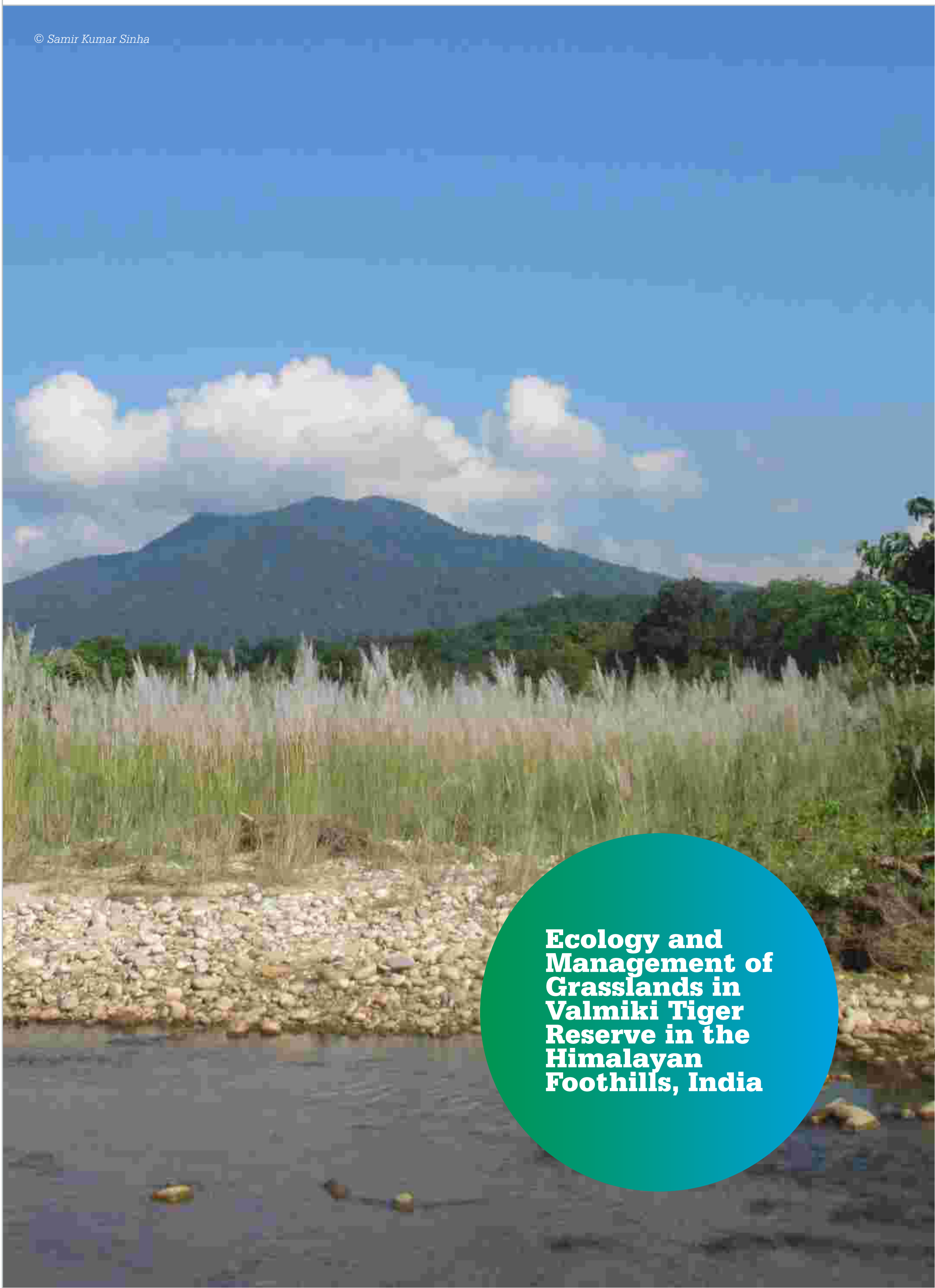

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Ecology and Management of Grasslands in Valmiki Tiger Reserve in the Himalayan Foothills, India

Abstract

Grasslands represent an important habitat in Valmiki Tiger Reserve (VTR) occupying about 5% of its geographical area. Prior to inclusion of this area under Project Tiger, this area was managed largely for commercial forestry leading to degradation and decline of grasslands. Excessive anthropogenic pressures and erosion also affected the extent and quality of grasslands in this reserve in the past. We conducted an ecological study on the grasslands of this reserve during 2011-14 with a view to establish baseline data and to provide insights for better management so as to maintain biodiversity and enhance carrying capacity of wild ungulates. This study found that the grasslands are spread over about 44 km2 in the reserve and can be categorized into three broad categories based on the habitat features. A total of 114 species of graminoids (grasses and sedges) were recorded from the reserve which is higher than many protected areas in terai-duar landscape in the Himalayan foothills. Average above ground net primary productivity of the grasslands ranged from 0.91 kg m^{-2} yr^{-1} in hilly terrain to 3.56 kg m^{-2} yr^{-1} along the flood banks of streams. In the recent years the management of tiger reserve has brought grassland management in its priority, although the practice is in nascent stage. We encapsulate findings of grassland management practices in similar habitats in India and Nepal, which will help the tiger reserve management in adopting appropriate methods. Use of fire as a tool for management should be used cautiously. Based on experiences elsewhere, we suggest maintaining patchiness and creating mosaic of treated and untreated grassy areas. We suggest streamlining the role of local villagers in management of grasslands with habitat management imperatives of the reserve. Also, adequate funds should be made available on time to the VTR management for treatment, protection and monitoring of grasslands.

Keywords: Biomass; Fire; Grassland; Productivity; Species Richness.

Introduction

Valmiki Tiger Reserve (VTR) in West Champaran district of Bihar is spread across 899 km^2 area, located between 83° 50' and 84° 10' E longitudes and between 27° 10' and 27° 03' N latitudes. The reserve is divisible into two zones, viz., 'bhabar' characterized by a hilly terrain with coarse alluvium and boulders, and 'terai', in the flat, low-lying area with fine alluvium and clay rich swamps. Both the belts represent a rich mixture of tall grasslands and sal (*Shorea robusta*) forests (Johnsingh et al., 2004).The reserve forms the Indian part of Terai-Duar Savanna Eco-region adjacent to Himalayan foot-hills.This area is listed among the 200 globally important eco-regions for its unique large mammal assemblage (Olson and Dinerstein,1998). Also, the terai riverine grasslands in the Himalayan foothills are among the tallest and most productive in the world (Lehmkuhl, 1989; Johnsingh et al., 2004).The eco-region is also most threatened due to rapid changes in the landuse and agricultural expansion (Olson and Dinerstein,1998).

In contiguity with Chitwan National Park and Parsa Wildlife Reserve in Nepal, VTR is also considered a part of the Chitwan Tiger Conservation Landscape (Dinerstein et al., 2006). Success of Chitawan and adjacent areas as tiger landscape can be largely ascribed to well-managed grasslands which ensure abundance of prey-base. Though, several studies have been conducted on the ecology, management and community uses of grasslands in Chitwan National Park (Lehmkuhl, 1989, 1992, 1994; Lehmkuhl, Upreti and Sharma, 1988; Peet et al., 1997, Peet, 2000; Dhungel and O'Gara, 1991; Joshi and Jha, 1995), scientific information on grassland ecosystem in VTR is scanty and limited to a few mentions in the working plans of the area and old shikar literature (Jha, 1971; Verma, 1982). According to Champion and Seth, (1968) the grasslands of VTR fall under the category of Eastern wet alluvial grassland (4D/2S2) which is considered as a seral stage of various forests found in the area, viz., Bhabar-Dun Sal Forest 3C/c2/b(i), Dry Siwalik Sal Forest 5B/c1/a, West Gangetic Moist Mixed Deciduous Forest 3C/c3/a, Khair-Sissoo Forest 1S/2, Cane Brakes 1B/e1, and Barringtonia

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Swamp Forest 4D/SS2. Based on the classification by Whyte (1957), grasslands of VTR may be broadly grouped under the *Phragmites-Saccharum* and *Arundinella* types dominated by *Phragmites karka, Saccharum spontaneum, Imperata cylindrica, Arundinella* spp., and *Chrysopogon* spp. Zoological Survey of India (1998) conducted a detailed faunal survey in the reserve. Based on this survey, fifty three species of mammals and 145 species of birds have been listed from the reserve (Chakraborty, De 1998).Major mammalian fauna from the reserve are tiger (Panthera tigris), common leopard (*Panthera pardus*), dhole or Indian wild dog (*Cuon alpinus*), sambar (*Rusa unicolor*), chital (*Axis axis*), hog deer (*Axis porcinus*), barking deer (*Muntiacus muntjak*), nilgai (*Boselaphus tragocamelus*), and Indian wild pig (*Sus scrofa*). However, abundance of these species and their relative use of grassland habitat have not been assessed.

The Wildlife Trust of India (WTI) conducted detailed studies on the habitat features of the VTR and generated information on density, abundance and diversity of trees, shrubs, and herbs and grasses (Sinha et al., 2004). Further, to understand the ecological status of the grasslands, specific studies emphasizing distribution, species richness and productivity of grasslands was conducted during 2011-14. Major goal of the study was to facilitate scientific management of grassland habitats and to enhance ecological understanding of these grasslands for long term conservation. Specific objectives of the study were: (i) to estimate the spatial extent and recent changes in the grassland habitat, (ii) to study the species richness and composition of grasslands, and (iii) to estimate the productivity of grasslands in VTR. This paper summarizes the broad findings of the study and suggests management recommendations.

