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.

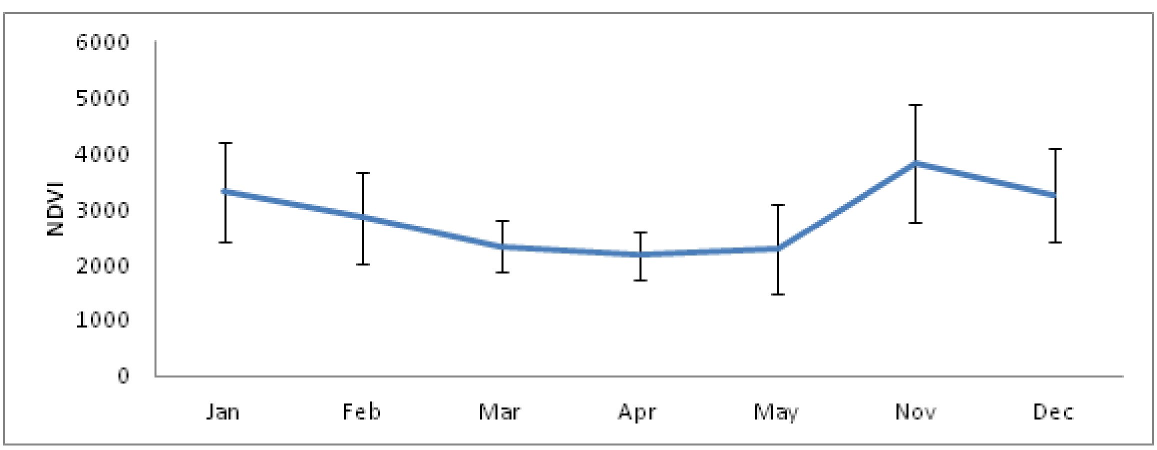
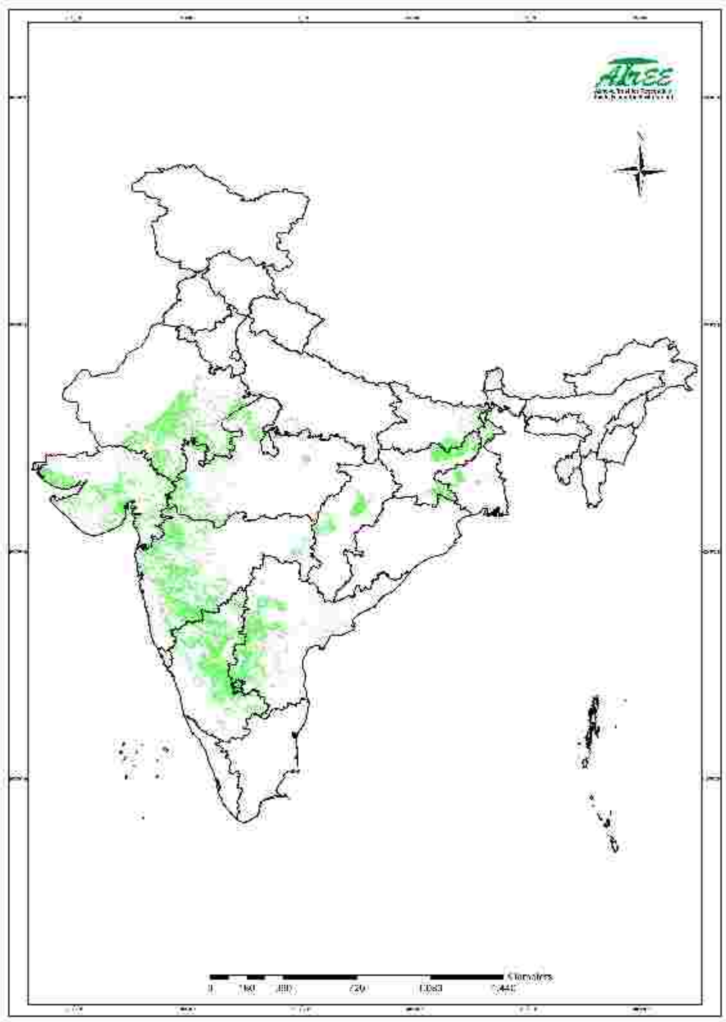


Figure 16.1 Seasonal trends in NDVI values of SSG sites across Peninsular India (Error bars are ±SD)

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)**

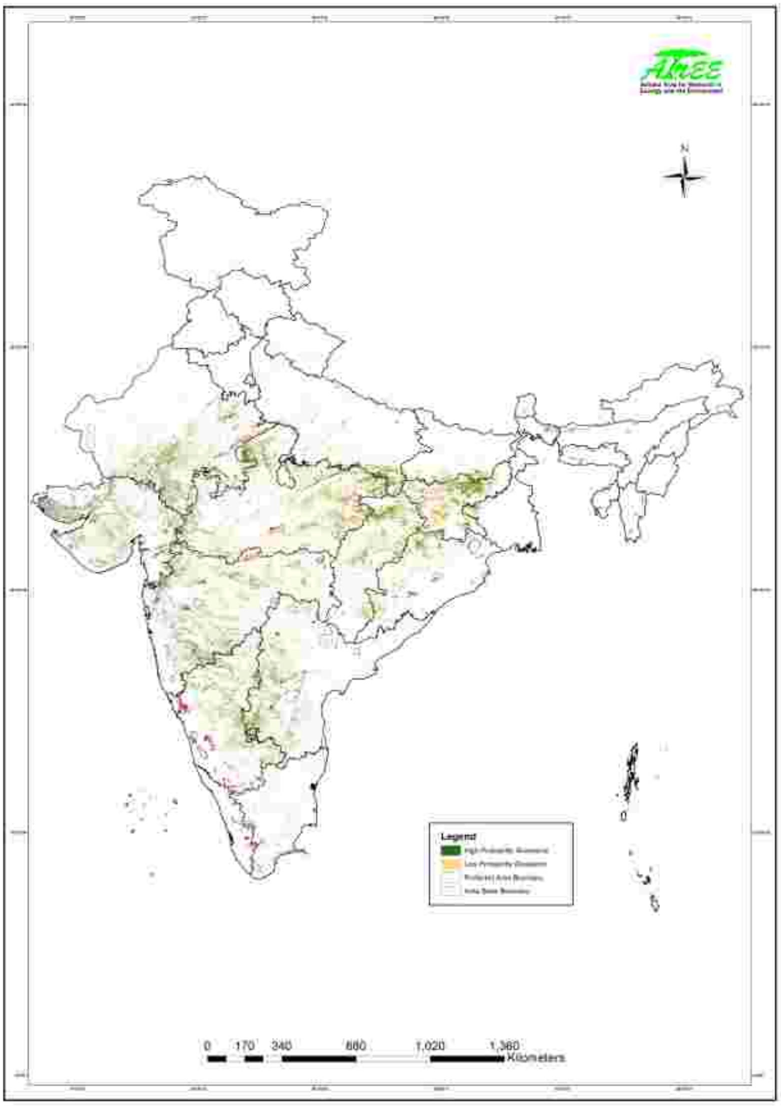


Figure 16.2 An unsupervised classification of MODIS NDVI showing the probability of semi-arid savanna grassland occurrence in India

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)**.

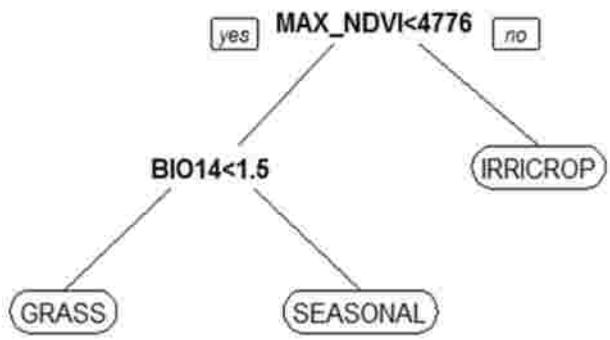


Figure 16.3 A rule-based regression tree prediction map of semi-arid savanna grasslands in India. The classification tree identifies the fundamental niche of the SSG.

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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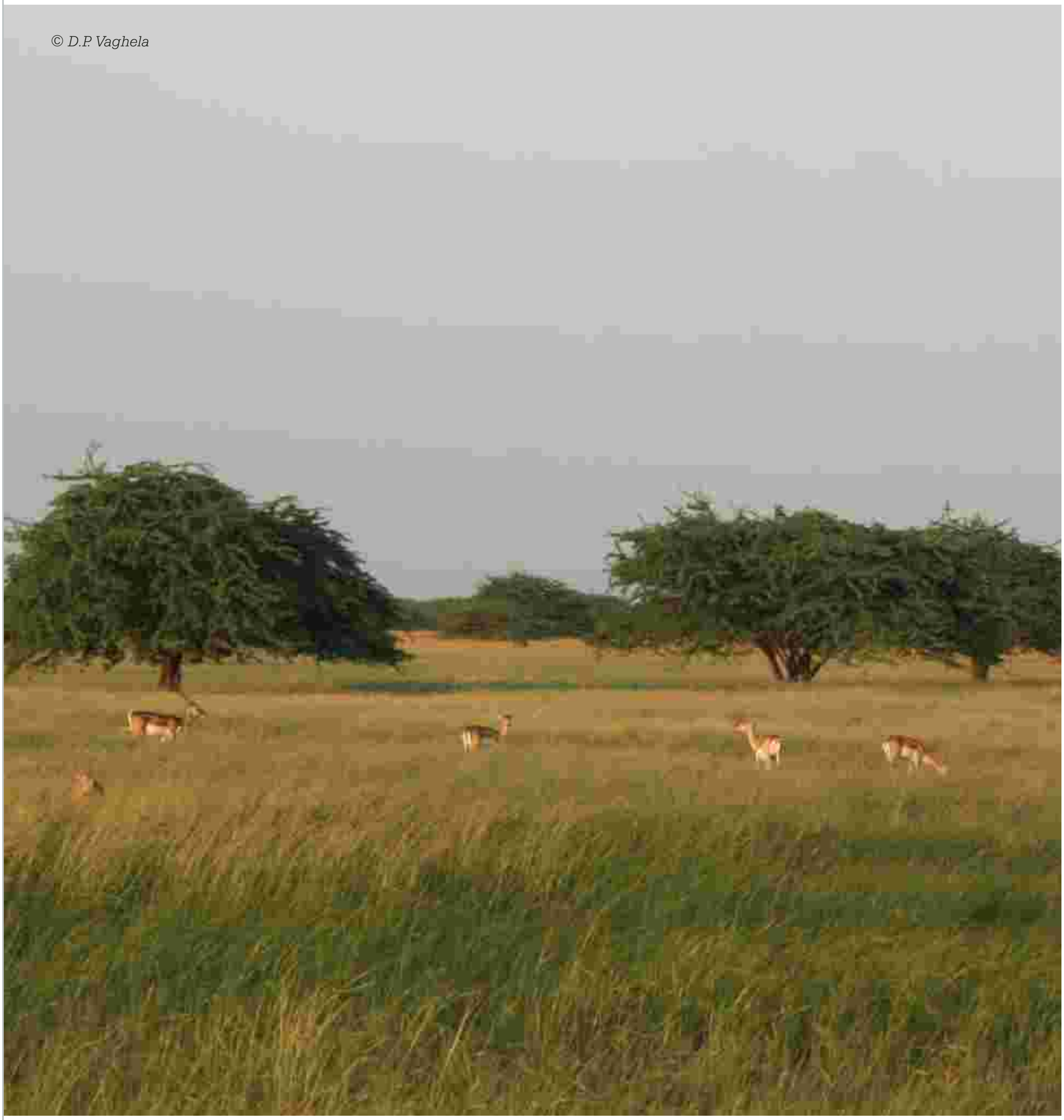

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References

Blasco, F., Bellan, M., and Aizpuru, M. (1996). A vegetation map of tropical continental Asia at scale 1: 5 million. Journal of Vegetation Science, 623-634.

Cabeza, M., and Moilanen, A. (2001). Design of reserve networks and the persistence of biodiversity. Trends in Ecology and Evolution, 16(5), 242-248.

Champion, S. H., and Seth, S. K. (1968). A revised survey of the forest types of India. New Delhi

Dabadghao, P., and Shankarnarayan, K. A. (1973). The grass cover of India. The grass cover of India.

Dutta, S., and Jhala, Y. (2014). Planning agriculture based on landuse responses of threatened semiarid grassland species in India. Biological Conservation, 175, 129-139.

Friedl, M. A., and Brodley, C. E. (1997). Decision tree classification of land cover from remotely sensed data. Remote sensing of environment, 61(3), 399-409.

Ganesh, T., and Kanniah, P. (2000). Roost counts of harriers Circus spanning seven winters in Andhra Pradesh, India. Forktail, 1-4.

Jensen, J. R. (1996). Introductory digital image processing: a remote sensing perspective. Prentice-Hall Inc.

Kawamura, K., Akiyama, T., Yokota, H. o., Tsutsumi, M., Yasuda, T., Watanabe, O., and Wang, S. (2005). Comparing MODIS vegetation indices with AVHRR NDVI for monitoring the forage quantity and quality in Inner Mongolia grassland, China. Grassland Science, 51(1), 33-40.

Lawrence, R. L., and Wright, A. (2001). Rule-based classification systems using classification and regression tree (CART) analysis. Photogrammetric Engineering and Remote Sensing, 67(10), 1137-1142.

Margules, C., and Pressey, R. (2000). Systematic conservation planning. Nature, 405(6783), 243-253.

McGarigal, K. (2001). Conservation Assessment and Prioritization Systems. http://www.umass.edu/landeco/research/caps/caps.html.

