, Phragmites karka, Brachiaria ramosa, Cynodon dactylon, Saccharum spontaneum, and Imperata cylindrica* | Hazarika et.al. (2012) |

| | | | | | |
|---|---|---|---|---|---|
| **Dudhwa NP (DNP)** | RRA in Kakraha Block (25 $km^2$) | 55 | 45 | *Saccharum spontaneum,Cyanodon dactylon,Arundo donax,Polytoca digitata, Hygroryza aristata, Vetiveria zizanioides, Imperata cylindrica, Themeda spp., Chrysopogen aciculatus, Paspalidum flavilum, Narenga porphyrocoma, Phragmites karka, Cyprus sp.* | Sinha et.al. (1991) |

# Appendix 2

Comparison table of home ranges and density estimates of Rhinoceros in various studies

| Place | Biologist | Home range Male (sq.km) | Home range Female (sq.km) | Density (individuals /sq.km) |
|---|---|---|---|---|
| Chitwan | A.Laurie (1972-76) | 3.26 | 3.26 | 4.83 |
| Chitwan | E. Dinerstein (1984-88) | 4.3 | 3.5 | 1.1 – 13.3 |
| Chitwan | N.Subedi (2012) | 20.54 ± 6.06 | 10.58 ± 1.34 | 2 |
| Chitwan | K.Adhikari (2015) | 10.67 ± 0.92 | 5.46 ± 0.65 | 0.83 |
| Bardia | S.Jnawali (1986) | 41.8 | 25.1 | 0.3 |
| Pobitora | R.Bhatta (2005-2010) | 17.15 | 17.15 | - |
| Dudhwa | Tripathi (2012) | 10.52 | 8.78 | 0.35-0.91 |
| Kaziranga | Foose and Strien (1997) | - | - | 2.79 |

# Appendix 3

List of food plants of Rhino found in intensive study area.
(arranged in descending order of prominence value)

| S.No. | Scientific Name | Family | Local Name | PV | % freq |
|---|---|---|---|---|---|
| 1 | *Calamus tenuis* | Arecaceae | Bet | 630.75 | 30.78 |
| 2 | *Phragmites karka* | Poaceae | Narkat | 412.79 | 14.27 |
| 3 | *Typha anguistifolia* | Typhaceae | Pater | 337.37 | 16.91 |
| 4 | *Saccharum arundinaeum* | Poaceae | Kari / Dhamsar | 304.58 | 13.34 |
| 5 | *Imperata cylindrical* | Poaceae | Dabhi | 294.10 | 20.21 |
| 6 | *Saccharum munja* | Poaceae | Munj | 280.04 | 9.91 |
| 7 | *Saccharum ravennae* | Poaceae | Dhamsar | 279.56 | 18.49 |
| 8 | *Sclerostachya fusca* | Poaceae | Ekra | 249.30 | 7.40 |
| 9 | *Vetiveria Zizanoides* | Poaceae | Katra | 244.98 | 19.68 |
| 10 | *Mallotus phillippensis* | Euphorbiaceae | Rohida | 240.72 | 31.84 |
| 11 | *Saccharum spontaneum* | Poaceae | Kharai | 226.22 | 19.02 |
| 12 | *Clerodendron infortunatum* | Verbenaceae | Bhant | 200.72 | 20.74 |
| 13 | *Carex vesicaria* | Cyperaceae | Kewti | 168.64 | 17.44 |
| 14 | *Fern* | Fern Family | Balya | 158.44 | 32.89 |
| 15 | *Ardisia solanacea* | Primulaceae | Majargarwa | 118.58 | 15.85 |
| 16 | *Murraya koengii* | Rutaceae | Kadhi patta | 110.84 | 23.78 |
| 17 | *Ziziphus sp.* | Rhamnaceae | Baer | 98.93 | 8.19 |
| 18 | *Syzygium cumini* | Myrtaceae | Jamun | 95.76 | 19.82 |
| 19 | *Desmostachya bipinnata* | Poaceae | Kush | 91.03 | 14.27 |
| 20 | *Holarrhena antidysenterica* | Apocynaceae | DudhKareya | 83.79 | 12.68 |
| 21 | *Colebrookea oppositifolia* | Lamiaceae | Ujla bhant | 79.82 | 17.97 |
| 22 | *Pogestimon benghalensis* | Lamiaceae | Kala bhant | 75.76 | 15.72 |
| 23 | *Ageratum conizoides* | Asteraceae | Bhant | 73.15 | 12.02 |
| 24 | *Mikania micrantha* | Asteraceae | | 72.10 | 13.47 |
| 25 | *Cyanodon sp.* | Poaceae | Dubh | 64.62 | 3.83 |
| 26 | *Phyllanthus sp.* | Euphorbiaceae | Sikat | 61.02 | 4.89 |
| 27 | *Ehretia laevis* | Boraginaceae | Datranga | 56.89 | 16.25 |
| 28 | *Acaciasp.* | Mimosaceae | Tairi | 55.86 | 5.81 |
| 29 | *Acacia catechu* | Mimosaceae | Khaira | 54.19 | 4.76 |
| 30 | *Litsea monopetala* | Lauraceae | Santhi/Chhakledi | 53.78 | 10.83 |
| 31 | *Curcuma sp.* | Zingiberaceae | Kachoorr | 51.96 | 0.40 |

| | | | | | |
|---|---|---|---|---|---|
| 32 | *Acacia concinna* | Mimosaceae | Tairi | 50.45 | 9.64 |
| 33 | *Trewia nudiflora* | Euphorbiaceae | Bhilore | 48.13 | 8.72 |
| 34 | *Ficus hispida* | Moraceae | Kathdumar | 47.52 | 8.19 |
| 35 | *Callicarpa macrophylla* | Verbenaceae | Budhiya mai ka lawa | 46.90 | 9.64 |
| 36 | *Bauhinia racemosa* | Caesalpiniaceae | Sahul | 45.84 | 8.32 |
| 37 | *Lantana camara* | Verbenaceae | Bhant | 45.23 | 1.45 |
| 38 | *Bridelia sp.* | Euphorbiaceae | Khaji/Kalaunjar | 42.57 | 6.74 |
| 39 | *Randia dumatorum* | Rubiaceae | Mauna | 41.50 | 2.64 |
| 40 | *Dysoxylum binectariferum* | Meliaceae | | 36.77 | 7.79 |
| 41 | *Leea sp.* | Leeaceae | | 35.31 | 3.17 |
| 42 | *Tamarix sp.* | Tamariaceae | | 34.64 | 0.40 |
| 43 | *Grewia sp.* | Tiliacea | | 33.34 | 7.13 |
| 44 | *Apluda mutica* | Poaceae | Basri | 29.67 | 5.02 |
| 45 | *Eragrostis ciliaris* | Poaceae | | 28.87 | 0.40 |
| 46 | *Hemarthria compressa* | Poaceae | Gadila | 28.13 | 6.74 |
| 47 | *Ficus racemosa* | Moraceae | Gular | 25.82 | 2.11 |
| 48 | *Enhydra fluctuans* | Asteraceae | | 25.00 | 0.13 |
| 49 | *Oplismenus burhmanii* | Poaceae | | 24.90 | 3.30 |
| 50 | *Polygonum hydropiper* | Polygonaceae | Lirbiriya | 23.50 | 4.76 |
| 51 | *Dalbergia sissoo* | Fabaceae | Sissam | 23.27 | 0.79 |
| 52 | *Aegle marmelos* | Rutaceae | Bel | 22.82 | 4.76 |
| 53 | *Mimosa himalayana* | fabaceae | Jharkatya | 20.79 | 0.92 |
| 54 | *Cyprus sp.* | Cyperaceae | Motha | 18.78 | 0.79 |
| 55 | *Cirsium arvense* | Asteraceae | | 17.15 | 3.30 |
| 56 | *Urena lobata* | Malvaceae | Laptewa | 16.33 | 5.55 |
| 57 | *Solanum xanthocarpum* | Solanaceae | Banrbhanta | 16.06 | 3.17 |
| 58 | *Sida acuta* | Malvaceae | Bariyar | 14.07 | 2.25 |
| 59 | *Cordia sp.* | Boraginaceae | | 12.93 | 4.36 |
| 60 | *Woodfordia fruticosa* | Lythraceae | Dhair | 12.02 | 1.19 |
| 61 | *Panicum miliare* | Poaceae | | 12.02 | 0.26 |
| 62 | *Vitis repanda* | Vitaceae | | 11.88 | 5.15 |
| 63 | *Solanum verbascifolium* | Solanaceae | Banrbaigan | 11.36 | 2.25 |
| 64 | *Terminalia bellerica* | Combretaceae | Bahera | 10.61 | 0.26 |
| 65 | *Anisomeles ovate* | Lamiaceae | Bhant | 10.25 | 1.45 |
| 66 | *Grewia tetrasperma* | Tiliacea | Pharsa | 10.00 | 0.13 |
| 67 | *Coffea benghalensis* | Rubiaceae | | 9.07 | 1.06 |
| 68 | *Sida cordifolia* | Malvaceae | Bariyar | 8.32 | 0.92 |
| 69 | *Desmodium pulchellum* | Fabaceae | | 8.13 | 1.72 |
| 70 | *Equisetum debile* | Eqisetacea | Hadjodwa | 6.94 | 1.72 |
| 71 | *Cassia occidentalis* | Caesalpiniaceae | | 6.93 | 0.53 |