Grassland types and survey methods

Stratification of grassland habitats: The grasslands of VTR can be broadly stratified into following categories:

I. Grasslands on dry alluvial banks: These grasslands are found on the dry stream beds with freshly deposited sand, boulders and pebbles. The streams flow mostly in north-south direction, viz., Manor, Bhapsa, Harha, Dhunghi, Ganguli, Dhodram, and Pandai. Sonha and Pachnad streams flow in east to west direction. These grasslands are dominated by *Saccharum spontaneum, Imperata cylindrica, Cymbopogon* spp., *Arundinella* spp., and *Themeda* spp, reaching a height of up to 3 meters. These grasslands, except in Madanpur block, are primarily surrounded by sal forests and support three major prey species viz., spotted deer, sambar and Indian bison.

II. Riverine grasslands in seasonally inundated banks: These grasslands are restricted to Gandak floodplains in Madanpur forest area. Floodwater reaches up to 2-3 meters in some parts of these grasslands annually and water table is very high throughout the year. These grasslands typically represent the Tall savannah vegetation characterized by scattered silk cotton trees (*Bombax ceiba*).Grasses are very tall and may reachup to 6 meters in height. Common species of grasses include *Saccharum ravennae, S. bengalense, Typha angustifolia, Phragmites karka, Arundo donax* and *Imperata cylindrica. Desmostachya bipinnata* and *Vetiveria zizanioides* are also found in some parts. These grasslands are primarily used by endangered hog deer (*Axis porcinus*). These grasslands also support a small population of greater one-horned rhinoceros (*Rhinoceros unicornis*), which migrate back and forth between Chitawan National Park and Madanpur grasslands along Gandak river (Sinha, 2011).

III. Hill side grasslands: These grasslands are found on open south facing slopes which are largely governed by frequent fires and dry and compact, skeletal soil (Jha, 1971). *Chrysopogon fulvus, Desmostachya bipinnata, Cymbopogan* spp., *Heteropogon contortus* and *Eragrostis bifaria* are common grasses in such areas. One of the characteristic grasses on steeper slopes is the Bhabbar grass (*Eulaliopsis binata*). General height of the grasses here is up 1.5 m. The forests have been divided into 6 forest blocks under administration of 8 forest ranges (Figure 9.1).

Table 9.1. Specific grassland sites for ecological study in VTR

S. No.	Site ID	Place	GPS Location	Grassland type
1	Site 1	Motor Adda	N27025.446' E83057.614'	Grasslands on dry alluvial bank
2	Site 2	Khiribari Hillock	N27025.696' E83057.821'	Hill side grassland
3	Site 3	Hathiyabiyan	N27025.527' E83058.832'	Grasslands on dry alluvial bank
4	Site 4	Naurangia	N27016.415' E83056.384	Riverine grasslands in seasonally inundated banks

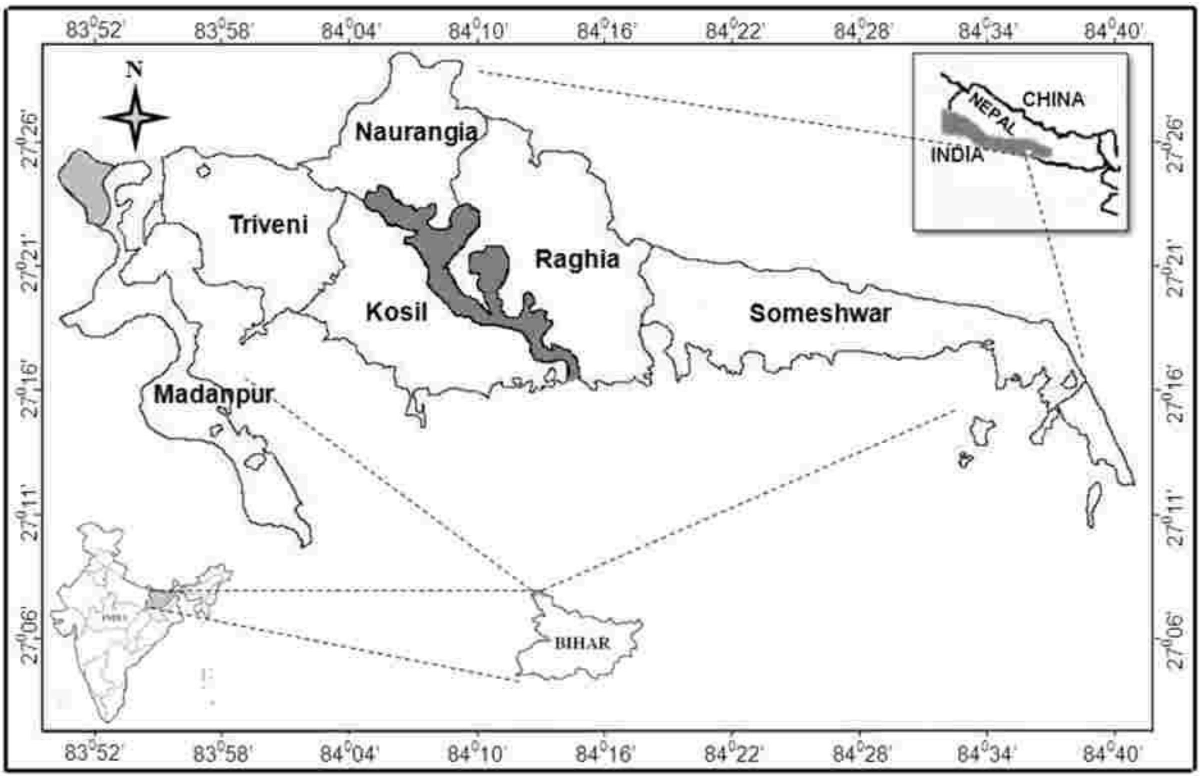

Figure 9.1 Map showing location of Valmiki Tiger Reserve and its Forest Blocks

Geo-spatial analysis of grasslands

Extent of grassland habitat in VTR was estimated using remote sensing and GIS tools. Forest Range was considered as unit for analysis. The analysis has been done for 8 forest ranges (Madanpur, Valmikinagar, Gonauli, Harnatanr, Chiutaha, Raghia, Gobardhana and Manguraha).High resolution LISS IV Satellite images were procured from National Remote Sensing Centre (http://nrsc.gov.in/) and archived Landsat images were downloaded from www.landsat.org for the purpose of geospatial analysis (Table 9.2).

Unsupervised classification of the satellite images was done with Geographic Resources Analysis Support System (GRASS) (http://grass.osgeo.org/) using Isocluster algorithm which determines the characteristics of the natural groupings of cells in multidimensional attribute space and gives the output in raster format. Broad habitats were classified in 8 classes; viz. Dense forest, Open forest, Grassland, Scrub, Water, Agriculture, Swamp and Riverbed (Figure 9.2). The LISS IV classified images were re-sampled to 30m for change detection analysis.Land-use change during 1989 and 2008-09 was assessed using the satellite imageries.

Table 9.2. Details of satellite imageries used for habitat mapping of VTR

Sl. No.	Satellite sensor	Path	Row	Resolution (in meters)	Year
1	IRS P6 - LISS IV	101	19	5.8	2009
2	IRS P6 - LISS IV	102	4	5.8	2009
3	IRS P6 - LISS IV	101	20	5.8	2009
4	IRS P6 - LISS IV	102	25	5.8	2008
5	IRS P6 - LISS IV	102	26	5.8	2008
6	LANDSAT TM	141	41	30	1989
7	LANDSAT TM	142	41	30	1989
8	LANDSAT TM	142	41	30	2009

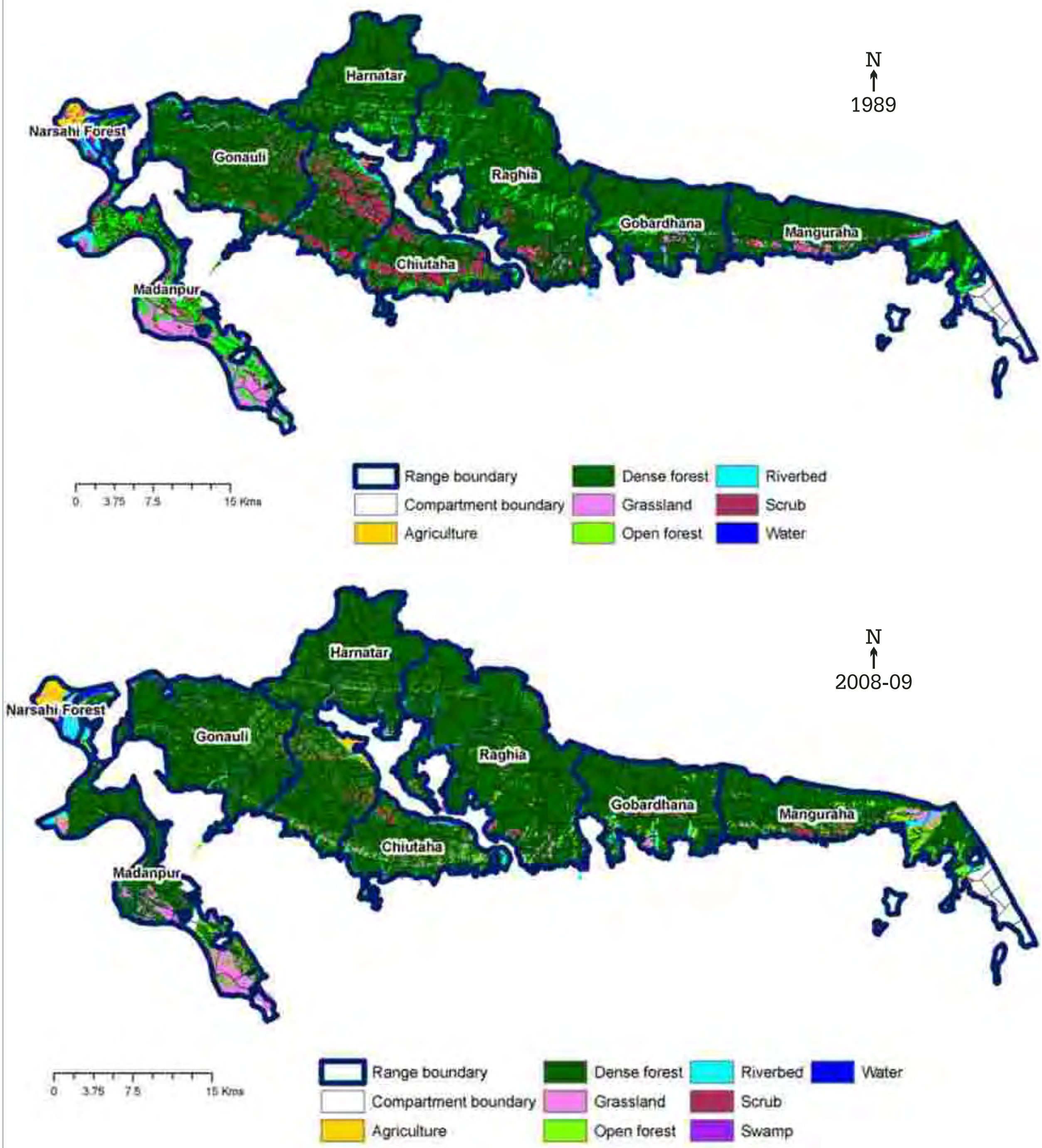

Figure 9.2 Land-use Land-cover of Valmiki Tiger Reserve in 1989 (above) and 2008-09 (below).

Assessment of Species Composition and Richness: Documentation of grass and sedge flora in VTR was done during August 2012 and August 2013. Flowering stage specimens were collected on monthly basis during 17-19th of every month from four sites (Table 9.1) of the three types of grasslands mentioned in earlier section. Herbaria of the grass specimen were prepared for identification. The grass samples were identified at the Wildlife Institute of India (WII), Dehradun. Index of similarity between the sites was calculated using Sorensen Index, a widely used method to measure similarity in species composition for two sites (Magurran 2004). The Index, regarded as one of the most effective presence/absence similarity measures (Southwoodand Henderson, 2000), was calculated comparing pair wise for two sites as per the equation given below. Plates 9.1 - 9.9 gives an overview of different grassland habitat in the study area.

$$Cs = \frac{2c}{a+b}$$

Where,

c= the total number of species present in both the samples (sites)

a= the number of species present in sample 1

b= the number of species present in sample 2.

Biomass productivity

Aboveground (primary) production of grasslands was estimated following the Harvest Method (Milner and Huges 1968). Size of the sample plot was 50 x 50 cm. Minimum number of plots required for sampling was statistically calculated for a minimum precision level of 10% (Milner and Huges 1968). Sampling was done in the three types of grasslands and four study sites mentioned in the previous section (Table 9.1). All grasses within the plot were clipped closed to the base using sharp steel sickle (five plots at each site) on monthly basis, at an interval of 4 weeks during March 2011-January 2012.

Cut samples were transported to field camp for weighing. Harvested biomass was weighed immediately after arrival at camp. The biomass was segregated into standing dead and green parts and weighed separately using a digital scale. The green biomass was air dried until constant weight was obtained.

Calculation of net primary production: If B1 is the aboveground biomass measured at the first sampling period (time t1) and B2 is the biomass at the second sampling period (time t2) and Bn is the biomass at the nth sampling period at the end of the growing season (time tn). Then, total annual net primary aerial production was calculated as follows;

(B2 - B1) + (B3 - B2) + ------------ + (Bn - Bn-1)

viz. Sum of n to 1 (Bn - Bn-1), and the mean daily net primary production: (B2 - B1) / (t2 - t1) or (Bn - Bn-1) / (tn - tn-1).

Following Milner and Hughes (1968), where biomass between successive samples decreased or remained the same, production was assumed as zero.

Results

Spatial extent and recent changes

It was found that grasslands occupy nearly 44.45 km^2 area in VTR. There has been very negligible increase in the extent of grassland in the reserve since1989 when the area of grasslands was 43 sq. km. Although, the extent of grasslands has remained nearly same, there has been conversion of forest into grasslands in some areas, and in other parts grassland also has given way to forests, keeping the total area of grassland almost same, but registering spatial shift in some patches. Table 9.3 shows different habitat categories in VTR in 2009. Highest cover of grassland was observed in Madanpur Range (Table 9.4).

Change detection analysis reflected an increase in riverbed, from 8 km^2 in 1989 to 12 km^2 in 2009, and reduction in grassland from 34 km^2 to 25 km^2 in Madanpur range during the period. The range lies along the left bank of the Gandak River which keeps on eroding the forest areas of Madanpur. In other ranges, there was a gain in extent of grasslands in the newly deposited substrate as a result of bank erosion. In the easternmost part of Someshwar block in Manguraha Range, increase in grassland area has been recorded during 1989 and 2009 due to reclamation of boulder and pebble mined areas in the Pandai River bed. Mining in the river bed was stopped after prohibition of mining activities in Protected Areas by an order passed by Honourable Supreme Court in 2002. This resulted into significant increase in grassland cover along the Pandai River.

Species richness and composition

Altogether, 58 genera comprising of 114 species of graminoids were recorded from all the grasslands. These species are distributed in three families (Cyperaceae-35 species; Poaceae-78 species; and Typhaceae-1 species). Eight specimens were identified up to genus level, while rest of the specimens were identified up to species level. Highest number of species belong to genus *Cyperus* (11 species), followed by *Fimbristylis* (10), *Panicum* (8), *Eragrostis* (6), *Digitaria* (6) and *Scleria* (4).Thirty eight genera were represented by one species, eight were represented by 2 species, and 5 were represented by three species each (Table 9.5). Species richness was highest at Site 4 (53 species), followed by Site 3 (48 species), Site 1 (43 species) and Site 2 (28 species). Grass species recorded in the present study in VTR is considerably higher as compared to available information on grass flora in other protected areas in the Terai-Duar landscape (Table 9.6). Similarity in species composition was highest between Site 3 and Site 4, while Site 2 is least similar to other sites,

thus dissimilarity in the grass species composition between plain and hilly areas is evident (Table 9.7).

Biomass production

Biomass production was high in the grasslands on dry alluvial banks i.e. Site 1(2.49 ± 0.59 kg m^{-2}) and Site 3 (2.87 ± 0.86 kg m^{-2}), while lowest biomass production was on the hill side grassland (Table 9.8). Peak biomass production in all types of grasslands in VTR is during rainy months - July and September. Biomass production gradually reduces after September and gets lowest during May-June. Proportion of dry grasses was high during March to May; however during these months green biomass availability was higher in the grasslands on dry alluvial banks of streams compared to other two types of grasslands (Figure 9.3). Inhill side grasslands, proportion of dry biomass was highest among all grassland types. Since Site 4 was under influence of domestic cattle grazing, biomass was found lower than other sites. Proportion of green grasses was consistently high throughout the year in this grassland. This may be the possible reason why domestic livestock (cattle) preferred this area.

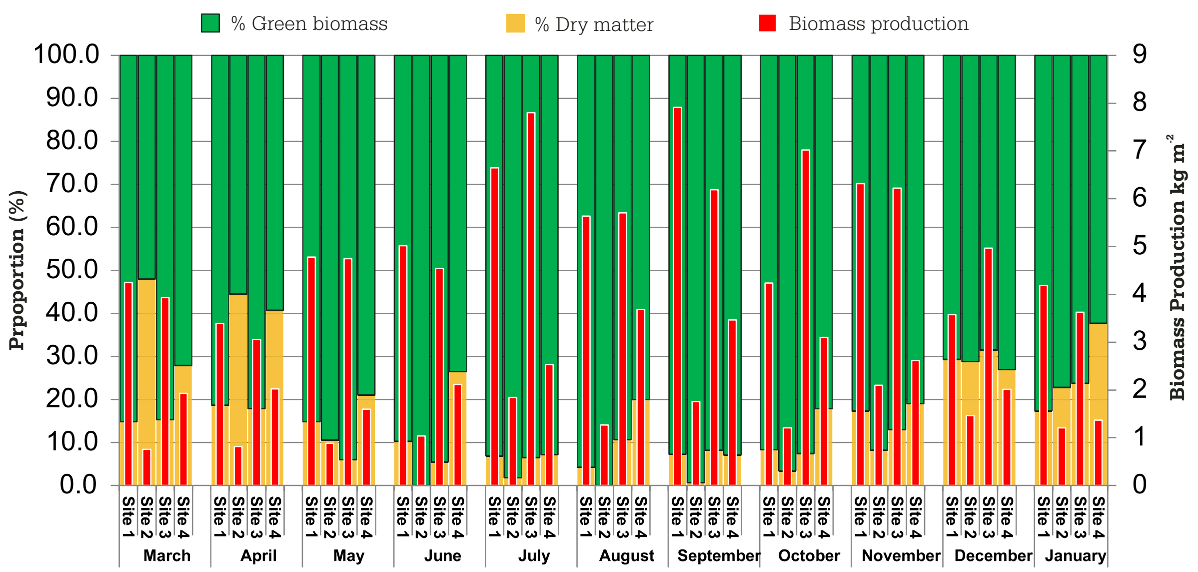

Figure 9.3 Monthly variation in proportion of green and dry biomass in different grassland types.

