Forest fragmentation in India

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Assessment of, and mapping the extent of forest fragmentation is one of the key requirements for undertaking any eco-restoration work. Using a moving window approach on high-resolution geospatial data on vegetation, a fragmentation index was computed across the entire Indian landscape. On the basis of the index, the forests areas were categorized as high, moderate, low or intact. It was observed that almost half of the forested land is intact in spite of tremendous population pressures, indicating effective protection. Most of the biodiversity-rich forests, such as evergreen, subtropical broadleaf and temperate broadleaf forests, are relatively intact or have a low degree of fragmentation. But highly fragmented regions across the Indian landscape harbour a number of endemic species, some of them of medicinal importance, that need conservation. This study presents an approach to mapping fragmentation caused by socio-economic drivers, namely shifting cultivation, forest villages, infrastructural development, mining and encroachment. This approach provides critical inputs to prioritization and conservation of forests and the associated biodiversity.

Keywords: Fragmentation, hotspots, landscape, remote sensing, vegetation types.

HUMANS have been dependent on forests from time immemorial, but in the last two centuries there has been extensive degradation of forested land, which has produced a mosaic of natural and managed ecosystems in the Indian landscape. Removal of forest cover has created isolated patches of forests, resulting in alteration of the composition, structure, extent and spatial patterns of forested land[1]. As ecological patterns, function and processes are associated with landscape shape, contiguity and distribution[2], forest fragmentation has serious consequences on the overall health of forest ecosystems through disruption of the contiguity of the landscape. The importance of forest fragmentation and its effect on ecosystem structure and function has been recognized for over half a century[3]. In the last few decades, the impacts of forest fragmentation on gene flow, faunal migration and food webs have been extensively studied[4]. Advances in remote sensing and geographic information system (GIS), as well as spatial analysis and modelling, have provided insights into the effects of forest fragmentation on landscape patterns, the biodiversity and ecological processes. India, which is tenth in the world in terms of extent of forest cover[5], faces a problem of forest fragmentation, mainly due to immense pressures exerted by its increasing population and its demand[6]. An estimation of the fragmentation status across India will provide important insights into the causes and effects of forest fragmentation of diverse ecosystems in the country.

The studies conducted during the last few decades to document the fragmentation of ecological units at the landscape level have used patch number, size, shape, abundance and forest matrix characteristics to characterize forest fragmentation[7–9]. The degree and spatial distribution of fragmentation determines the extent of degradation of ecosystems in a landscape[10,11]. This is facilitated by the synoptic nature of Earth observation data, which enables consistent characterization of the forest cover and fragmentation over space. Forest fragmentation, apart from leading to loss of valuable biological diversity, also leads to greenhouse gas emission due to increased rates of tree mortality at forest margins[12].

Several workers have documented fragmentation and its causes, mainly in the tropical rainforests of Africa and Amazonia[13,14]. There are only a few studies addressing the status of fragmentation and mapping it with respect to vegetation type in the tropical ecosystems of Southeast

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Asia. Quite a few approaches have been used to measure spatial fragmentation in the last decade. Riitters *et al.*[15] have used forest patch size and edge length as a measure of fragmentation and to describe landscape patterns, while others[1] have used a multivariate patch-based fragmentation measure to identify the intactness of forests. One of the most useful methods for measuring landscape-level forest fragmentation is the use of moving window fragmentation indices[16]. In the present work, we used the moving window approach to identify potential areas of forest fragmentation in the Indian landscape using customised software, SPALM for the purpose[17]. We computed the fragmentation index across the landscape and compared the variations in the context of vegetation type, and bio-geographic regions. Furthermore, we assessed the impact of anthropogenic pressures and cultural practices on forest fragmentation.

Study area

The study was carried out in the Indian landscape, lying north of the equator between 6°44′N and 35°30′N and 68°7′E and 97°25′E. India has a 7517 km long coastline. The total geographical area of the country is 3,287,590 km^2, with the total forest cover being 20.75% and being home to an estimated 1.2 million species. India's unique geography and geology strongly influence the climate, comprising six major climatic subtypes, viz. deserts in the west, alpine tundra and glaciers in the north, and rainforests in the humid tropical regions of the north-eastern and southwestern parts and the island territories, deciduous forest systems of Central India.

