Forest fragmentation impacts on phytodiversity – An analysis using remote sensing and GIS

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The present study deals with the forest fragmentation of Vindhyan highlands in the Indian dry tropical forests. The fragmentation scenario has been quantified using remote sensing data and GIS techniques. The remotely sensed data-derived vegetation map was an input to the fragmentation analysis. Transects were laid to inventory along different forest patch sizes of various communities to study the biodiversity levels. It was observed that with changing fragment, there is change in biodiversity levels. Hence, patch size might play an important role in the regulation of biodiversity levels. This information may provide an insight into the conservation strategy formulation for the fragmented dry tropical area.

The analysis has brought out that biodiversity levels are different in various fragments of different sizes. Small fragments are similar to each other in terms of species composition; similar is the case with large fragments in general. It was also found that the small and large fragments are dissimilar in terms of species composition. The diversity levels among the fragments of similar size class varied across the anthropogenic gradient. Analysis of species richness, diversity indices has helped in studying the patterns/levels of biodiversity in different fragment size classes along different levels of anthropogenic pressure. The merits of conserving the small and large fragments have been discussed.

BIODIVERSITY of the natural ecosystems of the world is under threat due to forest fragmentation. The process of forest fragmentation is a detrimental one and has been increasing alarmingly throughout the world, especially in tropical forests that has the bulk of biodiversity and, hence a major concern for the conservationists. Habitat fragmentation is the breaking up of a large portion of a forested land into several smaller portions. The forest fragmentation can be explained in two phases. The first phase results in the reduction of total amount of forest areas whereas the second phase leads to the isolation of smaller patches[1,2].

Various changes take place in the environment of forest landscapes as a result of increasing fragmentation. There are many physical and biological changes associated with forest fragmentation, such as habitat loss and insularization[3,4]. Apart from these, populations of forest species, both animals and plants are also affected. Some of the important consequences are reduction in the number of species, interference in dispersal and migration processes, altered ecosystem inputs and outputs, and exposure of isolated core habitats of the forest. All these mechanisms are responsible for the progressive erosion of biodiversity[5,6]. The environment of the fragments becomes conducive for weedy/exotic species. In some cases, the weedy species are incorporated into the remaining plant community and are responsible for the elimination of the species confined to the forest interior[7].

Remote sensing and GIS have been successfully employed to monitor the fragmented ecosystems and thus can prove to be important tools to address the impacts due to forest fragmentation. Various satellite sensors with different spatial resolution have been utilized in the study of forest fragmentation. Remote sensing is perhaps the only feasible way to map tropical forest fragmentation at regional and global scales, scientifically[8]. Improvements in technology and availability of imagery have been contributing significantly in many areas dealing with spatial and temporal dimensions, including forest ecosystem monitoring[9].

The present study is an attempt to investigate the process of forest fragmentation in Vindhyan highlands and to quantify its impact on phytodiversity of the region. The Vindhyan highlands are inhabited by tropical dry deciduous forest. These highlands are surrounded by upcoming industries and major thermal power plants of the region. Thus, the forests of this region have been under increasing anthropogenic pressure in the last decade[10]. The rate of deforestation[11] has increased from 1.35% per year between 1972 and 1983 to 2.79% per year between 1984 and 1988. As a result, large contiguous forests now exist as remnants of various sizes of plant communities. These forest remnants in the form of patches provide the last ray of hope in conserving the remaining biodiversity and the best possible way to do so is by protecting these fragmented habitats.

The present study has attempted to address the following important questions related to forest fragmentation: (1) How does forest fragmentation affect plant species composition and plant diversity? (2) What size of fragment maintains optimal species diversity? (3) Should large fragments be conserved or small ones?

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The objectives

The objectives of the study are: (i) Inventory of plant communities using multi-temporal satellite data; (ii) To study the biodiversity levels in various patch sizes; (iii) To study the effect of fragmentation on different plant communities; (iv) To understand the relationship between fragment parameters and biodiversity.

The study area

The Vindhyan highlands lie in between (21°29′–25°11′N) lat. and (78°15′–84°15′E) long. The study area chosen for analyses lies in between 83°:00′:00″–83°:15′:00″E long. and 24°:00′:00″–24°:30′:00″N lat. The highlands are located between the Gangetic plains and the Narmada valley. The forests of these highlands are tropical dry deciduous[12]. The dominant tree species are *Shorea robusta* C. F. Gaertn, *Hardwickia binata* Roxb., *Boswellia serrata* Roxb., *Lagerstroemia parviflora* Roxb., *Anogeissus latifolia* Wall. exBedd., *Lannea coromandelica* Merrill. and *Diospyros melanoxylon* Roxb. An overview of the study area is shown in Figure 1.

Experimental design

Fragmentation analysis was carried out around five locations in the study area. These locations were chosen so as to represent different levels of anthropogenic pressure expressed in terms of degree of forest fragmentation based on visual interpretation of satellite data (IRS-1D LISS III and PAN merged). The locations are Hathinala (HT), Renukoot (RK), Majhauli (MJ), Manbasa (MB) and Khatabaran (KH) villages. At Hathinala, the forests are relatively protected and thus are relatively less fragmented compared to the other locations. At the Renukoot site, the protection levels are similar; however, the community organization and fragmentation scenarios are different because of forest working histories as described by the earlier forest working plans. The forests around Majhauli are highly fragmented, perhaps due to encroachment. The local people also frequent the forests around Majhauli due to clearance of large tracts of forests for agricultural purpose. Forests around Manbasa work as a corridor connecting the forests of Hathinala and Muirpur and hence were considered in the transect study. At Khatabaran, the forests are rather contiguous; however, fragmentation is prevalent along the edges.