Plate 9.1: Grassland after treatment

Analysis of variance results show that the studied variables significantly differed across the sampling sites (biomass: F= 35.817, p<0.001; moisture content: F=28.584, p<0.001, and moisture percent: F=2.670, p= 0.048).

The estimated above-ground NPP in the grassland along stream beds i.e. Site 1 and Site 3 was 3.56 kg m^{-2} yr^{-1} and 3.39 kg m^{-2} yr^{-1}(Average: 3.48 kg $m^{-2}yr^{-1}$~ 34.78 tons ha^{-1} yr^{-1}). Among the four sites, lowest NPP (0.91 kg m^{-2} yr^{-}1 ~9.13 tons ha^{-1} yr^{-1}) was estimated at Site 2.The NPP in grazed grassland in alluvial plain (Site 4) was estimated to be 1.88 kg m^{-2} yr^{-1} (18.84 tons ha^{-1} yr^{-1}). It is expected that grazing by domestic and wild ungulates would reduce standing biomass and annual productivity (e.g., Younger, 1972; Heady, 1975; Crawley, 1983); however, in such highly productive grasslands it may also increase species diversity (Rusch and Oesterheld, 1997). It was observed that at Site 4 species richness was highest among all the sites, but productivity was lower than Sites 1 and 3. High productivity in Sites 1 and 3 can be attributed to high year round soil-moisture availability due to location along streams.

Table 9.3. Area under different land use land cover (LULC) category in VTR

LULC category	Area (sq. km.)%
Dense forest	711.1 (81.0)
Open forest	56.64 (6.4)
Scrub	17.6 (2.0)
Agriculture	12.84 (1.5)
Riverbed	25.81 (2.9)
Water	9.74 (1.1)
Grassland	44.45 (5.1)
Swamp	0.96 (0.1)

Table 9.4. . Forest Range wise area of grasslands in VTR (2008-09)

Forest Range	Area (sq. km.)%
Madanpur	25.00
Gonauli	2.00
Gobardhana	2.00
Manguraha	5.00
Raghia	5.00
Chiutaha	3.00
Harnatanr	2.00

Plate 9.2: Colonization of *Phoenix* in open forests

Table 9.5. Checklist and distribution [Presence (+), Absence (-)] of grass species in different grasslands in Valmiki Tiger Reserve, Bihar

S. No.	Species Name	Family	Site 1	Site 2	Site 3	Site 4
1	*Alloteropsis cimicina*	Poaceae	+	-	-	-
2	*Alopecurus nepalensis*	Poaceae	-	-	-	+
3	*Apluda mutica*	Poaceae	+	+	+	+
4	*Arthraxon* sp.	Poaceae	-	-	-	+
5	*Arundinella bengalensis*	Poaceae	+	-	+	-
6	*Arundinella nepalensis*	Poaceae	-	-	+	-
7	*Arundinella setosa*	Poaceae	-	+	+	-
8	*Arundo donax*	Poaceae	-	-	+	+
9	*Bothriochloa pertusa*	Poaceae	-	-	-	+
10	*Brachiaria ramosa*	Poaceae	+	-	+	+
11	*Brachiaria* sp.	Poaceae	+	-	+	-
12	*Brachiaria villosa*	Poaceae	+	-	-	-
13	*Bulbostylis barbata*	Cyperaceae	-	-	+	-
14	*Bulbostylis densa*	Cyperaceae	-	+	-	-
15	*Capillipedium assimile*	Poaceae	+	-	-	-
16	*Carex cruciata*	Cyperaceae	-	+	-	-
17	*Carex vesicaria*	Cyperaceae	+	-	-	+
18	*Chloris dolichostachya*	Poaceae	-	+	+	-
19	*Chrysopogon fulvus*	Poaceae	-	+	-	+
20	*Chrysopogon serrulatus*	Poaceae	+	-	-	-
21	*Cymbopogon martinii*	Poaceae	+	-	-	-
22	*Cymbopogon nardus*	Poaceae	-	-	+	+
23	*Cymbopogon distans*	Poaceae	+	+	-	-
24	*Cynodon arcuatus*	Poaceae	+	-	-	+
25	*Cynodon dactylon*	Poaceae	-	-	-	+
26	*Cyperus alulatus*	Cyperaceae	-	-	-	+
27	*Cyperus brevifolius*	Cyperaceae	-	-	-	+
28	*Cyperus cyperoides*	Cyperaceae	-	-	+	-
29	*Cyperus laxus*	Cyperaceae	-	+	-	-
30	*Cyperus niveus*	Cyperaceae	+	-	+	-
31	*Cyperus nutans*	Cyperaceae	-	-	+	-
32	*Cyperus pangorei*	Cyperaceae	+	+	-	-
33	*Cyperus paniceus*	Cyperaceae	+	-	+	-
34	*Cyperus pumilus*	Cyperaceae	-	-	+	+
35	*Cyperus rotundus*	Cyperaceae	-	-	+	-
36	*Cyperus* sp.	Cyperaceae	+	-	+	+
37	*Cyrtococcum accrescens*	Poaceae	+	-	-	-
38	*Dactyloctenium aegyptium*	Poaceae	+	-	-	-
39	*Desmostachya bipinnata*	Poaceae	-	+	-	+
40	*Dichanthelium oligosanthes*	Poaceae	-	-	-	+
41	*Dichanthium annulatum*	Poaceae	-	+	-	+
42	*Digitaria abludens*	Poaceae	-	-	+	+
43	*Digitaria ciliaris*	Poaceae	+	-	+	-
44	*Digitaria setigera*	Poaceae	+	-	-	-

S. No.	Species Name	Family	Site 1	Site 2	Site 3	Site 4
45	*Digitaria* sp.	Poaceae	+	-	-	-
46	*Digitaria stricta*	Poaceae	-	+	+	-
47	*Digitaria timorensis*	Poaceae	-	-	+	-
48	*Echinochloacolona*	Poaceae	+	-	-	+
49	*Echinochloa crus-galli*	Poaceae	-	-	-	+
50	*Eleusine indica*	Poaceae	+	-	-	-
51	*Eragrostis bifaria*	Poaceae	-	+	-	-
52	*Eragrostis cilianensis*	Poaceae	-	-	+	+
53	*Eragrostis gangetica*	Poaceae	-	-	+	+
54	*Eragrostis* sp.	Poaceae	-	-	-	+
55	*Eragrostis stenophylla*	Poaceae	-	-	-	+
56	*Eragrostis tenella*	Poaceae	+	-	-	-
57	*Erianthus rufipilus*	Poaceae	-	-	+	-
58	*Eriophorum comosum*	Cyperaceae	-	+	-	-
59	*Eulalia leschenaultiana*	Poaceae	-	-	-	+
60	*Eulaliopsis binata*	Poaceae	-	+	-	-
61	*Fimbristylis acicularis*	Cyperaceae	+	-	-	-
62	*Fimbristylis complanata*	Cyperaceae	-	-	-	+
63	*Fimbristylis corynocarya*	Cyperaceae	-	-	-	+
64	*Fimbristylis dichotoma*	Cyperaceae	+	+	+	+
65	*Fimbristylis ferruginea*	Cyperaceae	+	-	-	-
66	*Fimbristylis littoralis*	Cyperaceae	+	-	-	-
67	*Fimbristylis miliacea*	Cyperaceae	+	-	-	+
68	*Fimbristylis ovata*	Cyperaceae	-	+	-	-
69	*Fimbristylis schoenoides*	Cyperaceae	+	-	-	-
70	*Fimbristylis* sp.	Cyperaceae	-	+	-	-
71	*Fuirena pumila*	Cyperaceae	-	-	+	-
72	*Fuirena umbellata*	Cyperaceae	+	-	-	-
73	*Hemarthria compressa*	Poaceae	+	+	+	+
74	*Heteropogon contortus*	Poaceae	+	+	-	-
75	*Imperata cylindrica*	Poaceae	-	-	+	+
76	*Ischaemum indicum*	Poaceae	-	-	+	+
77	*Kyllinga brevifolia*	Cyperaceae	+	-	-	+
78	*Leersia hexandra*	Poaceae	-	-	+	+
79	*Lipocarpha chinensis*	Cyperaceae	-	-	+	-
80	*Microstegium ciliatum*	Poaceae	-	-	-	+
81	*Neyraudia arundinacea*	Poaceae	-	+	-	-
82	*Oplismenus compositus*	Poaceae	-	-	+	-
83	*Panicum antidotale*	Poaceae	-	-	+	-
84	*Panicum capillare*	Poaceae	-	+	-	-
85	*Panicum dichotomiflorum*	Poaceae	-	-	-	+
86	*Panicum miliare*	Poaceae	+	-	+	+
87	*Panicum paludosum*	Poaceae	-	-	-	+
88	*Panicumrepens*	Poaceae	-	-	-	+
89	*Panicum* sp.	Poaceae	-	-	+	+
90	*Panicum virgatum*	Poaceae	-	+	-	-
91	*Paspalidium flavidum*	Poaceae	+	-	-	+

S. No.	Species Name	Family	Site 1	Site 2	Site 3	Site 4
92	*Paspalumdistichum*	Poaceae	-	-	+	+
93	*Paspalum scrobiculatum*	Poaceae	-	-	+	+
94	*Perotis indica*	Poaceae	+	-	+	-
95	*Phragmites karka*	Poaceae	-	-	+	-
96	*Pogonatherum crinitum*	Poaceae	-	+	-	-
97	*Pseudosorghum fasciculare*	Poaceae	+	-	+	-
98	*Rottboellia exaltata*	Poaceae	+	-	+	+
99	*Saccharum arundinaceum*	Poaceae	-	-	-	+
100	*Saccharum ravennae*	Poaceae	-	-	-	+
101	*Saccharum spontaneum*	Poaceae	+	-	+	+
102	*Schoenoplectus mucronatus*	Cyperaceae	-	-	+	-
103	*Scleria lacustris*	Cyperaceae	-	+	-	-
104	*Scleria levis*	Cyperaceae	-	+	-	-
105	*Scleria lithosperma*	Cyperaceae	-	+	-	-
106	*Scleria sumatrensis*	Cyperaceae	-	+	-	-
107	*Setaria glauca*	Poaceae	-	-	+	+
108	*Setaria* sp.	Poaceae	+	-	+	-
109	*Setaria verticillata*	Poaceae	+	-	+	+
110	*Sporobolus diander*	Poaceae	-	-	-	+
111	*Sporobolus piliferus*	Poaceae	+	-	+	-
112	*Themeda arundinacea*	Poaceae	-	-	+	-
113	*Typha angustifolia*	Typhaceae	-	-	-	+
114	*Vetiveria zizanioides*	Poaceae	-	-	-	+
	Total species	**20**	**16**	**27**	**32**	

Plate 9.3: Grassland along a stream in Bhabar tract

Table 9.6. Grass species richness in some protected areas in Terai-Duar landscape

Location	No. of grass species	Reference	Remarks
Corbett Tiger Reserve, Uttarakhand	84	Datt et al., 2004	Study includes only Poaceae family.
Rajaji National Park, Uttarakhand	43	Kumar and Subudhi 2013	Study includes grasses in Gujjar rehabilitation site.
Chitwan National Park, Nepal	46	CNP 2015	
Dudhwa National Park, Uttar Pradesh	25	Kumar et al., 2002	
Kishanpur Wildlife Sanctuary, Uttar Pradesh	21	Kumar et al., 2002	
Katerniaghat Wildlife Sanctuary, Uttar Pradesh	101	Kumar et al., 2015	Study includes Poaceae, Cyperaceae and Typhaceae families
Gorumara NP, West Bengal	43	Ghosh, 2012	Study includes fodder species of Poaceae family.
Valmiki Tiger Reserve, Bihar	114	Present Study	

Table 9.7. Similarity matrix for the sampling sites

	Site 1	Site 2	Site 3	Site 4
Site 1	1.00	0.14	0.28	0.24
Site 2	0.14	1.00	0.14	0.13
Site 3	0.28	0.14	1.00	0.30
Site 4	0.24	0.13	0.30	1.00

Plate 9.4: Grassland in a valley

Table 9.8. Biomass production and NPP at different sites

Sites	Biomass (Mean ± SD)(kg m^{-2})	NPP(kg m^{-2} Yr^{-1})
Site 1	2.49±0.59	3.57
Site 2	0.65 ±0.22	0.91
Site 3	2.87 ± 0.86	3.39
Site 4	1.26 ± 0.33	1.88

Management practices and issues

Past Management in VTR

Valmiki Tiger Reserve was declared in 1994. During 1974 to 1994 this area was managed by the Bihar State Forest Development Corporation. Mandate during this period was plantation and exploitation of economically important trees and forests were worked as per different Working Plans, primarily emphasizing protection; improvement and maintenance of forest cover; conservation of soil and moisture and prevention of soil erosion; and sustained supply of good quality timber.

During 1971-82 emphasis was given on plantations of economically viable species on blanks, grasslands and areas covered with inferior miscellaneous forests to increase the productivity of the forests (Jha, 1971). The eastern wet alluvial grassland (4D/ 2S2) in almost all compartments of Madanpur block as extensive savanna grasslands, the grassy blanks along valley beds of Someshwar block and a few compartments of Triveni block were converted into monoculture of timber plantations leading to reduction in grasslands and meadows, which are crucial for herbivores. Conversion of grasslands into woodlands led to local extirpation of blackbuck (*Antelope cervicapra*) which was seen in Madanpur block till mid-1960s (Late R.B. Singh Per. comm.). Though present in adjoining Chitwan National Park, Bengal florican (*Houbaropsis bengalensis*) has become locally extinct from VTR (Islam and Rahmani 2000). The species was last reported from the area in 1980 (Mukherjee, 1986). Abundance of hog deer is also very low, though it is better in the grasslands along the Gandak River outside the protected area. Changing the suitable grasslands into woodlands could be the main reason of local extirpation of this species. After 1994, conversion of grasslands into woodlands came to a halt, but it remained neglected without any management interventions till recent past.

During different management regimes, the grasslands in VTR were primarily maintained by periodic inundation during the monsoon, and by fire and grazing besides collection of thatch by villagers, as in case of other terai areas (Dinerstein 1979 a). Not all the grasslands get inundated during the monsoon, and the grasslands on the stabilized soil are subjected to natural succession leading to gradual development of Khair (*Acacia catechu*), Sissoo (*Dalbergia sissoo*), and Semal (*Bombax ceiba*) in Madanpur block and forest in poorly drained soil and Sal (*Shorea robusta*) in well-drained soil.

The anthropogenic and natural influences operation in VTR grasslands can be summarized below:

i. Natural succession leading to conversion into woodland

ii. Recurrence of uncontrolled anthropogenic fire leading to change in species composition

iii. Cattle grazing and collection of thatch by locals

iv. Plantation of trees in grasslands

v. Colonization of invasive, exotic, unpalatable and fire resistant floral species such as *Mikania micrantha* in open moist grasslands along streams, *Phoenix humilis* in openings in hilly areas, *Eupatorium, Chromolaena* spp. in the blanks along roads.

In the open hill forests colonization of dwarf palm (*Phoenix humilis*) reflects recurrence of fire and resultant decline in soil moisture. Highest density of *P. humilis* was recorded in Manguraha Range, while in Madanpur the density was lowest (Sinha et al., 2004). Frequency of occurrence of *P. humilis* was highest in Raghia, where the species was present in 89% of the area (Table 9.9).

Current management practices: Grassland management interventions in VTR effectively started from 2011-12 onwards. Grasslands in the alluvial plains of Gandak River and along the streams in Bhabar areas in VTR are being managed primarily by manual cutting followed by burning before the onset of summer. Harrowing is also done in Madanpur's *Saccharum ravennae* dominated tall grasslands. To facilitate growth of grasses in open hilly areas colonized by dwarf palm, manual removal of the species is done in strategic areas. The current Tiger Conservation Plan (TCP, 2014) of the reserve prescribes use of fire as a tool for grassland management; identification of assemblages of grass species and their associates; management of grassland according to faunal diversity present therein; eradication of alien invasive plants;

no plantation in the grasslands; and protection of grasslands against uncontrolled fire.

We monitored habitat use by wild ungulates in a 'Cut and Burned' grasslands along a stream bed (Sonha River) for one year. The grassland (area: 20 ha) was treated in March 2013 by the VTR management. A strip transect of 100 x 4 m was marked in the treated plot and ungulate pellet groups/dung were counted on monthly basis. After counting, the pellets/dung was removed from the plot. Pellets of sambar and barking deer and dung of Indian bison were recorded in the sampled area. Use of the treated grassland by herbivores was highest after emergence of tender shoots immediately after the treatment (Figure 9.4). It is noteworthy that after grassland management intervention, population of Indian bison remained within VTR, while in earlier years they used to migrate towards suitable habitats in the adjoining Chitwan National Park (Sinha, 2012).

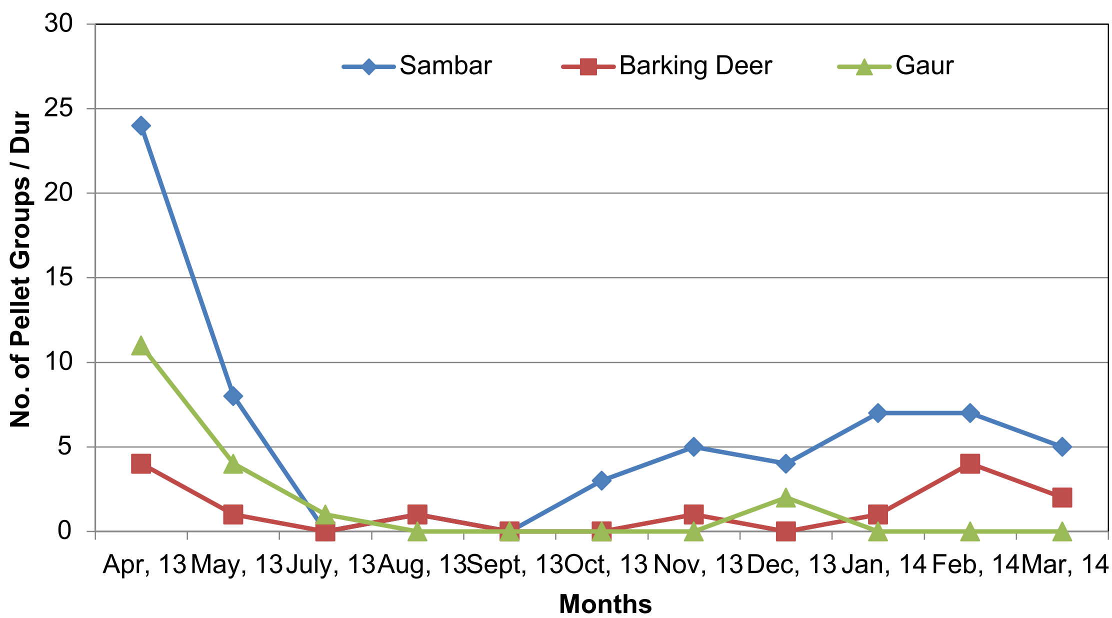

Figure 9.4 Habitat use by ungulates in treated grassland (cut and burned)

Table 9.9. Density and frequency of occurrence of *Phoenix humilis* in the Forest Ranges* of VTR

Forest Range	Density / ha	Frequency of Occurrence (%)
Gonauli	2928	26.3
Harnatanr	4264	79.9
Madanpur	400	1.3
Chiutaha	4748	80.7
Raghia	9256	88.5
Gobardhana	4764	61.8
Manguraha	9952	78.8

* A new forest range Valmikinagar has been carved out from Gonauli and Madanpur Ranges.

