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A method for assessing evergreen habitats using phytodiversity and geospatial techniques in tropical rain forests of Southern Western Ghats (India)

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Abstract We have used data generated using remote sensing and geographical information systems to categorize habitats, and then determined the relationship between the habitat categorizations and species-distribution patterns. A biologically rich hotspot—Kalakad-Mundanthurai Tiger Reserve, located at Southern Western Ghats, India, was chosen for this study. In order to spatially delineate areas of high species richness/diversity and endemic habitat zones, we have identified evergreen habitats in conjunction with landscape metrics, species assemblage, micro-habitats like slope, topography, species endemism, and proportion of core and edge species. A total of 236 species and 2,920 individuals were recorded using systematic stratified plots of 0.1 ha covering 47 plots. Hierarchical cluster analysis was done using Ward's method. Plot information was used to identify clusters based on species density. The analysis showed five species assemblages that are quite distinct from each other in terms of dominant species. The distribution of endemic and edge species, land cover heterogeneity, and continuity of patches in these clusters were evaluated to understand the degree of disturbance and intactness at landscape scale. Integration of species assemblages and topography brought out four major elevation-slope complexes. Information on species composition (robust field survey) with spectral (hybrid classification) properties has shown 72% overall accuracy and distinguished four evergreen sub-groups and other land cover classes. The developed approach assumes great importance in the assessment of biodiversity and prioritizing the areas of conservation.

Keywords Evergreen forests · Remote sensing · Species assemblages · Endemism · Conservation zones · Western Ghats

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Introduction

The Western Ghats (hereafter WG) represents one of the best non-equatorial tropical forests and is also considered one of the 34 biodiversity hotspots of the world (Nayar 1996; Myers et al. 2000). The WG has large environmental heterogeneity resulting from geographical and demographic variations. The complexity of physical features with corresponding variations in macro and microclimatic conditions are expressed by high diversity of species and various habitat formations in this region. Of the total tree species, 63% are endemics, confining to low- and medium-elevation evergreen forests (Ramesh et al. 1991). In recent decades, the WG has shown excessive alterations due to anthropogenic pressures posing severe threats on habitats, particularly evergreen habitats (Ramesh et al. 1997; Jha et al. 2000; Giriraj 2006). In this regard, the understanding of species distribution, habitat fragmentation, and identification of conservation zones in the wet evergreen forests is realized as very important.

The Agasthyamalai range (2,000 km^2), located at the southern end of the WG (in southern India), is known for high plant diversity, harboring 2,000 flowering plants with 7.5% endemism (Henry et al. 1984) and the flora of former Kalakad Wildlife sanctuary, which is now part of Kalakad-Mundanthurai Tiger Reserve (KMTR) that displays a 3.3% endemism (Parthasarathy 1988). Studies on floristic richness and diversity (Pascal 1988; Ganesh et al. 1996; Parthasarathy 1999, 2001; Devy and Davidar 2001; Dutt et al. 2002; Amarnath et al. 2003; Giriraj 2006) and floristic composition in conjunction with wildlife biology, habitat loss and disturbance factors (Ganesh et al. 1996; Parthasarathy and Karthikeyan 1997; Devy and Davidar 2001; Dutt 2001; Ganesh and Davidar 2001; Johnsingh 2001; Parthasarathy 1999, 2001; Sankaran 2005) were carried out in different parts of KMTR. Information on the distribution of endemic, rare, endangered, and threatened (RET) status was also studied in detail (Ahmedullah and Nayar 1987; Nayar 1996; Ramesh and Pascal 1997; Irfan-Ullah et al. 2007).

Studies in relation to vegetation type and forest density cover in KMTR using satellite remote sensing, bioclimatic and limited ground survey have also been conducted (FSI 2001; IIRS 2002; Pascal 1988; Ramesh et al. 1997). Further, the KMTR region of the WG has been classified based on landscape types consisting of topography, climate, population, agriculture, and vegetation cover (IIRS 2002; Nagendra and Gadgil 1998). These classifications reveal mostly local, scale-specific and limited studies at the landscape level. There are no comprehensive studies integrating satellite remote sensing, floristic composition and its spatial pattern to delineate areas of biodiversity conservation zones. Studies conducted are largely in temperate and alpine ecosystems, which are relatively homogenous, and species-poor communities (Gould 2000; Nagendra 2001; Vonlanthen et al. 2006) and very few in the tropics (Indian Institute of Remote Sensing [IIRS] 2002; Chandrashekhar et al. 2003; Giriraj 2006; Murthy et al. 2006).

Remote sensing-based habitat maps, in conjunction with information on species–habitat associations, are generally being used to derive information on the distribution of species, although a few exceptions may exist (e.g., Treitz et al. 1992; Murthy et al. 2006). The degree of correspondence between habitat maps and species distributions depends on the degree of habitat map generalization, and this could be optimized to get maximum information of species diversity (H') (Stoms 1992; Coops and Catling 1997). Habitat maps appear to be capable of providing information on the distribution of large numbers of species in a wide variety of areas; however, this is restricted to the spatial scale to tens of square kilometers. In smaller, local areas with limited species diversity, direct mapping can provide detailed information on the distribution of certain canopy tree species or associations. