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REVIEW ARTICLE

Sustainable Biodiversity Management in India: Remote Sensing Perspective

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Abstract Remote sensing, a state of art technology has gained significance due to its capability to map and monitor compositional, structural and functional biodiversity. Remote sensing data provides a perspective on how ecosystems and species are being affected by the multiple disturbances. This paper presents consolidated information of earth observation based biodiversity research and conservation applications in India. Progress achieved for understanding essential biodiversity variables with reference to species populations, species traits, community composition, ecosystem function and ecosystem structure have been reviewed. Studies mostly focused on remote sensing based biodiversity indicators in understanding of land cover, forest cover, forest type, fragmentation, biological richness, carbon stocks, fires and protected area monitoring at multiple spatial and temporal scales. Fine resolution understanding with reference to vegetation structure, function, distribution of threatened, endemic and invasive species is required for effective conservation strategies. The declining trend of deforestation and effectiveness of protected area network indicates India's commitment towards the global conservation targets. Ensured continuity of remote sensing can support in near real monitoring of habitats and achieving conservation effectiveness.

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1 Introduction

Explaining of biodiversity is one of the most complex issues in ecology. The concept of sustainable forest management is characterized by seven elements: extent of forest resources; forest biological diversity; forest health and vitality; productive functions of forest resources; protective functions of forest resources; socio-economic functions of forests; and legal, policy and institutional framework [1]. Ground surveying is the traditional method of obtaining biodiversity information. Monitoring of biodiversity with traditional methods often requires as much effort as compiling the initial inventory and is prohibitively expensive. Results of traditional methods cannot be extrapolated to the surrounding landscape or different temporal periods. There is a long-standing interest in assessing, monitoring and modeling the distribution of species [2]. Earth Observation gathers information about planet Earth's physical, chemical and biological systems using remote sensing technologies supplemented with ground-based observations. Satellite remote sensing provides global coverage and continuous measures about the condition of biodiversity and has the potential for conservation interventions across spatial and temporal scales [3]. Murthy et al. [4] has reviewed applications of remote sensing for biodiversity assessment. The spectral, spatial and temporal resolution of remote sensing data assumes that there are unique, definable types in the form of vegetation categories, communities and species. Spectral heterogeneity in remotely sensed images has been used as a proxy of species diversity for large areas in a reliable manner [5].

India with varied topography, land use, geographic and climatic factors can be divided into ten biogeographic zones [6]. India, a mega diversity country harbours about 8% of all species, including 47,513 species of plants and 91,000 species of animals. Of the 18,043 species of flowering plants of India, 4036 species (22%) are endemic [7]. About 27% of the population in India depends on forests for at least part of their subsistence and cash livelihoods, which they earn from minor forest produce [8]. To limit human activities on forests a network of 733 Protected Areas have been established, extending over 1,60,901.74 km^2 comprises 103 national parks, 537 wildlife sanctuaries, 67 conservation reserves and 26 community reserves [9]. India was one of the first countries to have a proactive legislation and enacted a Biological Diversity Act in 2002 to implement the provisions of Convention on Biological Diversity. The Biological Diversity Act, 2002 focused on the conservation of biological resources by facilitating access to local communities by a sustainable approach [10].

The role of earth observation data in biodiversity monitoring was recognised in targets to be achieved by 2020. Aichi biodiversity targets 5 (habitat loss, fragmentation and degradation), 7 (sustainable agriculture, aquaculture and forestry), 9 (control of invasive alien species) and 11 (protected areas) rely on earth observation data [11]. The sustainable development goal 15 of the 2030 Agenda is devoted to protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification and halt and reverse land degradation and halt biodiversity loss [12]. A strategy has been drawn by Indian Space Research Organisation (ISRO), Department of Space on harnessing the benefits of space applications in tune with the sustainable development goals. ISRO's Vision for 2017–2030 highlights bio-resources assessment, mapping of biodiversity and study of the impact of human activities to derive plans for conservation [13]. Indian Bioresource Information Network (IBIN) is being upgraded with larger participation of Biodiversity Resource Information Centres (BRICS) as a distributed national infrastructure to serve as online application services of bioresources of the country [14].

2 Tracking Biodiversity Targets and Remote Sensing

A National Biodiversity Action Plan (NBAP) was developed in 2008 and aligned to the Global Strategic Plan for Biodiversity 2011–2020. Using the Strategic Plan as a framework, India has developed 12 National Biodiversity Targets. National Biodiversity Target 3 envisages strategies for reducing rate of degradation, fragmentation and loss of natural habitats. National Biodiversity Target 4 envisions, invasive alien species and pathways to be identified and strategies to manage them developed so that populations of prioritized invasive alien species are managed. National Biodiversity Target 5 was on measures adopted for sustainable management of agriculture, forestry and fisheries. National Biodiversity Target 6 was meant for ecologically representative areas for biodiversity and ecosystem services are conserved based on protected area designation and other area based conservation measures covering over 20% of the geographic area of the country [10].