Materials and methods

Satellite data acquisition and preprocessing

Satellite data acquired for fragmentation analyses are as follows: IRS-1D LISS III of December 1998, April 1999 and March 2000. The LISS III scenes of the December and April season were rectified (image-to-image) and tiled.

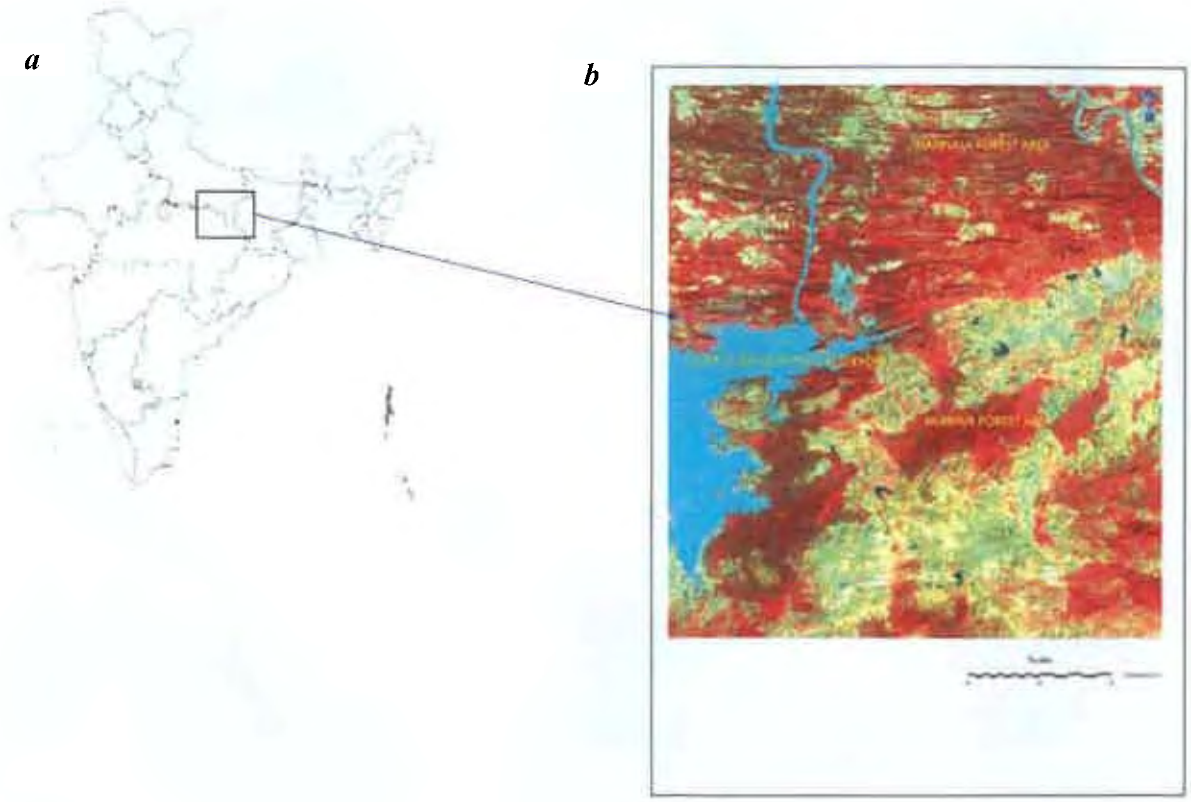

Figure 1. ***a***, Location of study area; ***b***, False colour composite of IRS-LISS III data.