The diverse ecosystems of India range from those of the Himalayan ranges and the Western Ghats, unique and among the most biodiversity-rich regions, to deserts such as the Thar and Kutch. Indian forests can be broadly classified into five major groups: moist tropical, dry tropical, montane subtropical, montane temperate and subalpine–alpine. These are further subdivided into 16 major forest types. These in turn have been further divided into 46 subgroups and 221 ecologically stable forest types, as defined by Champion and Seth[18]. Mapping the distribution of vegetation types and land use provides critical information for managing landscapes to sustain their biodiversity and the structure and function of the ecosystems.

Methodology

Satellite images

Cloud-free IRS 1C, 1D and P6 LISS-III satellite data (spatial resolution 23.5 m) for two seasons (moist season, October–December; dry season, February–April of 2005–2006) were used for vegetation-type mapping. Topographic maps, climatic maps and bio-geography maps were also used as additional inputs for the study.

Vegetation-type mapping

The vegetation-type mapping was carried out using two seasons' (dry and wet period) satellite images of IRS LISS-III data, on the basis of the phenology of the vegetation cover. On-screen digitization was adopted as delineation of the finer phenological and type variations[19]. Climatic and physiognomy-based classification was used to develop a vegetation classification scheme that broadly fits into the existing forest classification scheme of Champion and Seth. Ground truthing and existing descriptions[18] have been used to delineate vegetation types of ecological significance[20].

Landscape modelling

The number of patches of forest and non-forest types per unit area was taken as a working definition (Figure 1). A user grid cell of size $n \times n$ (where n represents the length of the grid along one side, say 500 m) was convolved with the spatial data layer of forest and non-forest grids. The number of forest patches within the grid cells was derived. The model was designed as a software module in the SPLAM software package[17]. The process was repeated by moving the grid cell through the entire layer. An output layer with patch numbers was derived, and an associated lookup table was generated that rescales the normalized data of the patches per cell in the range 0–10. The fragmentation was computed using the equation

$$\text{Frag} = f(n_F, n_{NF}), \quad (1)$$

where Frag is the fragmentation; n the number of patches, F the forest patches and NF the nonforest patches

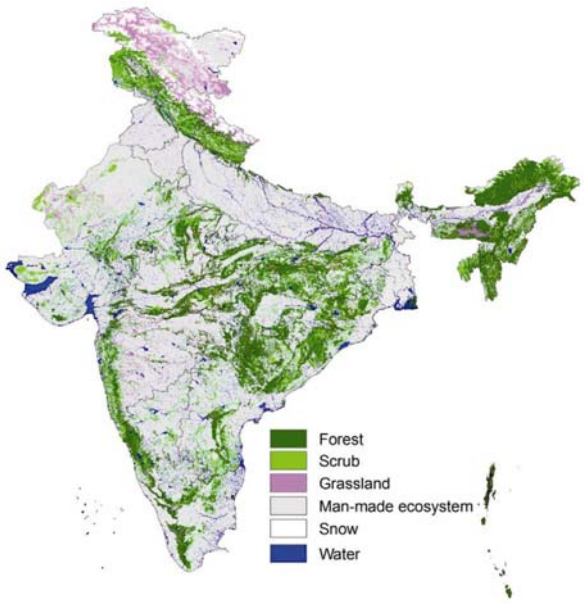

Figure 1. Forest cover of India.

('patch' has been defined as a nonlinear surface area differing in appearance from its surroundings)[21].

The fragmentation map created thus (Figure 2) has integer values ranging from 1 to 7. This is the fragmentation index map. The cells of this map were further classified as intact (index value 1, which means that there is only one forest pixel in the 500 m × 500 m window), low (index value 2, which means there are two forest patches in the window), medium (index value 3) and high (index values 4–7). The classification of the fragmentation map cells as intact, low, medium and high is based on histogram clustering (Figure 3) and expert knowledge.

Field sampling

The vegetation type map was used for developing a stratified random sampling method appropriate for phytosociological studies. The sample size was based on landscape variability and ranged from 0.002% to 0.005% of the strata area, depending on the complexity of the area.

Results and discussion

A total of 150 vegetation and land-use classes were mapped. Of the 86 forest classes mapped, 20 were mixed natural formations, 29 were gregarious formations, 21 were locale-specific formations, 13 were forest plantations, 6 were areas in stages of degradation. Apart from these two woodlands, 15 scrub/shrub lands and 15 grasslands were mapped. Forest cover map (Figure 1; aggregated from vegetation type map) has been used to determine the degree of fragmentation (Figure 2).

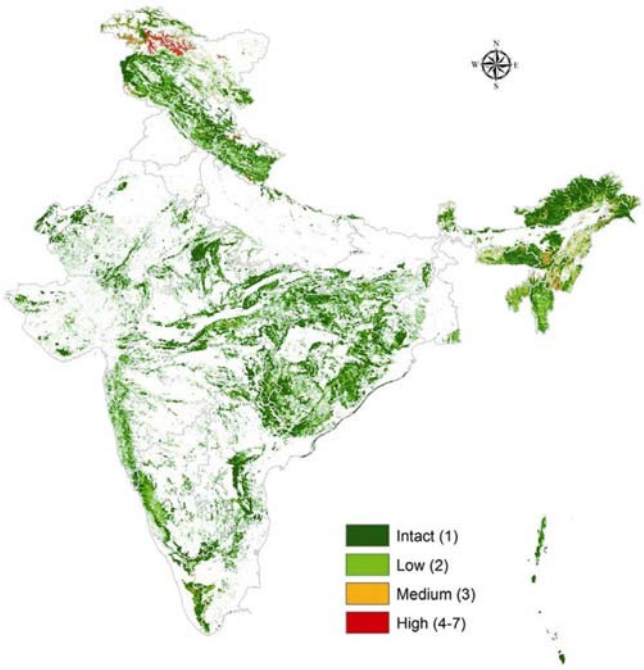

Figure 2. Fragmentation map of India.

Distribution of fragmentation across vegetation types

About 67.28% of the forested area in the Indian landscape was observed to be intact; 26.70% could be classified as low; 4.38% as medium and 1.64% as highly fragmented (Table 1). Among the major vegetation classes, mixed formations have the maximum intact forest (46.74%). On analysing the proportion of fragmentation among the major vegetation types, it was observed that forest plantations had the largest proportion of their area under high fragmentation (4.16%), followed by gregarious formations (3.02%). It is also interesting that the degraded forests, which are expected to have high fragmentation, have considerable area under contiguous forest cover. As the mixed natural formations are not managed forest ecosystems in the subcontinent, analysis of the fragmentation among the mixed natural formations will provide an insight into the extent and distribution of the fragmentation across natural vegetation types.

Analysis of the fragmentation status of different natural formations indicated that subtropical dry evergreen forests have proportionally the maximum intact forest area, followed by southern hilltop forests and semi-evergreen forests. The other natural formations having considerable intact forest area are evergreen and subtropical broadleaf forests. The reason for almost 90% of the subtropical dry evergreen forest existing as intact forest (Table 2) is the various levels of conservation in the form of institutional protection as well as social protection of sacred groves. The other forest types mentioned above having considerable intact forest area can be attributed to difficult terrain and limited accessibility[22]. Another interesting fact is that 73% of sal mixed moist deciduous forest is intact. Although these forests are on more hospitable terrain, there is no fragmentation in most of the areas. Apart from mining, the regions that harbour this forest type have undergone relatively little economic and human development. As the population here is

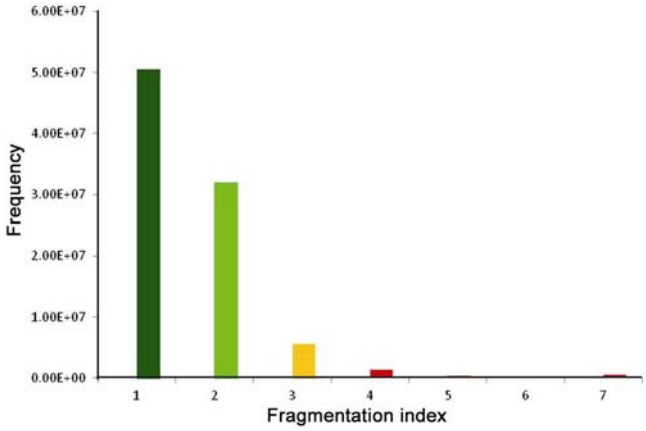

Figure 3. Histogram of the fragmentation index.