Recent advances in sensor technology offer great opportunities to monitor individual tree species using high spatial resolution imagery or imaging spectroscopy for mapping plant function and structural attributes, though in situ data is required to calibrate and validate the models and data products. A consistent approach is required to define and translate remotely sensed observation data into metrics (essential biodiversity variables) applicable to biodiversity monitoring [15]. Conceptual temporal and spatial hierarchical organization of vegetation features identifiable from remotely-sensed images and the required image pixel resolution for mapping the features is shown in Fig. 1.

2.1 Essential Biodiversity Variables

The Group on Earth Observations–Biodiversity Observation Network (GEO BON) developed the basic concept of essential biodiversity variables (EBVs) in 2012 [17]. Essential biodiversity variables were defined as 'measurements required for studying, reporting and managing biodiversity change'. The EBVs are based on remotely sensed observations that can be measured continuously across space as well as field observations from local sampling schemes that can be integrated into large-scale generalisations. The EBV framework highlights repetitive measures for the same taxa at the same locations or regions mostly at short-term intervals (1–5 years), while a few may be medium term (10–50 years). Vegetation height, canopy cover, greenness phenology and leaf area index are all variables suggested as potential continuous EBVs [18]. The three categories of biodiversity—composition, structure and function, integrates six classes of EBVs: genetic composition, species populations, species traits, community composition, ecosystem structure and ecosystem function (Table 1). The compositional diversity (taxonomic), functional diversity and structural diversity, integrates into a nested hierarchy that incorporates elements of each attribute at four levels of organization: regional

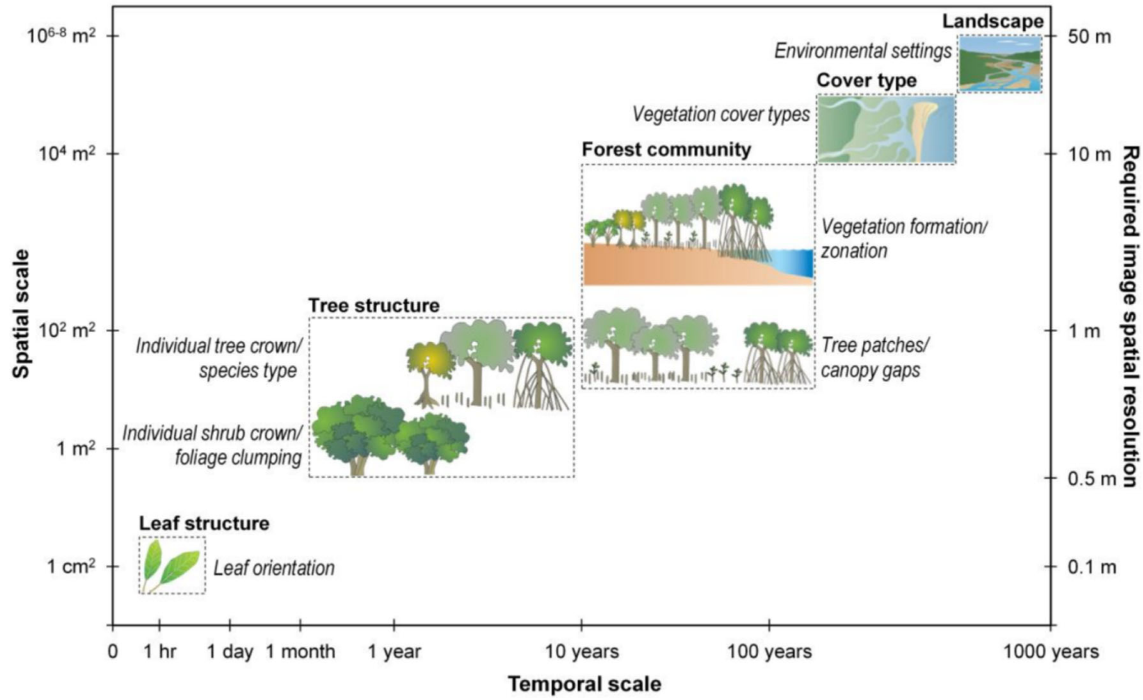


Fig. 1 Biodiversity information across the scales through remote sensing [16]

Table 1 Candidate EBVs that can be measured by remote sensing [15]

EBV class	Candidate remote sensing-EBV
Species populations	Species distribution
Species populations	Species abundance
Species traits	Leaf phenology
Species traits	Plant traits (ex. specific leaf area, leaf nitrogen content)
Community composition	Taxonomic diversity, relative cover of invasive alien species
Community composition	Functional diversity
Ecosystem function	Productivity (ex. NPP, LAI, FAPAR, biomass)
Ecosystem function	Disturbance regime (ex. Fire)
Ecosystem structure	Habitat structure (ex. Height, crown cover and density)
Ecosystem structure	Ecosystem extent and fragmentation (ex. Land cover, forest)
Ecosystem structure	Ecosystem composition by functional type

landscape, community-ecosystem, population-species and genetic [19]. It is important to recognize that while these levels can have a scale, levels are not scales.