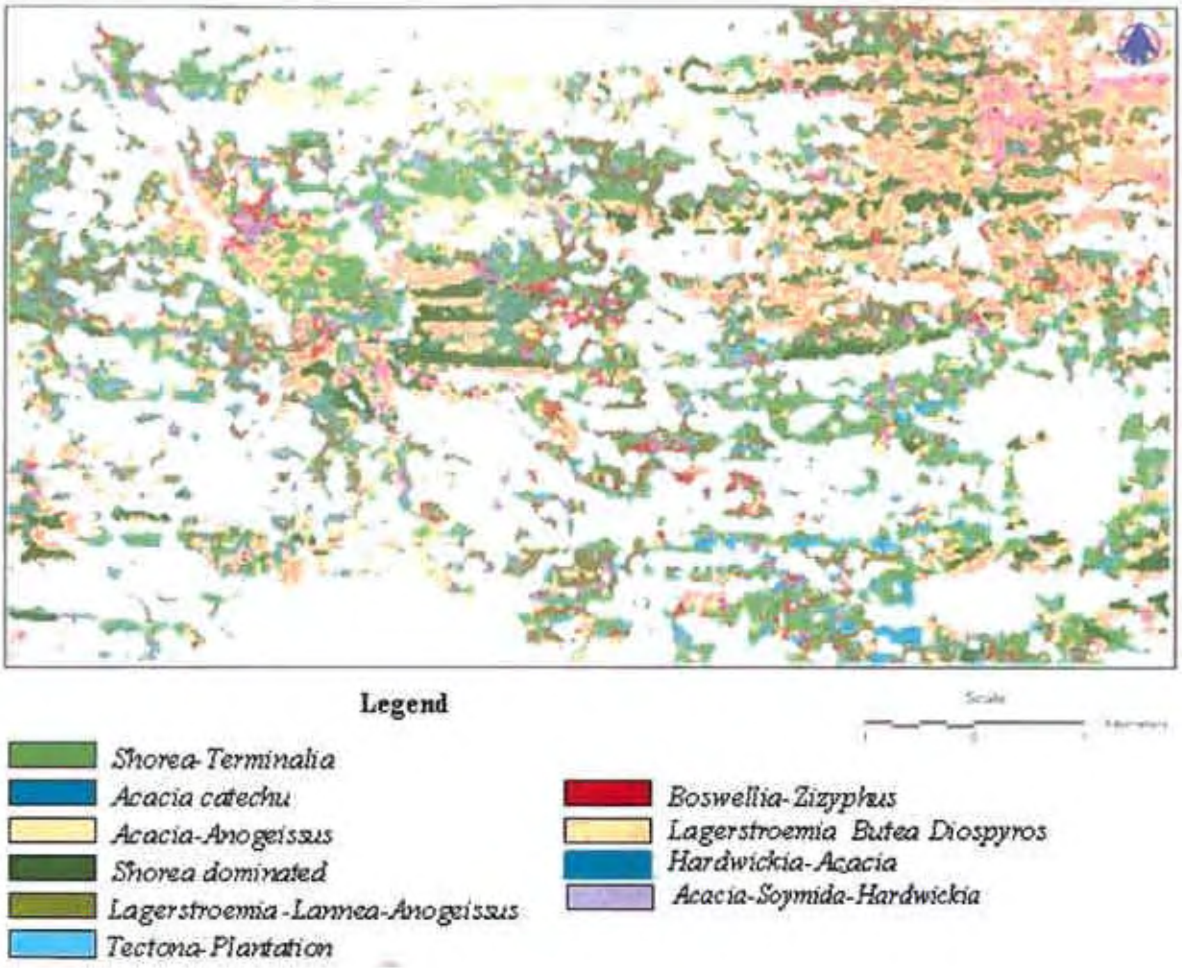

Figure 2. Classified image using IRS-1D LISS III of Hathinala forest area showing distribution of plant communities.

The tiled image was rectified with respect to the topobase at 1 : 50,000 scale. Twenty-five ground control points utilized were distributed uniformly in the study area. The root mean square error was brought to less than one pixel, iteratively. The slave image, was resampled to the first order of polynomial regression using nearest neighbour option.

The IRS-1D LISS III data of March was rectified with respect to the December data (image-to-image) in a similar manner. This image processing work was executed using UNIX-based image processing software ERDAS imagine (version 8.4) [13]. The study area was covered in two LISS III scenes, that were rectified, mosaiced and subsequently area of interest was extracted.

The input for fragmentation analysis was the classified satellite image dataset of the study area. It was observed that the plant communities in the Vindhyan highlands exist as small patches. It was difficult to extract pure training sets, as contiguous homogenous areas were not found for true representation of the plant community. Hence, in order to achieve precise delineation of plant communities, the need was felt to utilize the data obtained from Differential Global Positioning System (DGPS). Identified plant communities were polygonized on ground and data were collected. Each day, data were downloaded from the mobile GPS and base station GPS, and differential correction was applied as a result of post-processing. The DGPS data processing was executed in M-STAR software (version 1.0)[14]. Polygons were generated in ARC/INFO (version 7.2.1)[15] from the point data derived after post-processing. These polygons were utilized to derive training sets for classification.

Classification of satellite data

Multi-season data were considered to be advantageous for community-level classification as evergreen and deciduous species could be delineated due to asynchronous phenology. Using data of three dates, i.e. data during the months of December, March and April, multi-season classification was performed. The signature set was derived from the polygons generated by the DGPS data. The classification was performed with maximum likelihood algorithm using nearest neighbour technique (Figure 2).

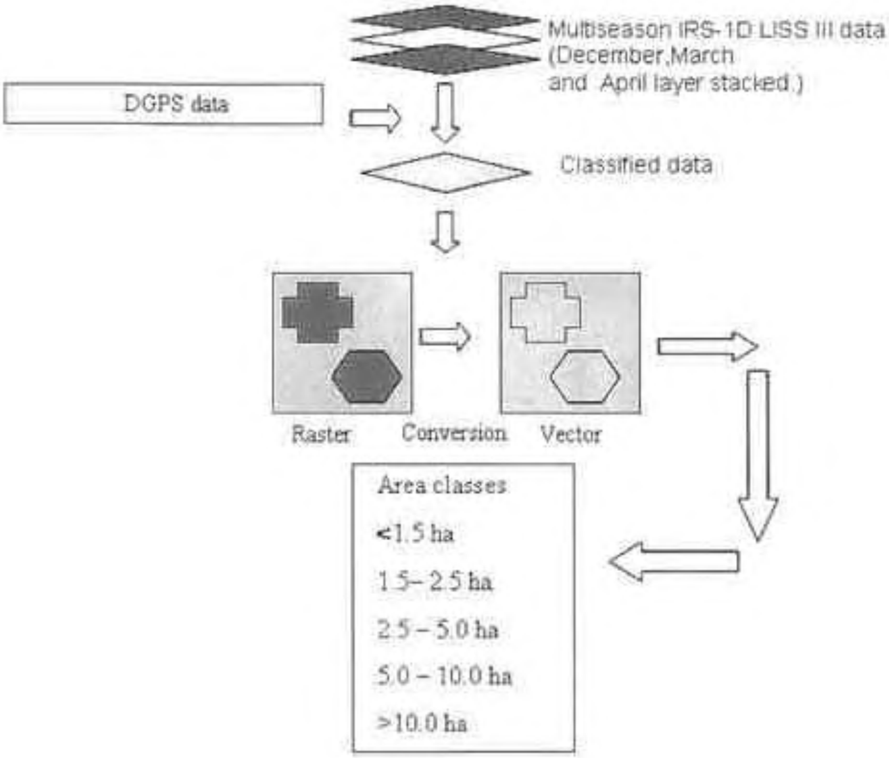

Figure 3. Flow chart showing methodology applied for fragmentation analysis.