Mishra, C., Allen, P., McCarthy, T., Madhusudan, M., Bayarjargal, A., and Prins, H. (2003). The role of incentive programs in conserving the snow leopard. Conservation Biology, 17(6), 1512-1520.

Misra, R. (1983). Indian savannas. Ecosystems of the World.

Moilanen, A., Franco, A., Early, R., Fox, R., Wintle, B., and Thomas, C. (2005). Prioritizing multiple-use landscapes for conservation: methods for large multi-species planning problems. Proceedings of the Royal Society B: Biological Sciences, 272(1575), 1885.

Moilanen, A., Meller, L., Leppänen, J., Montesino Pouzols, F., Arponen, A., and Kujala, H. (2014). Zonation spatial conservation planning framework and software. Version 4.

Ouyang, W., Hao, F., Skidmore, A. K., Groen, T. A., Toxopeus, A., and Wang, T. (2012). Integration of multi-sensor data to assess grassland dynamics in a Yellow River sub-watershed. Ecological indicators, 18, 163-170.

Pandey, C., and Singh, J. (1991). Influence of grazing and soil conditions on secondary savanna vegetation in India. Journal of Vegetation Science, 2(1), 95-102.

Pandey, C., and Singh, J. (1992). Rainfall and grazing effects on net primary productivity in a tropical savanna, India. Ecology, 2007-2021.

Peel, M. C., Finlayson, B. L., and McMahon, T. A. (2007). Updated world map of the Köppen-Geiger climate classification. Hydrology and Earth System Sciences Discussions, 4(2), 439-473.

Puri, G., Meher-Homji, V., Gupta, R., and Puri, S. (1983). Forest ecology. Volume I. Phytogeography and forest conservation. Forest ecology. Volume I. Phytogeography and forest conservation.(Ed. 2).

Ratnam, J., Bond, W. J., Fensham, R. J., Hoffmann, W. A., Archibald, S., Lehmann, C. E., Anderson, M. T., Higgins, S. I., and Sankaran, M. (2011). When is a 'forest'a savanna, and why does it matter? Global Ecology and Biogeography, 20(5), 653-660.

Rodgers, W., Panwar, H., and Mathur, V. (2002). Wildlife protected area network in India: a review. Wildlife Institute of India, Dehra Dun, India.

Roy, P., Behera, M., Murthy, M., Roy, A., Singh, S., Kushwaha, S., Jha, C., Sudhakar, S., Joshi, P., and Reddy, C. S. (2015). New vegetation type map of India prepared using satellite remote sensing: Comparison with global vegetation maps and utilities. International Journal of Applied Earth Observation and Geoinformation, 39, 142-159.

Sankaran, M., and Ratnam, J. (2013). African and Asian Savannas. In S. Levin (ed.), Encyclopedia of Biodiversity (Vol. 1, pp. 58–74). Elsevier Press. .

Scholes, R., and Archer, S. (1997). Tree-grass interactions in savannas. Annual Review of Ecology and Systematics, 517-544.

Shahabuddin, G., and Rangarajan, M. (2007). Making conservation work: Securing biodiversity in this new century. Permanent Black.

Shankarnarayan, K. (1977). Impact of overgrazing on the grasslands [India]. Annals of Arid Zone, 16.

Singh, P., Rahmani, A. R., Singh, K. D., Narain, P., Singh, K. A., Kumar, S., Rawat, G. S., and Chundawat, R. S. (2006). Report of the Task Force on Grasslands and Deserts (pp. 1-32): Planning Commission, Government of India.

Vanak, A. T., and Gompper, M. E. (2010). Multi-scale resource selection and spatial ecology of the Indian fox in a human-dominated dry grassland ecosystem. Journal of Zoology, 281, 140-148.

Vanak, A. T., Irfan-Ullah, M., and Peterson, T. (2008). Gap analysis of Indian fox conservation using ecological niche modelling. Journal of the Bombay Natural History Society, 105(1), 49-54.

Vavra, M. (2005). Livestock grazing and wildlife: developing compatibilities. Rangeland Ecology and Management, 58(2), 128-134.

White, R. P., Murray, S., Rohweder, M., Prince, S. D., and Thompson, K. M. (2000). Grassland ecosystems. World Resources Institute Washington, DC, USA.

Wikramanayake, E., McKnight, M., Dinerstein, E., Joshi, A., Gurung, B., and Smith, D. (2004). Designing a conservation landscape for tigers in human-dominated environments. Conservation Biology, 18(3), 839-844.

WRI. (1996). World Resources Report 1996. Washington, DC: World Resources Institute.