The set of earth observation based variables includes monitoring of land cover changes, protected areas, regional landscapes, habitat fragmentation, connectivity, vegetation community assemblages and structure, mapping spatial variation of species level traits, species patterns in environmental and disturbance gradient, functional diversity (biomass, carbon flux), invasive plant species, stress and disturbances on vegetation, status or habitat degradation, modeling species distribution, tree health and nutrient cycling [20].

The studies have been oriented towards remote sensing based indicators and attempted to answer the selected biodiversity conservation targets in India. The significant contributions which have relevance with biodiversity monitoring are highlighted in Table 2. However, these indicators measured for forests have relevance to essential biodiversity variables at national scale/regional scale. Examples of remote sensing based EBVs that can track ecosystem structure, function and community composition have been focused in the following sections.

2.2 Ecosystem Structure

Due to a lack of data on ecosystem extent, land cover is used as a proxy for ecosystems [15]. In this context, spatially explicit boundaries of land cover are important for sustainable management of biodiversity. Land use/land cover are also an important indicator of habitat. In India, optical satellite data being utilized for monitoring of land cover. Operational satellite data based land cover products are available from National Remote Sensing Centre

Table 2 Earth observation based products useful to monitor biodiversity and conservation at multiple spatial scales

S. no.	Product	Data used/year	Scale/resolution	EBV class	Highlights	References
1	Forest cover map (biennial)	Landsat MSS/TM/IRS LISS III1985-2015	1:250 K/1:50 K	Composition, structure	Tree cover maps of India (inside and outside forest areas)	State of forest reports, FSI (1987–2015) [26]
2	Forest cover map	Topographical maps: 1930; Landsat MSS: 1975, 1985; IRS LISS I: 1995; Resourcesat-1 and 2 AWiFS: 2005, 2013	1:250 K, 80, 72.5, 56 m	Composition	Spatial analysis for long-term forest cover change; use of natural forest definition	Reddy et al. [42] in Biodiversity and Conservation
3	Vegetation type and land cover map	IRS WiFS 1998	1:1 M	Composition	Mapping of major vegetation types using phenological investigations	Roy et al. [35] in Ecological Modelling
4	Forest type map	IRS 1D LISS III 2002	Grid dimensions of 2 ½′ and 2 ½′	Composition	Classification is based on Champion and Seth's scheme of forest types	FSI [38]
5	Vegetation type and land cover map	IRS LISS III 2005–2006	1:50 K	Composition	Classification scheme is focused on mixed, gregarious, locale specific and degradation classes	Roy et al. [36] Biodiversity characterisation at landscape level: national assessment
6	Forest type and land cover map	Resourcesat-2 AWiFS 2013–2014	56 m	Composition	Classification is based on ecological rule bases followed by Champion and Seth's scheme of forest types	Reddy [39] in Environmental Monitoring and Assessment
7	Spatial patterns of forest fragmentation	Forest cover map (Resourcesat-1 AWiFS 2005) and Fragstat	56 m	Structure	Forest fragmentation was analysed based on landscape indices	Reddy et al. [30] in Ecological Engineering
8	Forest fragmentation index	Forest cover map (IRS LISS III 2005–2006) and Spatial modelling	500 m × 500 m grid	Structure	Classification of the fragmentation map (high, medium, low)	Roy et al. [31] in Current Science
9	Landscape level biological richness map	Forest cover map (IRS LISS III 2005–2006) and spatial modelling	500 m × 500 m grid	Composition	Integrated product based on disturbance, terrain complexity, ecosystem uniqueness, species richness and biological value	Roy et al. [36]. Biodiversity characterisation at landscape level: national assessment
10	Intact forest landscapes	Multi-source data from 1930–2015	30 m	Composition	237 forest landscapes covering 5.4% of the natural forest area remained as intact in India	Reddy et al. [32] in Global and Planetary Change
11	Forest biomass carbon pool estimates	Multi-source data from 1930–2013	5 km grid	Structure and function	Forest canopy density maps and multi-source data were analysed	Reddy et al. [46] in Global and Planetary Change
12	Forest burnt area map	Resourcesat-2 AWiFS 2014	56 m	Function	Pattern of fire incidences and burnt area in vegetation types	Reddy et al. [48] in Current Science
13	Land use/land cover map (annual)	Resourcesat-1/2 AWiFS 2005–2016	1:250 K	Composition	Identified three cropping seasons for estimating net sown area	http://bhuvan.nrsc.gov.in [21, 24]
14	Land use/land cover map	IRS LISS III 2005–2006 and 2011–2012	1:50 K	Composition	Level III LULC maps of India prepared using three season multispectral data at five years interval	http://bhuvan.nrsc.gov.in [22, 24]
15	Land use/land cover map	Landsat MSS 1985, IRS LISS I 1995, Landsat TM/ETM+, Resourcesat-1 LISS III 2005	80, 72.5, 30, 23.5 m	Composition	Recorded overall land cover changes at 10 years interval	Roy et al. [23] in Remote Sensing; https://daac-news.ornl.gov/content/land-use-and-land-cover-india [34]

(NRSC), ISRO. National Remote Sensing Centre (NRSC) is generating the annual land use/land cover maps on 1:250,000 scale with focus on cropping patterns [21]. NRSC had prepared Level III land use/land cover maps of India using multi-season IRS LISS III data on 1:50,000 scale [22]. Forest is the second largest land cover in India after agriculture. Roy et al. [23] analyzed land use/land cover changes for 1985, 1995 and 2005. The digital land use/land cover maps of 1:250,000 scale, 1:50,000 scale and 1:10,000 scale of India were available in http://bhuvan.nrsc.gov.in [24].