Table 1. Area (km^2) under different fragmentation categories in different vegetation types

Major vegetation formations	Intact	Low	Medium	High	Total
Mixed natural formations	298,836	118,593	19,439	7,302	444,170
Gregarious formations	56,278	24,920	3,969	2,655	87,822
Locale-specific formations	4,465	4,086	905	200	9,656
Forest plantations	3,573	5,446	904	431	10,354
Degraded formations	43,653	23,600	5,188	1,381	73,823
Woodlands	7,068	5,900	575	46	13,588
Total	413,873	182,545	30,980	12,016	639,414

Table 2. Fragmentation (%) classes in different natural formations

Vegetation type	Intact	Low	Medium	High	Total
Evergreen	2.50	0.54	0.12	0.03	3.19
Southern hilltop	0.01	0.00	0.00	0.00	0.01
Secondary evergreen	0.05	0.01	0.00	0.00	0.06
Subtropical broadleaved hill forests/subtropical evergreen	4.31	0.87	0.27	0.07	5.52
Subtropical dry evergreen	0.03	0.00	0.00	0.00	0.03
Montane wet temperate	0.24	0.10	0.04	0.02	0.40
Himalayan moist temperate/temperate broadleaved forest	3.72	1.45	0.58	0.20	5.95
Subalpine	0.10	0.06	0.02	0.06	0.25
Semi-evergreen	5.03	0.99	0.17	0.04	6.23
Moist deciduous	16.22	6.99	1.24	0.41	24.86
Sal mixed moist deciduous	4.22	1.39	0.14	0.03	5.79
Teak mixed moist deciduous	4.75	2.33	0.21	0.03	7.31
Dry deciduous	18.78	8.21	0.89	0.26	28.15
Sal mixed dry deciduous	2.34	0.98	0.09	0.01	3.42
Teak mixed dry deciduous	1.06	0.76	0.07	0.00	1.90
Thorn forest	0.92	0.95	0.10	0.01	1.98
Bamboo mixed	0.83	0.17	0.02	0.00	1.02
Temperate coniferous	2.16	0.87	0.43	0.47	3.93
Pine mixed	0.00	0.01	0.00	0.00	0.01
Total	67.28	26.70	4.38	1.64	100.00

mostly tribal and has a history of co-existence with the forest, it is generally less exploited[23]. The largest absolute area of intact forest is in the dry deciduous forests, which constitute 18.78% of the total forested area in the country, followed by the moist deciduous forests, constituting 16.22% of the forested area. As these two forest types add up to more than 50% of the area of the mixed natural formation, institutional protection has ensured low fragmentation in these forests (Table 2).

Forest fragmentation across major biogeographic regions

The Deccan Peninsula has the largest extent of intact forest, followed by the North East (NE), the Himalayan region and the Western Ghats (Figure 4). The maximum area under high fragmentation was in the Himalaya, followed by NE India. This is mainly due to the traditional shifting cultivation, or 'jhum', followed in this region. Roy and Tomar[24] have shown that many of the forested regions in NE India have been degraded over time due to the shifting cultivation. The other regions in the Indian subcontinent that are high fragmented are parts of the Western Ghats and the Deccan Peninsula. In the Himalayan region the topography also plays an important role in high forest fragmentation, with the aspect and slope changing rapidly.