| | | | | | |
|---|---|---|---|---|---|
| 72 | *Boehmeria scrabella* | Urticaceae | | 6.26 | 0.66 |
| 73 | *Barleria sp.* | Acanthacea | | 5.31 | 0.92 |
| 74 | *Centella asiatica* | Apiaceae | Brahmibuti | 5.00 | 0.26 |
| 75 | *Xanthium strumarium* | Asteraceae | Laptewa | 5.00 | 0.13 |
| 76 | *Mimosa pudica* | Fabaceae | | 5.00 | 0.13 |
| 77 | *Flemingia paniculata* | Fabaceae | Banbariyar | 5.00 | 0.13 |
| 78 | *Adina cordifolia* | Rubiaceae | Karma | 5.00 | 0.13 |
| 79 | *Solanum nigrum* | Solanaceae | | 5.00 | 0.13 |
| 80 | *Artemisia sp.* | Asteraceae | | 4.95 | 0.26 |
| 81 | *Oxalis sp.* | Oxalidaceae | | 4.95 | 0.26 |
| 82 | *Achiranthes aspera* | Amaranthaceae | chirchira | 4.62 | 0.92 |
| 83 | *Smilax aspera* | Smilaceae | Gabnaha | 4.50 | 0.92 |
| 84 | *Paspalum scorbiculatum* | Poaceae | Kodwar | 4.16 | 2.11 |
| 85 | *Bombax ceiba* | Bombicaceae | Semal | 4.00 | 0.66 |
| 86 | *Desmodium sp.* | Fabaceae | | 2.89 | 0.40 |
| 87 | *Flemengia semialata* | Fabaceae | Banbariyar | 2.00 | 0.66 |
| 88 | *Ficus semicordata* | Moraceae | | 2.00 | 0.13 |
| 89 | *Grewia sapida* | Tiliacea | | 2.00 | 0.13 |
| 90 | *Fimbristylis sp.* | Cyperaceae | Motha | 1.00 | 0.13 |
| 91 | *Asparagus sp.* | Liliaceae | Santavar | 1.00 | 0.13 |
| 92 | *Xylosoma longifolium* | Salicaceae | | | |
| 93 | *Eupatorium odoratum* | Verbenaceae | | | |
| 94 | *Gnaphalium luteoalbum* | Asteraceae | | | |
| 95 | *Commelina sp.* | Commelinaceae | | | |
| 96 | *Argyreia sp.* | Convolvulaceae | | | |
| 97 | *Trichosanthes sp.* | Cucurbitaceae | Bankarela | | |
| 98 | *Gnetum sp.* | Gnetaceae | | | |
| 99 | *Shorea robusta* | Dipterocarpaceae | Sakhua | | |
| 100 | *Lagerstroemia parviflora* | Lythraceae | | | |
| 101 | *Syzygium operculatum* | Myrtaceae | | | |
| 102 | *Trema orientalis* | Cannabaceae | Bachkareh | | |

# Appendix 4

Prominence value of food plants of Rhino in Valmiki, Bardia and Chitwan

| Food species | VAL LC | Valmiki | VAL UC | Bardia | Chitwan |
|---|---|---|---|---|---|
| **Grasses** | | | | | |
| *Cyanodon sp.* | 62.4 | 64.6 | 66.9 | 95.9 | 324.8 |
| *Saccharum spontaneum* | 224.7 | 226.2 | 227.7 | 638.3 | 270.6 |
| *Apluda mutica* | 28.9 | 29.7 | 30.5 | 42.3 | 7.0 |
| *Arundo donax* | nil | nil | nil | 23.2 | 2.9 |
| *Desmostachya bipinnata* | 90.3 | 91.0 | 91.7 | 239.0 | 10.5 |
| *Imperata cylindrica* | 292.2 | 294.1 | 296.0 | 210.6 | 257.9 |
| *Cymbopogon sp.* | nil | nil | nil | 8.3 | 2.7 |
| *Saccharum munja* | 276.6 | 280.0 | 283.5 | 88.2 | 100.9 |
| *Narnga porphyrocoma* | nil | nil | nil | 16.8 | 207.6 |
| *Themeda sp.* | nil | nil | nil | 0.0 | 208.0 |
| *Chrysopogon aciculatus* | nil | nil | nil | 30.0 | 217.8 |
| *Erianthus ravennae* | 277.4 | 279.6 | 281.7 | 21.1 | 19.1 |
| *Vetiveria Zizanoides* | 243.4 | 245.0 | 246.5 | 37.6 | 12.0 |
| *Setaria pallide-fusca* | nil | nil | nil | 1.2 | 6.6 |
| *Oplismenus burhmanii* | 24.0 | 24.9 | 25.8 | 0.2 | 1.9 |
| *Panicum miliare* | 5.5 | 12.0 | 18.5 | 30.0 | 50.8 |
| *Brachiaria sp.* | nil | nil | nil | 30.7 | 13.0 |
| *Phragmites karka* | 408.7 | 412.8 | 416.9 | 10.8 | 9.7 |
| *Typha anguistifolia* | 335.3 | 337.4 | 339.5 | 0.3 | 4.0 |
| *Saccharum arundinaeum* | 302.1 | 304.6 | 307.1 | 2.6 | 16.8 |
| *Sclerostachya fusca* | 245.4 | 249.3 | 253.2 | nil | nil |
| *Hemarthria compressa* | 27.3 | 28.1 | 28.9 | nil | nil |
| *Paspalum scorbiculatum* | 3.9 | 4.2 | 4.5 | nil | nil |
| *Eragrostis ciliaris* | 22.2 | 28.9 | 35.5 | nil | nil |
| *Carex vesicaria* | 167.0 | 168.6 | 170.3 | nil | nil |
| | | | | | |
| **Browse** | | | | | |
| *Mallotus phillippensis* | 239.9 | 240.7 | 241.5 | 34.8 | 11.2 |
| *Ehretia laevis* | 56.5 | 56.9 | 57.3 | 14.8 | 43.2 |
| *Bridelia sp.* | 41.6 | 42.6 | 43.5 | 2.3 | 5.8 |
| *Ficus racemosa* | 23.6 | 25.8 | 28.1 | 0.6 | 3.1 |
| *Bombax ceiba* | 4.0 | 4.0 | 4.0 | 2.6 | 32.8 |
| *Syzygium cumini* | 94.9 | 95.8 | 96.6 | 14.9 | 6.7 |
| *Bauhinia racemosa* | 44.9 | 45.8 | 46.8 | 0.2 | 8.4 |