First forest cover assessment was made by National Remote Sensing Agency using Landsat MSS data at 1:1 M scale for two periods i.e. 1972–1975 and 1980–1982 [25]. Since 1987, biennial forest cover mapping is being done by the Forest Survey of India (FSI). FSI defines forest cover as all lands more than one hectare in area, with a tree canopy density of more than 10%, irrespective of ownership and legal status [26]. The mapping scheme of FSI using IRS LISS-III has three forest canopy density categories viz., 10–40%, 40–70% and $> 70\%$ crown cover on 1:50,000 scale. Increase in forest canopy density will provide additional habitat for native species and may minimize invasion by alien species. The study by NRSC [27] have provided quantification of natural forest cover change in India and defined forest as 'land spanning more than 1 ha, dominated with indigenous tree species having a minimum stand height of 5 m with an overstorey canopy cover greater than 10%'. Fractional forest cover maps pertaining to 1930, 1975 and 2013 and forest types were hosted in National Information system for Climate and Environment Studies (NICES) [28]. Reddy et al. [29] have predicted the forest cover of North East India and Andaman and Nicobar Islands for 2025.

Spatial landscape metrics indicates structural pattern and provides a key information on patch characteristics, connectivity or distance between patches and fragmentation by measuring patch composition, shape and configuration. Non-spatial landscape metrics focus on landscape patterns such as total number of patches and proportion of total area for each land cover class. The study of Reddy et al. [30] has provided national pattern of forest fragmentation in India. Roy et al. [31] have computed the fragmentation index at landscape level. Subsequently, degree of fragmentation was compared with vegetation types. The study by Reddy et al. [32] defines an intact forest landscape as a contiguous mosaic of naturally occurring ecosystems in a current extent of forest and showing no signs of human disturbance visible on satellite images. Remote sensing based case study has highlighted conservation concerns related to wildlife habitats and corridors [33].

2.3 Community Composition

IRS WiFS data was used for preparing vegetation type map of India on 1:1 M scale [35]. The vegetation classification scheme by Roy et al. (2012) was prepared focusing biodiversity prioritization, ecological uniqueness and naturalness [36, 37]. Forest Survey of India carried out forest type mapping based on IRS LISS III data of 2002 [38]. Forest type classification of Reddy et al. [39] classifies forests using multi-season Resourcesat-2 AWiFS data, ecological rule bases and the forest classes mapped according to classification scheme developed by Champion and Seth [40]. The forest type map at national level translated to the nomenclature of the existing land cover classification legends for integration [39]. Parallel efforts were being made to bring together forest types of bordering countries into a common classification scheme that will allow direct translation of forest types that extend across the international borders [41–43].

The study 'Biodiversity Characterization at Landscape Level using satellite remote sensing and Geographical Information System' was conducted by the Department of Space and Department of Biotechnology, Government of India [36]. This project provided information on the vegetation type, fragmentation, disturbance index and biological richness index [44]. As part of the project, field data was collected from a network of 16,500 sample plots covering 7,761 species of plants. The biological richness at landscape level was determined as function of ecosystem uniqueness, species diversity, biodiversity value, terrain complexity and disturbance index (Figs. 2, 3). This method of biodiversity characterization has the advantages over the traditional method of inventory i.e, has an ecological basis since many ecological components are considered and all the components have precise positional representation on earth surface [45]. However, community level biodiversity understanding is missing from the biodiversity monitoring system.

2.4 Ecosystem Function

Net primary productivity is the most relevant EBV and can be indirectly derived through integrated data of remote sensing and in situ observations. Carbon stored in the vegetation is principal variable which depends upon forest canopy density. Earth Observation based carbon stock products are not yet operational. As part of national carbon project, Reddy et al. [46] estimated above ground biomass carbon stock of Indian forests at 5 km grid level for 1930, 1975, 1985, 1995, 2005 and 2013. The multispectral sensors, the Moderate Resolution Imaging Spectroradiometer (MODIS) and Medium Resolution Imaging Spectrometer (MERIS) have been providing global observations over

Fig. 2 Flow chart showing methodology for biodiversity characterization at landscape level using remote sensing and GIS techniques [36]

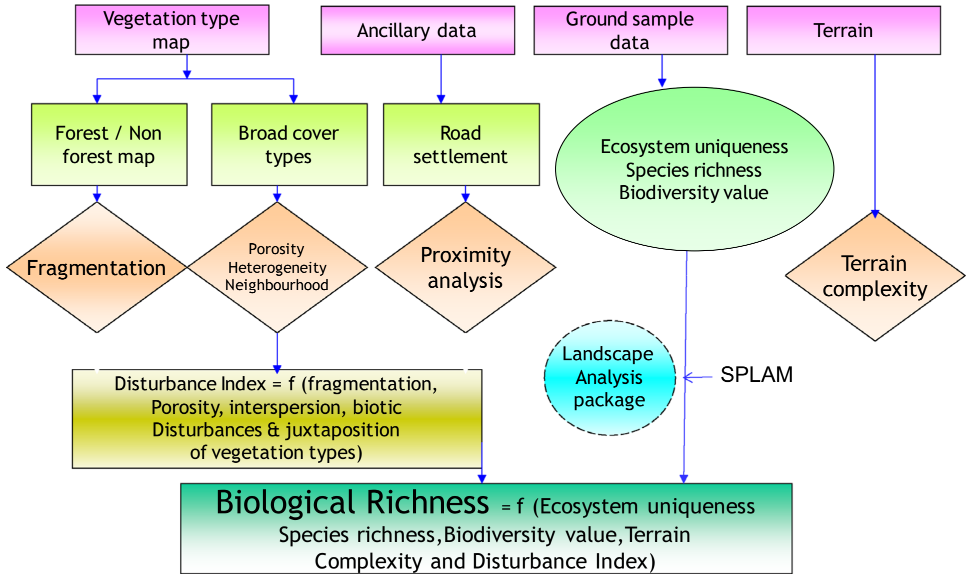
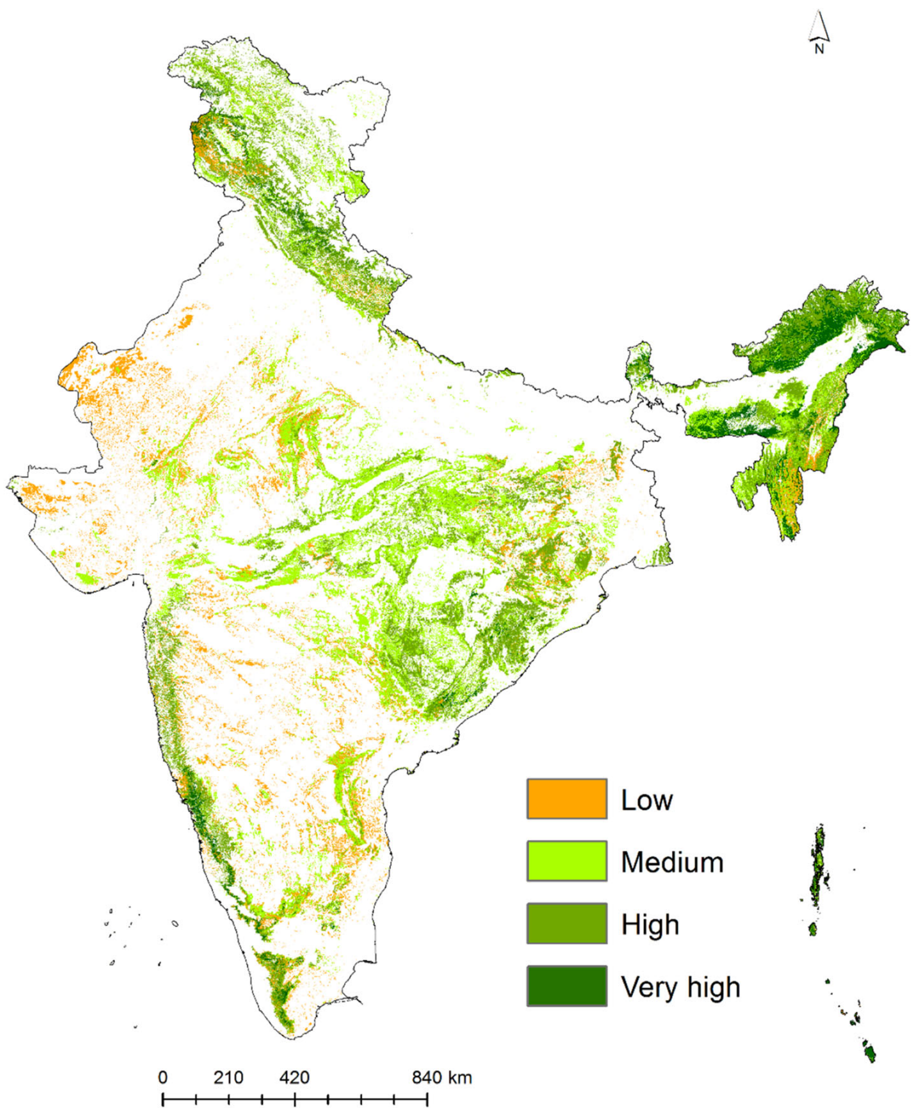


Fig. 3 Landscape level biological richness map of India [36]



broad scales since the early 2000s. Leaf area index (LAI) is a basic descriptor of vegetation condition can be measured and modelled across a range of spatial scales, from individual tree crowns or clusters to regions for a wide variety of physiological, climatological and biogeochemical studies. Study on evaluation of threat status of biodiversity at ecosystem level make an attempt towards actionable conservation prescription (Reddy et al. [47]). The first comprehensive forest burnt area assessment using Resourcesat-2 AWiFS data was conducted by Reddy et al. [48].