Fragmentation across biodiversity hotspots of the Indian landscape

As the Indian subcontinent has three biodiversity hotspots according to Conservation International[25], we tried to assess the fragmentation status of these unique and important regions, namely the eastern Himalaya, the Western Ghats and the Andaman and Nicobar Islands (Figure 5). Of these biodiversity hotspots, the Andaman and Nicobar Islands have 82.43% of their total geographic area under forest, followed by the eastern Himalaya (68%) and the Western Ghats (43.6%). A comparison of the fragmentation status in the biodiversity hotspots shows that the proportion of intact forest area is highest in the Andaman and Nicobar Islands, accounting for 78% of the forested area in the region. This is due to the fact that the Andaman Islands are isolated from the

mainland and have much less pressure due to the mainland Indian population and development. The eastern Himalaya has around 67% of intact forest area, followed by the Western Ghats, which has 58% of the area under intact forests. The proportion of area under high fragmentation is highest in the eastern Himalaya and constitutes around 3% of the forested area. This is due to the prevalence of shifting cultivation in the region[26]. The Western Ghats has 1.66% of the forested area under high fragmentation, mainly due to extensive cash crop plantation and developmental activities[27]. In the Andaman and Nicobar Islands, 0.94% of the forests which fall within high fragmentation areas consists mainly of various natural creeks and water bodies that fragment the natural vegetation on the coast.

Comparison of important eco-regions

The two regions of the Greater Himalaya differ a lot in terms of vegetation type, moisture regime, anthropogenic pressures and infrastructure development. The fragmentation in the eastern Himalaya is much lower than in the western Himalaya. The intact forest areas constitute around 67% of the total area in the eastern Himalaya, compared with 55% in the western Himalaya. This is due to greater development and population pressure on the western Himalaya. Hence, the western Himalayan forests are much more stressed. It is also observed that there is more forested area under high and medium fragmentation in the western Himalaya, constituting 10.85% and 8.71% of the forests, while the eastern Himalaya has 2.96% and 8.64% of the forested area under high and medium fragmentation respectively, although the absolute area under high fragmentation is greater in the eastern Himalaya.

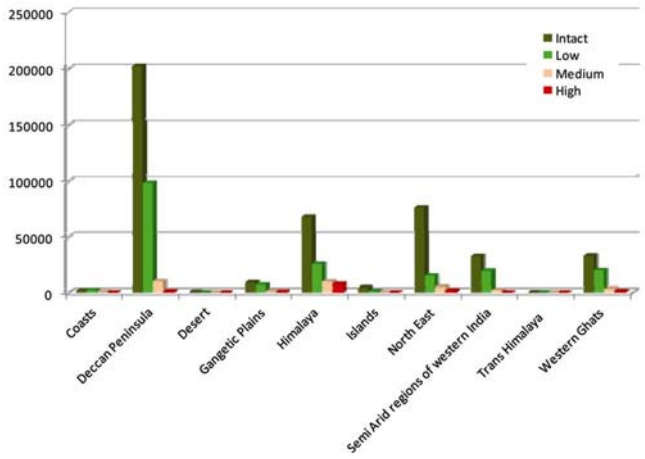

Figure 4. Forest fragmentation across major eco-regions (numbers along the *y*-axis indicate area in km^2).

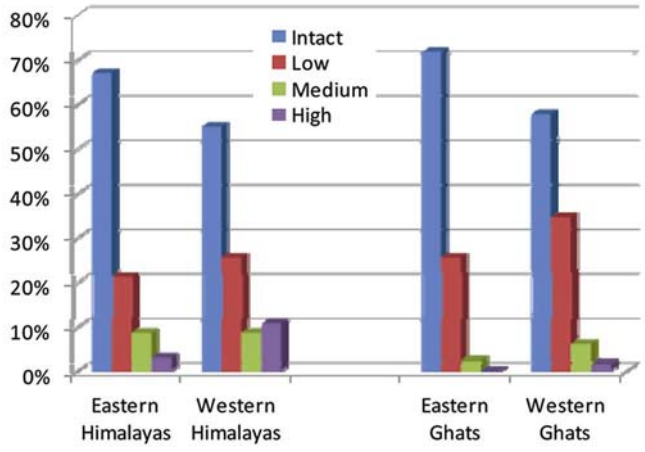

Figure 5. Comparison of forest fragmentation among similar bioregions.