| | | | | | |
|---|---|---|---|---|---|
| *Dalbergia sissoo* | 18.0 | 23.3 | 28.5 | 9.9 | 1.3 |
| *Trewia nudiflora* | 47.5 | 48.1 | 48.8 | 2.3 | 50.6 |
| *Grewia sp.* | 32.5 | 33.3 | 34.2 | 2.7 | 22.7 |
| *Callicarpa macrophylla* | 46.2 | 46.9 | 47.6 | 104.5 | 250.0 |
| *Colebrookea oppositifolia* | 79.2 | 79.8 | 80.4 | 37.1 | 285.7 |
| *Ziziphus sp.* | 97.3 | 98.9 | 100.6 | 173.8 | 15.8 |
| *Coffea benghalensis* | 7.9 | 9.1 | 10.3 | 0.0 | 27.2 |
| *Murraya paniculata* | nil | nil | nil | 0.0 | 22.8 |
| *Litsea monopetala* | 53.1 | 53.8 | 54.5 | 2.4 | 92.8 |
| *Calamus tenuis* | 628.7 | 630.8 | 632.8 | 26.3 | 0.0 |
| *Acacia concinna* | 49.8 | 50.4 | 51.1 | 15.1 | 68.1 |
| | | | | | |
| **Others** | | | | | |
| *Pogestimon benghalensis* | 74.9 | 75.8 | 76.6 | 27.4 | 115.8 |
| *Cirsium arvense* | 16.5 | 17.1 | 17.8 | 3.9 | 17.9 |
| *Solanum sp.* | nil | nil | nil | 1.2 | 12.9 |
| *Cassia tora* | nil | nil | nil | 29.2 | 287.0 |
| *Cassia occidentalis* | 5.9 | 6.9 | 7.9 | 0.4 | 6.1 |
| *Pteris sp.* | nil | nil | nil | 20.4 | 6.8 |
| *Urena lobata* | 15.9 | 16.3 | 16.8 | 3.2 | 10.4 |
| *Cyprus sp.* | 16.8 | 18.8 | 20.8 | 10.0 | 17.9 |
| *Artemisia sp.* | 3.4 | 4.9 | 6.4 | 2.6 | 90.2 |
| *Truimfetta sp.* | nil | nil | nil | 2.3 | 4.3 |
| *Sida acuta* | 13.5 | 14.1 | 14.6 | 0.2 | 10.3 |
| *Sida rhombifolia* | nil | nil | nil | 2.3 | 18.5 |
| *Piper nepalense* | nil | nil | nil | 1.3 | 7.8 |
| *Amaranthus spinosa* | nil | nil | nil | 0.7 | 0.2 |
| *Equisetum debile* | 6.2 | 6.9 | 7.7 | 2.0 | 11.3 |
| *Ageratum conizoides* | 72.1 | 73.2 | 74.2 | 0.6 | 64.2 |
| *Lippia nudiflora* | nil | nil | nil | 0.8 | 7.2 |
| *Winter composit* | nil | nil | nil | 0.2 | 2.1 |
| *Acanthasea* | nil | nil | nil | 0.0 | 4.1 |

**Abbreviations:** VAL_LC is Valmiki with lower confidence limit

VAL_UC is Valmiki with upper confidence limit

# Appendix 5

List of presence of major food species (number in %) of Rhino found in Nepal.

| Study area | CNP | CNP | Bardia | CNP (HDS) | CNP (CDS) | CNP (MS) | CNP (HDS) | CNP (CDS) | CNP (MS) | VTR |
|---|---|---|---|---|---|---|---|---|---|---|
| **Species/ Study done by** | **AL** | **ED** | **SG** | **NS** | **NS** | **NS** | **KA** | **KA** | **KA** | |
| *Saccharum spontaneum* | p | p | p | p (34) | p (22) | p (25) | p (21.2) | p (17.5) | p (18.1) | p |
| *Saccharum benghalensis* | p | p | p | | p (6) | p (4) | | p (8.0) | p (4.8) | p |
| *Cyanodon dactylon* | p | p | p | p (2) | | p (3) | p (5.8) | | p (8.1) | p |
| *Narenga porphyrocoma* | p | p | - | p (5) | | | p (10.1) | | | |
| *Arundo donax* | | | p | | | | | | | |
| *Brachiaria sp.* | | | | | | p (8) | | | | |
| *Hemarthria compressa* | | | | | | p (3) | | | p (4.5) | p |
| *Erianthus ravennae* | | | p | | | | | | | p |
| *Imperata cylindrica* | | | | p (27) | p (14) | p (8) | p (6.7) | | | p |
| *Eragrostis tenella* | | | | p (9) | p (9) | p (23) | p (3.14) | p (7.2) | | |
| *Phragmites karka* | | | | p (3) | p (7) | p (4) | | p (6.1) | | p |
| *Coffea benghalensis* | | p | - | | p (3) | | | p (5.9) | | p |
| *Murraya paniculata* | | p | - | | | | | | | |
| *Litsea monopetala* | | p | | | p (4) | | | | | p |
| *Trewia nudiflora* | | | p | | | p (4) | | | | p |
| *Mallotus philipinensis* | | | p | | | | | | | p |
| *Dalbergia sissoo* | | | p | | | | | | | p |
| *Callicarpa macrophylla* | p | | | | p (11) | | | p (10.9) | | p |
| *Calamus tenuis* | | | p | | | | | | | p |

**Abbreviations**- CNP-Chitwan National Park, HDS- Hot dry season, CDS-Cool dry season, MS- Monsoon season, AL- A.Laurie, ED-E.Dinerstein, NS- N.Subedi, KA- K.Adhikari, p- present

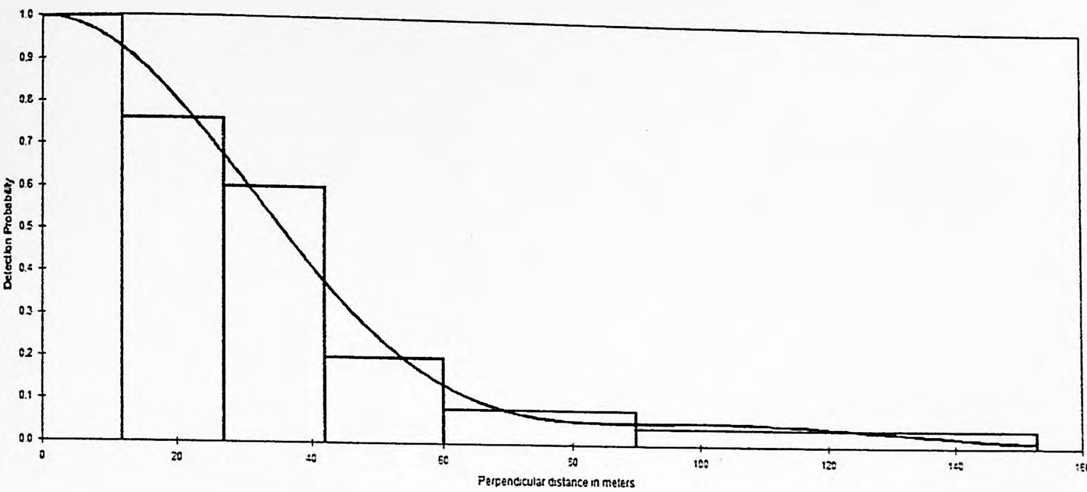
# Appendix 6

Comparison table showing prominence value of dominant food plants of Rhino within intensive study area.

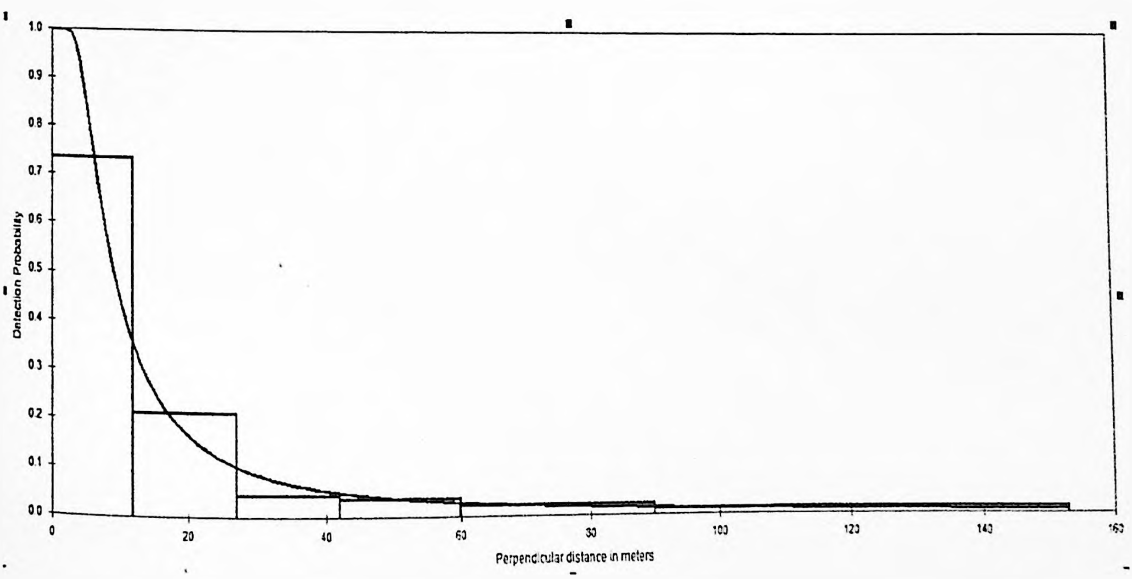
| Food species | Abbrev. | Madanpur | Madanpur RRA | Naurangia | Bhedihari |
|---|---|---|---|---|---|
| *Saccharum spontaneum* | SA_SP | 185.9 | 115.6 | 121.1 | 50.2 |
| *Saccharum munja* | SA_MU | 245.2 | 251.4 | 122.3 | 102.8 |
| *Saccharum arundinaeum* | SA_AR | 199.7 | 202.2 | 154.8 | 177.3 |
| *Saccharum ravennae* | SA_RA | 223.9 | 211.3 | 166.1 | 36.7 |
| *Imperata cylindrica* | IM_CY | 163.7 | 163.7 | 237.7 | 84.1 |
| *Vetiveria Zizanoides* | VE_ZI | 173.5 | 173.1 | 154.6 | 80.3 |
| *Typha anguistifolia* | TY_AN | 140.6 | 139.3 | 258.4 | 171.0 |
| *Phragmites karka* | PH_KA | 161.9 | 54.7 | 29.2 | 457.0 |
| *Cyanodon sp.* | CYN | 8.0 | 6.5 | 30.8 | 63.2 |
| *Coffea benghalensis* | CO_BE | 0.0 | 0.0 | 8.6 | 3.0 |
| *Callicarpa macrophylla* | CA_MA | 26.4 | 24.2 | 22.7 | 28.9 |
| *Mallotus phillippensis* | MA_PH | 133.5 | 49.0 | 168.2 | 106.3 |
| *Bauhinia racemosa* | BA_RA | 20.3 | 20.8 | 33.6 | 25.8 |
| *Randia dumatorum* | RA_DU | 5.7 | 5.0 | 43.3 | 0.0 |
| *Litsea monopetala* | LI_MO | 32.5 | 15.1 | 43.2 | 8.5 |
| *Ficus racemosa* | FI_RA | 2.1 | 2.0 | 4.0 | 29.3 |
| *Ficus hispida* | FI_HI | 18.4 | 12.2 | 35.0 | 29.4 |
| *Trewia nudiflora* | TR_NU | 7.4 | 6.5 | 29.6 | 39.6 |
| *Calamus tenuis* | CA_TE | 188.6 | 149.2 | 461.8 | 408.3 |
| *Ziziphus sp.* | ZIZ | 27.9 | 27.6 | 40.9 | 107.2 |
| *Acacia concinna* | AC_CO | 41.4 | 22.0 | 15.8 | 23.8 |

# Appendix 7

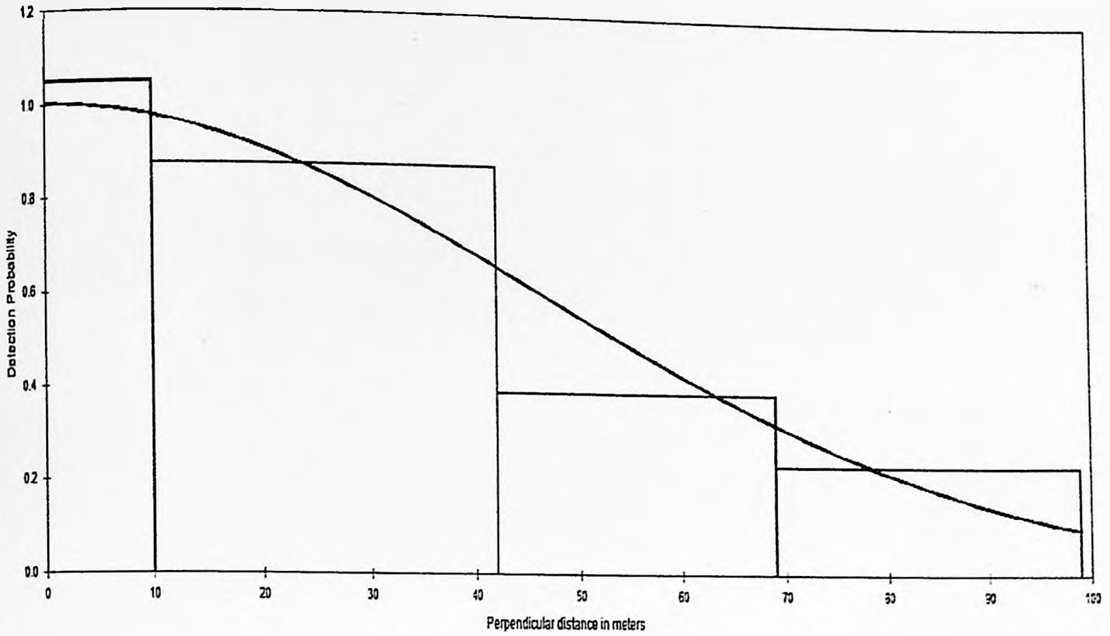
Response curves of different ungulates to their detection with increase in distance.



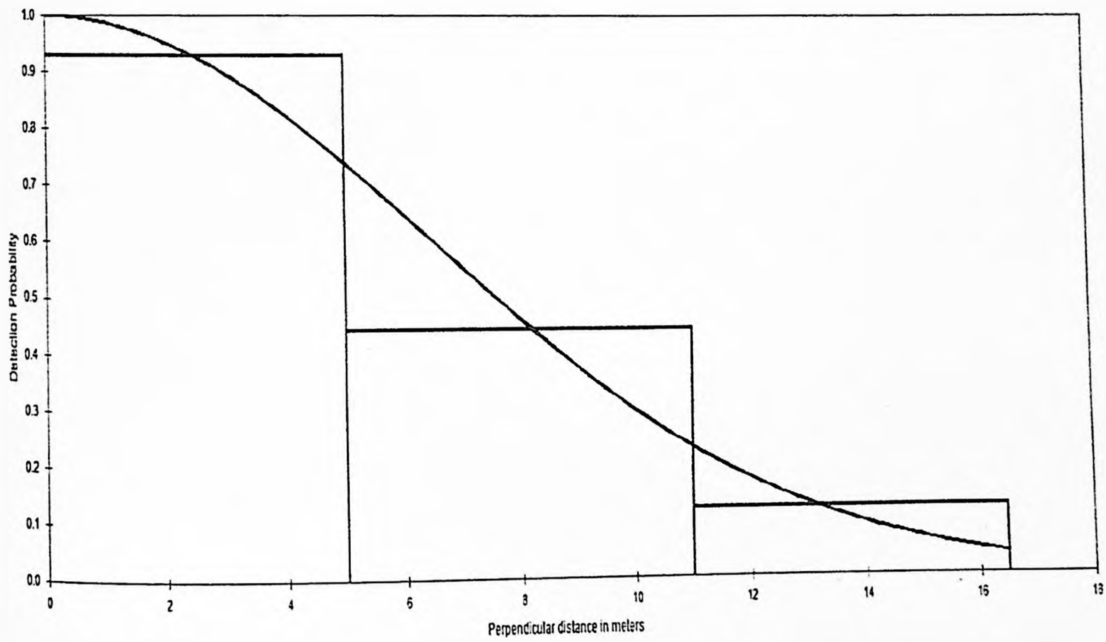

Histogram of distance data for Chital



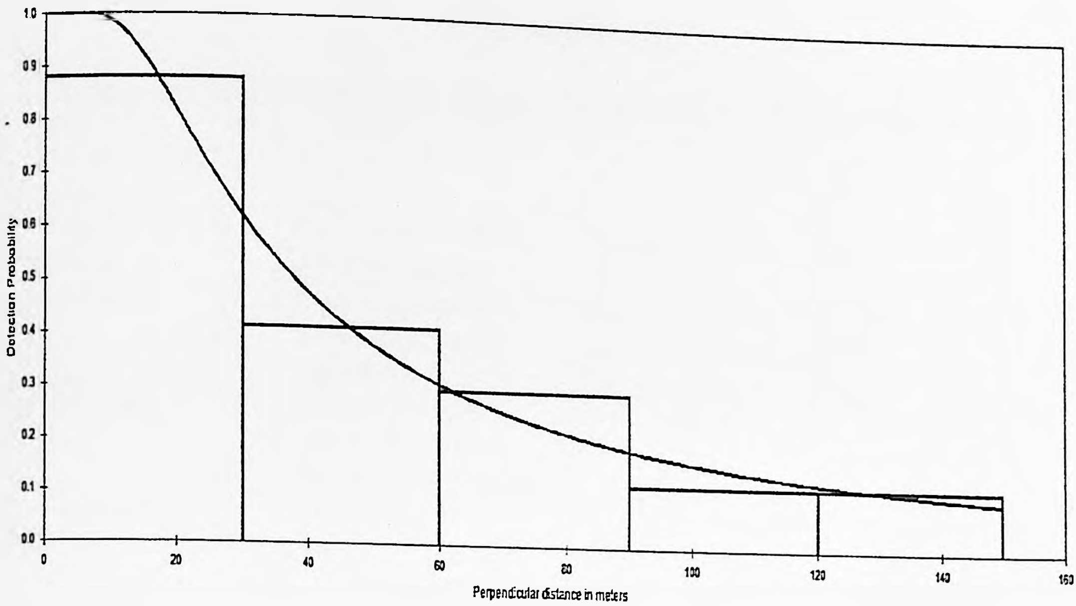

Histogram of distance data for Hog Deer




Histogram of distance data for Nilgai




Histogram of distance data for Wild Pig




Histogram of Distance data for Domestic Cattle

# Appendix 8

Comparison table of grassland communities of Terai found in different studies

| **Lehmkuhl (1994) Chitwan** | **Peet et al. (1999) 4 PA of Nepal** | **Kumar (2002) TCA** | **This study (2017) Valmiki** |
|---|---|---|---|
| Not identified | *Typha elephantine* (permanent water logged sites) | *Typha elephantina* (permanent water logged sites) | Not identified |
| Not identified | *Phragmites karka* (permanent water logged sites, Marshy) | Not identified | *Phragmites karka* (permanent water logged sites, Marshy) |
| Not identified | Not identified | *Vetiveria zizanoides-Saccharum spontaneum* (upland grasslands, well developed soils,heavily grazed) | *Typha anguistifolia-S. spontaneum-Imperata cylindrica-V zizanoides* ( slight low land, heavily grazed) |
| *Narenga porphyrocoma-Saccharum munja* (new river terraces influenced by fire and grazing) | *Imperata cylindrica-Narenga porphyrocoma* With *S.munja phase* (edges of wet sites, newer terraces) | *Cymbogon jwarancusa-Saccharum munja* (upland grassland,dry sites, frequently burned, least grazing) | *Saccharum munja* (upland grassland on well developed soil) |
| Not identified | *Imperata cylindrica* (dry sites, well developed soils, previously cultivated) | *Imperata cylindrica-D. bipinnata-Saccharum spontaneum* (upland grassland, drier sites, well developed soils) | Not identified |
| *Themeda arundinacea-Narenga porphyrocoma* (tall dense grassland,fire maintained savannah, on fairly drained soils) | *Themeda arundinacea* (Tall dense grassland,forest edge,well developed soil, influenced by fire) | *Themeda arundinacea-S. narenga-Apluda mutica* (Tall dense grassland at forest edge, well developed soils,influenced by fire) | Not identified |
| *Themeda arundinacea-Imperata cylindrica* (forest meadows and sal grassland ecotone) | Not identified | Not identified | Not identified |
| *S. spontaneum-S. spontaneum* (Floodplain grassland, alluvial soils) | *Saccharum spontaneum* (floodplain grassland, alluvial soil, often inundated) | *S. spontaneum-S. narenga-Apluda mutica* (floodplain grassland, often inundated) | Not identified |

| | | | |
|---|---|---|---|
| *Narenga porphyrocoma-Narenga porphyrocoma* (Wet, well drained soils, influenced by fire and grazing) | *Narenga porphyrocoma* (tall dense grassland, old river terraces, and wetter soils, influenced by fire) | *Saccharum narenga-Saccharum spontaneum-Apluda mutica* (Tall dense grasslands, old river terraces and wetter soils, influenced by fire) | Not identified |
| Not identified | Not identified | *Sclerostachya fusca-Saccharum spontaneum-Apluda mutica* (seasonally inundated, tall dense grassland) | *Sclerostachya fusca-Saacharum ravennae-Saccharum spontaneum-Carex vesicaria* (seasonally inundated, low land grassland) |
| Not identified | *Phragmites karka-Saccharum spontaneum* (seasonally inundated heavily grazed) | *Phragmites karka-Arundo donax* (tall dense grassland, seasonal and permanent marsh) | Not identified |
| *Saccharum spontaneum-Phragmites karka* (marshland) | *Phragmites karka-Saccharum spontaneum-Saccharum arundinaceum* (tall dense grassland, seasonal and permanent marsh) | Not identified | *Phragmites karka-Saccharum arundinaceum-Typha anguistifolia- Carex vesicaria* (Marshy lowland , grazed) |
| Not identified | Not identified | Not identified | *Typha anguistifolia-Saccharum arundinaceum-Saccharum spontaneum* (low land, near marshes, water logging for 5-6 months, burned, heavily grazed) |
| Not identified | Not identified | Not identified | *Phyllanthus –Carex vesicaria*-Ficus heterophylla (clayey soils, low land, near nalas, marshes) |

# Appendix 9

Comparison table for density estimate of Chital, Nilgai and Wild pig in VTR.

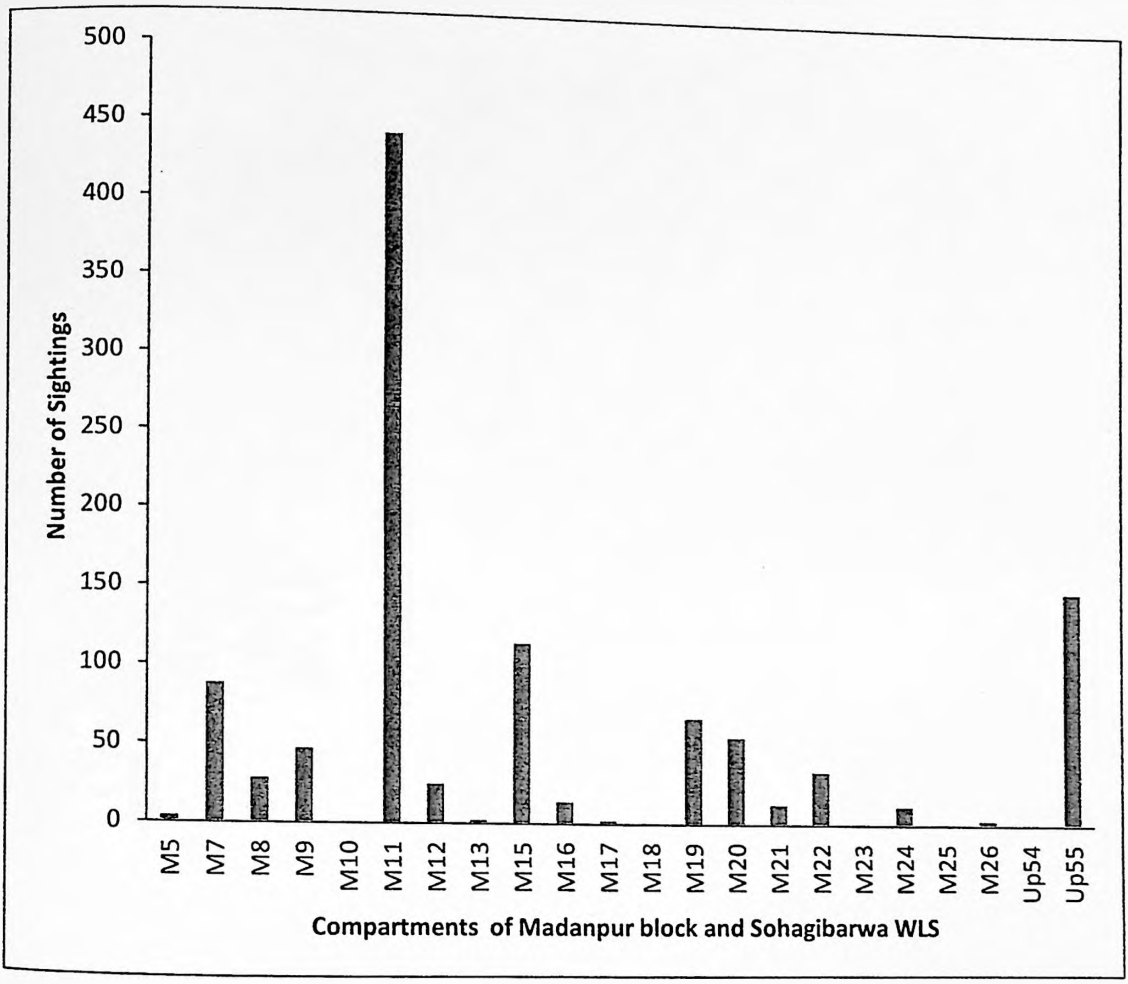
| Species | Model | Chi square P value | Effec-tive strip width (SE) | No. of groups detected | Mean Group size | Dete-ction proba-bility | Encou-nter rate (SE) per km | Group density (SE) per sq.km | Indiv-idual density (SE) per sq.km. |
|---|---|---|---|---|---|---|---|---|---|
| **Chital (VTR)** | Half-normal | 0.47 | 45.33 (5.04) | 204 | 4.98 (0.28) | 0.37 (0.04) | 0.075 (0.54) | 0.83 (0.10) | 3.98 (0.53) |
| **Chital (MB)** | Half-normal | 0.89 | 40.64 (3.38) | 68 | 3.90 (0.37) | 0.26 (0.02) | 0.41 (0.09) | 4.98 (1.23) | 19.46 (5.17) |
| **Nilgai (VTR)** | Half-normal | 0.67 | 50.35 (7.94) | 126 | 4.39 (0.35) | 0.54 (0.08) | 0.10 (0.015) | 1.009 (0.22) | 4.43 (1.05) |
| **Nilgai (MB)** | Half-normal | 0.79 | 55.89 (8.7) | 32 | 4.86 (0.87) | 0.56 (0.09) | 0.19 (0.07) | 1.70 (0.64) | 8.29 (3.46) |
| **Wild Pig (VTR)** | Half-normal | 0.93 | 41.23 (5.74) | 131 | 4.22 (0.27) | 0.41 (0.05) | 0.06 (0.003) | 0.78 (0.11) | 2.80 (0.46) |
| **Wild pig (MB)** | Half-normal | 0.87 | 7.99 (1.98) | 12 | 1.7 (0.27) | 0.5 (0.12) | 0.07 (0.02) | 4.47 (1.69) | 7.59 (3.11) |

**Abbreviation:**

VTR is Valmiki Tiger Reserve
MB is Madanpur Block
SE is standard error

# Appendix 10

Histogram of Rhino presence from different compartments of Madanpur Block, VTR and part of Sohagibarwa Wildlife Sanctuary, UP.