The error matrix was computed and the producer's accuracy, user's accuracy and overall accuracy were calculated for the classified dataset. Kappa statistic was also computed with the help of 256 random points.

Fragmentation analysis

The methodology applied for fragmentation analysis is shown in Figure 3. The classified data are converted into vector in (ARC/INFO version 7.2.1) of different size classes. Each community was divided into the following area classes: <1.5 ha, 1.5–2.5 ha, 2.5–5.0 ha, 5.0–10.0 ha, and >10.0 ha. Different communities with different size classes were given different symbology. It was overlaid on the topobase for field inventory and ground truth.

Ground truth

Ground inventory was done in various communities of various fragment size classes. Navigation function of GPS was utilized in order to reach a desired community as identified along the belt transects through remotely sensed data. To navigate through the plant communities, data in the form of waypoints and routes were used for the rover unit of GPS. In the present case, waypoints were selected from the satellite data (LISS III). Transects were chosen in a manner that they cover maximum number of communities of different sizes[17].

We have identified the transects with abbreviated location names. Immediate numerals denote the transect number at that particular location, such as HT1, and the second numeral followed by '_' sign shows the fragment number encountered (e.g. HT1_4) of the particular transect at that location. The transect length traversed was 1 km in each case. Along the transects, 25 m × 25 m plots were laid falling in the polygons of communities of different size classes for ground inventory for the different fragments belonging to different communities. Girth at breast height (GBH) of adult trees (≥ 30 cm) was recorded. In this manner we inventoried eight transects in the study area.

Diversity analysis

The phytosociological data collected were analysed for the diversity indices[18–20] as mentioned in Table 1.

Cluster analysis

Ordination summarizes the community data in relation to their habitat, which is based on the premise that similar species and samples are close together and dissimilar entities far apart. Cluster analysis is one such method of ordination, wherein similar clusters of species are grouped together and conceived as communities. In the present study, cluster analysis was performed based on the species attributes for small fragments (> 5.0 ha), large fragments (<5.0 ha) and

Table 1. Diversity indices

Simpson index[18]	$S = \sum_{i=1}^{m} p_i^2$	S = Simpson's index; p_i = Proportion of species i in the community
		Simpson's species diversity was used as $1-S$
Shannon–Weiner index[19]	$SW = \sum_{i=1}^{m} (p_i)(\log_2 p_i)$	SW = Index of diversity; p_i = proportion of the total sample belonging to the ith species
Species richness[20]	$SR = \frac{S-1}{\mathrm{Ln}(n)}$	S = No. of species; n = No. of individuals.

large and small fragments together to compare the similarity between sites based on the species composition of the fragments.

Cluster analysis was done using PC-ORD (version 4.0)[21] with Euclidean distance and Ward's group linkage method where the plot data were grouped and communities delineated. The cluster analysis was diagrammatically represented using the dendrogram. Analysis of variance was computed for diversity indices in various fragment sizes to see significant difference (SPSS version 8.0)[22].

Similarity analysis

Quantitative analysis of species richness among various fragment size classes was calculated using EstimateS (version 6.0b1)[23]. Various indices like Jaccard similarity index, Sorenson's incidence-based (SorensonInc) (qualitative presence/absence) index, Sorenson abundance-based (SorensonAbd) quantitative index and Morista–Horn index[24] were used.

Results

The plant community classification was achieved using multidate remotely sensed data. Multidate image classification resulted into relatively higher accuracy. The producer's accuracy ranged from 63.33 to 100% for different classes and user's accuracy ranged from 50 to 99.45% for different vegetation classes. The overall accuracy was 90.49% and the value of kappa statistics was 0.91. A vector layer was generated in the GIS domain from this classified image depicting the different community classes, where the fragments belonging to the different size classes for the different communities were segregated and made ready for field inventory.

Cluster analysis

The species composition patterns observed through the analysis have shown that they are different in the surroundings of five locations and also in various fragment classes. The five locations along the gradient of anthropogenic pressure exhibit different levels of fragmentation. Hathinala area has a relatively better protection measure enforced because of the forest department infrastructure available around and hence is relatively dense and more contiguous than the other locations. Around Majhauli area, the forests are fragmented, as biotic and anthropogenic disturbances are prevalent. At Khatabaran, the forests are more fragmented along the edges and it was observed that contiguous sites are still found inside the forests. Table 2 shows values of diversity indices of various fragments of different sizes in the study area.

It was observed that species diversity and species richness increase progressively from small to large fragments, as observed in the case of transects inventoried in Khatabaran and Renukoot. Small fragments, around Hathinala, Renukoot and Khatabaran show high values of species diversity and species richness. Around Manbasa, the small and large fragments show lower species diversity and species richness in comparison to other locations. Manbasa is located in the corridor, which connects the Hathinala forest area to the Muirpur forest area.