There is no detailed data available in India for invasive species distribution and impact of invasion across the ecosystems. Pasha et al. [49] had analysed the land cover conversions by tracking extent of *Prosopis juliflora* in Kachchh, Gujarat. Padalia et al. [50] modeled invasion range of *Hyptis suaveolens* in India using species distribution models. Adhikari et al. [51] identified the hotspots of alien species invasion in India through Ecological Niche Modelling using very coarse species occurrence data from the Global Biodiversity Information Facility. The study of Niphadkar et al. [52] demonstrate the facilitation by deciduous forests to the growth and spread of *Lantana camara* in Biligirangan hills, Western Ghats and highlighted the importance of using data at multiple scales for modelling invasion. In the present study, the level of alien plant invasion is analysed based on vegetation types derived through remote sensing and field observations from stratified random sampling and integrated into national scale generalization. The level of plant invasions in vegetation types of India was assessed using vegetation plot database formerly sampled for the purposes of landscape level biodiversity characterization [36].

The level of plant invasion in this study is calculated based on relative contribution of individuals of alien plant

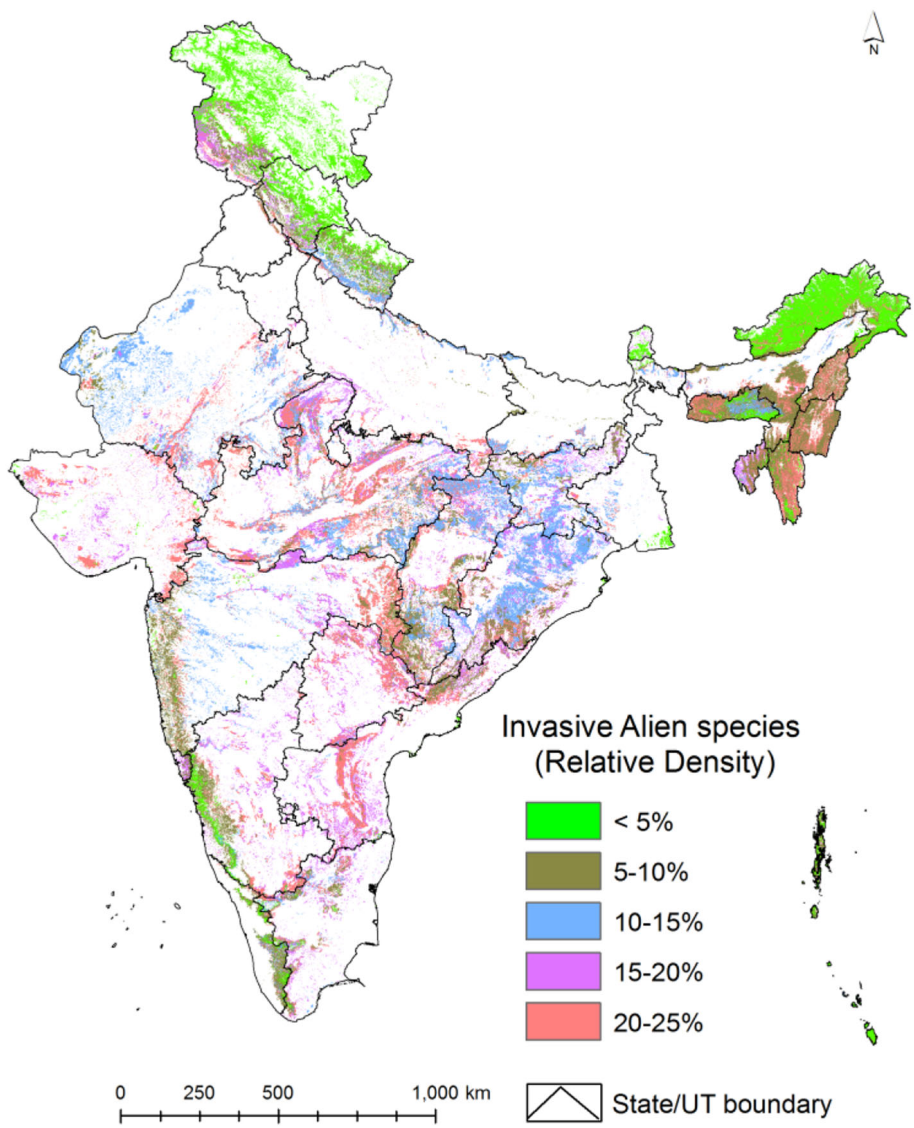


Fig. 4 Level of alien plant invasion across the natural vegetation types of India

species among individuals of all plant species occurring in a given vegetation type. The quantitative data on the proportion of individual alien species was combined along with different vegetation types and land cover map used to construct the first map of the level of alien plant invasion for India (Fig. 4). Of the 16500 sample plots studied across India, invasive alien species are distributed in about 60% of sample plots, with varying occupancy in terms of density, abundance and frequency. The riverine forest habitats have highest impact with representation 24.6% of invasive species populations, followed by dry deciduous forest (20.7%), thorn forest (20.4%), Teak forest (17.9%), Red Sanders forest (17.1%), tree savannah (16.4%), mixed scrub (16%), *Cenchrus-Dactyloctenium* grassland (14.6%), *Anogeissus pendula* forest (13.5%), mixed grassland (12.2%), desert dune scrub (11.9%), shrub savannah (11.3%), Sal forest (11.3%), *Sehima-dichanthium* grassland (10.7%), moist deciduous forest (10.5%), riverine grasslands (8.4%), subtropical pine forest (8.3%), *Lasiurus-panicum* grassland (7.8%), Bamboo forest (7.5%), semievergreen forest (7%), dry evergreen forest (6.6%), dry alpine scrub (5.5%), moist alpine scrub (5.5%), moist alpine pasture (4.9%), dry alpine pasture (4.7%), mangroves (4.3%), subtropical broadleaved hill forest (4%), Himalayan dry temperate forest (3.7%), wet evergreen forest (2.4%) and Himalayan moist temperate forest (1.2%). The top 10 invasive alien species of India based on ecological dominance are *Lantana camara*, *Senna tora*, *Chromolaena odorata*, *Ageratum conyzoides*, *Sida acuta*, *Prosopis juliflora*, *Hyptis suaveolens*, *Parthenium hysterophorus*, *Mikania micrantha* and *Cirsium arvense*. However, many of the invasive alien species are herbaceous and contributes for very low biomass levels in forests. High spatial resolution and hyperspectral imagery shows promising results with the combined use of GPS, GIS and ground surveys.

Evaluation of habitat monitoring at landscape level indicates effectiveness of protected area management in India. After notification, protected areas have succeeded in reducing the deforestation and fragmentation [53]. However, analyses of fire occurrences over a 10-year period have found fires in 281 Protected Areas of India, which indicates degradation [54].

2.5 Species Traits

Earth observation system measures spectral reflectance can directly or indirectly record the spectral traits of species. Earth observation derived phenometrics cover a suite of phenophases including start of season and end of season, length of season, seasonal amplitude and time-integrated series in terms of various vegetation indices. An emerging priority area for analyzing species traits is the identification of plant functional traits. Commonly measured traits used in the definition of plant functional types are plant height, life form, life span, leaf phenology, leaf size, timing of flowering and fruiting. Plant traits and trait variations are proxies of state, abiotic and biotic limitations. There is a need to analyse spectral signatures, patterns and heterogeneity through hyperspectral and very high spatial remote sensing data for better characterization of species composition and diversity.

2.6 Species Populations

Remote sensing cannot replace traditional in situ methods for inventories of species, except in case of very large species identifiable on airborne images and very high-resolution imagery collected by unmanned aerial vehicle [55]. Remote sensing and GIS supports species level distribution analysis to estimate area of occupancy and extent of occurrence. One of the priority areas could be development of baseline spectral data for the detection of plant species. Species distributions can be modelled by integrating point-based species observations, remote sensing based habitat and other relevant biophysical data. Earth observation has started to make intrusions into species level monitoring, including the detection of invasive species [3]. Spatial data generated through remote sensing is being used to study the effects of anthropogenic induced or climate change to develop predictions. Chitale et al. [56] have predicted that regions with higher moisture availability could serve as refugia for endemic plants in future climatic conditions.

3 Development of Biodiversity Observation System: The Gaps, Challenges and Way Forward

Remote sensing, GIS and in situ data are required to make spatially explicit continuous data for EBVs. The development of techniques for quantifying biodiversity at various levels is likely to be great challenge. Near real-time satellite remote sensing has a great potential for observation of habitat change and fires and monitoring of conservation effectiveness. There is a need for nationwide survey-gap analysis as an important initiative to determine the species populations and distribution. There is an information gap at national level for threatened ecosystems and missing linkages of ‘wildlife corridors’. There is a requirement of information on historical forest burnt areas to develop a systematic fire management strategy. There is a need to generate data on ecosystem irreplaceability and ecosystem vulnerability to determine the representativeness of Protected Area system.