**Note-** Up54 and Up55 are compartments of Sohagibarwa Wildlife Sanctuary, UP

# Appendix 11

## a) Habitat types of Madanpur Block

**Plate:** Barringtonia swamp in M19

**Plate:** Canebrakes

**Plate:** Riverine forest

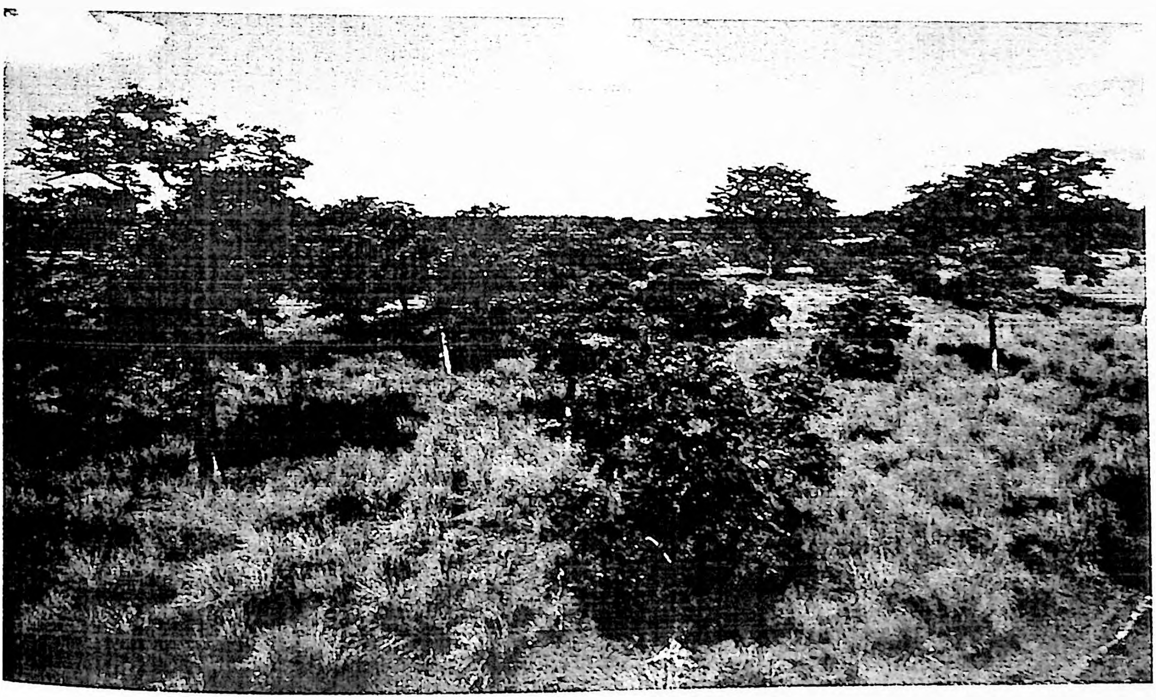


**Plate:** Upland Munj grassland in M5

**b) Fauna in field**

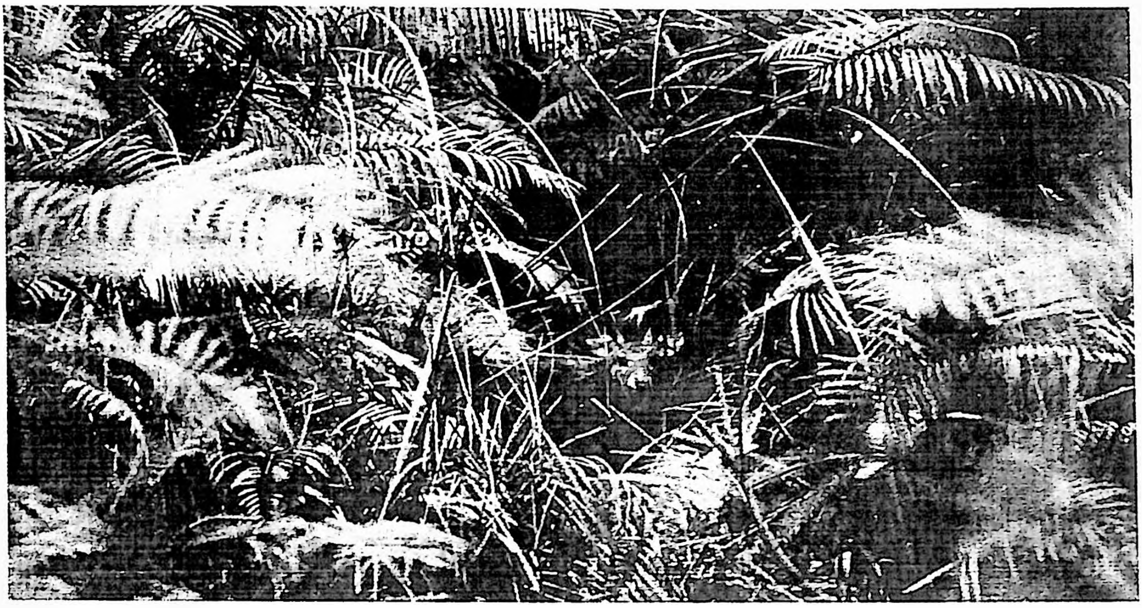


**Plate:** Curious hog deer taking refuge in canes during day

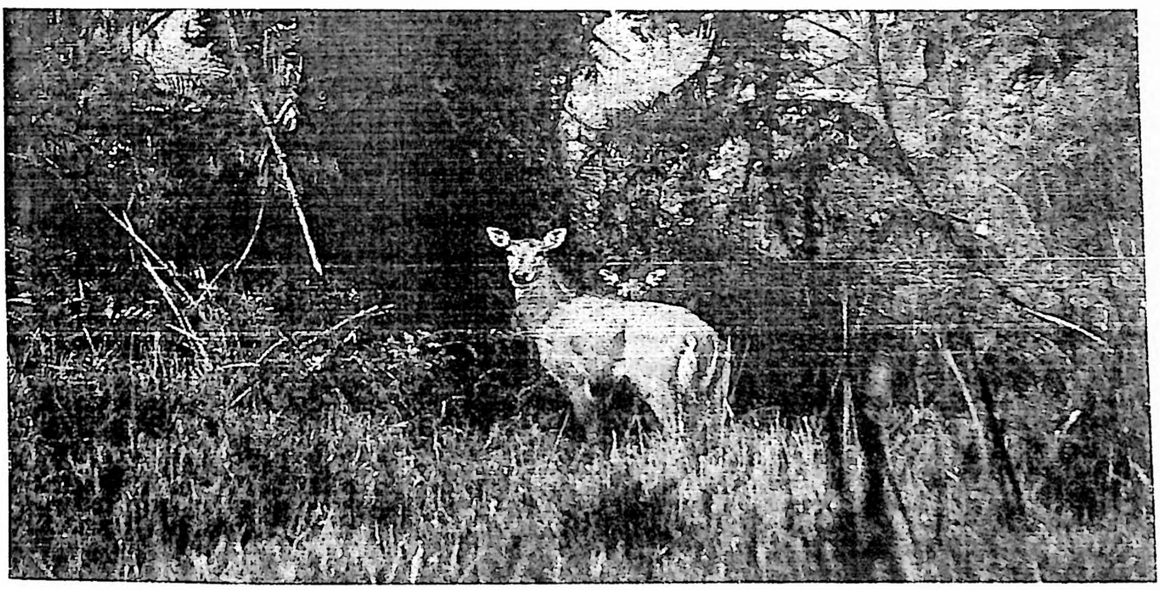


**Plate:** Nilgai utilizing the ecotone of forest and grassland

### c) Working in Field

**Plate:** Sampling in grassland