Source: *Sinha et al., , 2004*

Conservation implications

Grasslands form important habitats in all the protected areas along Bhabar-Terai and Duar areas. These grasslands, maintained by complex ecological processes, are rich in biodiversity and support high ungulates biomass which in turn supports high density of tiger (Lehmkuhl, 1989; Basnet, 1996; Smith et al., 1999; Shrestha, 2004). Many of the terai-duar grasslands and flood plain also harbour many threatened fauna such as critically endangered pygmy hog (*Porcula*

salvania, 1847), Bengal florican (*Houbaropsis bengalensis*), swamp deer (*Rucervus duvaucelii*), hog deer (*Axis porcinus*), hispid hare (*Caprolagus hispidus*) and lesser florican (*Sypheotides indicus*). Some of them are endemic to the Terai-Duar eco-region (Olson and Dinerstein, 1998;Rahmani et al., 1991; Dinerstein, 2003).

Management of these grasslands requires approaches which, on one hand maintain the key habitats of obligate species of the grasslands, and at the same time improve prey biomass to maintain tiger population. Poor management of grasslands in VTR in the past clearly reflects its impact on grassland dependent species. Prey biomass is also low, leading to low tiger density (Johnsingh et al., 2004; WTI, 2010). However, prey improvement has been recorded during 2003 and 2011, primarily due to improved protection measures and reduced anthropogenic disturbances (WTI, 2012). This has led to a significant increase in tiger population (Jhala et al., 2015). However, prey and tiger density in VTRis still much lower than other tiger reserves in the landscape.

The study conducted in VTR in the last 3-4 years has developed understandings on key aspects of grasslands for informed management decisions. Insights from the productivity estimation and understanding of extent of grasslands would be helpful in working out carrying capacity and undertake management interventions to improve herbivore biomass which is closely related to net above-ground primary production besides using standing crop biomass as an index of carrying capacity of animals (Coe et al., 1976; East, 1984; McNaughton et al., 1991). Higher grass species richness has been recorded in VTR than other Protected Areas in the Terai-Duar region. A thorough study on grassland composition in VTR has resulted into such a large number of species records. Species richness of grasses has slight effect on large ungulate carrying capacity of natural savanna ecosystems, since it allows complementary use of various vegetation components viz. grazing and browsing (Fritz and Duncan, 1994).

The results reflect that biomass production is high in dry stream beds and floodplains grasslands in VTR. In grasslands communities the constituent species attain their maximum biomass in different months (Ovington et al., 1963; Wiegert and Evans 1964; Malone 1968). Facilitative effect of legumes also contributes to a positive diversity-productivity relationship in grasslands (Lambers et al., 2004).Experiment by Kirilov (2006) inferred that herbivores spent longest time grazing in grass-legume mixed sward than the pure grass or legume sward, thus VTR requires attention on legume flora associated with the grasslands. Net primary productivity and its trend over time, can be used as a measure of grassland condition.

The extensive tall and mature grasses are not used for foraging by small and medium sized herbivore, but they are good for cover; and in contrary small grasslands provide good forage but a poor cover. Thus, management intervention is imperative to maintain the palatability as well as cover in the grasslands in VTR. To reduce the biomass of dry grasses in early summer months, early burning of grasslands in January-February in patches will create grazing lawns of small grassland communities in tall grasslands. Species diversity and richness of grasses is also higher in such grazing lawns as compared to tall grasslands (Karki et al., 2000).

Grassland management in Valmiki TR needs to be focused on; i) maintaining and recovering the existing grasslands for faunal biodiversity, ii) ensuring availability of palatable grasses to herbivores in pinch periods, and iii)to manage them to sustain a healthy prey base for tiger and other predators. Keeping in view the grassland types in Valmiki, different strategies for management are required for flat riverine areas and open hilly areas.

The grasslands / openings in hilly areas colonized by *Phoenix humilis* is suitable for large sized prey sepcies like sambar. Clearing *P. humilis* in small patches in openings in such habitats would faciliate its use by herbivores (WTI 2011).Patches of *Phoenix* are being removed by VTR management in suitable areas. The effort needs to be continued in a cyclic manner and a monitoring protocol be put in place to assess its effectiveness.

Management of grasslands in plain area is done by cutting and burning, and harrowing operations. Keeping in view the similarity in habitat features and grassland types, the VTR management can adopt other suitable treatments applied in other terai grasslands as in case of Chitwan National Park and other protected areas in Nepal (Peet et al., 2000; Lehmkuhl 2000) with appropriate changes to suit local conditions. Following sections summarizes the management practices experimented / implemented in terai grasslands, which can be helpful in managing grasslands in VTR

a. Cutting, burning and harrowing: Experiments in grasslands in Dudhwa Tiger Reserve (Kumar, 2000), have shown that harrowing and burning treatment promotes heavy grazing by hog deer and swamp deer in small and tall grassland communities, respectively. There was no difference in above ground biomass in tall as well as short grassland communities at the onset of the study. In harrowed and burned treatment, above ground biomass was low for initial few months as compared to other treatments (grass cut and burned; grass cut, removed and burned; and standing grass burned). But, in tall grassland the above ground biomass in directly burned area was higher as compared to other treatment.

In Bardia National Park, Karki (2000) recorded highest biomass in grasslands with 'cut' treatment, followed by 'cut and burned' and 'burned' plots after one month of treatment, and found highest ungulate use in 'cut' plots. However, it is

observed that cutting and burning of grasslands leads to temporary increase in the numbers of chital and swamp deer in *Imperata* grasslands as a result of high quality forage availability after the treatment (Dinerstein, 1979 b; Mishra, 1982; Moe and Wegge, 1997; Peet, 1997). However, it is not clear whether this ephemeral forage resource affects ungulate populations in the protected areas. Importantly, these practices deleteriously affect smaller cover dependent species like hispid hare and pygmy hog, and they are confined to uncut and unburned grassland patches (Bell 1986; Bell, Oliver and Ghose, 1990; Oliver and Deb Roy, 1993).

b. Rotational treatment and maintaining mosaic: For lowlands in Nepal, Wegge et al., (2000) emphasized different treatments for tall floodplains grasslands and shorter grasslands communities. For short grassland, rotational cutting and burning, with patch burning spread over a longer time during dry season has been suggested by Moe (1994); Peet et al., (1997), Karki (2000) and Peet et al., (2000). Emphasis has been laid on leaving some part of the grasslands uncut or unburned on rotational basis to create patches to maintain biodivesrity and provide cover to ungulates. This is important for grasslands not under influence of flooding. Patches of *Imperata cylindrica* can be left unmanaged for two to three years without a major turnover in species composition, or succession to tall grassland or forest, occurring more rapidly than in cut and burned grassland (Peet et al., 1999).

c. Fire as a grassland management tool: In dry months grasslands of VTR are under fireput on by graziers. Such fires are damaging to the grasslands and other vegetation and associated fauna. However, fire is extensively used for management of savanna grasslands to remove inedible plant material and eradicate / or prevent the encroachment of undesirable plant species besides influencing plant productivity and reducing the abundance of unpalatable species (Tainton and Mentis, 1984; Sweet, 1982; Trollope 1999). Absence or suppression of fire allows a rapid increase in woody plants in areas where there is an adequate seed source (Bragg and Hulbert, 1976).Since past few years, controlled fire is being used for grassland management in VTR. It is an economical and ecologically sound method of grassland management options (Munthali and Banda, 1992). However, long term effect of fire, if used untimely can be harmful. Timing of fire has pronounced effect on the ecology of grasslands. Summer and late autumn fire leads to grasslands deterioration (Pandey, 1988). Summer fire may retard the growth of the large, late flowering C4 grasses and allow a guild of early-flowering species to grow (Howe, 1995).

Experiments in similar grasslands in Chitwan National Park provides useful insights for VTR, as far as timing of use of fire is concerned. Lehmkuhl (1989) provides a fair picture of impact of timing of fire on production of different grasslands communities. Early (January) burning of *Imperata* grassland produced 20% more biomass than late (April) burning, and biomass production in burned area was more than double the production in unburned areas. Late burned areas were more grazed by wild ungulates and grazing lasted longer. In tall grasslands communities, production of *Narenga*

Plate 9.5: Grassland management by VTR management

porphorycoma was highest on the early-burn plot, intermediate on unburned plots and lowest on late-burn plots. Very little grazing was observed in this grassland type regardless of burning regime. In *Saccharum spontaneum* dominated grasslands-which is important for grazers, early-burn and unburned areas did not show any difference in production, while in late-burn plots production was one-fifth of the unburned plot. Thus, in all types of grasslands production was low in late burning.

