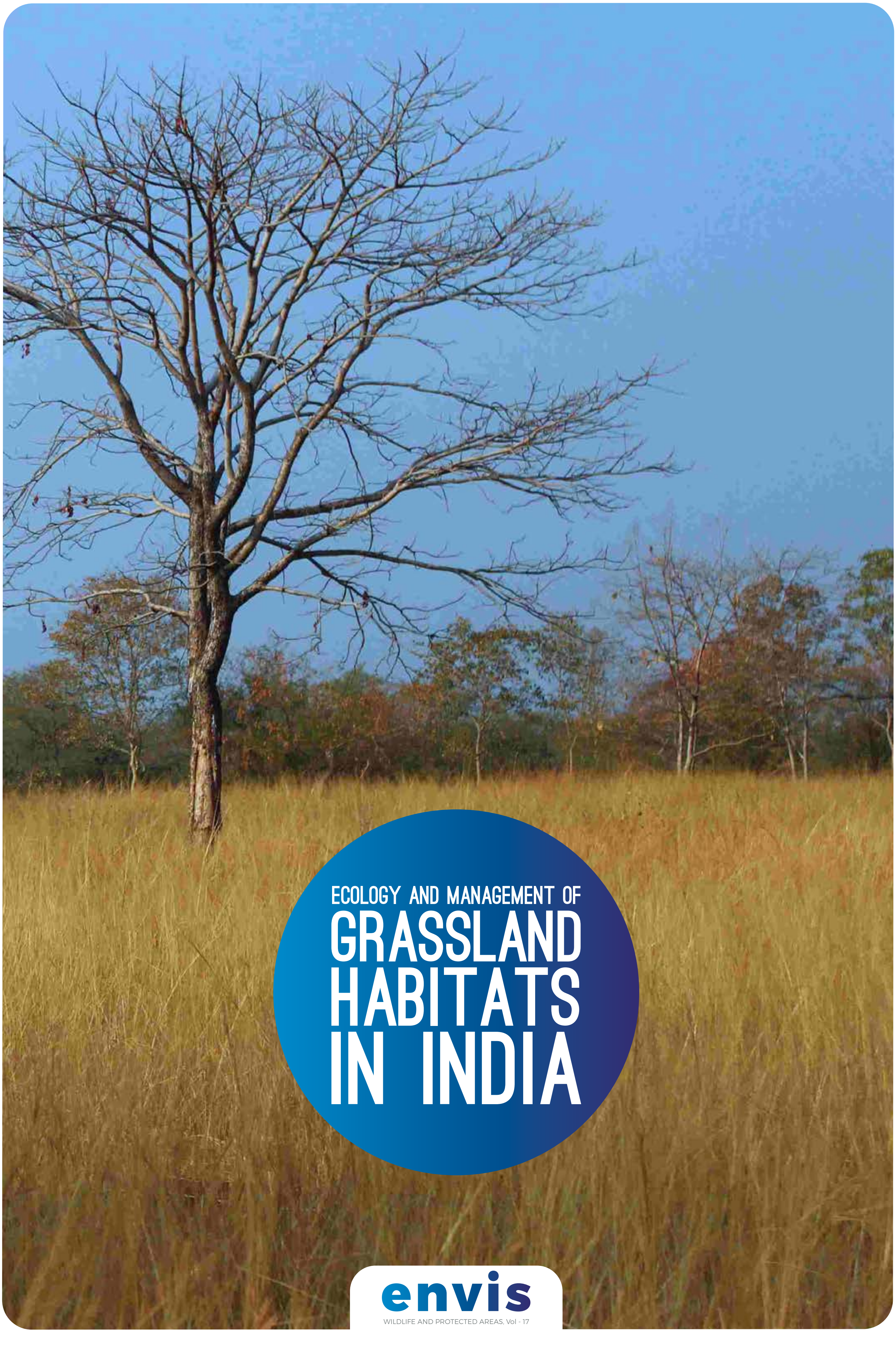

ECOLOGY AND MANAGEMENT OF GRASSLAND HABITATS IN INDIA

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WILDLIFE AND PROTECTED AREAS

The Environmental Information System (ENVIS) Centre at the Wildlife Institute of India, set up in September 1997, is part of the ENVIS setup of the Ministry of Environment, Forests and Climate Change, Government of India. It deals with general matters concerning 'wildlife' and specifically those related to 'protected area'. Its objectives are to :

- Build up information storage, retrieval and dissemination capabilities in subject areas related to wildlife science.
- Establish linkages with all information sources in wildlife conservation and management in the country and abroad for increasing the information content
- Respond to user queries by supplying substantive information in the form of published reports, documents, extracts, research papers and other unpublished and analysed information as far as possible
- Maintain links with other ENVIS Centres with the ultimate objectives of identification of data and knowledge gaps in specified subject areas and take action towards filling these gaps Publish bulletins on thematic focus areas
- Publish bulletins on thematic focus areas

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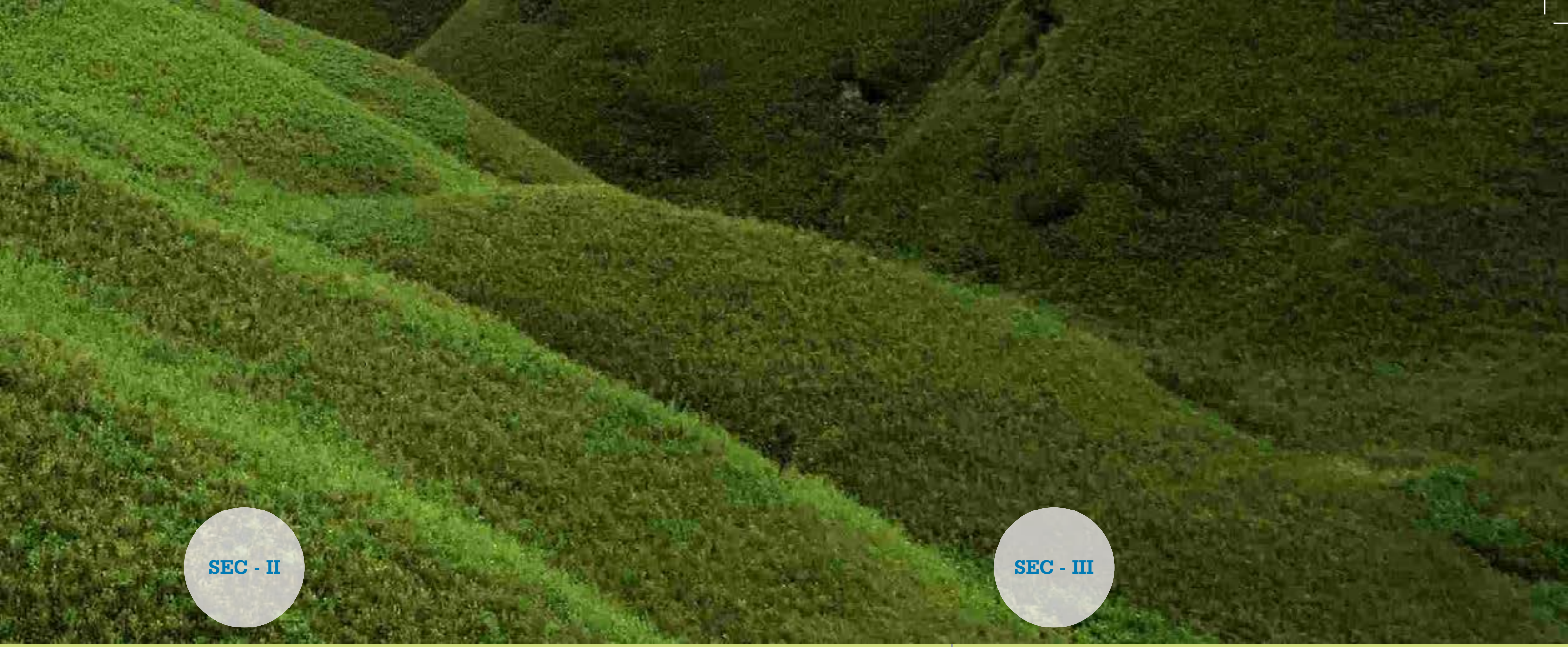

SEC - II

SEC - III

Director's Note

Habitat degradation and fragmentation induced by anthropogenic pressures are among the major drivers impinging upon earth's biodiversity and ecosystem services. The process of degradation and loss is more prevalent in the tropics and sub-tropics, where there is a greater demand on land for agriculture, infra-structure development and fodder production to meet the requirements of burgeoning human and livestock populations. Of the various terrestrial ecosystems, the grasslands of Asia-Pacific region are more vulnerable and most neglected in terms of effective management. Perusal of literature on Indian wildlife reveals that a large number of grasslands mammals and birds are threatened and several species have been pushed to the brink of extinction. Kashmir stag or Hangul (*Cervus elaphus hanglu*), Manipur deer or Thamin (*Cervus eldi eldi*), Swamp deer or Barasingha (*Rucervus duvauceli*), Great Indian rhinoceros (*Rhinoceros unicornis*), Hog deer (*Cervus porcinus*), Black buck (*Antelope cervicapra*), and Great Indian bustard (*Ardeotis nigriceps*) are some of the obligate species of grassland habitats that require immediate attention of conservation agencies in India.

India has achieved a considerable success in preventing the escalation of the rate of deforestation during last few decades. However, restoration of degraded grasslands has not received adequate attention. Spread over nearly one fourth of the geographical area, Indian grasslands are varied and rich in terms of their biophysical features. Besides their role as important wildlife habitats, they also form backbone of pastoral livelihoods. Conforming to the national and global conservation agenda, and in line with the National Biodiversity Action Plan, Wildlife Institute of India is committed to generate and disseminate scientific knowledge on various ecosystems in the country. This issue of ENVIS bulletin focuses on the state of the art knowledge on the grassland habitats contributed by leading wildlife ecologists and protected area managers in the country. The bulletin includes an inspiring foreword by India's noted and veteran grassland ecologist Professor J.S. Singh, review papers by selected authors and findings of detailed ecological studies by leading ecologists. It is hoped that the information contained in this issue will help in drawing concrete plans for sustaining grassland biodiversity and ecosystem services through better management, valuation, conservation and restoration.

V.B. Mathur
Director,
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Foreword

Grasses and grasslands occur on all continents, from the equator to the poles, and together with the grazing animals that coevolved with them, constitute the world's major food and biodiversity resources. As stated by G L Stebbins in 1981, 'Mankind has depended upon them for his existence ever since our remote ancestors ventured onto the savannas and began a new mode of existence'. Needless to say, grasses and grasslands have assumed immense ecological and economic significance for humans, and have strongly influenced the agrarian, agro-pastoral and pastoral communities since the dawn of civilization. Grasslands in the Indian sub-continent are particularly interesting as they have evolved under varied ecological conditions and represent at places edaphic, bio-edaphic and climatic climaxes, each stage harbouring a rich array of flora and fauna. They support a high density of domestic livestock which form the backbone of rural livelihood. However, it is a matter of grave concern that most of the grasslands in the sub-continent are degrading rapidly due to lack of proper management with far-reaching consequences including loss of biodiversity, ecosystem services and human well-being.

After the monumental work on the Systematics of Indian grasses by N.L. Bor in 1960, and pioneering efforts of Professor R. Misra who established the first school of ecology at Banaras Hindu University, Varanasi around same time, there was a spurt of basic research on the ecology of grasslands in India during 1960s and 70's. The Varanasi School promoted habitat approach to grassland ecology and contributed significantly towards our understanding of structure, functioning and dynamics of Indian grasslands under International Biological Programme. However, sustained and long term interdisciplinary research on Indian grasslands could not be continued.

It gives me a lot of satisfaction that the Wildlife Institute of India (WII) has emerged as one of the important centres of applied and multidisciplinary research in India. The present volume on 'Ecology and Management of Grassland Habitats in India' by WII brings out the state of the art information on a wide range of grassland ecosystems in the country. The chapters in this volume are quite informative and underscore the need for long term monitoring, participatory management for multiple functions, and eco-restoration, especially to cater to the needs of threatened grassland fauna. I congratulate WII and the Editors, G S Rawat and B S Adhikari, for bringing out this volume and hope that the ecologists and conservation agencies in the country will translate the recommendations given in this volume into action.

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MANAGING INDIAN GRASSLANDS FOR MULTIPLE FUNCTIONS: ACTION IMPERATIVES

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Grasslands are highly dynamic ecosystems encompassing all natural and semi-natural pastures, woodlands, scrub, and steppe formations dominated by grasses and grass like plants (Blair et al., 2014). They have closely co-evolved with grazing ungulates since Pleistocene, and played major role in the history of farming (Stebbins, 1981). Grasslands not only provide vital ecosystem services such as water and climate regulation in support of agriculture, biogeochemical cycling, carbon storage, cultural and recreational services, but also form backbone of livelihoods for all the pastoral communities (White *et al.,* 2000). Several food grains such as wheat, corn, rice, and millets which are crucial for human survival originated in the grasslands and thus serve as important reservoir of crop gene pool. In addition, they form critical habitat for a variety of wild herbivores and other faunal groups for their breeding, migration and wintering (Rahmani, 2006; Verma and Prakash, 2007). Owing to steady increase in human and livestock populations during last few decades, abrupt changes in land use practices, and transformation of traditional pastoral practices, most of the grasslands in the Asia-pacific region are degrading rapidly with far reaching consequences such as loss of biodiversity and ecosystem services, decline in quality and quantity of forage species, loss of pastoral livelihoods, and desertification (Faber-Langendoen & Jose, 2010; FAO, 2013).

Grasslands occupy nearly 24% of the geographical area in India which are spread across several bio-geographic regions and exhibit a wide range of ecological characteristics (Singh *et al.,* 1983). Major types of grasslands in the country are: Alpine moist meadows of the Greater Himalaya; Alpine arid pastures or steppe formations of trans-Himalaya; Hill-side grasslands in the mid-elevation ranges of Himalaya; 'Chaurs' of Himalayan foot-hills; Wet-alluvial or 'Terai' grasslands of Gangetic and Brahmaputra flood plains; 'Phumdi' or floating grasslands of Manipur; 'Banni' and 'Vidis' of Gujarat; Savannas of western and peninsular India; Plateau and valley grasslands in Satpuras and Maikal hills; Dry grasslands of Andhra Pradesh and Tamil Nadu plains; and 'Shola' grasslands of Western Ghats. Except alpine grasslands of the Himalaya and hill top grasslands of Western Ghats, most of the grasslands in the country are anthropogenic in origin and seral in nature evolved under the influence of fire, livestock grazing, clearing of forests, flood, and drought (Bor, 1960; Singh et al., 1983). The extant grasslands are prone to human encroachment, heavy infestation by unpalatable and thorny alien invasive plants (AIPs), soil erosion and compaction (Anon 2006). Currently, a large number of grassland fauna (**Appendix-I**) are under threat due to degradation and loss of grassland habitats and severe competition from domestic livestock.

Although grasses have wide ecological amplitude and several adaptations to withstand trampling, grazing, fire, flood and drought, they face severe competition for light and nutrients from aggressive woody species and AIPs. The nutrient rich sites such as relocated villages, abandoned agricultural fields and stream courses are particularly prone to invasion by woody species and easily transform into woodlands and dense thickets of unpalatable shrubs and opportunistic herbs. In many parts of central and south India overgrazing by domestic livestock, mining, wind-farms, plantations, canals and dams have led to degradation and loss of grassland habitats (Vanak, 2013). The 'Shola' grasslands of Western Ghats have largely suffered due to monoculture plantations of wattle, eucalyptus and invasion by exotics such as scotch broom (*Cytisus scoparius*) leading to their degradation (Sukumar et al., 1995; Srinivasan, 2011). Studies have shown that wet grasslands of *Terai* and *Duars* degrade fast if adequate space is not provided for the mosaics of early to mid-seral stages and 'natural' regimes of flood and fire are disrupted (Rawat, 2005). In most of the humid grasslands, maintenance of 'desirable' stages of succession requires very careful handling and sound management practices based on ecological principles.

Need for assessment of grass cover and long term ecological (interdisciplinary and coordinated) studies on various grasslands of India was felt strongly as early as 1970's (Dadabghao and Sankarnarayan,1973; Yadava and Singh, 1977). However, in the absence of integrated long term research and monitoring our understanding of Indian grasslands has not advanced much. The Wildlife Institute of India (WII) has been advocating for the restoration and long term monitoring of grasslands and other habitats since last three decades. In the recent years, the institute has come up with several plans for the recovery of endangered grassland fauna including Sangai or Manipur brow-antlered deer (*Rucervus eldi eldi*), Hangul or Kashmir deer (*Cervus elaphus hanglu*), and Great Indian bustard (*Ardeotis nigriceps*). These programmes will also have to be complemented and backed by restoration and monitoring of grassland habitats.

This issue of WII – ENVIS attempts at bringing updated ecological information on grasslands of India from the perspective of 'Wildlife Management'. The volume includes invited research papers, review articles, and short notes on the ecology and management of Indian grasslands from experienced wildlife ecologists and managers in the country. M. Chandran (Chapter 1) gives an update on classification of Indian grasslands and recommends detailed assessment and countrywide mapping. A few authors have contributed detailed review papers on bio-physical features, current conservation status and management issues in different grasslands, viz., Rangelands of Indian Trans-Himalaya (Amit Kumar et al., Chapter 2), 'Banni' Grasslands of Kachchh (Vijay Kumar et al., Chapter 3), and 'Vidis' of Saurashtra (Mehta, Chapter 4). Effects of management interventions on various grassland communities in Terai Conservation Landscape (Kumar et al. Chapter 5). Other papers are based on the in-depth ecological studies, viz., Factors driving the structure of 'Shola' grasslands in the Palni hills (Schmerbeck et al., Chapter 6); Recent changes in the 'Phumdi' grasslands of Loktak National Park (Tuboi et al., Chapter 7); Dynamics of grasslands in Kaziranga National Park, Assam (Vasu & Singh, Chapter 8). Sinha et al. (Chapter 9) have described ecology of grasslands in Valmiki Tiger Reserve, Bihar. Pandey (Chapter 10) gives a comparative account of grassland communities in Kanha Tiger Reserve based on rapid studies conducted during 1981 and repeat observations after an interval of 20 years. Three papers dealing with the first hand experience of managing and improving the grassland habitats viz., Management of grassland habitats in Satpura Tiger Reserve (Muratkar et al., Chapter 11); Ecology and management of grasslands in Melghat Tiger Reserve (Muratkar et al., Chapter 12); and Managing the saline grasslands in Velavadar National Park, Gujarat (Rathod, Chapter 13), Impact of fire on grasslands of Manas National Park (Ghosh, Chapter 15). Three papers deal with Indian savannas – one on the recent invasion by an aggressive native shrub *Adhatoda vasica* in savanna grasslands of Sariska Tiger Reserve (Bhatt et al., Chapter 14), second on the geo-spatial analysis (Vanak et al., Chapter 16), and third focused on the semi-arid habitats of lesser florican (Mohan et al., Chapter 17). We have included two interesting short notes in this bulletin, one on the importance of *Cynodon* patches as a lean season fodder resource for ungulates and as a nesting habitat for certain birds (Nair et al., Chapter 18), and 'The bygone glory of the dry plains of Tamil Nadu' (Johnsingh et al., Chapter 19). Chapter 20 provides an updated bibliography on the ecology and management of Indian grasslands and lists about 290 references published after 1975 and collated through various sources (Aggarwal et al.). We have also included an appendix at the end of the bulletin on the threatened faunal species of the diverse grassland habitats of India.

We hope that the field biologists, protected area managers and young researchers in India will find this volume highly informative and useful for their own research. This bulletin would encourage them to undertake in-depth studies on response of grasses and grasslands to various drivers of change and participatory action research on the restoration of degraded grasslands in their respective areas. Most of the papers in this volume recommend management of grasslands for multiple functions, and link conservation of grasslands with pastoral livelihoods. These linkages are important for the conservation and development agencies, which have immense responsibility of bringing various line agencies and local communities on board and coming up with appropriate policies and integrated plans for the management of Indian grasslands.

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Grassland Vegetation of India: An Update

01

Abstract

Grasslands of India have been classified by Dhadabgao and Sankarnarayan (1973) into five broad cover types. With the advancement of ecological studies on the grassland vegetation of the country it is evident that there are many more unique grassland types in various eco-climatic zones which have not been described. This article attempts to give an updated account of various grasslands in India which will serve as a baseline for researchers and form basis for the revised classification of Indian grasslands. These grasslands have been broadly grouped under coastal grasslands, riverine alluvial grasslands, montane grasslands, sub-Himalayan tall grasslands, tropical savannas and wet grasslands. The floristics of these grasslands and the threats faced by them have been discussed in this article.

Key words: Grasslands, classification, Poaceae, savannas, meadows, steppes

Introduction

Grasslands refer to vegetation community predominated by graminoids i.e., grasses and grass like plants.The major families found in the grasslands are Poaceae, Cyperaceae, Fabaceae and Asteraceae. The grasslands of the temperate regions also have high richness of Caryophyllaceae, Gentianaceae, and Rosaceae. The grasslands not only function as a major producer biome, but also serve as habitat to a variety of micro and macro fauna. The grasslands of the world are also under the threat of developmental activities and other land use changes resulting in habitat fragmentation, frequent fires and reduction in biodiversity. The Prairies of North America, Pampas of South America, the African Savannas, the Veldts of South Africa, the Caucasian Steppe, the Terai grasslands, the Alpine meadows of Himalaya and Shola grasslands of Western Ghats are some of the unique grassland of the world. The grasslands globally have been classified into Tropical Savannas, Temperate grasslands and Steppes. The Savannas are characterized by large areas of grasslands with scattered trees found in the tropical region, whereas the temperate grasslands are extensive stretches of tall grasslands in the temperate regions, while the Steppes refer to extensive stretch of short grasslands found in arid and semi-arid temperate high altitude regions. Dhadabgao and Sankarnarayan (1973) in their book "The Grass Cover of India" had identified the following five broad types of grass cover found in India:

1. ***Sehima*** - ***Dichanthium*** grasslands which are spread over the Deccan plateau, Chota Nagpur plateau and Aravallis, with an elevation range of 300-1200 m above mean sea level.
2. ***Dichanthium*** - ***Cenchrus*** - ***Lasiurus*** grasslands which are spread over northern parts of Gujarat, Rajasthan, Aravalli ranges, south-western Uttar Pradesh, Delhi and Punjab with an range of 150-300m above mean sea level.
3. **Phragmites** - ***Saccharum*** - ***Imperata*** grasslands which are spread over the Gangetic plains, Brahamputra Valley and the plains of Punjab, with an elevation rangeof 300-500 m above mean sea level.
4. ***Themeda*** - ***Arundinella*** grasslands spread over the foothills and lower hills of Manipur, Assam, northern parts of West Bengal, Uttarakhand, Himachal Pradesh and Jammu and Kashmir in the elevation range of 350-2000 m above mean sea level.
5. **Temperate** - **Alpine** grasslands- spread across the Himalayan States and the temperate high altitude areas of Nagaland, Manipur and Western Ghats above an altitude of 2000 m above mean sea level.

Subsequent to the work by these authors, several explorations and extensive surveys have been made to assess the grass cover and community classification in Indian grasslands. However, such efforts have not been made in a coordinated manner. Similarly, there has not been any attempt to revise the initial classification of grassland communities of India. The present article is an attempt to list and give a brief account of a few commonly found grassland types according to their biogeographic zones and some of their representative communities across the country so as to enable the future

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explorers and researchers to get a basic picture of the grasslands of India as well as to attempt mapping of various grassland communities, and conduct further ecological studies.

1. The Coastal Grasslands:

The grassland vegetation that is unique to the coastal regions across the world so far has not found any place in the classification of grassland communities. These are mostly found as gregarious single species communities. Such grasslands can be broadly classified into the following categories:

a. **Grasslands of the sea beaches**: The grasslands found on sea beaches can be broadly classified into the following:

i. **Mainland beaches** – These are grasslands communities found on the sea beaches of the tropical coasts. The most important grass species in these grasslands is the Rolling Dallis grass *(Spinifex littoreus)* which spreads along the sand dunes and beach sand over large areas with its long rhizomatous stolons. The male and female inflorescences are found on separate plant colonies. The female has large globular spiny inflorescences which once detached from the plant can roll in the wind along the beach sand thus enabling its dispersal. They are circum-global in nature and are found usually in pure patches or intermixed with *Ipomoea pes-caprae* on most of the undisturbed beaches in the equatorial regions of Asia, Africa and the Americas (**Plate 1.1**). *Trachys muricata* is another important grass species found on sea beaches. *Stenotaphrum dimidiatum* also form dense mats under coconut groves situated near the sea shores.

Plate 1.1 *Spinifex littoreus* on sea shore, Lakshadweep © *Prashant Awale*

ii. **Island beaches** – Sea shores of the islands across the world are inhabited by a short grass community of *Thuarea involucrata*, another dioecious grass species with long running stolons. They are seen as patches of green carpets on the sea beaches especially in the Andaman & Nicobar Islands and Lakshadweep. The fruit of this grass has a protrusion which grows into the sand thus enabling the germination of its seeds in the hostile environment.

b. **Salt marsh grasslands**: These are grasslands dominated by *Aleuropus lagopoides* found in extensive patches on saline areas frequently submerged by tidal waters of the seas. The Rann of Kachchh is one of the major habitats of this community and is found as pure gregarious population as well as associated with other herbaceous salt tolerant plants like *Sueda fruticosa. Aleuropus lagopoides* is characterised by long rhizomatous stolons bearing stems with short and narrow leaves with a terminal globose whitish inflorescence (**Plate 1.2**). This grass has been red-listed on account of small number of herbarium collections in the past but later on it was found that this status was as a result of under-exploration and the plant is found abundantly at several localities of coastal salt panson the western and eastern coast of India.

Plate1.2 *Aeluropus lagopoides* Salt marsh grasslands of Kutch (Courtesy: copalindia.blogspot.in)

c. **Mangrove grasslands:** These are grassland communities found along the marshy intertidal zone of the coastal regions and are usually found in patches between adjacent mangrove forests or areas close to sea beaches. The major grasses found in this community are *Myriostachya wightiana, Zoysia matrella, Sporobolus virginicus, Halopyrum mucronatum* and *Porteresia coarctata*, usually as monospecific patches. They are also found on the field bunds of cultivation or prawn hatcheries located near such mangrove zones. The mangroves of Bhitarkanika, Sunderbans, Pichavaram on the east coast and the mangroves of Goa, Bombay, Calicut, Kadalundi, Payyannur, and Quilon on the west coast are some of the areas where one or more of these species can be found. *Zoysia matrella* and *Sporobolus virginicus* can also be found near non-mangrove sea shores of Kanyakumari and areas which has an oceanic history close to it.

2. The Riverine Alluvial Grasslands

The riverine alluvium along the banks of major rivers is usually colonized by a primary successional tall grassland community dominated by *Saccharum spontaneum*, locally known as Kans. This grass has long stolons which spread across vast stretches of alluvial beds of the rivers (Plate 1.3). This primary successional community often gives way to riverine tree vegetation as one moves away from the flood bank. Such grasslands are common along the Ganga and Brahmaputra rivers and also in several other rivers in peninsular India like the Mahanadi, Godavari, Cauvery, Krishna, Narmada, and Bharatapuzha. The rivers of the Punjab also have such riverine alluvial grasslands. Such grasslands in Northern India are also dominated by *Saccharum bengalense* (Munj), which forms regular dense clumps. These grasslands are a visible treat while in flowering with the white silky showy panicles of *Saccharum spontaneum* and pink coloured effuse compound feathery panicles of *Saccharum bengalense*. These grasslands are also habitat to a variety of birds and mammals. *Saccharum bengalense* serves as an important livelihood source for villagers by means of harvest of the culms for thatching and weaving of baskets, chairs, ropes and many other artifacts. Ecologically, they provide soil binding services stabilizing and preventing the river beds and banks from erosion. The grasslands of Kaziranga National Park south of the Brahmaputra are also an example of riverine alluvial flood plain grasslands.

3. Montane grasslands

The mountainous regions of the country have different types of grassland communities based on their altitude, slope, aspect and rock strata. They occur as multi-species herbaceous communities over large tracts of land as well as intermixed with shrubs or as undergrowth in open to moderately dense forest areas. The montane grasslands of India can be broadly recognised into the following categories:

Plate 1.3 *Saccharum spontaneum*

a. **Himalayan Sub-tropical grasslands:** These are grasslands found on the southern slopes of the Himalaya between an altitudinal range of 1000 to 1800m and are usually found on steeper rocky slopes with shallow soils. They are also found as lush undergrowth in Pine forests during the rainy season (**Plate 1.4**). These grasslands are dominated by *Chrysopogon fulvus* and *Arundinella nepalensis* along with *Pennisetum orientale, Apluda mutica*,

Plate 1.4 Grasslands under the Himalayan Pine forests

Heteropogon contortus, Cymbopogon distans, Imperata cylindrica, Capillipedium parviflorum, Microstegium ciliatum and several other species of grasses, legumes and herbs from other families. These grasslands are highly vulnerable to forest fires during the dry summer season, but being fire hardy, the new shoots soon emerge from the underground rootstock providing valuable fodder to the grazing wild herbivores and domestic livestock during the lean season. These grasslands are used by the local communities for fodder collection during the winter after the seeds have fallen and stored for making hay for future use.

b. **Himalayan Temperate grasslands:** These are grasslands found on the slopes of the Himalayas in an altitudinal range of 1800 to 3000 m and are usually found on rocky slopes with shallow soils where there is sparse tree growth. These grasslands are dominated by *Chrysopogon gryllus, Andropogon tristis, Themeda anathera, Themeda tremula, Erianthus rufipilus, Miscanthus nepalensis, Brachypodium sylvaticum, Bromus unioloides* and several other grasses, sedges and are also rich in terrestrial orchids such as *Satyrium nepalense, Herminium lancium* and *Habenaria intermedia*. Asteraceae members such as *Erigeron* and *Anaphalis* also dominate such grasslands. The blades of *Chrysopogon gryllus* are used by the villagers for thatching purposes.

c. **Alpine meadows:** The grasslands found above the tree line on the southern face of the Greater Himalaya above an altitude of 3000 m and upto 5200 m are usually referred to as the Alpine meadows (Plate 1.5 & 1.6). They are known as Marg in Kashmir, Bugyal in Uttarakhand and by various other local names across the mountain range. Being above the tree line, these grasslands extend over several square kilometers and are usually under snow for a large part of the year and thus form a climatic climax community. However, certain lower sub-alpine areas also have similar grasslands forming edaphic climax due to the rocky substrata unsuitable for tree growth. The most dominant species found in these Alpine meadows is *Danthonia cachemyriana*, which provides nitrogen rich fodder to grazing sheep and other livestock and also to wild herbivores. The other major grasses include different species of *Poa, Festuca, Bromus, Briza, Calamagrostis, Agrostis*, etc. and also a plethora of herbaceous plants belonging to Rosaceae, Fabaceae, Asteraceae, Caryophyllaceae, Campanulaceae, Saxifragaceae, Lamiaceae, Apiaceae, Scrophulariaceae, and Orchidaceae. The alpine meadows are very rich in a variety of medicinal plants which are harvested by the local communities to sustain their livelihoods. Some of the shrubs such as *Rhododendron anthopogon, Rhododendron campanulatum, Juniperus, Cotoneaster, Cassiope fastigiata, Lonicera* spp., etc. also are found intermixed with these grasslands. The Chhipla Kedar alpine meadows in Pithoragarh district and Bedini Bugyal of Chamoli district of Uttarakhand are among the most extensive and contiguous patches of alpine meadows found in the Himalaya, each of which is above 300 sq. km in expanse. The alpine meadows above 3800 m also forms the habitat of the highly valuable Yar-tsa Gambu or the caterpillar mushroom (*Ophiocordyceps sinensis*), which is harvested soon after snow melt before the grasses grow to cover them up.

Plate 1.5: Alpine meadows, Kedarnath, Uttarakhand

Plate 1.6: *Danthonia cachemyriana*

d. **Trans-Himalayan steppes:** These are alpine meadows found in the northern face of the Great Himalaya, usually known as the Trans-Himalaya (Plate1.7 & 1.8). These areas on account of their location in the rain-shadow region of the South West Monsoons, are arid and very cold due to their proximity to Tibetan plateau and very high altitudes

Plate 1.7: Trans-Himalayan Steppes, Jeolingkong, Uttarakhand

Plate 1.8: Grazing in trans-Himalayan dry steppe, Nanhoti, Uttarakhand

usually above above 4000 m asl. Such grasslands are found in Ladakh in Jammu & Kashimir, Lahul, Spiti and Kinnaur districts of Himachal Pradesh and in Nilang, Niti, Malla Johar, Malla Darma and Lapthal areas of Uttarakhand, and Tso Lhamu plateau of Sikkim. These grasslands are dominated by short grasses which can be classified as 'Steppe' as per the global classification of grasslands. The major species include *Elymus nutans*, species of *Stipa*, *Agropyron*, *Poa*, *Calamagrostis,* and *Festuca* along with thorny bushes such as *Caragana, Astragalus*, *Lonicera* and also *Juniperus, Ephedra* and several herbs of various families e.g. Asteraceae, Saxifragaceae, Caryophyllaceae, and Scrophulariaceae. Grasses such as *Leymus secalinus* are found towards the Tibetan plateau which is a major fodder for the Tibetan Wild ass. *Orinus thoroldii* is found in sandy areas and on sand dunes of the cold deserts of the Satluj and Indus basins. These areas are often interspersed with lakes and marsh meadows dominated by *Kobresia* sedge and also grasses e.g. *Colpodium, Puccinella,* and *Catabrosa aquatica.* The Trans-Himalayan grassland communities of India are mostly extensions of the Tibetan floral elements.

e. **Grasslands of the North East Hills:** These are found in sub-tropical to temperate areas of the North Eastern Hill States south of the Brahmaputra (Plate 1.9). The major grasslands include the Dzukou valley in Nagaland and Manipur, Ukhrul grasslands of Manipur, Saramati grasslands of Nagaland, and the rolling downs of Shillong. These grasslands are characterised by a mixture of floral elements of the Himalayan region, South East Asia and peninsular India and hence form a unique biodiversity rich area. These grasslands are dominated by species of *Festuca, Bromus, Arundinella, Agrostis, Cyathopus, Coix, Tripsacum, Cymbopogon, Themeda villosa, Microstegium, Glyceria*, and *Gymnopogon*. The higher altitudes are also rich in orchids and lilies, species of *Aconitum, Fritillaria,* and *Selinum.* The lower hill slopes are rich in species of *Microstegium, Erianthus, Narenga fallax, Thysanolaena maxima* and a variety of montane bamboos.

Plate 1.9: Mountain grasslands of Dzukou valley, Nagaland

f. **Grasslands of Central Highlands:** These grasslands are found in the Central Indian highlands viz., Vindhyas and Satpuras. These hill ranges are considered the corridors between the Western Ghats and the Himalayas for migration of species. These grasslands are found intermixed with tropical dry deciduous forests on rocky patches

Plate 1.10: Grasslands of the Satpura, Pachmarhi, Madhya Pradesh

among sparse to open tree growth and can be ideally called montane or hill savannas. The grasslands on the steep slopes of Vindhyan ranges is dominated by Tripogon *jacquemontii*, which is found drooping down the slopes. The plateaus of Satpura ranges especially the Pachmarhi plateau (Plate 1.10) has several grasses such as *Manisuris forficulata*, *Arthraxon*, *Pennisetum*, *Diectomis*, *Schizachyrium*, *Cymbopogon*, *Themeda*, *Eragrostis* and *Dimeria* species.

g. **Western Ghats:** The grasslands of the Western Ghats are found on the rocky hill slopes, the high altitude rolling downs and on rocky plateau tops. These grasslands can be broadly classified into the following categories:

   i. Plateaus of North Western Ghats: These are grasslands found on the plateaus of the Western Ghats in Karnataka, Goa and Maharashtra. They are usually short grasses and are ephemeral in nature seen as a green flush during the monsoons and thereafter drying up and the seeds dispersed waiting for the rainfall next monsoon. Such grassland communities are common in Panchgani, Mahabaleshwar, Ratnagiri, and Kaas plateau. *Dimeria*, *Ischaemum*, *Manisuris*, *Arthraxon*, *Heteropogon*, *Arundinella*,*and Jansnella* along with several other herbaceous plants belonging to Gentianaceae, Fabaceae, Asteraceae, Melastomaceae, Scrophulariaceae and Lamiaceae dominate these grasslands.

   ii. Shola grasslands: These are high altitude grasslands of the Western Ghats having an altitude of above 1800 m upto the highest peak of Anaimudi at 2695 m above mean sea level. These grasslands are found between the shola forest patches that occur in the depressions created by watercourses flowing in these rolling downs (Plate 1.11). The shola grasslands are dominated by *Eulalia phaeothrix*, *Dichanthium polyptychum*, *Chrysopogon hackelli*, *Chrysopogon* as per, species of *Agrostis*, *Andropogon*, *Arundinella*, *Garnotia*, *Jansnella*, *Eragrostis*, *Poa*, and *Helictotrichon* along with several species of the *Strobilanthes* complex of Acanthaceae and several other families including Orchidaceae, Gentianaceae, Asteraceae, and Fabaceae. The grasslands of Eravikulam National Park, Mukurti Sanctuary, Kodajadri, Bababudangiri, Agastyamalai, Poochipara in Silent Valley National Park are all examples of shola grasslands. Unlike the plateau grasslands of Northern Western Ghats, these grasslands receive heavy rainfall throughout the year. One of the important tree species found at the edges of these grasslands is *Rhododendron arboreum* ssp. *nilgiricum*.

Plate 1.11: Shola grasslands of Nilgiris, Tamilnadu

   iii. South Western Ghats: The slopes of south Western Ghats of Waynad and Idukki districts of Kerala have more of forest grasses such as *Spodiopogon rhizophorus*, species of *Garnotia*, *Zenkeria*, and *Arundinella* and also vast stretches of *Pennisetum pedicellatum* and *Pennisetum polystachyon*. Several species of *Cymbopogon*,

Chrysopogon and *Themeda* are also very common in these grasslands. *Vetiveria lawsonii* is found in abundance in the grasslands of the Kabini in Nagarhole National Park. Short grasses such as *Lepturus repens* are also found in abundance as undergrowth in Bandipur, Nagerhole and Wynad wildlife sanctuaries. *Ischaemum zeylanicolum* dominates the undergrowth of forest areas at many places. *Dimeria* spp. are found in large expanse on rocky hills and their ephemeral flowering is a great delight to the eyes. *Jansenella griffithiana, Silentvalleya nairii* and *Chandrasekharania keralense* are some of the unique grasses found here. *Arundina graminifolia* is a unique orchid found in the grasslands of Silent valley.

h. **Eastern Ghats:** The grasslands of the Eastern Ghats are comparatively drier due to lesser rainfall and lower altitudes of around 700 m above mean sea level. They are highly discontinuous and in small patches unlike the Western Ghats. The major grass community is dominated by *Arundinella setosa* in the higher altitudes and *Aristida adscencionis*, *Heteropogon contortus*, *Sporobolus*, *Themeda*, *Chrysopogon*, etc. in lower areas. The Shevroy hills of Yercaud, Javadi hills and Malkanagiri represent such grassland communities.

I **Montane bamboo brakes:** These are grassland communities dominated by gregarious dwarf monopodial bamboo species, which when one looks from a distance gives the appearance of a normal grassland. These bamboos may be 1 to 5 metres tall depending on the species. The *Arundinaria densiflora* brakes of Western Ghats, *Arundinaria hirsuta* brakes of Khasi hills, *Arundinaria rolloana* brakes of Dzukou valley in Nagaland (Plate 1.12) and *Yushania anceps* brakes in the sub-alpine regions of Uttarakhand are some of the examples of montane bamboo brakes. They provide suitable habitat to a variety of pheasants and other birds and mammals and the young shoots are also food to a variety of animals including bears and rodents.

Plate 1.12: Montane bamboo brakes of *Arundinaria rolloana* in Dzukou valley

4. Sub-Himalayan Tall grasslands of Terai region

These hygrophilous grasslands are found along the length of the Sub-Himalayan belt where the slopes of the foothills converge with the plains of the Gangetic basin. These regions are rich in artesian springs making it ideal for tall grasses. The term Terai refers to this naturally irrigated belt of land and extends from Jammu till Arunachal Pradesh. The major grass species include *Narenga porphyrocoma, Saccharum bengalense, Saccharum spontaneum, Erianthus ravennae, Phragmites australis, Arundo donax, Cymbopogon flexuosus, Vetiveria zizanoides, Arundinella bengalense, Bothriochloa bladhii, Sorghum nitidum, Chionachne koenigii*, and *Coix lachryma-jobi*. The Terai grasslands are facing a severe threat due to draining out of water for irrigation purposes, land filling and development activities and rapid

urbanisation. The Terai grasslands are excellent habitat for the Great One-horned rhinoceros, which at present is limited to the flood plains of Assam, West Bengal and a few introduced populations in Dudhwa National Park in Uttar Pradesh.

5. Tropical Savannas

These are vast stretches of tall tropical grasslands interspersed with isolated or groups of trees and are found in Central and Western India. The tropical savannas of India can be broadly classified into the following:

a. **Desert Savannas:** These are savannas found in the Great Indian Thar Desert and are dominated by *Lasiurus scindicus* which is a good soil binder and sand dune stabilizer. Trees of *Prosopis cineraria* are found as isolated individuals or small groups. These grasslands are found in the Desert National Park and make a good habitat for the Great Indian Bustard and other animals (Plate 1.13). The Asiatic Cheetah *Acinonyx jubatus* once used to inhabit these grasslands before it became locally extinct. *Aristida* spp., *Sehima nervosum* and *Cenchrus biflorus* are some of the other dominant grasses found here. *Stipa grostisplumosa* is a dominant genus found on the sand dunes of the Thar Desert.

Plate 1.13: Tropical savannas of Desert National Park, Jaisalmer, Rajasthan

b. **Tropical savannas of Peninsular India:** These grasslands are found almost all over the Deccan plateau and Western India. They are dominated by *Sehima nervosum* and *Dichanthium annulatum* along with a plethora of other tall and small grasses such as *Eremopogon foveolatus*, *Pollinia fimbriata*, species of *Bothriochloa, Cymbopogon*, *Mnesithea*, *Rottboelia*, *Sorghum*, *Triplopogon ramossissimus*, *Dimeria*, and *Eulalia*. The grasslands of Saurashtra in Western Gujarat represent one of the largest stretch of Tropical savannas of Peninsular India. The Deccan plateau areas of Karnataka and Maharashtra also have several patches of Tropical Savannas and form good habitat for several herbivores such as black buck and also birds like the Great Indian Bustard and Lesser Florican.

c. **Northern Tropical Hill Savannas:** These are found as vast stretches of grasslands on hill slopes in the tropical areas of Northern India such as the Aravalis, Shiwaliks and the south facing slopes of the sub-Himalayan foothills. These grasslands are often intermixed with tree species such as *Acacia* spp., *Buchanania latifolia, Dalbergia oojenensis* and *Anogeissus latifolia*. The sub-Himalayan tropical hill savannas and Shiwaliks are dominated by *Chrysopogon fulvus*, *Neyraudia arundinacea*, *Arundinella bengalensis*, *Aristida cyanantha*, *Heteropogon contortus*, and *Imperata cylindrica* where as the Aravallis have more of *Cenchrus* spp., *Aristida adscencionis*, *Panicum*, *Chloris virgata*, *Eremopogon* and *Dichanthium annulatum*.

d. **Closed Sal Forest Grasslands:** This is a unique kind of grasslands found amidst Sal forests of the sub-Himalayan belt and also in Central India. These are closed grassland communities surrounded by Sal forests on all sides and are dominated by grasses like *Narenga porphyrocoma*, *Cymbopogon flexuosus*, *Themeda arundinacea*, *Chrysopogon*, *Desmostachya bipinnata*, *Dichanthium annulatum*, *Bothriochloa bladhii*, *Imperata cylindrica*, *Heteropogon contortus*, *Vetiveria zizanoides*, and *Imperata cylindrica* which provides excellent habitat for herbivores for grazing with the protection of the nearby forest areas too. Such grasslands are usually frequented by herds of elephants and deer and also makes good hunting ground for Tigers. Such grasslands are found in Rajaji National Park, Corbett National Park (Plate 1.14), Dudhwa in the sub-Himalayan belt and Kanha National Park in Central India. The fringes of these grasslands are dominated by *Chloris dolichostachya* which is a shade loving forest grass.

Plate 1.14: Grasslands of Dhikala, Corbett National Park, Uttarakhand

Plate 1.15: *Saccharum bengalense* at Dhikala grassland, Corbett NP, Uttarakhand

Plate 1.16: Montane grasslands of Dzukou valley, Nagaland

6. Wet grasslands

The semi-aquatic or wet grasslands are vast stretches found in the water-logged areas of the sub-Himalayan tracts, Terai, abandoned paddy fields, seasonal pools and shallow lakes, low lying areas near the sea coasts, the Phumdis of Manipur and also high altitude lakes. *Phragmites australis, Arundo donax, Erianthus ravennae, Saccharum spontaneum, Saccharum arundiaceum,* and some of the tall grasses found in such wetlands where as grasses such as *Paspalum distichum, Paspalum longifolium, Paspalum vaginatum, Isachne spp., Ischaemum indicum, Echinochloa crus-galli, Panicum repens, Eriochloa procera,* and *Panicum paludosum* are the small grasses seen in these wetlands.

Plate 1.17: *Myriostachya grasslands* along the creek Bhitarkanika. © *Bivash Pandav*

Floating grasses e.g. *Hygrorhyza aristata,* semi aquatic grasses e.g. *Leersia hexandra, Sacciolepis interrupta, Hymenachne acutigluma, Oryza rufipogon* and several semi-aquatic species of other families e.g. Pontederiaceae, and Hydrocharitaceae are unique to such semi-aquatic habitat. The mid altitude wetlands have *Glyceria tonglensis* and *Paspalum paspalodes* as the dominant species. The most well-known wetland grassland is the Loktak lake in Keibul Lamjao National Park, Manipur (**Plate 1.17 and 1.18**) having unique species like *Zizania latifolia* along with *Oryza, Phragmites* and other tall reeds. The swampy regions of the Terai have tall clumps of *Erianthus ravennae* along with *Typha, Saccharum and Phragmites.* The wetlands of Maharashtra are rich in grassland community dominated by *Coix gigantea.*

Plate 1.18: Coastal grassland: *Porteresia coarctata.* © *Bivash Pandav*

Threats to grassland communities

The grassland communities all over the sub- continent are facing several threats owing to severe anthropogenic pressures, land filling, grazing pressure, fragmentation, invasive species and to an extent climate change. Rapid urbanization and development of tourism amenities in and around natural, especially high altitude, grasslands have increased human interference and introduction of other grass species through construction material *viz.,* sand transported from other areas. Species such as *Saccharum spontaneum* have recently shown beginning of invasion in grasslands of mid altitude tourism destinations of Uttarakhand. The grasslands of the plateaus of the Western Ghats have seen sprouting of hotels and resorts thus destroying the local ecosystem. Species such as *Rhynchelytrum repens,* an ornamental grass, which had invaded several grasslands surrounding Bangalore and Hyderabad including several airports has now reached Dehradun, probably by dispersal of seeds by aircrafts plying all over the nation. The shola grasslands of Western Ghats have seen invasion of European bushes such as *Cystisus scoparius* and *Ulex europaeus.* Forest fires in grassland communities have played a major role in prevention of succession of grasslands into woodlands. However, frequent fires have also played a negative role in change in composition of grasslands from palatable species to non-palatable species, thus making it less suitable ecosystem for herbivores. Some of the examples are *Cymbopogon distans* taking over several areas of Pine forest grasslands in Almora district of Uttarakhand which otherwise was dominated by *Chrysopogon fulvus, Pennisetum orientale, Heteropogon contortus, Themeda anathera* and *Arundinella nepalensis.* Another grass which has taken over in frequent fire affected areas is *Imperata cylindrica.* The alpine meadows have also witnessed invasion of several species of *Rumex* and *Polygonum,* especially around livestock camps. Reduced snowfall in the treeline zone of alpine meadows have also resulted in invasion of lower altitude species into the tree line. Even grasses like *Cynodon dactylon* was found upto an altitude of 2900 m enroute to Kailas-Mansarovar in Pithoragarh towards the beginning of the alpine meadows of Chhialekh. Most of the semi-aquatic grasslands have witnessed rapid decline due to land filling for developmental activities. Even the abandoned rice fields are also victims of land filling and conversion of land use and agriculture systems for raising other crops such as Banana, Coconut, Rubber and vegetables.

Way Ahead

It is a major challenge for ecologists and botanists to map various grassland communities and compile their findings to bring about a revised classification of grassland communities of the Indian sub- continent. The above brief account of grassland communities of India is expected to serve as a starting point for bringing out a detailed classification of the grasslands of India and mapping of their zonation and distributional pattern. There are several unique grassland communities within the major groups and their association with certain other floral, climatic and geological parameters needs to be further explored. A database of various floral and faunal elements of each grassland community compiled over a period of time would help us in identifying spread and shrinkage dynamics, vegetation change, health of the habitat and identify the causes of changes vis-a-vis anthropogenic and climatic parameters. The transition of grassland communities over geological formations and agro-climatic and bio-geographic zones are also interesting topics for future research. Quantification of biomass, assessment of Carbon sequestration potential, threat assessment and conservation requirement need to be worked out in detail and other ecological studies need to be taken up as emerging researchers and ecologists.

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Rangeland Vegetation of the Indian Trans-Himalaya: An Ecological Review

Abstract

The Indian Trans-Himalaya (ITH) is characterized by sparse vegetation cover, low primary productivity and short growing season. Much of the area is unsuitable for cultivation but a large number of local and migratory pastoral communities use these areas for livestock grazing. Despite a high density of domestic livestock and low productivity, these rangelands support a rich assemblage of wild ungulates and other faunal groups. Though, several eco-floristic studies have been conducted in different parts of ITH, a comprehensive account on the distribution of major landform units or habitat types, and factors influencing the distribution of major vegetation communities across the larger landscape are needed. This paper gives an overview of vegetation structure and composition in the ITH across major landforms namely scrub steppe, scree slope, plateau/table land, marsh meadow, herbaceous meadow, moraine, dry sub-alpine & temperate forests and riverbed across the elevational gradients in ITH with their predominant species. We then provide an overview of vegetation structure and composition including patterns of species richness and diversity across various sub-regions, community composition, habitat use by wild ungulates and livestock, factors influencing the rangeland vegetation including topography and anthropogenic pressures. Major conservation issues such as degradation of pastures, need for eco-restoration and long term monitoring of rangeland vegetation are discussed.

Key words: Grazing, Ladakh, Landforms, North-West Himalaya, Wild ungulates

Introduction

Rangelands include natural grasslands, savannas, scrublands, steppes and wetlands dominated by grasses and grass-like plants predominantly used for livestock grazing. Spread over more than one third of the global land surface (Everitt et al. 1992), rangelands provide diverse ecosystem services and functions (Busby and Cox, 1994). They serve as main feed resource for traditional pastoral production system in many parts of the world and include about 70 percent of the feed for domestic ruminants. Other key ecosystem services from the rangelands include atmospheric carbon storage, watershed functions and critical habitat for a variety of flora and fauna.

The Indian Trans-Himalaya (ITH), located in the rain shadow zone beyond Greater Himalaya, has been used by a large number of local and migratory pastoral communities for livestock grazing since several centuries. This region is characterized by sparse treeless vegetation, often dominated by scrub, desert steppe or mixed herbaceous vegetation. Owing to extensive use of these areas for livestock grazing, they are often referred as rangelands. This region is also home to a large number of threatened species of flora and fauna. It is spread across three biogeographic provinces viz., 1A i.e., Ladakh Mountains in the north-west; 1B i.e., Tibetan plateau comprising of Eastern Ladakh, adjacent parts of Spiti, small pockets of Uttarakhand along northern frontiers and 1C i.e., Sikkim Plateau (Rodgers et al., 2000; WII, 2015; unpublished). These provinces are usually located above 4000 m above mean sea level and represent characteristic ecology and biogeography. The Trans-Himalayan rangelands are least influenced by summer monsoon and characterized by low productivity, extreme climatic conditions, high diurnal fluctuation in temperatures, scanty and erratic rainfall (<50mm), heavy winds and snowfall during winter. The region is generally considered floristically impoverished as compared to adjacent high altitude areas of Greater Himalaya (Mani, 1978; Schweinfurth, 1984). The vegetation of this region has been described by various authors as *Caragana-Lonicera-Artemisia* formation (Osmaston, 1922), Alpine steppe (Schweinfurth, 1959), Dry alpine scrub (Champion and Seth, 1968) and Alpine stony deserts (Puri et al., 1989).

The ITH has a unique physical, biological, hydrological and anthropological setting that is markedly different from that of the adjoining areas in the Greater Himalaya. This area is of considerable ecological and conservation significance which is crucial for pastoral production for the local herders as well as other ecosystem functions. The area forms upper catchment of several rivers such as Indus, Chenab, Satluj, Jahnavi or Jad Ganga, Alaknanda, Gori Ganga, Lasser Yangti, Kutti Yangti, and Teesta. These areas are quite distinct from the moist meadows of the Greater Himalaya in terms of

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physiognomy, plant community composition, primary productivity and patterns of seasonal use by the wild as well as domestic ungulates. This paper gives an overview of the rangeland vegetation in ITH including major landform units or habitat types across the elevational gradients, their ability to support populations of wild ungulates and domestic livestock and the factors determining the vegetation structure and composition.

Vegetation Structure and Composition

Phyto-diversity and Species Richness

The Indian Trans-Himalaya has been extensively surveyed in terms of eco-floristics by several workers. According to Srivastava (2010), the cold deserts of Western Himalaya are represented by ca. 1405 species, 490 genera under 98 families of flowering plants. Murti (2001) has reported about 347 species, belonging to 103 genera under 16 families of monocotyledons from the same region (Murti, 2001). Other workers, based on extensive floristic studies conducted in different areas have documented the richness of vascular plants e.g., Kachroo et al. (1977), Klimes (2003) and Klimes and Dickore (2005, 2006). Rawat and Adhikari (2005) recorded 232 species of vascular plants in ca. 300 sq. km area and identified several plant communities such as *Caragana-Artemisia*, *Artemisia- Kraschenennikovia* and *Artemisia-Tanacetum* in Changthang area of Ladakh. Rawat (2007a) estimated that a total of over 1800 species of flowering plants occur within the alpine region of Western Himalaya in an area of ca. 157,671 sq. km. Joshi et al. (2006) recorded 414 species of vascular plants from Nubra Valley, Ladakh. The patterns of plant species distribution in eight landscape types in Ladakh has been studied by Kala and Mathur (2002). In Trans-Himalayan region of Himachal Pradesh, Aswal and Mehrotra (1994) recorded 985 species from the Lahaul-Spiti. In recent floristic surveys of the cold arid regions of the state, Sekhar (2009) recorded 513 plant species belonging to 243 genera under 64 families from Pin Valley National Park while Chawla et al. (2012) reported 911 species of vascular plants in Kinnaur, Himachal Pradesh. The cold arid regions of Uttarakhand include Nilang, Mana and Niti valleys in Garhwal and Johar, inner Darma and Byans valleys in Kumaun. Very few studies have been done on the eco-floristics of these valleys. Naithani (1988) reported ca. 170 species of flowering plants from Nilang valley. However, Chandola (2009) recorded 441 species of vascular plants distributed under 229 genera and 72 families from the same valley. Efforts on ecological assessments of habitat types or landscape units in the alpine arid areas have not been carried out, except in Niti valley, which forms the buffer zone and cold arid region of Nanda Devi Biosphere Reserve. Kumar and Mitra (2015) recorded a total of 469 species belonging to 75 genera under 261 families of vascular plants. A perusal of literature on floristics of the ITH by various workers has been provided in Table 2.1.

Table 2.1. Details of floristic studies carried out in the Indian Trans-Himalaya.

Eco-floristic region & State	Area (sq. km)	Family	Genera	Species	Elevation range (m)	Author (s)
Cold deserts, Western Himalaya; J&K, H.P., UK	98,980	98	490	1405	4500-6000	Srivastava (2010)
Western Himalaya; J&K, H.P., UK	157,671	--	--	1810	3300-5600	Rawat (2007a)
Ladakh, J&K	97,782	51	190	611	2900-5900	Kachroo et al. (1977)
Ladakh, J&K	100,000	--	--	1180	3000-6000	Klimes and Dickore (2006)
Lower Ladakh, J&K	400	--	--	355	2750-4100	Klimes and Dickore (2005)
Western Ladakh, J&K	6523	51	159	301	2700-5300	Angmo (2013)
Eastern Ladakh, J&K	10,227	--	--	404	4180-6000	Klimes (2003)
Eastern Ladakh, J&K	6,912	43	127	272	4180-6670	Dvorsky et al. (2011)
Nubra Valley, J&K	22,656	56	202	414	2800-5400	Joshi et al. (2006)
Tso Kar Basin, Changthang, J&K	300	38	101	232	4400- 5500	Rawat and Adhikari (2005)
Lahaul and Spiti, H.P.	12,210	79	353	985	2000-6600	Aswal and Mehrotra (1994)
Pin Valley National Park, H.P.	1825	64	243	513	3300-6600	Sekhar (2009)
Kinnaur, H.P.	6400	114	450	911	--	Chawla et al. (2012)
Sangla Valley, H.P.	--	99	321	639	1800-4600	Devi et al. (2014)
Nilang Valley, UK	1,360	72	229	441	3000->6000	Chandola (2009)
Niti Valley, UK	726	75	261	469	3000->6000	Kumar and Mitra (2015)
Khangchendzonga National Park, SK	1784	67	243	585	4000-5000	Tambe (2007)

Abbreviations: J &K: Jammu and Kashmir, H.P: Himachal Pradesh, UK: Uttarakhand, SK: Sikkim

Plant community structure and composition

Most of the published studies on the plant community structure and composition pertaining to the ITH are from the Ladakh Mountains of the North-West Himalaya. For example, Dvorsky et al. (2011) identified eight distinct vegetation types and found scree as well as alpine grasslands as the most species-rich and reported altitude, soil moisture and salinity as the most important environmental factors influencing the species composition in Eastern Ladakh. In Ladakh, Rawat (2008) identified eight special habitats, viz., moist meadows, marsh meadows, craggy rock surfaces, scree bases, scrub steppe and sub-nival zones and remnant woodlands which harbours unique plant assemblages including some rare and threatened plants viz. *Colchicum luteum, Inula rhizocephala, Saussurea medusa, Allium przewalskianum,* and *Arnebia euchroma.* In a comprehensive effort covering Trans-Himalayan region of North-West and Western Himalaya, Rawat (2007a) identified eleven major vegetation communities, of which *Lonicera spinosa-Caragana versicolor-Oryzopsis lateralis* and *Thalictrum alpinum-Saussurea gnaphaloides-Trisetum aenium* showed highest diversity (2.27 and 2.37 respectively) and lowest (1.12) by *Phragmites australis-Lycium ruthenicum* community. Among the 16 plant communities observed in Tso-Kar Basin of Changthang Plateau, Eastern Ladakh, Rawat and Adhikari (2005) reported *Stipa-Alyssum-Oxytropis* and *Caragana-Poa* as the most extensive communities with respect to the aerial coverage. Kala and Mathur (2002) identified six communities in western Ladakh, viz., *Ephedra-Artemisia, Poa annua-Ranunculus hirtellus-Pedicularis oederi, Caragana brevifolia-Cotoneaster, Hippophae rahmnoides-Myricaria germanica, Artemisia-Salsola collina-Kraschenennikovia ceratoides* and *Agropyron-Trisetum-Oryzopsis-Carex*. In Nubra valley of Ladakh, Joshi et al. (2006) reported that herbaceous meadows on the gentle slopes had higher species diversity (1.2-2.29) and richness (14-21) followed by fell fields with species diversity (2.08-2.23) and richness (13-18) and least diversity was observed on scree slopes and on lower eroded slopes. The study also revealed that nearly 78-80% of plant species are restricted to the valley bottoms.

Of the 14 forest communities recorded from Lahaul valley by Singh and Samant (2010), tree density was found maximum for *Hippophae salicifolia* community (1850 individuals ha^{-1}), followed by *Fraxinus xanthoxyloides* (1000 individuals ha^{-1}), *Juglans regia-Ulmus wallichiana-Acer acuminatum* mixed (760 individuals ha^{-1}), *Abies pindrow-Pinus wallichiana* mixed (640 individuals ha^{-1}), *Juniperus polycarpos-Cedrus deodara* mixed (600 individuals ha^{-1}) while *Cedrus deodara-Acer cappadocicum* mixed community had lowest density (171 individuals ha^{-1}). Further, these authors have prioritized 15 habitats and 14 forest communities distributed between 2490-4000 m in the Lahaul Valley, Cold Desert Biosphere Reserve for conservation. Jisthu and Goraya (2008) identified six unique habitats such as moist meadows, riverine scrub, Juniper woodland and sub-alpine scrub, alpine dry scrub, alpine mixed communities and riverine scrub with respect to taxa of high conservation significance in cold deserts of Lahaul and Spiti valley and part of Pooh sub-division in Kinnaur, Himachal Pradesh.

In Niti and Nilang valleys of Uttarakhand state, the dry and undulating slopes in interior areas exhibit characteristic scrub steppe vegetation dominated by *Caragana versicolor, Lonicera spinosa* and *Potentilla rigida* and at places by *Krascheninnikovia ceratoides*. The unstable scree slopes harbour a distinct community characterized by *Aconogonum tortuosum, Eriophyton rhomboideum, Cicer microphyllum,* and *Cousinia thomsonii* (Chandola et al. 2008; Kumar and Mitra 2015).

In alpine meadows of north Sikkim, Tambe and Rawat (2008) reported the dominance of sedges namely *Kobresia nepalensis* on smooth slopes, *Kobresia duthiei* on broken slopes and *Kobresia pygmaea* and *Kobresia schoenoides* in dry meadows. The study also identified 11 vegetation types in the alpine landscape namely, 'krummholz' thicket, Juniper scrub, *Rhododendron* scrub, morainic scrub, *Salix sikkimensis* riverine thicket, *Myricaria rosea* riverine scrub, *Kobresia nepalensis* moist meadow, *Kobresia duthiei* moist meadow, *Kobresia pygmaea* moist meadow, *Deschampsia caespitosa* marsh meadow and *Anaphalis xylorhiza* dry meadow based on numerical classification.

Habitat use by wild ungulates and livestock in Indian Trans-Himalaya

Several workers have studied habitat use by wild ungulates and their interaction with domestic livestock in the ITH (e.g., Johnsingh et al., 1999; Mishra, 2001; Bagchi et al., 2002; Raghavan, 2003; Namgail et al., 2007; Rawat, 2007b; Chanchani et al., 2008; Hussain, 2009; Kumar and Mitra, 2015). Johnsingh et al. (1999) studied the ecology of the Ibex (*Capra sibirica*) in Pin Valley NP and its interaction with livestock. Mishra (2001) studied pastoralism, human-animal conflict and livestock competition with Blue sheep (*Pseudois nayaur*) in the Spiti valley, Himachal Pradesh and concluded the co-existence between pastoralism and wildlife is far from harmonious and suggested that majority of the rangelands of the valley are overstocked, as they are grazed at intensities much higher than what is biologically optimal. In Spiti, Himachal Pradesh, Bagchi et al. (2002) found that domestic goat and sheep imposed resource limitation on ibex and excluded them spatially. Ibex remained relatively unaffected by other livestock such as yaks, donkeys and cattle. Raghavan (2003) investigated the interaction between Ladakh urial (*Ovis orientalis vignei*) and livestock and opined that Urial may have been pushed to areas with sub-optimal resources, by livestock that used relatively resource rich areas. Namgail et al. (2007) reported a shift in the habitat use by the Tibetan Argali (*Ovis ammon hodgsoni*) in the presence of livestock in the

Gya-Miru Wildlife Sanctuary, Ladakh. Rawat (2007b) based on a landscape survey in Western Himalaya reported higher densities of livestock in the alpine areas of Uttarakhand compared to those of Himachal Pradesh and Jammu & Kashmir. Chanchani et al. (2010) studied seasonal distribution of four ungulates viz., Tibetan argali, Tibetan gazelle (*Procapra picticaudata*), Southern kiang (*Equus kiang polyodon)* and blue sheep (*Pseudois nayaur*) in Trans-Himalayan region of Sikkim. These authors found that argali was associated with sparsely-vegetated scree hills, gazelles frequently used valleys, basins and plateaus, kiang predominately used plateaus and gentle slopes and blue sheep were mainly seen on rocky or grassy slopes in the transition zone. According to these authors persistence of these ungulates in the small area of Sikkim plateau may be due to non-hunting practices of the local herders and absence of livestock grazing by domestic livestock during summer season. According to Hussain (2009) kiang showed complete separation with livestock (sheep, goat and horse) with respect to habitat preferences in Hanley valley of Changthang Wildlife Sanctuary, Ladakh. However, Kumar and Mitra (2015) in Niti valley of Nanda Devi Biosphere Reserve, Uttarakhand found that scrub steppe is used in high percentage by blue sheep and livestock and suggested that the area is avoided by blue sheep in the presence of domestic livestock.

Factors affecting rangeland vegetation in the Indian Trans-Himalaya

The Indian Trans-Himalaya is characterized by low productivity, high intensity of solar radiation and high degree of seasonality. The plant species in these altitudes exhibit several features such as reduced leaves, stunted growth, deep tap root system, xerophytic nature. Several factors such as climatic, topographical, bio-geographical and anthropogenic play important role in determining the vegetation structure and plant community composition in these areas. The key factors determining the vegetation of the Trans-Himalayan rangelands are summarized below:

Topography and altitude: Topographic features such as terrain, degree of slope and elevational gradients strongly influence the vegetation communities. For example, scrub steppe, one of the dominant physiognomic units in Trans-Himalayan region of Ladakh is found mostly on gentle slopes with adequate drainage (Rawat and Adhikari, 2005). Alpine grasslands and the sub-nival vegetation are common vegetation features of the landscape at the highest elevations (Dvorsky et al., 2011; Rawat and Adhikari, 2005). Table lands and undulating terrain harbour highest diversity of species in Ladakh (Kala and Mathur, 2002). Kumar and Mitra (2015) found that the species richness among various landforms was highest in morainic deposits (99 species) and scrub steppe (97 species) followed by scree slopes in Niti valley, Uttarakhand.

Moisture availability: In cold arid regions, vegetation types with respect to plant cover largely follow moisture and altitudinal gradients (Rawat and Adhikari, 2005; Dvorsky et al., 2011). The presence of typical plant formations along the river beds comprising of the species of *Myricaria, Salix* and *Hippophae* in entire ITH range corroborates the previous statement. Moist meadows having greatest species richness are mostly dominated by sedge such as species of *Carex* and *Kobresia* and moist areas above 5000m are usually dominated by *Thylacospermum-Arenaria* community (Rawat and Adhikari, 2005).

Anthropogenic factors: Alpine rangelands in the ITH have been used by local and migratory pastoral communities for seasonal livestock grazing since several centuries. Despite a harsh climate, poor vegetation cover and relatively low standing biomass, this area sustains a high livestock population (Rawat, 2007b). Alpine grasslands very likely experience the greatest grazing pressure compared to other areas and the prevalence and dominance of a specific group of plants is determined by grazing history of the region. The vegetation in and around animal resting places or camping sites is scattered along the elevation gradient quite haphazardly because its distribution is partly of human origin. Species such as *Rumex nepalensis, Urtica hyperborea, Chenopodium botrys*, mostly dispersed by livestock prefer growing in animal resting places which could be due to nitrogen enrichment of soil by their dung. Poor species richness compared to other habitats is mainly due to limited extent of these habitats and high disturbance regime which possibly reduce diversity by increasing plant mortality.

Phytogeographic affinities of Rangelands: Western Ladakh and adjacent mountain ranges, Eastern Ladakh, Lahaul and Spiti, Cold arid regions of Uttarakhand and Sikkim plateau represent different biogeographic sub-divisions and provinces. Accordingly, there is a gradual transition of species assemblage across the region from west to east. For example, *Haloxylon-Statice; Acantholimon-Thylacospermum* and riverine scrub vegetation especially *Tamarix-Hippophae rhamnoides* are confined to 1A. In the Sikkim plateau the lower fringes of rangelands have moist alpine scrub dominated by *Rhododendron setosum, Juniperus indica, Salix calyculata* and *Myricaria prostrata.* It is noteworthy that grassy meadows of *Danthonia cachemyriana* and tall forb communities in deep soil are more characteristic of the western Himalaya and are virtually absent in Khangchendzonga National Park, Sikkim (Rawat, 2005). Such differences in the vegetation are largely influenced by phytogeographic affinities with the surrounding regions. The sole presence of *Pinus gerardiana* in dry temperate forests of Kinnaur region compliments the above statement.

Distribution of species across major landforms or habitats:

A number of authors have attempted to classify landforms or habitats in the Trans-Himalayan region. These landforms vary in extent according to altitude and geographic locations. The present ecological review suggests eight major landforms or habitats namely herbaceous meadow, dry sub-alpine and temperate forests, moraine, scree slope, tableland, marsh meadow, riverbed and scrub steppe (Plate 2.1 - 2.12) across the elevational gradients in ITH with their predominant species (Table 2.2). Among various landforms,scrub steppe occupies larger area in all the Trans-Himalayan states followed by herbaceous meadow. The dry sub-alpine forests predominately of *Betula utilis* (remnant patches) and dry temperate forests (*Pinus wallichiana* and *Cedrus deodara*) in lower reaches of the interior valleys in Western Himalaya are relatively absent in North West Himalaya (Ladakh and Lahaul and Spiti). Due to comparatively narrow valleys in cold-arid regions of Uttarakhand and Kinnaur, Himachal Pradesh, the table lands and marshy areas are reasonably absent.

Plate 2.1: Herbaceous meadow

Plate 2.2: Dry Sub-alpine forests

Plate 2.3: Dry temperate forests

Plate 2.4 : Moraine

Plate 2.5 : Scree slope

Plate 2.6 : Table land

Plate 2.7 : Marshy area

Plate 2.8 : Riverbed

Plate 2.9: Scrub steppe vegetation comprising *Caragana-Krascheninnikovia* community in Niti valley, Uttarakhand

Plate 2.10: Overview of an alpine arid pasture in Spiti valley, Himachal Pradesh. ©*Yashveer Bhatnagar*

Plate 2.11: Alpine dry scrub (Scrub steppe) dominated by *Krascheninnikovia ceratoides,* a key stone species in Eastern Ladakh.

Table 2.2 Major landforms/habitats with respect to elevational range, characteristic and dominant vegetation in the Indian Trans-Himalaya.

Elevation range (m)	Landforms/ Habitats	Characteristic species	Reference
>5000	Scrub steppe	*Astragalus* spp., *Acantholimon lycopodioides, Thylacospermum caespitosum*	Rawat and Adhikari (2005), Rawat (2007a), Dvorsky et al. (2011)
	Scree slope	*Aconogonum tortuosum, Astragalus* spp., *Cousinia thomsonii, Cicer microphyllum*	Kala and Mathur (2002), Dvorsky et al. (2011), Angmo (2013)
	Plateau/Tableland	*Elymus nutans, Stipa* spp., *Oryzopsis munroi, Carex moorcroftiana, Oxytropis* spp., *Potentilla bifurca*	Kala and Mathur (2002), Angmo (2013)
	River bed	*Hippophae tibetana, Myricaria germanica, Salix flabellaris*	Joshi et al. (2006), Rawat (2007a)
4500-5000	Scrub steppe	*Caragana versicolor, Krascheninnikovia ceratoides, Lonicera spinosa, Astragalus* spp., *Elymus* spp., *Poa* spp.,	Rawat and Adhikari (2005), Tambe (2007), Dvorsky et al. (2011), Kumar and Mitra (2015)
	Scree slope	*Eriophyton rhomboideum, Cicer microphyllum, Aconogonum tortuosum, Cousinia thomsonii*	Kala and Mathur (2002), Dvorsky et al. (2011), Angmo (2013)
	Plateau/Tableland	*Agropyron* sp., *Trisetum* sp., *Oryzopsis* sp., *Carex* sp., *Oxytropis* sp., *Potentilla* sp.	Kala and Mathur (2002), Angmo (2013)
	River bed	*Hippophae tibetana, Myricaria germanica, Salix flabellaris, S. pycnostachya*	Joshi et al. (2006), Rawat (2007a)
4000-4500	Scrub steppe	*Caragana versicolor, Krascheninnikovia ceratoides, Juniperus* sp., *Lonicera spinosa, Astragalus* sp., *Ephedra gerardiana, Elymus* spp., *Poa* spp.,	Rawat and Adhikari (2005), Tambe (2007), Dvorsky et al. (2011), Kumar and Mitra (2015)
	Scree slope	*Eriophyton rhomboideum, Aconogonum tortuosum, Astragalus* spp., *Cousinia thomsonii, Cicer microphyllum*	Kala and Mathur (2002), Chandola (2009), Kumar and Mitra (2015)
	Marsh meadow	*Kobresia pygmaea, Carex* spp., *Blysmus compressus, Potentilla anserina, Pedicularis tubiformis*	Joshi et al. (2006), Tambe (2007), Angmo (2013), Kumar and Mitra (2015)
	Moraine	*Betula utilis, Cassiope fastigiata, Bistorta affinis, Salix denticulata*	Kala and Mathur (2002), Tambe (2007), Chandola (2009), Angmo (2013), Kumar and Mitra (2015)
	River bed	*Hippophae tibetana, Myricaria germanica, Salix flabellaris, S. pycnostachya*	Joshi et al. (2006), Tambe (2007), Rawat (2007a), Chandola (2009), Kumar and Mitra (2015)
3500-4000	Herbaceous meadow	*Kobresia* spp., *Carex* spp., *Trachydium roylei, Potentilla* spp., *Pedicularis* sp.	Joshi et al. (2006), Tambe (2007), Angmo (2013), Kumar and Mitra (2015)
	Moraine	*Betula utilis, Cassiope fastigiata, Bistorta affinis, Salix denticulata*	Kala and Mathur (2002), Tambe (2007), Chandola (2009), Angmo (2013), Kumar and Mitra (2015)
	Dry sub-alpine & temperate Forests	*Betula utilis* (remnant patches), *Juniperus semiglobosa, Pinus* spp., *J. indica, J. communis, Rosa* spp., *Berberis* spp.	Chandola (2009), Kumar and Mitra (2015)

Elevation range (m)	Landforms/ Habitats	Characteristic species	Reference
	River bed	*Hippophae rhamnoides, Myricaria germanica, M. elegans, Salix flabellaris*	Joshi et al. (2006), Tambe (2007), Rawat (2007a), Chandola (2009), Kumar and Mitra (2015)
3000-3500	Herbaceous meadow	*Trachydium roylei, Potentilla* sp., *Pedicularis* sp., *Bistorta* sp., *Anemone* sp.	Joshi et al. (2006), Tambe (2007), Angmo (2013), Kumar and Mitra (2015)
	River bed	*Hippophae rhamnoides, Myricaria germanica, M. elegans, Salix flabellaris*	Joshi et al. (2006), Tambe (2007), Rawat (2007a), Chandola (2009)
	Dry sub-alpine & temperate Forests	*Betula utilis* (remnant patches), *Juniperus semiglobosa, Pinus* spp., *J. indica, J. communis, Rosa* spp., *Berberis* spp.	Chandola (2009), Kumar and Mitra (2015)

Conclusion

Rangeland vegetation of the ITH is strongly influenced by topography, altitude, moisture availability and pastoral practices. Distribution and abundance of several plant communities can be predicted based on the land forms. There is an urgent need to carry out geospatial analysis of these rangelands and establish baselines for long term monitoring in a coordinated manner. A cadre of trained rangeland managers within Forest and Wildlife Departments would be needed to work closely with the pastoral communities (who have inherited rich knowledge on the management of livestock and optimum utilization of rangelands) so as to evolve strategies for better management. Some of the important parameters for monitoring rangeland vegetation and ecosystem health include: Land use and Land cover classes using Remote Sensing (RS) and Geographic Information System (GIS); Primary productivity and proportion of quality forage which determine the carrying capacity of rangelands and livestock production; Vegetation dynamics; Livestock composition; and Dependence of fuel wood for cooking and heating. Though a few attempts have been made to map the rangeland vegetation, land use and land cover for some pockets, a consolidated and comprehensive vegetation map for the entire trans-Himalaya would be needed for better conservation planning. Similarly geospatial analysis of rangelands showing the distribution of certain keystone species such as *Caragana versicolor* and *Kraschenninikovia ceratoides* would be crucial for predicting the dynamics of rangeland vegetation. For the restoration of degraded rangelands these species along with other leguminous forbs and grasses need to be taken up. Alpine marsh meadows dominated by *Kobresia pygmaea* are the crucial winter season grazing areas for livestock in Changthang, Ladakh. In order to conserve these critical winter feeding grounds of livestock and important wildlife habitats, e.g., nesting areas of threatened birds, it would be necessary to develop integrated rangeland management plans based on participatory processes. Self regulated and good herding practices traditionally followed by the herders in many pockets of ITH would go a long way in maintenance of alpine rangelands (Bhatnagar, 1997; Rawat, 1998; Mitra et al., 2013).

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Plate 2.12: Alpine marsh meadow in Ladhak.

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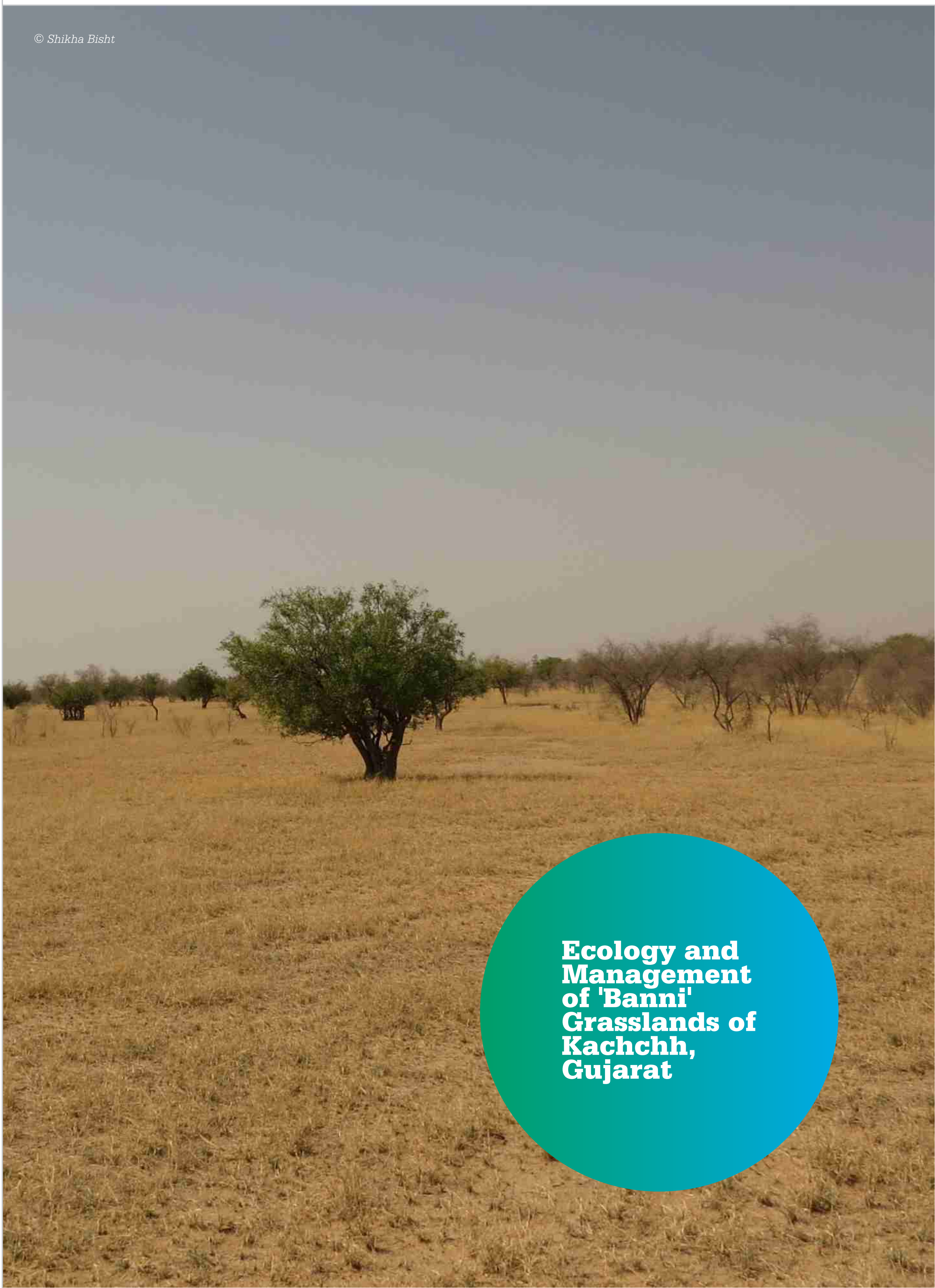

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Ecology and Management of 'Banni' Grasslands of Kachchh, Gujarat

Abstract

Banni grasslands, located along the northern border of Kachchh district in the state of Gujarat, are among the largest stretches of contiguous grassland in India. These grasslands are spread over an area of ca. 2618 km^2, and account for approximately 45% of the pastures in the state. Consisting of two ecosystems in juxtaposition, viz., wetlands and grasslands, Bannis fall under *Dichahnthium-Cenchrus-Lasiurus* type of grass cover. These grasslands harbor a rich array of flora and fauna including 192 species of plants, 262 species of birds, several species of mammals, reptiles and amphibians. Traditionally, Banni grasslands were managed following a system of rotational grazing. With the disintegration of traditional management practices, these grasslands are degrading rapidly due to excessive pressure from livestock grazing and increased soil salinity leading to invasion of *Prosopis juliflora*, water scarcity, climate change and desertification. This article provides a review of current status in terms of biophysical features, land use practices, threats and long term management strategies of these grasslands.

Key words: Banni grasslands; Desertification; Kachchh; Livestock grazing; *Prosopis juliflora*.

Introduction

Grasslands are defined as land covered with graminoid vegetation having less than 10% tree and shrub cover (White, 1983; House and Hall, 2000). Worldwide, grassland ecosystems are predominant in the areas of low-moderate annual precipitation, relatively thin soil, and naturally controlled by fire, grazing, drought and extreme fluctuation in temperatures (White et al., 2000). Much of the land surface in western India is characterized by such biophysical conditions which support one or other type of grassland, scrub savanna or savanna woodland. These habitats support a rich array of fauna, obligate to grasslands. In terms of land use, most of the arid and semi-arid grasslands have been used for livestock grazing by local communities since several centuries.

Kachchh district in the state of Gujarat is characterized by having vast stretches of saline desert, salt marshes and grasslands. The grasslands in this district are popularly known as 'Banni' which are spread over an area of ca. 2618 km^2 (SAC, 2002; GUIDE, 2007) and account for about 41% of the geographical area in the district. Flanked by Greater Rann of Kachchh in the north **(Figure 3.1)**, Bannis represent the largest stretches of contiguous grasslands in India. The word 'Banni' is derived from Kachchhi dialect, 'Bannai', which means freshly made, signifying the land that has been formed by detritus and sediments brought down by the rivers such as Indus, Luni, Banas and Saraswati, which in recent geological past, flowed through this area from the north and the east (Kadikar, 1994).

Banni region has a very fascinating history, geography, biodiversity and culture. Altogether, 13 different communities inhabit the area and vast majority belongs to the Maldharis who reside in 48 villages or 'wandh'. There is a traditional form of human-livestock-grassland interaction, which is still predominant in Banni. Maldharis have inherited traditional fresh water harvesting system known as Virda, traditional knowledge of medicinal plants and breeding drought tolerant highly productive livestock. The herders, especially the Maldharis of the area keep animals of superior breeds, supplying them to various parts of the state and even to other neighbouring states. However, due to establishment of milk co-operative societies, the people of Banni are inclined towards selling the animal products such as milk and butter. The Livestock of Banni area include cattle, buffaloes, sheep, goats, horses, donkeys and camel. There are two breeds of cattle, viz., Kankrej and Gir, of which Kankrej is the heaviest breeds of the Indian cattle and known for excellent drought resistance capacity.

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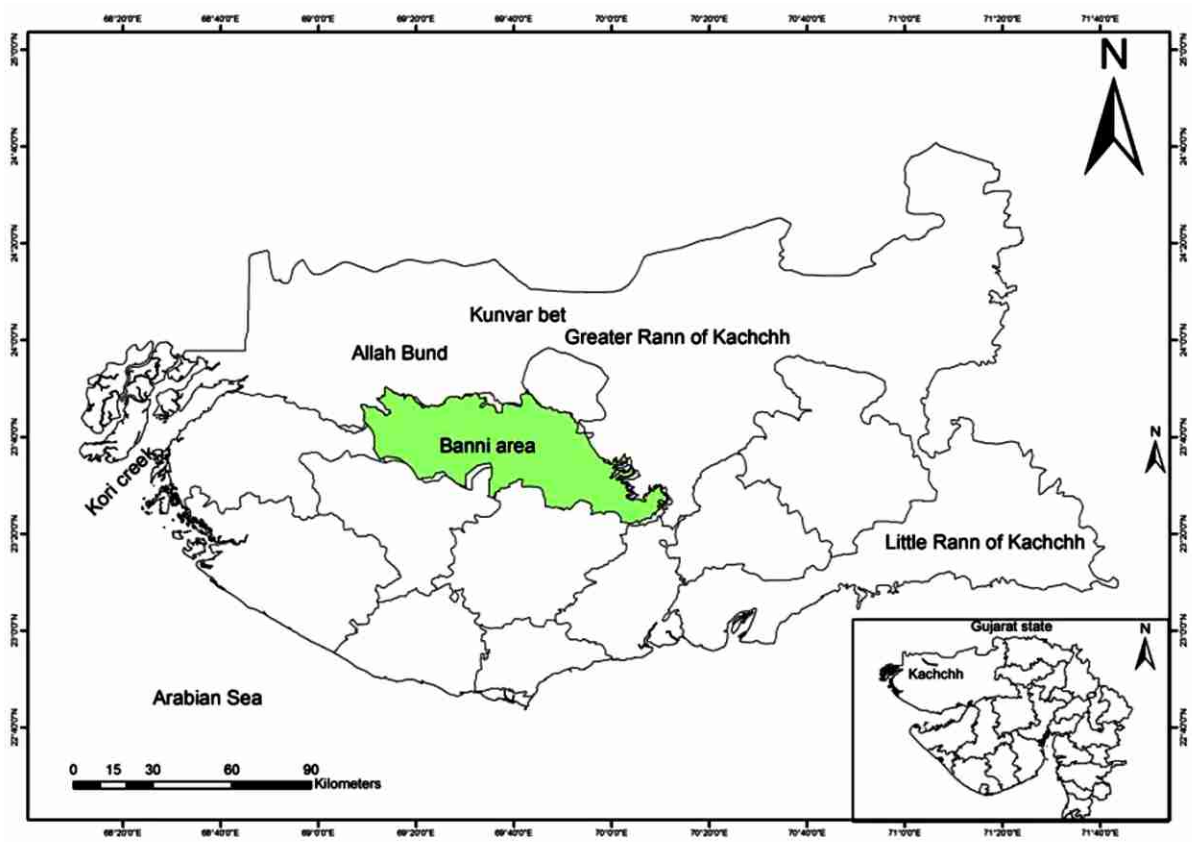

Figure 3.1. Kachchh District – Map Showing Location of Banni Grassland

Besides serving as a major grazing ground for the local herders, Banni grasslands serve as important habitat for a variety of wild fauna. However, unregulated grazing coupled with frequent droughts has led to degradation of Banni grasslands in recent decades. Several authors have raised concern over habitat degradation, desertification and increased salinity in and around Banni grasslands, e.g., Bhimaya and Ahuja (1969), Parikh and Reddy (1997), Singh and Jha (1992), Kanzaria (1994). Currently Kachchh district supports ca. 1.7 million heads of livestock which has increased from 9.40 lakh in 1962 to 17.02 lakhs in 2007 (GUIDE, 2010). This implies that these grasslands are the key to socio-economic growth in the state. Considering this, many government and non-government agencies have carried out investigations and suggested some remedial measures to improve the overall range condition of Banni (GoI, 1966; Ground Water Institute, 1974; ICAR, 1978; National Research Council, 1986; Soil Survey Division, 1986 and WRD and CDO, 1989). However, most of such recommendations were either never executed or were executed without an ecological approach. Therefore, rejuvenation of Banni and restoring it into a sustainable productive ecosystem calls for a holistic ecological approach.

This article deals with the ecological status of grasslands in western Gujarat with special reference to Banni grasslands of Kachchh. We present here a detailed account of its ecological status based on past studies by various agencies, recent assessments and suggest long term conservation and management strategies.

Biophysical Features of Banni Grasslands: An Overview

Banni grasslands consist of two ecosystems in juxtaposition, viz., wetlands and grassland. They provide habitat for resident as well as migratory birds, ideal conditions for many soil fauna and important habitat for typical grassland ungulates such as chinkara and blue bull (Plate 3.1). As per the classification of Dabadghao and Shankarnarayan (1973), Banni grasslands fall under *Dichanthium-Cenchrus-Lasiurus* type. Ecologically, these grasslands belong to the mid-successional/subclimax type of grasslands (Roy and Singh, 2013). The working plan of Kachchh Forest Division (1972) reveals that Banni was declared a 'Protected Forest' under section 29 of the Indian Forest Act (FCA), 1927, under the former Kachchh Government Notification No. HR/155/55 dated 11-5-1955, with an intention to manage the area under the jurisdiction of the State Revenue Department. The vegetation Banni of grasslands is dominated by grasses, few herbs, fewer shrubs and trees. Puri et al., (1959) made some observations on the grasses of Banni area and reported the occurrence of 12 important grass species from Banni. They included the Kachchh grasslands under desert grasslands and reported that there was a patch of *Acacia nilotica* forest at Bhirandiyara, which is located at central part of Banni grassland. Patel et al., (1961) studied the effect of cutting treatments on the grass yield and chemical composition with reference to the nutritional value of grasslands in the Banni area. Plant associations were also reported at Dhordo village, which is located at western part of Banni where the major association recorded, was *Prosopis with Salvadora* species (Pandya and Sidha, 1982).

Patel, et al., (2012) recorded a total of 49 herbaceous plant species, being used as fodder by livestock. In which, the maximum numbers of 21 species were recorded in *Echinocloa* and *Cressa* habitat; followed by 20 species in *Sporobolus* and *Eleusine* habitat; and 19 species in *Desmostachya-Aeluropus* and *Cressa* habitat. A total of 21 highly palatable species were recorded from *Echinocloa-Cressa* communities followed by *Sporobolus-Eleusine-Desmostachya* (18 species) and *Aeluropus-Cressa* (17 species). Based on a detailed floristic study conducted by GUIDE (2010), it is revealed that there are at least 192 species of vascular plants in these grasslands belonging to 142 genera and 50 families in Banni Grasslands **(Table 3.1)**. These species represent herbs (89 species), shrubs (31 species), trees (17 species), twiners and climbers (12 species), grasses (37 species) and sedges (6 species).

Table 3.1: Floral Diversity of Banni (Source: GUIDE, 2010)

Order	Monocotyledon	Dicotyledon	Total
Family	3	47	50
Genera	28	114	142
Species	45	147	192

The shrub and tree strata mainly consist of *Prosopis cineraria, Acacia* spp*., Salvadora* spp*., Capparis decidua, Tamarix* spp. *Prosopis juliflora*. Density of *P. juliflora* ranges from 96 to 1450 plants per hectare across Banni villages (GUIDE, 2010 and Patel et. al. 2012). The average density recorded during winter in western Banni was 668 individuals/ha, 858 individuals/ha in central Banni and 560 individuals ha^{-1} in eastern Banni. Altogether more than 37 grass species were recorded, some of the perennial and palatable grass species with high productivity being Sporobolus, Dichanthium, Cenchrus and Eragrostis. During the period between 2008 and 2012, the biomass studies were carried out in Banni grassland. It was found that total productivity was 3096.16 kg/ha of which only 33.06 per cent (1023.66 kg/ha) was of palatable, while rest was unpalatable. Of this, the productivity of palatable grass species was 483 kg/ha while that of herbs was 539.45 kg/ha (GUIDE, 2004).

Total 262 species of birds belonging to 153 genus of 51 families under 14 orders of Aves were recorded in Banni during the period between 2009 and 2011. Among the recorded birds, 118 were resident to Banni, 76 species were resident and rest of 68 species were migratory. On analysing the feeding habitats of recorded birds, it was found that, 87 species were insectivorous, 69 species omnivorous, 68 species carnivorous, 20 species granivorous, 15 picivorous, 2 species frugivorous and one nectarivorous species. According to the Indian Wildlife (Protection) Act, (1972), 3 species of the total recorded birds fall under Schedule I, Part III and rest of the 259 species belong to Schedule IV. Among the total recorded species of birds, 4 species are Critically Endangered category (CR), one species in Endangered (EN), 8 species under Vulnerable (VU), 11 under Near Threatened (NT) and rest of 238 species under Least concern (LC) category of IUCN Redlist 2011. Further, among the recorded species of birds, 166 species are terrestrial whereas rest of 96 species were aquatic (GUIDE, Unpublished data). Herpetofauna in Banni grasslands include five species of amphibians and 13 reptiles belonging to 13 families. Common species seen in these grasslands are *Naja oxiana* (Black cobra), *Trapelus agilis* (Brilliant Ground Agama), *Uromastrix hardwickii* (Spiny tailed lizard) and *Varanus bengalensis* (Bengal monitor lizard). The seven species belong to two suborder Souria (agamids) and serpent (snakes), they are reported under the family Agamidae (lizards), Scinsidae (skinks), Boidae (*Erix jhonii*) and Colubridae (*Tyas mucosus*). A total of six individuals of *Ophisops jerdoni* was recorded from *Suaeda* Scrub and also recorded in *Suaeda-Prosopis* and *Salvadora-Prosopis* habitats. *Uromatrix hardwikii* was recorded from five different habitats i.e. dense *Prosopis, Prosopis-Capparis, Prosopis-Suaeda-Callotropis* mix, *Suaeda-Prosopis* and *Suaeda* scrub. One individual of snake species, i.e. *Erix jhonii* was recorded in dense *Prosopis* habitat. The *Prosopis-Capparis* mixed forest had only one lizard species of *Calotes versicolor* and one snake species *Tyas mucosa*.

A total of 12 species of mammals belonging to 9 families were recorded in Banni area. They include 6 species of carnivores and 2 species of herbivores. The species recorded are *Gazella bennetti* (Chinkara or Indian gazelle), *Canis* *lupus* (Indian wolf), *Canis aureus* (jackal), *Boselaphus tragocamelus* (Nilgai), *Hyaena hyaena* (striped hyena) and *Vulpes bengalensis* (Indian fox).

Pattern of Habitat Use by Wildlife and Domestic Livestock

A study on the distribution pattern and habitat ecology of birds in Banni was conducted by GUIDE (Koladiya et al., 2014). A total of 91 species were recorded in various habitats of Banni grassland in which, 45 species in were recorded dense *Prosopis*, 56 in moderate *Prosopis*, 60 in sparse *Prosopis*, 28 in *Prosopis-Capparis* mixed, 50 in *Prosopis-Suaeda-Calotropis* mixed, 30 in *Prosopis-Salvadora* mixed and 40 in *Suaeda* dominant. Among the 7 habitats, sparse *Prosopis* habitat harbours diverse bird species with lowest mean population density of 9 individuals/km^2 whereas *Prosopis-Capparis* was the least preferred by the bird species. Thus, bird species diversity and their population density varied among various heterogeneous habitats of Banni grassland both in time and space.

On analysis of seasonal distribution of bird species in 7 identified habitats of Banni grasslands, it was found that sparse *Prosopis, Prosopis-Suaeda-Calotropis* and dense *Prosopis* were the preferred habitat during monsoon season; moderate *Prosopis*, dense *Prosopis* and *Suaeda* dominant are the preferred habitat during winter season while moderate *Prosopis* and *Prosopis-Suaeda-Calotropis* are the most preferred habitat during the month of summer. Mean population density (Mean $\pm$ SD) of birds was recorded highest during monsoon season (19.49 $\pm$ 4.64) and least density during summer season (4.12 $\pm$ 0.98). It was found that the highest population density of birds found in *Prosopis-Capparis* mixed habitat (29 individuals km-2) during monsoon and least density recorded in sparse *Prosopis* habitat (2.8 individuals km^{-2}) during summer season.

The livestock owned by Maldharis generally graze within or around the vicinity of village and have definite grazing routes. Cattle mainly feed on grasses in low to moderate saline areas while buffalo sustain with *Suaeda* which grow in high saline areas. Livestock and wild herbivores share the same habitat for grazing which may overlap at some places.

Key Drivers of Change

Banni, though declared as a protected forest in 1955, till recently was under the administrative control of the State Revenue Department. However, today the scenario has changed and the management control of Banni has been transferred to the State Forest Department. A detailed working plan for Banni was prepared for effective management of Banni (GUIDE, 2010). With the working plan in place, the management of collection, manufacture and removal of the forest produce, cutting of grasses and livestock grazing are being regulated. However, Banni grasslands continue to face degradation. Main drivers of change include increasing soil salinity, invasion by *Prosopis juliflora*, grazing pressures, water scarcity, climate change and desertification. These drivers are discussed below:

Soil Salinity

The soil of Banni is alluvial and sandy with inherent salinity. The soil salinity is highly variable from 1.0 to >15.0 M mhos/cm and the pH ranges between 6.5 and 8.5. About 60% soil consists of moderately fine texture with higher proportion of silt and clay (Singh and Kar, 2001). As a result, 70 per cent area of Banni falls under very slow to slow permeability range (0.00 to 0.13 cm/hr), which along with low elevation (without any gradient) causes flooding and water logging in many parts of Banni during rainy season (GUIDE, 1998).

Though the inherent salinity was existing during the early days in Banni, the rivers (Khari, Bhurud, Nara, Kalia, Kaswati and Panjora), which were flowing from the Kachchh mainland to Banni were not only depositing the detritus but also leached the salinity of the area during good rainfall years. Therefore, the salinity was not a serious problem in earlier days. Six medium dams namely Rudramata, Nirona, Nara, Kaila, Kaswati and Gajansar were constructed after 1960 along the rivers which completely stopped the fresh water flow into Banni and reduced the nutrient supply and leaching of the salinity except during very heavy rainfall years (GUIDE, 1998).

In addition to this, the Greater Rann has a depressed terrain lying between Banni and the Allah-Bund, which extends from the Kori creek eastwards up to Kuver bet, has been inundated by tidal waters of the Arabian Sea through the Kori creek. This has resulted in salinity ingression in about 12 out of 48 villages located along the north-western fringes of Banni. The spread of saline area in Banni is rapid during the recent years, about 50 per cent of the area contains very high (>15 M mohs/cm), 40 per cent moderate to high (3-15 M mohs/cm) and 10 per cent area facing low salinity (1-3 M mohs/cm) problems (GUIDE, 1998). In addition to these, the ground water in Banni is old sea and is unsuitable for any agricultural purposes except adding soil salinity through capillary actions and evaporations.

Further, break down of traditional management systems of the Banni people also forms a major problem in the increase of salinity of the area. During the earlier days, the dung of the grazing livestock was naturally ploughed back into the Banni soil that worked as the best natural manure and it also reduced the salinity of the area to some extent. However, of late, the farmers from Kachchh mainland have been buying cow dung from Banni in large quantities and carrying it to distant place from Banni. This has resulted in disruption of natural mineral cycling and decreased the soil fertility.

Such soil conditions with high level of salinity, low nutrients, low permeability and water logging minimize the potentiality of the area in terms of agricultural production and therefore grassland-based animal husbandry remains the only viable economic option in this area.

Invasion of *Prosopis juliflora*

The period 1960-61 was an important benchmark year in the ecological and socio-economic history of the Banni area when Gujarat State Forest Department took one of the major management interventions to stop the advancement of Rann on the northern fringes of Banni. As a follow-up of the recommendations of 3rd Planning Commission of Government of India, an area of about 31,550 ha was planted with exotic woody species, *Prosopis juliflora* for its ability to establish and survive in the saline soils and low moisture regimes, without evaluating its ecological and associated socio-economic consequences in the future.

The soil salinity situation favours hardy *P. juliflora* which has largely invaded into the ravines and wastelands in Gujarat (Pasiecznik et al., 2001). Though *P. juliflora* is able to thrive moderate (4-8dS/m) to strong (8-15dS/m) saline soils (density 970 individuals ha-1), their growth is better in non-saline or low saline soils (density 2,440 individuals ha-1) and this could be one of the major reason for its invasion into pristine grasslands (Deepa and Lakhmapurkar, 2009).

This is one of the major reasons for its invasion into the pristine grasslands of Banni. Further, the diversity of natural vegetation is low and includes species like *P. cineraria, Capparis decidua, Acacia nilotica* and *Salvadora* spp. These species occur in very few pockets in Banni and their density is low which could not be projected. This clearly indicates the replacement of native vegetation by *P. juliflora*. The principal factor in the process of invasion is the rapid and prolific seeding of mature *P. juliflora* (Zimmerman, 1991) and then facilitated by a curious reciprocal relationship with cattle. During late summer, in the absence of any grass or herbs, nutritious pods of *P. juliflora* forms a greater portion of diet of cattle and buffaloes.

Mature *P. juliflora* could produce ca. 630,000 to 980,000 seeds tree^{-1} year^{-1} (Felker, 1979) and Shukla et al., (1984) reported average pod production capacity as 20 kg/tree. As per Deepa and Lakhmapurkar (2009), average density of *P. juliflora* in all soil conditions is 2053 trees ha^{-1} in Banni. With the existing coverage, the P. juliflora has the capacity to produce 32, 99,446 Tons of pods per year (41 tons ha^{-1} year^{-1}). The seeds of *P. juliflora* have a thick seed coat that necessitates a treatment for quick germination otherwise, it takes long-time to disintegrate the seed coat and germinate under natural conditions. However, when livestock consumes the pods of *P. juliflora*, the seeds get required treatment in the digestive tract of livestock and the animal eventually void the seed through their excrement, frequently a considerable distance from the parent plant. The seeds, still viable, and well fertilized with adequate moisture (cow dung), show a surprisingly high germination rate. The ensuing southwest monsoon in Kachchh that is during late June or mid July supports the treated seeds for recruitment and regeneration.

As per an estimate, cattle defecate 14 times per day (Weeda, 1967) and taking this into account, 60,417 livestock in Banni (Census, 2007; GUIDE, 2010) alone would defecate over 8, 00, 000 times/day and possibly at different locations. This highlights an alarming rate of distribution of treated *P. juliflora* seeds in the Banni area. Further, use of stem as fuel wood by rural folk involves frequent lopping, upon which the root mass enlarges with rich food reserves, aiding rapid and robust regeneration. Further, trials conducted in many parts of the world and in India proved that the eradication of P. juliflora is impossible due to its hardy nature, root morphology and physiology and high level of coppicing capacity.

A study conducted by Space Application Center highlighted the spread of *P. juliflora* at the rate of 2,670 ha. year^{-1} during the period between 1980 and 1988, while it was 4,800 ha. year^{-1} during the period between 1988 and 1998 (Jadhav et al., 1992 and 1998). The results clearly showed the dominance of *P. juliflora* in Banni (86,569 ha) and a comparative analysis showed that during 1997 it occupied about 6.16 % of the total area of Banni increasing to 33.07 % in 2009. Sastry et al., (2003) reported that *P. juliflora* is expected to cover 56.42 % of Banni by 2020. Moreover, decrease in the *P. juliflora* with other vegetation by 74,012 ha. has indicated an aggressive encroachment of *P. juliflora* with the decline of native flora (Table 3.2). Further, the ratio of matured and recruitment category of *P. juliflora* estimated was 1:3 ratio (GUIDE, 2004) in Banni, which highlights the fact that if undisturbed or unmanaged, there could be an increase by three folds. Due to invasion of *P. juliflora*, most of the grassland area has already been turned into woodland and further increase of this species eventually reduce the grassland area of Banni. The pastoralists of Banni have adapted to these changes in plant species composition (due to *Prosopis* invasion), with major changes in livestock composition - principally shifted from more susceptible cattle to sturdy buffalo.

Besides, the area under *Suaeda* scrub and barren land has also increased by 15,684 ha (26 %) at the rate of 1,206 ha year^{-1} indicating an increase in soil salinity levels in Banni during the past 13 years.

Table 3.2. Major Landuse Classes in Banni (Percentage values given in parenthesis)

S. No.	Major Land Use Classes	Area (in ha) in 1997	Area (in ha) in 2009	Change in Area (in ha) 1997-09	Change in Area (in ha) 1997-2009	Per year Change in Area (in ha) in 1997-09
1	*P. juliflora* Dominant area	16,134 (6.16)	86,569 (33.07)	70,435	436.56	5,418
2	*P. juliflora* with other vegetation	1,17,879 (45.03)	43,867 (16.76)	-74,012	62.79	-5,693
3	Grass with sparse *P. juliflora*	51,396 (19.63)	44,091 (16.84)	-7,305	14.21	-562
4	Suaeda scrub (including Barren land)	60,889 (23.26)	74,998 (29.25)	15,684	25.76	1,206
5	Water bodies	15,474 (5.91)	10,672 (4.08)	-4,802	1.03	-369
	Total area	**2,61,772 (100)**	**2,61,772 (100)**			

Disintegration of Traditional Regulation on Livestock Grazing

During the period of princely rule (before 1947), the then Maharao declared Banni, with an area of 2,144 km^2 as a reserve grassland (Rakhal), where grazing by milching cattle and buffaloes was only permitted while sheep and goats were strictly prohibited. Further, the then Maharao did not permit Maldharis and Banniyaras (residents of the Banni) to settle in Banni. Hence, nomadic pastoral practices had prevailed for many years (Ramsingh Rathod, *Pers. Com.*). However, the situation has changed today and the Maldharis of Banni have adopted sedentary mode of pastoralism thereby exerting a constant pressure on the resources.

The traditional practices of regulated livestock grazing have disintegrated in the area and it has been seen that different species of livestock from other parts of the state and neighbouring states gained free entry into the area totalling to over 2 lakh livestock immigrate into Banni for grazing (GUIDE, 1998). Moreover, there is neither a declared grazing policy nor any systematic programme on improvement of grasslands in the state.

It is to be noted that, the water holes (Virdas) of the Banni villages played an important role in regulating the livestock grazing of an area. The grazing of livestock from one village to the boundary of the other was controlled only by banning the use of water to them. In the adverse climate, it is near impossible for the livestock to move over longer distances without adequate supply of water. Thus, the grazing of the livestock was permitted only within the vicinity of their village settlements. Today the scenario has changed and water, is no longer a factor, which governs the livestock grazing due to slacken in the use of virdas and water supply through pipelines. The 600 km long network of Banni pipeline is damaged by the Maldharis at places for providing drinking water to their livestock. This has also encouraged the massive immigration of livestock from other areas, thus, leading to overgrazing and degradation of the area. Heavy grazing coupled with stochastic events (temporary droughts, changes in soil conditions) may convert perennial vegetation into ephemeral vegetation (Christina, 1992). This situation leads to loss of soil cover, which further aggravates the degradation of the area. Among the three regions (east, west and central) of Banni, the eastern Banni has already lost its capacity and the western Banni is slowly losing its capacity to sustain both human and livestock populations. As a result, a maximum concentration of human and livestock population is located at central Banni region (GUIDE, 1998), exerting excessive pressures in this area which may lead to massive degradation due to over exploitation of resources.

The livestock population in Banni was 25,555 in 1977 which increased to 60, 417 in 2007. Overall animal composition in Banni has increased from 21939 ACU (Adult Cattle Unit- 1 Adult Buffalo is equallent to 4 Goats or 4 Sheep) in 1977 to 57898 ACU in 2007. The ACU has increased by 164 percentage which subsequently enhance the fodder demand from 153 tonnes/day in 1977 to 405 t day^{-1} in 2007 (7kg/ACU/day, as per Ahuja, 1994) highlighting a minimum fodder requirement of 1,47,825 t $year^{-1}$. Shrinking grassland due to invasion of *P. juliflora*, increasing salinity, and thereby decreasing the grassland area and its productivity has a cumulative impact on livestock based sustenance of Maldharis in Banni.

Climatic Factors

The climate of Kachchh is typically arid that experiences scanty and highly erratic rainfall with an average annual rainfall of 335 mm with high coefficient of variation. Drought is one of the most important natural phenomena

responsible for grassland degradation in Kachchh. However, through process of evolution, grass species have adapted to drought conditions that enable them to survive as a species, even though individual plants may succumb. Nevertheless, a severe drought causes drastic deterioration of the plant community regardless of severity of grazing pressure. Once the dry spell ends, the grassland recovery depends upon precipitation (moisture availability).

During the period between 1932 and 2013 (a span of 82 years), Kachchh district experienced a total of 48 drought years (59% of the period between 1932 and 2013) in which 26 years faced severe to very severe droughts. It is important to note that the number of severe droughts as well as severe consecutive droughts is on an increasing trend. Two consecutive severe droughts occurred during 1963-1964 and 1968-1969 followed by three consecutive droughts during 1972-1974 and 1985-1987, followed by four consecutive droughts from 2004 to 2007 **(Table 3.2)**. This situation predominantly affected the soil moisture and led to grassland degradation. Prolonged droughts affect the soil water balance and soil organic matter affecting biodiversity of soil biota. Soil stability may well decline as organic matter decreases, resulting in slower warming in summer, and also increased runoff and erosion (Bridges, 1997). Thus, soil and climate, the two of the most critical environmental parameters of life on earth are intimately interrelated and brought together. These factors have contributed to the deterioration of a major part of the grasslands of Banni as well as in Kachchh.

A recent study (between 2012 and 2015) by GUIDE assessed the impact of climate change on livelihoods in Kachchh including Banni. In which 403 respondents were interviewed through a structured questionnaire **(Figure 3.2)**. Majority of 43.7% of the respondents stated that the climate change is impacting on grasslands while 27.8 per cent of the respondents stated that animal husbandry will be impacted. A total of 75 per cent respondents stated that climate change is impacting animal husbandry and grasslands which is one of the prime livelihood resources for the inhabitants of Kachchh.

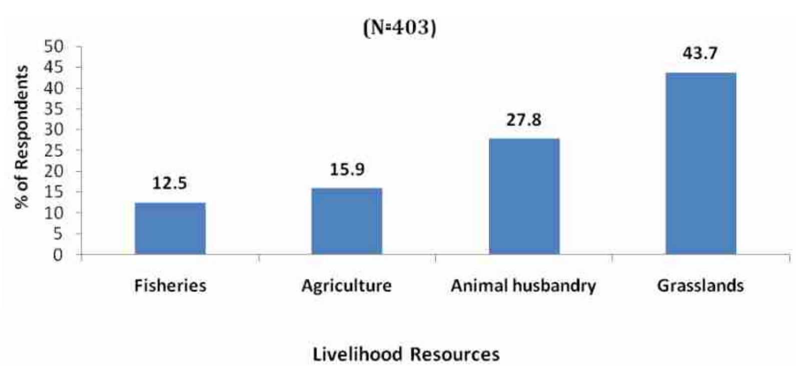

Figure 3.2. *Impact of Climate change on livelihood resources as perceived by local people around Banni Grasslands*

Another interesting fact is the occurrence of heavy rainfall in a single day that has increased drastically during recent years. The **Figure 3.3** highlights that the heavy rainfall days has increased from 1 day in a year during the period between 1973 and 1980 to 3 days in a year between 2001 and 2013. During the period between 2001 and 2013, very heavy rainfall (124.5 to 244.4mm) occurred 6 times, heavy rainfall (64.5 to 124.4mm) occurred 11 times and rather heavy rainfall (35.6 to 64.4mm) occurred 26 times in Kachchh **(Figure 3.3)**.

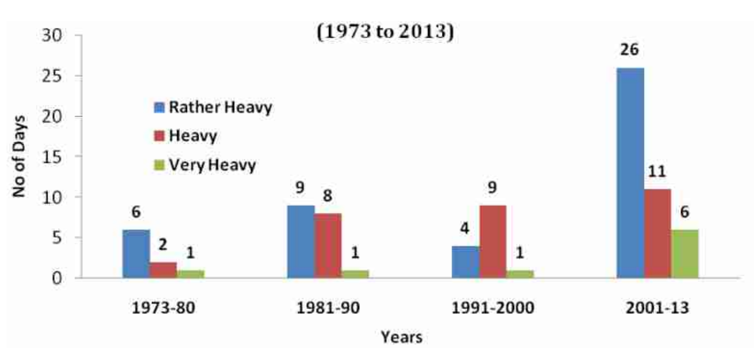

Figure 3.3. *Rainfall pattern in Kachchh from 1973-2013 (Source: GUIDE)*

Banni soil consists of recent alluvium mixed at places with aeolian sandy deposit and the entire area has deep to very deep clay and coarse textured soils in discontinuous patches. The presence of high silt and clay content lessen the vertical and lateral movement of surface and subsurface water and creates water-logging and flooding in low lying areas after monsoon (GUIDE, 1998). Thus the recent heavy rainfall in a single day creates water logging in low lying areas of Banni for number of days. The grasses and grass seeds submerged under water for long duration would decay or fail in germination. Flooding may also increase the incidence of soil-borne fungal diseases (Yanar et al., 1997.

Management Options

The degradation of Banni grasslands is largely attributed to breakdown of traditional resource management system which had helped in the maintainance of equilibrium between environmental system and human activity since several centuries (National Research Council, 1986). Recent interventions such as introduction of *P. juliflora*, introduction of additional livestock have led to reduction in carrying capacity of these grasslands. There is a need to improve the productivity of the existing grassland resources and also reclaim or restore the degraded grasslands to a possible extent. This would enhance the sustainability of the system and help in copping up with the increasing demands from the human and livestock sector. It is essential to maintain fewer and better breeds of livestock to avoid over grazing. This not only reduces the pressure on grassland and maintenance cost of the animals, but also generates sizeable income to the Maldharis. Development of grassland area for fodder security and grazing regulations are essential for maintaining the grassland in a sustainable manner. Appropriate management plan is required for managing *P. juliflora* as an alternative livelihood options and employment generation in Banni and Kachchh. *P. juliflora* has many economic values; pods (after removing the seeds) are highly nutritious which could be used to prepare cattle and human feeds. The seasoned wood of matured *P. juliflora* of more than 20 years old tree is comparable with teak wood for making essential household furniture. Further, being a leguminous plant, apart from enriching soil nitrogen content, it also reduces soil salinity and alkalinity to some extent.

Research to identify suitable remedial measures to control the soil salinity is the need of the hour. This is a core problem for all other issues including expansion of *P. juliflora* and barren lands as well decreasing grassland diversity and its productivity. Drains to leach soil salinity and introduction of saline tolerant grass/herbs would be an option under the scenario. In drought years, the fodder situation worsens which results in large quantities of fodder being imported by the government agencies. The main focus of the government agencies is to provide relief supplies to relieve immediate suffering as though the conditions involved were the result of true natural disasters that were unpredictable and basically temporary in nature. No effort is made to evolve strategies for permanent solutions. In addition, the livestock is forced to migrate to other parts of district or state, which leads to a host of new problems. During high rainfall years, it is flood that affects the animal and human beings and many times causes various diseases, fodder problems, shelter problems, etc. Appropriate disaster management for Banni region is essential to tackle during such calamities.

GUIDE, GEC and GSFD have initiated many grassland development programmes. The programmes need to be strengthened to cover more areas under restoration and undertaken through active participation of local villagers. This apart from fodder security generates employment opportunities to local villagers, enhance the land quality and improve the biodiversity.

To conclude the grassland degradation in Bannis is largely due to lack of management policy or failure of the policy. It is a prerequisite that the planning and policy needs to be integrated using the scientific and local knowledge for developing and utilizing the resource in a sustainable manner. The Banni working plan (2012) is in place and a separate Banni division was formed under the Kachchh Circle of the Gujarat State Forest Department. The forest law and regulation would help in better management of collection, manufacture and removal of the forest produce, cutting of grasses and pasturing of cattle, hunting, etc. However, appropriate awareness and cooperative approaches should be initiated to make this successful.

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Plate 3.1: An overview of a grassland

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The 'Vidis' of Saurashtra

04

Abstract

Saurashtra is located in the peninsular region of Gujarat state in Western India. This region is characterized by hot and semi-arid climate and typically thorn scrub vegetation with high proportion of graminoids commonly referred to as scrub savanna. These areas, locally called 'Vidi', have been used for livestock grazing by the pastoral communities. Despite their low primary productivity and sparse vegetation cover, Vidis serve as important habitat for a large number of threatened fauna and also as a source of fodder during extreme drought. Till the second half of the twentieth century, Vidis in Saurashtra were continuous and rich in grass cover. Expansion of agriculture, invasion of *Prosopis*, human habitation and industries brought a major change in land use pattern making present development unsustainable and induced fragmentation which resulted in patchy distribution of grasslands. This review paper summarises the ecological information on Vidis of Saurashstra and suggests management strategies for the long term conservation of these grazing lands.

Keywords : Grassland; Gujarat; Invasive; Management; Protected Area Network.

Introduction

Saurashtra is located the peninsular region of Gujarat state in the Western India, encompassing an area of 47000 km^2. It is spread between the latitudes 20° 50' and 23° 5' N and longitudes 69° 20' and 72° 10' E. It is flanked by the Gulf of Kachchh and coastal plains in the North, Arabian Sea in the West and South, Gulf of Khambhat in the South East and alluvial plains of Bhavnagar in the East. This region includes seven districts of Gujarat, viz., Surendranagar, Rajkot, Jamnagar, Porbandar, Junagadh, Amreli and Bhavnagar **(Figure 4.1)**. Recently, in the year 2013 four more districts were included in Saurashtra. These are Morbi (former part of Rajkot), Devbhoomi Dwarka (former part of Jamnagar), Gir Somnath (former part of Junagadh) and Botad (former part of Bhavnagar). The Saurashtra peninsula forms a rocky tableland comprising Deccan lava. The region is dominated by an undulating surface broken by hills and various dissecting rivers that flow out in various directions thus rendering a rugged topography. There are three distinct upland units stretching parallel to each other in roughly North-east to South-west direction. The eastern fringe of the peninsula that separates it from the mainland Gujarat is the low-lying ground marking a site of the former sea connection between the Gulfs of Kachchh and Khambhat. The region exhibits hot arid to semi-arid climate, aridity index ranging between 20-40 percent indicating a general deficiency of soil moisture for major part of the year (Jadav, 2010). Mean annual rainfall is about 580 mm and most of the area lies below 300 m asl. The mean annual temperature ranges from 26-27°C with mean minimum and maximums of 11-40°C and extremes being 5°C to 46°C. The relative humidity fluctuates between 65-70 percent. There are three distinct seasons, viz., winter (November – February), summer (March-June) and monsoon (July-October).

Biogeographically, Saurashtra region falls under the province 4B (Semi-arid Gujarat - Rajputana) flanked on all sides by 8A, i.e., West Coast (Rodgers et al., 2002). This region is characterized by having open scrub vegetation with high proportion of graminoids and commonly referred to as scrub savanna which intergrades into sparsely vegetated grasslands which have been used for livestock grazing since several centuries. These grazing lands are locally called Vidi (Gujarat Forest Statistics, 2012-13). According to Dabadghao and Sankaranarayan (1973), the grassland type of semi-arid regions comprising the states of Rajasthan and Gujarat, Western Uttar Pradesh, Delhi and Punjab is *Dichanthium - Cenchrus - Lasiurus* type represented by 11 perennial and 43 annual grass species. The grasslands in Saurashtra cover a total area of 1810 km^2 contributing 20.08 % to the total grassland cover of Gujarat state (State Forest Report, 2011). These

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grasslands form the lifeline of the cattle rearing communities of Saurashtra and Kachcch. The grasslands, apart from having their own ecological significance, form one of the most important sources of fodder, especially during fodder scarcity years (Sugoor and Ande, 2001).

Despite the immense ecological and socio-economic significance of Vidis, very few long term studies have been conducted on their dynamics, structure and function. This paper gives an overview of the recent studies conducted on these grasslands and suggests strategies for their long term conservation.

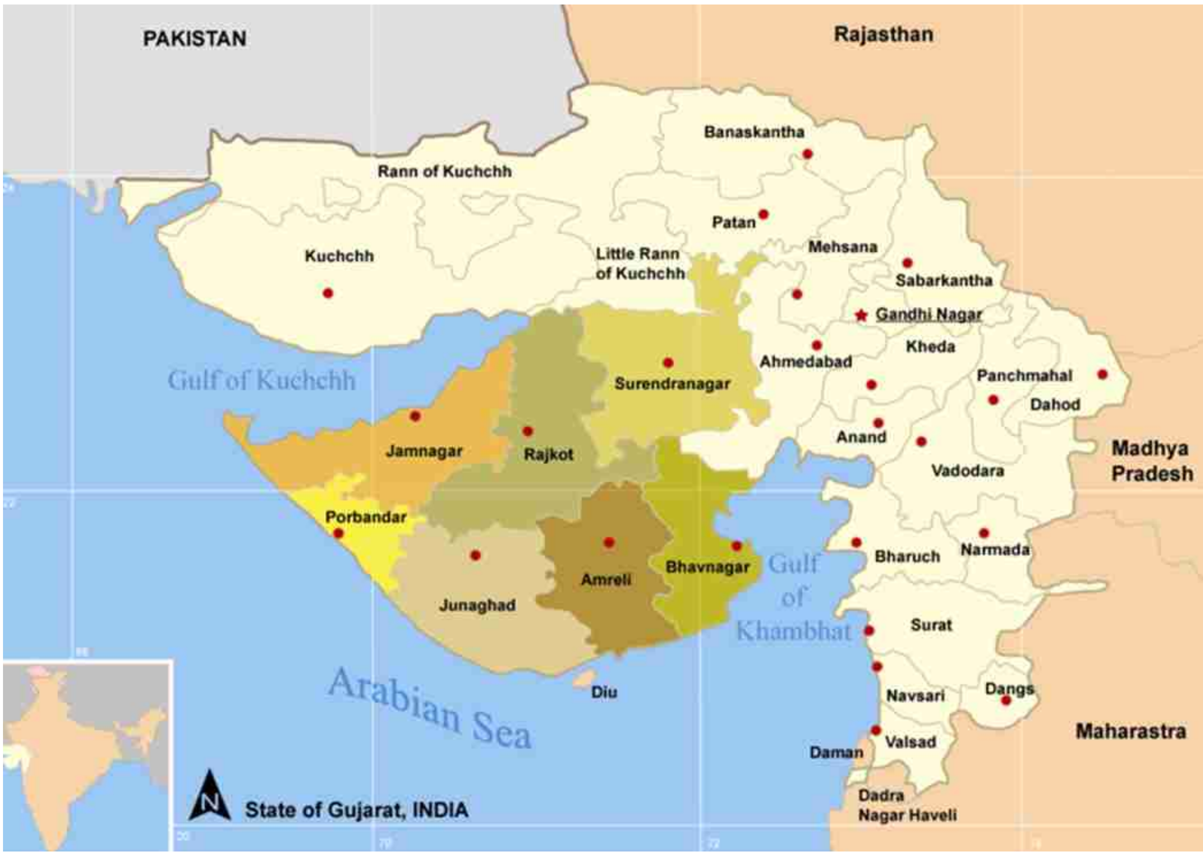

Figure 4.1. Administrative map of Saurashtra with its location in India and Gujarat

Ecological Status of Vidis

Gujarat Forest Statistics (2012-13) reveals that Vidis cover nearly 3.85% of the land surface in Saurashtra (Figure 4.2 & Plate 4.1). There are 106 reserved Vidis and 434 non-reserved Vidis in the region. For administrative purpose, these are distributed among seven administrative divisions, namely Jamnagar, Surendranagar, Bhavnagar, Dhari Gir East, Barda Wildlife Sanctuary, Jungadh and Gir West wildlife division. Jadav (2010) carried out extensive study on the community composition across grasslands of Saurashtra. He identified nine grassland communities (Table 4.1) in the region in relation to different habitats, micro-geomorphic conditions and other factors. *Sehima- Dichanthium* type was recorded in hilly to mild undulating terrain area on gravel soil and basalt underlying rocks. *Sehima- Aristida* type was recorded from hills, piedmont slopes, and foothills. Whereas in similar conditions with oceanic ecoclimate on level soils, as in the intervening valley portions *Dichanthium* type was found to be dominant. *Heteropogon – Cymbopogon* and *Bothriochloa – Aristida* communities are related to the habitat conditions. For example, *Bothriochloa – Aristida* community dominates on dry hills and hillocks with mild grazing. Low lying heavy soils and alluvial plains consisted *Cenchrus – Dichanthium* community. *Eragrostris- Aristida* community dominated highly degraded grasslands with sandy soil, along with *Cenchrus- Eragrostris- Aristida* community which dominate grasslands with similar conditions but with moderate use. *Aeluropus- Halopyrum- Urochondra* community was recorded from only one site of Surendranagar division which consist sandy, saline marsh condition and salt water creek.

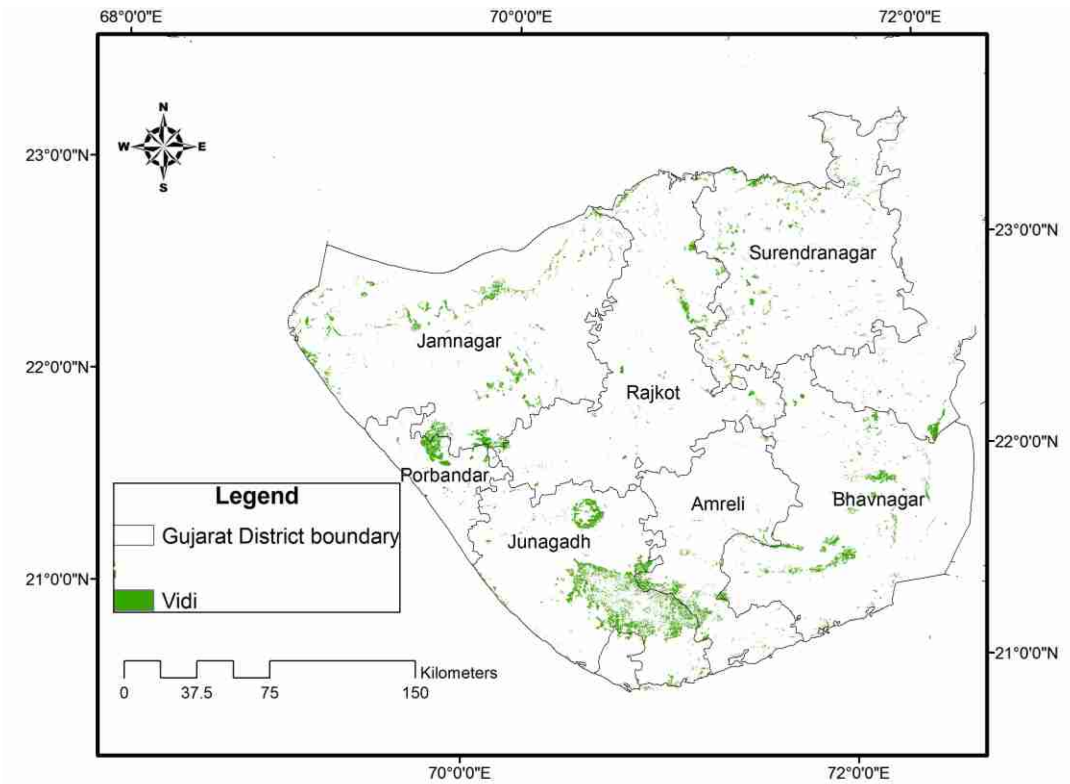

Figure 4.2. Map showing location of Vidis in Saurashtra

Table 4.1. Dominant grass community in various divisions in Saurashtra

Division	Dominant Grass Community
Junagadh	i. *Sehima - Dicanthium* ii. *Heteropogon - Cymbopogon* iii. *Bothriochloa - Aristida*
Bhavnagar	i. *Sehima - Dicanthium* ii. *Sehima - Aristida* iii. *Eragrostris - Aristida*
Dhari Gir (E)	i. *Sehima - Dicanthium* ii. *Sehima nervosum - Aristida*
Surendranagar	i. *Aeluropus - Halopyrum - Urochondra* ii. *Dicanthium annulatum* iii. *Cenchrus - Eragrostis - Aristida* iv. *Eragrostis - Aristida*
Jamnagar	i. *Sehima - Dicanthium* ii. *Heteropogon - Cymbopogon* iii. *Sehima - Aristida* iv. *Bothriochloa - Aristida* v. *Cenchrus - Dicanthium* vi. *Eragrostis - Aristida*
Rajkot	i. *Sehima - Dichanthium* ii. *Cenchrus - Dichanthium*

A total of 58 species were recorded from Saurashtra peninsula (Jadav, 2010), of which thirty eight species were perennial, seventeen species were annual and three species were annual-perennial in habit. A list of grass species recorded from Saurashtra in the study, along with its habit and palatability is given in **Table 4.2**.

Plate 4.1:. Vidis of Saurashtra

Table 4.2. Grass species recorded from Vidis of Saurashtra.
Abbreviations: P- Palatable, NP- Non-palatable, P (young) - Palatable in early stage of life cycle, PR- Perennial species, A- Annual species.

Sr. No.	Species	Habit	Local Name	Palatability
1	*Andropogon pumilius*	A	Zinzu,Govindvel, Baerki	P
2	*Apluda mutica*	PR	Bhangoru	P(young)
3	*Aristida adscensionis*	A or PR	Uth-Lampdo	NP
4	*Arundinella setosa*	PR	Bajariyu, Kotir,Tordia, Vad- bajariyu	P
5	*Brachiaria eruciformis*	A	Shimpi, Wag-hakt	P
6	*Brachiaria ramosa*	A	Chapar,Chapsura	P
7	*Cenchrus biflorus*	A	Motu-dhramanu,Sandbur,Anjan	P(young)
8	*Cenchrus ciliaris*	PR	Anjan, Dhraman	P
9	*Chionachne koenigii*	PR	Garolu,Karang	NP
10	*Coix lachryma-jobi*	A/ PR	Kahudo	P
11	*Cymbopogon martinii*	PR	Rosha grass, Pama- rosa, Roh	NP
12	*Heteropogon contortus*	PR	Dabhsuliyu,Kagadi,Ratad,Kusali	NP
13	*Ischaemum rugosum*	A	Barodi,Tiki-ghas, Gandharu	P
14	*Iseilema prostratum*	PR	Achi-ghas	NP
15	*Panicum antidotale*	PR	Dhansado,Dhuns-ghas, Karkariyu	P(young)
16	*Panicum turgidum*	PR	Taman, Mor-kuba, Gunchi	P(young)
17	*Paspalidium flavidum*	PR	Jinko samo, Goriu,Jungli barvat	P
18	*Paspalidium germinatum*	PR	samo, Goriu, barvat	P
19	*Saccharum spontaneum*	PR	Kans,Thatch,Chia	P
20	*Sorghum halepense*	PR	Baru	NP
21	*Sporobolous helovolous*	PR	Velari-marmar	P(young)
22	*Sporobolous indicus*	PR	Velari-marmar	NP
23	*Sporobolous marginatus*	PR	Marmar	NP

Sr. No.	Species	Habit	Local Name	Palatability
24	*Sporobolous verginicus*	PR	Marmar	NP
25	*Cynodon dactylon*	PR	Dharo, Dhrokhad	NP
26	*Dichanthium annulatum*	PR	Zinzvo, Marvel	P
27	*Eragrostis cilianensis*	A	Kalagi marmar	NP
28	*Eremopogon foveolatus*	PR	Saniyar	P
29	*Eulaliopsis binata*	PR	Sabai ghass	NP
30	*Hackelochloa granularis*	A	Kasiyu, Kasiyu ghass	NP
31	*Halopyrum mcronatum*	PR	Kans	P(young)
32	*Themeda cymbaria*	PR	Ratadun-ghas	P
33	*Themeda quadrivalvis*	A	Bhati, Glader grass	P
34	*Tragus biflorus*	A	Vandhariyu ghass	P
35	*Urochondra setulosa*	PR	Khariyu	P(young)
36	*Vetiveria zizanioides*	PR	Vetiver, Valo, Khas ghass	P
37	*Paspalum distichum*	PR	Moti Kodari, Kodri	P
38	*Sehima nervosum*	PR	Shaniyar, Sheda	P
39	*Iseilema laxum*	PR	Ghavlu,Shata,Dadhel	P
40	*Bothriochloa intermedia*	PR	Dharfo	P
41	*Bothriochloa pertusa*	A/ PR	Khetravjinjvo	P
42	*Bothriochloa ischaemum*	PR	Dungarijinjvo,Jenjavo	P
43	*Cenchrus setigerus*	PR	Dhamnu	P
44	*Cenchrus pennisetiformis*	PR	Motu Dhamnu	P
45	*Chloris barbata*	PR	Mindaliyu ghass	P(young)
46	*Chloris virgata*	A/ PR	Nanu mindaliyu	P
47	*Desmostachya bipinnata*	PR	Dharbh, Kusha	NP
48	*Dactyloctenium aegypticum*	A	Dharo	P(young)
49	*Digitaria adscendens*	PR		P
50	*Dinebra retroflexa*	A		P
51	*Echinochloa colonum*	A		P
52	*Echinochloa crusgalli*	A		P
53	*Elyonurus royleanus*	A		NP
54	*Themeda triandra*	PR		P
55	*Arthraxon lancifolius*	A		P(young)
56	*Melenocenchris jacquemontii*	A		P(young)
57	*Aeluropus lagopoides*	P		P
58	*Chrysopogon fulvus*	P	Dharaf	P

(**Source**- *Jadav 2010*)

Other than grasses, scattered growth of mostly thorny species, such as *Acacia nilotica*, *A. senegal*, *A. catechu*, *A. leucophloea*, *Zizyphus nummularia*, *Commiphora wightii*, *Maytenus emarginata*, *Balanites aegyptica*, and *Euphorbia* sp. etc are found in many Vidis (Jadav, 2010; Mehta, 2014). In some Vidis, especially of the Junagadh division along with the thorny species, *Boswellia serrata*, *Butea monosperma*, *Bauhinia purpurea*, *Terminalia crenulata*, and *Diospyros melanoxylon* were also present, which hinder production of better quality grasses by creating shade underneath. Along with these *Asparagus racemosus*, *Dalechampia scandens*, *Rynchosia minima*, *Phyllanthus racemosus* and *Cardiospermum halicacabum* are main climbers in the Vidis of Saurashtra (Jadav, 2010).

Vegda (2012) conducted work on the folk biological knowledge and utilization of grasses by people in Gujarat. The study mentions that eighteen wild grass species are used by native people in Saurashtra namely *Apluda mutica*, *Aeluropus lagopoids*, *Aristida adscensionis*, *Aristida histricula*, *Bothriochloa pertusa*, *Cenchrus ciliaris*, *Chloris barbata*, *Coix lachryma-jobi*, *Cymbopogon martinii*, *Cynodon dactylon*, *Dactyloctenium aegyptium*, *Desmostachya bipinnata*,

Dicanthium annulatum, Eremopogon foveolatus, Echinochloa colonum, Eleusine indica, Heteropogon contortus and *Themeda triandra.*

Till the second half of the twentieth century, Vidis in Saurashtra were continuous and rich in grass cover. Expansion of agriculture, invasion of *Prosopis*, human habitation and industries brought a major change in land use pattern making present development unsustainable and induced fragmentation which resulted in patchy distribution of grasslands of the region as observed today (Singh, 2001; Jadav, 2010; Mehta, 2014).

Patterns of Habitat Use by Wildlife and Domestic Livestock

The grasslands of Saurashtra are known to be home to a variety of native fauna. Most noteworthy species include the great Indian bustard (*Ardeotis nigriceps*), lesser florican (*Sypheotides indica*), harriers (*Circus* spp.), blackbuck (*Antilope cervicapra*), chinkara (*Gazella bennetti*), nilgai (*Boselaphus tragocamelus*), jungle cat (*Felis chaus*), Indian fox (*Vulpes bengalensis*), jackal (*Canis aureus*), lion (*Panthera leo*), and leopard (*Panthera pardus*). They attract a variety of birdlife and birds of various feeding guilds which occupy these patches of grasslands (Jadav, 2010). Data on grassland avifauna of Saurashtra dates back to 1950s with publications by Ali (1954) and Dharmakumarsinhji (1956). The recent surveys reveal that the great Indian bustard is not being seen in the Saurashtra anymore but historically they were very much present all over Saurashtra except Gir (Rahmani, 2005). The lesser florican is a resident migrant and is prominently seen during monsoon (breeding season) due to the characteristic display of males. The lesser florican has attracted a lot of attention of ornithologists and bird watchers, alike in the area with accounts by Dharmakumarsinhji (1950, 1978), Ali (1954-55), Sankaran (1991, 2000). These birds were observed in most grasslands of Saurashtra almost in all the districts till 1999 but recent surveys mention them being locally extinct from Surendranagar, Rajkot, Jamnagar, Porbandar, Junagadh and Amreli (Bharadwaj et al., 2011). The harriers are migratory and use the Vidis as roosting grounds. Among typical grazing ungluates, nilgai is the most common with average density of 38.24 individuals km^{-2} in the Vidis of Central Saurashtra (Mehta, 2014). The blackbuck and chinkara have a patchy distribution and occur in areas with high level of protection. The Vidis act as day-time refuge providing forage and shelter for these species and all these species are known to cause damage to crops to varying extents in the adjoining agricultural lands in the area (Mehta, 2014). The habitat use and ranging pattern by nilgai was found to fluctuate seasonally and was positively correlated to the availability of food in the Vidis in a particular season (Mehta, 2014). The grasslands are often over exploited by grazing activities by livestock. An average density of livestock in the grasslands in Central Saurashtra and in Eastern Gir was found to be 8.18 $\pm$ 1.33 SE km^{-2} (D.B. Mehta, unpublished data) and 28.73 km^{-2} (Banerjee et al. 2013) respectively. The livestock in Central Saurashtra were recorded in higher numbers during winter especially in Vidis where grazing is legally allowed in the season.

Management Issues and Strategies

Sugoor and Ande (2001) have provided a detailed account of the management practices in the grasslands of Saurashtra. The history of management practices in the region can be summarized under following chronosequence:

Past Management: According to Sugoor and Ande (2001) not much importance was given to management of Vidis during pre-independence period. After independence till 1959, management was done through District Administration. There was a "Ghas Khata" section in the Collectorate to look after protection and management of grasslands. Under this arrangement, 'Grade Chowkidar' and 'Godown Chowkidar' were responsible to protect the grassland and store the grass in godown respectively. Production of grass and its related operation was the duty of Grass Karkun whereas Grass Inspector was given the power to supervise the work of above staff. 'Grass officer' was in charge of several Vidis; monitoring the works and making payments. There was no management strategy with the administration during this period. The modus operandi was very simple. Cut the grass and store in the godowns for three years to supply the same during scarcity. The excess grass was stored in the form of 'ganjis' (openly staked grass bales) for one year and auctioned in the month of May-June. There were no serious efforts to minimize the storage losses or to convert inferior grass into durable hay. Hardly any steps were taken for the overall development of the grasslands. As a result, the grasslands suffered and lost their original production capacity.

Management under Forest Department: These grasslands were transferred to Forest Department in the year 1959-60 with the hope to improve their production status and the revenue supervising management personnel were transferred to Forest Department with change in name and designation. However, the establishment and methodology of management remained the same i.e. protection, collection, storage- no improvement works were carried out. In 1962, there was a shift in management of grasslands by Government wherein Vidis were categorized into reserved and non-reserved Vidis. Based on their production capacity, Vidis producing up to 93,000 kg of grass per annum were classified as non reserved Vidis and above this as reserved Vidis.

Reserved Vidis: At present Forest Department has an area of a 36,457 hectares (106 Vidis) under its control in Saurashtra (Gujarat Forest Statistics 2012-13). Entire management rests with the Forest Department and collected grass is supplied to Revenue Department for distribution. These Vidis are grouped into subgroups A and B, where A is not allowed to be grazed after harvesting of grass, whereas B is allowed. In 1972, Government made grassland improvement measures compulsory and stressed on proper storing of grass. The current management practices commonly include protection from grazing, protection from fire, soil moisture conservation, dribbling of quality seeds before monsoon, plantation of grass tussocks during monsoon, grass cutting after seeding, baling of grass, transportation of grass to nearest depot, storage of grass in stock yard or in stacks in open on platforms, transportation and distribution as per the orders issued by the relief commissioner in the drought hit areas to be sold at subsidized prices (Vegda, 2012).

Non-reserved Vidis: They cover a large area of 51,346 hectares (434 Vidis) in Saurashtra (Gujarat Forest Statistics, 2012-13) managed by Forest Department or auctioned annually to local bodies in the month of June-July to fulfil the local needs. In Gujarat there is a system to make these Vidis available to local bodies on priority basis. At present, priority is given to (i) Gaushalas or Panjarapole, (ii) Maldhari Co-operative Societies, (iii) Village Panchayats and (iv) Any other Milk Co-operative Societies. If none of them are keen to take non-reserved Vidis, these Vidis are put to open auction for collection of grass. It is to be noted that grazing is prohibited in both type of Vidis. The leasing organization is supposed to carry out the improvement works under the overall guidance of the Forest Department.

Village Gauchar and Private Vidis: There is another class of grasslands in the form of Gauchars and private Vidis too managed by respective Panchayats and owners, respectively. But these are not in a position to supply or support the fodder requirement of villages because they are over exploited and lack any efficient administrative network to regulate their use.

Current Management Issues: The main issues being faced by grassland management today include encroachment, developmental activities, mining, fragmentation, illegal grazing, invasion of alien species, human-wildlife conflict and poaching. The rural human population in Saurashtra is increasing at an average rate of 8.14% (Anon., 2013) which is directly or indirectly dependent on grasslands in the area. Most of the grasslands are increasingly bordered by agriculture and are facing heavy encroachment. Developmental activities in the form of Special Economic Zones (SEZ), industries, ill planned road network constructions are highly detrimental to the grasslands and result in fragmenting the already patchily distributed grasslands. Mining for sandstone is rampant in many of these areas usually along the borders of the Vidis. The Vidis are under immense grazing pressure with the livestock numbers increasing at the rate of 15.36% totalling to the number 27128200 in Gujarat (19th Livestock Census, 2012). 789 cases of illegal grazing were recorded in Saurashtra during the year 2012-13 (Annual Administration Report, Forest and Environment Department, Government of Gujarat) in spite of an area of 3820.74 sq km of area kept open for grazing partly or throughout the year. Prosopis invasion is a well-established fact in the country and the species is known to be aggressive in arid and semi-arid tracts, replacing native grasslands and thorn-less shrub lands. These grasslands harbour wild ungulates which cause a major concern in terms of human-wildlife conflict due to crop depredation. The nilgai and wild pig pose serious concerns for the management due to the extensive damage they cause (Mehta, 2014). Some Vidis in Bhavnagar, Amreli and Junagadh constitute the Greater Gir Landscape and hold populations of the Asiatic lion and leopards (Jadav, 2010) and are hence important ecologically. But this also implies the likely conflict that these animals would cause. Poaching of birds such as quails and partridges and mammals such as hare are not uncommon in these grasslands with seizing of nets and snares by the forest department often (D.B. Mehta, pers. obs.).

Conservation strategies

The scrub savannah ecosystem in Saurashtra not only serves as important habitat for a large number of faunal communities but also provides numerous ecosystem services to the local pastoral communities. Fragmentation and degradation of this ecosystem due to faulty land use practices and lack of proper management is likely to result in further decline of native threatened species and decline in pastoral production system. Yet, this ecosystem has not received the desired attention and has been largely neglected in terms of conservation and proper management, except grazing lands, especially in developing countries including India (Rahmani, 1989). Lack of a National Policy on grassland management, habitat degradation, plantations, poor land use planning, invasive species, inadequate coverage of grassland habitats within the protected areas are the major issues faced in conserving grassland habitats in the country. All the management practices outside protected areas currently are designed to supply fodder and are livestock centric. It is time that the management policies start taking the holistic management of these grasslands. Wildlife conservation and proper utilization of grassland habitats are not mutually exclusive (Rahmani, 2005). Any area developed for fodder production not only increases fodder and biomass which is beneficial to local communities but also helps bustards, floricans, wolves, blackbucks and all other wildlife. The key is to involve local communities and properly publicize the benefits of conservation. Once the villagers realize that wildlife conservation increases grass production or that their aquifers and wells are being restored as a result of protection, they will themselves come forward to protect grassland areas (Rahmani, 2005). Though the Vidis and other grasslands in Saurashtra have evolved under the influence of grazing

by wild and domestic ungulates since several centuries, sendentarization of graziers and round the year grazing pressures have led to their degradation in recent years (Rahmani, 2005). The maintenance and conservation of these grasslands thus depends on careful planning and management. Hence, there is a need to evolve a practical grazing policy and a governing and monitoring body for sustainable utilization of grasslands. There needs to be stringent protection and control from illegal and overgrazing of these grasslands. The non-reserved Vidis should be also declared as reserved Vidis under the Indian Forest Act and should be under the control and management of the Forest Department to restore habitats. The current management practice can influence the ecology of a species. For example, while studying the feeding habits of nilgai in central Saurashtra, it was found that the monsoon diet of nilgai was majorly contributed by grasses especially *Sehima nervosum*, a highly valued fodder grass species in the area while in winter there was a shift in the diet towards dicotyledonous food species (Mehta et al. 2013). This shift coincides with the harvesting season and no availability of grass for the nilgai and diversion towards crops. It would hence be worth trying selective harvest in the Vidis where in an area or patches scattered in the grassland are not harvested and left for foraging and more browse species that don't hamper the growth of grasses can be grown in the Vidis to minimize crop raiding events and help in increasing the social tolerance and reduce resentment towards wildlife by the locals, which would help in successful wildlife conservation (Mehta, 2014). Moreover, this would also result in the growth of good quality grass which could act as seed banks for areas that are heavily grazed.

Human encroachment in and around the Vidis and growth of *Prosopis* needs to be kept under check. Also, growth of fast growing woody species and thick canopy species such as *Acacia senegal* need to be prevented and lopping of these trees by the Forest Department to promote better grass cover should be undertaken. Mining activities need to be regulated and kept under check. Grasslands that are patchily distributed could be connected at a landscape level by developing wastelands into grasslands and help in grassland conservation at a landscape level. All Vidis that are part of the Greater Gir Conservation Area and are occupied by lions could be declared as reserved Vidis managed by the forest department and their habitat connectivity with Gir PA should be kept intact for long term conservation of Asiatic lions. The forest staff needs training and capacity building in order to scientifically manage grasslands and address issues in addition to facilitation of infrastructure by the government.

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Grassland Communities of Terai Conservation Landscape: Effects of Management Practices and Conservation Strategies

Abstract

Terai Conservation Landscape (TCL) was conceived as a system for landscape-scale conservation of large mammals, viz., tiger, one-horned rhino and Asian elephant along with their habitats, especially tall wet grasslands. This landscape encompasses a spatially heterogeneous landscape including two protected areas, viz., Dudhwa National Park, Kishanpur Wildlife Sanctuary, and two managed forests viz. North and South Kheri forest divisions, in the state of Uttar Pradesh. The landscape is characterized by a mosaic of moist deciduous sal (*Shorea robusta*) dominated forest interspersed with numerous swamps and tall, wet grasslands. We quantified the plant community structure and composition across major grasslands of TCL and assessed the effects of ongoing management practices on them. This paper highlights the need for adaptive management practices along with need for long term monitoring.

Key words: Burning; Harrowing; *Desmostachya bipinnata*; Terai grassland.

Introduction

Terai Conservation Landscape (TCL) was conceived as a vast extent of dynamic forest-grassland-wetland complex in flood plains of Sharada and Ghagara systems in Uttar Pradesh (UP), representing habitat for tiger, one-horned rhino and Asian elephant (Kumar, 1998, 2002, 2013, 2014; Kumar et al. 2002). Main features of this landscape are extensive tall wet grasslands which are among the home to a large number of threatened species. These grasslands represent successional continuum ranging from early seral stages established within new alluvial deposits to mixed wooded savanna like formations and climax forests dominated by gregarious sal (*Shorea robusta*). Sal occupies older, established and well drained alluvium while low lying and stream banks are areas that are replaced by riverine species such as *Syzygium cuminii* and *Trewia nudiflora* (Champion and Seth, 1968; Lemkuhl, 1994). In seasonally flooded alluvial flats, however, recurrence of early to mid seral communities represented by *Acacia catechu* and *Dalbargia sissoo* can be seen.

Several workers have studied structure and composition of grassland communities in Terai region of UP, e.g., Gupta and Shukla (1991); Pandey and Shukla (1999, 2003, 2005); Tripathi and Shukla (2007); Srivastava (1976); Shukla (2009); Biswas and Mathur (2003); Lahkar (2008); Khatri and Barua (2011). However, very few workers have conducted landscape level analysis of vegetation in relation to environmental changes in this region. Mathur et al. (2003) have identified nine different grassland communities in Dudhwa National Park which can be grouped into two categories, viz., the upland, dominated by short grasses upto 2m in height, e.g., *Imperata cylindrica, Desmostachya bipinnata* and the grasslands of lowlands characterized by tall (~ 6m) grasses dominated by *Sclerostachya fusca, Saccharum narenga* and *Themeda arundanacea*.

The grasslands in TCL have been extensively grazed, harvested, and annually burned since long time except in the Dudhwa National Park where livestock grazing and grass harvest have been officially banned for more than past 20 years. However, some level of illegal grazing and harvest of grasses in peripheral areas does take place and occasionally. Within Dudhwa, some grasslands were harrowed and burned to promote new grass growth during recent past. In order to assess the impacts of such management practices and to see the status of grasslands within the larger landscape, we initiated a study during 1998. The effect of different treatments and seasons on the above ground biomass and habitat use by two ungulates i.e. swamp deer and hog deer was measured to assess the effectiveness of different management practices by the park managers. The grassland management practices within the park were (1) grass cut and burned; (2) grass cut, removed, and burned; (3) grass harrowed and burned; and (4) grass burned for assessing the impact of different treatments on the above ground biomass and relative pellet occurrence of two ungulate species i.e. hog deer and swamp deer in in the short upland and tall lowland grassland types.

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Materials and Methods

Site description

The Terai Conservation Lanscape (TCL) is spread across four districts viz., Lakhimpur Kheri, Pilibhit, Shahjahanpur and Bahraich in the state of UP between 27° 49' and 28°43' N Latitudes and 81° 01' and 81° 18' E Longitudes. The TCL constitutes a spatially heterogeneous landscape of PAs, including Dudhwa National Park (DNP) and Kishanpur Wildlife Sanctuary (KWS), and managed forests (MFs) of North Kheri and South Kheri Forest Divisions within a matrix of private agricultural lands. The major portion of the TCL (~97%) comes under Lakhimpur Kheri with altitude ranging from 150 m in the south-east to 182 m in the north. The alluvial soils range from sandy in elevated areas and along the high banks of river to loamy in the level uplands, and clays in depressions. The climate of Terai region is typically tropical monsoon type with three distinct seasons: winter (mid October to mid March), summer (mid March to mid June), and monsoon (mid June to mid October). Temperature and humidity extremes occur in different seasons; heavy dew fall during winter, frequent frosts in December to mid February with January as the coldest month (mean maximum 19.6°C; mean minimum 8.8°C). May and June are the hottest months with mean maximum 42.7°C.

Grassland Sampling

The grasslands of TCL were stratified into two categories, viz., Upland and Lowland types. The former is characterized by sparse trees and shorter grasses while the latter is devoid of trees, mainly due to their annual flooding and burning. A total of 293 plots of 10m x 10m were laid covering 24 different patches in the upland and lowland grasslands. Cover and abundance were estimated for grasses, shrubs, herbs, and sedges. Data collection in grasslands was carried out in the post-rainy season i.e. October-December, 1999 and 2000, when the majority of grasses and other herbs were flowering, aiding identification, and also just before grasses were ready to be burnt in January-February. Lowland grasslands were inaccessible on foot due to surrounding swamps. Here plots of (10m x 10m) were marked and quantified from the elephant back. Cover/abundance for each species was rated on the Domin scale (1-10, or a "+" for solitary plants). This was done as described by Mueller-Dombois and Ellenberg (1974). Unknown species were described, numbered, and collected for later identification.

Treatments, Sampling and Data Analysis

Representative areas of the upland (*I. cylindrica – D. bipinnata*) and Lowland (*S. fusca – S. spontaneum*) grasslands in the Madria and Sathiana areas of the DNP were selected to test the effects of burning. Plots of 100 x 260 m (replicated three times) were laid out in each grassland type and split into five 100 x 50 m treatment sub-plots for the four burning treatment plus a control block which was separated by 10m fire-break. Before the burning treatments were applied, quadrats were sampled to establish a baseline for plant composition; phenology, grass height, above-ground total biomass and pellet count (swamp deer and hog deer) were done in January 1998. The different treatments (i.e., grass cutting, removal, harrowing) were completed by 25 January followed by burning on 28 January, 3 February, and 5 February for three consecutive years i.e. 1998, 1999, and 2000, respectively.

Standing biomass was assessed in 10 random 1 x 1m quadrats in each treatment plot. Standing biomass (live and dead) was cut at the ground level with sickles and weighed in the field. Biomass was sorted and fresh weight for each species recorded. Sub-samples (about 100g) were chopped, transferred to separate paper bags, weighed, dried in a hot-air oven at 800 C and weighed to determine dry weight. The values for the 10 plots were averaged to provide a biomass estimate for treatment plots at each sample date. The grassland classification analysis was carried out using the polythetic divisive clustering technique TWINSPAN (Hill, 1979). Pseudo-species cut levels were set at 2%, 5%, 25%, 50%, and 75% cover, whilst all other options were set to default levels. The groups resulting from the TWINSPAN analysis are summarized in the present study by including only indicator species and strongly preferential species for each group to avoid producing long lists of species (Peet et al., 1997).

Aboveground biomass and relative pellet occurrence data were initially analyzed using 2-way Analysis of Variance (ANOVA) to investigate the effect of treatments and seasons individually. Subsequently multiple range comparisons were done for each grassland type using Tamhane's T2 Test to detect effect of interactions among different treatments and seasons. SPSS/PC+ based software was used for all analyses (Norusis, 1994).

Results

In all, nine species assemblages were identified through TWINSPAN analysis in the present study. These assemblages include only indicator species and strongly preferential species. The first division of samples separated the outlying *Typha elephantina* assemblage at 81%, which generally occurs in water logged areas. The second split divided the Upland and Lowland communities at 75% dissimilarity, and further separated out at different level of dissimilarity. These assemblages along with their habitat specificity are as follows:

1. *Typha elephantina* (TE) assemblage - Permanently water logged sites.
2. *Vetiveria zizanioides -Saccharum spontaneum* (VZSS) assemblage – Upland grassland well developed soils heavily grazed.
3. *Cymbopogon jwarancusa – Saccharum bangalense* (CJSB) assemblage - Upland grassland, dry sites frequently burned, least grazing
4. *Imperata cyclindrica – Desmostachya bipinnata – Saccharum spontaneum* (ICDBSS) assemblage - upland grassland, dry sites well developed soils.
5. *Themeda arundinacea – Saccharum narenga- Apluda mutica* (TASSAM) assemblage -Tall dense grassland, often at forest edge, well developed soils influenced by fire.
6. *Saccharum narenga – Apluda mutica* (SNAM) assemblage - Flood plain grassland alluvial soils influenced by fire
7. *Saccharum narenga – Saccharum spontaneum – Apluda mutica* (SNSSAM) assemblage – tall dense grassland, old river terraces and wetter soils influenced by fire
8. *Sclerostachya fusca – Saccharum spontaneum – Apluda mutica* (SFSSAM) assemblage - seasonally inundated tall dense grassland.
9. *Phragmites karka – Arundo donax* (PKAD) assemblage - Tall dense grassland, seasonal and marsh.

Dabadghao and Shankarnarayan (1973) in their classification of Indian grasslands had recognized just one cover type from Terai region, i.e., *Phragmites – Saccharum – Imperata*. However, they had identified 19 principal grass species as constituents of this cover type all across Gangetic and Brahmaputra flood plains. However, their classification does not account for the diversity of plant species assemblages in the Terai grasslands as have been identified by Lehmkuhl (1994), Peet et al., (1997), and the present study.

The effect of the four burning treatments on the above-ground biomass (AGB) revealed that three grasses formed the bulk of cover and standing biomass i.e., *I. cylindrica, D. bipinnata* and *V. zizanoides* in the Upland grassland. Similarly, *S.fusca , S. narenga and S. spontaneum* formed largest proportion of the standing biomass in the Lowland grassland. The dominance of these species was maintained under all the treatments. The only exception was the harrowed-burned treatment in the lowland grasslands that were invaded by *Desmostachya bipinnata* and persisted for more than 3 years.

The managed (burned) plots showed an increase in the number of shrubs, herbs, sedges and ferns. Thus, treated plots were heterogeneous in composition and structure, whereas the unmanaged plots were more homogeneous. The increase in number of herbaceous and other species was a result of disturbance by different burning regimes. These disturbances resulted in decreased canopy density and an increase in gaps in the managed grassland swards into which other species invaded. Earlier studies have reported a general principle that herbaceous species have a greater capacity than the dominant inferior competitors to colonize gaps in disturbed communities (Horn and MacArthur, 1972; Crawly and May, 1987; Peet et al., 1997). Different burning regimes substantially reduced standing biomass immediately after each of the treatments. However, at the end of three consecutive years of different burning treatments, only a marginal difference in AGB values was registered in each case. Lowest AGB (16%) was under the harrowed-burned treatment given to the Upland grassland. The Lowland grassland also responded similarly to the four treatments over the three years and there was a maximum decline of AGB to the extent of 14%. Thus marked negative effect of the harrowed-burned treatment on AGB was evident in both the type of grasslands and also at all stages of the experiment.

There were significant differences between the AGB for the four treatments. However, the multiple comparisons using Tamhane's T2 Test showed that there was no significant difference between (1) cut-burned and cut – removed - burned; (2) cut-burned and burned; and (3) Cut-removed - burned and burned alone treatments on their corresponding values of AGB in the Upland grassland. Likewise, the cut-burned and cut-removed-burned treatments in the Lowland grassland also had no significant difference. This result supports earlier findings of Peet et al. (1997) which showed that there was no difference ($p < 0.001$) in cutting alone, burning alone and cutting and burning combined.

The Null hypothesis that there is no effect of treatments and seasons on the above ground biomass in both the type of grasslands was rejected. Multiple comparisons performed using Tamhane's T2 test showed that there were no significant differences between (i) cut-burned and cut-removed-burned; (ii) cut-burned and burned; (iii) cut-removed-burned and burned treatments in the Upland grassland on the basis of their corresponding AGB values (Table 5.1). Likewise, the cut-burned and cut-removed-burned treatments in the Lowland grassland had no significant difference. All other comparisons among treatments in the both grassland types were highly significant at the 0.05 level.

Table 5.1. Multiple comparisons for the above ground biomass among different treatments in the Upland and Lowland grasslands using Tamhane's T2 Test

Treatment (I)	Treatment (J)	Upland Grassland Mean Difference (I-J)	Upland Grassland Significance (P)	Lowland Grassland Mean Difference (I-J)	Lowland Grassland Significance (P)
Control	Cut-Burn	340.0	.000***	994.6	.000***
	Cut-Removed	356.0	.000***	1055.8	.000***
	Harrowed-Burned	455.7	.000***	1311.3	.000***
	Burned	302.4	.000***	471.7	.000***
Cut-Burned	Cut-Removed -Burned	16.0	.998NS	61.2	.961NS
	Harrowed-Burned	115.7	.000***	316.7	.000***
	Burned	-37.6	.510 NS	-422.9	.000***
Cut-Removed-Burned	Harrowed-Burned	99.6	.000***	255.5	.000***
	Burned	-53.6	.099 NS	-484.1	.000***
Harrowed-Burned	Burned	-153.3	.000***	-739.6	.000***

****- Significant at the 0.001 level; NS – Non-Significant.*

Nevertheless, the effect of four burning treatments on the species composition and standing biomass of major grass species was prominent in both the grasslands. *I. cylindrica*, the major contributor to the standing biomass in the Upland grassland declined considerable (40-53%) in its AGB in all treatments at the end of three years. The maximum loss (53%) was in the harrowed-burned treatment while the minimal loss (40%) was in burned alone treatment. The opposite effect was evident in the control block where *I. cylindrica* AGB increased by 10% by the end of experiment. In contrast to *I. cylindrica, D. bipinnata* increased its contribution to AGB from 1% to 37% in three treatments (cut-burned; cut-removed-burned; and cut-burned) and the control. The maximum gain was in the harrowed-burned treatment which favoured *D. bipinnata* at the expense of *I. cylindrica*.

The burned only treatment was the exception in which *D. bipinnata* declined by 4% in its AGB at the end of three years. The decrease of *I. cylindrica* and the increase of D. bipinnata can be attributed to the fact that the *I. cylindrica* is a sod-forming species that grows in dense swards (Lehmkuhl, 1989) whereas *D. bipinnata* and other grasses such as *V. zizanoides, S. spontaneum* and *S. narenga* have a clumped habit, often with wide spacing between clumps. *I. cylindrica* is also known to be very susceptible to shading; perhaps the dead material on the unburned (control) plots and burned alone treatment with remnant unburned portions shaded the surface sufficiently to depress surface temperature, nitrogen mineralization and growth from basal meristems (Weaver and Rowlands, 1952; Lehmkuhl, 1989). Thus, on one hand the shading effect must have influenced new growth and AGB, whereas on the other hand, intense grazing and utilization of new growth by wild ungulates in the four burned treatments may explain the reduction in I. cylindrica AGB. *D. bipinnata* was definitely favoured by the open conditions created in the Upland grassland by different burning treatments except the burned alone treatment. *D. bipinnata* which was otherwise absent in the Lowland grassland prior to the commencement of experiment in January 1998 abruptly emerged and established in the harrowed-burned treatment. In contrast, *S. fusca and S. narenga* were adversely affected in the harrowed-burned treatment with AGB of both species significantly reduced by 47% and 53%, respectively by the end of three years. The managed Upland and Lowland grassland plots distinctly favoured wild ungulates, particularly immediately after the treatments were applied and during summer. Thus, the management objective of promoting new growth and palatable grass during the lean season was achieved. The swamp and hog deer had greater relative pellet occurrence in the harrowed-burned and burned alone treatments in the Upland grassland. In the Lowland grassland, the harrowed-burned and cut-burned treatments were most favorable, while the burned alone treatment was for the most part avoided. The relative pellet occurrence of swamp deer and hog deer substantially increased in the four managed Lowland grassland plots than the control plot immediately after they were treated. The values of relative pellet density ranged from 58.3 pellet groups/ha to 172.5 pellet groups/ha in the burned alone and cut-burned treatments, respectively in April (1998-2000). This was followed by a considerable decline in the ungulate use in all the four managed Lowland grassland plots. Gradual decline further continued in all the cases even in the month of October (1998-2000) and finally the lowest values were recorded in January, 2001 after the three years of repeated treatments. The open ground situation due to the cut-burned, cut-

removed-burned, and harrowed-burned treatments was more selected than the burned alone treatment. Both the ungulates used open areas for resting while new tender shoots for foraging. In all the cases, the values of pellet counts in the unmanaged plot (control) remained low. These low values can be attributed to the fact that the unmanaged grassland continued to have tall, dense coarse grass, which could not attract swamp deer and hog deer. It is also possible that the dense grass situation might have also affected an efficient counting of pellets while it was easier to locate pellet groups and count them in the four managed grassland plots.

The *Imperata cylindrica–Vetiveria zizanoides* community in the Upland grassland supported grazing throughout the year, particularly in the harrowed-burned and burned alone treatments. Hog deer grazed more heavily in the harrowed-burned and burned alone treatments, but selected plots subjected to burning alone since this type of treatment left more cover to hide in. Hog deer selected relatively much less two other treated areas. Swamp deer also used more the harrowed-burned and burned alone treatments than the two other treatments.

ANOVA results showed a highly significant difference between all the treatments and seasonal use of managed Upland grassland by swamp deer and hog deer (Table 5.2). The multiple comparisons among treatments revealed a highly significant difference in use of the control vs. treatment plots. The ANOVA results showed a highly significant difference in the pellet counts of swamp deer and hog deer under the four different treatments given to the Lowland grassland.

Table 5.2. Effect of different burning practices on the relative pellet occurrence of swamp deer and hog deer in the upland grassland in a full factorial ANOVA design

Source of Variation	Degree of freedom (df)	F-Ratio*
Model	24	24.257
Treatments	4	28.477
Seasons	4	72.112
Treatment seasons	12	6.366
Total	**366**	

Discussion

Studies by Karki (1997), Mishra (1984), Brown (1997) and Peet et al. (1997) have indicated that the Terai grasslands are maintained in part through human intervention. This study also corroborates the earlier observations and reveals that current rates of biomass removal are not adversely affecting the condition of the tall grasslands. Rather, the current practices bring benefits to both local communities and to wildlife. However, whether the practices are sustainable, and in what way they can be regulated, is open to question. Present study showed that there was no significant difference in the overall standing biomass among the four treatments when compared to the control plot. At the same time, earlier studies (e.g. Peet et al. 1997; Kumar et al., 2002) and data presented here all report the increases in abundance and AGB of *D. bipinnata* (a species of relatively poor value to wildlife and local people) and a decrease in preferred grass species in the managed plots, particularly the harrowed-burned treatment. The resultant change of the Upland grassland dominated by *I. cylindrica* and the Lowland grassland dominated by *S. fusca, S. narenga* and *S. spontaneum* to a homogenized grassland dominated by *D. bipinnata* due to repeated harrowed-burned treatment is a major management concern unless regular monitoring of species composition and abundance is instituted.

It is also clear that ending the current practices of cutting and burning would remove the real benefit of the availability of new growth of palatable grasses to ungulates during the lean period. Grass removal by local communities and periodic burning are also helping in controlling hotter and destructive summer fires by reducing fuel loads which has a positive effect on the ecology of these grassland systems. Therefore, maintaining the status quo, by annual cutting and burning would provide ungulates with summer forage from the regenerating grassland also well provide important subsistence resource to local communities. Most studies have confirmed that biomass removal of whatever form (including grazing; Lehmkuhl, 1989) resulted in a similar species composition, abundance, structure, and standing biomass at the time of termination of experiment. However, the harrowed-burned treatment has marked influence on the species composition, standing biomass, phenology, and ungulate use. In view of the above, it is evident that some sort of patch cutting and burning of both the grassland types would produce a mosaic of suitable habitats for the persistence of diverse faunal species in Terai (Plate 5.1 - 5.3). Staggered cutting and burning would also create different patches providing varying forage and cover conditions. However, patch size would be critical for success; a patch too large would be hard for

herbivores to crop fast enough to keep the grass short, and a patch too small might be overgrazed and may not provide adequate benefits to warrant management.

Conclusion

It was found that harrowing as a management practice did not result in the improvement of grassland quality and rather it resulted in the proliferation of coarse and poor quality grasses such as *D. bipinnata*. This implies that this practice should not be continued for the management of grasslands within Terai PAs. While the other management practices, such as burning, cutting and removing of dry biomass, and grazing helped in regeneration of desirable species. Hence judicious use of these tools could help in maintenance of grassland quality. Creating mosaics of different successional stages and creation of different grassland patches proved to be better for ensuring spatial distribution of grazing ungulates.

Recommendations

(a) Most of the hygrophilous (tall wet) grasslands in the TCL are highly threatened. All such grasslands outside the PAs form important corridors for threatened grassland fauna. Hence, such patches need to be given high priority for conservation.

(b) Several grassland patches are degrading rapidly due to over grazing by domestic livestock and infestation by alien invasive species and encroachment by woody species. There is a need to manage such degraded grasslands especially outside the PAs.

(c) Ideal season to burn Terai grasslands is peak winter i.e, before February 15, because the nesting of the birds starts after that. Moisture regime of the grasslands should be taken into cons detain before burning.

(d) In recent years, the Terai of U.P. has become prone to highly destructive flash floods which affect the grasslands. These grasslands are managed by burning and the effects of flooding, therefore monitoring protocols need to be developed.

(e) Intensive research work by Kumar et al. (2002) on tall grasslands of Dudhwa Tiger Reserve and the adjoining North Kheri and South Kheri Forest Divisions should be replicated for the entire Terai ecosystem, from Rajaji National Park to the Brahmaputra floodplains.

(f) Adaptive management is very important for the grassland patches which support species of conservation concern, e.g., Bengal Florican, because if these patches experience succession from short grasslands to tall grasslands these endangered species will also disappear.

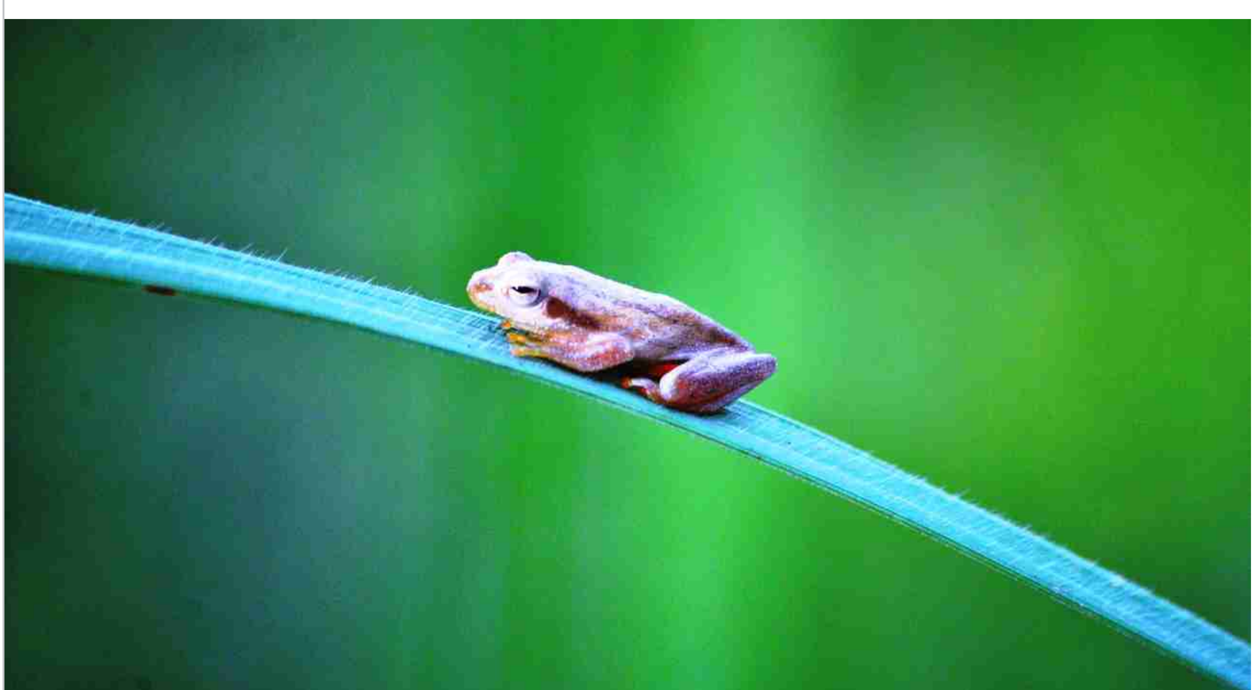

Plate 5.1: Dudhwa Reed Frog

Plate 5.2: Pied bushchat

Plate 5.3: Use of fire for habitat improvement © Karma C. Bhutia

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Does Fire Make the Edge Between Grasslands and Sholas in the Western Ghats? Observations from the Palni Hills

Abstract

We investigated soil properties, vegetation structure and composition as well as signs of disturbances on grassland-shola-edge at two locations in the Palni Hills, an eastern off shoot of the Western Ghats, South India. We also assessed the fire frequency in the upper Palni hills with Landsat data between 2000 and 2012. We found that soil properties, vegetation structure and composition as well as disturbance signs were of a fire prone grassland and ecotone. According to the Landsat data 90 % of the grasslands faced fire during the 12 years of observation. Our hypothesis was that fire prevents the forest succession on grasslands which is in accordance with the literature of the early 20^{st} century. More recent studies oppose this and state that frost, wind or the edaphic factors maintain the high elevation grasslands of the Western Ghats. We reviewed this debate concluding that fire is the only valid explanation for the appearance of the sharp ecotone between grassland and forest. To test this hypothesis we assessed soil and vegetation properties in grassland, on the ecotone and in the forest (2, 1, 2 plots along a transect vertical to the ecotone respectively). We found a significant increasing trend in humus depth, soil depth and fertility and all over plant diversity towards the forest interior. All vegetation formations showed abundant regeneration of tree species, while the number and diversity reduced drastically with increasing tree size, especially on grasslands. All trees on grasslands showed signs of fire while only 5% and no trees were burned in the ecotone and Shola respectively. Signs of grazing and trampling were present in almost all the plots, the former being predominant in the grasslands while the latter in the ecotone.

Based on the study and review of literature we conclude that fire keeps the grassland-forest edge stable, though the sources of fire are not known. For the grassland management we recommend to understand the interplay of fire regimes and biodiversity. Based on this fire should be applied in a controlled manner, if the conservation of grasslands is the focus of landscape management.

Keywords: Biodiversity; Fire; Grassland-Shola-ecotone; Soil; Western Ghats.

Introduction

The high elevation grasslands of the Western Ghats harbor an inimitable community of endemic species (Thomas and Palmer, 2007) and are therefore considered a conservation priority (Robin and Nandini, 2012). To conserve these ecosystems, accordant concepts for their management need to be in place. Such management plans need to be developed based on knowledge about the dynamics these ecosystems perform as a reaction to site conditions and disturbances. This goal has not been achieved yet. Rather a debate has been going on,almost since the beginning of the last century, on the origin of these grasslands (Vasanthy 1988; Sukumar et al. 1993, 1995; Caner et al. 2007) and the drivers that maintain them today (Champion 1936; Bor1938; Meher-Homji 1967; Jose et al., 1994). In this context it is often concluded that grasslands and forests represent a stable coexistence under the similar climate (Robin and Nandini, 2012; Bunyan et al., 2012). Only a few voices state that human driven disturbance shape the grassland-Shola mosaic and their sharp edges even though for lower elevations (e.g. Puyravaud et al., 1994).

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In the light of what is known today about the ecosystem dynamics of grasslands and savanna (e.g. Favier et al., 2004; Furley, 2010; Ratnam et al., 2011) and the potential of landscapes below the altitudinal and latitudinal tree line to carry forest (Paulsen and Körner, 2014), the process underlining the existence of these grasslands should be self-evident. The way of thinking here is straight forward: Below the tree line each unit of terrestrial surface, that is capable of supporting forest, should carry trees if sources of seeds are within the regional species pool. Severely degraded lands can be seen as potential forest if trees can establish at some point of the forest succession. Trees cannot emerge when they are kept from doing so. Based on this hypothesis, any grassland below the treeline must develop into forest, with a few exceptions of sites that are too moist, too dry, too cold and too saline to support tree growth. If such inhibiting environmental conditions do not exist and trees do not regenerate, some other agents prevent the forest from establishing. This means that the succession from grassland to forest is inhibited at a very early stage. These patterns might appear as theory in landscapes where there are hardly any forest left, but are more evident in landscapes, like the high elevation areas in the Western Ghats, where grasslands and forests appear right beside each other. Such landscapes not only prove that the site conditions under which grasslands exist have the potential to support forest, but also guarantee the availability of tree propagules.

We assume, based on the above mentioned framework, that the Western Ghats have the capacity to support forest vegetation from the bottom to the top elevations. Therefore, the high elevation grasslands must be maintained by some external agent. Our hypothesis is that the main factor inhibiting forest succession from grassland to forest is fire. We test this hypothesis by investigating the differences in soil fertility, vegetation composition, and the signs of disturbances the vegetation carries between grassland, grassland-forest edge and forest in the upper Palni Hills. We further correlate land-cover with fire frequency as predicted by Landsat imageries over 12 years in the same landscape.

This paper summarizes the findings of study in the grassland-Shola mosaics of Palni hills. We give a brief review of literature on the nature of the grassland-Shola mosaic, methodology along with results. We then discuss the results and management implications.

Grassland-Shola Complex: A Review

In the high altitudes of the Western Ghats (above 1700 m) patches of grassland and tropical montane forest (locally known as Sholas) exist juxtaposed to each other forming sharp edges (Bunyan et al., 2012; Senft, 2009). We define ecotone "as transition zones between adjacent 'ecological systems', which are particularly considered as transition between 'patches'" Maarel (1990). This means we are talking about sharp edges between two ecosystem that differ significantly in structure and species composition (see also Senft 2009). According to the concept that a given landscape under the same climate should carry the same vegetation type if undisturbed (climatic climax concept by Clements, 1916) with some differentiation brought about by different edaphic conditions (Whittaker, 1953), one would expect an uniform vegetation community at the high elevations of the Western Ghats. However, grasslands and shola forests, two contrasting ecosystems occur in these ranges besides each other. This has been explained with different theories since the beginning of the last century. In the following section we summarize the major views on the nature of this complex.

Several authors have noted that of the grassland-Shola mosaic in the Western Ghats, grasslands are predominantly found on the hilltops and ridges while Sholas are confined to the valleys (Matthew 1999; Bunyan et al. 2012;). However, such a pattern is not uniform across the landscape and Shola forests appear in valleys, slopes, as well as ridge tops (Plate 6.1, also Figure 1c in Robin and Nandini, 2012).

Meher- Homji (1965, 1997) suggests frost as the main driver inhibiting the establishment of frost sensitive tropical tree species in the grasslands of hill tops, where only species with temperate origin are found. This hypothesis cannot be supported any more after Lengerke (1977) showed that frost in the Nilgiris, where most of the grasslands appear on hilltops and slopes, occurs mainly in valleys and are seldom on slopes or even hill tops. Wind is another explanation (Balasubramanian and Kumar, 1999) why Shola forest does not appear on hilltops. Here we have similar arguments: if wind is the main driving factor, we should see a regular pattern where Shola forests do not appear on sites exposed to wind, but this is not the case (Plate 6.1). Edaphic factors (lack of nutrients and soil depth) are also seen as reasons reducing the capacity of these hills to bear Shola forest. Empirical studies revealed the soil below grassland is shallower and less fertile (Jose et al. 1994) as compared to forest. However, grasslands are much more prone to erosion than forest (Breashears et al., 2003) and show low soil productivity which can lie below the erosion rate (Hancock et al. 2015). If the detected soil differences are the reason for the sharp grassland- Shola edge, a re-colonization of grassland by Shola forest wouldn't be possible. However, it has been proven that this took place several times over the last 18000 years (Sukumar et at.,1993, 1995; Caner et al., 2007) and therefore this hypothesis can also be dismissed.

Plate 6.1: Shola forest on hilltops and slopes at around 2000 meter above sea level, Kookal, Palni Hills, India.

The only explaining factor that remains is fire (see Plate 6.2). The interaction between fire regime and forest succession has been widely studied across the world but there are very limited studies in India. There is abundant evidence that fire can arrest the succession from of grassland and savannahs to forest (Hopkins, 1992; Favier et al., 2004; Bond et al., 2005; Furley, 2007; Ratnam et al., 2011). Fire also has a direct degrading effect on the soil by altering its properties such as increasing water repellence and indirectly by removing the vegetation and therefore enhancing soil erosion (Schmerbeck and Fiener, 2015). However, fire is hardly seen as a driving factor of the grassland-Shola mosaic today. During the first half of the last century certain authors had opined that fire and grazing keep the Shola form establishing on grassland (Champion, 1936; Bor, 1938) but this theory was opposed strongly by Meher-Homji (1965, 1997) and Bunyan et al., 2012). Today only a few researchers allocate a significant role to fires in determining the grassland-Shola edge (e.g. Thomas and Palmer, 2007) while it is otherwise widely ignored, even by researcher who experience it on the spot (Srinivasan et al., 2015).

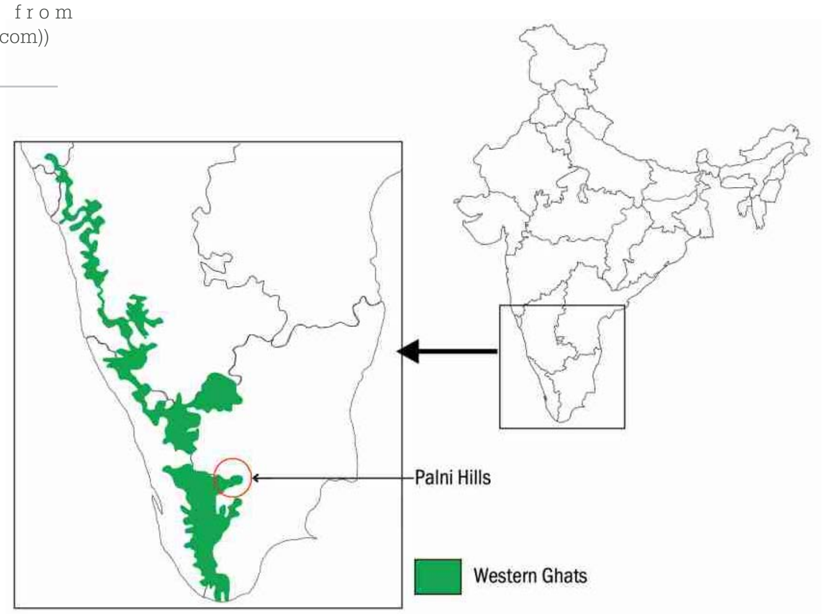
To test our hypothesis i.e., 'main factor inhibiting forest succession from grassland to forest is fire', we take a closer look at the ecotone between these two ecosystems and include fire signs and other disturbance in our assessment, unlike most studies in the past.

Methodology

Study area

The study was conducted in Palni hills (also Palnis), an eastern offshoot of the Western Ghats, lying between 10° 5'- 10° 25' N latitude and 77° 15'- 77° 50 E longitude **(Figure 6.1)**, covering an area of 2,068 km^2 (Matthew, 1999). These hills fall in two altitudinal zones- the upper and lower Palnis. Our study was conducted in the upper Palnis, which range between 1000-2200 m elevation and cover an area of around 385 km^2 (Matthew, 1999). The upper Palnis are an undulating plateau interspersed with occasional peaks along with a few ravines or valleys (Matthew, 1999). The mean monthly temperature ranges from 12°C-23°C in summer and 8.3°C-17.3°C in winters while frost occurs occasionally (Matthew, 1999). The average annual precipitation in the region is around 2800 mm (IMD Data, 1901-2003), accompanied with storms and cyclones.

Figure 6.1*:* Location map of Palni Hills (Dutta 2013; (modified from http://www.mapsofindia.com))



Sampling design

Our sample sites lie between 1900-2200 m elevations. The sampling design chosen for the study ensures that we capture vegetation and disturbances in grassland, edge and the Shola forests on similar site conditions. For achieving this we selected two south facing sites (Kukkal and Vattakanal) with vertical edges between grassland and Shola. The vertical edges ensured an equal influence of slope on edaphic and vegetation characteristics from grassland to Shola.

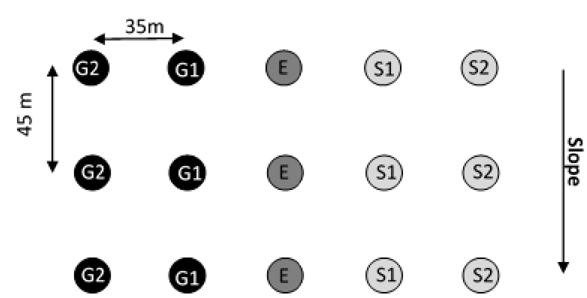
Two ecotones were sampled at Kukkal and Vattakanal each with 3 transects. Each transect was perpendicular to the edge. A minimum distance of 45 m was maintained between each transect **(Figure 6.2)**. Each transects had five plots, at a distance of 35 m from the centers of neighboring plots. These five plots include two plots on grassland (G1 and G2), one in the edge between Shola forest-grassland (E) and two in Shola forest (S1 and S2). Grassland and Shola plots were marked as 1 & 2, 1 being the plot close to ecotone and 2 being the plot far from the ecotone. A nested plot design was used for vegetation data collection **(Table 6.1)**.

Plate 6.2*:* Burned grassland in Nadugani Mattam (Nilgiris)

Table 6.1. Plot size and data collected in different vegetation strata (dbh= diameter at breast height). Damage signs like fire, cutting, trampling and grazing/browsing were recorded on individual, species and plot level.

Plot Size (A=area)	Vegetation strata studied	Data collected
5m × 5m: A=25m²	All life forms:	Plot information: damages
	Lower layer ≤1.3m Middle layer >1.3m - 5m Upper layer >5m	Species information: botanical name, species coverage
r = 1.49m : A= 7m²	Seedling 1: Trees Height <30cm	Species information: Botanical name, number of individuals
r = 2.52m : A= 20m²	Seedling 2: Trees Height 30 cm - ≤130cm	
r = 3.99m : A= 50m²	Sapling 1: Trees Height >130cm, dbh ≤3cm	
r = 5.64m : A= 100m²	Sapling 2: Trees Height >130cm, dbh >3 - ≤7cm	
r= 12.52m : A= 500m²	Mature trees dbh >7cm	Species information: Botanical name, DBH and damages

Figure 6.2: Diagrammatic representation of the sampling methodology used for vegetation assessment (G= Grassland, E=Edge, S=Shola)



Soil samples were taken from the center of the 5×5m plot up to a depth of 90 cm using a soil profiler. The depth of humus was assessed by measuring the thickness of the different layers: L (un-decomposed fresh litter), Of (fermentation horizon consisting of consolidated, still recognizable litter fragments), Oh (humification horizon consisting of amorphous humic substances). A soil textural triangle (Caspari and Schack-Kirchner, 2008) was used to analyze the texture of the A horizon. Soil samples were tested for percent soil organic carbon (SOC) and available nitrogen using the Walkley-Black's (Walkley and Black, 1934) and the alkaline permanganate method (Sailaja and Prasad, 2012), respectively. Available potassium (kg/ha) was calculated using the Ammonium acetate extraction (Leaf, 1958; Simonis and Németh, 1985).

Data analysis

Soil characteristics, Shannon-Wiener diversity index and species richness were compared using One way-ANOVA and Turkey-HSD post-hoc. The species composition between the vegetation types were compared using multi response permutation procedure (MRPP) in PC-Ord ver. 6.0.

To assess the fire frequency satellite data of Landsat 5 TM and Landsat 7 ETM+ from the year 2000 to 2012 (no data available for 2001, 2003 and 2010), both pre-fire and post-fire data were acquired. The Scan Line Correction (SLC-off) of data from Landsat 7 ETM+ was corrected by the gap filling method according to Mallick et al., 2013. The Normalized Burn Ratio (NBR) of both pre and post fire as well as the differenced Normalized Burn Ratio (dNBR) was calculated of each year following the methodology of Miller et al., 2008. Based on dNBR values the image was classified into burnt and not burnt (Key and Benson 2004). Fire frequency was estimated based on dNBR values of 185 random points, generated using ArcGIS software. We found fire presence in Sholas in our fire frequency dataset even though all possible sources of error were eliminated. However, fire does not occur in Shola (Dutta, 2013).

Therefore, the occurrence of fire on Shola was treated as an error. The highest value for fire frequency in Sholas was 4. Thus the error value 4 was subtracted for the entire data set. The methodology used for fire frequency assessment has been elucidated in **Figure 6.3.**

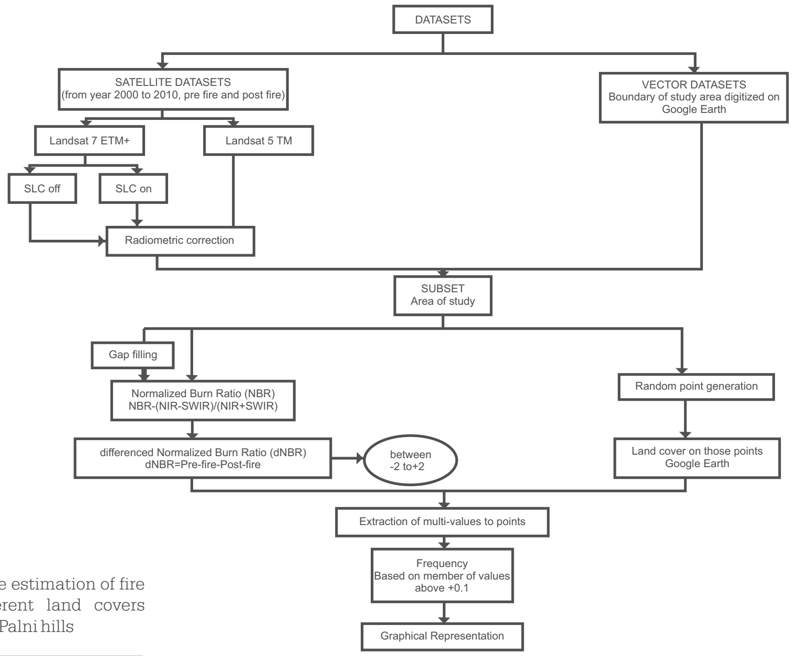


Figure 6.3. Flow diagram for the estimation of fire frequency for different land covers classes in the upper Palni hills

Results

Soil features

In general we observed an increase in the soil fertility from the open Grassland into the forest interior. The humus layers were thicker under Shola and ecotone compared to Grassland. This difference was significant for the Of and Oh layer. The soils under forest were in generally deeper with less difference between the ecotone and Shola plots (**Table 6.2**).

Table 6.2. Average depths in cm and p-values for two soil horizons and three humus layers for the different vegetation formations. Different letters indicated significant differences at significant levels of p=0.05 (values for soil layer for A+B).

Soil layer			**Vegetation formation**			**P-value**
	G2	G1	E	S1	S2	
A	13.44	11.61	28.61	30.44	30.61	0.0031
B	14.57	16.44	27.95	29.00	26.28	0.0352
Sig. A+B	a	a	b	b	b	
Humus layer						
L	0.67^{a}	0.57^{a}	1.27^{a}	1.16^{a}	1.33^{a}	0.0481
Of	0.57^{a}	0.50^{a}	2.04^{b}	2.22^{b}	2.22^{b}	< 0.001
Oh	0.34^{a}	0.44^{a}	2.93^{b}	2.60^{b}	3.18^{b}	< 0.001

The texture of the A-horizon between the three vegetation types differed significantly (p-value = 0.0163) with clay content increasing form grassland to forest. Organic Carbon (OC) was significantly lower in grassland while the values for the ecotone are similar to those of the forest. The soils under grassland contained significantly less nitrogen and potassium than under forest while the values for the edge for the former were more towards the grassland and for the latter towards forest (**Table 6.3**).

Table 6.3. Average value for the concentration for available macro nutrients and for the A horizon for the different vegetation formations. Different letters indicated significant differences at significant levels of p=0.05

Parameter observed	Vegetation formation				
	G2	G1	E	S1	S2
SOC (%)	6.35^{ab}	5.57^{a}	8.38^{b}	8.27^{ab}	8.68^{b}
N (%)	0.01^{ac}	0.01^{a}	0.01^{ac}	0.02^{bc}	0.03^{b}
P (mg/kg)	0.07^{a}	0.08^{a}	0.15^{a}	0.20^{a}	0.17^{a}
K (kg/ha)	118.97^{ab}	94.08^{a}	158.92^{b}	202.47^{ab}	130.42^{b}

Stand characterization and understory floristic composition of grassland, ecotone and Shola

A total of 185 vascular plant species were found in all plots, from which grassland, ecotone and Shola contributed 54, 120 and 116 species respectively. Only 22% of the grassland species where actually grasses while the remaining species were herbs and shrubs. The plant diversity increased in general toward the forest interior (Figure 6.4). The herb layer showed the highest values while the trend of increasing diversity towards the forest interior remained high. The diversity in the middle layer was significantly higher for the ecotone while the upper layer showed the highest value for Shola forest (Figure 6.4). The ecotone was distinguished from the other two formations by a significant higher cover of shrubs though statistically ecotone and Shola were not significantly different (p>0.05 for lower, middle and upper layer).

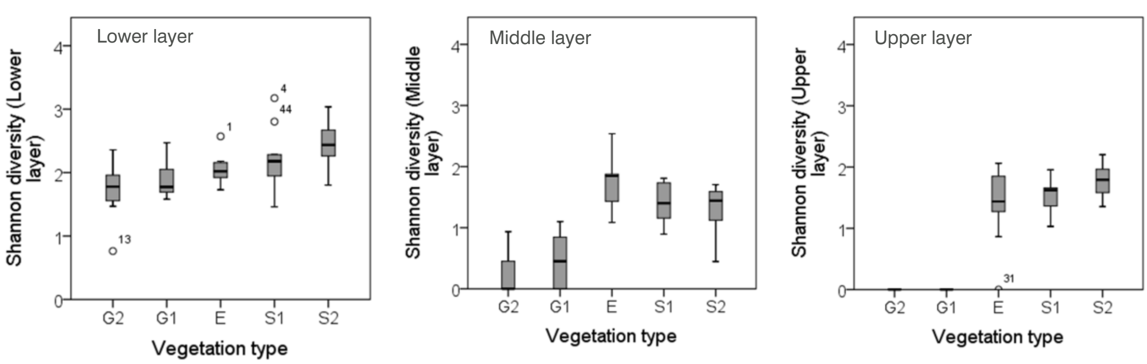


Figure 6.4. Shannon-Wiener Index (H') (Box plots showing (median, 95% confidence interval, standard deviation and outliers) for all vascular plants in the lower, middle and upper layer of the vegetation formations

The difference in species compositions of the different formations was also reflected by the MRPP analysis which separated the formations clearly (T value close to -20). The homogeneity within the sample formation was low (A value of 0.153 out of 1 for full homogeneity).

Density and diversity of tree regeneration

We found abundant tree regeneration in all regeneration categories in the edge and in Shola forest (Table 6.4). Grasslands show relative high tree density per hectare for the trees < 30 cm and slightly lower values for seedlings of a size between 30 cm and 1.3 m. Within the forest and at the ecotone the trends is similar but with much higher numbers of regenerating trees.

Table 6.4. Average number of trees/ha^{-1} regenerating within the different regenerations categories within the different vegetation formations (St.Dev = Standard Deviation, for other abbreviations see methodology).

Seedling 1	**Average/ha.**	**St. Dev.**	**Seedling 2**	**Average/ha.**	**St. Dev.**
G2	714	171	G2	500	141
G1	571	153	G1	389	129
E	5463	617	E	1596	139
S1	4389	472	S1	1349	143
S2	4286	455	S2	1533	146
Sapling 1	**Average/ha.**	**St. Dev.**	**Sapling 2**	**Average/ha**	**St. Dev.**
G2	0	0	G2	30	5
G1	44	15	G1	0	0
E	659	70	E	291	34
S1	584	52	S1	278	25
S2	719	62	S2	279	25

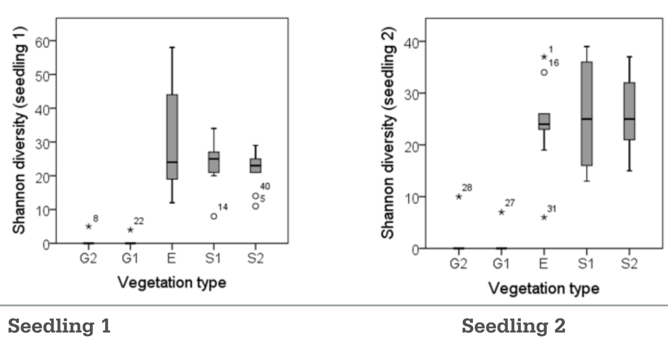
The diversity among the regenerating trees was very low on grassland (average H' close to 0) and significantly higher for ecotone and forest interior. Both ecotone and Shola were significantly different **(Figure 6.5)** from grassland ($p<0.01$) and both were not significantly different from each other ($p>0.05$). The tree species regenerating on grassland include *Vaccinium leschenaultia, Rhododendron arboreum* ssp. *nilagiricum, Syzygium densiflorum* and *Daphniphyllum neilgherrense.*

Rhododendron arboreum was the only species represented in the mature tree layer of grasslands with an average basal area of 4.23 m^2/ha and 1.30 m^2/ha (G1, G2 respectively). Grassland plots G2 and G1 were significantly different in comparison to Shola ($p<0.05$). The basal area per hectare was significantly higher in case of ecotone (74.10 m^2/ha) as compared to grasslands (G2 plots) ($p<0.05$). However, it was significantly lower than Shola (average values for S1 and S2 close to 138 m^2/ha).

The diversity for mature trees based on basal area per species for ecotone and Shola was significantly different from grassland ($p<0.01$) but there were no significant differences between the ecotone and Shola ($p>0.05$).

Signs of disturbance

Almost all grassland plots had signs of fire on plot level while the sings increased towards the edge **(Figure 6.6)** and 100% of the trees found on G 1 and 2 plots were burnt whereas only 5% of trees found in ecotone had fire signs. Fire was absent in Shola forest **(Figure 6.7)**. All vegetation formations showed signs of grazing and trampling while G2 and ecotone showed the highest values.



Sapling 1 **Sapling 2**

Figure 6.5. Shannon Wiender Index (H') (Box plots showing (median, 95% confidence interval, standard deviation and outliers) for the different regeneration categories

Figure 6.6. Ratio of plots in % with signs of disturbances across vegetation formations

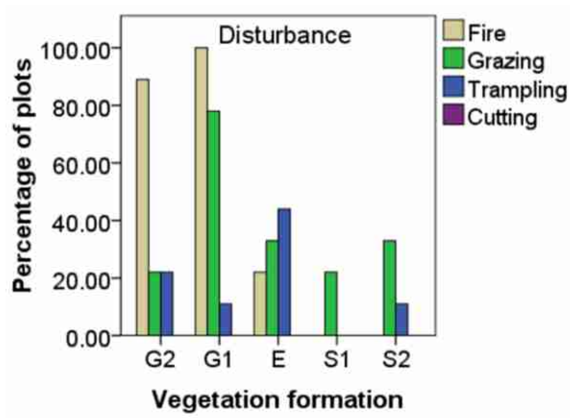
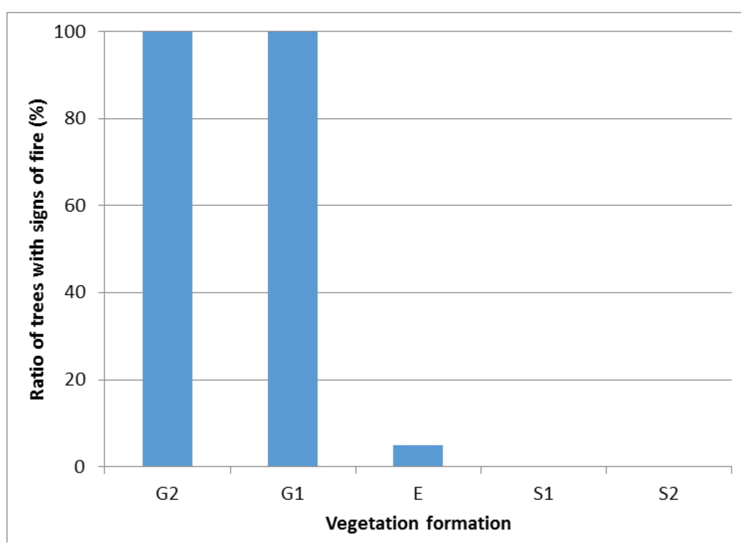


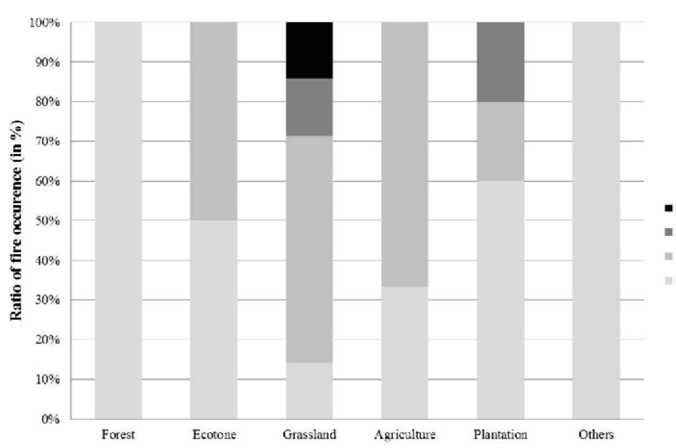
Figure 6.7. Ratio of mature trees in % showing signs of fire across vegetation formations (G=Grassland, E=Edge, S=Shola)



Occurrence of fire in grasslands

The analysis of the Landsat data indicated fire presence in plantations, agricultural land, ecotones between land cover classes and grasslands. Grasslands had the highest fire frequency with up to 3 fires during the observation period and only 10% of them did not face fire (Figure 6.8).

Figure 6.8. . Proportion of fire frequency classes (0, 1, 2, 3 fires from 2000-2012) in % for different land cover classes in the upper Palni hills



Discussion

This is the first time to our knowledge that the grassland-Shola-ecotone has been studied in the high altitudes of Palni hills. Similar studies have been conducted in the Malnad region (Karnataka) at lower elevations (550-1100 m) by Puyravaud et al., (1994) and in Eravikulam (Kerala) at the same elevation as our study (2000m) by Jose et al. (1994, 1996). Our results for soil features are in concurrence with both these studies which found deeper soils, a higher clay content and higher values for carbon, nitrogen and potassium under forest. Additionally, Jose et al. (1994) detected almost equal values for phosphorus for grasslands and Sholas. Our findings match in principle the current knowledge about the impact fire has on edaphic factors. Fire in general has a detrimental effect on SOC (Mataix-Solera et al., 2011), and soil nutrients (Kumar et al., 2013). However the effect may not be consistent among experimental designs and sites. For nitrogen a loss seem to be evident (Fynn et al., 2003) while potassium might remain unaffected (Paliwal and Sundaravalli 2002) and the available amount of phosphorus might increase under the effect of fire (Romany et al., 1994).

However, the general lower capacity of the soil does not hinder tree species from regenerating but keeps most of them from growing into adults (see Table 6.4 in combination with the values for basal areas on grasslands). An important factor to determine the number and composition of establishing trees is the fire frequency (Bowman et al., 2013) and the season in which fire occurs (Bond and Wilgen, 1996). The exact number of fires occurring on a spot in the Palni hills are not known, as no publicly available records are maintained. Our estimate can be expected to correlate with true fire frequency values to some extent. However, the error in fire signal over Sholas indicates that it does not reflect the exact ground reality. A frequency value of 1 fire occurring in a span of 12 years is rather low. However, the actual occurrence of fire, in combination with grazing (Figure 6.6) is sufficient to eliminate most of the regenerating tree species from grasslands leaving only *R. arboreum* as an adult tree. This regeneration pattern of native trees does not apply for the *Acacia mearnsii*, a pioneer tree species originating from Australia (Orwaet al., 2009). It was brought to the Palni hills in 1860s and spreads today in grassland ecosystems (Matthew, 1999). Under the nursing effect of this tree, Shola trees can establishon former grasslands (Dixit, 2015) and these systems become increasingly fire resistant.

The most important questions that persist for researchers are: How did the grasslands persist since the Last Glacial Maximum when the environmental conditions were suitable for grasslands (Caner et al., 2007). Another pertinent question that needs to be answered by the forest managers is: what are the causes of fires in these grasslands today?

Some researchers answer the first question with a variation in temperature and rainfall since LGM (e.g. Sukumar et al., 1993, 1995; Caner et al., 2007) during which it is assumed that the tree line was below the elevations having grasslands today (Caner et al., 2007). The earliest settlements in the Western Ghats are dated back to 2000 years before present (BP) (Caner et al., 2007), based on which researchers do not consider the influence of humans as an explaining factor for the presence of grasslands prior to this time (Srinivasan et al., 2015). The presence of settlements proves that humans have been in the area since then, but it does not prove that they were absent prior to this time period. The fact that humans have shaped the terrestrial surface of the earth with fire is accepted globally (Bowman et al., 2011) as well as for India (Pyne, 1990). This impact is expected to date back to a much longer time period of up to 50000 years (Bowman, 2009). In the Western Ghats, Chandran (1997) has been able to place the use of fire by hunter-gatherers up to 12000 years BP, stating that hunting and gathering took place even prior to this. The synergy of these factors makes it very likely that humans, knowing about the advantage of using fire for hunting (Gott, 2005) kept patches of grasslands open while the forest gradually moved back to higher elevations.

Therefore, our answer to the question if fire makes the edge between grassland and Sholas is "yes". Today, however, there are no statistics on the sources of these fires, at least not for the upper Palnis. However, it is likely that these fires escape from agricultural burning adjacent to the grasslands. Other sources could be deliberately burning to maintain grass growth for grazing or accidental fires from burning waste.

Management implications

The high elevation grasslands in the Western Ghats are the habitat of many endemic species and form a significant part of the Western Ghats' biodiversity. The protection of these grasslands and preventing them from converting into any other vegetation formation is therefore vital. So far these grasslands have been maintained accidentally as their occurrence is dependent on a relative low frequency. If these fires would stop, for instance by the enforcement of law, the succession towards forest, supported by exotic species, is likely to occur, which will lead to a significant reduction of the area under grassland. The implication of such a change on the biodiversity of the region has not been studied yet, but it will certainly cause a significant shift in population dynamics, species composition and possibly lead to the loss of some species. In order to maintain the grasslands fire needs to be regulated and the establishment of fast growing woody species needs to be controlled (Srinivasan, 2012). To do so, first of all the optimal fire frequency and season of buming must be known to support and not destroy the current compositions of the grasslands. Further, to avoid unregulated fires the sources of fire must be known. It would also help if additional knowledge is created on species and ecosystem

interaction around these grassland to enable a planning on landscape level. If ecosystem services flow from grasslands, Sholas and the landscapes they appear in as a whole, is known, the management can incorporate them in optimization of trade-offs between ecosystem services.

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Recent Changes in the Phumdis of Keibul Lamjao National Park, Manipur and Management Implications

Abstract

Loktak Lake and the Keibul Lamjao National Park (KLNP) in the state of Manipur, North-east India support unique wetland vegetation, i.e., floating meadows, locally known as 'Phumdi'. These are made up of a heterogeneous mass of soil, vegetation and organic matter. They occur in varying thickness ranging from a few centimeters to about 2.5 m with one-fifth of it floating above and four-fifth submerged under the water. Phumdis play a crucial role in the survival of the endangered Eld's deer or Sangai (*Rucervus eldii eldii*) as they provide necessary space, shelter and forage for the species. Despite their tremendous significance very little is known about the dynamics, structure and composition of these meadows. We conducted floristic studies on the phumdis of KLNP area during 2005-2010. A total of 185 plant species belonging to 50 families and 121 genera were recorded. Poaceae was the dominant family followed by Cyperaceae and Asteraceae. The dominant species of the meadows were *Zizania latifolia, Hedychium coronarium, Impatiens* sp., *Cyperus difformis, Cyperus rotundus* and *Polygonum* spp. The species common to both the meadows and terrestrial habitat were *Phragmites karka, Capillipedium assimile, Leersia hexandra, Oenanthe javanica* and *Cyanotis barbata*. Perusal of past records reveals that noticeable changes have taken place in the structure and composition of phumdis in KLNP. This may be due to the changes in the hydrology of the lake and de facto extraction of plant species by the local communities. In order to maintain the natural growth and dynamics of the phumdi it is suggested to allow the phumdi to settle on the ground between February to May and prevent burning, trampling and uprooting of vegetation from the phumdis.

Keywords: Floating meadows; species composition; Nativity; Habitat specificity; Keibul Lamjao National Park

Introduction

Various forms of wet or floating meadows have been reported globally which form important component of wetland vegetation distributed from the sub-arctic to the tropics (Hammond et al., 2008). Swarzenski et al. (1991) used the term 'floating marsh' to refer to wetlands in which the "floating mats of vegetation are thick enough to support a person's weight". Natural floating meadows are relatively rare and typically form when masses of terrestrial peat are torn off by the storms or when the buoyant peat uplifts from the floor of basins following inundation (Van Duzer, 2004). The plant species play significant role in determining the structure and composition of the natural floating meadows (Azza et al., 2000). The roots of floating plants determine the thickness of the mats by binding the organic material together (Sasser et al., 1991). The floating meadows appear to be less frequent in Asia, but buoyant thick floating mats occur in Thailand (Peck, 2000), floating loose and unconsolidated peat mat in Japan (Haraguchi, 1991), or floating platform comprising heaps of decomposing water hyacinth in Bangladesh, locally called 'dhap' (Islam and Atkins, 2007).

In India, the characteristic floating meadows are confined to the Loktak Lake, a large but shrinking freshwater body in the upper basin of the Manipur River. This area forms a distinctive part of the Indo - Burma biodiversity hotspot. Loktak is one of the largest freshwater lakes in India, though, much of which has been reclaimed for agriculture in recent decades. The floating meadows, locally known as phumdi(s) play a significant role in determining the nature of the wetland ecosystem as well as in the local livelihoods. Phumdis are a heterogeneous mass of soil, vegetation and organic matter in various stages of decomposition that occur in different thickness ranging from a few centimeters to about 2.5 m. With the reed *Phragmites karka* as the most dominant species, the other important species in the phumdi are *Eichhornia crassipes, Oryza sativa, Zizania latifolia, Cynodon dactylon, Sagittaria* sp., *Saccharum bengalense, Leersia hexandra* and *Carex* spp. (Sanjit et al., 2005).

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With no definite shoreline, the expanse of water and depth of the Loktak Lake varies seasonally. The Keibul Lamjao National Park (KLNP), located in the southern part of the Loktak Lake is a sole habitat of the endangered Eld's deer or the Manipur Brow antlered deer, locally known as Sangai (*Rucervus eldii eldii*). The Park supports the largest expanse of floating meadows covering 22.3 km^2 (Hussain et al., 2006). The increasing demand for goods and services provided by the Loktak lake ecosystem and the resultant pressures on the wetland have led to its degradation, threatening the survival of the endangered Sangai and livelihoods of the local communities' dependent on it.

The vegetation composition of the phumdi is believed to be changing over the years (Shyamjai, 2002). The habitat in the Park is declining primarily due to the change in water regime from the construction of the Ithai barrage. Prior to commissioning of the Loktak Multipurpose Project in the year 1983, water in the Lake exhibited broad seasonal changes. The phumdis, which used to settle during lean season and get replenished with soil and nourishment, are now continuously flooded resulting in their thinning, making them increasingly defunct in supporting the weight of the deer. During the dry period when the phumdis used to settle down, the nutrients and minerals were drawn by the phumdi vegetation from the bottom of the Lake. This natural cycle of floating and sinking of phumdi used to be maintained in KLNP. Maintenance of high water level in the Lake throughout the year for Loktak Multipurpose Project has broken this annual cycle and phumdi remains flooded throughout the year and periodic supply of nutrients and minerals during dry season is no more available to phumdi vegetation. Therefore, the growth of vegetation on phumdi and their thickness is believed to be gradually decreasing (Tuboi and Hussain, 2014). It is feared that eventually the phumdi may not be able to support the weight of the animal that is considered to be one of the limiting factors for the Sangai population.

The wetland vegetation exhibits diversity, ranging from microscopic to multi-cellular forms, and mainly constitutes of herbaceous species with an occasional shrubby species (Adhikari and Babu, 2008). The vegetation of the phumdi not only plays a crucial role in governing the wetland processes of the Loktak Lake but also influences hydrological regimes, harbors rich biodiversity, supports productive fisheries and provides several economically important plant species to the local communities. Keeping in mind, the important role played by the vegetation of the floating meadows for the ecosystem as a whole, particularly for the Sangai and the hog deer, the present study was conducted during 2006-10 to gain an insight into the vegetation composition and distribution of the economically important plants of the Park. As the Park has large expanse of floating meadows interspersed with open water and hillocks, comprehensive understanding of the vegetation composition of the Park will be helpful in effectively managing the Park.

This paper summarizes the plant species composition of the floating meadows of KLNP, identifies the changes taking place in the vegetation structure and suggests measures for minimizing such changes that may prove detrimental to both the ecosystem and its dependent species.

Study area

The study was conducted in the Keibul Lamjao National Park (KLNP), Manipur, India located in the Barak-Chindwin-Irrawaddy Basin (**Figure 7.1 & Plate 7.2a,b**). The KLNP is situated in the South-eastern fringes of the Loktak Lake. The Park lies between latitudes 24°26 to 24°31' N and longitudes 93°49' to 93°52' E. The ambient temperature around KLNP ranges from 1.7oC (January) to 36.4oC (May). During winter, low temperature, heavy dew and early morning frost characterize the climatic condition. There is heavy rain during June to September, and less or little rainfall from December to February. The annual rainfall is 1460 mm. Humidity is highest in August, with daily humidity measuring as much as 81% and least in March at 49%. In 1953, the Sangai which was believed to be extinct was rediscovered by E.P. Gee (Gee, 1960). Due to the persistent efforts of E.P. Gee, the Sangai was declared a protected animal and its habitat, Keibul Lamjao covering an area of about 52 km^2 was declared a sanctuary in 1954. In 1959, the total area was reduced to about 27 km^2. With a view to ensuring protection for the species, the Keibul Lamjao was declared protected in 1965, a reserved forest in 1974 and finally a National Park in 1977 (Singh, 1992). The Park received National and International attention when Loktak Lake was declared as a site of International Importance (Ramsar site No. 463, Designation Date: 23 March 1990) (Hussain et al., 2006). Presently the Park occupies an area of 40.05 km^2 out of which 26.41 km^2 is covered by a thick and almost contiguous mat of floating meadows (Tuboi, 2013).

The floating meadows of the Park vary in thickness, based on which the Park can be divided into the Western thick phumdi zone, Eastern thin phumdi zone and Northern open water and very thin phumdi zone. The construction of Ithai Barrage (1983) has affected the natural process of phumdi formation (Sanjit et al., 2005) which led to the rapid changes in the lake ecosystem. More than 185 species of grasses and sedges have been recorded from the meadows, of which *Zizania latifolia, Phragmites karka, Saccharum bengalense, Hemarthria compressa, Leersia hexandra, Carex* spp., *Oryza rufipogon* and *Capillipedium* spp. constitute the major primary food items of the Eld's deer (Tuboi et al., 2012).

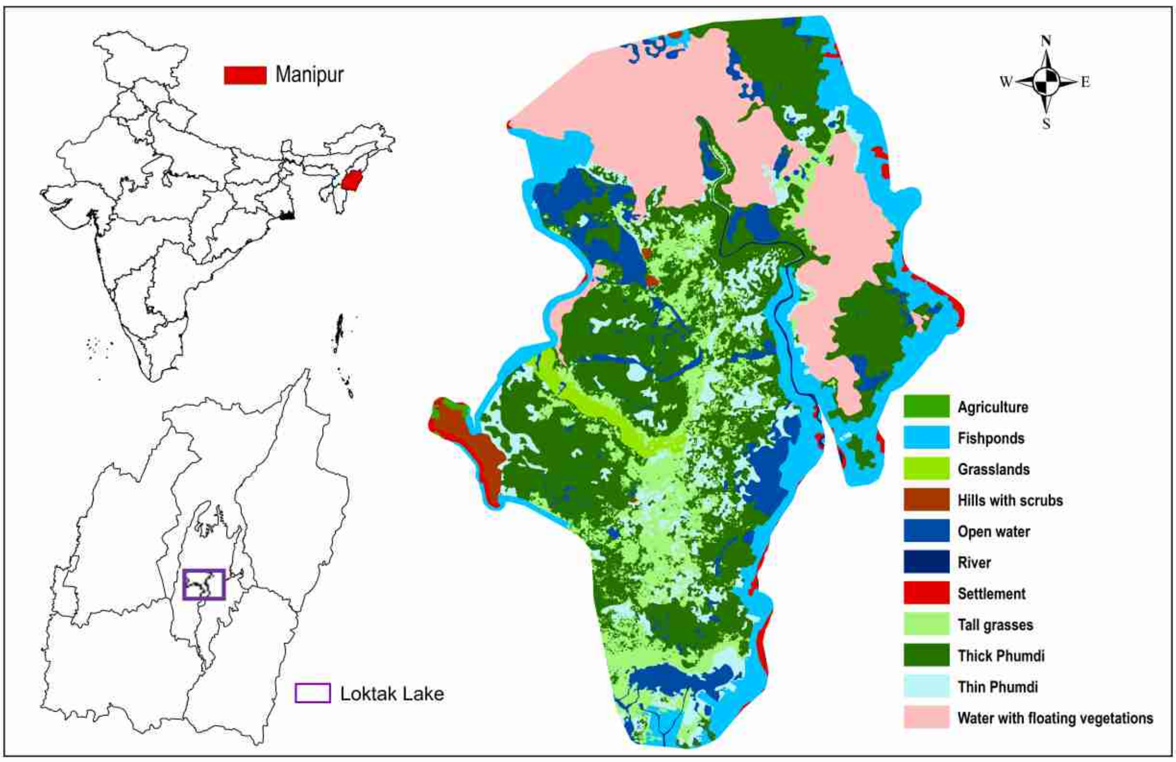

Figure 7.1. Location map of Keibul Lamjao National Park, Manipur and the land use-land cover types.

Methods

An extensive floristic survey was carried for the entire year in the Park so as to cover all the annual, as well as perennial plant species. However, during winter (November-January), due to high water level, sampling was restricted to mostly thick meadows. The KLNP and the adjacent areas of the Park were divided into 51 grids of 1000 x 1000 m. Depending on the open water and thickness of meadows 2 to 3 line transects of 500 m each were laid randomly on each of these grids. Quadrates of 0.5 x 0.5 m were laid randomly on these transect to study the dominant plant species and association among them. In each plot, the number of plant species present and their number were recorded. Plant samples were collected from the different mosaic of habitats viz., floating vegetation, hard ground and submerged areas. The collected specimen were numbered and pressed for the preparation of herbarium (Jain and Rao, 1977). The habitat types from which the sample was collected and the numbers of species present in each microhabitats were also recorded. Identification of plants in the field was done with the help of 'A Manual of Aquatic Plants' (Fassett, 1997) and 'The grasses of Burma, Ceylon, India and Pakistan' (Bor, 1960). Unidentified plants specimen were brought to Wildlife Institute of India (WII), Dehradun for further examination and cross verification.

To examine the changes in the plant species composition transects of 500 m were laid from the edge of the grassland towards the interior of the Park. In each transect quadrates of 50 cm x 50 cm were randomly laid at every 100 m distance. Counts of different tillers of grasses and average heights were recorded. During the study, information on resources extracted by local people and the parts extracted were also recorded so as to quantify the rate of extraction. We compared the extent dominant species and their present occurrence in the park based on past records and published information (Singh, 1992; Shyamjai, 2002; Shamungou, 2002; Sanjit et al., 2005).

Results

Plant species composition

A total of 185 plant species belonging to 50 families and 121 genera were recorded in the Keibul Lamjao National Park **(Appendix I)**. These include 13 species of climbers, 33 grass species, 30 species of sedges, five ferns species, 97 species of herbs and seven shrub species. Out of 185 species, only 90 were recorded in the floating meadows and open water, 19 in terrestrial habitats and 76 species in both terrestrial and floating habitats. The species of the floating meadows consisted of 11 grasses, 27 sedges, 49 herbs and three ferns belonging to 32 families. The terrestrial species consisted of

six species of grasses, four climbers, nine herbs and one species of shrub belonging to 11 families **(Figure 7.2)**. The species of both the floating and terrestrial habitat comprise of 16 species of grasses, nine climbers, three sedges, two ferns, 40 herbs and five shrubs belonging to 30 families. Poaceae was the dominant family with 33 species followed by Cyperaceae with 30 species and Asteraceae with 14 species. Twenty-three families were found to have a single species **(Figure 7.3)**.

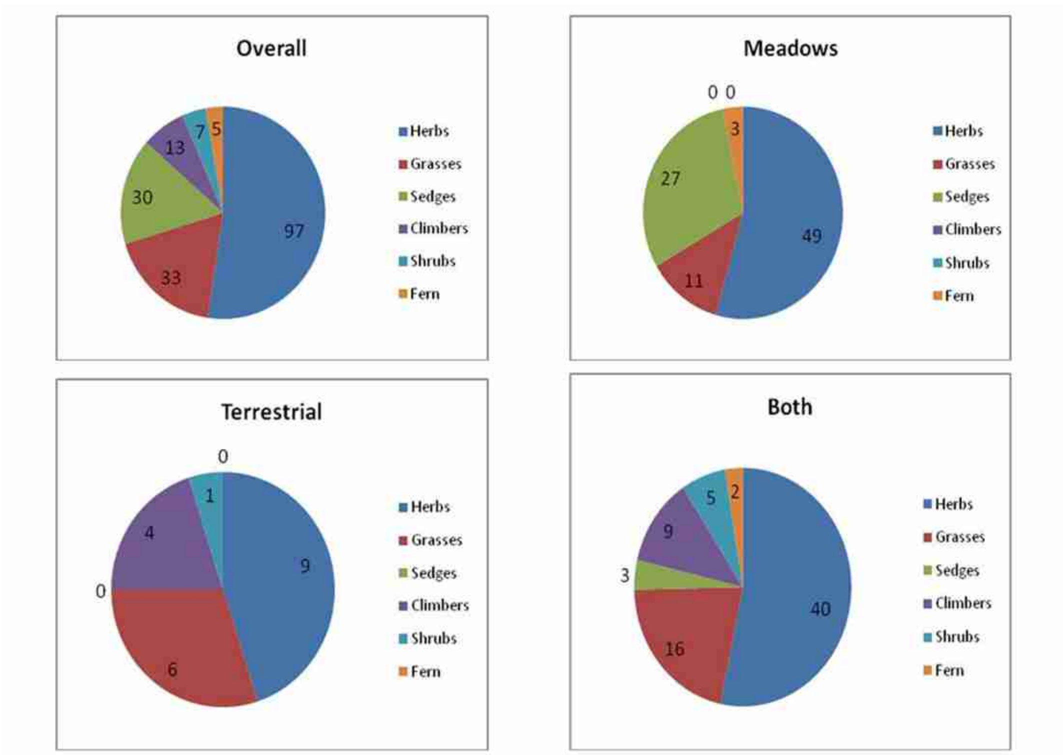

Figure 7.2: No of species in different habitat types of the Keibul Lamjao National Park, Manipur.

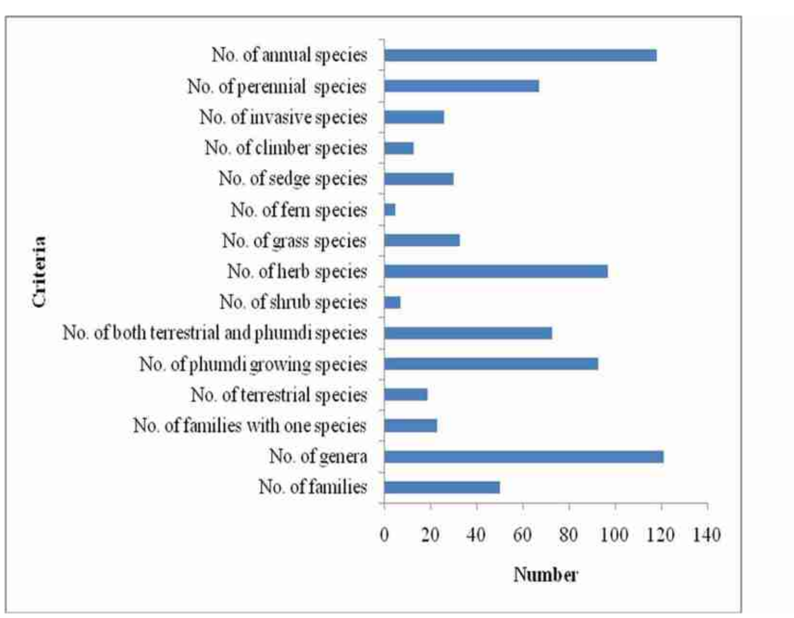

Figure 7.3: Details of the dominant families and habitat types of the plant species of Keibul Lamjao National Park, Manipur.

Habitat specificity

Since the Park has a mosaic of microhabitats (floating meadows, open water and terrestrial), the type of plants found in each habitat was also recorded. The percentage distributions of the species in the different habitats were: 48.6% in the floating meadows, 41.1% in both the floating meadows and terrestrial habitat and 10.3% only in terrestrial habitat. The dominant species found in the floating meadows were *Zizania latifolia*, *Hedychium coronarium*, *Impatiens* sp., *Cyperus difformis*, *Cyperus rotundus* and *Polygonum* sp. and the dominant species in the terrestrial habitat were *Dactyloctenium aegyptium*, *Ipomoea nil* and *Cynodon dactylon*. The species common to both the floating meadows and terrestrial habitats were *Phragmites karka*, *Capillipedium assimile*, *Leersia hexandra*, *Oenanthe javanica* and *Cyanotis barbata*. The common species floating or submerged in the open water were *Azolla pinnata*, *Ceratophyllum demersum*, *Hydrilla verticillata*, *Salvinia cucullata*, *Salvinia molesta*, *Utricularia* spp., *Nymphoides cristata* and *Pistia stratiotes*.

Occurrence of herbs was found to be the highest in both the floating meadows and terrestrial habitats (54.4% and 47.4% respectively) followed by sedges in the floating meadows (30%) and the grasses in the terrestrial habitat (26.3%). Herbs showed the highest percentage of distribution of the species common to both floating meadows and terrestrial habitats (52.6%) followed by grasses and climbers (21.1% and 11.8%, respectively). In the overall distribution of the plant species of the Park, herbs showed the highest percentage (52.4%) followed by grasses and sedges (17.8% and 16.2% respectively).

Extraction of plant species by local communities

Resource extraction occurred not only in the peripheral areas but throughout the Park. Besides depending on the Park for commercial sale of vegetables and fishes, it was also found that people depended on the Park for fuel wood for subsistence and fish feed. A total of 26 economically important plant species used by the local people for various purposes has been identified in the Park (Table 1). The most important plant species extracted for subsistence use and commercial purposes were *H. coronarium*, *Oenanthe javanica*, *Nymphaea* sp. and *Euryale ferox*. *Phragmites karka*, *Z. latifolia*, *L. hexandra*, *Scirpus* spp., *S. spontaneum*, *A. donax*, *Imperata cylindrica* and *Coix lacryma-jobi* were extracted by the local people for fencing, fuel wood and thatching the roof of huts **(Plate 7.1)**. The important fodder species identified in the Park were *Z. latifolia*, *C. demersum*, *H. verticillata*, *Limnophila* sp. and *L. hexandra*. *Ageratum conyzoides*, *Alpinia allughas*, *H. coronarium*, and *Fureina umbellata* are used for medicinal purposes. *Cyperus* sp. and *Scirpus lacustris* were extracted for making handicrafts especially mats **(Table 7.1)**.

Table 7.1. A list of the economically important plant species of Keibul Lamjao National Park, Manipur.

Uses	Plant species	Parts used
Vegetables	*Alternanthera philoxeroides, Alternanthera sessilis, Centella asiatica, Oenanthe javanica,*	Leaf, stem
	Alpinia allughas, Hedychium coronarium	Stem, young shoot
	Euryale ferox, Nymphaea sp.	Seeds
Thatching material	*Imperata cylindrica, Zizania latifolia*	Leaf, stem
Fuel	*Arundo donax, Coix lahcryma-jobi, Phragmites karka, Saccharum spontaneum*	Stem
Handicrafts	*Cyperus spp., Scirpus lacustris*	Stem
Medicinal purposes	*Centella asiatica, Ageratum conyzoides, Alpinia allughas, Hedychium coronarium Ludwigia adscendens, Oxalis corniculata, Vetiveria zizanioides, Fureina umbellata*	Leaf, young shoots Leaf, young shoots
Fodder	*Alternanthera philoxeroides, Alternanthera sessilis, Leersia hexandra, Polygonum* sp.*, Zizania latifolia,*	Leaf, Stem
	Ceratophyllum demersum, Hydrilla verticillata, Limnophila sp	Whole plant

Changes in Phumdi Vegetation

Due to the recent changes in the Loktak Lake and its catchments area, both natural and manual proliferation of Phumdis is taking place. Recent studies have also shown that the Phumdi area in the lake has increased. However, it is of little use to Sangai as recently formed Phumdis are thin. In 1989, the Phumdi area was 116.4 km^2 while in 2002 it increased to 134.6km^2 with maximum increase recorded in the central zone of the lake (Singh and Khundrakpam, 2009). It has been reported that the

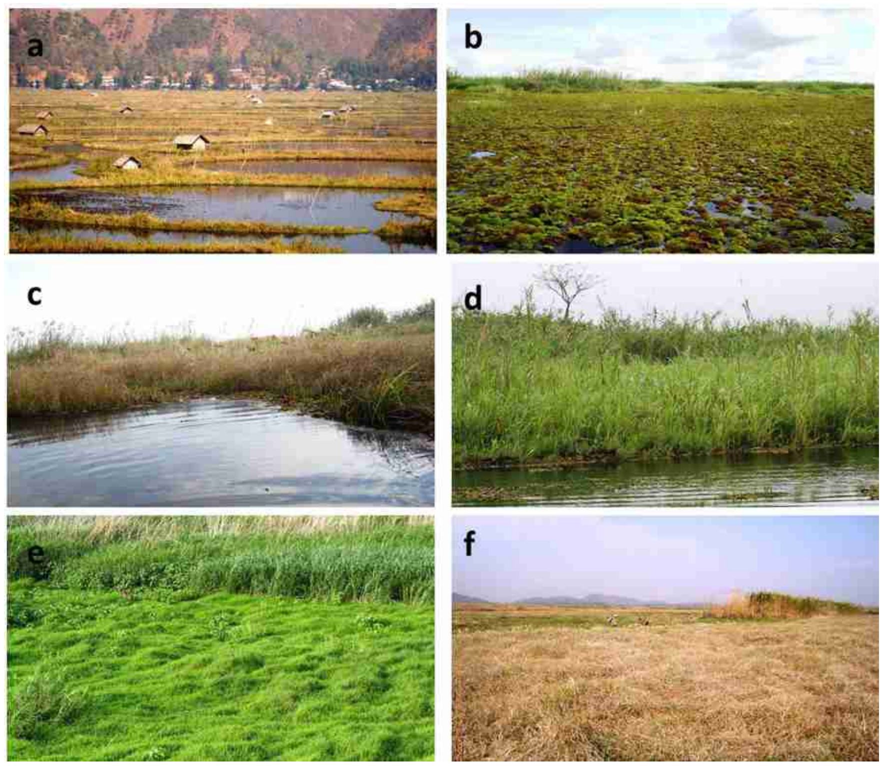

Plate 7.1 Views of Phumdis in different seasons of Keibul Lamjao National Park, Manipur (a) Athaphum fishing (b) *Salvinia molesta* in open water after monsoon in September (c) view of phumdi in winter (d) view of phumdi in summer (e) view of hard ground in summer (f) view of hard ground in winter.

proliferation rate within six months is about 0.8 –2 m area in the lake and 0.1 m in the KLNP (Shyamjai, 2002). The data available from earlier studies of 1980s and 1990s (Shamungou, 2002) suggest that vegetation composition of the Phumdi in the Park is changing. During the present study, 185 plant species were recorded as compared to 223 reported by Singh (1991). Besides 145 aquatic, semi-aquatic and terrestrial plant species were reported by Shyamjai (2002) and 117 reported by Angom and Gupta (1999). Earlier studies conducted in 1986 by Singh (1992) reported that *L. hexandra* dominated the Phumdi with about 25% of occurrence followed by *Z. latifolia* (18.3%), *P. karka* (14.4%) and *C. assimile* (11.1%). In a similar survey in 1996, he reported that percentage occurrence of *Z. latifolia* and *P. karka* had reduced to 14.6% and 10% respectively while it had increased to 32.5% in the case of *L. hexandra* and 14.2% in *Capillipedium* sp. (Shamungou, 2002). During the present study the percentage occurrence of *Z. latifolia* was 8.06%, *P. karka* was 6.41%, *L. hexandra* was 11.39 and *Capillipedium* sp. was 10.06 % (Table 7.2) indicating extent of change in these species.

Table 7.2. Percentage of occurrence of plant species during 1986, 1996 and 2010 in Keibul Lamjao National Park,

Botanical name	Local name	1986	1996	2010
Zizania latifolia	Ishing kambong	18.3	14.6	8.06
Phragmites karka	Tou	14.4	10	6.41
Saccharum bengalense	Khoimom	4.7	4.2	3.69
Narenga porphyrocoma	Singut	1.9	2.5	NO
Leersia hexandra	Hoop	24.7	32.5	11.39
Carex sp.	Hundang	3.9	3.1	0.29
Oryza perennis	Wainu chara	7.7	1.8	0.13
Coix lachrymal-jobi	Yawa chaning	4.2	1.6	0.14
Capillipedium sp.	Wana manbi	11.1	14.2	10.06
Others		8.6	15.5	16.93

Source: *Singh (2002).*

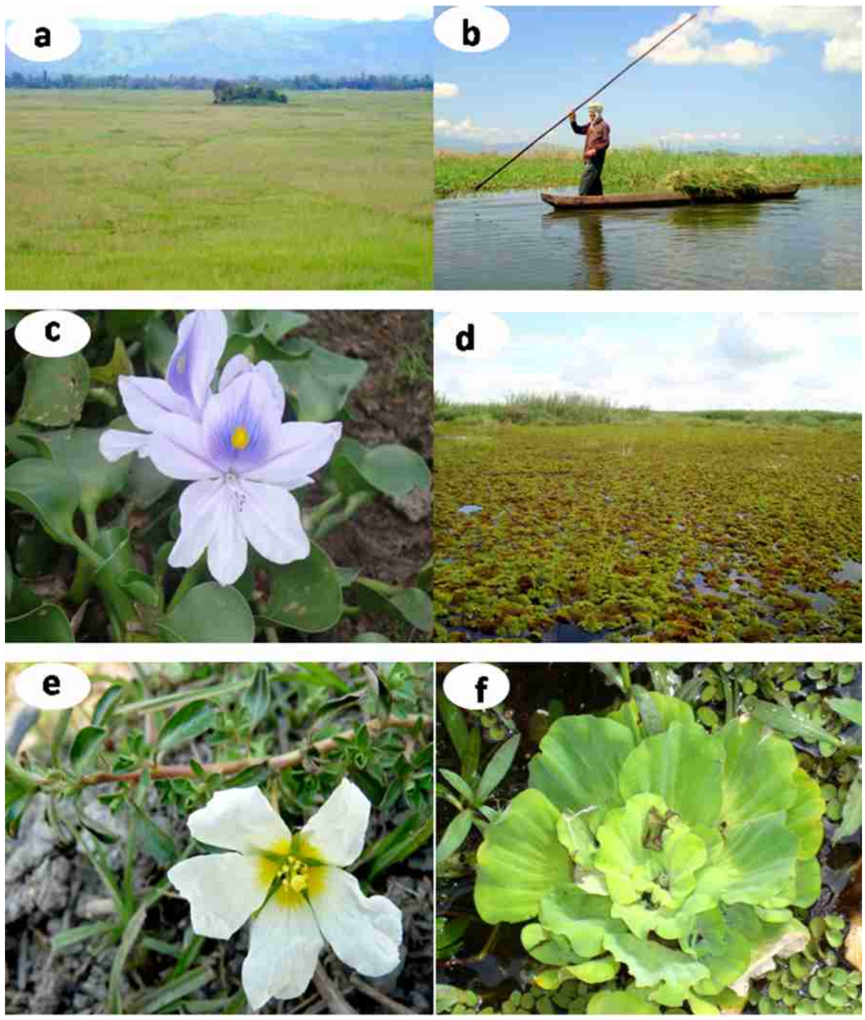

Plate 7.2. Some invasive plant species of the floating meadows of Keibul Lamjao National Park, Manipur (a) a view of the Park (b) extraction by local people (*Zizania latifolia*) (c) *Eichhornia crassipes* (d) *Salvinia molesta* (e) *Ludwigia adscendens* (f) *Pistia stratiotes*.

During the present study, a total of twenty-six species of alien invasive plants were recorded from the study area, viz., *Ageratum conyzoides, Alternanthera philoxeroides, Blumea* sp., *Chamaesyce hirta, Crassocephalum crepidioides, Crotalaria* sp., *Cyperus difformis, Echinochloa crus-galli, Eclipta prostrata, Eichhornia crassipes, Impatiens balsamina, Imperata cylindrica, Ipomea* sp., *Ludwigia* sp., *Ludwigia adscendens, Mikania micrantha, Monochoria vaginalis, Oxalis corniculata, Pistia stratiotes, Salvinia molesta, Sida acuta, Solanum nigrum, Sonchus* sp., *Stachytarpheta jamaicensis, Urena lobata* and *Xanthium strumarium*. Out of these, three species viz. *Salvinia molesta, Eicchornia crassipes* and *Pistia stratiotes* are free floating hydrophytes (Plate 7.2).

As part of the management practices annual burning and fire line cutting of the Phumdi is done during February-March. The local people also sometimes burn the phumdis so that fresh young shoots can come up for extraction. Studies have shown that burning affects vegetation composition (Gill et al., 2002; Dornbush, 2004; Khatri and Barua, 2011). This could be one of the factors contributing to the change in vegetation composition observed in the Park.

Discussion

The understanding of plant species composition in a habitat is crucial for understanding the succession and change in vegetation structure over time due to natural and anthropogenic impacts. The ecological structure of the plant species is the result of a rich array of factors relating to both the physical and the biological environment. The plant community structure represents a community's ability to capture and utilize resources (i.e., sunlight, water, and nutrients) from different positions in the canopy and soil profile. Often grazing and human interferences alter the plant community structure and composition of grasslands (e.g. Kala et al., 2002). These changes in the composition and structure influence forage production, habitat values and, ultimately, the sustainability of the habitat to support itself (Kamau, 2004).

The vegetation, particularly in the floating meadows, plays a crucial role in governing the processes and function of the Loktak Lake. Apart from the moisture loving, submerged aquatic plants, the presence of terrestrial plants can also be attributed to the floating mats of vegetation (Sharma et al., 2002). These floating mats of vegetation influence hydrological regimes, harbor rich biodiversity, support productive fisheries and provide several economically important plant species to the local communities (Trisal and Manihar, 2002). The floating meadows also provide biological sinks for nutrients and are critical to the maintenance of the water quality of the lake. Shamungou (1999) reported the proportion of fodder grasses as 58% and shelter grasses as 42%. However, our field observations during the study revealed that the occurrence of food plants had further decreased over the years, and the ratio of shelter to food species now stood at 27: 37. This trend suggests that the availability of food plants has also reduced along with loss in shelter plants species of Sangai and hog deer such as *P. karka, Z. latifolia* and *S. spontaneum*. There has been a high degree of change in the plant composition in the grassland that is not beneficial for the Sangai. This decline in food plants could also be due to the fact that non-palatable grasses have started replacing the palatable ones. Successions in grassland take place in nature, but the anthropogenic disturbances have altered the species composition in the grasslands. The growth in burnt grassland areas of the Park were usually dominated by *Pteris* sp. Unpalatable species such as *Pteris* sp., P*ersicaria perfoliata* and *Eupatorium* sp., together, occurred in more than 20% of the quadrats in the present study that was not the case earlier.

The most important plant species associated with the wild ungulates in the Park are *Z. latifolia, L. hexandra, Capillipedium* spp., *Scirpus* spp., *S. spontaneum, H. coronarium, P. karka, A. donax, O. javanica, C. lachryma-jobi, Setaria* spp. and *H. compressa*, which are also harvested by the local people. The tall grass species especially *P. karka, A. donax* and *S. spontaneum* act as a shelter for the Sangai and are extracted on a daily basis for household used. The favorite food plants of the Sangai such as *Z. latifolia, L. hexandra, Capillipedium* spp., *P. karka, A. donax* and *S. spontaneum* are also harvested in large quantities.

Although, *Z. latifolia* and *L. hexandra* were harvested in large quantities they did not contribute directly to the income of the family unlike *H. coronarium* and *O. javanica* which are extracted in huge amounts every day throughout the growing season mainly for commercial purposes. During the growing season, these two species provide an important source of livelihood for the local people. The people are mainly dependent on *Z. latifolia, C. demersum, H. verticillata, Limnophila* spp. and *L. hexandra* which are used as fodder for the fish farms in and around the Park. Fish farming being the main source of livelihood for the people living around the Park, the extraction of fish fodder is done all year round. *P. karka, A. donax* and *S. spontaneum* used for fencing and as fuel, are also extracted in large quantities by the households all year round. It can be stated that poverty (Osman et al., 2000; Roderick and Hirsch, 2000; Sills et al., 2003; Belcher and Kusters, 2004; Tickin, 2004; Quang and Anh, 2006), lack of alternate livelihoods (Richman, 2004) and excessive dependence on biomass resources of the park are the major management issues around KLNP. According to the survey conducted during early part (Trisal and Manihar, 2004) of the last decade, it was estimated that 33% of the lakeshore households harvest aquatic vegetation for use as fuel; 18% for use as vegetables; 2% for use as fodder and 1% for manufacturing handicrafts.

The role of anthropogenic activities might have resulted in the change in the composition of plant species and degrading the grassland habitat of the KLNP. Apart from resource extraction, Athaphum fishing in which huge chunks of Phumdis are cut off to create a fish pond inside the lake itself affects the floating grassland of the Lake and the Park. Fire could be another factor that might have contributed to the change. Fire is not only significant in maintaining an open sward, but also has the potential to control the invasion and spread of exotic species in native grasslands (Stuwe and Parsons, 1977; Stuwe, 1986).

During the present study, it was found that unpalatable plants such as *Pteris* sp. have invaded in areas that were burned; this needs to be substantiated by further research. Khatri and Barua (2011) also reported that frequent burning in the *Phragmites karka* dominated grasslands of Kaziranga National Park leads to replacements by *Saccharum, Themeda* and *Imperata* species. Though few studies have verified the claims that fire is beneficial, the burning season has remained the least understood component of the disturbed regime (Gill et al., 2002). Burning may also exert selective pressure, altering the composition of the native community over the years in Prairie grasslands (Dornbush, 2004). Another probable reason for the change in the composition may be the changes in the hydrological regime of the lake due to the construction of the Ithai barrage and excess nutrient loading. Kosygin (2002) had reported that the annual inflow of nitrate nitrogen was 372.6 ton, out of which 76.8 ton enters the Loktak Lake. The nitrogen concentration of the lake water was estimated at 2.3 g m-3. Thus high load of nutrients in the lake water may also have led to the proliferation of floating meadows in open waters of the lake. This might also be one of the causes for the change in the overall grassland composition as nitrogen addition experiments in grasslands indicate that one of the consequences was a reduction in plant diversity (Aguiar, 2005) dominance of a few species and suppression of many other species (Silvertown, 1980).

Management Recommendations

Our study shows that changes are taking place in the floating meadows of the Park. These changes are affecting the habitat of the Sangai in terms of change in plant species composition and deteriorating habitat due to proliferation and thinning of the Phumdis. The invasive plant species recorded in the Park are aggressive colonizers especially around disturbed areas, common in stagnant or slow-flowing waters. The invasion potentially leads to a decrease in species richness, as native species are replaced. Over the years, the thickness of the Phumdis of the Park is reducing and becoming thinner that might explain the colonization of the invasive species. The majority of the people residing around the Park are also dependent on the bio-resources from the park for their livelihoods, and the local economy is based on it. Over-harvesting and unscientific management may have led to the change in the grassland composition that is not favorable for the conservation of Sangai. Based on the findings of the present study, following recommendations for proper maintenance of the grassland composition are made:

1. The construction of the Ithai barrage has played a significant role in the present status of the Lake's ecosystem, as the barrage blocks both the outlet channels, Ungamel and Khordak. Since the Park remains flooded during the monsoon to early winter making some of the areas inaccessible to the ungulates, therefore maintaining the water level through a consultative process is imperative for the survival of Sangai.
2. The Phumdis that used to settle during lean season and get replenished with soil and nourishment are now continuously floating resulting in their thinning, making them increasingly defunct in supporting the weight of the Sangai. Hence, allowing a significant portion of the phumdis to settle during the lean season (February – April) by reducing the water level of the Lake is recommended.
3. Natural growth and thickening of the Phumdis is critical for the survival of Sangai. It is also seen that the newly formed Phumdis are unable to support the weight of the Sangai. Since the proliferation is mainly due to the excessive nutrients from pollutants that enter the Park from the Loktak Lake and remain trapped inside the Park due to the Ithai barrage, the opening of the barrage during monsoon, when the influx of pollutants is highest, is recommended.
4. Since the Phumdis are formed from dead and decaying vegetation matter, resource extraction inside the Park should be checked as the removal of plants reduces the amount of rootmass needed for the formation of the Phumdi. Also, the soil particles in the phumdi are held together by the roots of the plants (e.g., that of *Hedychium coronarium*), extraction of which reduces the thickness of Phumdis. Hence, controlled/regulated harvesting and moderate cutting/harvesting of the plants resources is recommended to provide optimum food plants and shelter plants for the Sangai
5. Grazing of cattle in the Park, especially in the periphery, should be regulated so as to reduce the pressure on the Park and reduce competition and spread of diseases to the wild ungulates.
6. Food, in abundance in the thick meadows, is crucial for the existence of Sangai in the Park. Therefore, it is important to maintain the integrity of the phumdi thickness for the long term conservation of the Sangai.
7. Burning of the grassland as a part of management practice, as well as by the local communities, leads to the loss of dead and decaying plant material that is essential for the formation of Phumdi. Hence, in order to maintain the thickness of the Phumdi, the grassland should be cut and left as such so that the base material for the formation of Phumdi is not lost.
8. Monitoring of invasive species is required which can be done through qualitative approaches such as species inventory (seasonally) and quantitative approaches using phytosociological methods for early detection of problematic species and the rapid assessment of the status and movement of invaders and their potential ecosystem impacts.

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APPENDIX 1

List of plant species from the Keibul Lamjao National Park, Manipur, India. Note: Habit: Herb (H), Climber (C), Shrub (S), Sedge (Sd), Grass (G), Floating or Phumdi (P), Terrestrial (T), Phumdi / Terrestrial (P/T)

Scientific Name	**Family**	**Habit**	**Habitat**
Apluda mutica L.	Poaceae	G	P/T
Arundo donax L.	Poaceae	G	P/T
Capillipedium assimile (Steud.) A.Camus	Poaceae	G	P/T
Coix aquatica Roxb.	Poaceae	G	P
Coix lacryma-jobi L.	Poaceae	G	P
Cymbopogon sp.	Poaceae	G	P/T
Cynodon dactylon (L.) Pers.	Poaceae	G	T
Cyrtococcum sp.	Poaceae	G	P/T
Dactyloctenium aegyptium (L.) Willd.	Poaceae	G	T
Echinochloa colona (L.) Link	Poaceae	G	P/T
Echinochloa crus-galli (L.) P. Beauv. var. *breviseta* (Döll) Podp.	Poaceae	G	P/T
Echinochloa crus-galli var. *crus-galli* (L.) P. Beauv.	Poaceae	G	P
Eragrostis gangetica (Roxb.) Steud.	Poaceae	G	P/T
Eragrostis sp.	Poaceae	G	P
Erianthus ravennae P. Beauv.	Poaceae	G	P/T
Hemarthria compressa (L.f.) R.Br.	Poaceae	G	P
Hygroryza aristata (Retz.) Nees ex Wight and Arn. *(Hygroryza aristata Nees)*	Poaceae	G	P/T
Imperata cylindrica (L.) Raeusch.	Poaceae	G	P/T
Isachne globosa (Thunb.) Kuntze	Poaceae	G	P
Leersia hexandra Sw.	Poaceae	G	P/T
Oryza rufipogon Griff.	Poaceae	G	P
Oryza sativa L. Poaceae	G	P/T	
Panicum paludosum Roxb.	Poaceae	G	P/T
Panicum sp.	Poaceae	G	P
Paspalum scorbiculatum Steud.	Poaceae	G	P
Phragmites karka (Retz.) Trin. ex Steud.	Poaceae	G	P/T
Saccharum bengalense Retz.	Poaceae	G	T
Saccharum munja Roxb.	Poaceae	G	P/T
Setaria glauca P. Beauv.	Poaceae	G	P/T
Setaria pallidefusca (Schumach.) Stapf and C.E.Hubb.	Poaceae	G	P/T
Setaria verticillata (L.) P.Beauv.	Poaceae	G	T
Vetiveria zizanioides (L.) Nash	Poaceae	G	T
Zizania latifolia (Griseb.) Turcz. ex Stapf	Poaceae	G	P
Bulbostylis barbata (Rottb.) C.B.Clarke	Cyperaceae	Sd	P
Carex cruciata Wahlenb.	Cyperaceae	Sd	P
Carex sp.	Cyperaceae	Sd	P
Cyperus alopecuroides Thunb.	Cyperaceae	Sd	P
Cyperus alulatus J.Kern	Cyperaceae	Sd	P
Cyperus brevifolius Hassk.	Cyperaceae	Sd	P
Cyperus compressus L.	Cyperaceae	Sd	P
Cyperus cyperoides (L.) Kuntze	Cyperaceae	Sd	P/T
Cyperus difformis L.	Cyperaceae	Sd	P

Scientific Name	Family	Habit	Habitat
Cyperus globosus Baldw. ex Torr.	Cyperaceae	Sd	P
Cyperus iria L.	Cyperaceae	Sd	P
Cyperus niveus Retz.	Cyperaceae	Sd	P
Cyperus nutans Vahl	Cyperaceae	Sd	P
Cyperus pygmaeus Rottb.	Cyperaceae	Sd	P/T
Cyperus rotundus L.	Cyperaceae	Sd	P
Cyperus triceps F.N.Williams (*Kyllinga triceps* Rottb.)	Cyperaceae	Sd	P/T
Eleocharis acutangula Schult.	Cyperaceae	Sd	P
Eleocharis atropurpurea (Retz.) J. Pres.	Cyperaceae	Sd	P
Eleocharis dulcis (Burm.f.) Trin. ex Hensch.	Cyperaceae	Sd	P
Eleocharis palustris F.Muell.	Cyperaceae	Sd	P
Fimbristylis bisumbellata Bubani	Cyperaceae	Sd	P
Fimbristylis dichotoma (L.) Vahl	Cyperaceae	Sd	P
Fimbristylis miliacea (L.) Vahl	Cyperaceae	Sd	P
Fimbristylis schoenoides Vahl	Cyperaceae	Sd	P
Fimbristylis tetragona R.Br.	Cyperaceae	Sd	P
Fuirena umbellata Rottb.	Cyperaceae	Sd	P
Scirpus juncoides Roxb.	Cyperaceae	Sd	P
Scirpus lacustris L.	Cyperaceae	Sd	P
Scirpus mucronatus Roxb.	Cyperaceae	Sd	P
Scleria oblata S.T. Blake ex J.Kern	Cyperaceae	Sd	P
Ageratum conyzoides (L.) L.	Asteraceae	H	P/T
Artemisia nilagirica (C.B.Clarke) Pamp.	Asteraceae	H	T
Blumea sp.	Asteraceae	H	P/T
Centipeda minima (L.) A. Br. and Asch.	Asteraceae	H	P/T
Crassocephalum crepidioides (Benth.) S.Moore	Asteraceae	H	P/T
Enydra fluctuans Lour.	Asteraceae	H	P
Eupatorium odoratum L.	Asteraceae	H	P/T
Grangea maderaspatana (L.) Desf.	Asteraceae	H	P/T
Gynura sp.	Asteraceae	H	P
Mikania micrantha Kunth	Asteraceae	C	P/T
Siegesbeckia orientalis (L.)	Asteraceae	H	P/T
Sonchus spp.	Asteraceae	H	P/T
Spilanthes acmella (L.) L.	Asteraceae	H	P/T
Xanthium strumarium L.	Asteraceae	H	P/T
Persicaria sp.	Polygonaceae	H	P
Polygala arvensis Willd.	Polygalaceae	H	P/T
Polygonum barbatum L.	Polygonaceae	H	P
Polygonum chinense L.	Polygonaceae	H	P/T
Polygonum flaccidum Roxb.	Polygonaceae	H	P
Polygonum lapathifolium L.	Polygonaceae	H	P
Polygonum sp	Polygonaceae	H	P
Polygonum sp.	Polygonaceae	H	P
Borreria pusilla DC.	Rubiaceae	H	P/T
Galium mollugo L.	Rubiaceae	H	P
Galium sp.	Rubiaceae	H	P/T
Galium sp.	Rubiaceae	H	P/T

Scientific Name	Family	Habit	Habitat
Oldenlandia corymbosa L.	Rubiaceae	H	P/T
Paederia foetida L.	Rubiaceae	C	P/T
Spermacoce hispida L.	Rubiaceae	H	P/T
Wendlandia wallichii Wight and Arn.	Rubiaceae	S	P/T
Commelina appendiculata C.B.Clarke	Commelinaceae	H	P/T
Commelina benghalensis L.	Commelinaceae	H	P/T
Commelina longifolia Lam.	Commelinaceae	H	P/T
Cyanotis barbata D.Don	Commelinaceae	H	P/T
Floscopa scandens Lour.	Commelinaceae	H	P/T
Murdannia nudiflora (L.) Brenan	Commelinaceae	H	T
Argyreia nervosa (Burm.f.) Bojer	Convolvulaceae	H	P/T
Ipomoea aquatica Forssk.	Convolvulaceae	H	P
Ipomoea fistulosa Mart. ex Choisy	Convolvulaceae	S	P/T
Ipomoea hederifolia L.	Convolvulaceae	H	T
Ipomoea nil (L.) Roth	Convolvulaceae	H	T
Ipomoea pentaphylla Jacq.	Convolvulaceae	H	P/T
Aeschynomene indica L.	Fabaceae	H	P
Atylosia scarabaeoides Benth.	Fabaceae	C	P/T
Crotalaria sp.	Fabaceae	H	P
Desmodium gyrans DC.	Fabaceae	H	T
Desmodium heterocarpon (L.) DC.	Fabaceae	H	T
Rhynchosia minima (L.) DC.	Fabaceae	C	P/T
Ludwigia prostrata Roxb	Onagraceae	H	P
Ludwigia adscendens (L.) H. Hara	Onagraceae	H	P
Ludwigia clavellina M. Gómez (*Jussiaea repens* L.)	Onagraceae	H	P
Ludwigia octovalvis (Jacq.) P.H.Raven (*Oenothera octovalvis* Jacq.)	Onagraceae	H	P/T
Ludwigia sp.	Onagraceae	H	P
Lindernia cordifolia Merr.	Scrophulariacea	H	P/T
Lysimachia javanica Blume	Scrophulariacea	H	P
Limnophila heterophylla (Roxb.) Benth.	Scrophulariacea	H	P
Lindenbergia sp.	Scrophulariacea	H	P
Limnophila rugosa (Roth) Merr.	Scrophulariacea	H	P
Actinostemma tenerum Griff.	Cucurbitaceae	C	P/T
Benincasa hispida (Thunb.) Cogn.	Cucurbitaceae	C	P/T
Zehneria wallichii (C.B. Clarke) C. Jeffrey	Cucurbitaceae	C	T
Zehneria scabra (L.f.) Sond	Cucurbitaceae	C	T
Euryale ferox Salisb.	Nymphaeaceae	H	P
Nymphoides cristata (Roxb.) Kuntze	Nymphaeceae	H	P
Nymphaea nouchali Burm.f.	Nymphaeceae	H	P
Nymphaea sp.	Nymphaeceae	H	P
Hydrocotyle sibthorpioides Lam.	Apiaceae	H	P
Centella asiatica (L.) Urb.	Apiaceae	H	P/T
Oenanthe javanica (Blume) DC.	Apiaceae	H	T
Phyllanthus urinaria L.	Euphorbiaceae	H	T
Glochidion multiloculare (Rottler ex Willd.) Voigt	Euphorbiaceae	S	P/T
Euphorbia hirta L.	Euphorbiaceae	H	P/T
Urena lobata L.	Malvaceae	H	P/T

Scientific Name	Family	Habit	Habitat
Sida rhombifolia L.	Malvaceae	H	T
Sida acuta Burm.f.	Malvaceae	H	P/T
Alternanthera philoxeroides (Mart.) Griseb.	Amaranthaceae	H	P
Alternanthera sessilis (L.) R.Br. ex DC.	Amaranthaceae	H	P/T
Pistia stratiotes L.	Araceae	H	P
Colocasia antiquorum Schott	Araceae	H	P/T
Impatiens balsamina L.	Balsaminaceae	H	P
Impatiens sp.	Balsaminaceae	H	P
Eriocaulon sp.	Eriocaulaceae	H	P
Eriocaulon truncatum Buch.-Ham. ex Mart.	Eriocaulaceae	H	P
Lemna perpusilla Torr.	Lemnaceae	H	P
Spirodela polyrhiza (L.) Schleid.	Lemnaceae	H	P
Cissampelos pareira L.	Menispermaceae	C	T
Cyclea sp.	Menispermaceae	C	T
Salvinia cucullata Roxb.; Wall.	Salviniaceae	F	P
Salvinia molesta D. Mitch.	Salviniaceae	F	P
Solanum torvum Sw.	Solanaceae	S	T
Solanum nigrum L.	Solanaceae	H	P/T
Triumfetta pilosa Roth	Tiliaceae	H	P
Triumfetta rhomboidea Jacq.	Tiliaceae	H	P/T
Utricularia sp.	Utriculariaceae	H	P
Utricularia sp.	Utriculariaceae	H	P
Stachytarpheta jamaicensis Vahl	Verbenaceae	H	P/T
Clerodendrum indicum (L.) Kuntze	Verbenaceae	S	P/T
Hedychium coronarium J. König	Zingiberaceae	H	P
Alpinia allughas Roscoe	Zingiberaceae	H	P
Sagittaria sagittifolia L.	Alismataceae	H	P
Azolla pinnata R. Br.	Azollaceae	F	P
Cassia occidentalis L.	Caesalpiniaceae	H	T
Drymaria cordata (L.) Willd. ex Schult.	Caryophyllaceae	H	P/T
Ceratophyllum demersum L.	Ceratophyllaceae	H	P
Hydrilla verticillata C. Presl	Hydrocharitaceae	H	P
Hydrolea zeylanica (L.) Vahl	Hydrophyllaceae	H	P
Mosla dianthera (Buch.-Ham. ex Roxb.) Maxim.	Lamiaceae	H	P/T
Lygodium flexuosum (L.) Sw.	Lygodiaceae	C	P/T
Rotala rotundifolia (Buch.-Ham. ex Roxb.) Koehne	Lythraceae	H	P
Osbeckia stellata Buch.-Ham. ex D. Don	Melstomataceae	S	P/T
Monochoria vaginalis C. Presl	Monochoriaceae	H	P
Habenaria sp.	Orchidaceae	H	P
Oxalis corniculata L.	Oxalidaceae	H	P/T
Passiflora foetida L.	Passifloraceae	C	P/T
Eichhornia crassipes Solms	Pontederiaceae	H	P
Potamogeton nodosus Poir.	Potamogetonaceae	H	P
Pteris sp.	Pteridaceae	F	P/T
Rubus sp.	Rosaceae	S	P/T
Selaginella amblyphylla Alston	Selaginellaceae	F	P/T
Sparganium erectum L.	Typhaceae	H	P
Vallisneria spiralis L.	Vallisneriaceae	H	P
Ampelocissus latifolia (Roxb.) Planch.	Vitaceae	C	P/T

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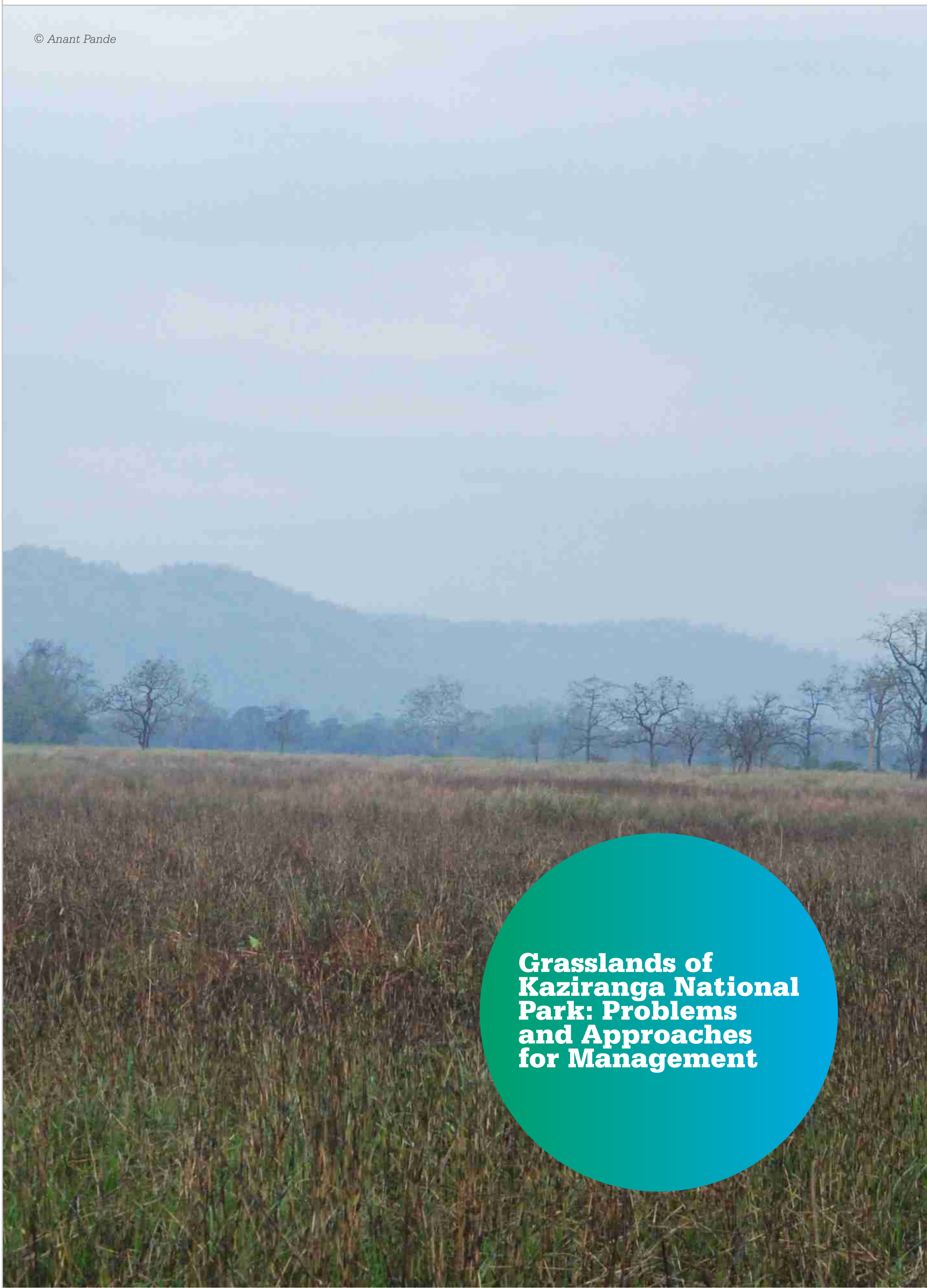

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Grasslands of Kaziranga National Park: Problems and Approaches for Management

Abstract

The flood plains of Ganga and Brahmaputra Rivers are well known for their unique grasslands. Frequent flooding and changes in pattern of channels accompanied by extensive erosion and deposition of sediment generates ideal conditions for such grasslands. The world famous Kaziranga National Park, located in the floodplains of Bramhaputra, represents typical wet grasslands. About 64% of the park area is occupied by tall grasses (61%) and short grasses (3%). Predominantly, tall grass species such as *Saccharum spontaneum, Imperata cylindrica, Saccharum bengalense* are present in low lying areas; *Vetiveria zizanioides* prefers upland areas, whereas *Phragmites karka* and *Themeda arundinacea* prefer the marshy areas. However, changing flood regime, siltation, fire coupled with invasion of *Mimosa invisia* are affecting, vegetation composition and suitability of the habitat for the native fauna adversely. In view of the changing landscape and taking into account the present ethnic diversity, anthropogenic pressure and presence of endangered large mammals in the par, there is a need to conserve and protect this natural heritage in a holistic manner. The present paper describes the vegetation dynamics of the grassland habitats in the park and provides, management recommendations to combat the issues affecting the grasslands.

Keywords : Kaziranga National Park; Management issues; Tall grasslands; Vegetation dynamics; Weed invasion

Introduction

Grasslands are ecosystems dominated by vegetative component comprising herbaceous species (Coupland 1979). While expansion of agriculture, human settlement and land use changes have resulted in conversion of highly productive grasslands for agriculture and artificial pastures (White et al., 2001; Suttie et al., 2005; Yang et al., 2015); invasion by woody perennials has resulted in drastic changes in the functional ability of these ecosystems (Gioria and Osborne 2014). Hygrophilous or tall wet grasslands are considered as wet savannahs adapted to very wet climate. Ecosystem that serves as habitat for a number of threatened fauna, obligate to grasslands of various types of tropical grasslands, hygrophilous grasslands in the flood plains of Ganga and Bramhaputra Rivers are of special interest due to their high primary productivity and ability to withstand frequent fire and flood.

The hygrophilous grasslands have evolved along the river courses where large seasonal variation in rainfall results in flooding and the overspills from the river flows into the surrounding plains (Krafter et al., 1992). Regular flooding, gravel and mud shifting, formation of oxbow lakes, nutrient rich woods and meadows are the characteristic features of a dynamic floodplain ecosystem (Bayley, 1995; Bissels et al., 2004). The riverine tall wet grasslands of Ganga and Brahmaputra in the foothills of the Himalaya are typical example of floodplains ecosystem in India (Kumar and Subudhi 2013). These floodplains are developed on river deposited silt and often dominated by pure dense stands of 6-8m tall perennial grasses and form a dynamic complex with interspersed woodland and swamps. High water table, annual flooding, high level of moisture availability and the synergistic influence of annual grassland fires are characteristics of this complex ecosystem (Lehmkuhl, 1994; Peet et al., 1997).

The flood banks of Brahmaputra River is characterized by its enormous volume of sediment load leading to continuous changes in channel morphology, rapid bed aggradations and bank line recession and erosion (Sarma and Basumallick, 1980; NRSA, 1980; Naik et al., 1999; Mani et al., 2003). The river has braided channel along its course in the alluvial plains (Goswami et al., 1999). The lateral changes in channels cause severe erosion along the banks leading to a considerable loss of good fertile land each year (Bhakal et al., 2005; Sarma et al., 2007). Bank oscillation also causes a shifting of outfalls of its tributaries that brings newer areas under waters (Kotoky et al., 2005; Das and Saraf 2007). High floods result

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in large scale breaches of the existing embankments bringing vast areas under flood inundation. Stream-bank erosion further damages infrastructure causing significant problems in adjusting water-discharge and represent up to 80- 90% of the sediment load in streams and rivers (Simon and Rinaldi 2000). Total maximum daily sediment load is a significant source of sediment and nutrient pollution affecting the water quality, vegetation composition and fish spawning habitat adversely. Despite of the destructive nature of floods, new habitats are created such as fish spawning areas, crane roosting habitats (Johnson 1994; Flosi et al., 1998), irregular banks as habitat for invertebrates, fish, and birds and substrate for the establishment of riparian vegetation (Florsheim et al., 2008; Miller and Friedman 2009).

The grassland habitats along Brahmaputra are highly threatened due to excessive agricultural expansion. Even within Protected Areas such as Kaziranga National Park (KNP), grassland habitats are prone to conversion into woodlands or degradation due to invasion by exotic aggressive weeds. In this paper we describe the issues concerned with management of grassland habitats of KNP with special reference to tall wet grasslands.

Study area

Kaziranga National Park

Kaziranga landscape is formed by complex of sprawling grasslands, numerous water bodies and woodlands that make an ideal mix of habitats for a variety of flora and fauna. KNP and its six additions are situated in three civil districts namely Golaghat, Nagaon and Sonitpur in the state of Assam. The park is located between 26°30' N to 26°50' N and 92°50' E to 93°41' E coordinates bounded by the Brahmaputra river on the north and Karbi Anglong hills on the south covering an area of 859.4 km^2 that includes 429.93 km^2 area of KNP vide Govt. Notification No.FOR/WL/722/48/45, dated 11-02-1974 with effect from 01-01-74 and the areas vide subsequent notifications as six additions. National Highway (NH) 37 passes along the southern boundary of the national park. The lithic formation represents grey silt and fine to medium sands which form the recent composite floodplain with numerous meander scars and scrolls. The climate of the national park is subtropical monsoon type differentiated into three seasons viz. summer, monsoon, and winter. The winter season spans between November and February and characterized by mild and dry conditions with a temperature range of 5 - 25°C. During this season, the wetlands called 'beels' and water channels (nallahs) get dried up (Mathur et al., 2005). The hottest months are July and August with maximum temperature going up to 35°C.

Mean annual rainfall is 2,220 mm mostly during the months of June to September. Because of rise and fall of water table of the Brahmaputra River, the park gets submerged due to the unique flooding pattern of the Brahmaputra River. Due to back flow of river 'Mora Diffolu' from the west, large areas in western range are submerged initially, making an ideal condition for development of short grass areas along the water bodies. Nearly 100 km bank-line of Brahmaputra has many openings at different elevations from east to west that facilitates rising of the waters of the river into the park replenishing the water bodies and then spilling to the grassland areas and the adjoining high grounds depending upon the level of water and its duration in the main river. In the final stage, when flood peaks rise above the floodplain surface, the overtopping of bank-line results into heavy inflow of excess water of the river into the park. This situation, if prolonged, creates high flood condition resulting in heavy damage to infrastructure and wildlife and also results in migration of some animals to the elevated and forested regions outside the southern border of the park. In this migration process, mortality due to vehicle hit on NH 37 and drowning when trapped in floating vegetation also occurs. The ecological and biological process in the evolution and development of the riverine floodplain ecosystem of this park is also influenced by the oscillatory character of Brahmaputra River under riverine and fluvial processes.

This floodplain is also dotted with wetlands locally known as beels, which harbour varieties of flora and fauna. The major vegetation types of KNP comprise of five forest types or biomes viz., (1) Eastern wet alluvial grasslands (4D / 2S2), (2) Assam alluvial plains semi-evergreen forests (2B/C1a), (3) Tropical moist mixed deciduous forests (3C3), (4) Eastern Dillenia swamp forests (4D/SS5) and (5) Wetlands (Champion and Seth, 1968).Water bodies cover about 6% of the park area (Table 8.1). The park harbours about 440 plant species, 35 species of mammals, 480 species of birds, 60 species of reptiles, 24 species of amphibians, 42 species of fishes and 491 species of butterflies. However, recurrent flood, erosion and alluvial deposition are resulting in establishment of early succession species such as *Imperata cylindrica, Phragmites* and *Saccahrum* in low lying areas and *Vetiveria zizanioides* on the elevated ones (Khatri and Barua 2011).

Maximum area of the park is occupied by tall grasses followed by woodlands and short grass area. About 64% area of the Kaziranga National Park (KNP), particularly the western part, is occupied by the grasslands that include both tall grasses and short grasses. Rowntree (1954) classified the grasslands of Assam into two associations, i.e. (i) *Imperata - Saccharum –Themeda* type; and (ii) *Alpinia – Phragmites- Saccharum* type. The former develops on higher well drained lands whereas the latter develops on recent alluvium of rivers and flood plains, where *Bombax* and *Albizzia* are common tree associates. Tall grasslands consists mainly *Saccharum* spp., *Saccharum ravennae, Arundo donax, Phragmites karka, Imperata cylindrica, Neyraudia reynaudiana* etc. These grasses occupy the newly formed areas along the river course and wetlands but mixed sometimes with *Tamarix dioica.*

Table 8.1. Land use- land cover statistics of Kaziranga National Park, Assam in different years.

Land cover type	Percent area cover		
	(Kushwaha, 1997)	(RFRI, 2011)	(Das et al., 2014)
Woodlands	27.95	29.30	21.8
Tall grass	61.01	57.00	50.6
Short grass	3.01	7.00	7.7
Water body ('beels')	5.96	6.00	-
Jia Diffolu	0.97	-	-
Mora Diffolu	0.70	-	-
Sand bars	0.40	-	-

Vegetation dynamics

There are marked seasonal variations in the habitat, the vegetation and the areas of animal concentration in the park mainly between the winter and monsoon seasons. With the advent of winter, the shallow wetlands and streams and the shallow banks around the perennial wetlands starts drying up with simultaneous regeneration and growth of shorter grass species. These are the areas where animals concentrate for grazing immediately after the receding of the monsoon. The tall coarse grasses dry up during December to January and are burnt annually. These burnt sites attract several ungulate species to feed on the partially burnt stems of the reed grasses (Vasu, 2003). As soon as the Park gets a few winter showers, new growth of grasses shoots up in the burnt patches, where the animals concentrate to relish the tender shoots. With gradual increase of the rainfall during the monsoon, the grasses in the burnt patches grow up very quickly resulting in turning up of tender shoots into coarse blades (pers. obs.). As the temperature shoots up, the animals prefer to remain near the water sources, i.e. wetlands and streams. But with setting in of monsoon the shallow wetlands and streams are filled up at first by the rainwater and then by the floodwater leading to gradual movement of animals to higher grounds, which are mainly situated around the woodlands. When more and more areas are submerged by flood water, animals start migrating to the nearby Karbi Anglong Hills and other adjoining areas.

Majority of species in the park have site preferences depending upon the moisture conditions of the soil. *Saccharum spontaneum, I. cylindrica, Saccharum bengalense, Saccharum narenga, Neyraudia reynaudiana, Cymbopogon flexuosus* occur in the newly formed floodplain along the river. *S. spontaneum* (Ekora), the most common, widely distributed and preferred species for the One-horned Rhinoceros grows in elevated areas, which get exposed after being flooded during rains. Borota Kher (*Saccharum bengalense*), Ulu Kher (*I. cylindrica*) occupy comparatively drier areas, while Khagori (*P. karka*) and Meghela (*Saccharum arundinaceum*) are found generally in low-lying damp areas. Nal (*A. donax*) is the species of water logged and marshy places (Vasu 2003). The short grasslands covers about 3% of the park and mostly found in the open areas near the 'beels' which remain inundated during monsoon and dry up during winter supported by loam soils. The woodlands are represented by variety of subtypes or different stages of succession and edaphic variations. Some of the important trees in the park are *Mangifera indica, Delonix regia, Terminalia myriocarpa, Bombax ceiba* and *Ficus* spp.

Species of *Imperata, Phragmites* and *Saccharum* are considered the early succession species of this floodplain and occupy the low lying areas of the park under fluvial action and flooding. This association also develops in woodlands when periodic flooding ceases and soils stabilize. *Phragmites karka – Imperata cylindrica* assemblage is generally favoured by extreme wet and marshy condition, whereas *Phragmites karka – Sacchrum narenga – Imperata cylindrical* assemblage occupy relatively lower end of the moisture gradient. Shorter perennial grasses such as *Imperata cylindrica* and *Vetiveria zizanioides* occupy generally drier and well drained elevated area with better developed soils but mixed sometimes with scattered trees or shrubs (Khatri and Barua 2011; Kumar and Subudhi, 2013). *S. spontaneum* has been observed to colonize the river banks after the retreat of monsoon floods (Dinerstein, 2003).Though natural disturbances determine the forest dynamics and affect the tree diversity at local and regional scales (Attiwill, 1994; Sheil, 1999), the anthropogenic disturbances contribute in regulating the regeneration dynamics, structure and floristic composition of grasslands (Ewel et al., 1981; Horn and Hickey, 1991). Fire is an important anthropogenic factor in KNP that stimulates the growth of many palatable and nutritious grass species preferred by the grazing ungulates. The annual flooding replenishes the soil with nutrients and allows regeneration of flood adapted species (Loeb et al., 2009; Manral et al., 2012). These key factors operate in tall wet grasslands at the landscape level creating a mosaic of seral stages that are exploited by the resident ungulate (Banerjee 2001). The changes in structural attributes of the grassland are also related to disturbance regimes (Cannon et al., 1994; Wright 2005). Decreased grassland area at the expense of tropical deciduous

and tropical semi-evergreen forests and development of two new forest types viz., tropical evergreen and moist deciduous forests are the recent changes in vegetation dynamics of KNP (Medhi and Shaha 2014). Decline in area of wetlands under sedimentation and silt deposition and its conversion into grassland followed by invasion of *Mimosa* species are also influencing the vegetation composition and dynamics of the park.

Problems of grassland management

A number of fresh water lakes (beels), marshy areas, seasonally inundated lowlands and a large number of riverine sandbars and islands were, till recently, an ideal wetland ecosystem of the Brahmaputra floodplain. However, the devastation of these wetlands started with the arrival of water hyacinth a century ago. Extensive growth of this weed leads to eutrophication by slowing down water movement and depositing debris at the bottom of the water bodies. The anthropogenic factors such as large scale deforestation in the hilly catchments practice of shifting cultivation, and human intervention in the river system like encroachment in the floodplains, and destruction of natural wetlands cause degradation of wetlands. The floods in the region have also made a quantum leap after the massive earthquakes of 1897 and 1950, both of magnitude 8.7 on the Richter scale. As usual such earthquakes generate large quantities of sediment that enter the river system as sludge and disturb the normal regime over a period of several decades (World Bank, 2006). Gradual silt deposition and rising of the riverbed affect run-off from the catchment areas during the monsoon (Bhatt, 2013).

Changes in grasslands area

The grassland associations include mono-specific stands of tall grass viz., *S. spontaneum* (4–6 m), *S. bengalense, S. narenga* and *Themeda arundinacea* (5–7 m) or mixed sometimes with short grass species such as *I. cylindrica, Chrysopogon aciculatus, Eragrostis* spp. etc (Dinerstein and Price 1991; Dinerstein 2003). The short grasses usually occur at elevated area with relatively less moisture and are intensively grazed by the rhinos and other herbivores or sometime mixed within tall grasslands. KNP is losing its area due to river action every year particularly from the northern boundary, though the points of erosion changes with the change in the river course (Gilfellon et al., 2003). The gravity of the situation can be judged from the fact that the estimated area of the park in 1998 was only 40,790 ha against the notified area of 42,993 ha in 1974. Though sometimes the areas eroded earlier are restored by heavy silt depositions, but recent estimate indicates a loss of about 11.7% core area of the park due to erosion of Brahmaputra (Das et al., 2014). Thus, loss of area due to erosion is a part of ecosystem processes in the floodplains of Brahmaputra. To check this phenomenon, erosion control structures were erected along the bank-line. However, these structures are affecting the flow of excess water from the river into the floodplains (KNP) which in turn upsets the ecosystem functions that help in creating a variety of habitats suitable for different flora and fauna species and their assemblages. Hence, a better understanding of the flooding pattern and corresponding processes in ecological framework is required in order to take immediate steps for erosion control. The recent six additions to KNP which includes the river in the park northern boundary and river islands (Chapories) has helped in restoring lost habitats due to erosion to a great extent. Land cover change analysis during 1990 to 2009 indicates conversion of 0.38 % short grass area into 'beel' (Table 8.2).

Table 8.2. Land use- land cover statistics of Kaziranga National Park, Assam in different years.

	1990		2009	
Land cover classes	**Area (ha)**	**Percentage (%)**	**Area (ha)**	**Percentage (%)**
Short grassland	7706.97	9.1	9313.09	11.0
Tall grassland	25529.03	30.3	20320.09	24.1
River	17993.52	21.3	11907.17	14.1
Tropical deciduous forest	3525.78	4.2	4104.32	4.9
Tropical evergreen forest	7899.83	9.4	11395.84	13.5
Braided Bar	18797.32	22.3	25066.63	29.7
Wetland (beel)	2895.67	3.4	2240.98	2.7
Total	**84348.12**	**100**	**84348.12**	**100**

The short grassland areas and 'beels' area are interchangeable to some extent i.e when water level recedes in the 'beels' short grassland area increases, whereas a reverse trend has been observed when water level increases during the floods (Kushwaha et al., 2000a, b). The conversion of tall grassland to short grassland area (3.6 %) and 'beel' (1.3 %) could be considered as a positive change since Rhinos and the other herbivores forage extensively on the short grassland areas. A 6.2% reduction in tall grassland areas due to expansion of forested areas has been observed indicating an overall decrease on grassland areas. Though, the conversion of tall grass to short grass (3.6 %) and 'beel' (1.3 %) could be considered as a positive change, but reduction in tall grasslands was because of the expansion of forested areas into grasslands. Further, conversion of tall grassland areas to tropical deciduous forest accounted for 0.9 % and tropical semi-evergreen forest for 1.2 % that has resulted in reduced grassland areas. Increase in the other forest classes has also been observed, i.e. tropical evergreen (4 %) and moist deciduous (0.7 %). In addition, invasion of *Mimosa diplotricha* and *M. invisa* in short and tall grassland areas has also reduced the grassland areas. However, this data slightly differ with that of Das et al., (2014), where these authors reported 50.6% area of the park under grassland, followed by 21.8% under forests and 7.7% area under short grasses.

Siltation

The areas under river and 'beel' in KNP are declining from 21% and 3.4% in 1990 to 14% and 2.6% in 2009, respectively. Decreased in area under 'beels' are due to sedimentation and silt deposition and its conversion into short grassland (0.4%) and tall grassland (0.6%) areas (Medhi and Shaha 2014). Sedimentation along the riverbanks also adds nutrients to the ecosystem, which increases the net primary productivity (Khatri and Barua, 2011; Chitale et al., 2012).

Increasing pollution load

Regular flooding and silt deposition replenishes the soil with nutrients and allows regeneration of hygrophilous species (Loeb et al., 2009; Manral et al., 2012). Increased silt deposition and nutrient addition in tall wet grasslands results in a mosaic of seral stages. However, high enrichment of cadmium (Cd) and chromium (Cr) along the road side soils of KNP and their accumulation in the biological system of the park needs attention. The origin of these heavy metals was observed from both geogenic and anthropogenic sources (Devi et al.,, 2015). The accumulation of other heavy metals such as iron (Fe) and nickel (Ni) was also observed maximum in the smooth bark surfaces of *Trema orientalis* and *Tectona grandis*, whereas the concentration of cobalt (Co) and copper (Cu), manganese (Mn) and Cr, lead (Pb) and Cd were observed high in bark surfaces of *Streblus asper, Mangifera indica* and *Lagerstroemia* spp.

Biological Changes in Grasslands

Invasion of weeds

One of the major threats besides poaching is infringement of invasive species in the grassland and wetland habitats. This reduces the availability of suitable forage species to meet the requirements of Rhino and other the mega herbivores. *Mimosa invisa, Chromolaena odorata, Mikania micrantha, Ipomoea carnea* and *Lantana camara* are some important alien species in Rhino habitats (Lakher et al., 2011). About 43% of KNP area is at varying degree of risk from of invasion by two species of *Mimosa* belonging to the family Mimosaceae, i.e. *M. diplotricha* and *M. invisa* (Vattakkavan et al., 2002; RFRI, 2011). Both species are straggling herbs seen climbing to the top of several meters high elephant grasses. The quick growing herb not only destroys the grasses, but it hampers the free movement of wild animals also. Mimosin, a harmful toxin present in this species are known to affect herbivore population particularly ruminants (Mathur et al., 2005). *Mimosa* invasion started in the grasslands of the Baguri Range (western range) of the park in the mid-1990s and later spread all over the park. This issue of invasive species particularly by Mimosa spp. was highlighted around 2001–02. The spread of *Mimosa* spp. is mostly through dispersal of seed which is facilitated by vehicular movements and annual flooding coupled with high soil moisture condition and favourable temperature for its growth and regeneration in the park (Lucia et al., 2004; Chauhan and Johnson 2008) which is indicated by its high regeneration status ranging between 270 and 780 individuals per sq meter (RFRI, 2011).

Grazing by domestic Livestock

There is always an active interaction between KNP and the landscapes surrounding it for maintaining the flows of organisms, water, nutrients, and energy. Land use change occurring in surrounding areas of the park affects the dynamics of the park (DeFries et al., 2005). People also settle along with their cattle on the sandy areas bordering the park after the flood recedes leading to increased grazing pressure on the park resources. In general, communities living in and around the park are financially poor and rely on the local ecosystem for fuel wood, fodder, water, grazing and other ecosystem services. Highly variable resource use patterns as a function of caste/ethnic group, educational level, socioeconomic and immigration status of households, and location with respect to the park and wildlife corridors have significant impact on conservation and management of the park (Srivastava 2007). There is an urgent need for regional-scale land use planning for the surrounding park areas and human-dominated landscapes to balance conservation goals with livelihood needs for fuelwood, fodder and other ecosystem services.

Conservation Strategies

A century old effort in protection and *in-situ* conservation has made the grasslands flora and fauna of KNP to sustain in such a manner that one of the largest assemblages of flora and fauna can be seen here. The prominent among the mega-fauna are the Great Indian one horned. Rhinoceros (*Rhinoceros unicornis*), the Asiatic wild buffalo (*Bubalus bubalis*), the Asian elephant (*Elephas maximus*), the swamp deer (*Rucervus duvaucelii ranjitsinhi*) and the tiger (*Panthera tigris*). However, high variation in attitudes and awareness as a function of ethnic group, educational level, and socio-economic status, indicates the need for economic interventions within some communities. Further, the predicted land use/land cover (LULC) map of Kaziranga-Karbi Anglong corridor indicates an expansion of agricultural and plantation areas. An estimate indicates that only 25.66% of the present dense forest and 20.72% of open forest will remain by 2030, while areas under agriculture and plantation will increase by 33.91 and 5.33%, respectively (Sharma and Sarma, 2014). A highly localized development schemes and participatory approaches to resource management at the village level, coupled with greater efforts at education will be more appropriate to achieve conservation and development goals (Heinen et al., 2009).

Grassland management

To understand the changes in land use practices, identifying the processes that led to degradation and factors governing the rehabilitation processes is essential. Maintaining a higher level of herbage mass by promoting highly adaptable and palatable grasses optimize plant biodiversity and enhance productivity (Wang et al., 2011). Annual burning is being practiced as a tool for habitat management for both upland and lowland grasslands for quite some time and through this management practice provides new forage to wild herbivores. The fire helps in the maintenance of grasslands by arresting succession from grassland to forests, increases productivity of grasses and provides high quality forage. The burning also enhances visibility facilitating anti-poaching surveillance to counter methods of poaching adopted by organized gangs of poachers (Vasu 2002). Because of probable change in grassland composition, a detailed study on tall and short grasslands and the impact of annual burning on the grassland habitats is required. Identifying the factors leading to the creation of short grasslands and evolving strategies to reduce the stocking of ungulate in some of the Ranges of the park is the required for increased efficiency. Preparation of high grounds should be done in such a way that they do not affect the drainage pattern and wetlands. Identifying some inviolate areas within the park where fire and other human interventions can be minimized and the effect of protection can be compared by periodic monitoring, restoration of water bodies, channels and the maintenance of the corridors will enhance efficient management of the park.

Control of Mimosa invasion

High seed production rate and long seed viability, favourable environmental condition and efficient seed dispersal make the control measures of *Mimosa* spp. very difficult (Chauhan and Johnson, 2008; RFRI, 2011). Although fire is used as control measures to check the invasion, various studies (Triet et al., 2001; Byers et al., 2002; RFRI, 2011) have recommended complete eradication of *Mimosa* spp. from the park area. An effort has also been made by the park management to control the invasive species by way of uprooting, but this process is not continuous and follow-up action is also not adequate. *Mimosa* is present in most of the sectors of the Park which requires constant monitoring and practices to control them in varying extent and intensity. As has been shown by earlier control measures in the park, for complete eradication process, the plant could be completely uprooted rather than cutting from the base to achieve better result. October to early December (time of seed maturation) followed by May to June (regenerated seedlings at the ground) are the best eradication period, i.e. twice a year (RFRI, 2011).

Management of Beels

For the wetland management, regular monitoring of these wetlands is necessary to sustain both flora and fauna of the park. There should be a desiltation process in planned and phased manner. Monitoring of the wetlands against pollution should also be carried out. To check the ecological linkages and integrity of the available wetlands in the protected area with Brahmaputra and continued sustainability of the wetlands, long termed or periodic monitoring is required.

Recommendations

The Kaziranga landscape with its unique mosaic of wetlands (beels), grasslands (tall and short) and forests habitat characterize riverine and fluvial processes which represents a spectacular ongoing ecological and biological process due to periodic flooding in the evolution and development of the riverine flood plain ecosystems (UNESCO, 2003). The

landscape is amongst the last surviving floodplains ecosystems of large river systems in the world. The landscape offers one of the largest assemblages of mega herbivores such as one-horned rhinoceros, elephant, Asiatic wild buffalo, swamp deer, sambar etc. in the wild which contributes towards outstanding universal values of Kaziranga and the need to maintain the integrity of its rich biological heritage as world heritage site. Feeding guilds and variety of suitable habitats greatly depends on landscape linkages with adjoining Karbi Anglong hills that provides suitable habitats for elephants in their natural movement range. The barrier effect along the National Highway and disturbances in hills results in restriction in the movement of animals outside the park and increases grazing pressure of the grassland ecosystem. Increasing number of wild buffalos coupled with feral buffalo population is also reflecting visible changes in the tall grassland presence in many areas of the Park. Last decade has witnessed loss of many such areas in western range of the park where this phenomenon is very severe. Management of wild buffaloes based on carrying capacity determined by using their habitat use with respect to rhinos and elephants are urgently required to reduce further loss of juxtaposed tall and short grass combinations. Landscape connectivity with Karbi Anglong hills in the south and river Brahmaputra and its islands in north and connecting forest areas in other adjoining territorial divisions needs to be protected and maintained for long term survival of these mega herbivore assemblages.

Assessment and monitoring along with appropriate action are required for understanding of various processes e.g., rising levels of river bed and the wetlands because of sedimentation and organic matter load from invasion of water hyacinth. Detailed study on tall and short grasslands and impact of the present management interventions in the form of controlled annual burning is required for long-term management of habitat for its suitability for rhinos. This should include identifying the factors leading to the creation of short grasslands and evolving strategies to reduce the stocking of ungulate in some of the areas for increased efficiency. Also since short grasses such as *Hemarthria compressa* are preferred forage species for rhinos (Vasu, 2003), such grasslands especially surrounding the Shola beel in the eastern range need to be monitored and conserved. These grasses could also be promoted to reduce erosion along the banks. There is a need to design a technique aided by constant monitoring and investigation as part of a long term strategy. Concerted efforts are needed to control all invasive species and a better understanding of the causes of their spread to implement pre-emptive measures. Further, the cost and difficulty of eradication increases exponentially with each season of delay. Government agencies, institutions and individuals in rhino bearing areas lack adequate knowledge about the ecological and environmental consequences caused by invasive alien species and how to address it. Hence emphasis should be given to apprise policy makers, managers, conservationists, media and the academic community about this threat. Future microsite planning approach for conservation and development of the area should also consider the high ethnic diversity, high human population densities and grassland land-dependent large mammal populations.

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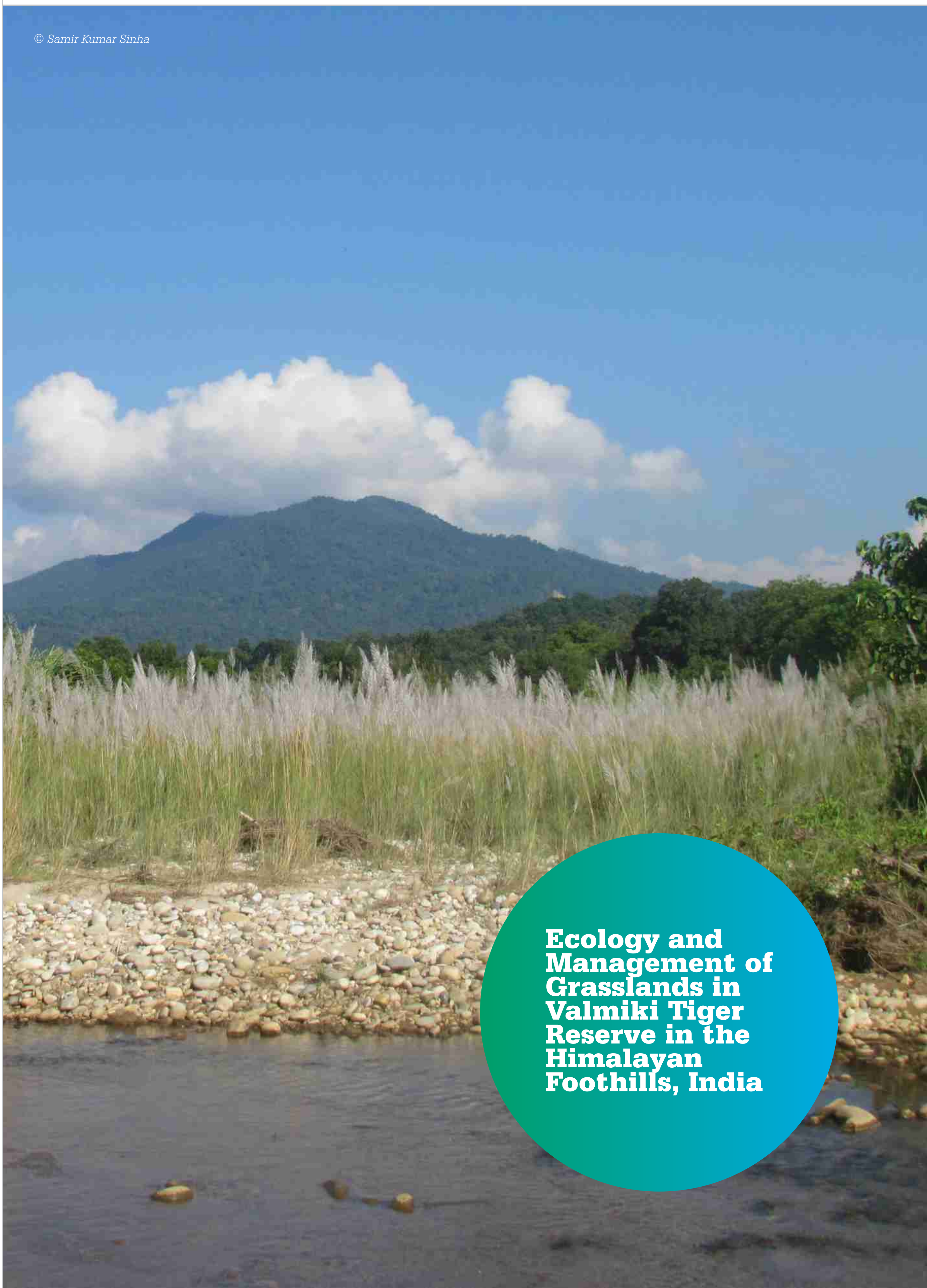

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Ecology and Management of Grasslands in Valmiki Tiger Reserve in the Himalayan Foothills, India

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

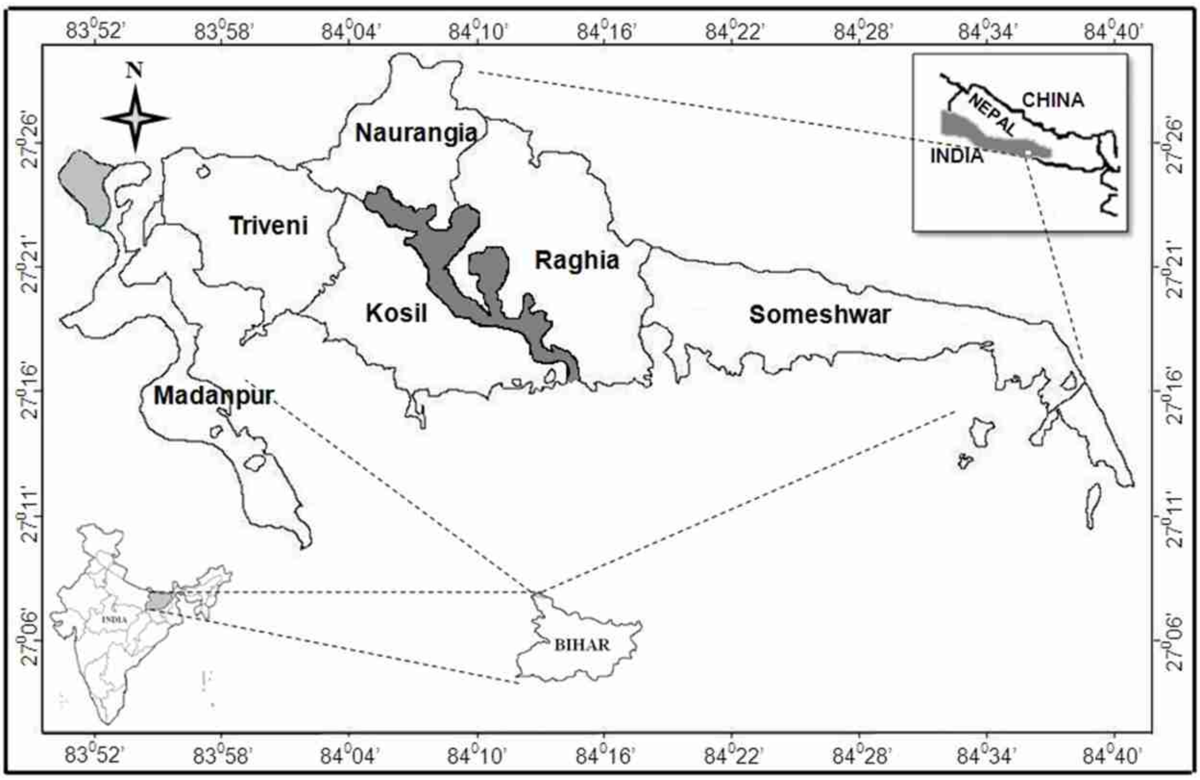

Figure 9.1 Map showing location of Valmiki Tiger Reserve and its Forest Blocks

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

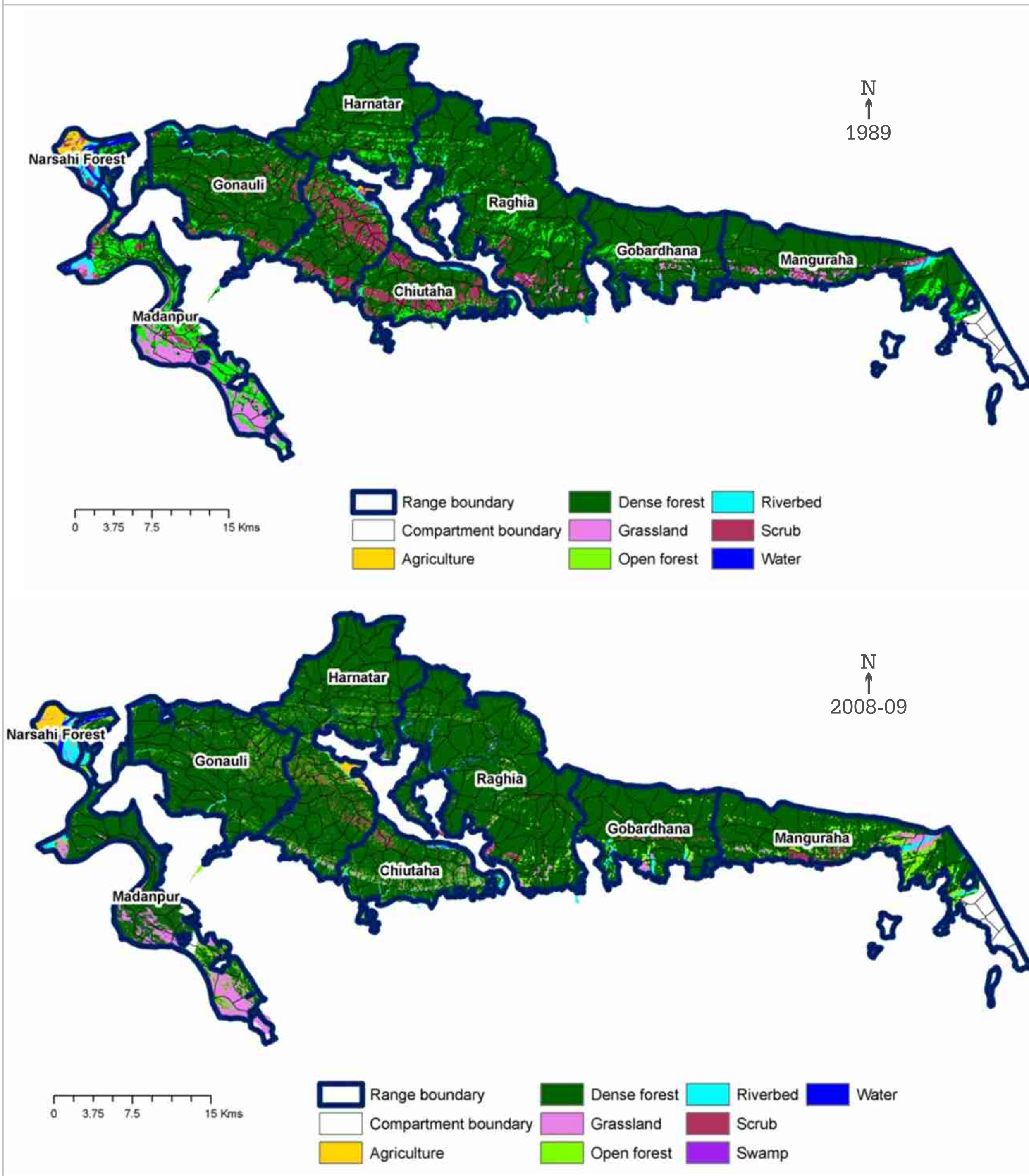

Figure 9.2 Land-use Land-cover of Valmiki Tiger Reserve in 1989 (above) and 2008-09 (below).

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.

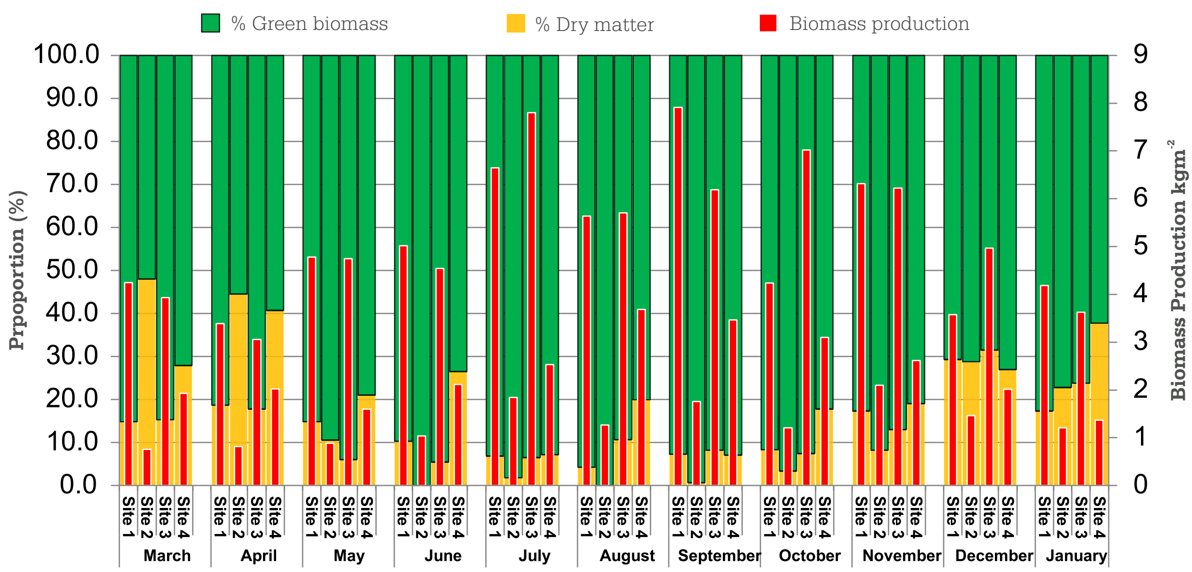

Figure 9.3 Monthly variation in proportion of green and dry biomass in different grassland types.

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}. / m^2 / yr 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).

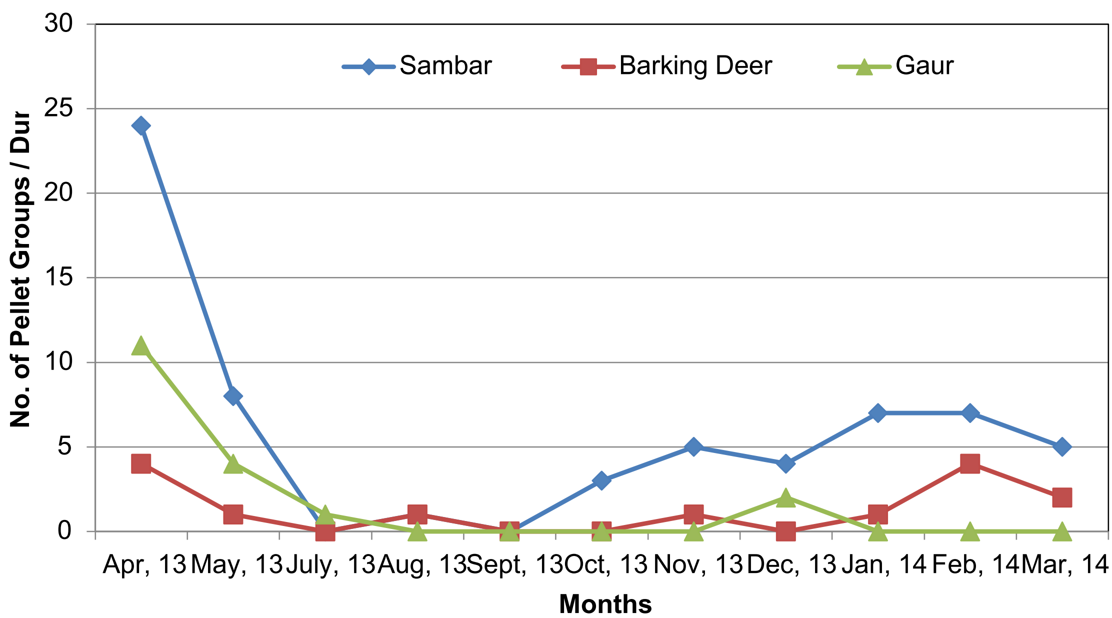

Figure 9.4 Habitat use by ungulates in treated grassland (cut and burned)

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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Dynamics of Grassland Communities in Kanha Tiger Reserve, Madhya Pradesh: Ecological and Management Implications

Abstract

The grasslands of Kanha Tiger Reserve (KTR) are mostly anthropogenic in origin derived from frequent fires and relocation of villages with the commencement of Project Tiger in 1974. Geospatial analysis of the KTR reveals that there are about 241 patches of grasslands covering nearly 8% of the core zone (940 km^2). An ecological study of 38 grasslands within KTR was conducted during 1979-1981. After a period of 20 years, these grasslands were reassessed in the year 2003-2004 to understand the spatio-temporal changes in the structure and composition of grassland communities. The study reveals that there has been an increase in the proportion of unpalatable and fire resistant grasses, weeds and woody species in several grasslands since 1981. In several grasslands the perennial rhizomatous species have been replaced by the annual and ruderal species resulting in the decline in forage quality as well as quantity. Judicious use of fire and exclosures for the management of degraded grasslands and regular monitoring of grassland communities in response to management interventions are recommended.

Key words : Grassland communities; Forage production; Habitat management; Weed eradication; Impacts of fire.

Introduction

Most of the grasslands in India are believed to be anthropogenic in origin, derived primarily from clearing of the forests for human settlements, cultivation and livestock grazing (Bor, 1960; Whyte, 1964, 1968; Billore, 1978). These grasslands harbor a number of native grasses, herbs, and shrubs. Depending upon the intensity of livestock grazing, frequency and seasonality of fire and inherent property of soil, several grassland communities can be identified within the same eco-climatic zone (Pandey, 1983; Misri, 2006; Kotwal, 2011). Such communities, especially within the protected areas are liable to change rapidly due to autogenic as well as allogenic changes.

Kanha Tiger Reserve (KTR), located in the Maikal hills of Central India, has had a long history of research and management owing to its home to threatened grassland fauna especially the Hard ground Barasingha (*Rucervus duvauceli branderi*) and other ungulates which form the prey base for the tiger (*Panthera tigris*). This reserve forms a part of the Central Indian Highlands occupying the southern part of Mandla and north-eastern parts of Balaghat districts between 20°1'5" to 22°27'48" E latitude and 80°26'10" to 81°04'40" N longitudes. This area was used extensively for collection of non-timber forest products (NTFPs) as well as livestock grazing by indigenous ethnic communities, viz., Gonds and Baigas prior to 1935. Practice of shifting cultivation was widely used by them in the forested valleys and plateaus until this practice was prohibited in 1968. In the year 1935 an area of 252 km^2 was declared as Wildlife Sanctuary where livestock grazing was stopped. This area was upgraded as National Park in 1955. In 1964, more area was added to the national park making the total area of 318 km^2. In 1970, a part of north of Banjar river of Balaghat district was joined to southern part of the park enlarging it to 466.6 km^2. In 1974 with the advent of the Project Tiger, about 489 km^2 areas of Halon and Banjar valleys were annexed with the national park. Subsequently, all forestry operations and cattle grazing were completely stopped and a few villages were relocated from the core zone of the park (Panwar, 1973). At present total area of the park is about 1949 km^2 with core zone (940 km^2) and buffer zone (1009 km^2; Gopal and Shukla, 2001). Most of the area of reserve is occupied by forest while 8% of the total area falls under grassland (Table 10.1).

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Table 10.1. Distribution of grasslands in five Ranges of core zone in KTR

Range	No. of Grassland Patches	Total Area (sq. km.)
Kanha	101	27.31
Kisli	21	2.85
Mukki	34	16.1
Bhaisanghat	27	14.86
Supkhar	58	18.77
Total	**241**	**79.99**

(**Source:** *Gopal and Shukla, 2001*)

Ecological studies on the grasslands of KTR were conducted extensively by Pandey (1983) and Pandey and Hardaha (2007). Pandey (1983) identified as many as 38 patches of grasslands in the park, most of which were in the evacuated villages, especially in Supkhar, Bhaisanghat, Mukki, Kanha and Kisli ranges. A total of 16 grassland communities across the gradients of fire and grazing intensity were identified by Pandey (1983) in KTR. Fire and grazing have been the key drivers of change in grasslands of the park Pandey and Hardaha (2007). Major objectives of the study were to detect changes in the structure and composition of grassland vegetation at various localities of KTR. This paper deals with the broad findings of this study major changes observed in the grassland communities and their extent in certain localities of KTR based on the comparative studies conducted during 1979- 1981 and 2003-04 by the author. Management implications are discussed and a few recommendations have been given.

Methodology

The grasslands of KTR were stratified into three broad categories based on the topography and past history of management viz., (i) Grasslands on plateaus 'dadars' (ii) Valley grasslands , and (iii) Hygrophilous grasslands along fresh alluvial banks and streams. These grasslands are distributed in different ranges within core zone of KTR. General survey of the selected grasslands was made in the peak growth period i.e. September-October by adopting the method as suggested by Pandey (1983). For the assessment of community structure, quadrat method was adopted following Misra (1968). 100-150 quadrats of 1x1m were laid in selected grassland of all community types depending upon the area of the grassland. Various parameters such as density, frequency (%) abundance, Importance Value Index (IVI) were analyzed by adopting standard ecological methods (Misra, 1968; Cottom and Curtis, 1956; Smith, 1980). Community types are based on the ocular estimation of % cover and height. Above ground biomass was harvested in plateau and valley grasslands within quadrats of 1x1m in selected areas. An enclosure of 20x20m was erected to see the impact of differential grazing on the plant communities. Fresh as well as dried biomass of each collected sample was weighed separately for estimation of forage production of the grasslands.

Results and Discussion

Major changes in the community structure and composition observed with respect to the plateau, valley and riverine grasslands between 1979-81 and 2002-03 are summarized below:

Plateau grasslands

Most of the existing grasslands situated on the plateau of Kanha and Bhaisanghat ranges of KTR have been originated in different period with the advent of project tiger in 1974. Characteristic species of plateau grasslands were *Iseilema anthephoroides, I. laxum, Themeda laxa, T. triandra, Heteropogon contortus, Dichanthium annulatum,* and *Imperata cylindrica*. The meadows in the valleys were dominated by *Apluda mutica, Bothriochloa intermedia, Capillipedium parviflorum, Chionachne koenigii, Coix lachryma-jobi, Cymbopogon martinii, Dichanthium caricosum, Eragrostiella brachyphylla, Eragrostis tenella, Heteropogon contortus, Imperata cylindrica, Iseilema anthephoroides, Ophiuros exaltus, Pennisetum hohenackeri, Sorghum nitidum, Themeda laxa* and *T. triandra*.

The dominant communities viz., *Dichanthium annulatum-Dimeria ornithipoda, D. ornithipoda, Heteropogon contortus, Themeda triandra-D. ornithipoda, Heteropogon contortus- Dichanthium annulatum* were subjected to low grazing pressure and frequent accidental fire. In due course of time, with increased grazing pressure and induced/accidental fire, forage composition was observed to have changed with increasing proportion of unpalatable grasses and weed species after a period of 20 years. However, the utility percent of plateau grasslands were higher in comparison to valley grasslands.

Kudai dadar, was one of the best-managed grassland dominated by *Themeda triandra-Ischaemum indicum* community during 1979–81 (Pandey 1981). The community structure of this grassland envisaged the maximum utility percent (56.5%) based on the palatable grasses associated with the community. Similarly, Bamhni dadar was represented *Ischaemum indicum-Heteropogon contortus* community (Table 10.2 and 10.3).

Valley Grasslands

The valley grasslands were dominated by *Themeda triandra-Eragrostis tenella, Themeda triandra–Themeda quadrivalvis, Heteropogon contortus-Saccharum spontaneum, Ischaemum laxum-Imperata cylindrica, Imperata cylindrica- Heteropogon* contortus communities during 1979-81, which were subjected to moderate grazing and frequent fire. The most palatable graminoid species in the area were *Themeda triandra, H. contortus, Dichanthium annulatum, Ischaemum indicum, Bothriochloa odorata, Cynodon dactylon, Chrysopogon fulvus, Iseilema laxum, Panicum montanum, P. flavidum, Themeda quadrivalvis* and *Rottboelia perforata*.

After a period of 20 years, the community structure in valley grasslands has been changed and in many places there is a preponderance of coarse fire resistant grasses and weedy species. Most noteworthy change in the grasslands of the valleys is replacement of tall perennial species into annual short grasses such as *Dimeria ornithopoda* and several coarse and less palatable species e.g., *Desmostachya bipinnata*. Specific examples of changes observed in the valley grasslands are as follows:

Kanha meadow

Kanha meadow represented the oldest grassland in KTR, occupying about 4.1 sq. km. area and exhibits the signs of retrogression due to congregation of grazing ungulates, compaction of soil and frequent burning. The Kanha meadow was largely under *Saccharum spontaneum-Eragrostis uniloides community* during 1979-81 (Pandey, 1983). After a period of more than 20 years, the species composition of this grassland seems to have changed into *Dimeria ornithopoda-Desmostachya bipinnata community*. It can be inferred that overgrazing and selective removal of palatable species has led to preponderance of annual species characteristic of fire prone and highly trampled areas e.g., *Desmostachya bipinnata, Aristida setacea, Imperata cylindrica, Setaria glauca* and *Eragrostis* spp.

Experimental closure of grasslands in Kanha meadow for five years and protection from grazing and fire have shown changes in structure and composition in terms of increase in cover of palatable and fire sensitive species. It was observed that towards the end of five years *Ischaemum indicum* predominated the grassland. Similar enclosures are recommended in other heavily degraded parts of KTR.

Kisli Meadow

Grassland patches of Kisli are also among the oldest in KTR, which have been subjected to regular grazing by ungulates since long past. Common species of grasses preferred by grazing ungulates in Kisli meadow during 1979-81 were *Bothriochloa odorata, B. pertusa, Cynodon dactylon, Eragrostis unioloides, Heteropogon contortus, Ischaemum indicum* and *Themeda triandra*. Presently this meadow is dominated by unpalatable alien invasive species such as *Sida spinosa, Ageratum conyzoides* and *Leucas aspera*. Similarly, saplings of tree species viz., *Buchnania lanzan, Phoenix acaulis, Terminalia tomentosa* and *Bombax ceiba* can be seen in Kisli maidan.

Sonph Meadow

As in case of Kanha and Kisli, Sonph maidan was also affected by excessive grazing and frequent fires in the past. Presently this grassland is dominated by *Setaria glauca, Eragrostis tenella, Apluda mutica, Aristida setacea, Arthraxon hispidus, Hemarthria compressa, Imperata cylindrica, Kylinga triceps* and *Vetiveria zizanioides*.

Hygrophilous Grasslands

Most of the grasslands situated along the rivers and streams are known as "bahera" maidan in the valley of KTR. These grasslands have originated on freshly deposited alluvial soils along the perennial/seasonal water sources and occupied the small open patches. Major communities along seasonally inundated courses include *Phargmatis karka, Themeda arundinacea, T. laxa, T. quadrivalvis, Saccharum spontaneum* and *Vetiveria zizanioides* (Table 10.2). During recent years several stream bank grassland communities have been taken over by *Imperata cylindrica, Ischaemum indicum, Bothriochloa odorata, Ischaemum indicum, Iseilema laxum, Pasapalum scrobiculatum, Themeda quadrivalvis* and *Themeda triandra*. Other species which have taken over these grasslands at present include *Arthraxon hispidus, Hackelochloa granuaris, Setaria glauca, Sorghum nitidum, Cyperus difformis* along with weedy species such as *Achyranthes aspera, Ageratum conyzoides, Artemisia parviflora* and *Celosia argentia* (Table 10.2).

Table 10.2. Major changes in grassland community structure in Kanha Tiger Reserve between 1979-81 and 2003-04

Grassland Type	Major communities recorded in 1979-81	Dominant Communities recorded during 2003-04
Plateau Grassland (Dadars)	*Dichanthium annulatum - Themeda triandra*	*Heteropogon contortus - Dimeria ornithopoda*
	Dichanthium annulatum - Dimeria ornithopoda	*Dimeria ornithopodaoda - Panicum montanum*
	Heteropogon contortus - Iseilema laxum	*Chionachne koenigii - Imperata cylindrica*
	Themeda triandra - Heteropogon contortus	*Heteropogon contortus - Themeda triandra*
	Themeda triandra - Themeda quadrivalvis	*Themeda triandra - Ischaemum indicum*
	Themeda triandra -Dimeria ornithopoda	*Ischaemum indicum - Heteropogon contortus*
Valley Grasslands and meadows	*Dichanthium annulatum - Heteropogon contortus*	*Themeda triandra - Bothriochloa odorata*
	Heteropogon contortus - Dichanthium annulatum	*Themeda triandra - Heteropogon contortus*
	Heteropogon contortus - Themeda triandra	*Imperata cylindrica - Ischaemum indicum*
	Themeda triandra - Imperata cylindrica	*Dimeria ornithopoda - Ischaemum indicum*
	Themeda quadrivalvis - Heteropogon contortus	*Arthraxon lancifolius - Heteropogon contortus*
	Iseilema lexum - Imperata cylindrica	*Imperata cylindrica - Themeda triandra*
	Imperata cylindrica - Heteropogon contortus	*Imperata cylindrica - Bothriochloa pertusa*
Hygrophilous Grasslands (Stream courses)	*Saccharum spontaneum - Eragrostis unioloides*	*Dimeria ornithopoda - Desmostachya bipinnata*
	Themeda triandra - Eragrostis tenella	*Imperata cylindrica - Ischaemum indicum*

(**Source:** *Pandey and Hardaha, 2007)*

Forage production in grasslands of Kanha during 2003 was found to be slightly lower as compared to 1979-81 (Table 10.3). Estimated production of forage in this grassland was recorded to be 981 g m^{-2} in control/protected area and 946 g m^{-2} in unprotected / open grassland. Though, there was slight decline in biomass production during 2003, the proportion of biomass contributed by less palatable species is not ascertained.

The estimated forage production in protected (control) and unprotected grazed plot was recorded to be 565 and 298 g m^{-2}, respectively in Kisli maidan. The contribution of palatable species was recorded to be less in unprotected grassland. Only few species i.e., *Bothriochloa odorata, B. pertusa, Eragrostis unioloides, Heteropogon contortus, Ischaemum indicum* and *Themeda triandra* were recorded as palatable species. However, biomass of valley grassland was found to be varied, ranging from 584 to 944 g m^{-2} in the protected area (enclosure) and 390 to 875 g m^{-2} in open grazing lands (Table 10.3).

Grasslands in recently evacuated Indri village exhibited luxuriant growth of palatable grasses. The contribution of palatable grass species was found to be more in comparison to other grasslands of this category. This grassland is dominated by *Themeda triandra-Heteropogon contortus* community along with other palatable grasses viz., *Bothriochloa odorata, Eragrostis tenella, Ischaemum indicum, Ischaemum rogosum, Panicum montanum, Paspalidium flavidum, Iseilema laxum, Oryza rufipogon* and *Digitaria longifolia*. However, as of now, abundance of the grazing ungulates in these grasslands is relatively low (Personal observations). As in case of several village relocation sites, this area is not free from unpalatable weedy species such as *Ageratum conyzoides, Lantana camara, Parthenium hysterophorus, Xanthium strumarium* and *Cassia tora*. The biomass of grassland of this category was recorded to be 367 g m^{-2} in the protected area and 350.46 g m^{-2} in open grazing land.

Table 10.3. Average aboveground biomass production of grasslands of various categories (dry weight g m-2 in protected and open grazed grasslands) in KTR (2003-04).

Grassland Type and Locality	Protected Site		Grazed Area	
	Grassland Community	Above Ground Biomass (g m-2)	Community type	Above Ground Biomass (g m-2)
Kanha Meadow	*Dimeria ornithopoda Ischaemum indicum*	981.80	*Dimeria ornithopoda Desmostachya bipinnata*	946.60
Kisli Meadow	*Aristida setacea Ischaemum indicum*	565.96	*Aristida setacea Ischaemum indicum*	298.40
Recently evacuated Indri Village	*Heteropogon contortus Themeda triandra*	367.28	*Heteropogon contortus Themeda triandra*	350.46
Abandoned arable Kudai Dadar	*Themeda triandra Ischaemum indicum*	944.90	*Themeda triandra Ischaemum indicum*	875.98
Abandoned Bamhni Dadar	*Ischaemum indicum Heteropogon contortus*	657.73	*Ischaemum indicum Heteropogon contortus*	585.10
Abandoned Sonph Meadow	*Dimeria ornithopoda Saccharum spontaneum*	584.06	*Dimeria ornithopoda Saccharum spontaneum*	390.00

Management implications

Grazing regimes and grasslands:

Continuous heavy grazing by ungulates, particularly in PAs, can lead to degradation of grasslands due to selective removal of palatable species and infestation by invasive species. Generally, grasses exhibit strong seasonality in terms of nutrient level and palatability thereby ensuring seed production and ungulates exhibit spatio-temporal shifts in their habitat use and forage selection. Creation of artificial water holes, salt-licks, fresh growth of grass subsequent to burning may influence the movement of ungulates in an area. Therefore, the management has to take these aspects into consideration for manipulating the grazing regimes in the grasslands. In case of KTR, it may be advisable to exclude some of the heavily trampled and degraded grassland patches for 2-3 years so that highly palatable species are recovered and seed banks are created.

In KTR it was evident that Kush (*Desmostachya bipinnata*) covered most of well-drained area by replacing *Saccharum spontaneum* and *Imperata cylindrica* which were selectively overgrazed over the years. *D. bipinnata* represents the degraded grassland least preferred by the ungulates (Martin, 1978; Pandey, 1983).

Fire as a tool for management:

Grasslands of KTR are usually burnt during late November till June. After fires, new growth of the perennial grasses is induced and attracts the ungulates in the pinch period. Some of the important palatable species having new sprouts attract heavy grazing. Fire resistant species viz., *Imperata cylindrica, Themeda quadrivalvis* and *Desmostachya bipinnata* tend to dominate the grasslands by suppressing the several annual and palatable grasses. In addition to fire, soil moisture also plays an important role in the phenology of grasses during winter and summer seasons.

During early phase of Kanha management cool (winter) burning of meadows is said to have positive effect on production of palatable biomass. It is likely that during the early phase the soil in Kanha meadow was relatively porous and moist, allowing better growth of grasses subsequent to cool burning. However, subsequent congregation of ungulates and regular burning seems to have adversely affected the species composition leading to preponderance of unpalatable fire resistant grasses and weedy species (Parihar and Kotwal, 1989). Therefore, the management needs to judiciously use fire to influence the production of green forage in the KTR and avoid congregation of herbivores.

Management of Alien Invasive Plants

Most of the grasslands situated in the fringes of the core zone viz. Supkhar, Silpura, Jatadabra, Bansbahara, and Kamko Dadar infested by *Ageratum conyzoides, Bidens biternata, Lantana camara, Sida cordifolia* and *Parthenium hysterophorus.* Grasslands of Mukki and Bhaisanghat situated in outer part of the core providing congenial conditions for *Lantana camara, Petalidium barlerioides, Achyranthes aspera* and *Acanthospermum hispidum*. Most of the grasslands of central part of Kanha range are infested by weeds such as *Pogostemon benghalensis* (marmari), *Blumea* *mollis, Borreria stricta, Sida spinosa* along with other common weeds and affected the yield of palatable grass species. *Parthenium hysterophorus* as one of the noxious weed has invaded in recently evacuated arable lands of Sondhar and Indri maidans of Kisli range and Rounda maidan of Kanha range. However, *Parthenium hysterophorus* has also occupied the area along water bodies and gradually colonizing and spreading in the heavy grazed area of the grasslands. The park management needs to take up restoration of these grasslands by curbing the larger seed banks and weed infested areas on a regular basis.

Conclusion

A comparative assessment of grasslands in KTR during 1979-81 and 2002-03 revealed that most of the valley grasslands (meadows) within the reserve have changed drastically resulting in preponderance of less palatable and fire resistant grasses and decrease in cover of perennial fodder species. Several grassland patches have been taken over by alien invasive species as well as woody species leading to forest succession. Temporary ungulate proof exclosures and judicious use of fire are recommended to maintain the structure and composition of grassland habitats and also to influence the spatio-temporal use of ungulates in the park so as to avoid over grazing.

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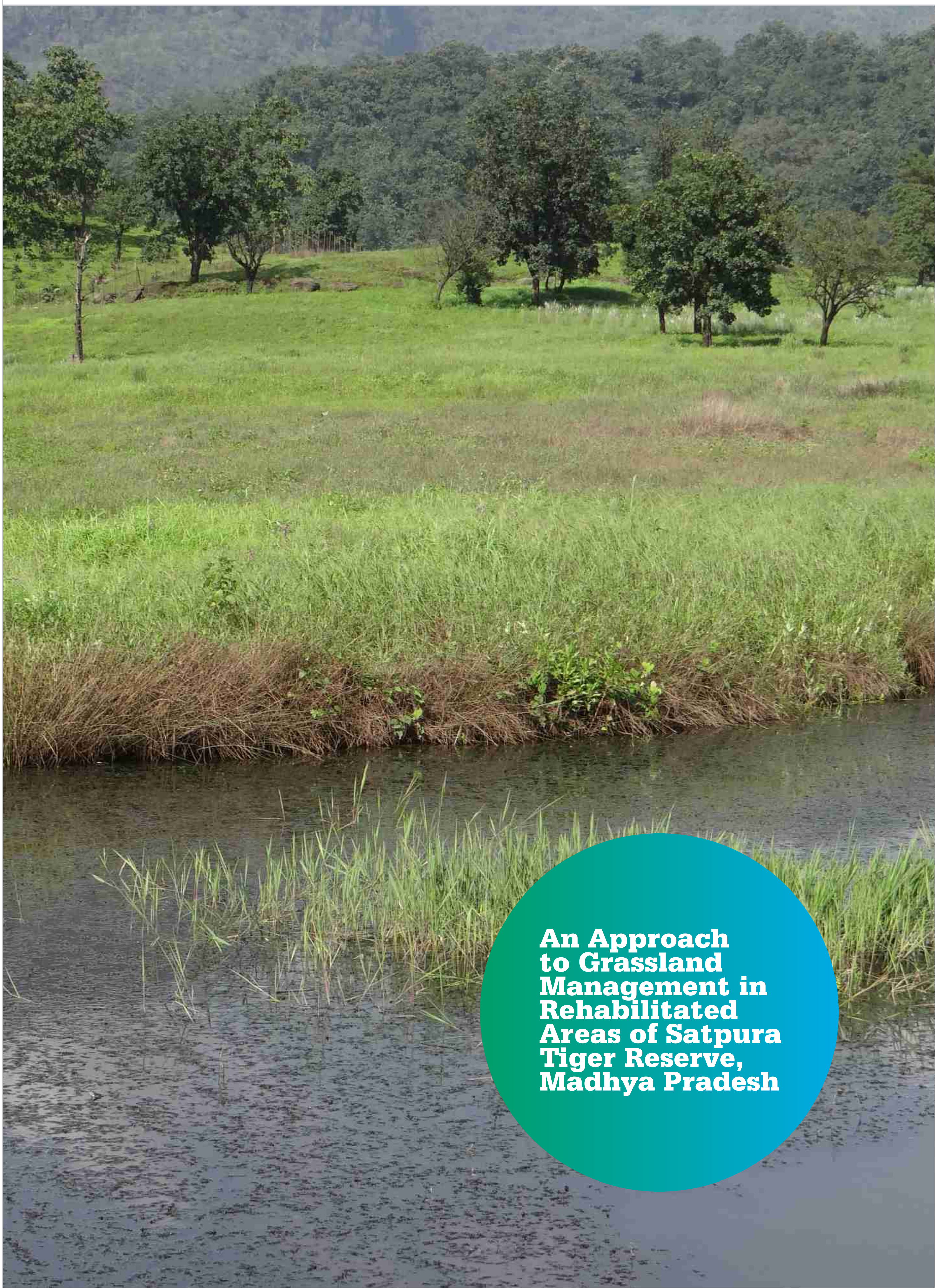

An Approach to Grassland Management in Rehabilitated Areas of Satpura Tiger Reserve, Madhya Pradesh

Abstract

Satpura Tiger Reserve (STR), located in Hoshangabad district of Madhya Pradesh, represents Central Indian highlands and is spread over an area of 2140 km^2. This reserve is well known for its diverse forest types, rich flora and fauna. In order to maintain a healthy prey-predator population, the park management has taken up several steps for improvement of wildlife habitat. This includes restoration of degraded grasslands so as to increase productivity of palatable and preferred grasses. We selected degraded grasslands within STR and conducted systematic survey of herbaceous species. Grassland development areas were located in the villages viz., Bori, Badkachar, Churna, Dhai, Kakdi, Parsapani, Pattan, Nimghan, Rorighat, and Sakot. Annual grasses and Alien Invasive Plants were targeted for replacement by perennial tussock forming grasses and forbs. Seeds of palatable grasses were collected with the help of trained field staff and propagated within nurseries and later planted in selected areas. This paper deals with the status of grassland habitats and results of participatory approaches on these grasslands.

Keywords: Alien Invasive Species; Grassland habitat; Management of Grasslands; Satpura Tiger Reserve.

Introduction

Satpura hill ranges located in the catchments of Narmada and Tapi rivers in Central India form important geographical feature in the subcontinent which separate north India from the Deccan (Krishan, 2013). These ranges are well known for their ancient geological origin, diverse topography, rich biodiversity and cultural heritage. These ranges support a rich array of vegetation types including Dry Deciduous Forests, Savannah Woodlands, Thorn Scrub, and scattered grasslands. Most of the hill slopes, savannah woodlands and other undulating areas harbor grasslands and other herbaceous vegetation depending upon the past and present land use, substrate and various other factors. Considering the hydrological and conservation significance of these areas the Government of Madhya Pradesh has set aside a series of wildlife protected areas in this region such as Bori Sanctuary, Pachmarhi Biosphere Reserve, Satpura National Park and Pachmarhi Sanctuary, collectively designated as Satpura Tiger Reserve (STR; area ~ 2140 km^2). The STR is characterized by presence of Tropical Moist Deciduous forests, of which major floristic elements are sal (*Shorea robusta*), teak (*Tectona grandis*), mahwa (*Madhuca latifolia*), jamun (*Syzygium cuminii*), bel (*Aegle marmelos*), and bamboo species (*Dendrocalamus strictus, Bambusa bambos*). The dominant species of fauna found in the area include tiger, leopard, sloth bear, wild dog, jackal, sambar, gaur, barking deer, blue bull, chital, chausingha, ratel, flying squirrel, wild pig, langur, giant squirrel, mouse deer, chinkara, porcupine, and occasionally python.

Grasses and grassland habitats form the backbone of tiger conservation in Satpura Tiger Reserve (STR). With increasing abundance of wild ungulates and over grazing by domestic livestock in the village fringes, there has been a decline in grass cover. Dominant grasses in STR, in terms of cover and abundance, include *Heteropogon contortus, Andropogon pumilus, Chrysopogon fulvus, Themeda quadrivalvis, Apluda mutica, Dichanthium annulatum, D. caricosum, Cymbopogon martinii, Eragrostis unioloides, Setaria intermedia, Setaria verticillata, Setaria pumila,* and *Sporobolus diander*. Although, most of these species are adapted to grow on relatively nutrient poor soil, rocky substratum and frequently grazed areas, at several places the grasslands are severely degraded as evident from high proportion of annual grasses and unpalatable and Alien Invasive Plants (AIPs). Empirical evidences and interaction with the management authorities revealed that many grasslands were degrading rapidly. An intensive study was under taken in order to enumerate the palatable grasses from STR and identify various species. This paper deals with the practical field inputs added for the development and management of grasslands in the relocated sites of the STR.

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Approaches to restoration of grasslands in Satpura Tiger Reserve

The grassland restoration and development works were taken in the village relocation sites. Such sites were dominated by various grasses such as *Dichanthium annulatum* (Plate 11.1), *Heteropogon contortus, Eragrostis viscosa, Cynodon dactylon, Apluda mutica* and few AIPs such as *Xanthium strumarium, Parthenium hysterophorus, Ageratum conyzoides, Commelina paludosa, Achyranthes aspera* and *Sida cordifolia*. All the village relocation sites were assessed in terms of species composition, proportion of palatable and unpalatable species, proportion of annual grasses and cover of AIPs. The field staff of STR was oriented towards identification of palatable grasses. All highly palatable perennial grasses were identified and their seeds as well as rhizomes were collected for propagation at rehabilitation sites. Subsequently nurseries were raised for highly palatable species of grasses and other forbs. About 2 ha area was selected and fenced to raise the plantation stock. After 2 years the grass seeds were collected from these nurseries (in December) for further propagation in restoration sites.

In addition to grasses, several native browse species and wild fruit bearing plants were selected for propagation. Simultaneously, removal of Lantana and enrichment of grasses were taken up during monsoon season. Removal of AIPs was taken up 3-4 times in a year which played important role in easy establishment of grasslands. For the restoration of grasslands we selected several weed infested and degraded sites within STR. Such sites included past village grazing lands and abandoned agricultural fields are relocation of the villages, viz., Bori, Dhai, Churna, Kakadi, Sakot, Khakrapura, Pattan, Rorighat, Badkachar, Nimghan, Birjikhapa, Kukra, Nandner, Nankot, Dhargaon, Paraspani (Matkuli), and Parsapani (Bagara Buffer). These grasslands were selected for management inputs because such areas have potential to become prime habitats for grazing ungulates (Plate 11.2).

The wild fruit trees of the natural grasslands which were retained in the grasslands were *Cordia dichotoma, Terminalia chebula, Terminalia alata, Zizyphus mauritiana, Zizyphus rugosa, Madhuca latifolia, Buchanania lanzan, Cassia fistula, Aegle marmelos,* and *Phyllanthus emblica*. The following species were selected for propagation in the reserve based on their preference by wild ungulates (verified from the experienced field staff): 1) *Dichanthium annulatum* , 2) *Dichanthium caricosum,* 3) *Dichanthium strictum,* 4) *Iselima laxum,* 5) *Iselima prostratum,* 6) *Heteropogon contortus,* 7) *Eleusine indica*, 8) *Chloris barbata*, 9) *Paspalidium flavidum*, and 10) *Cynodon dactylon*.

Plate 11.1: *Dicanthium* seed plot at Pattan

The following leguminous species associated with the grasses were propagated in the grassland development areas: *Atylosia scarabaeoides*, *Rhyncosia minima* var. *minima*, *Rhyncosia minima* var. *laxiflora*, *Vigna trilobata* Syn. *Phaseolus trilobus*. The grasses and wild leguminous plants form the good heterogeneous association of the grasses in the natural grasslands.

Observations

Species composition at village relocation sites: Major communities (identified based on dominant species) at different village relocation sites along with other associated species have been given in Table 11.1.

Table 11.1. Grasslands Communities and Associated forage plants at different village relocation sites in STR

Grassland Type	Location	Association
Short grassland : ***Dichanthium-Iselima***	Churna	*Dicanthium annulatum , Eragrostis viscosa , Cynodon dactylon*
	Sakot	*Dicanthium annulatum , Eragrostis viscosa , Indigofera linifolia (Leguminous plant)*
Intermediate : ***Dichanthium - Themeda***	Khakrapura	*Dicanthium annulatum , Cynodon barberi , Andropogon pumillus , Iselima prostratum , Chloris virgata*
	Pattan	*Dicanthium caricosum , D. annulatum , Apluda mutica , Imperata cylindrica , Iselima laxum , Chloris virgata , wild legumes.*
	Parasapani (Buffer)	*Heteropogon contortus , Iselima laxum . Paspaladium flavidum , Dicanthium annulatum.*
Taller : ***Themeda - Heteropogon***	Bori	*Themeda quadrivalvis , Dicanthium caricosum , Saccharum spontaneum , Heteropogon contortus , Vetiveria zizanioides , Chloris barbata*
	Rorighat	*Apluda mutica, Themeda quadrivalvis , Heteropogon contortus , Chloris virgata , Dicanthium annulatum , Eragrostis tenella.*
	Nimghan	*Apluda mutica , Themeda quadrivalvis , Heteropogon contortus*
	Kankadi	*Themeda quadrivalvis , Dicanthium annulatum , Saccharum spontaneum , Heteropogon contortus , Eleusine indica , Sorghum halepense*
	Dhai	*Themeda quadrivalvis , Dicanthium caricosum , Saccharum spontaneum , Heteropogon contortus , Vetiveria zizanioides , wild legumes*

Species composition in savannah woodland and other habitats:

Grasses growing on dry region rocky substrata: *Arthraxon lanceolatus* var. *lanceolatus, Alloteropsis cimicina, Andropogon pumilus, Aristida adscensionis, A. funiculata, A. hystrix, A. redacta, , Arundinella tuberculata, Cenchrus ciliaris, C. fulvus, C. polyphyllus, Eragrostiella bifaria, Heteropogon contortus, H. ritchiei, Lophopogon tridentatus, Melanocenchris jacquemontii, Microchloa indica, Oropetium roxburghianum, O. thomaeum, O. villosulum, Tripogon jacquemontii* and *T. pungens*

Grasses growing on Ghat Slopes: *Arthraxon lanceolatus* var. meeboldii, *A. lanceolatus* var. *raizadae, A. lanceolatus* var. *villosus, Arundinella pumila, Dichanthium armatum, D. maccannii, D. parviflorum, Heteropogon triticeus, Ischaemum dalzellii, I. semisagittatum, Spodiopogon rhizophorus* and *Themeda quadrivalvis*

Grasses of steep slopes and hanging rocks: *Arthraxon jubatus, Ischaemum nervosum, I. sulcatum, Pennisetum orientale, Pseudodicanthium serrafalcoides, Tripogon bromoides* and *Melanocenchrus jacquemontii*.

Grasses of low elevation lateritic rocks: *Arundinella nervosa, A. setosa, Chrysopogon fulvus, C. polyphyllus, Dimeria bicornis, Oryza rufipogon* and *Sacciolepis indica* var. *intermedia*.

Grasses of stream beds rocks: *Arundinella nepalensis, Coix lacryma-jobi, Dichanthium glabrum* and *D. tuberculatum*.

Grasses on the Plateaus : *Themeda, Heteropogon, Dicanthium, Cynodon, Apluda, Chloris barbata, C. virgata, C. gyana, C. dolichostachya, Brachiara mutica, Eleusine indica, Eleusine glauca, Panicum typhoides* and *E. gigantean*.

Fodder value and main features of 10 important fodder grasses: Characteristic features of key fodder grasses along with their nutrient contents are given in Table 11.2 & 11.3.

Table 11.2. Characteristic features of key fodder grasses in Satpura Tiger Reserve along with their nutrient contents

Name of grass	Ecological features and nutrient values
Dichanthium annulatum	Perennial, palatable pasture grass
Dichanthium caricosum	Propagation by seeds, rhizome, stolons 2) Perennial, palatable short day plant grass 3) Grow in variable soil-Alkaline, Acidic soil. 4) Shows heterogeneous association with other grasses. 5) Easy to establish 6) Good soil binder. 7) A tolerant grass.
Iselima laxum	Indicator of good soil moisture. 2) Perennial, palatable grass. 3) Good soil binder 4) Tolerant grass.
Sehima nervosum	A taller grass with homogeneous type of grassland. 2) Soil binder grass. 3) Biomass can maintain by cutting the grass thrice in a year. 4) Grow in murmi, red soil.
Chloris virgata	Grass of smaller grassland. 2) Grass with large leaf blade, ligules maintain water content in the aerial part.
Heteropogon contortus	Tolerable grass 2) Grow in acidic, red murmi soil. 3) A grass with large number of rhizomes 4) Good soil binder in hilly areas. 5) Good % of seed dispersal. 6) Palatable, perennial grass.
Cynodon dactylon	Well ecologically adopted grass. 2) Amphiterrestrial grass, develop in submerged condition and terrestrial habitat. 3) High % of water content in ligules and leaf lamina 4) Perennial, palatable, soft grass of smaller grassland. 5) A long day grass. 6) Ethno-botanically and Ethno-veterinary point of view important t grass.
Iselima prostratum	Perennial, palatable grass. 2) Due to prostrate habitat a good soil binder grass. 3) Indicator of good soil moisture.
Paspaladium flavidium	Perennial, palatable grass 2) Indicator of high altitude, acidic soil. 3) Grass with large leaf lamina, soft. 4) Good soil binder.
Digitaria stricta	Grass of intermediate grassland. 2) Annual, palatable grass 3) Good fodder grass 4) Grow in any type of soil. 5) Shade loving grass.

Plate 11.2: Chital in grasslands of Satpuda Tiger Reserve

Table 11.3. Chemical composition of palatable grasses

Name of grass	Annual / Perennial	Starch (%)	Proteins (%)	Fiber (%)	Moisture (%)
Dichanthium annulatum	Perennial	40 - 51	7.5	28-30	56
Dichanthium caricosum	Perennial	46 - 50	7.5	33.2	46
Iselima laxum	Perennial	31 - 40	5.5	23-28	76
Sehima nervosum	Perennial	55.8	7.5	32.8	36
Chloris virgata	Annual	48.2	7.1	29.6	67
Heteropogon contortus	Perennial	46. 51	6.5	36.8	66
Cynodon dactylon	Perennial	48.7	7.8	38.6	76
Iselima prostratum	Perennial	42 - 57	9.5	18-21	66.8
Paspaladium flavidium	Annual	34-38	7.2	32-36	48
Digitaria stricta	Annual	39-42	7.8	37-45	56
Apluda mutica	Annual	29-32	8.2	39-46	32
Chrysopogon polyphyllus	Perennial	57-59	8.4	37-41	38
Themeda quadrivalvis	Annual	42-8	7.1	38-41	28
Themeda triandra	Annual	43.2	7.9	43-45	58-60

Grasslands palatability and productivity is determined by the chemical composition and biomass of the grasses. The grasses having biomass more than >7 tons per hectare are listed in Table 11.4.

Table 11.4. Grass species with high biomass (>7 t ha^{-1})

S.no	Name of grass	Annual / Perennial	Grass biomass (t ha^{-1})
1	*Dichanthium annulatum*	Perennial	6-7
2	*Dichanthium caricosum*	Perennial	7-9
3	*Iselima laxum*	Perennial	5-7
4	*Sehima nervosum*	Perennial	8-10
5	*Heteropogon contortus*	Perennial	7-9
6	*Cynodon dactylon*	Perennial	6-7
7	*Themeda quadrivalvis*	Annual	9-10
8	*Bothriochloa pertusa*	Perennial	7-11

Recommendations

Since tropical grasslands are mostly seral in nature and liable to be taken over either by woody species or unpalatable invasive plants, persistent efforts are required to maintain a rich mixture of perennial grazing resistant species in the restoration sites (Plate 11.3 - 11.5). Based on the experience gained in Satpura TR, the following recommendations are made for restoration of grassland habitats in Central Indian PAs:

i. All gregarious and fast growing annual weeds should be uprooted, dried and burnt before May. Second and third round of weed removal should be done during July and September – October before they flower and fruit.

ii. All areas where soil has been exposed due to removal of weeds, rhizomes and seeds of perennial grasses and legumes should be sown before the onset of monsoon (second half of May to first week of June).

iii. A separate nursery should be established in vicinity of grassland development site, preferably closer to Range Office or fringes of the park where seedlings and rhizomes of fruit bearing, tussock forming grasses, and other browse plants such as native bamboos should be collected and reared ahead of planting season.

iv. For collection of seeds of legumes and preferred fodder grasses, September – October is the best period of flowering and fruiting.

v. For the first 3-4 years all grassland development areas will need tending and biannual cutting of perennial grasses so as to enhance tiller production and establishment of grass seedlings. Fencing of smaller strips till the establishment of grassland patches and shifting of such fences (strips) is recommended till the larger areas are covered under stable grassland patches.

Plate 11.3: Grass biomass management

Plate 11.4: Grassland at Chruna, Satpuda Tiger Reserve

Plate 11.5: Field training to forest staff for grassland management

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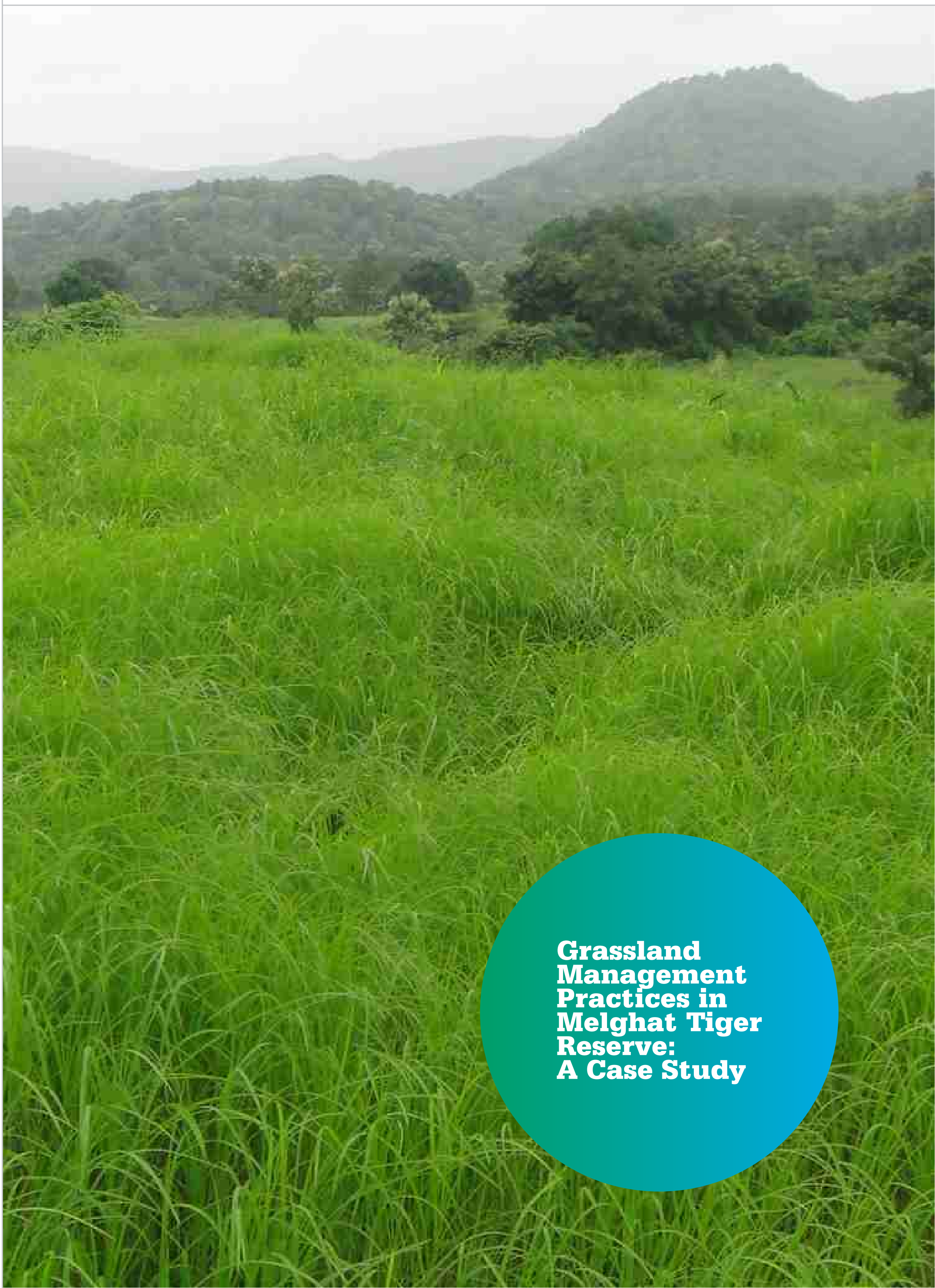

Grassland Management Practices in Melghat Tiger Reserve: A Case Study

Abstract

Melghat Tiger Reserve (MTR), established during 1973-74, has had a long history of scientific management. It is spread over nearly 1677 sq. km. The major vegetation type in the reserve is tropical dry deciduous forest, dominated by teak (*Tectona grandis* L.). As part of habitat improvement programme the management authorities relocated ten villages from the MTR during 2010 -11. The evacuated villages were taken up for development of grassland habitats and removal of alien invasive species. Prior to management intervention systematic studies were conducted on the richness of grass species, successional trends and extent of AIS. This paper summarizes the broad findings of the study along with management recommendations.

Keywords: Alien Invasive Species; Grasses Ecology; Habitat Management; Melghat Tiger Reserve.

Introduction

Melghat Tiger Reserve (MTR) was among the first batch of nine protected areas (PAs) notified under this name during 1973-74. It is located in northern part of Amravati District of Maharashtra State in India. The Tapi River and the Gawilgadh ridge of the Satpura Range form the boundaries of the reserve. The Tapi river flows through the northern end of the MTR. Presently, the total area of the Reserve is 1676.93 sq. km., with 361.28 sq. km. of core and remaining under buffer. Nearly 21 km^2. of the reserve is under non-forest category that includes agricultural fields and grasslands. Previously, Melghat Sanctuary was created in 1985 with an area of 1597.23 sq. km. Gugamal National Park was carved out of this Sanctuary in 1987. Melghat means 'meeting of the ghats'. The forest is mostly tropical dry deciduous in nature, dominated by teak (*Tectona grandis* L.) that fall under sub-group 5-A 'Southern Tropical Dry Deciduous Forests' (Champion and Seth, 1968).

Melghat Tiger Reserve is characterized by varied topography and soils which provide diverse ecological conditions supporting a large number of plant communities including grasses. Undulating and hilly terrain with poor soil usually support dense patches of grasslands and woodlands. Similarly, plateaus with intensive livestock grazing and past cultivation are also rich in grasses. Distribution of various grassland communities, mechanisms of their nutrient uptake, morphological adaptations, diversification and speciation are important areas for investigation. Taking into account the importance of all grasses, attempts have been made to study their taxonomy, association, distribution, adaptations, diversification and speciation through field survey and laboratory work. A few workers have conducted extensive survey of grassland flora during past 20 years or so (Salunkhe, 1995; Potdar, 2006; Yadav, 2010). Dhore (1988) reported 91 species of grasses from MTR.

As part of habitat improvement programme the management authorities of MTR relocated ten villages from the reserve during 2010-11. The evacuated villages were taken up for development of grassland habitats and removal of alien invasive species. Prior to management intervention systematic studies were conducted on the richness of grass species, successional trends and extent of AIS. A few sites were taken up for the restocking of palatable grasses. This paper deals with the experiences gained and lessons learned on the management of grasslands in the MTR.

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Materials and Methods

Based on the detailed observations and ranking of grasses in terms of their palatability, we propagated highly preferred species in degraded areas. For this purpose a total of 10 sites were taken for grassland by wild ungulates development covering an area of about 2 hectares for sowing of grass seeds, removal of unpalatable herbs such as *Ageratum*, *Argemone*, *Oxalis*, and *Celosia*. Palatable grasses selected for establishment of grass seed banks included: *Dichanthium annulatum*, *D. caricosum*, *D. strictum*, *Iselima laxum*, *I. prostratum*, *Heteropogon contortus*, *Eleusine indica*, *Chloris barbata*, *Chloris virgata*, *Paspaladium flavidum*, *Apluda mutica*, *Cynodon barberi*, *Themeda triandra*, *Sehima nervosum* and *S. sulcatum*. For soil enrichment following native leguminous plants were planted in the area: *Atylosia scarabaeoides*, *Teramnus labialis*, *Rhyncosia minima var. minima*, *Rhyncosia minima* var. *laxiflora*, *Sesbania bispinosa*, *Phaseolus radiatus*, *Vigna trilobata* Syn. *Phaseolus trilobus*.

Major findings and Lessons Learned

I A total of 143 species of grasses were recorded in MTR (Plates 12.1 - 12.5). Of these, 55 species form bulk of the forage for wild ungulates. The dominant grass species in the order of their dominance (cover x abundance) are *Heteropogon contortus*, *Andropogon pumilus*, *Chrysopogon fulvus*, *Themeda quadrivalvis*, *Themeda triandra*, *T. laxa* and *Apluda mutica*. Other species common in heavily trampled and overgrazed areas are *Cymbopogon martini*, *Eragrostis unioloides*, *Setaria intermedia* and *Sporobolus diander*.

ii. The grassland communities in MTR can be broadly divided into two categories, viz., (i) Ephemeral communities comprising mainly of the grasses that complete the life cycle during rainy season or after rainy season. Characteristic species include *Arthraxon lancifolius*, *Arundinella pumila*, *Sporobolus coromondeliana*, and *Digitaria ternata*. (ii) Perennial communities dominated by tussock or rhizomatous species such as *Heteropogon contortus*, *Andrpogon pumulus*, *Chrysopogon fulvus*, *Dichanthium caricosum*, and *Pennisitum hohenackeri*.

iii. Well established grasslands (relatively stable areas) were dominated by species of *Themeda quadrivalvis*, *Heteropogon contortus*, *Ischaemum indicum*, and *Apluda mutica*. Towards higher slopes and undulating areas: *Dichanthium annulatum* and *D. pertusum* were dominant species. Hence it can be stated that *Dichanthium* spp. represent more stable grassland communities in MTR.

iv. Natural grasslands within the tiger reserve are dominated by the taller grasses such as *Heteropogon contortus*, *Chloris gayana*, *Themeda quadrivalvis*, *Apluda mutica*, *Sehima sulcatum*, *Ischaemum nervosum*, *Ischaemum sulcatum*, *Vetiveria zizanioides*, *Dichanthium caricosum*, *Aristida hystrix* and the intermediate grasses such as *Paspaladium flavedium*, *Chloris gyana*, *Chloris truncatia*, *Iselima laxum*, *Imperata cylindrica* and the smaller grasses such as *Chloris barbata*, *Chloris virgata*, *Iselima prostratrum*,*Cynodon barberi*, *Cynodon dactylon*, *Dichanthium annulatum*, *Digitaria bicornis*, *Digitaria stricta*, *Brachiaria ramosa*, *Setaria intermedia*, *Setaria verticellata*.

v. The following Alien Invasive Species (AIS) of plants were recorded in the village relocation sites of MTR: *Alternanthera sessilis*, *Alternanthera pungens*, *Ageratum conyzoides*, *Celosia argentea*, *Argemone mexicana*, *Leucas biflora*, *Hyptis suaveolens*, *Cassia tora*, *Parthenium hysterophorus*, *Sida acuta*, and *Malvastrum coromandelianum*.

Based on experiments done on grassland development in selected areas of MTR following lessons were learned:

(a) Instead of creating uniform grassland patches, creation of mosaics of grasslands and mixture of browse species in between was much better for round year availability of forage. Hence it is recommended to plant seedlings of certain wild fruit trees in patches. The species recommended for forage enhancement include: *Cordia macleodii*, *Cordia dichotoma*, *Terminalia chebula*, *Terminalia allata*, *Syzygium cumini*, *Zizyphus rugosa*, *Madhuca latifolia*, *Buchanania lanzan*, *Cassia fistula*, *Aegle marmelos*, *Eugenia jambolana*, and *Phyllanthus emblica*. It is recommended that temporary exclosures of wire *Terminalia allata* mesh (upto 5' x 20' x 20') at frequent intervals may be erected for a period of 5- 10 years so as to allow establishment of fruit bearing trees.

(b) Prior to plantation of palatable grasses all AISS need to be eradicated from the grasslands. The species recommended for plantation in grassland development area include *Dichanthium caricosum*, *Dichanthium Annulatum*, and *Sacciolepis indica*. It is important to create the multi-species stands rather than patches dominated by single species.

(c) The collection of the seeds of wild legumes in proper period is important. The seed collection should be in the month of November – December.

(d) Common grasses of MTR along with their palatability index are shown in (Table 12.1).

Table 12.1. Common grass species of MTR and their palatability

S. No.	Botanical name	Flowering and fruiting	Palatability
01	*Acrachne racemosa*	Aug- Sep	Palatable
02	*Andropogon pumilus*	Oct	Palatable
03	*Apluda mutica*	Oct	Palatable
04	*Apluda varia*	Oct	Palatable
05	*Aristida funiculata*	Aug-Dec	Non Palatable
06	*Aristida reducta*	Aug-Dec	Non Palatable
07	*Anthraxon lancifolius*	Aug-Dec	Non Palatable
08	*Anthraxon ciliaris*	Oct	Non Palatable
09	*Anthraxon lanceolatus*	Sept	Non Palatable
10	*Arundinella pumila*	Aug-Dec	Non Palatable
11	*Bambusa arundinacea*	--	Non Palatable
12	*Bothrichloa bladhii*	Jan	Palatable
13	*Bothrichloa tuberosa*	Dec	Palatable
14	*Brachiaria mutica*	Aug-Sep	Palatable
15	*Brachiaria ramosa*	Aug-Sep	Palatable
16	*Brachiaria replans*	Aug-Jan	Palatable
17	*Brachiaria eruciformis*	Aug-Dec	Palatable
18	*Cenchrus cilliaris*	Nov-Feb	Palatable
19	*Chloris barbata*	Aug-Jan	Palatable
20	*Chloris virgata*	Aug-Jan	Non Palatable
21	*Chloris dolichostachya*	Aug-Oct	Non Palatable
22	*Chloris gyana*	--	Non Palatable
23	*Chrysopogon fulvus*	Sept-Dec	Palatable
24	*Chrysopogon polyphyllus*	Dec	Palatable
25	*Coix aquatica*	Oct	Non Palatable
26	*Coix gigantica*	Oct	Non Palatable
27	*Coix lacryma-jobi*	Oct	Non Palatable
28	*Cymbopogon martinii*	Sept-Jan	Non Palatable
29	*Cynodon dactylon*	Whole year	Palatable
30	*Cynodon barbari*	Aug-Dec	Palatable
31	*Dactyloctenium aegypticum*	June-Jan	Non Palatable
32	*Dactyloctenium indicum*	Oct	Non Palatable
33	*Dendrocalamus strictus*	Oct	Non Palatable
34	*Dicanthium aristatum*	Oct	Palatable
35	*Dicanthium nodosum*	Aug-Nov	Palatable
36	*Dicanthium annulatum*	Whole year	Palatable
37	*Dicanthium caricosum*	Aug-Jan	Palatable
38	*Dicanthium filiculme*	Sep-Dec	Palatable
39	*Digitaria abludens*	July-Dec	Palatable
40	*Digitaria cilliaris*	July-Dec	Palatable
41	*Digitaria stricta*	Aug-Sep	Palatable
42	*Dinebra retroflexa*	Oct	Palatable
43	*Echinochloa colonum*	July-Feb	
44	*Eleusine glauca*	Aug-Jan	Palatable
45	*Eleusine indica*	Aug-Jan	Non Palatable

S. No.	Botanical name	Flowering and fruiting season	Palatability
46	*Eragrostiella biferia*	Aug-Jan	Non Palatable
47	*Eragrostiella coromondeliana*	Aug-Jan	Non Palatable
48	*Eragrostiella brachylla*	Aug- Oct	Non Palatable
49	*Eragrostris major*	Oct	Non Palatable
50	*Eragrostris cillianensis*	Oct	Non Palatable
51	*Eragrostris japonica*	Sep-Dec	Non Palatable
52	*Eragrostris tenella*	Oct	Non Palatable
53	*Eragrostris namaquensis*	Oct	Non Palatable
54	*Eragrostris tenuifolia*	Sep-Oct	Non Palatable
55	*Eragrostris unioloides*	Aug-Feb	Non Palatable
56	*Eragrostris viscosa*	July-Dec	Non Palatable
57	*Eragrostris minor*	Whole year	Non Palatable
58	*Ermepogon foveolatus*	July-Dec	Non Palatable
59	*Euilalia trispicata*	Aug-Sep	Non Palatable
60	*Heteropogon contortus*	Sep-Dec	Palatable
61	*Heteropogon melanocarpon*	Nov	Palatable
62	*Imperata cylindrica*	Dec-Jan	Palatable
63	*Ischaemum pilosun*	Sept-Mar	Palatable
60	*Ischaemum rugosum*	Aug-Jan	Non Palatable
64	*Iseilema laxum*	Aug-Jan	Palatable
65	*Iseilema prostratum*	Dec	Palatable
66	*Melanocenchris jacquemontii*	Aug-Dec	Non Palatable
67	*Mnesithea granularis*	Aug-Dec	Non Palatable
68	*Oplismenus burmannii*	Aug-Dec	Palatable
69	*Oplismenus compositus*	Aug-Dec	Palatable
70	*Oryza rufipogon*	Sep-Jan	Palatable
71	*Panicum antilotale*	Oct-Jan	
72	*Panicum psilopodium*	Aug-Oct	Palatable
73	*Panicum sumatrense*	Sep-Oct	Palatable
74	*Paspalidium flavidium*	Aug-Dec	Non Palatable
75	*Paspalidium jeminatum*	Aug-Jan	Non Palatable
76	*Paspalum canare*	Aug-Oct	Non Palatable
77	*Paspalum paspalodes*	Sept-Dec	Non Palatable
78	*Pennisetum pedicellatum*	Sept-Jan	Palatable at
79	*Pennisetum perpureum*	Sep-Nov	Non Palatable
80	*Pennisetum americanum*	Aug-Sept	Palatable
81	*Pennisetum orientale*	------	Non Palatable
82	*Pseudanthistiria heteroclita*	Sept-Oct	Palatable
83	*Pseudanthistiria hispida*	Oct	Palatable
84	*Rottbolia cochinchinensis*	Aug-Sept	Non Palatable
85	*Saccharum spontaneum*	Oct-Feb	Non Palatable
86	*Sacciolepis indica*	Sept-Dec	Palatable
87	*Sehima nervosum*	Sept-Dec	Palatable
88	*Sehima notatum*	Aug-Dec	Non Palatable
89	*Sehima sulcatum*	Aug-Dec	Non Palatable
90	*Setaria intermedia*	Aug-Jan	Palatable
91	*Setaria tomantosa*	Aug-Jan	Palatable

S. No.	Botanical name	Flowering and fruiting season	Palatability
92	*Setaria italica*	Sept-Nov	Palatable
93	*Setaria pumilla*	Aug-Jan	Palatable
94	*Setaria verticillata*	Aug-Nov	Palatable
95	*Sorghum bicolor*	Oct	Non Palatable
96	*Sorghum halepense*	Oct	Non Palatable
97	*Sorghum vulgare*	Oct	Non Palatable
98	*Sporobolus coromandelianus*	Aug-Dec	Non Palatable
99	*Sporobolus indicus*	Aug-Dec	Non Palatable
100	*Thelepogon elegans*	Aug-Jan	Non Palatable
101	*Themeda triandra*	Sept-Jan	Palatable (Young Stage)
102	*Themeda quadrivalvis*	Aug-Jan	Palatable (Young Stage)
103	*Themada australis*	Oct	Palatable
104	*Themeda laxa*	Oct	Palatable
105	*Tripogon jacquemontii*	Aug-Jan	Non Palatable
106	*Vitivera zizanoides*	Nov -Dec	Medicinal grass
107	*Cymbopogon martinii*	Oct	Medicinal grass
108	*Zoysia japonica*	Sept	Non Palatable

Plate 12.1: *Sehima nervosum*

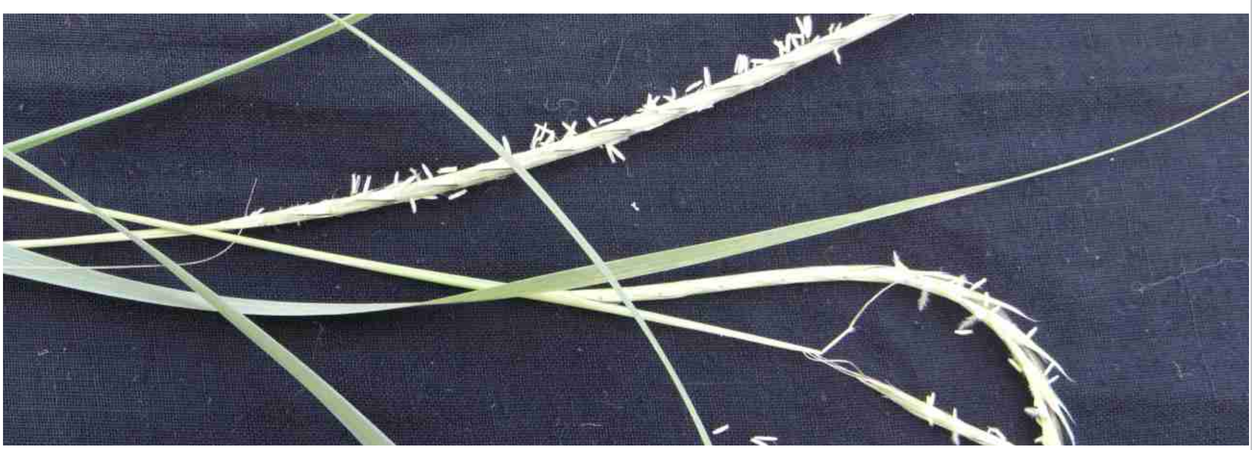

Plate 12.2: *Sehima sulcatum*

Plate 12.3: *Brachiaria mutica*

Plate 12.4: *Themeda triandra*

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Ecology and Management of Coastal Saline Grasslands of Blackbuck National Park, Velavadar, Gujarat

Abstract

The 'Bhal' tract characterized by semi-arid, flat, saline lands in the coastal district of Bhavnagar in Saurashtra region of Gujarat State is popular for its unique saline grasslands. Much of these grasslands are now confined to the Blackbuck National Park (BNP), Velavadar. Blackbuck NP is well known for its grasslands and associated faunal species. The National Park encompasses 3,452 ha area. Saline grasslands are predominated by *Sporobous virginicus* (Dharant), *Sporobolus madraspetansis* (Moti Dharant) and *Dichanthium annulatum* (Jinjvo) dominated grasslands. The entire landscape has been influenced by proliferation of exotic woody shrub/ tree *Propsopis juliflora* at the cost of sparse interspersed native shrubs and trees viz. *Salvadora*, *Acacia* spp. those have declined drastically in the region. Major attractions among faunal species of the landscape are Blackbuck (the North-Western Blackbuck, *Antilope cervicapra rajputanae*), Indian wolf (*Canis lupus*), Stripped hyena, Jackal, Blue bull, Jungle cat, Mongoose, Black naped hare, etc. About 190 bird species have been recorded from the protected area during different seasons. Among them, Lesser Florican and Harriers are important species. The diversity and abundance of flora and fauna in BNO and surrounds are high. BNP is being protected for its diverse conservation values. Over the past three decades or so, grasslands ecosystem in BNP is being protected from different various anthropogenic factors so as to ensure ecosystem integrity and maintenance of conservation values of the park and of the entire landscape. The park, therefore, requires 'active management' in terms of management of grassland-shrub land complex of BNP so as to help the habitat and species to recover and also to maintain diversity and abundance of flora and fauna. The climate change, agriculture expansion, and mounting pressure of developmental projects are emerging challenges which may result into changes in land use pattern in the surrounding lands.

Keywords: Bhal; Blackbuck; Grassland; Lesser Florican; Harriers; *Prosopis juliflora.*

Introduction

The Blackbuck National Park (BNP), Velavadar located at latitude 21°56' and longitude 70°10' in the Northern Bhavnagar District is a part of flat Eastern coast of Saurashtra peninsula, on the coast of Gulf of Cambay (Khmbhat) (**Plate 13.1 - 13.2**). The vast coastal plain from Khambhat to Bhavnagar is locally known as 'Bhal', literal meaning the fore head because of its flat vast extent. Before advent of agriculture and at much later stage the advent of a woody shrub *Prosopis juliflora*, this region was predominated by the coastal grassland ecosystem. The featured mammals of the grassland ecosystem were the Blackbuck and the Indian Wolf. The grassland ecosystem of Blackbuck National Park (BNP), Velavadar and adjoining areas act as suitable nesting site for the local migratory Lesser Florican and communal roosting site for migratory Harriers. The Lesser Florican and three species of Harriers namely Pallid Harrier (*Circus macrourus)*, Eurasian Marsh Harrier (*Circus aeruginosus*) and Montagu's Harrier viz., (*Circus pygargus*) have been assigned the conservation status of Endangered or Near Threatened species, respectively by the IUCN Red List. Besides conserving the representative wildlife and biodiversity, the BNP provides significant ecological and environmental services to the adjoining areas. Prominent among them are environmental amelioration and biological control of insect pest in agriculture farmlands by predatory birds. The Park also contributes in preventing soil erosion and ingress of salinity in this coastal area. The whole natural entity of BNP including the relic coastal grassland ecosystem and its associated biota with the highly endangered species call for sustained conservation efforts.

The State Government had timely notified a part of present BNP as a National Park as early as in 1976. The legal status assigned to this ecosystem, coupled with focused management and support of the people facilitated conservation of this

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coastal grassland ecosystem, particularly featured biota. Over past four decades or so, time to time adoption of appropriate conservation strategies and management interventions have yielded encouraging results which is evident by rapid recovery of grassland habitat (diversity and productivity) and increasing populations of prominent faunal species such as Blackbuck and Indian wolf, nesting and breading of Lesser Florican during every monsoon and large congregation of Harriers in BNP. BNP is eulogized as the Asia's largest winter roosting place of Harriers. One of the sustained conservation efforts of the Gujarat Forest Department was to prepare and implement the management plan for Blackbuck National Park, Velavadar from year 1995 onwards. Since then, it has been continued by ensuring timely revision of the management plan based on new researches and monitoring information.

Undoubtedly, BNP is one of actively managed parks, as such BNP lies in arid to semi-arid zone and rainfall received in the area during monsoon season is scanty and erratic. However, park management has observed changes in rain pattern and in recent years, the area has received more than average rainfall. In the past, this area experienced drought every alternate year which was believed to eradicate the weed naturally. More than average annual rainfall may have substantial long term impact on grassland diversity and resultant vegetation mosaic.

It is very important to study the coastal grassland ecosystem in context of herbivores and other fauna and the impact of the management interventions by the State Forest Department prescribed in previous management plan(s).

Review of Literature

The review of existing literature on grasslands of BNP is scanty. Following documentation is relevant and was reviewed so as develop an insight on the grassland ecosystem of the BNP and its management. The management plan of the Blackbuck National Park, Velavadar by (Singh and Rana, 1995) provides much desired information on diversity, management issues and proposed management interventions of grassland-shrub land complex in BNP and status, distribution and abundance of featured species. First revision of the Management Plan of BNP was done by Pathak, (2002). Ranjit Sinhj (1989) dealt more intensively on population dynamics, ecology and behavour of Blackbuck. Habitat mapping using remote sensing by Patel (1999), Anon (2001) and GEER Foundation (2008) has described about the changes in the complex and dynamic ecosystem by studying spatio-temporal differences in land use and land cover. Singh, Vora, et al (1997) studied environment impact assessment of Sardar Sarovar Project on BNP whereas GEER Foundation (2008) has described about the likely changes due to canal network in the 'Bhal' region.

Ecological Status

The BNP and adjoining lands under the control of Forest Department support the coastal grassland ecosystem with associate endangered biota including the Black Buck, the Indian Wolf, Lesser Floricans, four species of Harriers and many others. Of total 21 sanctuaries and 4 National Park of the Gujarat state, the BNP represents a site specifically for wildlife of grassland ecosystem under the Biogeographic Zone 4- Semi Arid Zone and 4A Rajwada bio-geographical province.

The BNP consists of Reserved Forest areas of villages Velavadar, Kanatalav, Adhelai and Bhadbhid. The management plan of BNP also includes Reserved Forest areas of village Rajgadh, Mevasa, Ganeshgadh, Savainagar and Madhiya those are adjoining to the BNP, Velavadar (Table 13.1).

Table 13.1. Extent of the Blackbuck National Park

Name of the area	Area in sq.km.
Blackbuck National Park, Velavadar	34.5200
Rajgadh Reserve Forest	4.8003
Mevasa Reserve Forest	4.7309
Ganeshgadh Forest	2.5000
Madhiya Reserve Forest	5.4633
Savainagar Reserve Forest	5.0867
Total	**57.1012**

Source: *Pathak et al. (2002)*

Geology, Rock and Soil

The coastal plains are made of deep deposition of saline alluvium. As per the long term study of sea level, geomorphology and associated subjects including archaeology have established that the 'Bhal' tract was under sea and due to triple action of: (a) tectonic upheaval, (b) receding of sea and, (c) deposition of coastal alluviums have given rise to this saline to semi- saline lands. The soil mainly constitutes clay and silt with varying degree of salinity.

Terrain

The terrain is mainly a flat coastal plain with elevation varying from 5.5 m to 9.0 m above mean sea level. The eastern side of the BNP is influenced by the high tides in the creeks. The main river of the National Park is Alang, which along with its tributary divide the Park area into three different zones. The drainage is towards south-east. This river is ephemeral and contains or drains rainwater only during monsoon. Low lying coastal terrain is susceptible to frequent inundation by floodwater during monsoon. Inundation coupled with clayey soil gives rise to water logged marshy conditions in BNP. This seasonal water logging pose difficulty for the Blackbuck, as they tend to die enmass if trapped to live in inundated/water logged area for considerable long period.

Climate

Climate of the BNP tropical monsoon climate with three distinct seasons viz. (i) winter from November to February; (ii) summer from March to June; and (iii) Monsoon from July to October. As the time series climate data of BNP are not available, the climate data of Velavadar National Park has been taken into consideration for describing climate. One rain gauge was installed at Velavadar and rainfall data were regularly recorded during the monsoon. Climate of the area is semiarid with very low average rainfall of about 460 mm. The significant feature of this semi arid coastal climate is recurrent scarcity with deficit monsoon rains. Monsoon of year 1999 and 2000 were such deficit monsoon years with total rainfall of 476 mm and 201 mm, respectively. During the monsoon of 2001, the PA had received 612 mm of rains. At this level performance of monsoon, i.e. 612 mm of rains in 32 rainy days there was no natural inundation of water in the National Park or adjoining areas.

Vegetation

The 'Bhal' was open treeless habitat except few groves of Salvadora spp. but Prosopis juliflora an exotic species has colonized large uncultivated lands. Few trees of *Acacia nilotica* (Desi Babul) and *Acacia cineraria* (Khijado) also occur. The dominant grass species are: *Sporobous virginicus* (Dharant), *Sporobolus maderaspatanus* (Moti Dharant), *Dichanthium annulatum* (Jinjvo) and other grass species found in the area are *Eremopogon foveolatus, Echinochloa colonum, Aeluropus lagopoides, Aristida adscensciondis* and *Chloris virgata*.

The Gujarat Ecological Education and Research Foundation have interpreted satellite imagery of the BNP for the year 1984, 1994, 1998 and 2011. The habitat types identified by each of the satellite imagery are given at Table 13.2 and maps generated of habitat types (land use/land cover) interpreted based on satellite imageries of year 1984, 1994, 1998 and 2011 are presented in Table 13.2.

Table 13.2. Habitat types of BNP using satellite data of different years

Land use / Land cover Classes	Area in different Years (ha.)						
	1984	1987	1990	1994	1998	2007	2011
Grass dense	444.30	346.30	719.80	757.20	740.40	596.40	735.33
Grass sparse	1593.30	1427.70	703.40	991.00	1332.60	1460.40	909.54
Prosopis dense	138.70	220.50	365.40	411.90	215.60	105.42	117.86
Prosopis sparse	334.30	183.40	163.00	93.60	293.80	119.58	331.23
Salt affected area without vegetation	209.50	126.80	82.70	70.20	355.30	237.58	472.12
Salt affected area with vegetation	241.80	794.50	449.10	443.10	36.70	160.49	173.16
Mudflat area without vegetation	101.40	7.80	151.30	131.80	157.30	634.08	540.59
Mudflat area with Vegetation	232.50	229.30	660.80	378.10	246.00	55.07	79.23
Water body	112.30	71.80	112.60	131.20	17.60	39.34	49.30
Agriculture Fallow Land					12.80		
TOTAL	**3408.10**	**3408.10**	**3408.10**	**3408.10**	**3408.10**	**3408.36**	**3408.36**

I) It was observed that the area under dense grass cover has increased from 596.40 ha. in 2007 to 735.33 ha. in 2011 mainly due to transformation of the sparse grass cover patches into the dense grass cover patches.

(II) The area under spare grass cover decreased from 1460.04 ha. in 2007 to 909.54 ha. in 2011 mainly due to the transformation of the sparse grass cover in the dense grass cover as well as to the sparse *Prosopis cover*.

(III) The area under dense *Prosopis juliflora* cover slightly increased from 105.42 ha. in 2007 to 117.86 ha. in 2011.

(IV) The area under sparse *Prosopis juliflora* cover increased from 119.58 ha. in 2007 to 331.23 ha. in 2011.

Above habitat types support diverse flora with higher diversity of grass and shrub species. Dominant tree species is *Prosopis juliflora* and other species: *Acacia nilotica, Salvadora persica, Prosopis cineraria* were observed in adjoining Reserved Forest area (BNP Plan 2013-14)

Ecological succession and ecosystem processes

The saline area in the 'Bhal' tract borders the tidal zone and appears to have resulted recently from flooding during extremely high tides. Mudflats of the 'Bhal' rise gradually due to deposition of silt brought by rivers. Through process of changes and ecological succession, mudflat in the zone gets converted in saline area, which gradually transforms into pioneer stage of the grasslands when area is protected from grazing. Invasion of *Prosopis juliflora* interrupts the existing succession stages and converts area into shrub land before reaching to the relatively stable grassland ecosystem (Pro-climax). In 'Bhal', ecological succession is of primary kind and autotrophic in nature. At present, pace of initial stage of succession is slow due to biotic pressure. Broadly, ecological succession without interruption of Prosopis juliflora in area can be seen in following stages.

Pioneer stage I

Saline tolerant grasses and sedges are normally seen in saline area during rains because fresh water and nutrients brought by rains moderate salinity and facilitate growth of vegetation. Salt tolerant grasses and shrubs like *Cyperus rotundus. Suaeda nudiflora* and *Sporobolus* spp. grow at some places. *Cyperus rotundus* is the first species to appear and forms a carpet like cover in the depressions. *Suaeda* spp. appears on ridges and slightly raised land in high tidal zone and saline area.

Stage II

Pioneer stage is followed by a set of other plant community in this serial stage. Species recorded in this stage are *Suaeda* spp., *Sporobolus coromandalis. Eragrostis* spp., *Aristida* spp., *Cressa cretica, Cyperus rotundus* becomes quite sparse and grow only in depressions. At this stage *Chloris virgata* and *Aeluropus lagopoides* are also seen at places.

Stage III

Species of second stage improve the edaphic condition but fail to compete with new plant community in changed environments. In this stage, regeneration of *Prosopis juliflora* appears at certain places and its population grows with improvement in the site condition. *Aeluropus lagopoides, Triantheme* spp., *Portulaca* spp. and *Chloris virgata* are the important species of this stage. *Suaeda nudiflora* is also found in elevated soil with high moisture content. Invasion of Prosopis juliflora accelerates the process of site improvement, which can be conveniently utilized at certain stage to convert shrub land into stable grassland community of the Bhal region.

Stage IV

Species mentioned in above stages are replaced by new set of species like *Echinochloa colonum. Dactyloctenium* spp., *Chloris virgata, Eremopogan fovelatus, Eleusine compressa, Aristida* spp., *Cenchrus* spp. etc. If dispersal of *Prosopis* seed is adequate, regeneration of *Prosopis juliflora* takes place at very fast rate and colonizes site within short period. Careful removal and control of regeneration of *Prosopis juliflora* is of immense use for improvement of site as well as development of the grassland.

Stage V

Eragrostis fovelatus, Eleusine compressa along with *Aristida* spp. are the dominant at this stage. Other associates like *Cyperus* spp. are found in patches. *Sporobolus marginatus, Sporobolus nelvolus* along with *Dichanthium annulatum* start colonizing.

Stage VI - Stable stage

Ecological succession does not stop at this stage but *Dichanthium annulatum* and *Sporobolus* spp. form almost pure patches, which remains stable for long period. *Dichanthium annulatum* constitutes pure patches in stretches as seen in BNP. If climatic condition remains stable for years to come and salinity reduces, such grassland gradually transforms into tree land. Species of this stage are highly palatable and considered to be good habitat for the Blackbuck, Lesser Florican (*Sypheotides indica*) and varieties of other birds.

Ecological succession from Stage I to Stage VI is achieved in long duration but preventing invasion of *Prosopis juliflora* in Stage III, IV and V may be utilized to reduce the time period required for getting grassland of the Bhal region. BNP is only protected grassland in the 'Bhal' region, and has gained great importance for conservation of biotic community of the area. Control/eradication of *Prosopis juliflora* in about 587 ha area of shrub land in BNP from 2001-02 to 2011-12 is an example of successful conversion of *Prosopis juliflora* shrub land into grassland (BNP Management Plan 2002 and 2013-14)

Fauna

The prime faunal species found in this landscape are Blackbuck (*Antilope cervicapra rajputanae*), Indian wolf (*Canis lupus*), striped hyena, Golden jackal, Blue bull, Jungle cat, common mongoose etc. Three poisonous snakes namely Indian cobra, Saw scaled viper and Krait along with common and monitor lizards are commonly found. About 189 bird species have been recorded in the PA during different seasons. Among them, Lesser Florican and three species of Harriers Pallid harrier (*Circus macrourus*), Montagu's harrier (*Circus pygargus*) and Eurasian marsh harrier (*Circus aeruginosus*) are important species found in this landscape. Monitoring or population estimation of flagship species i.e. Blackbuck and important bird species like lesser florican and harriers are being carried out every year and documented since 1995.

Pattern of habitat use by wildlife or domestic livestock

Traditionally the land treated as 'Vidi' (a grassland reserve, firstly protected during monsoon, than grass is being harvested after November and dry grass stored for livestock and then free grazing by livestock allowed) by erstwhile princely state of Bhavnagar. This same practice has been continued even after country's independence. The Blackbuck population declined from 8,000 in 1947 to 200 in 1966 due to over use of the habitat by livestock. In 1969, the sanctuary was established with an area of 8.9 sq. km. Subsequently, the area was increased to 17.88 sq. km. In 1976, the status was upgraded to that of National Park. The harvesting of the grass was then stopped. Due to continuous efforts of the frontline staff against illegal livestock grazing, the landscape has restored with luxuriant grassland with climatic climax species of *Dichanthium annulatum* and *Sporobolus* spp. as associates.

Now diverse habitats in BNP are mainly used by wildlife. To sustain the palatability of different grasses, rotational harvest of grass in six series and four sub-series in each series was prescribed in first Management Plan of BNP (1995). This activity was to be carried out by Forest Department and adequate budget was also projected in the Management Plan. But, due to one or other reason the budget was not allotted and work could not be carried out. As the activity required to be carried out to sustain the palatability of grass, this priority management activity was then carried out with the help of local communities. Villagers from adjoining villages are allowed to harvest the grass in pre-defined strips and two-third part of the harvested grass is allowed to be taken away by villagers as head loads whereas one third parts is stored in grass godown to use for stall feeding by wild animals during pinch period. The harvested grass strips were observed and found to be used by Blackbucks for foraging as new fresh shoots comes out after harvesting the grassland strips and visibility also improves due to open wide strip. The lesser florican are also found making their territory mostly in the harvested strips due to edge effect. They usually display in open grassland and hide themselves whenever require for security in tall grass areas. Harriers also roost in tall grass during winter.

Grasslands of the BNP are being protected from almost all anthropogenic factors, but to sustain the mosaic of different grass successional patches, considerable management interventions are required. The climate change is the most challenging factor which may result into change in land use pattern. The annual rainfall during recent years has increased and drought has become rare. This has negative as well as positive impacts on habitat. Development activities like major irrigation scheme namely Sardar Sarovar Project is believed to induce changes in cropping pattern which may attract herbivores from BNP for crop raiding throughout the year. This may consequently result into wildlife-human conflict and changes in spatial patterns in PA.

The grassland ecosystem also suffers from high salinity and aridity; severe scarcity periods are also experienced frequently. The south-eastern part of the BNP is influenced by tides bringing more salinity. Increasing population of Blue bull in BNP is likely to create imbalance as it causes competition with Blackbuck population and overuse of habitat by them. Inundation and water logging during floods also has immense adverse impact on habitat. *Prosopis juliflora* is the species vigorously invading the grassland. The pods are being consumed by blue bull as well as Blackbuck and seeds excreted out with faeces. These seeds get germinated during monsoon. *Prosopis juliflora* seedlings germinated require immediate removal from grassland habitats. This is being accomplished by manual removal/ uprooting along with its root system every year to restrict the invasion of *Prosopis juliflora* in the grassland.

Management practices and issues

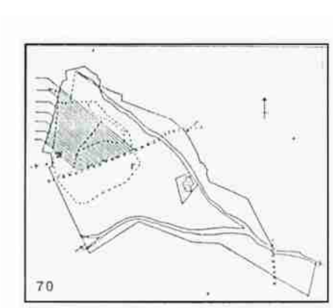
Improvement of grassland

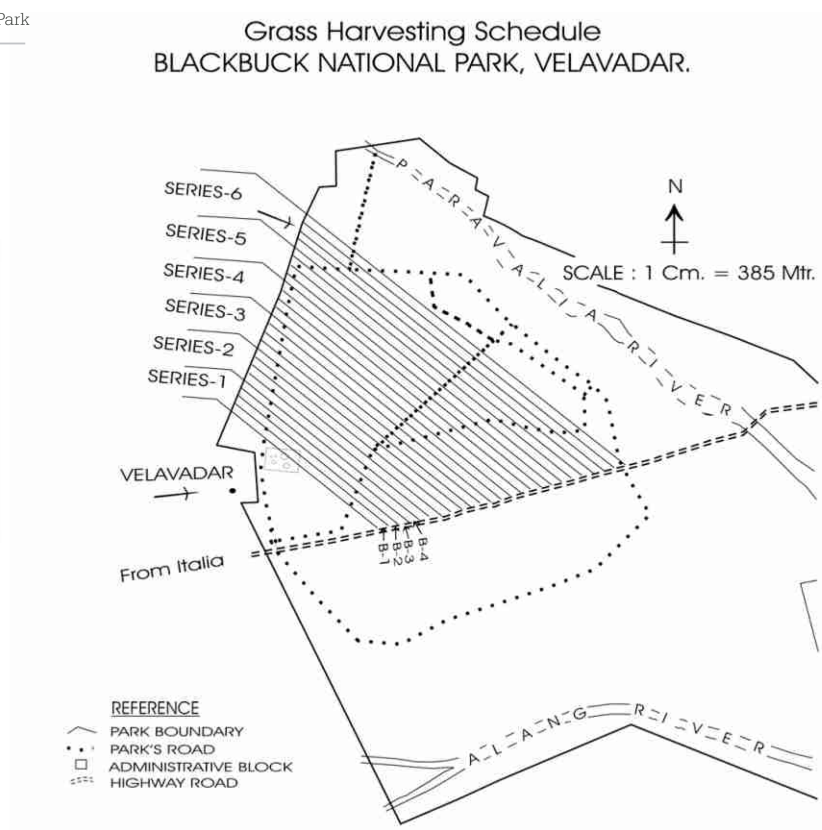
First management plan (1995-2002) of BNP aimed to increase grassland area from 29% to 36% of the total area of the park; i.e. 1225 ha. After five years of first management plan, the grassland cover increased to 2072 ha. (Patel, 2001). This included 740 ha. dense grassland area whereas 1,332 ha. sparse grassland owing to sustained management efforts which on one hand included protection against illegal livestock grazing and on the other hand adoption of improvement practices by harvesting grass in series/sub-series/strips as well as control of Prosopis juliflora and other weeds. Hence, the grassland improvement programme continued for subsequent five years in prescribed manner, but aimed to maintain the quality of grassland not to increase the area under grassland.

Blackbuck prefers short-grass tract, as it is observed that the animal normally move out of a terrain where grass is over 40 cm tall. At certain places in Gujarat, the Blackbuck moves to 'Vidis' after harvesting of grasses. There is enough grass in the grassland but animal move to shrub land and saline area during winter. Thick growth of grass remains unutilized. Conservationists feel that tall grasses in the BNP should be harvested from select area to develop better habitats for the animal species of concern. Usually, height of various grass species exceeds 60 cm during normal or excessive rain years in BNP. Over 700 ha. area supports thick and tall grass cover whereas rest of grasslands have medium or poor grass vegetation. The Management Plan prescribes for cutting of grass from good areas as part of fire lines.

If grasses were cut before flowering in some area, it would sprout and grow up to short height. Dew and air moisture increase during winter and this help in growth of sprouted grass shoots in harvested area. Such area may be of immense use by Blackbuck. The Plan also prescribes for harvesting of grass on rotation basis and remaining grass areas would be preserved as shelter and food for Blackbuck and other wildlife. Every area under good grassland would be harvested after four years. There are black patches or saline area in the grassland and some area have poor grass cover. Thus, only about 560 ha under good grass cover may be available for harvesting along fire lines. Entire grass area is divided into six harvesting series with approx. 90 ha. each, and 24 plots. Approximately 23 ha. area from each series need to be harvested every year. Thus, total 560 ha. of grasslands is planned for rotational harvesting. One plot every year would be harvested in first week of October, other plots in November. Demarcation of plots and series are given in map-VII and strips are indicated in perpendicular to the prevailing wind direction in summer so that grass harvested in strips can serve as fire lines. Details about distribution and demarcation of series and plots have been indicated in the **Figure 13.1**.

Figure 13.1: Map of Blackbuck National Park





Removal of *Prosopis juliflora* seedling from grassland:

The grasslands in BNP is vulnerable to *Prosopis* spp. invasion as the pods are consumed by Blackbuck as well as Blue bull in winter and summer. In the month of November labourers are engaged every year to uproot the seedlings of *Prosopis juliflora* from grasslands. The park management is spending around 1.5 man-days per hectare for this activity.

In the past (1990), most of the park area has been converted in to shrub land due to *Prosopis juliflora* invasion. The managers then started removal of *Prosopis juliflora* along with its root system manually and after 1998 with the help of JCB machines. Then, the land ploughed and left for the succession. The areas were converted into grassland habitats within five years while adopting protection from any type of grazing in such treated areas. The first management plan also prescribed that the 1/3 of the total area of BNP should be kept under *Prosopis juliflora* shrub land as such habitat is used by wolves to rest during day time. Therefore, removal of *Prosopis juliflora* shub land was discontinued from peripheral areas after t revision of the first management plan in 2002.

Conservation implications

The coastal saline grassland is very sensitive and fragile. The area is low lying and vulnerable to flood and water logging. The soil is black clayey which has high water holding capacity; hence percolation of rain water is very low. The pH of the soil varies from 7.8 in 12 inch depth to 8.4 in one inch depth. The sodium ion found 3520 ppm at 12 inch depth where as 140 ppm at 1 inch depth. The upper layer of soil contains low sodium due to washing of the salt during rain water runoff. The layer of grass clumps helps the soil to restrict erosion and improves the percolation of rain water. The fissure development in the soil is common as the moisture evaporation takes place in November.

During water logging condition trampling by cattle may lead to serious damage to the clumps of the grass. Hence, due protection measures are crucial during monsoon. The well surfaced roads help in protection and continuous movement of the staff is possible. The economy of local villagers is based on cattle. There are more than 5000 cattle herds around the National Park. The local pastorals (Maldharis) often graze their cattle illegally in BNP and occasionally attack on the staff. The park managers have successfully tackled the situation and protected the grassland. Consequently they started reducing the number of cattle and most of them migrated towards south Gujarat and Maharashtra where they found good returns on sale of milk and enough fodder and water for their cattle. Some of them still migrate seasonally, at their village during monsoon and again migrate towards south Gujarat after December. The staff posted here are mostly local and well motivated and they deal with any situation. They keep themselves vigilant and have very excellent network system of informants. The following are suggested for the r improved management of BNP and maintenance of grassland habitats

Plate 13.1: Grassland view of Velavadar NP

Plate 13.2: Grassland of Blackbuck National Park, Velavadar © *Anirudh Vasava*

- The posting of the adequate protection staff is very important for BNP.
- The park roads should be maintained well as they serve several functions like communication for patrolling, as raised platform for rescue of wild animals during water logging condition and for tourism purposes.
- The rain water drainage should be checked well so that there should not be water logging condition for more than 24 hours. The management has to keep watch while constructing any low level deep structures on internal roads.
- The monitoring of grassland along with rainfall pattern should be developed and the analysis and documentation is required. This should be well prescribed in management plan.
- A study on foraging and food preference should be conducted for Blackbuck as well as Blue bull and degree of competition for preferential forage should be understood so as to know the habitat use pattern form time to time. Development of irrigation facilities in surrounds may induce change in cropping pattern which may invite crop raiding by wild animals, ultimately lead to underuse of the grassland habitat and changes in grass mosaic.
- Weed removal and control is also an important and time bound operation to be prescribed in management plan and funds for that activity should be allotted to carry out the operations to protect grassland habitats.
- A detail study of grass mosaic along with climatic and soil condition should be carried out and long term action plan should be prepared to notice the changes in biodiversity and habitat.
- The management plan should be reviewed at every five years and necessary actions should be prescribed on the basis of continuous monitoring of the grass mosaic and habitat use.

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Pattern of Invasion by *Adhatoda vasica* in Savannas of Sariska Tiger Reserve, Rajasthan, Western India

Abstract

As part of global experiments on Savanna vegetation, we examined the ecological characteristics of an important semiarid savanna in the Indian sub-continent i.e Sariska Tiger Reserve, Rajasthan, Western India during April 2009 to May 2011. 149 plots across five line transects were sampled for phyto-sociological interpretation in the Sariska-Kalighati valley which is the largest savanna valley habitat in the study area. Plots were segregated on the presence/absence of native invasive species *Adhatoda vasica* and community analysis revealed a total of eleven communities (five from infested plots and six from non-infested plots) and communities having similar composition were compared. Tree density, seedling density, species richness of shrubs and herbs and diversity and evenness of herbs was higher in non-infested plots. Sapling density did not follow a trend. Evenness of shrubs was lower in non-infested plots. Furthermore, mapping of *Adhatoda vasica* in the study area revealed that 5.22 km^2 (26.1%) of the Sariska-Kalighati valley was under infestation and three sites were compared following removal of this species which resulted in increased sapling density, shrub density and grass cover and decreased seedling density and herb density.

Keywords: *Adhatoda vasica*; invasion; Sariska Tiger Reserve; savanna; semi-arid.

Introduction

The tropical and sub-tropical vegetation dominated by grasses, interspersed with a discontinuous cover of trees and shrubs is generally termed as savanna (Huntley and Walker, 1982; Frost et al., 1986). Although the term savanna is believed to have originated from an Arawak word which meant 'land without trees with much grass either tall or short' (Beerling and Osborne, 2006), now largely used to denote the land with both grasses and trees. This definition of savannas holds true for a wide range of climatic conditions i.e., from the tropics to the taiga. From a global perspective, there are large changes in the physiognomy of savanna communities, both across and within continents substantially due to differences in the physical environments. They cover about an eighth of the global land surface, covering over half the area of Africa and Australia, 45% of South America and 10% of India and Southeast Asia. The savanna vegetation in India is largely distributed in the semi-arid tracts of western, central and peninsular India and can be seen in a few protected areas (PAs) including Sariska Tiger Reserve in the state of Rajasthan.

Sariska Tiger Reserve (STR), located in the world's oldest hill ranges, i.e. Aravallis, its repository of serene forests, wide valleys and sprawling plateaus, was recently in the limelight due to local extinction of its flagship species i.e. tiger (*Panthera tigris*). This reserve happens to be the westernmost limit of tiger distribution in India. Very few areas in the tiger range have a typical semi-arid savannah vegetation. Across their range of occurrence, savannas are extremely variable in their physical and structural attributes. They encompass a gradient from nearly pure grasslands to closed woodlands, exhibit differences in the characteristics of dominant trees (fine-leaved and broad-leaved), herbaceous vegetation (tall to short grasses, vegetated and bare patches), plant life-history characteristics (deciduous to evergreen trees, annual to perennial grasses), tree spatial patterns (random, regular, or clumped) and plant and soil nutrient status (nutrient-poor or dystrophic savannas vs. nutrient-rich or eu- trophic savannas; House et al., 2003; Sankaran and Anderson, 2009). Today, savannas constitute the world's second largest biome, covering ~ 33 million km^2 or nearly 20% of the earth's land surface (Scholes and Walker,1993; Ramankutty and Foley,1999; Beerling and Osborne, 2006). They are widespread across Africa, Asia, South America and Australia, and cover more than half the area of the southern continents. They are host to approximately one-fifth of the world's population (Young and Solbrig, 1993) who are socio-

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economically dependent on savanna by enterprising in pastoralism or agriculture and wildlife reserves or tourism (Werner, 1990). Despite such an important holding in the nature's index they have been neglected in terms of ecological studies. Initial studies as late as 1967 were undertaken by Lamotte and associates in the Ivory Coast, followed by Medina in the Venezuelan llamos. American and British scientists in Tanzania, Kenya and Uganda contributed significantly in understanding the role of wild herbivores in tropical savannas thus being fruitful only to range managers or cattle ranchers (Huntley 1982). Savannas are comprised of interspersed life forms viz. herbaceous species and woody species that are competing plant types. To explain the coexistence of trees and grasses in savanna systems, Walter (1971) focused in his hypothesis of the separation of rooting niches on the competition for soil moisture in different soil horizons. According to Walter (1971), trees have access to water in deeper soil horizons, whereas grasses are superior competitors for water in the upper horizons (Walker and Noy-Meir 1982). Detailed field studies led to the rejection of the Walter hypothesis as the singular explanation for tree-grass coexistence (e.g., studies in West Africa: Le Roux et al., 1995; Seghieri, 1995; Mordelet et al., 1997; Le Roux and Bariac 1998). This approach is also known as the “bottom up” model where a characteristic tree–grass ratio is expected for a given set of rainfall and soil conditions, with tree cover increasing as one moves from arid to mesic sites. Another polarized view is the “top down” model where primacy is given to the roles of disturbances such as herbivory and fire in regulating savanna structure. Both fire and grazing act to regulate tree cover in savannas by imposing demographic bottlenecks ,or in some cases eliminating bottlenecks, to tree recr uitment and establishment (Higgins et al., 2000; Sankaran et al., 2004; Bond, 2008).

In the 'bottom-up' perspective, savannas are viewed as 'stable' systems to the extent that disturbances such as fire and grazing, although capable of shifting the balance between trees and grasses, are not prerequisites for the persistence of both life-forms in the system. In the top-down view, savannas are essentially considered to be 'unstable' systems. Pure forests and grasslands are presumed to be the only stable states, and disturbances such as fire and grazing permit savannas to exist by 'buffering' the system against transitions to either extreme (Jeltsch et al., 1996, 1998, 2000; Higgins et al., 2000). Savannas exist because of factors that favor tree establishment at the arid end of the rainfall gradient, and factors that prevent canopy closure at the mesic end. Beside soil moisture, several other environmental parameters have been discussed to be important for the maintenance of savannas such as nutrient availability, fire, grazing and browsing, geology and geomorphology, soil, cultivation history, and termites (Frost et al., 1986; Furley et al., 1992; Furley, 1999; Scholes and Archer, 1997, van Langevelde et al. 2003) and however complexly these factors interact the degree may vary between different savanna types. Jeltsch et al. (2000) proposed in a unifying concept of tree-grass coexistence to focus on ecological buffering mechanisms which prevent the savanna system from crossing the boundaries to other vegetation systems, i.e. pure grassland and closed forest.

Historical evidence from India indicate that with the beginning of Pliocene period, deciduous trees replaced the evergreen vegetation over much of the country, while parts of Thar Desert came to be covered by desert scrub (Gadgil and Meher-Homji, 1985). Even during this dry epoch, however there was hardly any natural grassland, with only a few species of grasses at the border or in dry open forest (Whyte, 1980). According to Gadgil and Meher-Homji (1985 in Saha, 2002) the practice of setting intentional fires has been in place for the past 50,000 years and is responsible for major modifications of the vegetation character (Pyne, 1994). According to Misra (1983), the tropical sub-humid and dry deciduous forests of India, which once covered large parts of the country, have been almost completely replaced by savannahs, a transformation most likely caused by fire. This paper deals with recent changes in structure and composition of savannah vegetation due to rapid spread by an unpalatable native shrub, *Adhatoda vasica* (Syn. *Justicia zeylanica*) in STR. Pattern of invasion by this species and management implications are discussed.

Study Area

The study was conducted in STR, Rajasthan, India **(Figure 14.1)** which is situated between Longitudes 79°17'N to 76°34' N and Latitudes 27° 5' E to 27° 33' E. The area was a hunting reserve of the erstwhile princely state of Alwar before being declared as a Sanctuary in 1958 and later as a Tiger reserve in 1978. The altitude varies from 540 m to 777 m and topography of undulating plateau- lands and wide valleys otherwise unknown in the Aravalli system constitute the major part of the reserve of Sariska. Still the hills maintain the Aravalli character of sharp hogback ridges (Sharma, 1983). The major part of the area is occupied by rocks of the pre-Cambrian era comprised of Banded Gneissic Complex, Delhi system and Aravalli system of quartzites, conglomerates, grits, limestone, phyllite, granites and schists (Pascoe, 1950; Sankar, 1994). The depth of the soil layer is more than 1 m in valleys, whereas it is only a few centimetres deep on the hill slopes. The soil is sandy loam and alkaline with pH varying from 7.25 to 8 (Yadav and Gupta, 2006).

Although, latitudinally the study area falls under sub-tropical zone, climatically it falls under hot arid steppe category (Kottek et al 2006). It has a distinct winter from December to February, summer is dry and extends from mid-March to June accompanied by hot westerly winds known as loo, monsoon commences from July until mid-September and post-monsoon from mid-September to October. The study area also receives occasional winter and summer rains. Presence of fog during winters has also been observed. The temperature varied from 52° C to 1° C during the study period. The relative

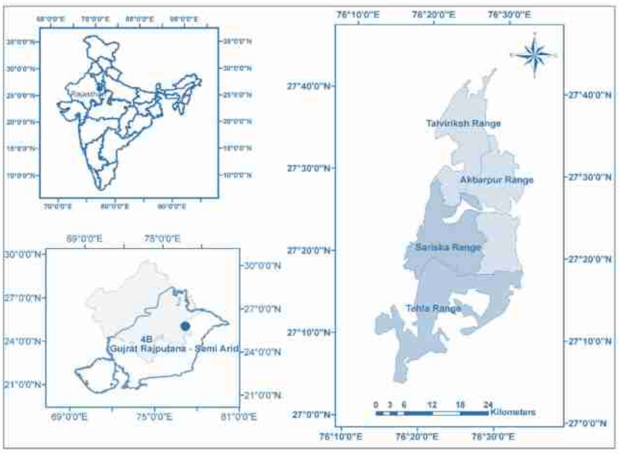

Figure 14.1 The Study Area

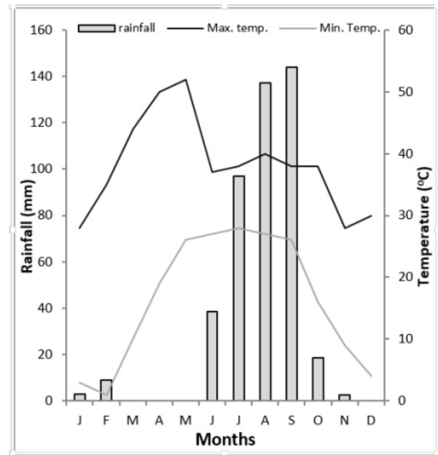

Figure 14.2 Ombrothermic diagram for the study area Sariska Tiger Reserve, Rajasthan during June 2009- May 2010

humidity is high during monsoon and ranged from 52% to 2% (**Figure 14.2**). The annual rainfall recorded for the study period (June 2009-July 2010) was 735.1 mm. The park supports carnivore species such as reintroduced tigers (*Panthera tigris*), leopard (*Panthera pardus*) and striped hyena (*Hyaena hyaena*) alongwith wild herbivores such as chital (*Axis axis*), sambar (*Rusa unicolor*) and nilgai (*Boselaphus tragocamelus*). Omnivores found are wild pig (*Sus scrofa*) and golden jackal (*Canis aureus*). Rhesus macaque (*Macaca mulatta*) and common langur (*Semnopithecus entellus*) are the two primates found here. Sankar et al., (1993) listed a checklist of 211 bird species belonging to 52 families in STR. These include 73 migratory and 120 resident species and a number of aquatic birds also visit the park during winter. There are 32 villages within the Tiger Reserve and of them ten are situated in the notified National Park. Due to presence of villages inside and on the periphery of STR a large number of livestock such as buffalo, cattle, goat along with feral cattle are found in the study area which increases the grazing pressure The people residing within the reserve belong to Gurjar and Meena communities. These local residents are mainly occupied in agriculture and animal husbandry. Their only source of income is the production of milk and milk-based products. Apart from livestock grazing, local people commonly collect grasses and lop trees for their livestock and fuelwood requirements (Kumar and Shahabuddin, 2005).

According to Champion and Seth (1968), the forests of STR fall within Northern Tropical Dry deciduous (Group V) and Northern Tropical Thorn Forests (Group VI). Although, Vyas (1967) had documented some flora of Sariska as a part of floral study of North-East Rajasthan including Sariska. Parmar (1985) was the first to study the flora of this park exclusively. In 2008, Sankar et al. studied vegetation composition and structure and mapped vegetation types of the entire STR. The Sariska-Kalighati valley, which appears as savanna is mostly dominated by *Acacia* dominated forest, Butea monosperma forest, *Zizyphus mauritiana* forest and thorn scrub and this study focused on investigating the structure and composition of savannas of Sariska.

Subsequently, Sankar (1984) also observed that *A. vasica* had assumed the status of "weed" in STR and reported that the ungulates such as chital and sambar were using patches of *Adhatoda* only for cover but these species were not found feeding on it. The Working Plan records of the forest division indicated that *Adhatoda* was always considered as a shrub more so for its numerous medicinal properties and hence there was never a need for it to be considered as an invasive species. But recent observations in the study area have highlighted the fact that the species being unpalatable has increased manifold and replaced the native palatable vegetation. Sankar et al. (2008) also mentioned that *Adhatoda* was a native understory species but had become common in disturbed and over grazed areas and appeared to suppress grass and other native herbaceous species but at the same time the eradication should be such that cover for predators is not lost completely. This study was conducted during 2009-2011.

Methodology

Five line transects of 1.5 km each was laid in the Sariska-Kalighati valley which is the largest valley habitat in STR and a 10 m radial plot was laid at every 50 m for trees, 5 m concentric plot for shrubs and 6, 1m X 1m for herbs and grass cover for enumeration of tree, shrub and ground layers. Density, frequency and basal area of each species in each plot were calculated to seek importance value index (IVI). Importance Value Index (IVI) is the sum of relative density, relative dominance and relative frequency for a species (Curtis and Mclntosh, 1950). The data collected was subjected to multivariate analysis; using TWINSPAN (Hill, 1979). Species richness (a-diversity) of the vegetation cluster was calculated as the average number of species per stand and Shannon– Wiener index for the relative evenness and Diversity (Pielou, 1975; Magurran, 1988). Population structure of dominant tree species from each community was evaluated separately dividing them into seedlings, saplings and different girth classes viz., 30-61.4 cm, 61.5-91.4 cm, 91.5- 121.4 cm, 121.5-151.4 cm, 151.5-191.4 and above 191.5 cm.

For mapping the invasion of *Adhatoda vasica*, a hand held GPS was used to locate the geographical coordinates of the path walked with a distance of 5-10 m between two consecutive points. The infested area was delineated and the boundary was walked so as to enclose the infested area in the polygon. Effort was made to cover all the infested areas into polygons. These points were plotted in ArcGIS 9.2 (ESRI, 2006) to estimate the invasion, along with the major roads, villages, chowkis and drainage pattern and also the area under invasion was calculated. Two locations were randomly selected where *A. vasica* had been manually removed, one location where eradication was done within 1 year and at another where it was done before 2 years. Ten plots of 10 m radius were laid randomly in each of the two locations and vegetation parameters were recorded following aforementioned methods. These were compared to locations where no removal had been done.

Results

Of the 149 plots sampled, *Adhatoda* was present in 73 plots. TWINSPAN dendrogram divided the data set into 11 communities, five were identified for *Adhatoda* present area **(Table 14.1)** and six from Adhatoda absent area **(Table 14.2)**. We compared the differences in sapling and seedling densities, diversity indices for effect of *Adhatoda* infestation in similar communities and four communities were marked for the evaluation as these were found to have similar species composition. In *Acacia–Zizyphus* woodland and *Balanites aegyptiaca* scrubland, seedling and sapling density was found to be greater in *Adhatoda* absent area **(Figure 14.3)**. By contrast in *Prosopis juliflora* scrubland, *Adhatoda* infestation facilitates the sapling and seedling establishment and no seedling and sapling occurrence was observed in non-infested area. In *Acacia-Grewia* scrubland, seedling numbers were greater in non-infested area whereas saplings were more in *Adhatoda* infested area. In case of scrubland, *Adhatoda* infestation did not seem to have a significant effect on grass cover **(Figure 14.4)**, however, grass cover for *Acacia-Zizyphus* woodland was decreased by the infestation of *Adhatoda*. Species count for shrubs was found to be higher in *Adhatoda* absent areas for all the communities however **(Figure 14.5)**. Evenness was found to be higher in *Adhatoda* present areas. Diversity was lower in *Adhatoda* present areas for *Prosopis juliflora* scrubland and *Balanites aegyptiaca* scrubland but higher in *Acacia- Zizyphus* woodland and *Acacia- Grewia* scrubland. Species count for herbs also showed a similar trend as shrubs. Evenness and Diversity in herbs was lower in *Adhatoda* present areas for three out of four communities **(Figure 14.6)**.

Population structure for dominant tree species were observed for each community and it was observed that in *Adhatoda vasica* present area, *Z. mauritiana* showed a stable population growth, *A. leucophloea* and *A. catechu* showed interrupted regeneration. However, *Anogeissus pendula* had higher number of seedlings but they were unable to survive due to anthropogenic pressures such as lopping and grazing. Hence, a few trees of lower girth classes were represented in *A. pendula* forests. *B. monosperma* trees showed presence of higher girth class individuals and no sapling and lower girth class individuals. In Adhatoda absent communities, *Z. mauritiana* and *A. catechu* showed a stable population growth. *A. leucophloea* showed a youthful population structure. *B. monosperma* showed a declining type of structure. *A. pendula* showed extremely high number of seedling and sapling but due to grazing pressures, very few could successfully survive to the next girth class. For *Balanites aegyptiaca*, seedlings were found to be lesser than saplings in all the communities. Presence of Adhatoda limited the sapling and seedling density in most communities but it increased the species count and diversity for shrubs and herbs and species evenness in herbs. In case of scrubland, *Adhatoda* infestation did not seem to have a significant effect on grass cover however grass cover for *Acacia-Zizyphus* woodland was significantly decreased by the infestation of Adhatoda.

The following map **(Figure 14.7)** shows the extent of invasion of Adhatoda vasica along the 20 km^2 valley of Sariska-Kalighati. The area under invasion was calculated to be 5.22 km^2 which is 26.1 % of the area that was studied. **Plate 14.1** depicts the invasion in a *Butea monosperma-Acacia catechu* woodland within the study area. Within one year of removal, the total seedling and sapling density was found to be 334.39 ind/ha. and 25.48 ind/ha. *Anogeissus pendula* was the only species in seedling stage with 50% frequency. *Adhatoda vasica* was found to have maximum density (29058.82 ind/ha.) followed by *Grewia flavescens* (3529.41 ind/ha.) in shrubs and Elytraria acaulis (21666.37 ind/ha.) in herbs. Species richness for herbs was found to be 8. Grass cover was found to be 16% within a year of removal.

Table 14.1. Communities with *Adhatoda* infestation

Communities	Density					Basal area	Diversity			Species richness			Evenness		
	Tree	sapling	seedling	Shrub	Herb		Tree	Shrub	Herb	Tree	Shrub	Herb	Tree	Shrub	Herb
Adhatoda-Balanites aegyptiaca	66.6	469.0	256.8	2406.4	10*104	1.127	0	1.58	2.04	1	12	17	0	0.63	0.72
Adhatoda- Acacia leucophloea	47.7	441.9	346.3	1973.8	8.4*104	1.273	1.30	1.32	1.72	5	13	16	0.81	0.51	0.62
Adhatoda-Acacia leucophloea-Butea monosperma	52.6	272.8	325.3	7109.9	5.8*104	4	1.59	0.68	2.22	6	10	20	2.85	0.29	0.74
Adhatoda-Acacia catechu-Zizyphus mauritiana	86.1	43.09	277.2	865	6.5*104	1.574	1.31	0.59	1.98	6	9	18	0.73	0.26	0.68
Adhatoda-Prosopis juliflora	23.8	652.9	684.7	705.8	9.8*104	0.699	0.64	1.16	1.77	2	8	12	0.92	0.56	0.71

Table 14.2. Communities without *Adhatoda* infestation

Communities	Density					Basal area	Diversity			Species richness			Evenness		
	Tree	sapling	seedling	Shrub	Herb		Tree	Shrub	Herb	Tree	Shrub	Herb	Tree	Shrub	Herb
Zizyphus mauritiana-Butea monosperma	*65.02*	*113.4*	*85.4*	*414.1*	*7.7*104*	*3.05*	*0.80*	*0.97*	*1.63*	*4*	*5*	*18*	*1.11*	*0.60*	*0.56*
Acacia catechu-Zizyphus mauritiana	*62.1*	*285.0*	*406.1*	*735.2*	*7.6*104*	*2.018*	*0.90*	*1.29*	*1.71*	*4*	*7*	*14*	*0.65*	*0.66*	*0.65*
Prosopis juliflora-Lantana camara scrubland	*115.4*	*955.4*	*298.6*	*1073.5*	*9.9*104*	*5.462*	*1.06*	*1.49*	*0.83*	*5*	*8*	*11*	*1.7*	*0.72*	*0.34*
Acacia-Grewia flavescens	*59.7*	*441.9*	*346.3*	*1779.4*	*8*104*	*1.798*	*1.18*	*1.94*	*2.43*	*4*	*12*	*17*	*0.85*	*0.78*	*0.85*
Acacic leucophloea-Zizyphus nummularia-Prosopis juliflora- scrubland	*24.8*	*127.4*	*60.16*	*2300.7*	*8*104*	*0.928*	*1.28*	*0.58*	*2.21*	*4*	*8*	*16*	*1.77*	*0.28*	*0.79*
Prosopis juliflora	*47.7*	*5.31*	*5.31*	*215.6*	*3.6*104*	*2.535*	*0.34*	*0.75*	*0.92*	*2*	*3*	*8*	*0.5*	*0.69*	*0.44*

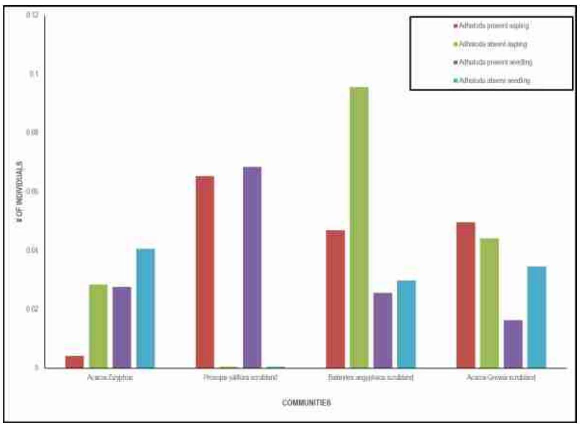

Figure 14.3 Seedling and sapling population for various communities under presence and absence of *Adhatoda*

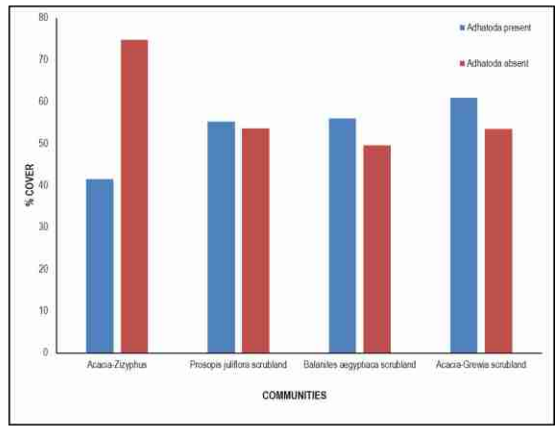

Figure 14.4 Grass cover in *Adhatoda* infested and non- infested communities

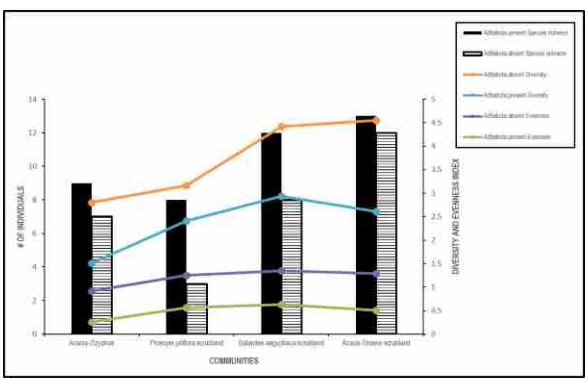

Figure 14.5 Variation in Richness, Evenness and Diversity for herbs in different plant communities plant communities

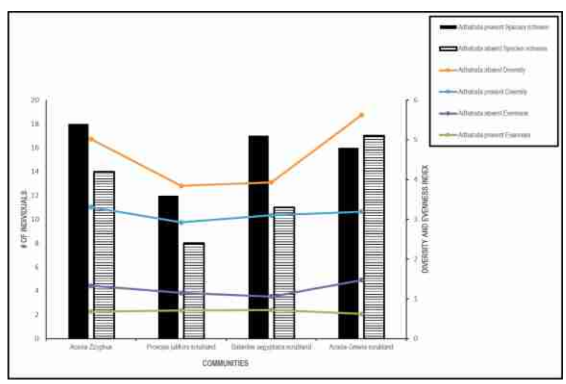

Figure 14.6 Variation in Richness, Evenness and indices diversity indices for shrubs in different

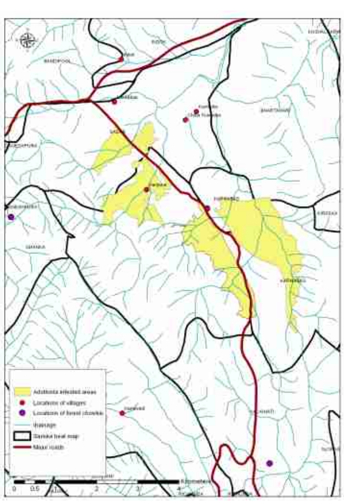

Figure 14.7 Extent of *A. vasica* invasion along the Sariska valley

Plate 14.1 *A. vasica* invasion in a *B. monosperma- A. catechu* woodland

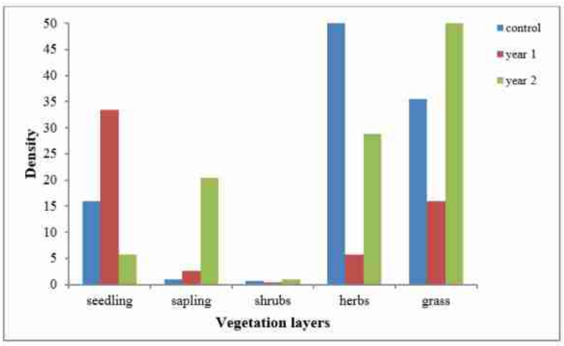

Figure 14.8 Observed densities for different vegetative layers

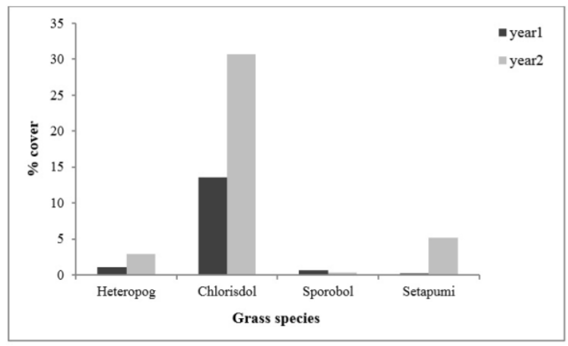

Figure 14.9 Changes in grass cover after removal of *Adhatoda vasica*

Within two years of removal the total seedling and sapling density at this site was found to be 57.32 ind/ha and 203.82 ind/ha. *Balanites aegyptiaca* was found to have highest seedling and sapling density among others (41.4 ind/ha and 178.34 ind/ha). In shrubs, *Adhatoda vasica* had maximum density (14941.18 ind/ha) and *Capparis decidua* had the minimum density (352.94 ind/ha). For herbs, *Dicliptera verticillata* (116666.8 ind/ha) had highest density. Species richness for herbs was found to be 12. Grass cover was found to be 52.58% at this site **(Figure 14.8 & 14.9)**.

Discussion

The savanna mosaic of Sariska was formed by interspersed layers of tree savanna and shrub savanna or scrubland savanna. Tree savanna was dominated by *Acacia leucophloea, Butea monosperma*, *Acacia catechu* and *Zizyphus mauritiana* interspersed throughout the landscape. The common grasses were *Chloris dolichostachya, Heteropogon contortus and Desmostachya bipinnata* which were approximately. 1-1.5 m high. These grasses also suppressed young seedlings by blocking sunlight reaching the ground but protected them from frost bite and grazing by herbivores such as spotted deer. *Grewia flavescens* and *Capparis sepiaria* were major shrubs found here.

Scrub savanna was characterized by presence of *Balanites aegyptiaca* and *Zizyphus nummularia* alongwith dominant grass species that were short in height including *Cynodon dactylon*, *Tragus roxburghii* and *Sporobolus coromandalianus*. The grass layer was low enough to allow penetration of sunlight for seedlings but provided no protection to seedlings from frost. Thickets of *Grewia flavescens, Capparis sepiaria, C. decidua, G. tenax, Ehretia laevis, Lantana camara, Adhatoda vasica, Prosopis juliflora* and *Dichrostachys cinerea* formed the savanna mosaic. Fodder for wild ungulates was majorly provided by shrubs such as *Grewia flavescens and Capparis sepiaria* and *Acacia* spp. *Capparis sepiaria* fulfilled fodder requirements during dry season when all other species had lost their green matter (Rodgers, 1990a). It was found that *Adhatoda vasica* was more prevalent in relatively moist areas. This implies that available soil moisture was used by perennial shrubs such as *A. vasica* and trees from the end of rainy season (September) until this water is depleted by the beginning of winter (November), when most of the annual plants disappear and the perennial plants begin to show certain adaptive changes. During remainder of the dry cold and hot seasons, a partial or absolute status quo is maintained in the soil moisture mainly in the open. Transpiration is eliminated by shedding of leaves. Leaflessness is a characteristic physiognomic feature of the Indian arid zone vegetation (Sen, 1973). There was a distinct seasonal behavior pattern among the ungulates and carnivore species in the landscape. During monsoon when water and food was abundant everywhere, the ungulates were observed at all places as opposed to winter and dry season when they formed aggregates and grouped near artificial and supplemented water resources.

The study reveals that manual removal of *Adhatoda* resulted in increased sapling density, shrub density and grass cover and decreased seedling density and herb density **(Figure 14.8 & 14.9).** Grass cover showed an inversely proportional relationship to seedling and herb density, one of the possible explanations could be the increased competition imposed on seedling and herb establishment by grass. Population regeneration for *Adhatoda vasica* indicated that mature individuals and seedlings decreased by uprooting within 1 year of removal and further decreased within 2 years of removal. Increase in individuals of middle aged category was observed over time. The absence of seedlings of tree species like *Butea monosperma, Zizyphus mauritiana, Acacia leucophloea* and *Acacia catechu* in the invaded areas showed that it inhibited their seedling growth. *Anogeissus pendula* was the lone species that was observed to produce seedlings within the invaded areas as it finds conducive shade ample environment under the thick canopy of *Adhatoda*.

Management recommendations

a. Management of grazing pressure: It would be desirable to keep grazing pressure by domestic livestock at low level so that palatable native grasses such as *Cynodon dactylon, Heteropogon contortus* and *Chloris dolichostachya* can regenerate. This could include spelling paddocks when seasonal conditions are appropriate and careful placement of watering points, fences and saltlicks. Dense regeneration of invasive native plants may be a symptom of changes associated with grazing management. "Total grazing pressure' should be considered as the effect not only of wild ungulates, but domestic stock as well.

b. Monitoring: Regular monitoring for invasion, early response and regular follow up would help in planning management action.

c. Managing VDC: The weeds can be removed by the village development committees (VDC) and put to ethno-medicinal use. Since *Adhatoda vasica* is known to possess wide spectrum of medicinal properties including positive effects on inflammatory diseases (Chakraborty and Brantner, 2001) therefore, it can be used as an alternate source of income generation by VDC's.

d. Supplementation: Removal of *Adhatoda* should be followed by external supplementation of grass species such as *Cynodon dactylon, Heteropogon contortus* and *Chloris dolichostachya* which may increase the chances of restoration of the area rather than increase of other suppressed opportunistic invasive species.

Acknowledgements

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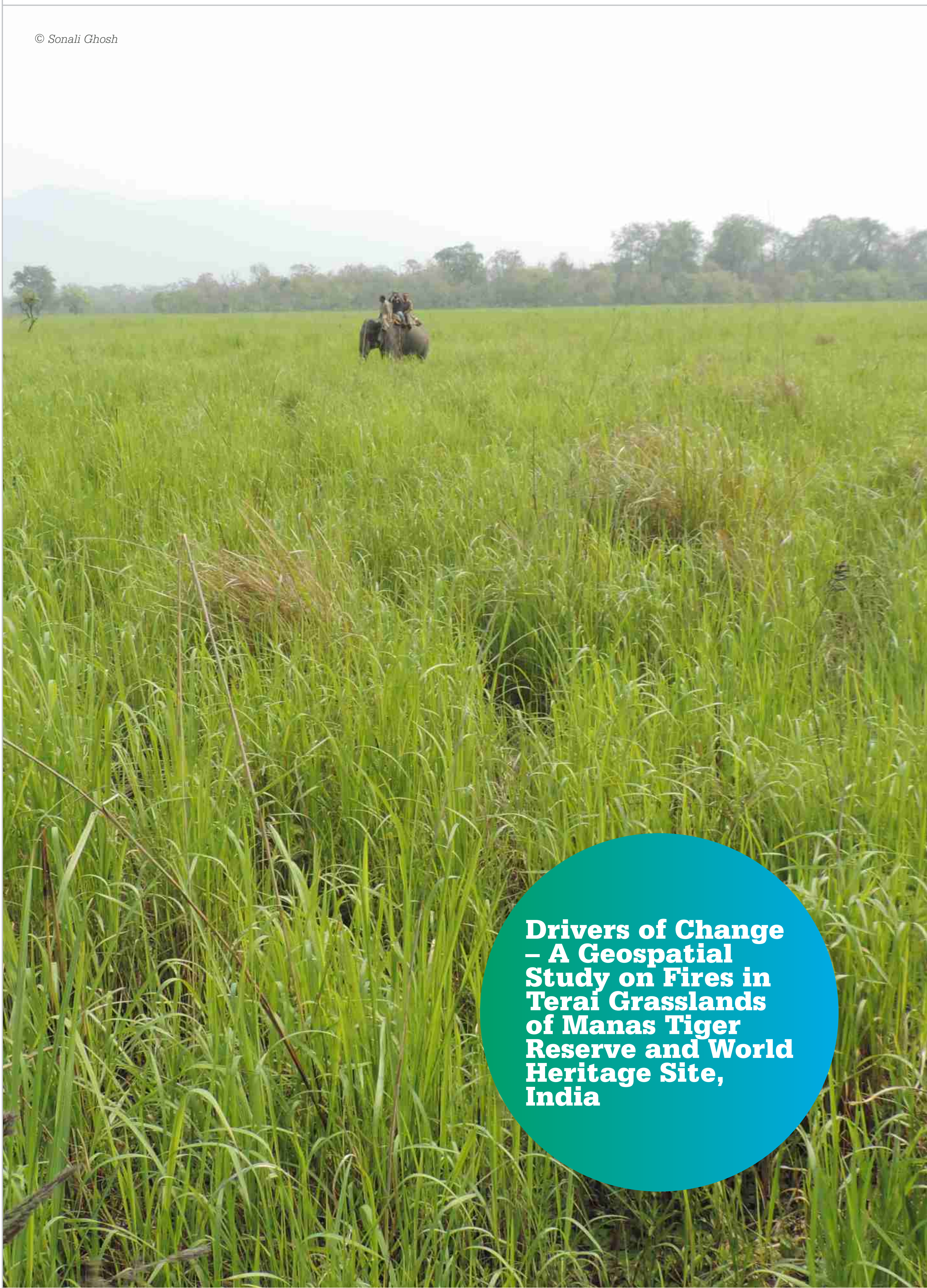

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Drivers of Change – A Geospatial Study on Fires in Terai Grasslands of Manas Tiger Reserve and World Heritage Site, India

Abstract

The Terai region in the Indian subcontinent is regulated by annual floods and fires which also result in a permanence of a seral stage dominated by tall grasslands. Most of these grassland fires are historically of anthropogenic origin and have resulted in an interesting pattern of fire adapted species of wild flora and fauna. The last remaining habitats of the Terai grasslands are today confined within Protected Areas such as Manas Tiger Reserve, Assam, where this study assessed the temporal and spatial patterns of fire using historical MODIS satellite data. Results indicated that fire was a major driver of landscape dynamics and change within the Terai grasslands. A high concentration (over 63%) of the total incidents of fire was recorded within the core area (National Park) of the Tiger Reserve between 2000-2012, whereas the highest occurrences were recorded between December and March in a given year. The impacts of these annual fires on grassland composition, animal species behavior and the overall management issues have been discussed in the paper.

Key Words: Brahmapurta; Grasslands; Kaziraga National Park; Landscape dynamics; World Heritage site

Introduction

The Terai grasslands located in the flood plains of Ganges and Brahmaputra adjacent to Himalayan foot-hills are among the most productive terrestrial ecosystems in the world. Characterized by flood and fire adapted tall grasses usually >2 m in height, these grasslands support very high biomass of grazing ungulates (Seidensticker et.al., 2010; Plate 15.1). In India, these grasslands extend through the provinces of Uttarakhand, Uttar Pradesh, parts of Bihar, West Bengal and Assam. The area is characterized by heavy rainfall (1800-4000 mm), clayey soil and swamp lands. These grasslands are home to globally endangered species such as greater one-honed rhinoceros (*Rhinoceros unicornis*), Asiatic wild buffalo (Bubalus bubalis), Indian bison or gaur (*Bos gaurus*) and the Asiatic elephant (*Elephas maximus*). Besides, several endemic species adapted to grassland habitats are found in these areas, viz., hispid hare (*Caprolagus hispidus*), pygmy hog (*Porcula salvania*) and the Bengal florican (*Houbaropsis bengalensis*). The apex predator of this ecosystems, i.e., tiger (*Panthera tigris*) is distributed all across these grasslands and some of the well managed protected areas under Terai grasslands in the region such as Kaziranga National Park are known to support the highest densities in the world (Karanth et.al, 2004; Ahmed et.al., 2010) in places such as, India.

Most of the Terai grasslands in India overlap with regions of high human population growth. As a result, the remaining natural grasslands are under heavy anthropogenic pressures leading to fragmentation and degradation. These grasslands have evolved under recurrent fire and flood since millennia (Dabadghao and Shankarnarayan, 1973). These authors have classified the Terai grassland as of the *Phragmites*- *Saccharum*- *Imperata* community type. *Phragmites karka* dominates in an undisturbed state. Persistent burning and harvesting exposes the typically wet soil to desiccation, with result that *Saccharum spontaneum* and *Imperata cylindrica* eventually dominate. It has been observed that continued burning and grazing of *Saccharum* and *Imperata*, leads to grassland dominated by *Imperata*. Eventually fire also facilitates woody succession by removing heavy litter accumulation (Lehmkuhl 1989, Sarma et.al., 2008). Thus, frequency, size and intensity of fires, in particular, are such that these regulate the entire floodplain savannah grassland ecosystem in the Indian subcontinent (Figure 15.1).

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Figure 15.1 The broad extent of Terai (floodplain) grasslands in the Indian subcontinent

Ecological studies on the impacts of fire on Terai grasslands and associated faunal communities are rather limited (Lehmkuhl 1989). Based on a comprehensive research in Nepal, Peet et al., (1997) concluded that graminoids represent resilient group of plants which recolonize after fire treatment, and the richness of plant species increases slightly after burning these grasslands. Burning of grasslands during the early dry-season (also termed as controlled burning) has been recognized as the optimal method to prevent more serious consequences by wildfire. Wildlife managers, use control burning for two main reasons: to manage the build-up of flammable fuel (live and dead vegetation), consequently reducing the impact and difficulty of suppression of wildfires, and to increase grazing lands for large herbivores in aid of the park's biodiversity and other environmental values. However, the evidence to support this is equivocal, and has shown varying results (Andersen et al., 2005).

Manas Tiger Reserve (MTR; 26°30'N to 26° 45' N latitudes and 89° 45' E to 92° 30' E longitudes), located in the districts of Kokrajhar, Chirang, Buxa and Udalguri in north-west Assam represents one of the prime grassland habitats in India. It forms a contiguous boundary with Royal Manas National Park of Bhutan in the north, while to the west, it is separated from the Buxa Tiger Reserve of West Bengal by the River Sankosh. The Reserve has a total area of 2837.31 sq km out of which 526.22 sq km is the core and 2310.88 sq km is buffer area respectively **(Figure 15.2)**. It reserve has a unique distinction of being a Natural World Heritage Site, a Tiger Reserve, an Elephant Reserve, Biosphere Reserve and Important Bird Area. Evolutionarily, it is the entry point of tigers into India and combined with Buxa-Nameri-Pakke-Namdapha TRs and Protected areas in Bhutan and Myanmar and forms the single largest tiger conservation landscape for tiger in the world (Sanderson et al., 2006).

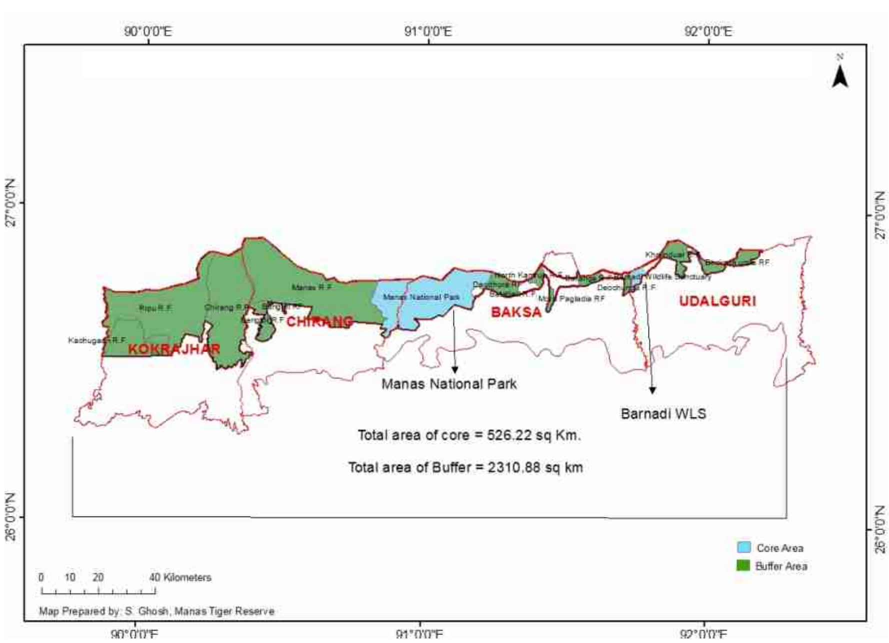


Figure 15.2 Map showing the extent of Manas Tiger Reserve in Assam, India.

According to Champion & Seth (1968), six subtypes of forests occur in the Reserve

- Sub-Himalayan light Alluvial semi-evergreen Forests
- Eastern Bhabhar type Sal (*Shorea robusta*) forest
- East Himalayan moist mixed and dry deciduous forests
- Low alluvial savannah woodlands
- Assam valley semi-evergreen forests
- Eastern wet alluvial grasslands (Terai Forests)

A total of 43 different grass species have been reported with a preponderance of species such as *Imperata cylindrica, Saccharum naranga, Phragmites karka* and *Arundo donax*. There is also a variety of tree and shrub species such as *Dillenia pentagyna* (which dominates the swamp forest), silk cotton Bombax ceiba (a dominant of the savanna woodland), *Phyllanthus emblica*, and shrub species of *Clerodendrum, Leea, Grewia, Premna, Mussaenda, Sonchus, Osbekia* and *Blumeria*. A wide variety of aquatic flora occur along river banks and in the numerous pools some 374 species of dicotyledons, including 89 trees, 139 species of monocotyledons including 43 species of grass, and 15 species of orchid have been identified from the core of the Reserve (Hajra and Jain 1976).

Broadly, the grasslands of MTR are divisible into two types: (i) Low alluvial savanna woodland and (ii) the semi-evergreen alluvial grassland. These are created and maintained by burning, and on a smaller scale, by flooding and grazing animals. The riparian grasslands are the best tiger habitat and also well suited to the Asiatic water buffalo, gaur, swamp deer, elephant and waterbirds (Ghosh 2009). Since both types of grasslands exhibit differential response to fire and other factors, it was pertinent to investigate the dynamics of vegetation at a landscape level. Therefore a study was conducted during 2010 -2013 (Ghosh, 2013) with the following questions in mind:

- How are fires, spatially dispersed within MTR? Are there any areas of high intensity and what causes these?
- What are the spatial and temporal patterns in fires and in what way can they be studied using RS data?
- How does fire influence landscape dynamics and vice versa. Do fires get impacted by anthropogenic sources such as proximity to roads and settlements?

This paper deals with the broad findings based on rapid assessment of grassland habitats using combination of field investigation and remote sensing tools.

Material and Methods

Obtaining the Fire data

Initially, the spatial and temporal patterns of fires within MTR were analyzed over a period of 12 years (Figure 15.3). MODIS active fire data between 2000 to 2012 was downloaded from FIRMS at their website, http://earthdata.nasa.gov/data/near-real-time-data/firms. The dataset downloaded comprised of daily fire observations acquired from the Aqua and Terra satellites. Each overpasses the study area a total of four times daily. Each fire point contained information on the exact time and day of detection, a global georeference system location (longitude, latitude), the brightness of the fire and classified confidence level.

Methods of fire analysis

Temporal patterns -Temporal changes in fire frequency were investigated on a monthly and yearly basis for dry seasons (October-May) from 2000 to 2012. Monthly changes were studied for each season as well as for the twelve seasons combined. For correlations with landcover, the total incidence of fire during the study period was extracted for the four types of landcover (Dense Forest, Open Forest, Grasslands and Wetlands) described above, and fire density calculated as the number of fires per km^2 of the total land cover area. Fire occurrence and density in each land cover type were also obtained for three distinct periods of the dry season viz. early (October–December); mid (January–February), and late (March–May).

Spatial patterns- The effect of distance from roads, rivers, campsites as surrogates of anthropogenic influences within MTR (and therefore increasing the probability of ignition), were used to correlate with fire distribution. Using these line and point vector layers, the minimum distance from a line/ point buffer to the nearest fire point was calculated using ARC GIS software. To investigate the relationship between fire occurrence and distance from each geographical feature, multiple ring buffers (at every 500 m) around each point and line vector layer (Road, water body, settlements and forest camps) was created and the fire frequency counted for each interval to obtain a set of response and explanatory variables; fire frequency and distance, respectively. Each fire point was measured from closest point of line geographical features in meters. The dataset was then analyzed by regression, using a simple linear Regression model. The statistical software MINITAB 15 and MS Excel was used for the analysis.

Fire in relation to bioclimatic variables- To investigate whether rainfall and annual temperature was a factor in predicting fires, the mean annual temperature and mean annual precipitation was obtained from Worldclim that provided free global climate data on a spatial domain (http://www.worldclim.org/bioclim; Hijmans et.al., 2005). The data is provided under BIOCLIM model and has been generated through interpolation of average monthly climate data between 1960-90 periods from global weather stations on a 30 arc-second resolution grid (1 km^2 pixel resolution). Variables included are monthly total precipitation, and monthly mean, minimum and maximum temperature, and 19 derived bioclimatic variables.

Detecting fire intensive areas- To identify areas within MTR that have a high concentration of fire occurrence and evaluate fire distribution patterns at a landscape level, all active fire data were combined together into one layer and converted into a raster dataset for density analysis using a kernel density estimation tool in Arc GIS. Spatial distribution of the fire points collected during all eleven years were modelled as density "kernel" functions which weights frequency of location based on 2-dimensional Gaussian distribution, with the density represented as contour plots on a surface.

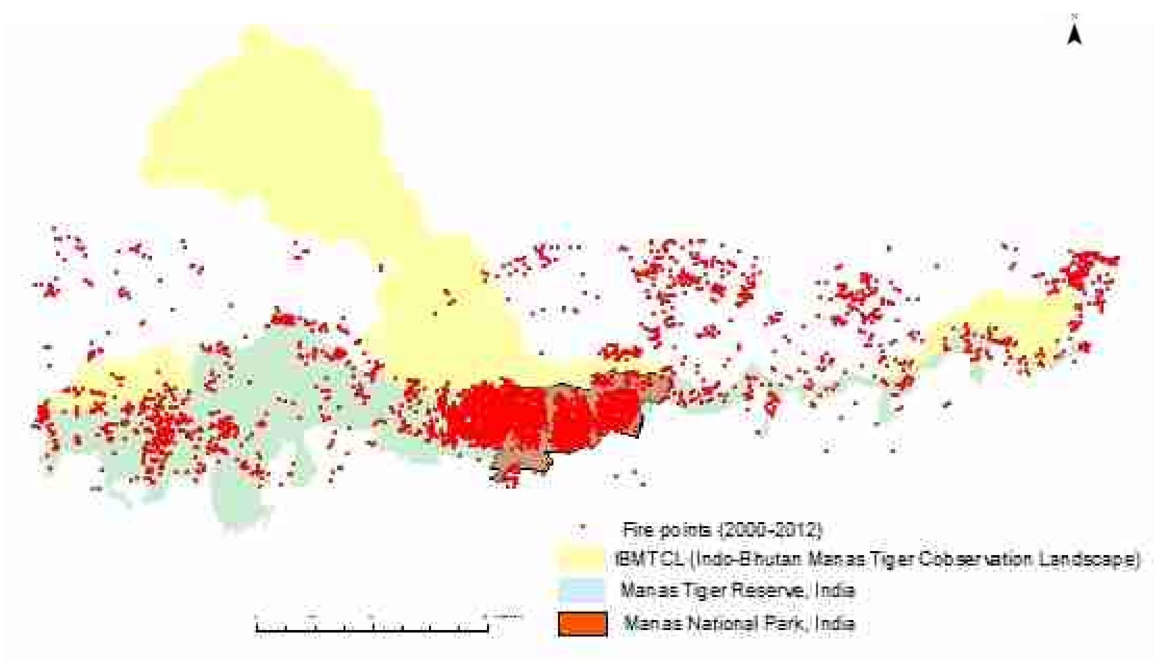


Figure 15.3 Spatial distribution of fires as detected by MODIS between Nov 2000-June 2012.

Results

A total of 2751 fire incidents at 1 km^2 pixel resolution were detected by MODIS in MTR from December 2000 to August 2012 **(Figure 15.4)** . Out of these, 1749 fires (63.57% of the total fires) were within Manas National Park. Almost no fire was detected during the very wet season that ranged from June to September. 71 % of total fires occurred during the mid (January-March) burning season, whereas the late (April-September) burning season accounted for only 2% of the total fires. The highest fire incidents were in the month of March and there was a significant correlation between fire occurrence and distance from roads in MTR. For MNP, Three distinct intensively burnt areas were identified that corresponded with grasslands and wetlands in the MNP.

Temporal patterns of fires

The total yearly number of fires recorded within the MTR increased substantially from around 5 at the start of the study period (Dec 2000) to over 300 in 2004 **(Figure 15.5)**. There was a large inter-annual variation in monthly patterns of fire occurrence; the highest recorded in 2011 (394) during which highest monthly fires were recorded in December (102). The patterns clearly indicated that 2002, 2004 and 2011 were exceptionally dry years when high incidents of fires were recorded. The transitional period before and after the monsoon season (the first and the last two months of the-dry season) experienced fewer fires. The common pattern of fire occurrence was a distinct increase from December to January after a low during October-November, with the number of fires declining after February and dropping even further from April to May. December-March had the highest frequencies of fire and accounted for bulk of the fire occurrences.

Fires also have a strong correlation to land cover as is evident from **(Figure 15.5)**. The temporal distribution of fires expressed as proportions of fire frequencies during the early, mid- and late periods varied greatly among the land cover types. For example, fire frequency in wetlands and grasslands was highest in the mid- season (Jan-Feb), whereas in case of dense forest and open forest it was the late and early burning season respectively **(Figure 15.6 & 15.7)**. The likely explanation for this is that the grasses growing in water bodies and the grasslands region mature and reach senescence possibly between January and February. The open forest areas are covered with scrub which is likely to be intentionally burnt at the onset of the winter season by cattle graziers to provide fresh fodder to livestock during the lean and dry period. The dense forests are semi-evergreen and hence are prone to fires only when there are excessive dry conditions during the late burning season.

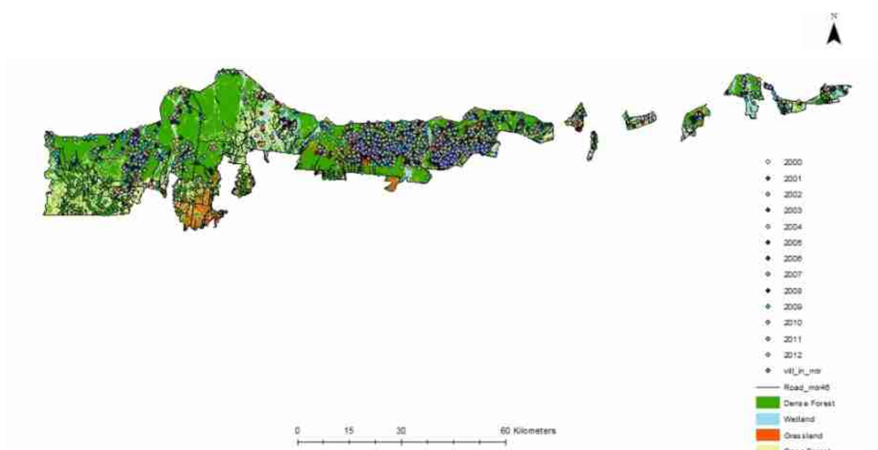


Figure 15.4 Temporal distriution of Fires as detected by MODIS between Nov 2000-June 2012

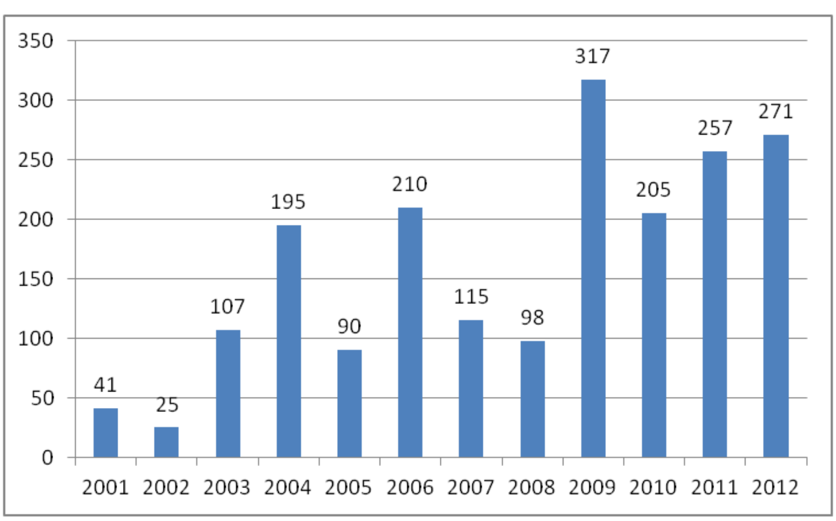


Figure 15.5 Annual Fires in relation to land cover in Manas Tiger Reserve

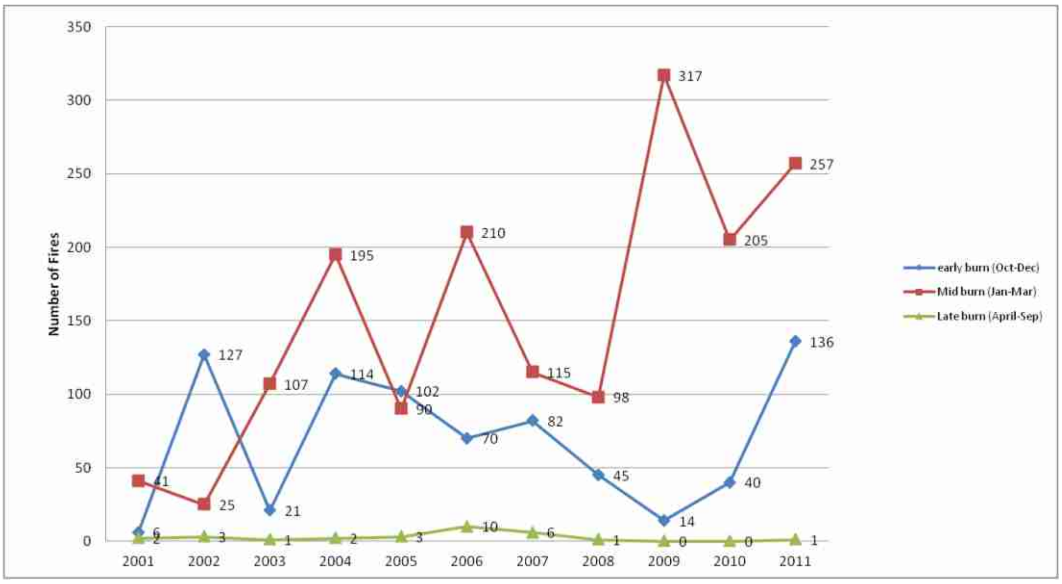
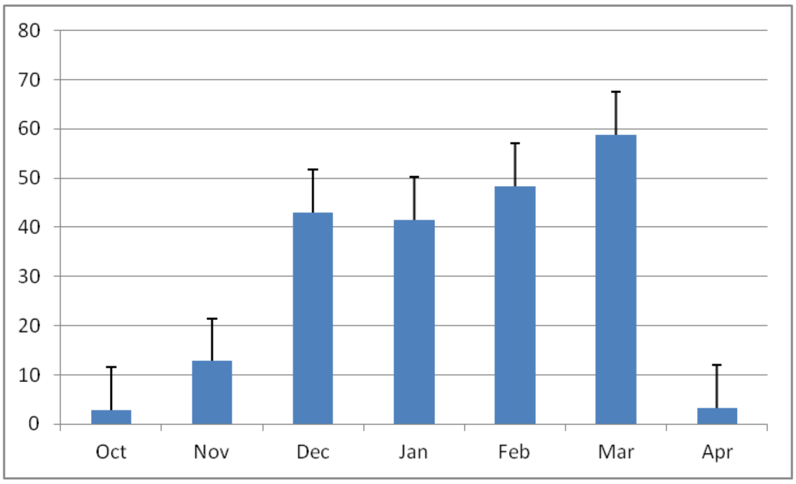


Figure 15.6 Temporal patterns of early, mid and late fires within Manas Tiger Reserve



	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Mean	2.92	12.77	42.92	41.46	48.38	58.69	3.31
SE	0.99	3.99	10.74	8.31	10.45	18.47	2.21

Figure 15.7 Mean and (1 standard error) of monthly fire records in MTR from 2000 to 2012.

More than half of the total land area in the MTR is covered with closed canopy dense forest and they reported the highest incidents of fire (42%) but the lowest density of fire at 0.64/ km^2. Whereas, grasslands occupied only 15.05% of the total area but accounted for the highest density of fires (at 5.13/km^2) even wetlands had highest density of fires compared to dense forests indicating the presence of dry and combustible grassland areas in the river islands. Open forests also had high incidents of fires clearly indicating the anthropogenic influence of fire origins. There was also a difference in the number of fires reported per month in each land-cover type. The means of fires reported varied as 8.7 ± 4.25 fires per month in dense forests, but was more regular in grasslands, open forest and wetlands. Overall, highest incidents of fires were in the month of March making it a critical period for fire-protection.

Spatial patterns of Fire

Fires were greatly influenced by distance from anthropogenic influences within the Tiger Reserve. There were statistically significant ($p<0.05$) correlations between fires and distances to some of the geological features. The closest fit between the observed and predicted fire frequencies was found for the fire- road and wetland-fire datasets .

Fires were inversely correlated with roads and waterbodies and the highest frequency was detected within one km of the variable. Roads are known to be a major cause of wildlife incidents worldwide and the prime reason for this is the human presence and the accidental/ deliberate firing of dry areas in the vicinity for utility purposes.

In case of waterbodies, the river islands and sand banks support grasslands of fodder value and it is likely that they are also burnt for livestock in the winter season. No significant relationship was found between fires and villages although the trend line indicates that, large uncontrolled fires are often encouraged within 5-10 kms of a village. This way, the free ranging livestock is able to easily access new fodder and yet be confined as when required.

Fire incidents were reduced closest to the vigilance camps put up by the forest department. However, they increased with distance from camps before gradually declining in areas where possibly there was no human presence (Figure 15.8).

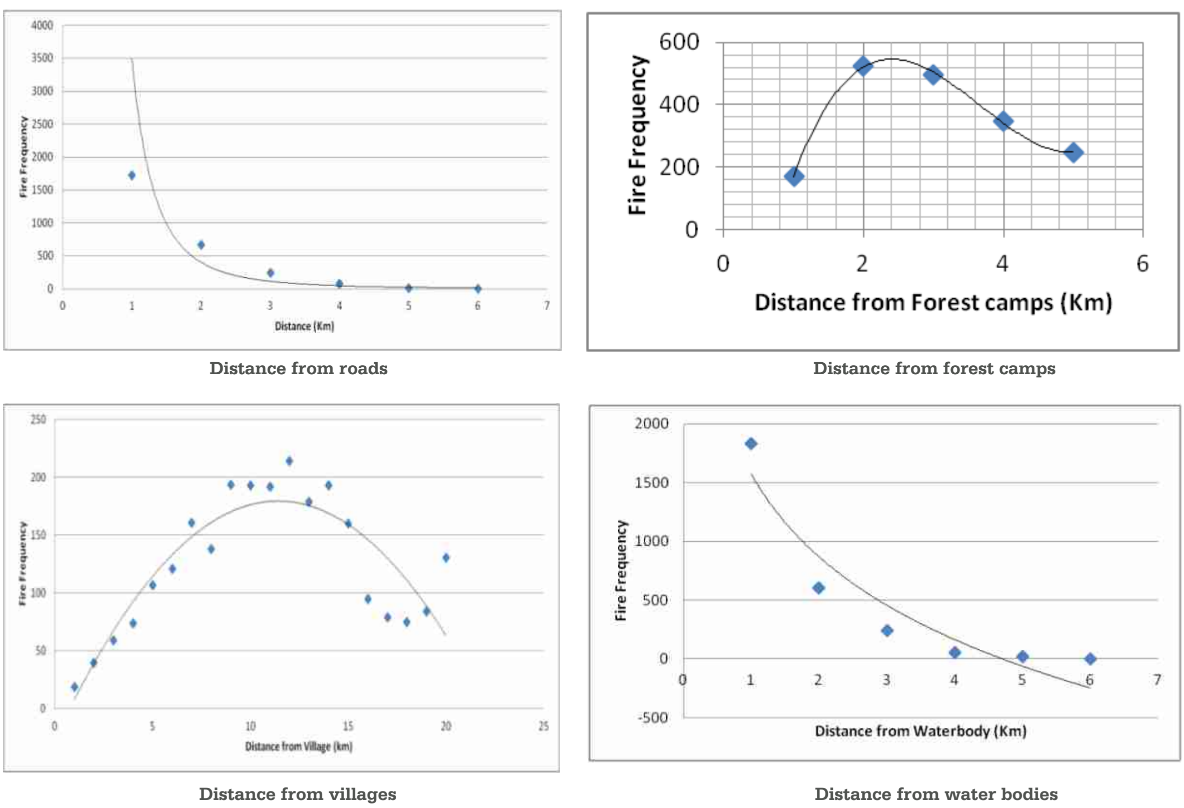


Figure 8 Spatial Distribution of fires with respect to anthropogenic variables in Manas Tiger Reserve

Fire in relation to Bioclimatic variables

The mean annual temperature in the fire areas was found to be in the range of 23.6 - 24.5 degree Celsius. Highest number of fires was recorded at 24.3 degrees although no statistical correlation could be established.

The mean annual rainfall in the fire areas was found to be between 3003 - 3485 mm. The number of fires were highest at 3251 mm, although again no statistically significant relationship could be found. The average rainfall of the area in the past 8 years indicates that excessive dry conditions do influence higher incidents of fire in the park. For example, the highest incidents of fires ($N=271$) was recorded for 2011 which was also comparatively a dry year (<2675 mm).

Detecting Fire intensive areas

The fire density map **(Figure 9)** for MTR indicates that fire locations were not evenly or randomly distributed throughout the Reserve. In fact, fire was concentrated (over 63%) within MNP where four distinct areas of heavy burning could be located. The largest concentration was located along the western part of the park under Panbari range, while the others were spread across the grasslands along Manas-Beki rivers and low lying grassland areas of Bansbari and Bhuyanpara ranges. Almost all the forest fragments on the eastern side of the Reserve in Barnadi Wildlife Sanctuary, Dhansiri and Udalguri forest divisions were influenced by medium occurrences of fire. Incidents of fire along the Bhutan border in Kachugaon and Haltugaon forest divisions were also low as these were largely covered with dry deciduous and semi-evergreen forest types. Such high concentration of fire within 300 sq km of the reserve clearly indicates the impact of fire on regulating the landscape dynamics.

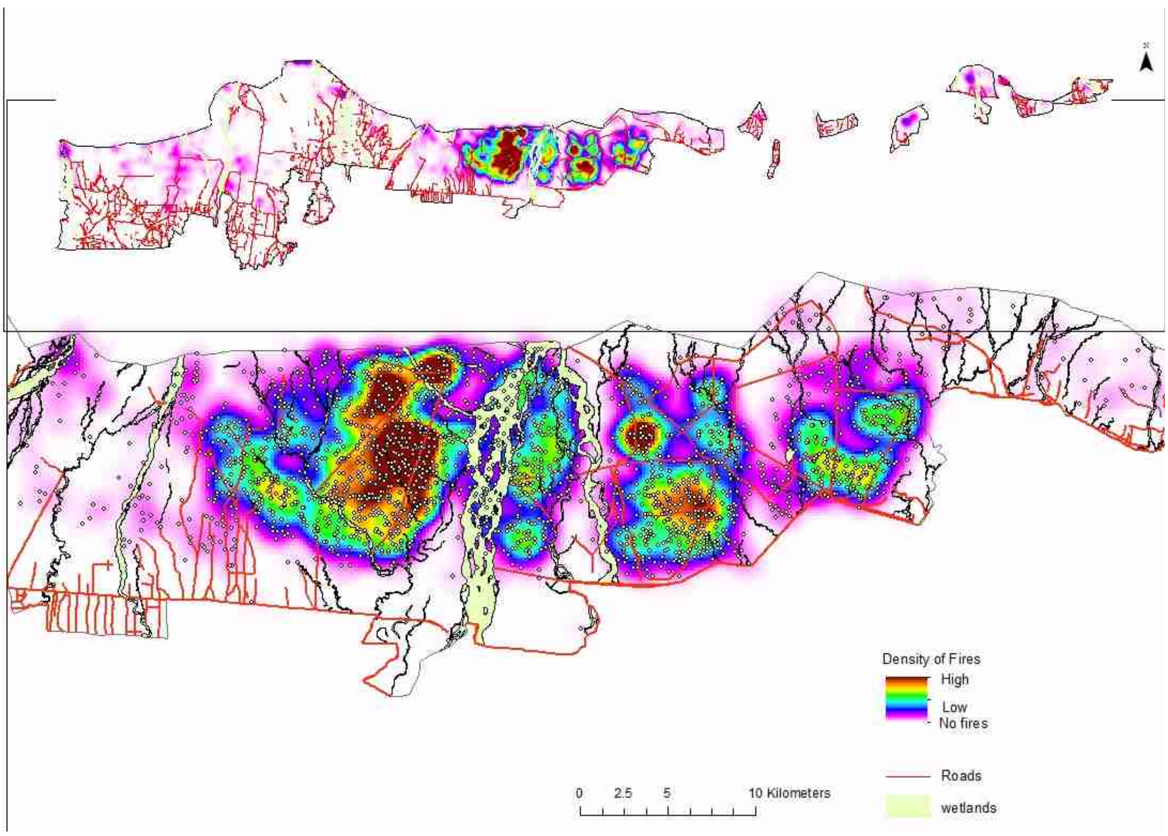


Figure 15.9 Density of fire occurrence in MTR during 2000-2012

Discussion

Although active fire data from MODIS has been claimed as a 'snap-shot measurement, it is a practical tool that can be used to identify areas at risk of fires by giving park managers information about where uncontrolled burning takes place.

There are however a few limitation of remote sensing for fire detection in the tropics, as it was observed during this study. The major issue is in the use of derived products and the associated incidence of omission errors (Eva and Lambin 1998). Oversight of fires can be likely if the duration of a fire was shorter than six hours, since fire observations are made four times a day from the Terra AM (10:30 and 22:30). Similarly, small scale (< 500 m^2) fires as in the case of shifting cultivation may not be detected or flagged by the coarse resolution of the MODIS sensor (Roy and Behera, 2005). *Jhum* or shifting cultivation is prominent and quite common in the Bhutan forest areas; however they were not detected in the present study. In a survey to test fire detectability by MODIS, Jin et al., (2003) recorded twice as many fires on the ground as were registered by MODIS. Whether this is the case for the data gathered for the Manas National Park (MNP) will need to be established.

Another major limitation in the study was the lack of information on the size of fire-affected areas essential to estimate fire impact on vegetation or landscape changes. This would have ultimately effected the animal movement and some supplemental research has been undertaken through the detection of burn scars using higher resolution radiometers, such as AVHRR and ASTER (Eva & Lambin 1998). Despite this limitation, MODIS active fire data has been most useful in identifying temporal patterns of burning in the MTR, and for detecting seasonal and yearly variation in the number of fires.

Landscapes in the MTR were classified broadly for this analysis, as more refined analyses of variation within habitats (e.g. different grasslands classified by height or composition) was not possible. However, results from this study clearly showed that most fires occurred in grassland areas. Moreover, distance analyses reveal that most fires occurred closest to roads, and waterbodies. Yearly changes in the number of fires in the Reserve indicated that a significantly higher number of fires were recorded during 2002-2003. Before this period (since 1989), the park was inaccessible to local people due to political insurgency. On the other hand, because the fire records used in this study could not discriminate between controlled and uncontrolled burning, it is also possible to assume that the increase in fires reflects the use of prescribed fires started by park staff. The detection of illegal burning within the park would be possible, only if records of prearranged fires (including time and exact location) were kept by park staff, to contrast with data supplied by MODIS.

Conclusion

The present study clearly indicates that fire is a major driver of landscape dynamics and change within Terai grasslands. Their high concentration (over 63%) as in case of a small core area of 500 sq. km in Manas National Park also indicates the co- evolution of fire-climax vegetation types that are periodically regulated by fires on an annual basis. This fire-climax vegetation mainly comprises of tall and short grasslands associations as have been reported by field studies earlier (Lahkar, 2008). Such tall and short grasslands are true representative of the Terai region and have been mostly converted to agriculture elsewhere. It is only in Protected Areas that they are able to exist as patchy fragments albeit in a natural state, and hence of high conservation value. These grasslands are regulated by fires in the dry season and floods during the wet season thereby making them highly productive throughout the year. This also attracts a large number of herbivore prey that in turn supports large carnivores such as tigers. Therefore protection and management of such fire-intensive areas will be critical for survival of tigers and other large carnivores in the area.

The highest occurrences of fires were recorded between December and March indicating this being the crucial season for fire management. Fires were triggered by anthropogenic sources such as roads and they are in all likelihood for deliberate reasons such as improved access and for grazing by livestock. Fires also occur in the wetland areas indicating the seasonal nature of these water bodies. A very dry season combined with draught can perhaps lead to water scarcity and therefore suggests the need to build and manage permanent waterholes in areas where highest number of fires are periodically recorded. In areas outside the National Park, fires are also along roads and in the vicinity of human settlements. Law enforcement and vigilance during the fire season has found to be very effective in controlling accidental fires and it is in this case that remote sensing can aid in forest protection measures.

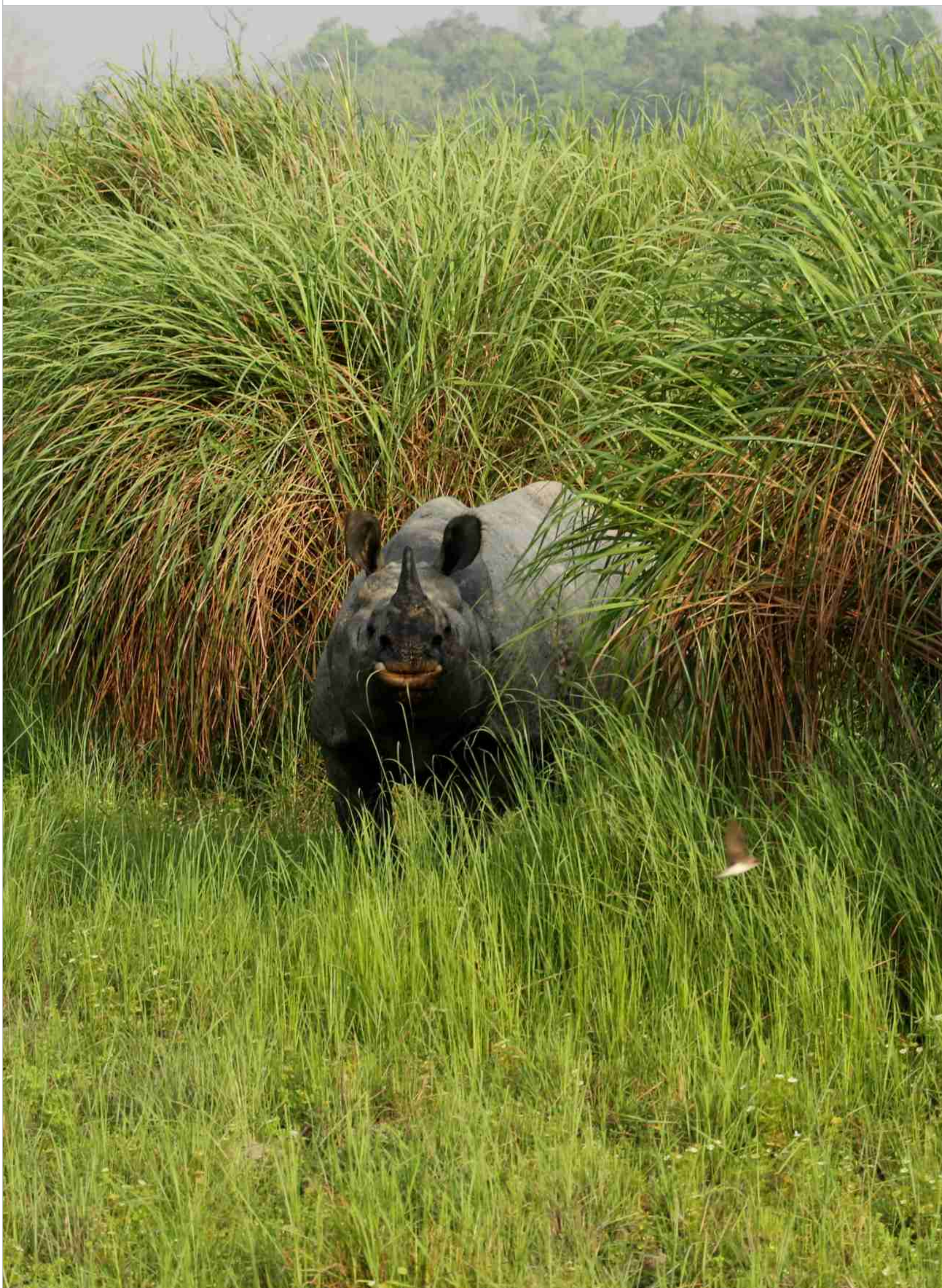


Plate 15.1 A Rhino in the *Saccharum* grassland © Karma C. Bhutia

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Extent and Status of Semi-arid Savanna Grasslands in Peninsular India

Abstract

The semi-arid savanna grasslands (SSG) of peninsular India are important habitats with a unique assemblage of endemic species. They are also critical to millions of pastoralists and agro-pastoralists for whom these are the major grazing areas for their livestock. Yet, the forest-centric bias towards vegetation classification in India has failed to properly recognise this biome, and as a result, it has been neglected and subject to large-scale landuse change. Most efforts at mapping the extent of this biome using remote sensing data have tended to underestimate the extent due to difficulties in differentiating between grass cover and dryland agriculture. We used a novel approach of using multi-date MODIS NDVI data and an unsupervised classification to create a probabilistic output of SSG occurrence. We also used ancillary data to predict occurrence of SSG using NDVI and Bioclimatic layers with a regression tree rule-set classification, which identifies the bioclimatic envelope of SSG, and the predicted extent. To determine the current protection status of SSG, we conducted a GAP analysis with the current protected area network. The results show that the SSG biome is primarily spread over eleven states of India with 1.2 to 9.1% coverage of the geographic area for the high probability of SSG occurrence class. However, the overall protection status of SSG in these states is low, with only 0.1 to 8.7% under the PA network. The states with the highest area of SSG include Maharashtra, Gujarat and Rajasthan. To conserve and manage the last remaining areas of SSG in the country, we suggest a sentinel landscape approach, with a systematic conservation prioritisation exercise combining both biodiversity value as well as human-use to ensure a sustainable and equitable use of these threatened ecosystems.

Keywords: Threatened biome; Obligate species; Endemic species; Spatial extent; Remote sensing; MODIS NDVI; Regression tree classification

Introduction

Savannas, classically defined as systems with a continuous understorey of grasses, and a discontinuous upper storey of trees (Scholes and Archer, 1997), are the second most widespread biome on Earth. They cover approximately 20% of the Earth's surface area, and support a large proportion of the human population, livestock biomass, and the highest densities and diversity of wild herbivores and carnivores in the world (Sankaran and Ratnam, 2013). Although the term savanna evokes an imagery of vast open grasslands with scattered trees, the actual tree cover can be highly variable, ranging from the "classic" savanna grassland to heavily wooded "forest-like" systems (Ratnam et al., 2011).

In India, semi-arid savannas have traditionally been considered as a "degraded" state of tropical dry forests e.g. Misra (1983); Pandey and Singh (1992), developed and maintained due to anthropogenic activities such as deforestation, grazing, fire and other disturbances (Misra 1983; Pandey and Singh 1991). Most of the earlier vegetation and biogeographic classifications of Indian biomes do not recognise savannas as a distinct biome. Indeed, most widely accepted work on the classification of Indian vegetation have included woodlands and grassland savannas either under tropical dry forests or as tropical scrub and thorn forests (Champion and Seth, 1968; Dabadghao and Shankarnarayan, 1973; Shankarnarayan, 1977). For example, Champion and Seth (1968) classify the savanna grasslands of the Deccan plateau as Southern Tropical Thorn Forests. Blasco et al. (Blasco et al., 1996) categorise the vegetation falling in the semi-arid zone as either thickets, mosaic of thicket savannas, and tall and shrub savannas. Yet, large areas of peninsular India are within the global bioclimatic envelope for tropical savanna grasslands (White et al., 2000). According to the Pilot Analysis of Global Ecosystems – Grasslands, 17% of India's land mass is classified as having grasslands (White et al., 2000). This seeming disconnect in reconciling India's savanna vegetation types to global patterns of savanna distribution can be attributed to historical colonial roots in forestry, silviculture and timber extraction (Ratnam et al., 2011).

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Dabadghao and Shankarnarayan (1973), in their comprehensive survey of grass resources of India recognise two "types of grass covers" that correspond to what we may describe as semi-arid savanna grasslands: The *Sehima-Dichanthium* Type of peninsular India, including the Central Indian plateau, the Chhota Nagpur plateau and the Aravalli ranges potentially covering 174,000 km^2 and; the *Dichantium-Cenchrus-Lasiurus* type spread over the arid and semi-arid regions of Rajasthan, Gujarat, western Uttar Pradesh, Delhi and Punjab covering an area of approximately 436,000 km^2.

The semi-arid savanna grasslands (SSG) of peninsular India not only support a vast proportion of India's agro-pastoralist community, but are also home to several obligate grassland species, many of which are threatened or endangered. Unfortunately, the remaining SSG have not received the level of attention from conservationists or policy makers that is necessary (Rodgers et al., 2002; Singh et al., 2006), resulting in a lack of protection for both the livelihood dependent pastoralists as well as endangered and endemic wildlife which occupy this habitat (Vanak et al., 2008; Vanak and Gompper 2010). Government policy officially declares much of these grasslands, scrub and thorn forests as 'waste' or 'unproductive land' (http://dolr.nic.in/wasteland.htm). For example, in one of the largest Indian states, Maharashtra, over 15% of the state's land area of scrub, grassland and grazing land is categorized as "wasteland".

The categorizations of semi-arid savannas as wastelands, and the subsequent lack of adequate protection have resulted in this biome facing the greatest anthropogenic threat - from overgrazing, conversion to irrigated agriculture, industrialisation, urbanisation, forestry plantations, soil and water conservation measures (check dams, contour trenching) and most recently, bio-fuel plantations, solar and wind farms. Because of the historical bias towards forested areas, most vegetation maps of India continue to misclassify SSG as scrub or thorn forest, or as degraded pastureland (Roy et al., 2015). There is thus, little work done on describing the spatial distribution of SSG in India and their current status.

Mapping the distribution of SSG in India with traditional remote sensing techniques that use single types of data and supervised or unsupervised classification is challenging for several reasons, viz. the lack of habitat homogeneity due to intensive human utilisation; spectral mismatching between "natural" and derived savanna grasslands as a result of deforestation, extensive grazing and burning; and, spectral mismatch between grasslands and regenerating fallow lands in agricultural matrices. In this study we use a novel multi-method classification scheme for detecting and mapping SSG in peninsular India. Using these maps, we then ascertain the current conservation status of these areas with a GAP analysis of the protected area network for conservation of this biome. Finally, we define a framework for conservation and monitoring of SSG using a network of sentinel sites that represent both the faunal and floral diversity as well as traditional forms of landuse.

Methods

Study Area

The study area for analysis was the Indian region that is climatically classified under a 'Hot-Arid-Steppe type' and 'Tropical-Savanna type' climate, as per the Köppen-Geiger climate classification of Peel et al.,(2007). The floristic affinities of this mapping area lie in the *Sehima-Dichanthium* and the *Dichantium-Cenchrus-Lasiurus* type of grasslands (Dabadghao and Shankarnarayan, 1973).

Data and Analysis

Unsupervised classification of MODIS data

Moderate Resolution Imaging Spectrometer (MODIS) data for the year 2011 (cloudless months-Jan, Feb, Mar, Apr, May, Nov, Dec) were downloaded from the Glovis website (http://glovis.usgs.gov/). Previous studies indicate that MODIS Normalised Difference Vegetation Index (NDVI) data can be used not just to detect grasslands, but also assess the phenology and forage quantity and quality (Kawamura et al., 2005). Eight different tiles of MODIS NDVI data covered the whole of India. Use of NDVI data was integral to estimate the total production, and the difference between the maximum and minimum NDVI as a measure of seasonality. Unsupervised classification on individual tiles using ISODATA algorithm (ERDAS Imagine 10) was performed to classify areas that had a high probability of falling in the SSG classification. Because MODIS data is at a relatively coarse scale, and there is a chance for spectral mismatching, we also created a second class that had a lower probability of being in the SSG zone. The validation of the result of unsupervised classification was done with ground truthed points available from secondary sources (Vanak et al., 2008) and field surveys. The result of this process was a grassland occurrence probability map covering the whole of peninsular India.

Rule-based classification using regression tree

The sole use of spectral information contained within remote sensing data can have its disadvantages, especially in classification accuracy (Lawrence and Wright, 2001). Use of ancillary data along with spectral information from remote sensing has proven to be effective in distinguishing between different land cover classes (Jensen 1996). To incorporate these ancillary data, we used a classification and regression tree approach in this study. We combined 18 Bioclim variables (http://www.worldclim.org/bioclim) with monthly NDVI values from December 2010 to April 2011 (MODIS 16 day 250m, Source: GLOVIS), elevation (DEM), rainfall and potential evapo-transpiration (PET) in a regression based classification tree. The rules were obtained by using recursive partitioning and regression trees (Breiman et al. 1984). The (rpart) package of R statistical software was used. Land-type was the response variable and consisted of three categories: grassland, irrigated crop and seasonal crop. A total of 301 data points were used. The resultant map shows areas that fall under the bioclimatic envelope for SSG in India. We excluded the high-altitude deserts of the trans-Himalaya for the purpose of this analysis.

Field survey for fine scale mapping

Large contiguous networks of SSG were identified using MODIS probability maps. Random points across the high probability grassland areas were generated for field ground truthing. Field surveys were carried out in 54 districts of the four states. A total of 14,485 kilometres of road survey effort and >100 km of foot survey effort yielded >500 ground control points of various classes.

Results

Using the difference in NDVI over the months (Figure 16.1) allowed us to determine the seasonal changes in biomass production and create signatures that differentiated SSG from dryland agricultural areas. The use of MODIS NDVI data (unsupervised classification) produced maps with high and low probability of grassland occurrence. The map covering the entire country had a user's accuracy of 85% and producer's accuracy of 65% (Figure 16.2). A state wise analysis of the area under these two classes in twelve states shows an average of 4.7% (range 1.2 – 9.1%) under the high probability of occurrence class and 9.1% (range 1.6 – 21.9%) area under low probability of occurrence (Table 16.1). The states of Maharashtra, Gujarat and Madhya Pradesh had the largest extent of SSG occurrence.

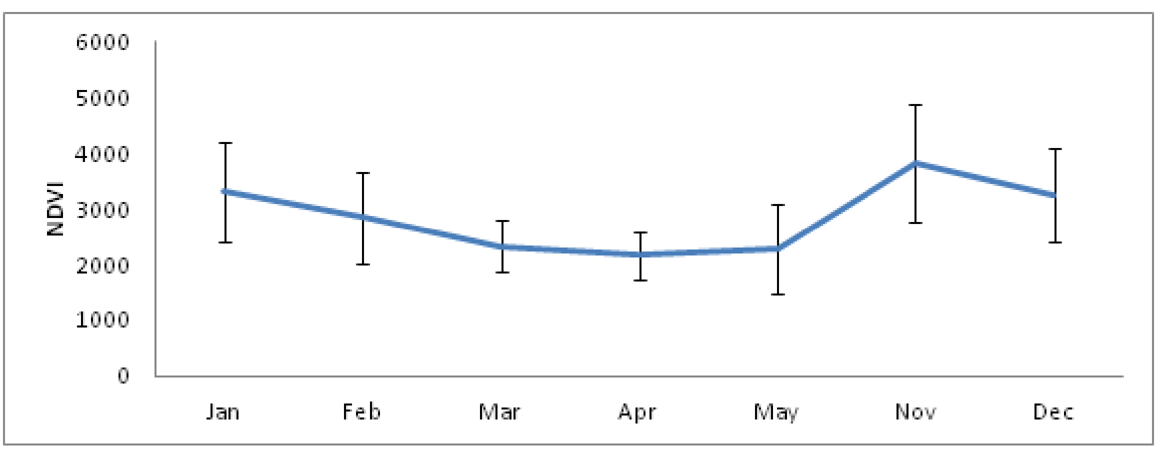
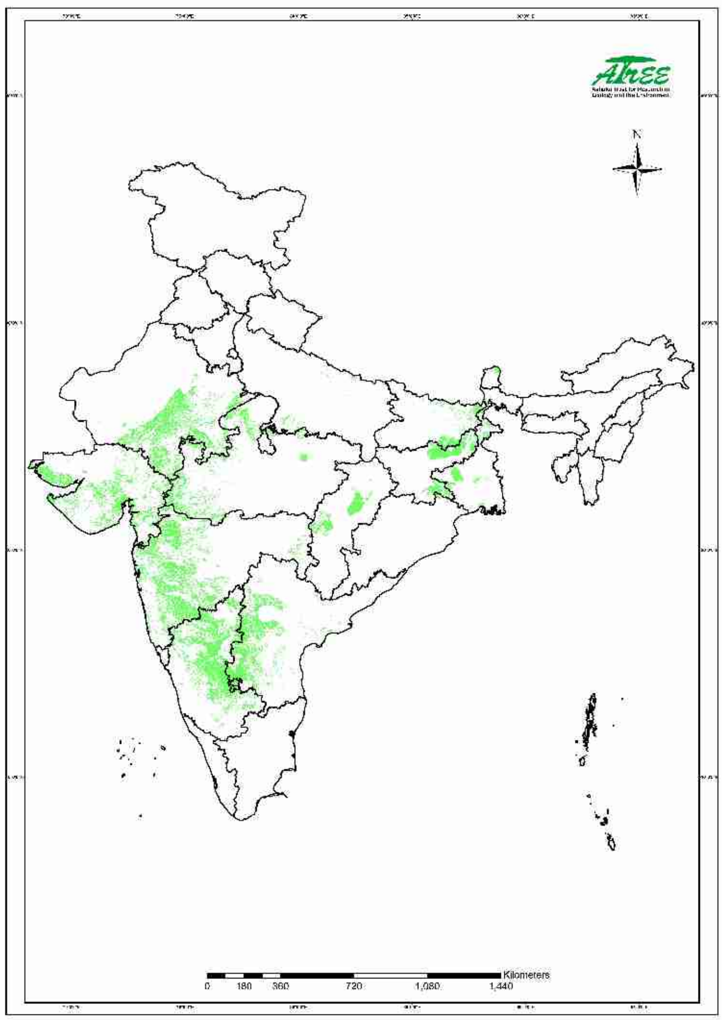


Figure 16.1 Seasonal trends in NDVI values of SSG sites across Peninsular India (Error bars are ±SD)

A GAP analysis of protected area coverage of the savanna grassland map derived from the MODIS NDVI classification revealed that only an average of 2.7% (range 0.1 – 8.7) of SSG are covered under the PA network of eleven states where they primarily occur (Table 16.2). The states that had the maximum area of SSG under the PA network included Gujarat, Rajasthan and Uttar Pradesh.



Grassland prediction areas

Table 16.1. Area of Savanna grasslands in each state from MODIS NDVI classification

Name of the State	Area of the State (sq. km)	Area under high probability of grassland occurrence (km^2) (% of total area of the State)	Area under low probability of grassland occurrence (km^2) (% of total area of the State)
Andhra Pradesh (Unified)	268748	10233 (3.8)	17832 (6.6)
Chhattisgarh	130380	6336 (4.9)	17620 (13.5)
Gujarat	179482	16327 (9.1)	10652 (5.9)
Jharkhand	76714	6280 (8.2)	16860 (22.0)
Karnataka	189349	10996(5.8)	16213 (8.6)
Madhya pradesh	296366	15544 (5.2)	46274 (15.6)
Maharashtra	297341	17584 (5.9)	31166 (10.5)
Orissa	150115	2654 (1.8)	9750 (6.5)
Rajasthan	330083	14401 (4.4)	19298 (5.9)
Tamil nadu	131080	1534 (1.2)	2154 (1.6)
Uttar Pradesh	232142	3916 (1.7)	7416 (3.2)
Total	**2,281,800**	**105,807 (4.6)**	**195,238 (8.6)**

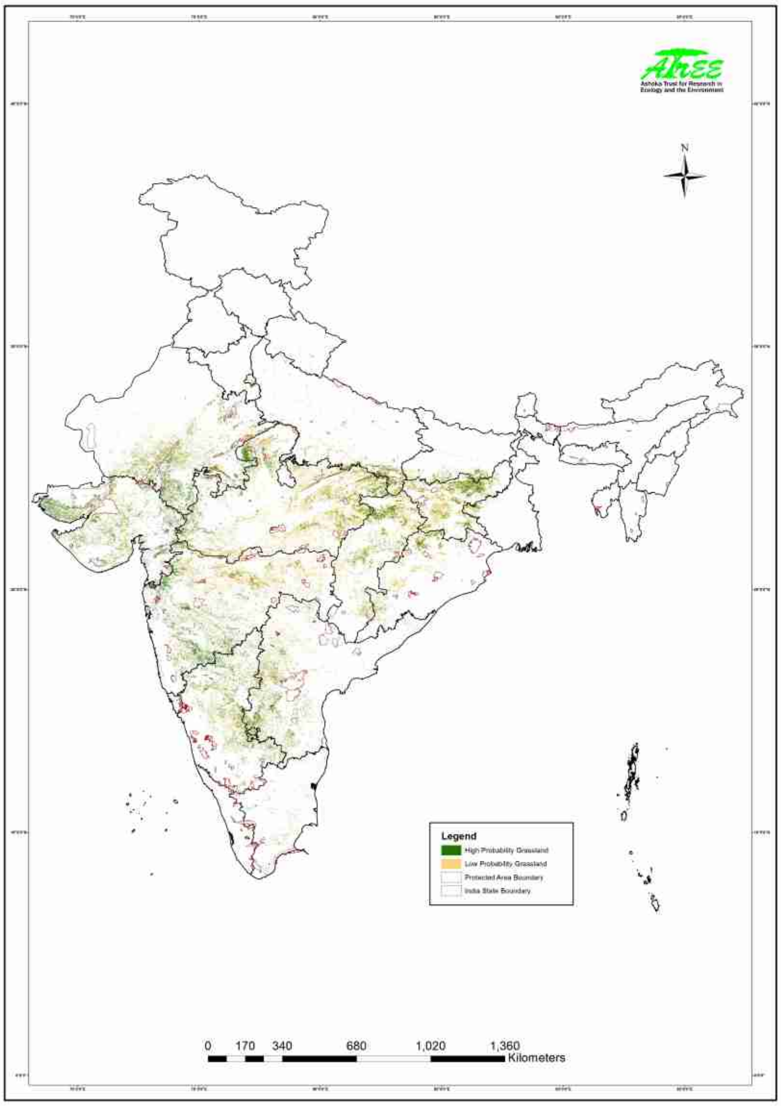


Figure 16.2 An unsupervised classification of MODIS NDVI showing the probability of semi-arid savanna grassland occurrence in India

Table 16.2. Area of savanna grasslands in each state that are covered by the protected area network

State	Total protected area (km^2)	Area (km^2) under high probability of grassland occurrence (% PA)	Area (km^2) under low probability of grassland occurrence (% PA)
Andhra Pradesh (Unified)	13919	175 (1.3)	469 (3.4)
Chattisgarh	1973	3 (0.1)	17 (0.9)
Gujarat	17315	866 (5.0)	447 (2.6)
Jharkhand	3224	6 (0.2)	85 (2.6)
Karnataka	7288	7 (0.1)	4 (0.1)
Madhya Pradesh	7223	207 (2.9)	356 (4.9)
Maharashtra	9283	100 (1.1)	511 (5.5)
Rajasthan	9650	839 (8.7)	768 (8.0)
Tamil Nadu	6720	31 (0.5)	80 (1.2)
Uttar Pradesh	**4847**	**331 (6.8)**	**300 (6.2)**

Rule-based classification using regression tree

The use of MODIS NDVI combined with ancillary data produced a map covering the entire country that predicted SSG occurrence. In the final pruned tree the following covariates emerged: maximum NDVI at the first level followed by precipitation of the driest month. The probability of the rule resulting in a grassland site was 0.63. This map had a user's accuracy of 95% and producer's accuracy of 79.2% **(Figure 16.3)**.

Where MAX_NDVI is the maximum NDVI value from December to June and BIO14 is the precipitation of driest month. A total of 5 nodes were generated and the resulting rules were used to generate maps on a countrywide scale using raster calculator of Arcmap 9.3 **(Figure 16.3)**.

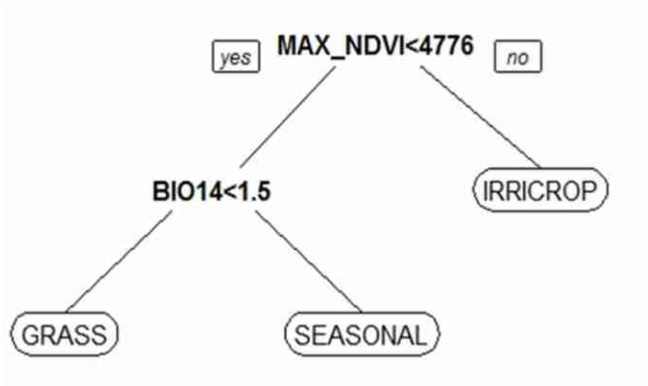


Figure 16.3 A rule-based regression tree prediction map of semi-arid savanna grasslands in India. The classification tree identifies the fundamental niche of the SSG.

Discussion

The notion that forests are India's natural vegetation cover has resulted in an important habitat, the semi-arid savannas, being neglected for decades. Using multiple methods we were able to create maps of the semi-arid savannas of peninsular India. These maps show for the first time the possible extent of this unique biome in India, as well as the precarious nature of its status under the formal protected area network.

Among the peninsular states, Maharashtra, Gujarat and Madhya Pradesh have the largest extent of area under SSG **(Table 16.1)**. However, the protection status of these areas is poor with between 0.1 to 8.7% of the area under the formal PA network. For example, the state of Maharashtra which has the largest extent of grassland areas has only 1% of area under protection. Comparing the current extent of SSG to the predictive maps from the rule-set classification shows that large parts of peninsular India within the bioclimatic envelope for SSG are now either under the low probability category or have been converted to other land uses.

Novel analysis

Mapping SSG in India is generally challenging for several reasons, as mentioned previously. Our use of multi-date NDVI derived from the MODIS data, and the regression tree analysis combining ancillary data with remote-sensing data allowed us to generate maps with a fairly high accuracy. The classification or decision trees have been proven to be superior to maximum likelihood classification and linear discriminant classification (Friedl and Brodley 1997; Friedl et al. 1999). In this study, the maps produced by the classification tree helped define areas within the bioclimatic envelope of SSG across the country. However, the model over predicted at certain locations where there were large patches of old fallow land.

NDVI is used in a variety of analyses concerning terrestrial ecology (Ouyang et al. 2012). The coverage of MODIS and the availability of 16-day composites of every month were the biggest advantages of using this data. The grassland prediction maps produced by combining with ancillary data represented the major grassland areas with a high accuracy (81%). When overlaid with high resolution maps made using LISS IV imagery, it was found that the extents of grassland area matches well by visual assessment (Vanak, A.T. unpublished). Also, the model accounted for seasonal variation, which facilitated separation of grassland and other spectrally similar land cover classes.

Conservation planning

The Task force on Grasslands and Deserts set up by the Ministry of Environment & Forests, Government of India (Singh et al. 2006z), has reported that more than 50% of the fodder for India's 500 million livestock comes from grasslands, scrub and thorn forests. Therefore these biomes are not just important for wildlife but are critical for the vast majority of the rural agro-pastoralist community. India has the largest livestock population in the world (WRI 1996), with a very high dependence on the semi-arid savanna grassland biome. Despite this, there is as yet no comprehensive policy on the management and conservation of these ecosystems (Singh et al. 2006). This lack of focus on savanna grasslands has hampered execution of systematic conservation policies at the landscape level for India.

India's high human population and the scale of human-modification of savanna grasslands make the implementation of typical conservation measures unfeasible. For example, it is impractical to create large protected areas solely to conserve grassland ecosystems because of the high level of human dependence and fragmentation of the habitat. Novel approaches to conservation are, therefore, required for such modified landscapes (Moilanen et al. 2005). The management and conservation of these fragmented and human-dominated regions requires delineation of high-priority habitats where populations of endangered species are most likely to persist in the long-term (Margules and Pressey 2000; Cabeza and Moilanen 2001).). Because of the multiple-use nature of these landscapes, conservation strategies also need to incorporate human-use and prudent natural resource management that is compatible with wildlife conservation within the planning framework (Mishra et al. 2003; Wikramanayake et al. 2004; Vavra 2005; Shahabuddin and Rangrajajan 2007).

Identification of priority landscapes for conservation is also dependent on the biological values associated with those landscape types. The presence of endangered and critically endangered species in any particular landscape increases its value, even if the threats and associated mitigation requirements are high. The SSG landscape is home to 18 endemic bird species, two of which, the Great Indian bustard and the Lesser florican, are critically endangered. The populations of both these obligate grassland species have declined drastically over the years due to historical hunting, but more recently, due to loss of habitats (Dutta and Jhala 2014). As a result, the Indian bustard is now extinct from approximately 90% of its former habitat (Dutta and Jhala 2014). Other species such as the Indian wolf, Indian fox, Blackbuck and Chinkara are all endangered species whose populations have also declined over the years. Due to the accelerating loss of habitat and increased conflict with humans, these species face an uncertain future. Furthermore, the dry grasslands are particularly important as wintering grounds for a diverse group of migratory birds, especially raptors (Ganesh and Kanniah 2000).

The prioritization of landscapes for conservation of multiple species in human-dominated areas is recognised as a key global challenge. Several frameworks such Conservation Assessment Prioritization System, MARXAN (http://www.uq.edu.au/marxan/) and ZONATION (Moilanen et al. 2014), have been developed to address this issue. Identifying key areas for conservation is a critical first step, but zonation, planning and site-level implementation are crucial to the success of any long-term conservation solution. We propose that such a sentinel landscape approach be taken to monitor key grassland habitats to maximise the biological values as well as balance human-use of these areas for long-term sustainability and habitat persistence.

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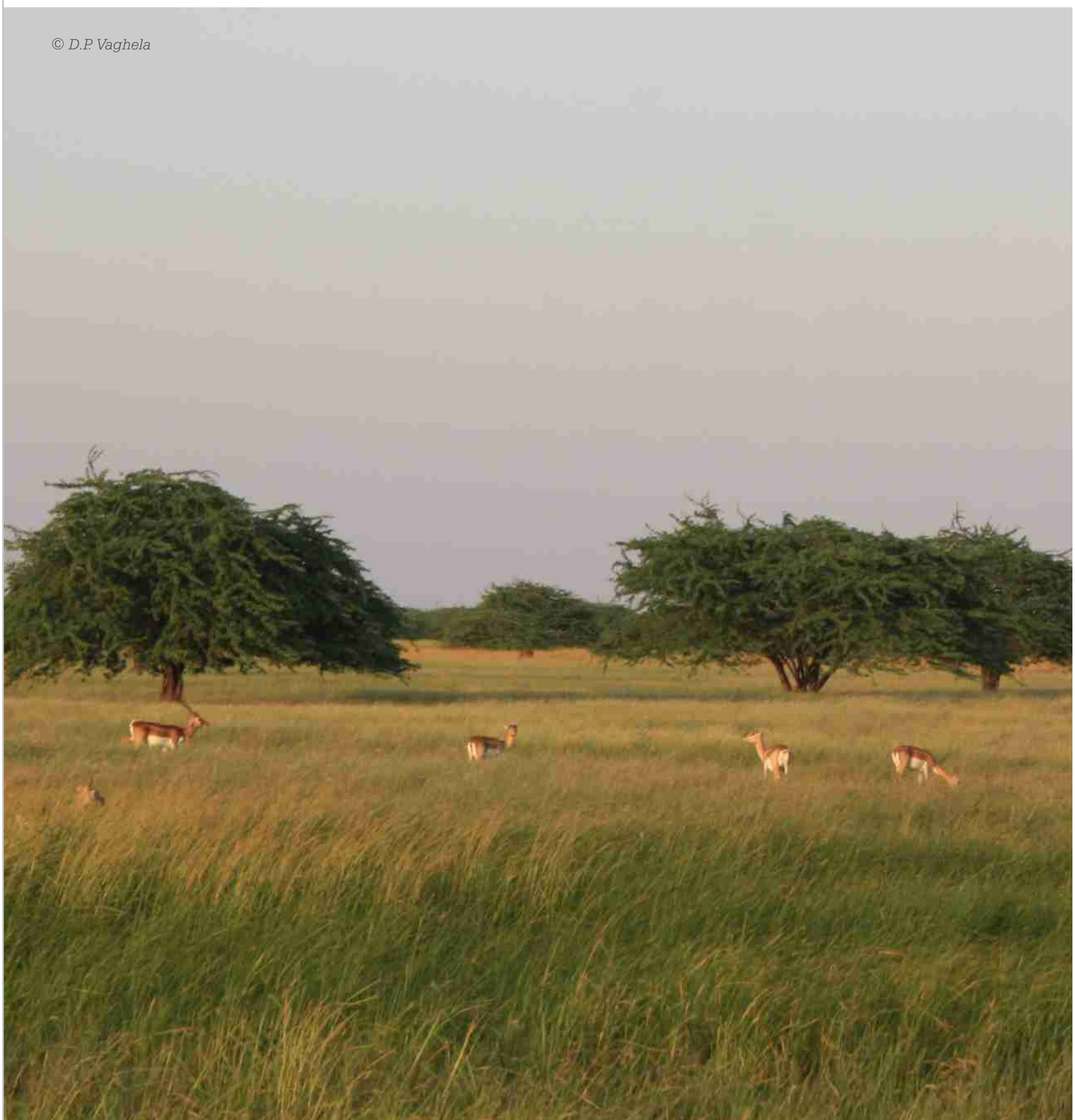
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Ecology and Management of Semi-arid Grasslands in India with Special Reference to Endangered Lesser Florican *Sypheotides indica* Miller

Abstract

Semi-arid grasslands in western India dominated by zspecies are well-known for globally threatened bustards especially the Lesser Florican and the Great Indian Bustard. In past three decades, most of these grasslands have been either degraded or converted for other land-uses, resulting in rapid decline of breeding habitats of lesser florican. Further, there is no information about the non-breeding habitat of this species. In this context, Wildlife Institute of India has initiated a study aimed to understand the migration pattern of lesser florican and identify critical grassland habitats to prepare a comprehensive conservation plan. Satellite tracking of two male lesser floricans in the year 2014 revealed that males could shift their territories within an arena. It was earlier believed that lesser floricans are long distance migrants and their foraging grounds might be in Western Ghats and Gangetic Plains. However, a tagged florican migrated just 94 km south of its breeding ground, indicating small distance migration and natal philopatry during next breeding. Both breeding and non-breeding habitats of lesser florican are semi-arid grasslands that are under immense anthropogenic pressures such as plantation, agriculture expansion, mining, wind/solar power mills, etc. Overgrazing, invasive alien species, high use of pesticides and changes in traditional crop pattern are also major threats to these grasslands and its dependent fauna. Therefore, a national policy for sustainable management of semi-arid grasslands in India is being suggested in this article.

Key Words: Sypheotides indica, Satellite Tracking western India, Grassland fauna, Semi arid grassland.

Introduction

The semi-arid grasslands in western India have evolved over several centuries under the influence of low-moderate precipitation, sustainable levels of grazing by wild and domestic ungulates and peculiar soil. These grasslands are home to several native fauna including critically endangered birds such as Great Indian Bustard (*Ardeotis nigriceps*), Lesser Florican (*Sypheotides indica*) and winter visitor Houbara Bustard (*Chlamydotis undulata*). Endemic to Indian sub-continent, the Lesser Florican is the smallest member of bustards in the world. It is commonly seen during monsoon season in the eastern parts of Rajasthan, western parts of Madhya Pradesh, Gujarat and in some parts of southern India. Locally called 'Kharmor', katkata or fudakkaro in Rajasthan, Tilor in Kutch and Saurashtra area; Dumbharo in other parts of Gujarat (Collar and Andrews, 1988). Among mammals Indian grey wolf (*Canis lupus*), Indian fox (*Vulpes bengalensis*) and Blackbuck (*Antelope carvicapra*) also take refuse in these grasslands. Currently most of these species are facing threats due to habitat degradation, fragmentation and shrinkage owing to lack of clear policies on the grasslands and faulty land use practices (Rahmani 2006). Therefore, an urgent need is felt to protect and restore the degraded semi-arid grasslands not only for bustards but also for the associated species which can be protected from local extinction (Dutta 2014) and also these ecosystems are managed for sustaining livelihoods of thousands of pastoral communities.

The tropical grasslands in India vary considerably in terms of physiognomy from sparsely vegetated arid grasslands to semi-arid swards, savannahs, and hygrophilous grasslands. Grasslands occupy nearly 39% of the country geographical area. It is estimated that approximately 15, 6000 km^2 area is considered as waste land which is also used for seasonal livestock grazing (Misra 1983). Pastures and grasslands are in different stages of degradation and destruction due to agriculture expansion, urbanization and infrastructure development. The grasslands in India are broadly classified into five types **(Table17.1)** including, *Phragmites - Saccharum - Imperata* grasslands covering 53.7 %, followed by *Sehima - Dichanthium* 33.4 %, *Dichanthium - Cenchrus – Lasiurus* 8.3% and *Themeda - Arundinella* 4.4 %.

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Table 17.1. Types of grasslands in India.

S.no	Type of grasslands	Area (in sq.km)	Grass Species	Climate	Region
1.	*Sehima - Dichanthium grasslands*	17,40,000	*Dichanthium annulatum, Sehima nervosum, Bothriochloa pertusa, Chrysopogon fulvus, Heteropogon contortus, Iseilema laxum*	Semi-arid	Central Indian Chota Nagpur plateau, Aravallis
2.	*Dichanthium - Cenchrus - Lasiurus grasslands*	4,36,000	*Cenchrus ciliaris, C. setigerus, D.annulatum, Cymbopogon jawarancusa, Cynodon dactylon, Eleusine compressa, Lasiurus sindicus, Sporobolus marginatus, Dactyloctenium sindicum*	Arid, Semi-arid,	Northern parts of Gujarat, Rajasthan, Aravalli ranges, Southwestern Uttar Pradesh, Delhi and Punjab
3.	*Phragmites - Saccharum - Imperata grasslands*	28,00,000	*Imperata cylindrica, S. spontaneum, Phragmites karka, Desmostachya bipinnata, Bothriochloa intermedia, Vitevaria zizanioides, Imperata cylindrica, and Saccharum arundinaceum*	Dry-sub-humid, Semi-arid	Gangetic plains, the Brahamputra Valley and the plains of Punjab
4.	*Themeda - Arundinella grasslands*	2,30,400	*Arundinella benghalensis, A. nepaolensis, Bothriochloa intermedia, Chrysopogon fulvus, Cymbopogon jwarancusa, Apluda mutica, Arundinella khaseana, Pennisetum flaccidum*	Humid, Moist -sub-humid.	Manipur, Assam, West Bengal, Uttar Pradesh, Himachal Pradesh and Jammu and Kashmir
5.	*Temperate - Alpine grasslands*	Data not available	*Agropyron conaliculatum, Chrysopogon gryllus, Dactylis glomerata, Danthonia cachemyriana, Phleum alpinum, Carex nubigena, Poa pratensis*		Temperate and cold arid areas of Jammu and Kashmir, Himachal Pradesh, Uttar Pradesh, West Bengal and the northeastern states.

Source: *Modified from Singh et al. (2014).*

Semi-Arid grasslands of India

Based on grass species which dominates the area, there are eight types of grasslands in India. But in Gujarat, South-west Rajasthan and western Madhya Pradesh are dominated by three types *Dicanthium- Cenchrus, Sehima-Dichanthium* and *Cymbopogon* (Whyte, 1957) based on climatic conditions these are semi-arid grasslands (Champion & Seth, 1968). The semi-arid grasslands of western India spread across four states such as Gujarat, Rajasthan, western Madhya Pradesh and Maharashtra. All these grasslands areas fall in to arid and semi-arid region characterised by *Sehima - Dichanthium, Dichanthium - Cenchrus – Lasiurus* grasses. Most of these grasslands are either owned by people or by the revenue department or largely used for fodder. However, some portions of grasslands are under the control of the State Forests Departments. Some of these grassland patches have been brought under the umbrella of protected area network. In Gujarat, Blackbuck National Park, Velavadar, Kutch Great Indian Bustard Wildlife Sanctuary, Gaga, Gir National Park, Rann of Kachchh Wildlife Sanctuary, Narayan Sarovar (Chinkara) Wildlife Sanctuary, Chharidhandh Community Reserve are some of the protected areas notified for the conservation of grassland habitat and associated faunal species. Desert National Park in Jaisalmer and Barmer districts of Rajasthan, Karera Bird Sanctuary, Sailana Khamor Wildlife Sanctuary and Sardarpur Kharmor Wildlife Sanctuary in Madhya Pradesh and Great Indian Bustard Wildlife Sanctuary in Maharashtra are protecting some portions of semi-grasslands and their associated fauna and flora.

The semi-arid region of India with average rainfall varying from 400 to 1000 mm, is largely dominated by grasses and shrubs. Analysis of meteorological data of India for past 40 years reveals that the semi-arid region is increased in considerable range in India due to either poor rainfall or lesser rainy days. While area under semi-arid region increased in Madhya Pradesh, Uttar Pradesh and Bihar, it is said to have decreased in the states of Rajasthan and Gujarat, due to increase in arid region (Figure 17.1. Kesava Rao et. al. 2013), which is also one of the attributes for shrinkage of grasslands in western India.

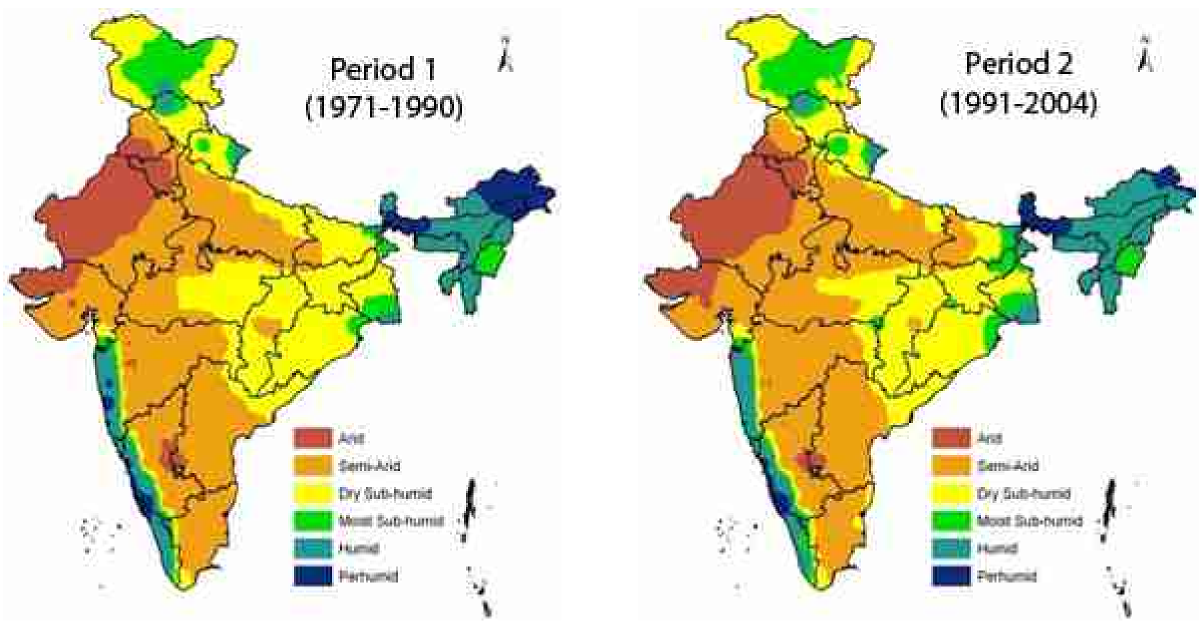

Figure 17.1 The maps showing distribution of climatic zones and expansion of arid and semi arid regions in India (Source: Kesawa Rao et al. 2013)

The semi-arid grasslands of India harbour wide variety of fauna and important fodder species. The grasslands are economically valuable as the local people mostly depend on fodder from grasslands for their livestock. Further, the grasslands can also act as a gene bank for preserving natural fodder species in wild for future benefits. Apart from its high economic value, it also has high ecological and conservation values, for example, more than 90% of endangered Lesser Florican breeds in these grasslands and about 90% of critically endangered the Great Indian Bustard population residing in the same grassland plains of semi-arid region in Rajasthan, Gujarat, Madhya Pradesh and Maharashtra. Moreover, threatened mammals such as Indian grey wolf (*Canis lupus*), Golden jackal (*Canis aureus*), Indian fox (*Vulpes bengalensis*), Indian gazelle (*Gazella bennettii*), Blackbuck (*Antelope cervicapra*), Striped hyaena (*Hyaena hyaena*), Caracal (*Caracal caracal*), Desert cat (*Felis libyca*) and Indian hedgehog (*Paraechinus micropus*) are also typical species of grasslands habitats. Monitor lizard (*Varanus bengalensis*) and Spiny-tailed Lizard (*Uromastix hardwickii*) are important reptiles of these grasslands which need immediate conservation attention. The semiarid grasslands are also roosting sites for all harrier species during their non-breeding season. Table 17.2 shows the status of the population.

Table 17.2. Bird species inhabiting the semi-arid grasslands of India

S.no	Species	Status	
		IUCN	WPA 1972
1.	Long-billed Vulture (*Gyps indicus*)	CR	I
2.	Slender-billed Vulture (*Gyps tenuirostris*)	CR	I
3.	Eurasian Griffon (*Gyps fulvus*)	LC	IV
4.	Egyptian Vulture (*Neophron percnopterus*)	EN	IV
5.	White-backed Vulture(*Gyps bengalensis*)	CR	I

S.no	Species	Status	
		IUCN	WPA 1972
6.	Red-headed Vulture (*Sarcogyps calvus*)	CR	IV
7.	Laggar Falcon (*Falco jugger*)	NT	I
8.	Saker Falcon (*Falco cherrug*)	EN	I
9.	Peregrine Falcon (*Falco peregrines*)	LC	I
10.	Red-headed Falcon (*Falco chicquera*)	NT	I
11.	Lesser Kestrel (*Falco naumanni*)	LC	IV
12.	Tawny Eagle (*Aquila rapax*)	LC	IV
13.	Steppe Eagle (*Aquila nipalensis*)	LC	IV
14.	Imperial Eagle (*Aquila heliacal*)	VU	IV
15.	Lesser Spotted Eagle (*Eagle Aquila pomarina*)	LC	IV
16.	Common Buzzard (*Buteo buteo*)	LC	IV
17.	Long-legged Buzzard (*Buteo rufinus*)	LC	IV
18.	Upland Buzzard (*Buteo hemilasius*)	LC	IV
19.	Short-toed Snake Eagle (*Circaetus gallicus*)	LC	IV
20.	Eurasian Marsh Harrier (*Circus aeruginosus*)	LC	IV
21.	Eastern Marsh Harrier (*C. Spilonotus*)	LC	IV
22.	Hen Harrier (*C. Cyaneus*)	LC	IV
23.	Pallid Harrier (*C. Macrourus*)	LC	IV
24.	Pied Harrier (*C. melanoleucos*)	LC	IV
25.	Montagu's Harrier (*C. Pygargus*)	LC	VI
26.	Rain quail (*Coturnix coromandelica*)	LC	IV
27.	Grey Francolin (*Francolinus pondicerianus*)	LC	IV
28.	Lesser Florican (*Sypheotides indica*)	EN	I
29.	Great Indian Bustard (*Ardeotis nigriceps*)	CR	I

Lesser Florican

Lesser Florican is endemic to Indian subcontinent (Plate 17.1). Once it was widely distributed in low-lying open grasslands and seen throughout the year. Before the advent of green revolution (before 1960) its breeding areas were almost all in parts of north-western India such as districts of Nasik, Ahmednagar and Sholapur of Maharastra, eastern Haryana and the Kathiawar Peninsula (south-central and south Gujarat) (Goriup and Karpowicz, 1985). Due to agriculture expansion and other developmental activities grassland habitats underwent rapid degradation. Consequently, florican population has immensely declined and became rare. However, it can be frequently seen during monsoon but currently the breeding areas are in isolated patches those leftover in southern Rajasthan, southern and eastern Gujarat, and western Madhya Pradesh (Sankaran 1991, 1994b).

Lesser Florican is an indicator of healthy semi-arid grassland ecosystem and monsoon when they occur in good number in north-western part of India (Manakadan & Rahmani 1999). Continuous increase of anthropogenic pressure in the semi-arid grasslands of Western-India had significantly affected on the Lesser Florican breeding and its population. In general, the population of Lesser florican seems to be at declining trend in these grasslands (Table 17.3). Unfortunately, the more sightings of Lesser florican in the agriculture landscape in the recent past is also not a good sign for the long term conservation of this species.

Table 17.3. Population of status of Lesser Florican in semi-arid grasslands of India

State	District	1982	1989	1994	1999	2010	2014
Gujarat	Bhavnagar	0	2	35	19	27	26
	Amreli	0	NV	0	0	0	NV
	Junagarh	21	0	4	4	0	NV
	Jamnagar	34	NV	1	2	0	NV
	Rajkot	21	NV	27	42	0	NV
	Surendranagar	NV	NV	2	NV	NV	NV
	Kachchh	NV	8	36	67	22	1
	Punchmahal	NV	20	6	11	5	NV
Madhya Pradesh	Ratlam	36	28	25	55	8	7
	Jhabua	5	9	3	1	2	3
	Dhar	14	11	13	7	2	0
Rajasthan	Bhilwara	NV	NV	NV	3	5	0
	Tonk	NV	NV	NV	2	2	NV
	Ajmer	NV	NV	NV	4	3	40
	Pratapgarh	NV	NV	8	25	8	NV
	Total males seen	65	90	161	303	84	57
	Estimated Number in Total	4374	1672	2206	3530	NC	NC

Source: *1982 to 2000 G.S. Bhardwaj (2011), WII progress 2014*

Status of important grassland habitats in India used by Lesser Florican

Breeding habitats

Ajmer: Ajmer district, Rajasthan, dominated by the mosaic of agriculture fields and grasslands, is also well known for the Floricans. It was observed that this area holds largest congregation of breeding floricans during the monsoon. The Lesser Florican (*Sypheotides indica*) is still found during monsoon in small numbers. In 2013, nearly 120 male floricans were seen by the local staff (Rajender Singh *pers com*. 2013) in and around Sonkhaliya.

Most of these areas are under the cultivation with the Kharif crops such as jowar, bajra (Millet), Black gram, Cotton, Soybean etc. and rabi crops such as wheat, gram, mustard and barely in small irrigated areas with well and bore wells. The area is also dominated with *Prosopis juliflora, Capparis decidua,* and *Calotropis procera* etc. Floricans use these agriculture crops and adjoining grasslands to establish their lek area. Though, they use crop fields for display and foraging but they also seek the nearby grasslands as shelter during any kind of threats.

Shahpura: Shahpura and adjoining areas of the district Bhilwara other important Lesser florican breeding sites in Bhilwara district of Rajasthan that lies between 25° 50' 44" N, 74° 39' 21" E to 25° 39' 26" N, 74° 59' 51" E. These areas are also comprises of dry arid agricultural lands, thorny shrubs. Most of the crop lands are live-fenced with live Thor (*Euphorbia nerifolia*) to prevent the loss from of Blue bull (*Boselaphus tragocamelus*) and livestock population.

Sailana: This area falls in Malwa plateau (north-central India) latitude 23°27' N and longitude 75° E in the State of Madhya Pradesh, and largely used for cattle grazing. A portion of grasslands due to the habitat of of Lesser Florican, the Madhya Pradesh government has declared "Sailana Kharmor Wildlife Sanctuary" in June 1983. Every year, this 354 hectares of protected grasslands act as an area for lekking floricans during breeding season every year. This sanctuary with open and undulated landscape with scattered with stunted *Butea monosperma* and *Lantana camara* bushes as bare land during summer and after rains it become an excellent grassland (Rahmani & Sankaran, 1985).

Petlawad: A sloppy and undulated grasslands under Jhabua Forest Division in Malwa plateau, Madhya Pradesh, located between 22°53'45" N 74°51'02" E to 22°51'32' 'N 74°48'51" E also is a potential site for floricans, every year it supporting 5 to 10 male individuals. Vegetation is mainly grasses, *Butea monosperma* and *Lantana camara*.

Sardarpur: Approximately 8 sq km area of these grasslands is also an exclusive protected area for Lesser floricans during breeding season, which lies between 22°46'21"N, 74°54'50"E to 22°43'53" N, 74°53'38" E in Madhya Pradesh. Topography of the grassland are mainly undulating slopes connected with Petlawad grasslands by fragmented and degraded patches of grasslands. Vegetation compositions of this grassland is similar to Sailana and Petlawad mainly with grasses, *Butea monosperma* and *Lantana camara*.

Dahod: Approximately 18 sq.km under Dahod Forest Division near Rampura village, Gujarat, slope and undulated grasslands acts as breeding area for Foricans it lies 22°50'38" N, 74°12'27" E to 22°48'25"N 74°09'40" E in Malwa Plateau but in recent past year (since monsoon 2012) according to local people there were no sighting records due to gradual changes in vegetation composition as tree cover increases in the area.

Blackbuck National Park, Velavadar: The area is well known as paradise for Lesser floricans located in Bhavanagar district along the costal of Arabian sea. The total area of this protected area is 34.08 sq.km, out of which 9.79 sq.km area is occupied by grasslands serving as breeding habitat for the florican. It is also world's largest communal roosting site for harriers. Major herbivores in the area is Black buck and blue bull. Agriculture land lying adjacent to these protected grasslands is important refuge and foraging ground for the florican.

Naliya: Naliya grasslands (Lala Bustard Wildlife Sanctuary and adjacent grasslands) is a vast area with an approximate area of fifty thousand hectares along the coast of Arabian Sea in Kutchch distrct of Gujrat lies on N 23° 30.00' latitude and E68° 45.00' longitude. Grass patches and crop lands spread within this area support as a breeding ground for Lesser florican and native for Great Indian Bustard.

Grasslands or croplands in Amreli district and Gir National Park in Gujarat, Pratapgarh, Pali and Tonk districts of Rajasthan, Pune and Washim districts of Maharashtra holds outstanding breeding population during monsoon.

Non-breeding habitats

Lesser Floricans are well known to breed in the grasslands of western India but their non-breeding habitat was not known. In this context, the Wildlife Institute of India has been conducting a study to understand the migratory and movement patterns of floricans within and outside the breeding areas using the satellite tracking techniques. In 2014, we were able to tag two male floricans with PTTs in the agriculture fields of Sonkhaliya landscape near Nasirabad area of Ajmer district of Rajasthan. The post tagging behaviour of the two floricans (FLORIKIN-I and FLORIKIN-II) are described below.

A. **FLORIKIN-I:** 18g PTT (Platform no.125812) Florikin-I, was tagged with Agros PPT-100 which spent 112 days and left the breeding ground on 11th November 2014. The bird flew for 94 km towards down south direction and settled down in grasslands at north of Bhilwara, Rajasthan. Florikin-I crossed this distance in 5 days 8 hours with four stopovers. East stopover last one to two days. All the stopovers were in the croplands and grasslands. Florikin-I flew at the speed of 0.73 km/hr which include the stopover time.

B. **FLORIKIN-II:** That was tagged with 22g GPS/Argos PTT had failed after 35 days but had provided much more precise insight to the lekking behaviour of this species. The available data shows Florikin-II, It was found that the florican could shift the displaying territory within an area during a breeding season. Three times this bird had shifted his territory and spent considerable time in each territory and displayed. All these three territories of Florikin-II were within the home range of 6.8 sq.km (MCP 100%).

Plate 17.1: Lesser florican female © Surendra Singh Chauhan

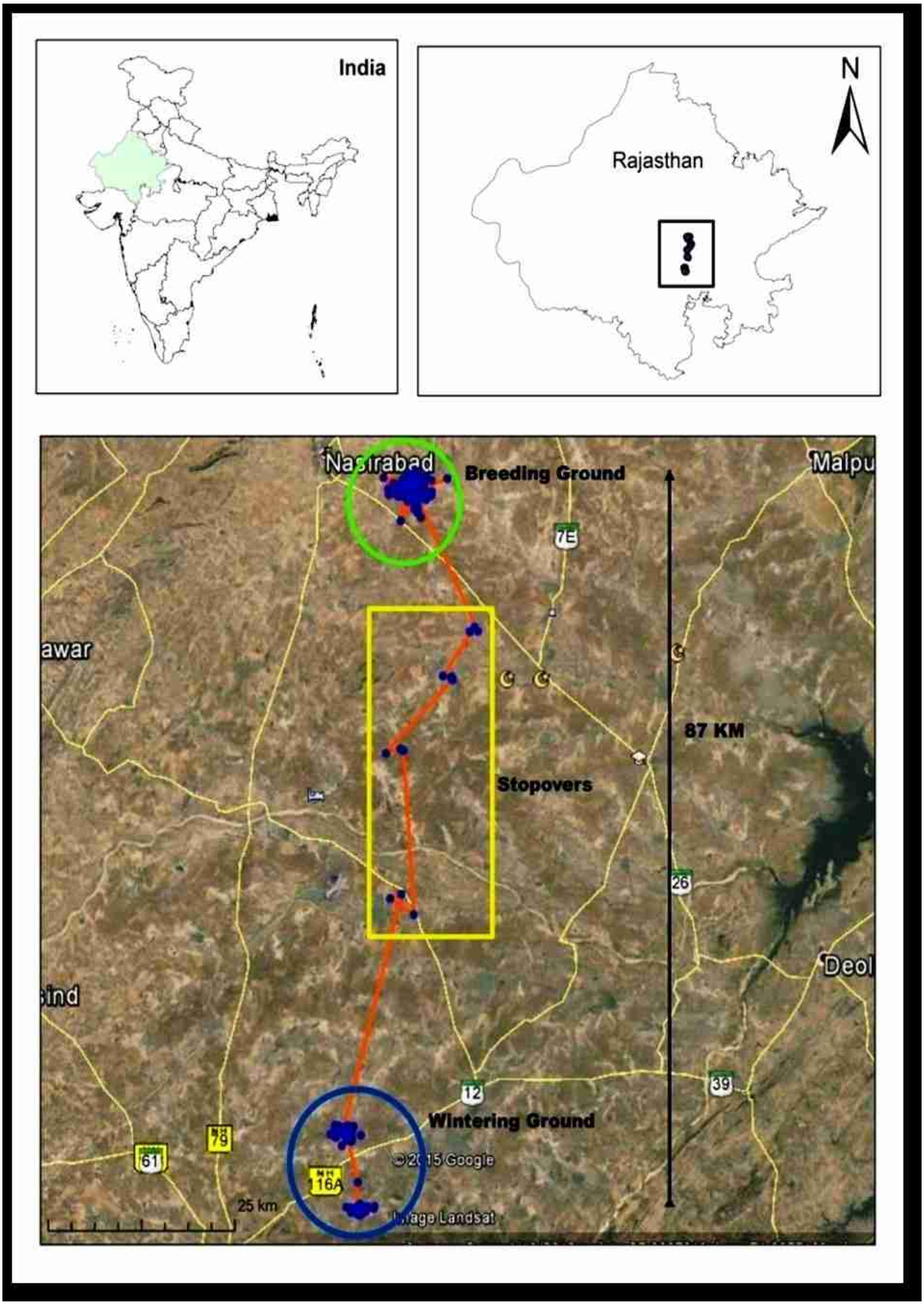

Figure 17.2 Movement of a Lesser Florican fixed with PTT, from August 10th 2014 to March 29th 2015.

Our preliminary observations on one of male florican, which could retain the functional PTTs till 15th June 2015 revealed that the florican did not migrate longer distance. They seem to be migrating to nearby grasslands soon after their breeding seasons located about hundred kilometres away. However, this needs to be confirmed after tracking some more floricans. If the floricans do not migrate long distance and restrict to other parts of semi-arid grasslands during the non-breeding seasons then the importance of semi-arid grasslands goes up several folds with respect to long term conservation of lesser florican in the country.

Threats to semi-arid grasslands in Western India

Lack of National Policy on grasslands

Due to inadequate grassland conservation policy and management practices or a mindset that assumes grasslands as wastelands, many of the state owned grasslands and village pasture lands have been planted extensively with tree species including *Prosopis juliflora* (Bhardwaj et al 2011). Similarly, thousands of hectares of pure patches of grasslands in Thar landscape have been planted with Israeli babul (*Acacia tortilis*) under different afforestation schemes run by the State Forest Departments. Several grasslands in the regions have been converted into either woodlands or crop lands. In addition, due to excess of grazing most of remaining grasslands are in different stages of degradation. Many of the grasslands belonging to state forests departments commonly known as grass birds were auctioned every year. Instead of harvesting the grass manually after the monsoon season, the contractors many times lease out these areas to the local graziers due to non-availability of man power to cut grasses. Herds of cattle throng these grasslands and render a great disturbance to the breeding floricans, even trampling their nests and eggs. Complete removal of grasses from grassland also not conducive for florican to breed in the next year but most of private and government owned grasslands were observed with harvesting of entire grasses leaving no habitat for wildlife.

Habitat degradation and loss

Of the 169 potential grasslands where floricans could be found in the north-western India, 24 grasslands are still believed to be conducive for floricans for breeding. This was largely due to degradation of grasslands, which have failed to attract floricans. Floricans like pure but undisturbed grass patches with mosaics having older tussocks previous years to settle down at the beginning of breeding season. Changes in land-use pattern over the decades have resulted in a drastic decline of grassland habitat in the north-western India. Many of these grasslands were reclaimed for agriculture to meet the demands of the growing population. Ever growing cattle population in the region have also caused overgrazing of the grassland habitats (Sankaran 2000). In many areas, most of protected grasslands were lost to agriculture, leased to graziers or ploughed up, a situation that was particularly alarming in privately owned grassland (Sankaran 1995). Grasslands in the Nalliya area of Kachchh which was known to be an important region for florican conservation had been encroached dramatically by immigrants from Haryana, who are ploughing up florican habitats for cotton cultivation, causing a huge loss of habitat for both bustards and local herdsmen. Moreover, degradation of grasslands in Gondal, Rajkot, Jamnagar, Ratlam, and Dhar districts in the north western India either completely failed to attract florican or attract few individuals.

Plantation and spread of invasive species

It was observed that grasslands have wrongly been considered as waste land and hence large scale plantation was carried out in many grasslands in the north western India. Grasslands with plantation were avoided by the florican as these birds prefer pure grasslands with few trees here and there. Because of plantation, several potential grasslands of florican failed to attract these birds nowadays.

Invasion of alien *Prosopis juliflora* was reported in several grasslands in the north western India. Apart from *Prosopis*, several other tree species were also observed invading in the grasslands largely due to grazing.

Use of pesticides

Lesser Florican is an omnivorous species. Intake of florican include many types of invertebrate: grasshoppers, beetles, flying ants, hairy caterpillars, centipedes, worms, frogs, small lizards and various planta parts: crop shoots, leaves, herbs and berries. Insect form the large part of diet of the Lesser florican (Sankaran, 1995). Crop fields in semi-arid and arid zones are known to be excellent breeding ground for insects. Most of florican sightings during present survey were at the fringes of grasslands which were adjoined with crop fields. It shows that the florican prefer this area largely due to more availability of insects in the region. Use of pesticide in the adjoining agriculture fields around the florican grasslands is being drastically reducing the foods availability. Moreover, insect with pesticide may also threaten the floricans health.

Indiscriminate developmental activities

Windmills in or around the florican habitat are also seems to be threatening bustard in general and floricans in particular. Once the Great Indian Bustard Sanctuary (Lala village) use to attract several floricans had failed to have single florican

this year might be due to mushrooming of windmills around this sanctuary. Apart from windmills, urban expansion, expansion of agricultural activities, road etc in the grasslands are also posing threat to this species.

Poaching

Displaying male floricans are easy victims of poaching. Severe hunting pressure in the last century could have eradicated most of male population (Hume and Marshall 1879-1881, Baker 1921-1930, Birdlife International, 2001), appears to have affected the species drastically (Sankaran 1993). Because of its delicate flesh and excellent taste florican became a best sport-birds of both native people and colonial sportsmen (Jerdon 1839-1840). Sporadic incidences of hunting of this species reported during our survey. However, hunting is not seems to a major threat as most of villagers sympathetic to floricans.

Inadequate Protected Area coverage

Presently semi-arid grasslands are represented by only less than five protected areas in the country which are crucial for the conservation of florican/bustards in the north western India. These include Sailana Kahrmor Sanctuary and Sadarpur Florican Sanctuary both in Madhya Pradesh are exclusively notified for Lesser Florican and Velavadar WLS is for Black Buck in Gujarat. There is also one sanctuary called Great Indian Bustard WLS Kutchh part Gujarat which is chiefly for GIB but it is also a habitat of Lesser Florican. Sailana Kharmor Sanctuary and the Velavadar Blackbuck National Park were the only two wildlife protected areas reported with floricans during our survey. Velavadar NP is the only grassland in the north western India observed with increase in population of Lesser florican in the last three decades was largely due to better grassland management and protection. Some of the protected grasslands in the region were also unfit for florican largely because of these grasslands managed only for fodder.

Strategies for the management of semi-arid grasslands with species reference to Lesser floricans

National policy on the management of grasslands

It is important to have a National Policy on Grasslands Management in India appreciating the ecological services provided by this ecosystem. Currently, grasslands are by and large considered as wastelands due to lack of understanding about their ecological services. The practice of tree plantation by the forest department in grasslands or grass birs should be avoided. Under the umbrella of Joint Forest Management/ Eco-development or social forestry schemes tree plantations were carried out in a major scale which is harmful to floricans and their habitats as well as associated species in the grasslands. Moreover, current practise of looking grasslands as source of only fodder for cattle needs to be reconsidered. Sustainable use of grassland resources without harming their ecological services needs to be emphasised in the National Policy. The Policy is also required to be suggesting the wildlife especially bustard friendly grassland management in India.

Restoration of degraded grasslands with the involvement of local communities

Less than five protected areas (grasslands) are existing exclusively for the conservation of florican/bustards in the north western India. Less than 5% of globally endangered Lesser florican habitat is protected by Wildlife (Protection) Act, 1972. Since the protected florican habitats are comparatively better than non-protected grasslands, it would be better to bring more grasslands under the Wildlife Protected Areas of India by declaring more grasslands as 'Conservation or Community Reserves'. It is urgently required to bring some of the grasslands in Nalliya region in the protected area network. Similarly, some grasslands in Gonda and Rajkot districts as well as in Ratlam and Dhar districts. Grasslands around Sailana are also need to be declared as 'Community/Conservation Reserve' with consensus of local communities. And then the grasslands in the protected areas are need to be managed to fulfil the habitat requirement of bustard in general and Lesser florican in particular.

Control and management of alien invasive plants in grasslands

Eradication of *Prosopis juliflora* and other invaded tree species from the selected grasslands in the north-western India should be taken up immediately. Eradication and monitoring of invasive species in the grasslands should be a continuous programme following the guidelines of IUCN-Invasive Species Specialist Group.

Long term monitoring of floricans and their habitats

The Lesser Florican *Sypheotides indica* population and range is decreasing at an alarming rate due to breeding habitat loss and threats in the non-breeding habitats, believed to be in south and south-east India. Their breeding habitats have sharply declined in north-western India, which is believed to be a major cause for the decline of this endangered species, and there is hardly any information its non-breeding habitat which is supposed to be in Central and South India. A number of studies have been carried on its population status, habitat-use and behaviour in the breeding grounds, but there is practically no information about their habitats, ecology and behaviour in non-breeding habitats, the knowledge of which is crucial for their comprehensive conservation plan preparation. It is important to know the status of non-breeding habitat of florican using satellite tracking techniques, understand the migration pattern/movements, and investigate its current status and distribution in north-western India, which could lead to data on the species in other areas. There is also need of continuous monitoring of Lesser Florican and its habitat in the states of Rajasthan, Madhya Pradesh, Gujarat and Maharashtra. Studies on impact assessment of mega and even so called eco-friendly projects like wind mills on the Lesser Florican should be initiated. A study on the effects of pesticides and insecticides on Lesser Florican is still lacking there should be a study on theses issues.

Involvement of voluntary action groups and private sectors for restoration of grasslands and grassland fauna

Floricans prefer pure but undisturbed grass patches with mosaic of last year grasses to settle down at the beginning of breeding season. Therefore, it is recommended to leave mosaic of old grasses during harvesting for floricans as well as other grassland wildlife. Instead of leasing out grasslands for grazing it would be better if the grasses are manually cut after the monsoon season that will prevent trampling of cattles on florican nests as well as spreading of invasive tree species in the grasslands. Pesticides use in adjoining agricultural fields found to be detrimental for the survival of floricans, therefore, local communities need to be advised the ill effects of pesticide use and they should be compensated if they incur any loss due to non-use of pesticides around florican habitats.

The financial incentive scheme of Madhya Pradesh Forest Department for rewarding the villagers for giving the information of the presence of bird in their agricultural land needs to be thoroughly reviewed and it may be started in others states of Rajasthan and Gujarat, if it is found be worth. An awareness and sensitisation programme for the conservation of Lesser Florican and its habitat should be initiated by all the state forest departments in the states of Rajasthan, Madhya Pradesh and Gujarat. This should be further supplemented with eco-tourism and sensitive florican watch activities. Local communities need to involved in the management of grasslands and they need to be told the reason behind the decline of florican as well as deterioration of their grasslands. There was an initiative in Naliya, where grasslands grazing/harvesting was regulated with the help of local communities. Because of this some grasslands in Naliya region were not disturbed during the breeding season of florican. This initiative was implemented in collaboration with Forest Department, Revenue Department and Local community. If this model works successfully then the same may be tried elsewhere in the country. Plate 17.2 - 17.4 shows glimpses of tagging and release of Lesser Florican.

Apart from declaring some of important grasslands as conservation/community reserves, it would also be required to modify the current use of grasslands in the north-western India. Instead of allowing livestock grazing all over grasslands, certain portion of grasslands need to be protected at least for a year period. Next year, these protected grass patches may be used as fodder but protecting other parts of grasslands for another year use. This kind of practice would help the floricans to settle down and to breed.

Plate 17.2: Releasing the tagged Lesser Florican

Plate 17.3: Tagged individual in flight

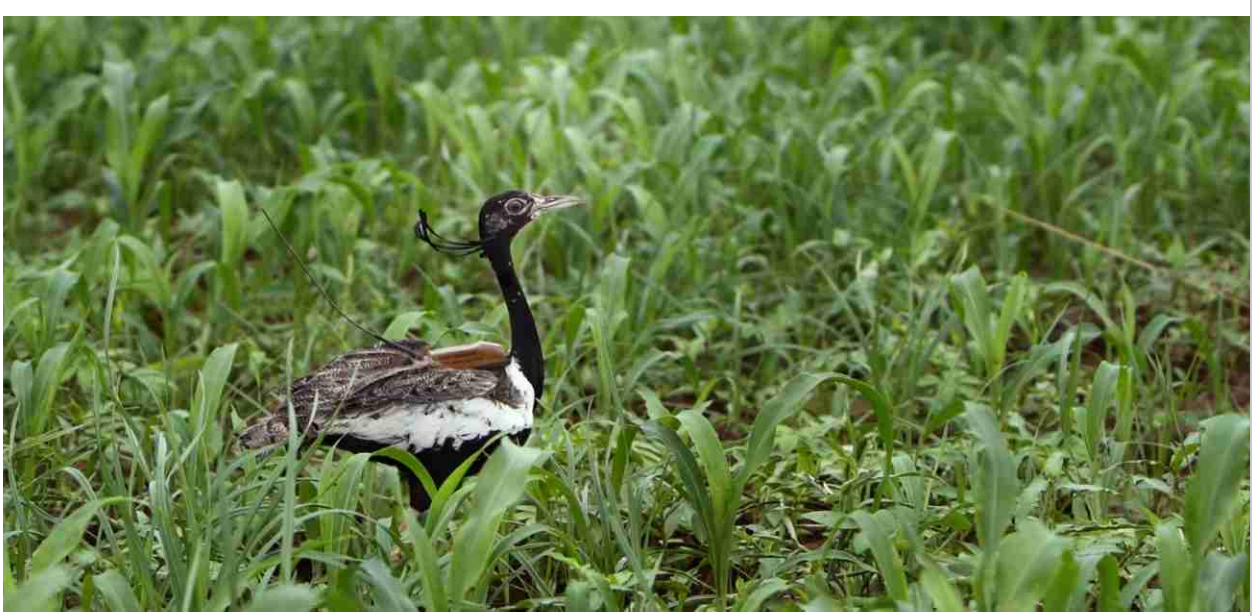

Plate 17.4: Tagged Lesser Florican

Acknowledgement

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Cynodon dactylon (L.) Pers.: a Pinch Period Fodder Resource for Wild Ungulates and Nesting Habitat for Certain Ground-nesting Birds

Introduction

Cynodon dactylon L. Pers., (Vern. 'Doob Ghas', Darb, Durva, Harali) or Bermuda grass, is a mat forming perennial grass widely distributed in warmer parts of the world. It spreads mainly by rhizomes, stolons, and less frequently through seeds (National Plant Data Center). Being an excellent soil binder, this species has been widely used the world over for erosion control, turfing and as a fodder grass. It can withstand sedimentation and long periods of inundation and prefers full sun, growing rapidly at air temperatures exceeding 30°C. It is associated with several religious ceremonies and Hindu rituals and has been widely used for curing several ailments as an ingredient of Indian ayurvedic medicine since ancient times (Ambasta, 2012; Ashokkumar et al., 2013). Though its fodder value and soil binding properties are well known, its role in supporting wild ungulate populations, especially during the pinch period has not been highlighted adequately except for a few studies (Biswas and Sankar, 2002; Wegge et al., 2006; Nayak et al, 2013). Similarly, importance of *Cynodon glades* as a nesting habitat for certain ground-nesting birds do not find a mention in literature. Here, we present some anecdotal observations on use of this species by wild ungulates and birds as a pinch period forage and nesting habitat respectively, mainly from the shores of Hirakud reservoir fringing Debrigarh Sanctuary, Odisha and underline its conservation significance.

Observations

Use of *Cynodon* patches by ungulates

It has been observed that besides borders of cultivated fields, roadsides and abandoned places, *Cynodon* colonizes seasonally inundated and draw-down areas of reservoirs and dams in many parts of tropics. Extensive glades of *Cynodon* can be seen along the margins of Hirakud reservoir in Odisha, Kalagarh reservoir in Corbett Tiger Reserve in Uttarakhand, Periyar Tiger Reserve in Kerala and Tawa reservoir and Pench Tiger Reserve in Madhya Pradesh to name a few.

Debrigarh Wildlife Sanctuary covering an area of 353.81 km^2, located in the Bargarh district of western Odisha is fringed by the sprawling 746 km^2 Hirakud reservoir in its North and East. The sanctuary with its relatively undisturbed forests is well-known in the state of Odisha for its excellent sightings of wildlife. During the peak summer in mid May-June, the reservoir level reaches a minimum at about 590 feet and the shoreline recedes to a kilometre or more in certain places. During this time along the exposed shoreline, wherever soil cover is present, a dense growth of short mat-like growth of *C. dactylon* proliferates. Apart from Asian elephant (*Elephas maximus*) the sanctuary has a sizeable population of Gaur (*Bos gaurus*), Sambar (*Rusa unicolor*), Spotted Deer (*Axis axis*), Nilgai (*Boselaphus tragocamelus*), Chousingha (*Tetracerus quadricornis*) and Wild pig (*Sus scrofa*). The forest type is largely dry deciduous with a good growth of the solid bamboo (*Dendrocalamus strictus*) apart from a large number of grazing and browsing species. However, during the summer months starting from March to May, most of the trees shed their leaves and the undergrowth becomes sparse. Further, except for a few rocky pools almost all natural water sources also dry up. Therefore, food and water becomes scarce for wildlife during this period and particularly, the month of May constitutes the crucial pinch period when the shoreline is clothed by a profuse growth of *C. dactylon*, except for the highly eroded bouldery slopes. The grass spreads quite rapidly forming a dense mat-like growth. Observations during the summer seasons of 2010, 2011 and 2012 revealed that four species of ungulates, viz., Gaur, Sambar, Chital and Chousingha regularly forage on the doob grass. During this time, herds of Gaur and Sambar come down from the hills and spend the entire peak summer in and around the reservoir fringes, primarily for utilising the grass fodder. Elephants too tend to spend most of their time around the reservoir during this period and feed heavily on *C. dactylon*, often using their feet to unearth tussocks of grass, which they then feed upon. Though focused studies are required to validate these observations, it is likely that *C. dactylon* probably constitutes the

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zmost important fodder for the afore-mentioned species during the crucial pinch period and thus helps the Sanctuary in supporting relatively high densities of these species. Further studies in some of the afore-mentioned sites elsewhere in India might reveal a similar pattern.

Nesting habitat for birds

Apart from being an important fodder resource, the thick carpet of doob grass was also observed to be a favoured nesting habitat for a number of ground-nesting passerine birds such as Oriental Skylark (*Alauda gulgula*) and Indian Paddy field Pipit (*Anthus rufulus*). These species were noticed to build their nests inside the thick cover of the *C. dactylon*. However, one species which showed a marked preference for *C. dactylon* was Oriental Pratincole (*Glareola maldivarum*), which seemed to be obligatory to such patches, particularly where it was interspersed with boulders and rocks. Black-winged Stilt (*Himantopus himantopus*) and occasionally, the Little Tern (*Sterna albifrons*) were also seen to nest in *C. dactylon* covered islets, using the grass as a nesting material to line their skimpy ground nests (Plate 18.1 - 18.3).

Conclusion

Though not published, similar observations on the role of *Cynodon* as a crucial pinch period resource exist from other reservoirs of Odisha such as Kuldiha, Rengali and Hadgarh (M.V. Nair *pers obs.*; Pratyush Mohapatra and Aditya Panda pers. comm.) as well as other parts of the country such as Pench (Biswas and Sankar, 2002), Kanha-Pench corridor (Nayak et al., 2013); Ramganga reservoir area of Corbett TR (Bivash Pandav *pers. obs*). Other than wild herbivores, the domestic livestock residing inside protected areas are also heavily dependent on *C. dactylon* during the dry season. With the onset of dry season, Gujjar communities residing in Kalagarh (part of Corbett Tiger Reserve) and Lansdowne forest divisions in Uttarakhand move in to the banks of Sonanadi, Palain and Ramganga along the Kalagarh reservoir with their buffaloes to exploit the lush growth of *C. dactylon*, thereby leading to intense competion with wild herbivores such as spotted deer and elephant. Hence, the role of *Cynodon dactylon* as a pinch period resource could be very important, especially in dry deciduous forest areas where inland waterbodies / reservoirs exist. Therefore, Protected Area managers having reservoir fringes within their sanctuaries can attempt to propagate *C. dactylon* artificially through rhizomes, stolons or transplanting matted rolls. Once established, this hardy fodder grass spreads rapidly, can withstand long periods of submergence and can really serve to supplement the available fodder resources for wild ungulates during the resource crunch period. However, it has to be borne in mind that it can also be highly aggressive, crowding out most other grasses and invading other habitats. Hence, care should be exercised in planting it in areas harbouring unique and habitat-specialist indigenous plant communities.

Plate 18.1: Lark sp in *Cynodon* grassland

Plate 18.2: Eggs of Black-winged Stilt

Plate 18.3: Oriental pratincole

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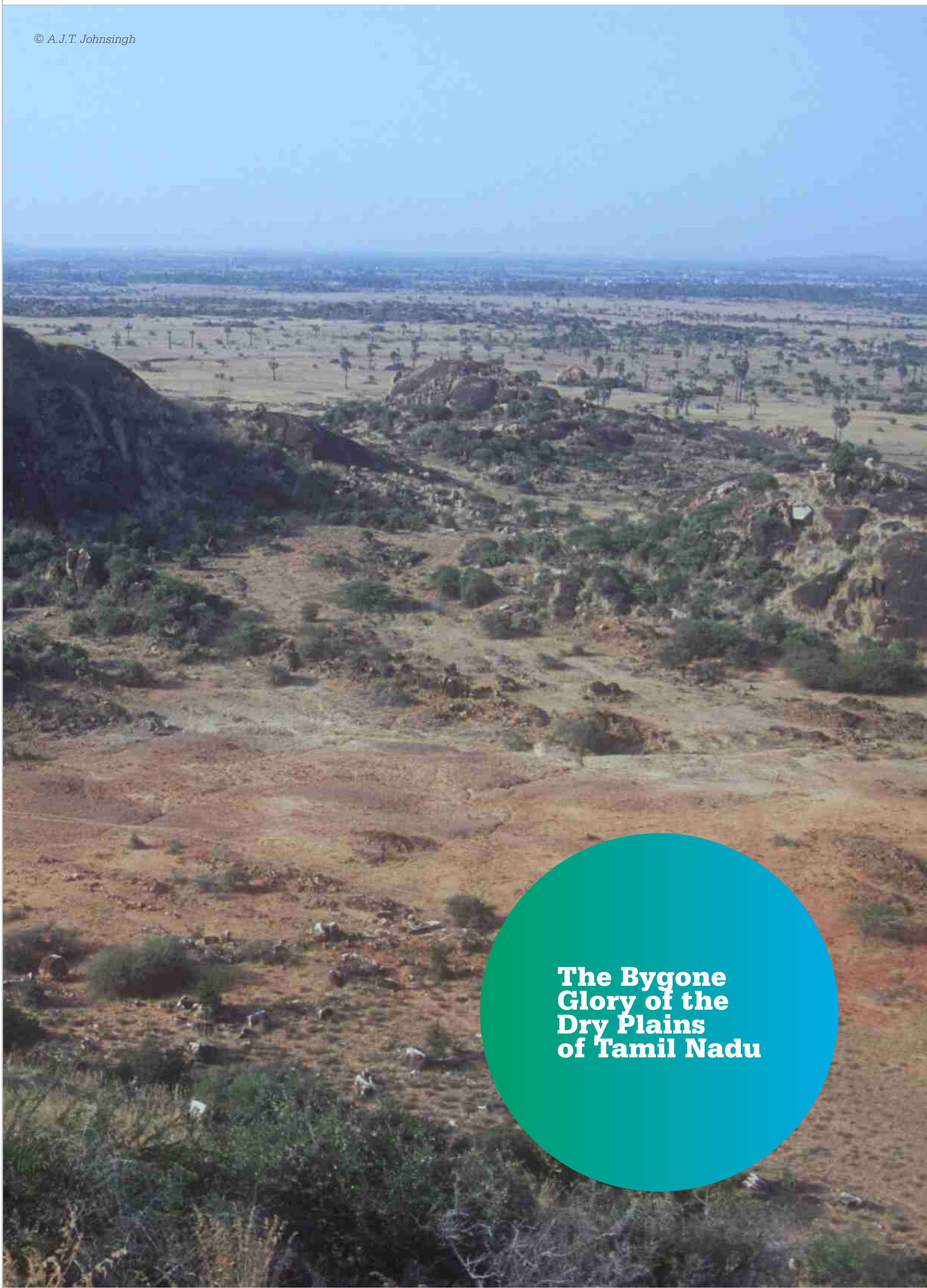

The Bygone Glory of the Dry Plains of Tamil Nadu

19

The landscape in the former three southern districts of Tamil Nadu (Ramanathapuram, Madurai and Tirunelveli) is largely flat punctuated by low-lying hills. High mountains of the Western Ghats form a wall all along the western border of Tirunelveli district and continue along the western boundary of the Ramnadand Madurai districts. The south-eastern parts of Tirunelveli district had beautiful blood-red sand dunes with patches of umbrella thorn (*Acacia planifrons*), magnificent banyan trees *(Ficus bengalensis)* in the shallow valleys of the dunes and palmyrah (Borassus flabellifer) trees with more often only the crowns visible above dunes. Unregulated and illegal mining for minerals is reported to have destroyed the ecology and beauty of these sand dunes.

Before the invasion of mesquite *Prosopis juliflora* and before large tracts of land went under agriculture, the vegetation in the dry plains had vast areas under grass species such as *Aristida setacea, Cenchrus ciliaris, Chloris barbata, Cynodon dactylon, Eleusine indica, Heteropogon contortus and Perotis bibaria.* Common herbs were *Aerva lanata, Barleria prionitis, Cassia tora, Leucas aspera, Ocimum sanctum, Sida cordifolia* and *Solanum xanthocarpum*. The most common edible climber species were scarlet fruit ivy gourd *Cephalandra indica* and *Cissus quadrangularis*. *Cassia auriculata, Calotropis gigantea* and *Euphorbia antiquorum* were the common bushes.

The most common trees were palmyrah, neem (*Azadiracta indica*), white-gulmohar (*Delonix elata*), Indian beech *(Pongamia glabra)*, portia tree (*Thespesia populnea*), peepal (*Ficus religiosa*) and banyan (*Ficus benghalensis*). Conspicuous reptiles were garden lizard *(Calotes versicolor*), fan-throated lizard *(Scitana ponticeriana*), saw-scaled viper (*Echis carinatus*), common cobra (*Naja naja*) and rat snake (*Ptyas mucosa*). Characteristic bird fauna were black-bellied finch lark *(Eremopterix griseus)*, crow pheasant (*Centropus sinensis*), grey partridge (*Perdix perdix*), red-winged bush lark *(Mirafra erythroptera)* and yellow-wattled lapwing *(Vanellus malabaricus)*. Noteworthy mammals that are found even today are Madras hedge hog *(Hemiechinus nudiventris*), soft-furred field rat *(Millardia meltada*), three-striped palm squirrel *(Funambulus palmarum)*, black-naped hare *(Lepus nigricollis*), common Indian mongoose *(Herpestes edwardsii*), small Indian civet *(Viverricula indica*), jungle cat *(Felis chaus*) and Indian fox *(Vulpes bengalensis*). Golden jackal *(Canis aureus*) has disappeared in the recent decades.

The remarkable aspect of this landscape in the past was that, it had an abundance of blackbuck *(Antilope cervicapra*) as well as cheetah *(Acinonyx jubatus*). Then the area of undivided Tirunelveli district was 11, 568 sq.km and it should have had a minimum of 5000 sq.km blackbuck habitat. The depredation by cheetah on sheep and goat was possibly so rampant that the Government more or less declared cheetah a vermin and rewards were given. In Tirunelveli district, 16 cheetahs were killed for Rs. 287 (rate of Rs. 18 each) in 1874, 16 individuals in 1875 and 11 individuals in 1876 (Rangarajan, 1998). The once abundant blackbuck in Tirunelveli district is now confined to the Vallandu hills which have plant species such as *Albizzia amara, Dichrostachys cinerea, Dodonaea viscosa* and *Euphorbia antiquorum*. The area has been notified as a Blackbuck Sanctuary by the Tamil Nadu government. There could be a maximum of 40 blackbucks which at night leave the hills to forage in the adjoining agriculture fields.

Now if one travels from the temple city of Madurai to Tirunelveli, he or she will see only a sea of *Prosopis juliflora* in uncultivated areas. This aggressive exotic has not only smothered the valuable grasslands but by the strength of its deep rooted system has successfully competed with the native fibre-rooted palmyrah trees pushing the palm species to extinction in rain deficient areas a phenomenon reported with the date palms *(Phoenix dactylifera*) in Yemen (Spate Irrigation Network, 2014). Recovering the glory of the short grasslands in the dry plains of the southern districts of Tamil Nadu is a task beset with the formidable challenge of eradication of *Prosopis juliflora*.

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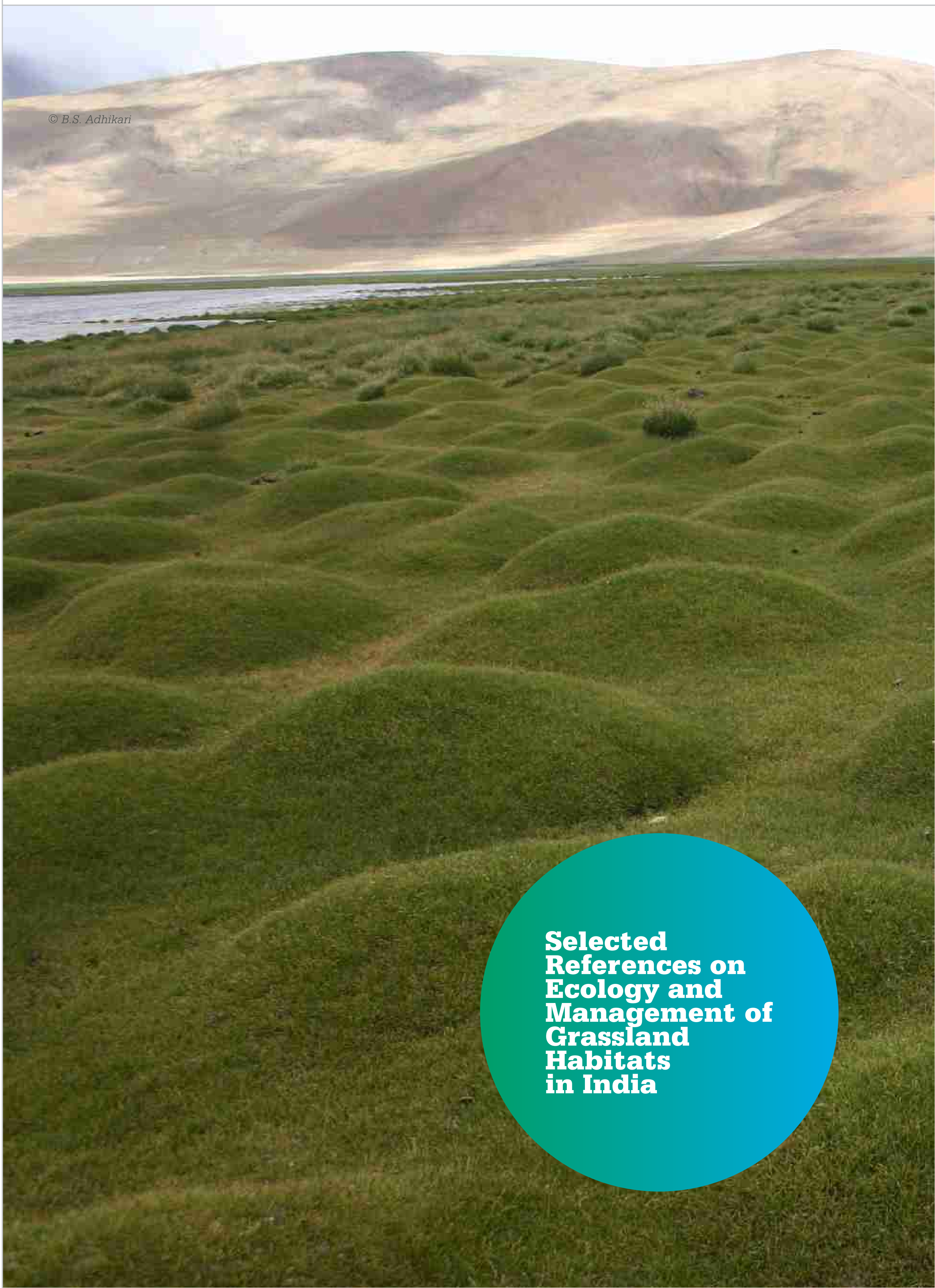

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Selected References on Ecology and Management of Grassland Habitats in India

Introduction

A large volume of scientific information on Grassland habitats is widely scattered in India. It would be critical to access appropriate and relevant literature on the subject due to absence of proper documentation. This compilation is the first attempt to collate the existing publishing information on 'Ecology and Management of Grassland Habitats of India' containing 291 references.

The following secondary sources have been consulted during the compilation of this bibliography:

WII Library and Documentation Centre in-house Databases

i) Reprint Database

ii) Book Database

iii) WILD Database (Indexing and Abstracting Database of Indian Wildlife)

iv) MPBIB Database (Bibliography on Wildlife and Protected Area management in Madhya Pradesh)

v) Indian Mammal Research bibliographic database

vi) e-Resources

The bibliography has been categorized according to mainly five document types (Research Papers; Thesis; Reports; Books/Book Chapters and Paper Presented in Conferences/Seminars etc.) and it is further classified into two parts (i.e. Animal Ecology and Grassland Ecology) to make it user friendly.

Bibliometric Analysis

The bibliographic output was subjected to the following bibliographic analysis in order to understand chronological development, types of document sources, subjects and studies conducted in different Biogeographic Zones and authorship pattern.

References are broadly arranged chronologically in Table-1 into following two groups -

a. Published before 2000

b. Published on or after 2000

The Trends of chronological development of literature has been shown in Table 20.1. The percentage of research papers is 62% while rest other categories together is 38%.

Table 20.1. Chronological Development

S.N	Time period	No. of References		Total References	
		Animal Ecology	Grassland Ecology	Number of References	Percentage
1	Published before 2000	33	148	181	62.2%
2	Published on or after 2000	54	56	110	37.8%
	Total	**87**	**204**	**291**	**100%**

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The breakup of types of documents included in the bibliography is shown in **Figure 20.1 & 20.2**. The data reveals that out of 291 publications, a majority (n= 150) are research papers.

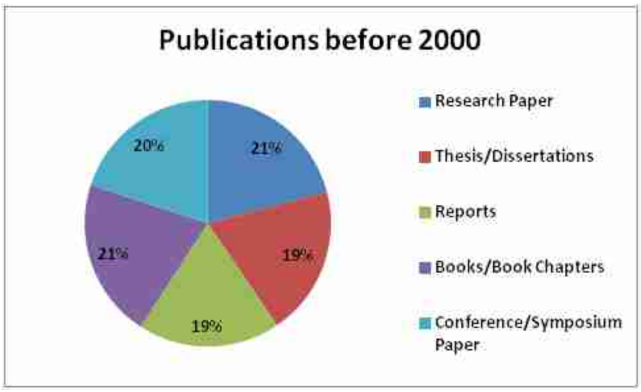

Figure 20.1 various types of publications on grasslands published before year 2000.

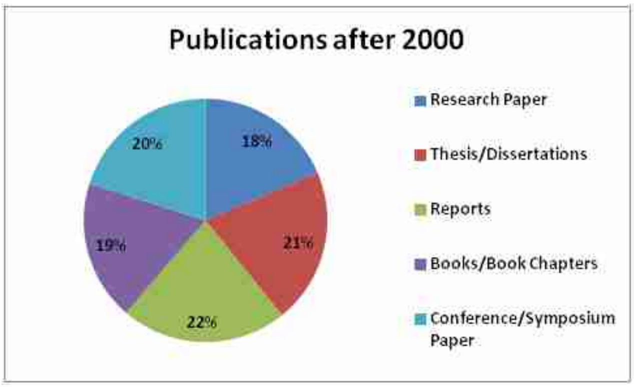

Figure 20.2 various types of publications on grasslands published before year 2000.

Each reference in the bibliography has been analysed on the basis of 10 broad subject headings as shown in **Figure 20.3 & 20.4.** Studies before the year 2000 were mostly focused on grazing lands or pasture lands and ecological surveys which have shown a shift towards studies on pastoralism and conservation & management of grasslands in the recent years.

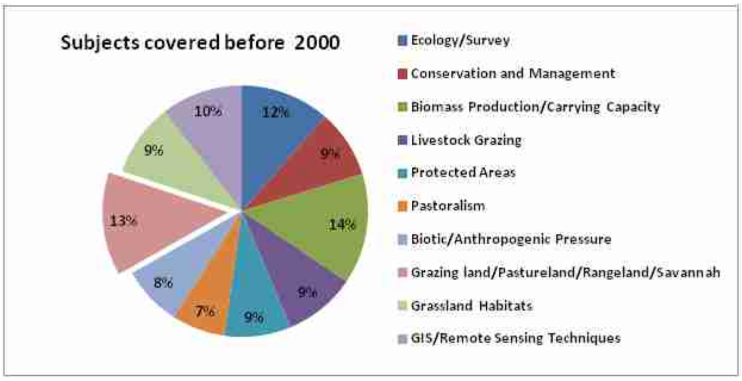

Figure 20.3 Subject headings covered in publications before the year 2000

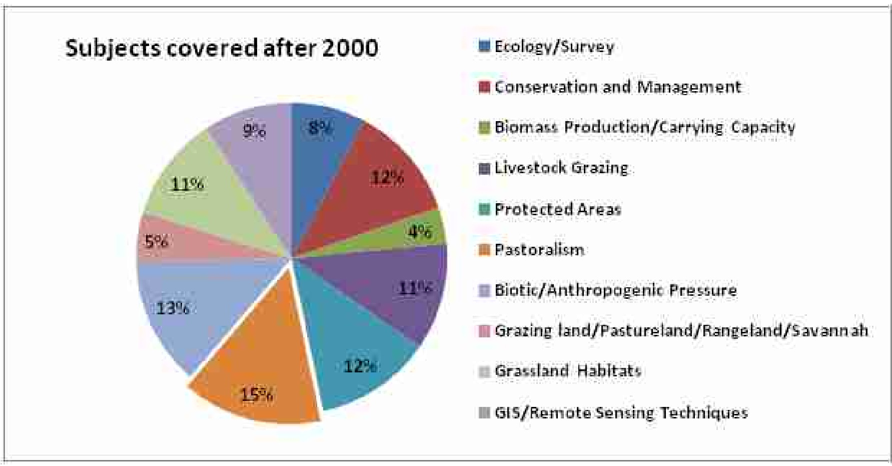

Figure 20.4 Subject headings covered in publications after the year 2000

The references were also analyzed by Biogeographic zone wise in Table 2. Following data reveals that maximum number of studies related to Grasslands Habitats have been carried out in Himalayan Region (Biogeographic Zone – 2).

Table 20.2. Biogeographic Zones where the studies have been conducted

S.N	Biogeographic Zone	Before 2000	After 2000	Total
1	Trans-Himalaya	5	22	27
2	Himalayas	56	23	79
3	Desert	16	11	27
4	Semi-arid	10	3	13
5	Western Ghats	16	15	31
6	Deccan Peninsula	18	4	22
7	Gangetic plains	20	14	34
8	North-East	3	8	11

For the convenience of the user, this bibliography is also available in database form at WII's Library and Documentation Centre. It is hoped that providing information both in traditional printed form as well as through machine readable database will be very useful and act as a ready reference to both professional and amateur wildlife ecologists and protected area managers, interested in the grassland habitats of India. We would also like to add that this database is not complete. While all possible efforts have been made to cite the references as accurately as possible, it is probable that some mistakes have remained, largely owing to the compilation of the majority of references from secondary sources. We would be grateful if such mistakes are brought to our notice for correction and continuous updation of this database.

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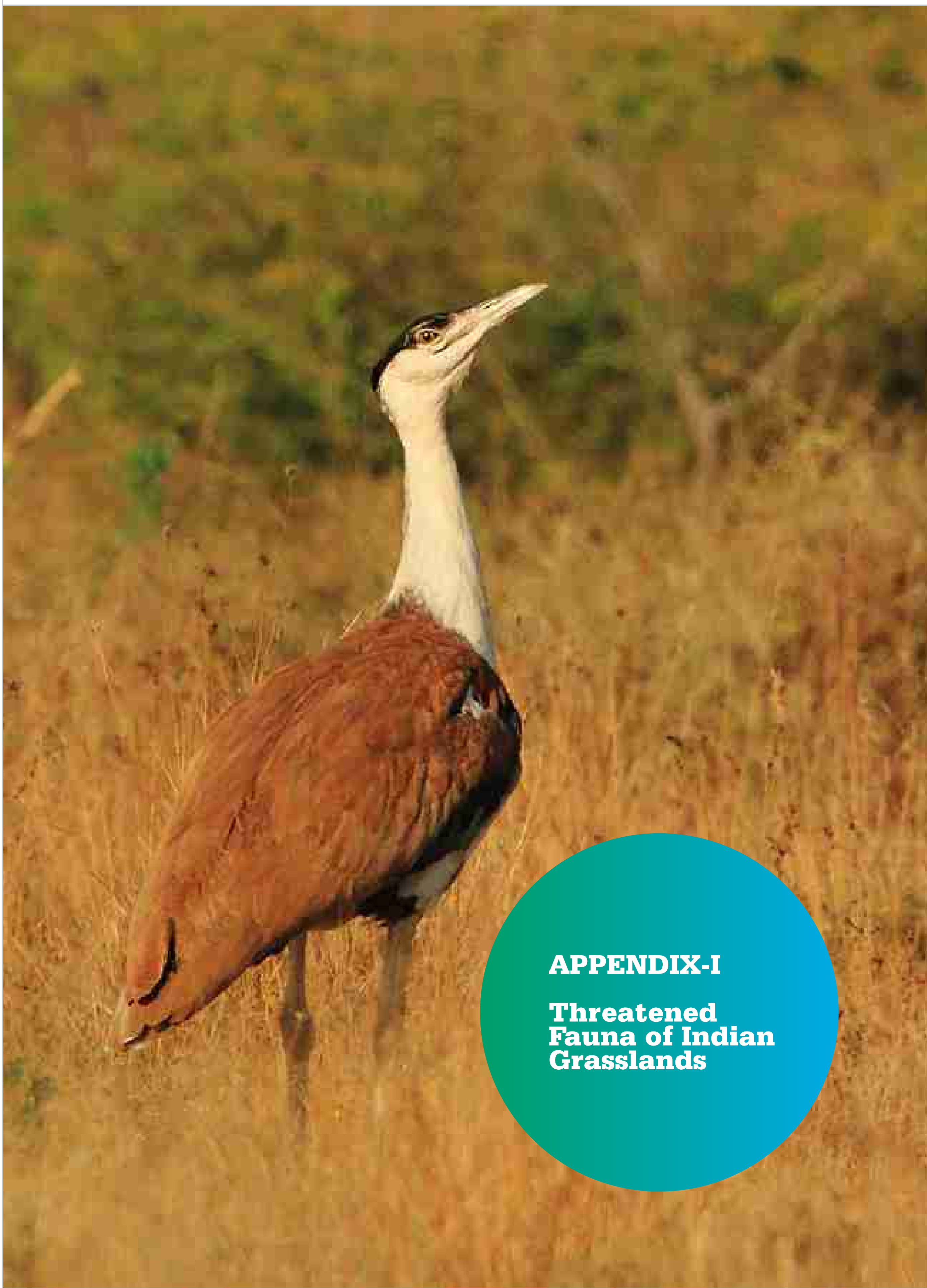

APPENDIX-I

Threatened Fauna of Indian Grasslands

Threatened fauna of Indian Grasslands (Source: Anonymous 2006)

Species	Schedule of WPA	IUCN Status	Habitat
Tibetan Antelope/ Chiru Pantholops hodgsonii	I	EN	Cold Desert
Tibetan Gazelle Procapra picticaudata	I	NT	Cold Desert
Tibetan Wolf Canis lupus chanco	I	LC	Cold Desert
Tibetan Fox Vulpes ferrilata	I	LC	Cold Desert
Black-necked Crane Grus nigricollis	I	VU	Cold Desert, Grassland
Chinkara Gazella bennettii	I	LC	Desert, open scrub
Lesser Florican Sypheotides indica	I	EN	Grassland
Asiatic Wildcat Felis silvestris ornata	I	LC	Hot Desert
Desert Fox Vulpes vulpes pusilla	II	LC	Hot Desert
Asiatic Wild Ass/ Khur Equus hemionus khur	I	EN	Hot Desert
Asian Houbara Chlamydotis macqueenii	I	VU	Hot Desert
Indian Fox Vulpes bengalensis	II	LC	Hot Desert, grassland
Indian Desert Monitor Varanus griseus	I	LC	Hot Desert, grassland
Spiny-tailed Lizard Saraa hardwickii	II	LC	Hot Desert, grassland
Great Indian Bustard Ardeotis nigriceps	I	CR	Hot Desert, grassland
Laggar Falcon Falco jugger	I	NT	Hot Desert, grassland
Saker Falcon Falco cherrug	I	EN	Hot Desert, grassland
Red-headed Falcon Falco chicquera	I	NT	Hot Desert, grassland
Caracal Caracal caracal	I	LC	Hot Desert, grassland
Golden Jackal Canis aureus	II	LC	Hot Desert, grassland, etc
Peregrine Falcon Falco peregrinus	I	LC	Hot Desert, grassland, etc
Lesser Kestrel Falco naumanni	IV	LC	Hot Desert, grassland, etc
Tawny Eagle Aquila rapax	IV	LC	Hot Desert, grassland, etc
Steppe Eagle Aquila nipalensis	IV	LC	Hot Desert, grassland, etc
Eastern Imperial Eagle Aquila heliaca	IV	VU	Hot Desert, grassland, etc
Lesser Spotted Eagle Clanga pomarina	IV	LC	Hot Desert, grassland, etc
Eurasian Buzzard Buteo buteo	IV	LC	Hot Desert, grassland, etc
Long-legged Buzzard Buteo rufinus	IV	LC	Hot Desert, grassland, etc
Upland Buzzard Buteo hemilasius	IV	LC	Hot Desert, grassland, etc
All species of Harriers Circus spp.	IV	-	Hot Desert, grassland, etc
Short-toed Snake Eagle Circaetus gallicus	IV	LC	Hot Desert, grassland, etc
Red-headed Vulture Sarcogyps calvus	IV	CR	Hot Desert, grassland, etc
White-backed Vulture Gyps bengalensis	I	CR	Hot Desert, grassland, etc
Long-billed Vulture Gyps indicus	I	CR	Hot Desert, grassland, etc
Slender-billed Vulture Gyps tenuirostris	I	CR	Hot Desert, grassland, etc
Eurasian Griffon Gyps fulvus	IV	LC	Hot Desert, grassland, etc
Egyptian Vulture Neophron percnopterus	IV	EN	Hot Desert, grassland, etc
Indian Wolf Canis lupus	I	LC	Hot Desert, grasslands
Jungle Cat Felis chaus	II	LC	Hot Desert, scrub jungle
Nilgiri Tahr Nilgiritragus hylocrius	I	EN	Shola grassland
Blackbuck Antilope cervicapra	I	NT	Short grass plains
Manipur Brow-antlered Deer/Sangai Rucervus eldii	I	EN	Wet grassland
Swamp Deer/ Barasingha Rucervus duvaucelii	I	VU	Wet grassland
Hog Deer Axis porcinus	III	EN	Wet grassland

Species	Schedule of WPA	IUCN Status	Habitat
Hispid Hare Caprolagus hispidus	I	EN	Wet grassland
Pygmy Hog Porcula salvania	I	CR	Wet grassland
Indian Rhinoceros Rhinoceros unicornis	I	VU	Wet grassland
Bengal Florican Houbaropsis bengalensis	I	CR	Wet grassland
Swamp Francolin Francolinus gularis	IV	VU	Wet grassland
Lesser Adjutant Leptoptilos javanicus	IV	VU	Wet grassland
Greater Adjutant Leptoptilos dubius	IV	EN	Wet grassland
Jerdon's Babbler Chrysomma altirostre	IV	VU	Wet grassland
Black-breasted Parrotbill Paradoxornis flavirostris	IV	VU	Wet grassland
Marsh Babbler Pellorneum palustre	IV	VU	Wet grassland
Finn's Baya Ploceus megarhynchus	IV	VU	Wet grassland
Asiatic Wild Buffalo Bubalus arnee	I	EN	Wet grassland, Forest

*Anonymous (2006). Report of the Task Force on Grasslands and Deserts. Planning Commission, Govt. of India, New Delhi

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Wildlife Institute of India