Now we discuss the fragmentation scenario in the light of cluster analysis with reference to the three area classes for different communities, as discussed earlier at different sites. They are the small fragments, the large fragments and the small and large fragments together. In the first case where only small fragments have been analysed, it was observed that the fragments within a site have shown highest similarity with respect to each other. The next level of similarity is exhibited by the small fragments between the sites of Hathinala, Majhauli and Manbasa. The similarity shown by the small fragments within and between different sites with similar level of fragmentation leads to the observation that the process of accommodation of species/individuals operates in a similar manner for the smaller size of patches (Figure 4 *a*). In the case of large fragments (<5.0 ha), a different scenario is observed in species diversity at locations Khatabaran, Manbasa and Renukoot. Except for the two large fragments at Manbasa having 100% similarity in terms of species composition, this group shows nearly 50% similarity with the fragment at Renukoot and the fragment at Khatabaran shows no similarity with any of the fragments (Figure 4 *b*). In the case of small and large fragments analysed together, it was observed that small fragments are more similar to each other, and they show high dissimilarity with the large fragments, which are rather

Table 2. Diversity indices in various fragments of different sizes

Transect	Community	Fragment size (in ha)	Shannon–Weiner index (SW)	Simpson index of dominance (S)	Species richness (SR)
KHBT	*Terminalia/Shorea/Diospyros*	< 1.5	3.90	0.89	9
	Acacia catechu	< 1.5	4.28	0.86	12
	Lagerstroemia–Tectona	5.0–10.0	4.04	0.80	7
	Lagerstroemia–Tectona	2.5–5.0	4.30	0.69	6
	Butea–Diospyros	> 10	5.47	0.93	16
RK1	*Boswellia serrata*	< 1.5	3.47	0.50	3
	Acacia catechu	2.5–5.0	4.39	0.59	5
	Shorea/Boswellia	> 10	5.41	0.87	13
MJ	*Acacia catechu*	< 1.5	2.46	0.20	2
	Shorea mixed	< 1.5	4.22	0.83	9
	Terminalia/Shorea/Acacia	< 1.5	5.13	0.91	14
RK2	*Acacia–Soymida*	>10	5.58	0.84	13
	Acacia catechu	< 1.5	5.22	0.76	12
MB1	*Lagerstroemia–Butea–Boswellia*	> 10	4.30	0.86	10
	Acacia–Lagerstroemia	> 10	4.76	0.87	12
MB4	*Lagerstroemia parviflora*	< 1.5	3.46	0.48	4
	Lagerstroemia/Diospyros	< 1.5	3.67	0.36	3
	Lagerstroemia/Anogeissus	< 1.5	2.34	0.43	2
MB8	*Lagerstroemia/Diospyros*	< 1.5	2.62	0.75	4
	Lagerstroemia/Diospyros	< 1.5	2.62	0.64	3
	Lagerstroemia/Acacia	< 1.5	1.84	0.40	1
	Lagerstroemia/Anogeissuss	< 1.5	2.95	0.12	2
HT1	*Boswellia serrata*	< 1.5	3.83	0.80	7
	Acacia/Anogeissus	< 1.5	4.60	0.89	10
	Boswellia/Acacia	< 1.5	5.37	0.82	10
	Acacia catechu	< 1.5	3.19	0.19	3
	Acacia catechu	1.5–2.5	3.48	0.65	5

Table 3. Correlation coefficient (r) values ($P = 0.001$) between Jaccard similarity index and Sorenson incidence, Sorenson abundance and Morista–Horn index respectively

Type of fragment	Jaccard/Sorenson incidence (r)	Jaccard/Sorenson abundance (r)	Jaccard/ Morista–Horn (r)
Small	0.982	0.978	0.976
Large	0.801	0.998	0.998
Small and large	0.982	0.949	0.977

dissimilar amongst themselves in terms of species composition (Figure 4 *c*).

A specific observation was made for the fragments *Acacia catechu* community of small fragments that was encountered at different sites – Khatabaran, Majhauli, Renukoot and Hathinala. It is seen that at two sites, Khatabaran and Renukoot, the *A. catechu* community shows high values of diversity indices and species richness (Table 2). However, at the next two sites, Majhauli and Hathinala, the *A. catechu* community shows relatively lower levels of diversity. Thus, it is seen that in this case, the fragments of the same community (of similar size) show different levels of diversity along different degrees of fragmentation. This is in agreement with the fact that at Khatabaran and Renukoot, the *Acacia* community is less fragmented compared to that at Hathinala and Majhauli.

Similarity indices

Analysis of similarity indices (Jaccard similarity index, Sorenson's incidence-based (qualitative presence/absence) index, Sorenson abundance-based quantitative index and Morista–Horn index) were made for the three area classes, i.e. the small, large, and small and large fragments. We found very high level of intercorrelation between three indices (Table 3) and thus only Jaccard similarity index has been used in further analysis.