But a comparison of the Western Ghats and the Eastern Ghats showed that, contrary to popular belief, the latter has around 72% of the forested area is intact, compared with the former, where around 58% of the forest area is intact. This is an interesting result as the Western Ghats, a known global biodiversity hotspot, has proportionally less area under low fragmentation compared to the Eastern Ghats. So it is possible that the Eastern Ghats also harbours a large number of endemic plant and animal species and that they have been relatively less explored. Even if we compare the proportion of high fragmented areas in the Western Ghats and Eastern Ghats, the former has around 1.66% and 6.08% of the forested area under high and medium fragmentation respectively, compared with only 0.2% and 2.37% respectively, in the latter. This may be due to a considerable population of indigenous people with a history of conservation of the vegetation cover[28] and less economic and infrastructural development.

Influence of fragmentation on the phytosociology of the Indian landscape

The impact of fragmentation on the number of recorded species followed an expected trend. The intact forest areas had a total of 6660 species, with herbs contributing 3962 species, followed by trees (2072 species) and shrubs (1882 species). The mismatch between the total number of herb, shrub and tree species and the total species is because of the different habits of a particular species in different geographic conditions. Regeneration was greatest in the intact areas, with 778 species of seedling and sapling. Around 384 species of climber, epiphyte and other life-forms were recorded in the intact areas. The low-fragmentation class areas also harbour a considerable number of species, with a total of 4840 species being recorded in this category and had 2913 herb, 1289 shrub and 1665 tree species. A total of 2505 species were recorded in the area under medium fragmentation, which includes 1315 herb, 587 shrub and 929 tree species. This area also had 97 species of other life-forms (Table 3).

Table 3. Habitat-wise distribution of species (medicinal, economic, endemic, and rare, endangered and threatened (RET)) across fragmentation index classes in India

	Fragmentation class			
	Intact	Low	Medium	High
Life-form distribution				
Herbs	3530	2913	1315	490
Shrubs	1715	1289	587	259
Trees	2026	1665	929	444
Sapling/seedling	778	571	201	80
Others	384	300	97	35
Distribution of economically important plants				
Medicinal plants	1637	1512	965	502
Economic plants	2431	2191	1414	670
Distribution of endemic and RET plants				
Endemic	603	483	278	127
RET	27	19	8	2

The high fragmented areas recorded 1125 species of which 490 were herb, 259 shrub and 444 tree species. The regeneration potential was observed to be lowest in this region, with only 80 seedling and sapling species observed.

The number of medicinal and economically important species across the fragmentation index classes is shown in Table 3. The intact areas were seen to have the highest number of medicinally important and economically important species – 1637 and 2431 respectively. The low-fragmentation areas had 1512 medicinally important species and 2191 economically important species. The medium-fragmented areas had 965 and 1414 medicinally important and economically important species respectively. While the high-fragmented areas had 502 and 670 medicinal and economic species respectively. The intact and low-fragmentation areas had the most endemic species – 603 and 483 respectively. The number of endemic species in the highly fragmented areas was only 127, but these species are in dire need of conservation. During field sampling, 27 rare, endangered and threatened (RET) species were sampled in the intact areas, 19 in the low-fragmented areas, 8 in the medium-fragmented areas and 2 in high fragmented areas (Table 3).

Conclusions

The Indian landscape has around 20% of the total geographic area under forest cover and around half of this area shows low fragmentation, probably owing to institutional, and/or social protection[29]. The fragmentation is also linked to the socio-economic and cultural practices, and to a large extent to the economic and infrastructural development in the region[30]. Thus development appears to act in conflict with conservation. The demand for resources to uplift the economic status of the local population and building of roads for better connectivity invariably lead to forest fragmentation[31]. The areas that are losing the natural cover and associated species due to various socio-economic and anthropological influences are basically losing a host of numerous medicinal and economically important plants apart from the endemic species. Increased fragmentation in these areas, for example NE India and the Western Ghats, will lead to loss of the important, sometimes priceless, gene pool, which has potential for development of modern drugs.

The entire database on the spatial distribution of forest fragmentation is available on the web as part of the Biodiversity Information System (www.bis.iirs.gov.in). The dataset can be downloaded freely in the actual resolution for the area of interest. The database is available as raster data, which can be used to identify the areas that need protection and those undergoing forest degradation at the local level. It can also be used to identify the core areas of a forest for conservation. These data may also be used to study the patterns of spread of invasive species in the forests of India.

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