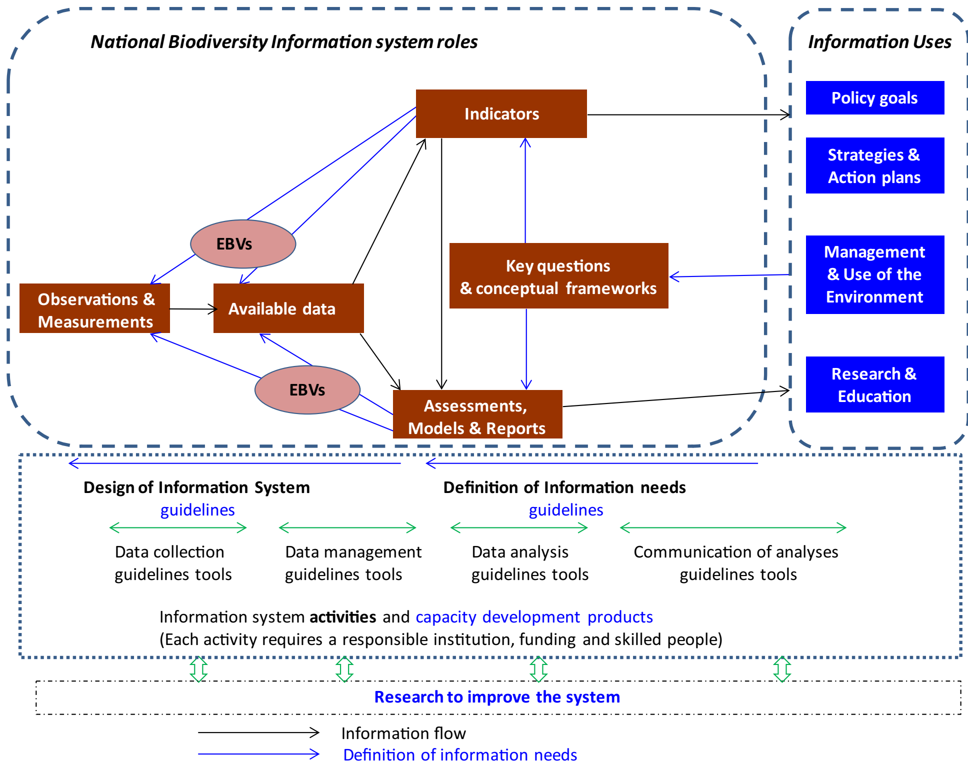


Fig. 5 Conceptual framework for a national or regional biodiversity observation system [15]

Efforts are needed to estimate animal species distributions by modelling ecological niches. Remote sensing still has the limitation of mapping individual tree species especially in a tropical forest with multiple layers of species within a few meters [57]. With greater number of habitats and species, distributed across a variety of stages of growth and succession, with complex canopy structures and overlapping crowns tree species delineation depends on site conditions and is typically suitable at community level. Evaluation of species distribution models and species characteristics provides considerable promise for modeling endemic and threatened species [58]. Active remote sensing data both SAR and LiDAR have the potential for estimating above ground biomass, height and cover of woody vegetation and can provide three-dimensional structure of any area [59]. RADARSAT-2 and ALOS PALSAR have shown immense potential for mapping wildlife habitat, especially when integrated with optical data through data fusion [60]. When analysing forest species indicators, such as birds and wildlife richness, remote sensing data could be used either as a proxy or it could be combined with in situ observation data and modelled to produce habitat suitability and distribution maps [61].

There is a need to define and map plant communities in terms of vegetation characteristics that represent fine-scale variations in regional climate, topography, site-specific moisture, stand structure and underlying ecological processes or degradation. Use of very high spatial resolution satellite data is required to provide key spatial information on ecosystem extent, habitat fragmentation and signs of disturbance in complex terrain. Tree species classification and regrouping into forest stands may be effectively possible with high spatial resolution satellites (0.5–10 m), like GeoEye, RapidEye, IKONOS, OrbView, QuickBird, WorldView. Such type of information is useful in delineating habitat for the conservation strategies, expressing changes in forest composition and structure after natural and anthropogenic disturbances and allows linking ground measurements to remote sensing data. Species diversity is influenced by both leaf traits and canopy structure, as further affected by the seasonal expression of these leaf and canopy features [62]. Because leaf traits and canopy structure vary between species and can provide a surrogate (or proxy metric) for traditional metrics based on species richness. Fully understanding the leaf traits may provide key indicators of community diversity and ecosystem function.

Detailed analysis of essential biodiversity variables with reference to vegetation classification at species and community level, vegetation community assemblages and structure at fine scale, mapping spatial variation of species level traits and assemblages, species patterns in environmental and disturbance gradients, mapping of functional vegetation diversity, mapping disease and invasive alien plant species, modeling distribution for threatened and endemic species are priority areas and have inadequate or missing to understand the national monitoring of biodiversity. In spite of the high potential of remote sensing, conventional methods of species exploration are required to cover the overall spectrum of biodiversity and to provide location specific historical information. The coordination of global efforts in monitoring is still largely to be accomplished along with the use of Earth Observation information [15]. Considering this, GEO BON is focusing on partnerships to build biodiversity observation systems and to allow for the integration of biodiversity observations to inform national reporting (Fig. 5).

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