along with forest staff and assistants

**Plate:** Sampling in swampy Phragmites (Narkat) in M19

### d) Management issues in Park

**Plate:** Bagaha-Chhitauni Railway track and road in Madanpur

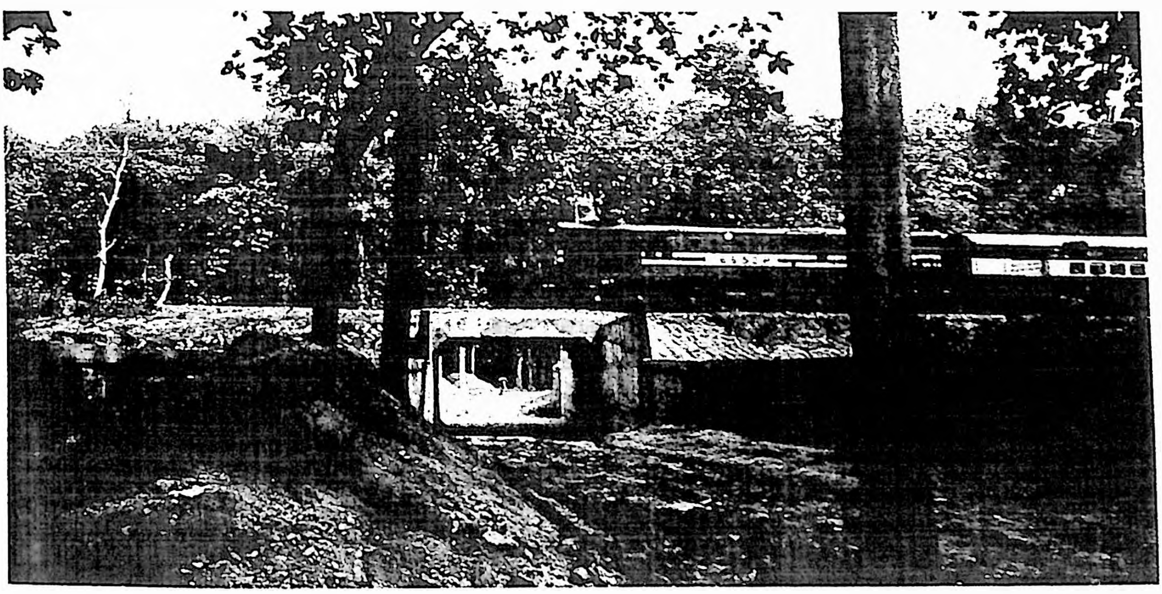


**Plate:** Underpass below raiway track

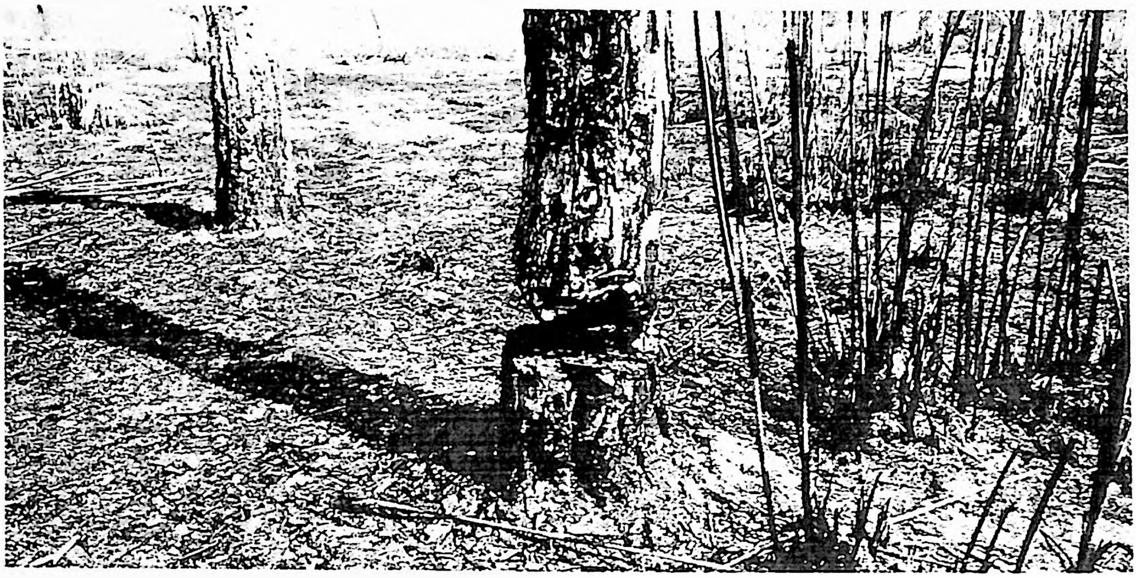


**Plate:** Burning and subsequently facilitation for felling of trees

**Plate:** Human induced fire in grassland

**Plate:** Truck overload with Kharai (thatch grass- *Saccharum spontaneum*)

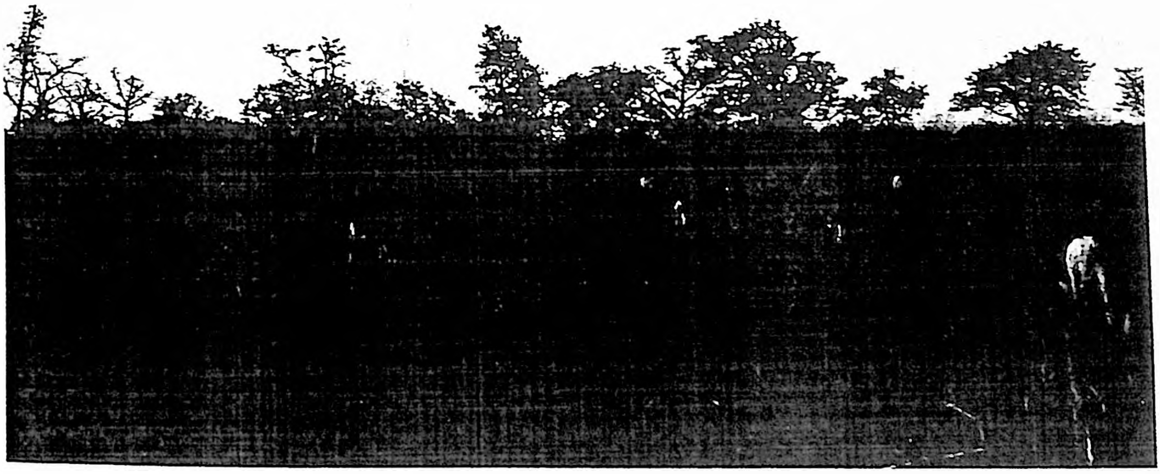


**Plate:** Cattle grazing in grasslands