In the case of small fragments, in the first case, it is seen that fragments within a site show similarity in species richness, whereas fragments occurring at different sites show dissimilarity in terms of species richness (Table 4). For example, between HT1_1 and HT1_3, the value of Jaccard similarity index is 0.45. In another example, between fragments HT1_1 and KH21_1, the value of Jaccard simi-

Table 4. Jaccard similarity index between small fragments of the study area

HT1_1	HT1_2	HT1_4	HT1_3	HT1_5	KH21_1	KH21_2	KH21_4	MB4_1	MB4_2	MB4_3	MB7_1	MB8_1	MB8_2	MB8_3	MB8_4	MJ1_1	MJ3_1	MJ6_1	RK1_1	RK2_2
–	0.14	0.14	0.45	0.29	0	0.2	0.14	0.25	0.29	0.13	0.38	0	0.29	0	0.29	0.13	0.36	0.54	0.11	0.29
–	–	0	0	0.5	0	0.09	0	0.33	0.5	0	0.25	0	0	0	0	0	0	0.08	0	0.07
–	–	–	0.11	0	0	0.09	1	0	0	0	0	0	0	0	0.5	0.5	0.13	0.08	0	0.07
–	–	–	–	0.1	0.15	0.25	0.11	0.09	0.1	0.1	0.08	0.1	0.1	0	0.22	0.22	0.42	0.47	0.09	0.41
–	–	–	–	–	0	0.08	0	0.25	0.33	0	0.2	0	0	0	0	0	0.11	0.15	0	0.13
–	–	–	–	–	–	0.21	0	0	0	0	0	0.14	0	0	0	0.14	0.17	0.12	0	0.11
–	–	–	–	–	–	–	0.09	0.17	0.08	0	0.07	0.08	0	0	0.08	0.18	0.27	0.41	0.08	0.37
–	–	–	–	–	–	–	–	0	0.2	0.09	0.17	0.09	0.09	0	0.2	0.2	0.29	0.35	0	0.25
–	–	–	–	–	–	–	–	–	0.25	0.4	0	0.25	0	0.25	0.67	0	0.1	0.23	0	0.13
–	–	–	–	–	–	–	–	–	–	0.33	0.5	0	0.33	0	0.33	0	0.11	0.15	0	0.13
–	–	–	–	–	–	–	–	–	–	–	0.2	0.33	0.33	0	0.33	0	0.11	0.07	0	0.06
–	–	–	–	–	–	–	–	–	–	–	–	0	0.5	0	0.2	0	0.09	0.21	0	0.12
–	–	–	–	–	–	–	–	–	–	–	–	–	0	0	0	0.33	0.11	0.07	0	0.06
–	–	–	–	–	–	–	–	–	–	–	–	–	–	0	0.33	0	0.11	0.15	0	0.06
–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0	0	0	0	0	0
–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.33	0.25	0.15	0	0.13
–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.25	0.15	0	0.13
–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.4	0.1	0.35
–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.07	0.47
–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.2

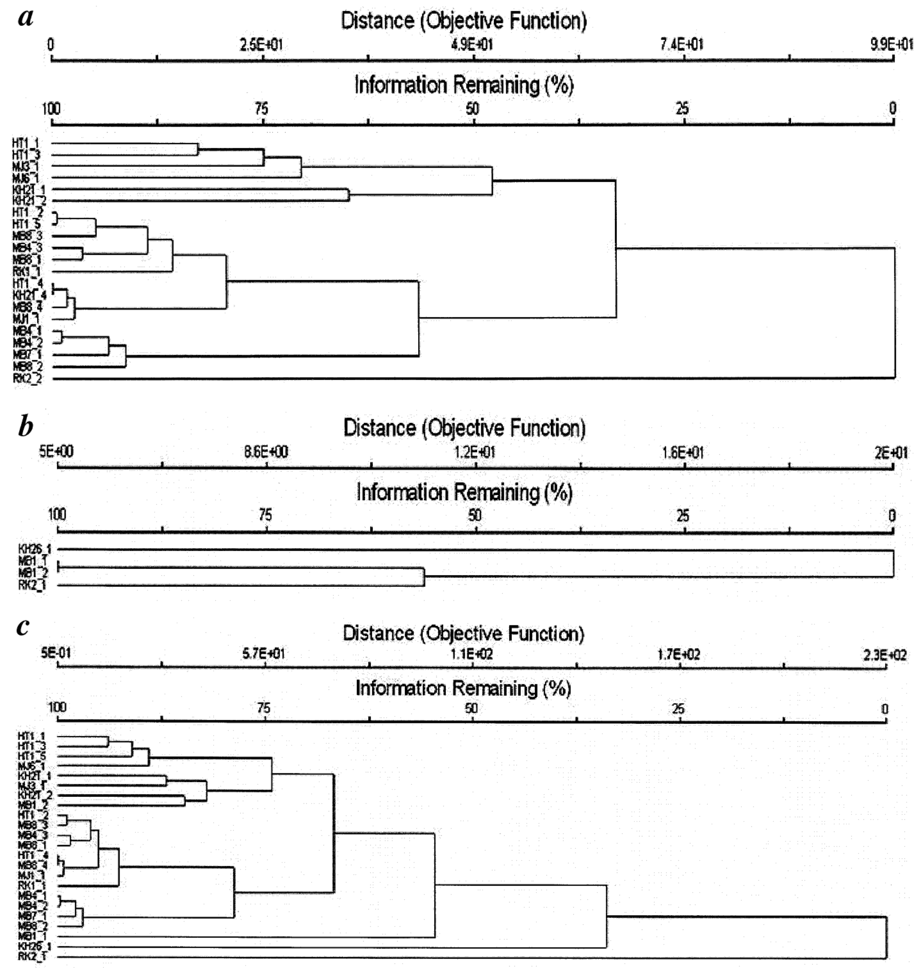

Figure 4. Dendrogram of (*a*) small fragments (*b*) large fragments and (*c*) small and large fragments of various plant communities.