Fire has bad impacts on grasslands if not used appropriately. It accelerates erosion and causes loss of soil nutrients and forage, and adverse changes in species composition, increased weeds and undesirable herbs and consequently decreased animal performance (Trollope, 1999). Summer fire causes depletion in root system of grasses, thus affecting growth in following dry season and causing damage to grasses. Keeping in view the merits and demerits of fire on

Plate 9.6: Grasses in forest opening

Plate 9.7: Hill side grasslands with *Phoenix*

grasslands, it is suggested that VTR management should use fire as a tool cautiously considering the bad effects it poses on the ecosystem in long run. The following measures are suggested for improvement and better management of grasslands in the VTR:

Plate 9.8: Grassland in Pandai River after mining ban

Plate 9.9: Ingression of woodland in grasslands

i. Species composition and assemblage of grasses in different grasslands should be identified and recorded for future monitoring.

ii. A detailed survey needs to be done to know the occurrence and status of grassland obligate species such as bengal florican, hispid hare, and hog deer in VTR. This can be followed by taking appropriate measures for recovery of these species in healthy grasslands.

iii. The grasslands under treatment should be monitored to study the effects of treatment on change in species composition and herbivore use.

iv. The grasslands should be protected against uncontrolled fire and domestic livestock grazing.

v. Leguminous plants and microbes are crucial for healthy grasslands, thus apart from grass species, these floral groups should also be studied, enlisted and monitored.

vi. Local people collect and use tall grasses for thatching purposes. A habitat management plan should be developed and incorporated in the Tiger Conservation Plan to streamline grass collection by villagers with the grassland management objectives of the reserve. It will also help eliciting their support for the VTR on one hand, and it will also reduce the cost of involving labour for the purpose.

vii. To inculcate interest on grassland ecology and management among frontline staffs, they should be involved in preparing herbarium of grasses found in their jurisdiction, and monitoring of grasslands after treatment.

viii. Experiments should be conducted to control *Mikania micrantha* and other invasive species in the grasslands.

ix. Grassland management requires a significant quantum of fund on time for treatment, protection and maintenance. Thus, adequate fund should be made available on time to the VTR management.

x. Plantation should not be done in grasslands and woody invasion should be cleared at regular intervals to maintain it.

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References

Basnet, K. (1996).Biodiversity inventory of Royal Bardia National Park. Report No. 2. Kathmandu: BICP/WWF Nepal Program.

Bell, D.J. (1986). A study of the hispid hare *Caprolagus hispidus* in Royal Sukla Phanta Wildlife Reserve, Western Nepal: A Summary Report.Dodo23: 24-31.

Bell, D.J., Oliver, W.L.R. and Ghose, R.K. (1990).The hispid hare *Caprolagus hispidus*. Rabbits, Hares and Pikas. Status Survey and Conservation Action (eds J.A. Chapman and J.E.C. Flux), pp. 128-136. IUCN, Gland.

Bragg, T.B. and Hulbert, L. C. (1976). Woody plant invasion of unburned Kansas bluestem prairie. Journal of Range Management, 29: 19–24.

Chakraborty, S., Bhattacharyya, T.P. and De, J. K. (1998).Faunal Composition with special reference to Mammals. Fauna of Conservation Areas No.10: Fauna of Valmiki Tiger Reserve (ed Director), pp. 1-41. Zoological Survey of India, Calcutta.

Champion, H.G. and Seth, S.K. (1968).A Revised Survey of the Forest Types of India, Government of India, Manager of Publications, Delhi, India.

CNP. (2015).Chitwan National Park and its Buffer Zone Management Plan, 2013-17. Department of National Parks and Wildlife Conservation, Government of Nepal.

Coe, M.J., Cumming, D. H. M. and Phillipson, J. (1976).Biomass and production of large African herbivores in relation to rainfall and primary production.Oecologia, 22: 341-354.

Crawley, M. J. (1983).Herbivory: The dynamics of animal-plant interactions. University of California Press, California.

Datt, B., Rana, T.S., Hussain T., Pande, H.C. and Rao, R. R. (2004). Floristic diversity of Corbett Tiger Reserve, Uttaranchal: an overview, Phytotaxonomy, 3, 24-31.

Dhungel, S. K. and O'Gara, B. W. (1991). Ecology of the hog deer in RCNP, Nepal. Wildlife monographs, 119: 1-40.

Dinerstein, E. (1979a). An ecological survey of the Royal Karnali-Bardia Wildlife Reserve, Nepal. Part 1: Vegetation, Modifying Factors, and Successional Relationships. Biological Conservation, 15: 127-150.

Dinerstein, E. (1979 b). An ecological survey of the Royal Karnali-Bardia Wildlife Reserve, Nepal Part 2: Habitat / Animal Interactions. Biological Conservation, 16: 265-300.

Dinerstein, E. (2003). The return of the unicorns: the natural history and conservation of the greater one-horned rhinoceros. Columbia University Press, New York.

Dinerstein, E., Loucks, C., Heydlauff, A., Wikramanayake, E., Bryja, G., Forrest, J., Ginsberg, J., Klenzendorf, S., Leimgruber, P., O'Brien, T., Sanderson, E., Seidensticker, J. and Songer M. (2006).Setting Priorities for the Conservation and Recovery of Wild Tigers: 2005–2015. A User's Guide.WWF, WCS, Smithsonian, and NFWF-STF, Washington DC, New York.

East, R. (1984). Rainfall, soil nutrients status and biomass of large African savanna mammals. African Journal of Ecology,22: 245-270.

Fritz, H.and Duncan, P. (1994).On the carrying capacity for large ungulates of African savanna ecosystem. Proceedings of Royal Society of London-Biological Sciences, 256: 77-82.

Ghosh, S. B. (2012). Biodiversity and wild fodder of Gorumara National Park in West Bengal, India. Journal of Environment and Ecology, 3(1): 18-35.

Gibson, D. J. (2009).Grasses and Grassland Ecology, Oxford University Press, New York.

Heady, H. (1975).Rangeland Management. McGraw-Hill Book Company, New York.

Howe, H.F. (1995). Succession and fire season in experimental prairie plantings. Ecology, 76: 1917–1925.

Islam, M. Z. and Rahmani, A. R. (2000). Important Bird areas in India: Priority sites for conservation. Indian Bird Conservation Network: Bombay Natural History Society and BirdLife International (UK).

Jha, Y. P. (1971).Revised working plan for the forests of Champaran forest division, Bihar, 1971-72 to 1980-81. Working Plan and Research Circle, Ranchi, Bihar.

Jhala, Y. V., Qureshi, Q. and Gopal, R. (2015).The status of tigers in India 2014. National Tiger Conservation Authority, New Delhi and the Wildlife Institute of India, Dehradun.

Johnsingh, A.J.T., Ramesh, K., Qureshi, Q., David, A., Goyal, S.P., Rawat, G.S., Rajapandian, K. and Prasad, S. (2004). Conservation status of tiger and associated species in the Terai Arc Landscape, India. RR – 04/001, Wildlife Institute of India, Dehradun.

Joshi S, R. and Jha P. K. (1995).Biomass production in grasslands of RCNP, Nepal. Ecoprint, 2 (1):40-45.

Karki, J. B., Jhala, Y. V., and Khanna, P. P. (2000). Grazing lawns in terai grasslands, Royal Bardia National Park, Nepal. Biotropica ,32(3): 423-429.

Karki, J.B. (2000). Impacts of grassland management practices on grassland communities at Royal Bardia National Park, Nepal. Grassland ecology and management in Protected Areas of Nepal: Proceeding of a workshop (Vol 1), Action summary (eds C. Richard, J.P. Sah, K. Basnet, J. Karki, B. Subba, and Y. Raut), pp. 36-37. International Centre for Integrated Mountain Development, Kathmandu, Nepal.

Kirilov, A., Vasilev, E. and Dimitrova, A. (2006). Assessment of palatability of different grass and legume species, and of their combinations. In: Sustainable grassland productivity: Proceedings of the 21st General Meeting of the European Grassland Federation, Badajoz, Spain, pp. 363-365.

Kumar H., Mathur, P.K., Lehmkuhl, J.F., Khati, D.V.S., De R. and Longwah, W. (2002).Management of Forests in India for Biological Diversity and Forest Productivity, A New Perspective - Volume VI: Terai Conservation Area (TCA). WII-USDA Forest Service Collaborative Project Report, Wildlife Institute of India, Dehradun.

Kumar, A., Bajpai, O., Mishra, A.K., Sahu, N., Behera, S.K., Bargali, S.S. and Chaudhary, L.B. (2015). A checklist of the flowering plants of Katerniaghat Wildlife Santuary, Uttar Pradesh, India. Journal of Threatened Taxa, 7(7): 7309-7408.

Kumar, H. and Subudhi, S.P. (2013). Assessment of grass species diversity and wild animals occurrence in van gujjars relocated site of the Rajaji National Park in Uttarakhand, Northern India. Cibtech Journal of Zoology, 2(1): 30-39.

Kumar, H. (2000). Effects of management practices on the grassland vegetation and the use by ungulates in Dudhwa National Park, Uttar Pradesh, India. Grassland ecology and management in Protected Areas of Nepal: Proceeding of a workshop (Vol 2), Technical and status papers on grasslands of Terai Protected Areas (eds C. Richard, K. Basnet, J.P. Sah and Y. Raut), pp. 74-83. International Centre for Integrated Mountain Development, Kathmandu, Nepal.

Lambers, J.H.R., Harpole, W.S., Tilman, D., Knops, J. and Reich, P. B. (2004). Mechanisms responsible for the positive diversity–productivity relationship in Minnesota grasslands. Ecology Letters,7: 661–668.