Table 5. Jaccard similarity index between various large fragments of the study area

Fragment	KH26_1	MB1_1	MB1_2	RK2_1
KH26_1	–	0	0.35	0.27
MB1_1	–	–	0.38	0.35
MB1_2	–	–	–	0.32

larity index is 0 and it shows dissimilarity. Similar is the case between fragments HT1_1 and MB8_3, HT1_1 and MB8_1. An exceptional case is observed in the fragments of Hathinala. It was observed that between fragments HT1_2 and HT1_4, HT1_2 and HT1_3 the values of Jaccard similarity index show dissimilarity (Jaccard = 0).

The analysis of similarity indices among large fragments shows that the fragments occurring at the same location are similar in species richness, whereas fragments of different locations show less similarity in species richness. For example, between fragments Kh26_1 and MB1_1, the value of Jaccard similarity index is 0. Whereas between the two large fragments at Manbasa, i.e. MB1_1 and MB1_2, the value of Jaccard similarity index is 0.38 (Table 5).

The analysis of species richness among small and large fragments shows that small fragments of different locations are similar in terms of species richness, whereas they are less similar to the large fragments. For example, the value of Jaccard similarity index when compared between the small fragments HT1_1 and HT1_5 is 0.45. Whereas between HT1_1 (small fragment) and KH26_1 (large fragment), the value of Jaccard similarity index is 0.28 (Table 6).

Analysis of variance

The analysis of variance (Table 7) shows that the biodiversity levels are significantly different for different sizes of fragments. Hence, the analysis shows that fragment size plays an important role in regulating the biodiversity levels.

Discussion

The present analysis shows that biodiversity levels are different in various fragments of different sizes. Small fragments are similar to each other in terms of species composi-

Table 6. Jaccard similarity index between small and large fragments of the study area. Large fragments are KH26_1, MB1_1, MB1_2 and RK2_1

Fragment	HT1_1	HT1_2	HT1_4	HT1_5	HT1_3	KH21_1	KH21_2	KH26_1	MB1_1	MB1_2	MB4_1	MB4_2	MB4_3	MB7_1	MB8_1	MB8_2	MB8_3	MB8_4	MJ1_1	MJ3_1	MJ6_1	RK1_1	RK2_1
HT1_1	–	0.14	0.14	0.45	0.1	0	0.08	0.28	0.42	0.19	0.25	0.25	0.13	0.33	0	0.25	0	0.29	0.13	0.33	0.5	0.11	0.28
HT1_2	–	–	0	0	0.1	0	0.08	0.06	0.1	0.08	0.25	0.33	0	0.2	0	0	0	0	0	0	0.07	0	0.06
HT1_4	–	–	–	0.11	0.1	0	0.08	0.06	0.1	0.08	0	0	0	0	0	0	0	0.5	0.5	0.11	0.07	0	0.06
HT1_5	–	–	–	–	0.46	0.14	0.24	0.19	0.27	0.24	0.08	0.09	0.1	0.08	0.1	0.09	0	0.22	0.22	0.38	0.44	0.09	0.39
HT1_3	–	–	–	–	–	0.13	0.38	0.3	0.33	0.22	0.08	0.08	0	0.15	0.09	0.08	0	0.09	0.2	0.27	0.5	0.08	0.37
KH21_1	–	–	–	–	–	–	0.27	0.28	0.13	0.27	0.1	0.11	0	0.09	0.13	0.11	0.14	0	0.13	0.23	0.17	0	0.15
KH21_2	–	–	–	–	–	–	–	0.47	0.38	0.41	0.23	0.15	0	0.13	0.08	0.07	0.08	0.08	0.17	0.31	0.44	0.07	0.4
KH26_1	–	–	–	–	–	–	–	–	0.3	0.33	0.25	0.19	0.06	0.24	0.06	0.19	0.06	0.13	0.13	0.32	0.43	0	0.28
MB1_1	–	–	–	–	–	–	–	–	–	0.38	0.4	0.3	0.09	0.36	0	0.3	0.01	0.2	0.09	0.27	0.5	0.08	0.3
MB1_2	–	–	–	–	–	–	–	–	–	–	0.33	0.25	0.08	0.21	0.08	0.15	0.08	0.17	0.17	0.31	0.37	0	0.27
MB4_1	–	–	–	–	–	–	–	–	–	–	–	0.75	0.2	0.5	0	0.4	0.25	0.2	0	0.18	0.29	0	0.18
MB4_2	–	–	–	–	–	–	–	–	–	–	–	–	0.25	0.6	0	0.5	0.33	0.25	0	0.2	0.21	0	0.19
MB4_3	–	–	–	–	–	–	–	–	–	–	–	–	–	0.17	0.33	0.25	0	0.33	0	0.1	0.07	0	0.06
MB7_1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0	0.6	0.2	0.17	0	0.17	0.27	0	0.17
MB8_1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0	0	0	0.33	0.1	0.07	0	0.06
MB8_2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.33	0.25	0	0.2	0.21	0	0.12
MB8_3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0	0	0.11	0.07	0	0.06
MB8_4	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.33	0.22	0.14	0	0.13
MJ1_1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.22	0.14	0	0.13
MJ3_1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.44	0.09	0.39
MJ6_1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.06	0.5
RK1_1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.19

Table 7. Analysis of variance showing significant difference in biodiversity levels for different size classes

		Sum of squares	df	Mean square	*F*	Sig
Diversity index	Between groups	3.314	2	1.567	4.508	0.044
Shannon–Weiner	Within groups	3.129	9	0.348		
	Total	6.263	11			
Species richness	Between groups	106.473	2	53.236	5.666	0.026
	Within groups	84.561	9	9.396		
	Total	191.034	11			

tion; similar is the case with large fragments in general. It is observed that there is less similarity between small and large fragments in terms of species composition. Besides, the diversity levels among the fragments of similar size class varied across the anthropogenic gradient, i.e. through five locations. Analysis of species richness, diversity indices (Shannon–Weiner and Simpson index) and various similarity indices has helped in studying the patterns/levels of biodiversity in different fragment size classes along different levels of anthropogenic pressure.

In order to have both qualitative and quantitative analysis of species richness among various types of fragments, cluster analysis and various similarity indices were analysed. The purpose of cluster analysis was to define fragments based on their similarities in species composition, which is expressed in the dendrogram. The purpose of analysing similarity indices is to have a quantitative estimate of similarity among the various fragments. Similarity between two fragments can be described not only as a function of the number of common and unique species, but also of the amount of each species present[25]. Use of different similarity indices minimizes the probability of the computed results being dependent on the specific properties of a particular index[26]. Neither species richness nor species density alone in isolation is considered to be the complete and comprehensive method for measuring diversity. However, patterns of diversity are sensitive and reflect according to the measure used[27].

Species assemblages found in small patches are not simply a random subset of the species pool found in large patches, because both patch quality and community structure change with the site or geography of the patch[28]. The following possible mechanisms may explain the process of biodiversity erosion. First, it is seen that the remaining fragments represent only a sample of the original habitat; many species will be eliminated by chance (initial exclusion). One of the possible reasons could be the loss of habitat itself. This kind of situation was encountered in case of *Acacia* community, where a decrease in species diversity as a result of increased fragmentation was observed. Secondly, the modified landscape in which the fragments exist may be inhospitable to many native species, thus preventing normal movement and dispersal of plant species. Thirdly, small fragments contain fewer habitats and support smaller populations of native species, which are therefore susceptible to accelerated disappearance and are likely to intercept the paths of dispersing individuals (species–area effects)[29]. Small fragments in the study area were observed to be less diverse than the large fragments.

As a result of fragmentation and its impact on biodiversity, it was observed that the average population size of forest species is on the decline and they face danger of accelerated rate of exploitation[30]. For example, *Shorea robusta* trees are being preferentially removed for their higher timber value. A similar example of exploitation is of *A. catechu* species for its commercial value (for *Khair* which is extracted from its bark). Hence these two tree species are vulnerable for further exploitation, if proper measures are not taken for their protection.

Fragmentation threatens different species in different ways, depending on species-specific characteristics and the type of environment. Fragmentation also affects different species at different life stages. Some species are specialized to the microclimate of the forest, and such species are affected by the fragmentation, since no suitable habitat is available for them as time proceeds and continuous forest are fragmented. Economically and commercially important species undergo higher degree of poaching and extraction, e.g. for food, fuel, timber and medicinal uses. Many forest fragments are readily accessible to humans due to high edge–interior ratios.

Approach for conservation

A judicious approach for conservation would include proper measures be taken to protect both small and large fragments. Large fragments may inhabit more species richness, primarily because they cover a wide geographic scale[31]. They would also serve the purpose of representativeness of ecosystem types.

In communities, species richness follows a consistent pattern, that is, with increasing fragment size the number of species increases. Large fragments have more habitat variety, inhabit both common and uncommon species, and larger the population size lower is the rate of extinction. Generally, large areas tend to retain higher stability than small areas. Hence, to maintain maximum diversity, large fragments should be preserved. Forest interior species are less likely to be found in small fragments because of edge effect. To preserve the sensitive interior species, large tracts of forests should be protected. There are relative advantages of conserving either several small or single large fragments. For example, in conserving a single large fragment, the advantage is low negative edge effect, whereas the disadvantages are low species richness, low abiotic and biotic heterogeneity of patches, and low immigration of many species due to different landscapes. In conserving several small fragments, the advantages are high species richness, high abiotic and biotic heterogeneity of patches, and high immigration of species. The disadvantage is high negative edge effects[32–34]. In order to optimize biodiversity levels, conservation measures should be addressed at landscape level, particularly in the case of plant communities which require small areas and are sensitive to microhabitat variations.

Conclusion

It can be concluded from the above study that small and large fragments inhabit completely different community structures as seen from the differences in species composition. It is observed that biodiversity levels operate differently with changing fragment size classes. Thus, in this context, it is suggested that small fragments of Hathinala and large fragments of Khatabaran need more attention. At Hathinala, the fragments have exhibited high diversity. Large fragments at Khatabaran have shown high diverse conditions which support the fact that large contiguous patches are present, which need to be protected from disturbances occurring along the edges. At Manbasa, which is supposed to act as a corridor, it is advisable that the large fragments be protected against getting fragmented into smaller ones. This corridor may further act as a connecting link for the Hathinala and Muirpur forests. Small fragments at Majhauli are to be protected from the local activities taking place. At Renukoot, both small and large fragments have shown high diversity, though they are different in species composition with the fragments at other locations. Thus, both small and large fragments should be protected.

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