Lehmkuhl, J. (1992). Above ground production and response to defoliation on a native pasture in lowland Nepal. Tropical Grasslands,26:82-88.

Lehmkuhl, J. (2000). The organization and human use of terai riverine grasslands in the Royal Chitwan National Park, Nepal. Grassland ecology and management in Protected Areas of Nepal: Proceeding of a workshop (Vol 2), Technical and status papers on grasslands of Terai Protected Areas (eds C. Richard, K. Basnet, J.P. Sahand Y. Raut), pp. 37-49. International Centre for Integrated Mountain Development, Kathmandu, Nepal.

Lehmkuhl, J. F. (1994). A classification of subtropical riverine grassland and forest in Chitwan National Park. Kathmandu, Nepal. Vegetatio, 111: 29-43.

Lehmkuhl, J. F., Upreti R. K. andSharma U. R. (1988). National Parks and Local Development: Grasses and People in Royal Chitwan National Park, Nepal. Environmental Conservation, 15(2):143-148.

Lehmkuhl, J.F. (1989).The Ecology of a South-Asian Tall-grass Community. Ph.D. Thesis, University of Washington.

Magurran, A. (2004). Measuring biological diversity. Blackwell Publishing, Oxford.

Malone, C.R. (1968). Determination of peak standing crop biomass of herbaceous shoots by the harvest method. American Midland Naturalist, 79: 429-435.

Mathur, P.K. and Midha, N. (2008).Mapping of National Parks and Wildlife Sanctuaries, Dudhwa Tiger Reserve, WII-NNRMS-MoEF Project, Final Technical Report, Wildlife Institute of India, Dehradun, India.

McNaughton, S.J., Oesterheld, M., Frank, D. A. and Williams, K. J. (1991). Primary and secondary production of ecosystems. Comparative analysis of ecosystems. patterns, mechanisms and theories (eds J.J. Cole, G. M. Lovett and S. E. G. Lindsay), pp. 120-139. Springer, New York.

Milner, C. and Hughes, R. E. (1968). Methods for the measurement of the primary production of grassland. IBP Handbook No. 6. International Biological Program, Blackwell Scientific Publications, Oxford and Edinburgh.

Mishra, H. R. (1982) The ecology and behaviour of Chital (*Axis axis*) in the Royal Chitwan National Park, Nepal. Ph.D. thesis, University of Edinburgh.

Moe, S. R. (1994). Distribution and Movement Pattern of Deer in Response to Food Quality and Manipulation of Grassy Habitat: A Case Study With Emphasis On Axis Deer (*Axis axis*) in Lowland Nepal. Ph.D. thesis, Agriculture University of Norway.

Moe, S.R. and Wegge, P. (1997). The effects of cutting and burning on grass quality and axis deer (*Axis axis*) use of grassland in lowland Nepal. Journal of Tropical Ecology, 13, 279–292.

Mukherjee, A.K. (1986) The ecology and conservation of Bengal Florican *Eupodotis bengalensis* (Gmelin). Wildlife Wealth of India: Resources and Management (ed. T.C. Majupuria), pp 305-311. Tecpress Service, Thailand.

Munthali, S.M. and Banda, H. M. (1992). Distribution and abundance of the common ungulates of Nyika National Park, Malawi. African Journal of Ecology, 80, 203-212.

Oliver, W.L.R. and Deb Roy, S. (1993). The Pigmy Hog (*Sus salvanius*). Pigs, Peccaries and Hippos Status Survey and Action Plan (ed. W.L.R. Oliver), pp. 121-129. IUCN, Gland.

Olson, D. and Dinerstein, E. (1998). The Global 200: A Representation Approach to Conserving the Earth's Distinctive Ecoregions. Conservation Biology, 12 (3), 502-515.

Ovington, J.D., Heitkamp, D.and Lawrence, D.B. (1963) Plant biomass and productivity of prairie savannah, Oakwood and maize field ecosystems in Central Minnesota. Ecology, 44, 52-63.

Pandey, A.N. (1988) Short-term study of recovery of Tropical Grassland following seasonal burning. Tropical Ecology, 29, 159-170.

Peet, N. B., Bell, D.J. and Watkinson, A.R. (2000). Managing the terai grasslands in Nepal: Recent research and future priorities. Grassland ecology and management in Protected Areas of Nepal: Proceeding of a workshop (Vol 2), Technical and status papers on grasslands of Terai Protected Areas (eds C. Richard, K. Basnet, J.P. Sahand Y. Raut), pp. 30-36. International Centre for Integrated Mountain Development, Kathmandu, Nepal.

Peet, N. B., Watkinson, A. R., Bell, D. J. and Sharma, U. R. (1999). The conservation management of *Imperata cylindrica* grassland in Nepal with fire and cutting: an experimental approach. Journal of Applied Ecology, 36, 374-387.

Peet, N.B. (1997). Biodiversity and management of tall grasslands in Nepal. Ph.D. thesis, University of East Anglia, Norwich.

Peet, N.B., Watkinson, A.R., Bell, D.J. and Brown, K. (1997).The management of Tall Grasslands for the Conservation of Biodiversity and Sustainable Utilization. Research Report. Department of National Parks and Wildlife Conservation, Nepal and East Anglia.

Rahmani, A.R., Narayan, G., Rosalind, L., Sankaran, R. and Ganguli-Lachungpa, U. (1991). Status of Bengal Florican *Houbaropsis bengalensis* in India. Journal of Bombay Natural History Society, 88, 349-375.

Redmann, R.E. (1992). Primary productivity. Ecosystems of the world: natural grasslands: introduction and western hemisphere, Vol. 8A (ed, R.T. Coupland), pp. 75–94. Elsevier, Amsterdam.

Rusch, G. M. and Oesterheld, M. (1997). Relationship between productivity and species and functional group diversity in grazed and non-grazed pampas grassland, Oikos, 78 (3): 519-526.

Shrestha, M.K. (2004).Relative Ungulate Abundance in fragmented landscape: Implications for tiger's conservation. Ph.D. thesis, University of Minnesota.

Sinha, S. K. (2011). Nature assisted re-establishment of Greater one-horned rhinoceros, *Rhinoceros unicornis* in its historical distribution range. Current Science, 100(12): 1765-1766.

Sinha, S.K. (2012). Indian bison *Bos gaurus* in the Shiwalik hills–Gangetic Plains landscape in India. Current Science, 103(5):466-67.

Sinha, S.K., Easa, P.S. and Kumar, A. (2004). Strengthening the protection and management of Valmiki Tiger Reserve, Bihar, India. Report submitted to the US Fish and Wildlife Service. Wildlife Trust of India, Delhi

Smith, J.L.D., McDougal, C., Ahearn, S.C., Joshi, A. and Conforti, K. (1999). Metapopulation structure of tigers in Nepal. Riding the tiger: tiger conservation in human dominated landscapes (eds, J. Seidensticker, S. Christie and P. Jackson), pp. 176-189.Cambridge University Press, Cambridge.

Southwood, R. and Henderson, P.A. (2000). Ecological Methods. Blackwell Science, Oxford.

Sweet, R. J. (1982). Bush control with fire in *Acacia negrescens/ Combretum piculatum* in savanna in Botswana. Proceedings of Grasslands Society of South Africa, 17: 25-28.

Tainton, N.M. and Mentis, M.T. (1984). Fire in grasslands. Ecological effects of fire in South African ecosystems (eds V. Booysenand N. M. Tainton), pp. 115-147. Springer Verlag, Berlin.

TCP (2014). Tiger Conservation Plan of Valmiki Tiger Reserve, West Champaran, Bihar.

Trollope, W.S.W. (1999). Veld burning. Veld and pasture management in South Africa (ed N.M., Tainton), pp. 217-243, Shutter and Shooter, Pieternmaritzburg.

Verma, U.(1982). Shikaraur Sanrakshan, Ashok Press, Patna.

Wegge, P., Janwali, R.S., Storaas, T. and Odden, M. (2000). Grasslands and large mammal conservation in the lowland terai: A preliminary synthesis based on field research conducted in Royal Bardia National Park, Nepal. Grassland ecology and management in Protected Areas of Nepal: Proceeding of a workshop (Vol 2), Technical and status papers on grasslands of Terai Protected Areas (eds C. Richard, K. Basnet, J.P. Sah, and Y. Raut,), pp. 30-36. International Centre for Integrated Mountain Development, Kathmandu, Nepal.

Whyte, R. O. (1957). The grassland and fodder resources of India, Monograph No. 22, Indian Council of Agricultural Research, New Delhi.

Wiegert, R.C. and Evans, F.C. (1964). Primary production and the disappearance of dead vegetation on an old field of South Eastern Michigan.Ecology,45: 49-63.

WTI (2010). Monitoring of tiger and its principal prey in Valmiki Tiger Reserve, Bihar, India. Report submitted to US Fish and Wildlife Services. Wildlife Trust of India, Delhi.

WTI (2011). Conservation action for habitat and prey species recovery in Valmiki Tiger Reserve, Bihar, India. Wildlife Trust of India, New Delhi.

WTI (2012). Facilitating the recovery of tiger populations and their prey base in Valmiki Tiger Reserve through community support. Report submitted to Nature and Biodiversity Conservation Union (NABU). Wildlife Trust of India.

Younger, V.B. (1972). Physiology of defoliation and regrowth. The Biology and Utilization of Grasses (eds V.B Younger and C.M. McKell), pp. 292-303.Academic Press, New York.

ZSI (1998). Fauna of Conservation Areas No. 10: Fauna of Valmiki Tiger Reserve. Zoological Survey of India, Calcutta.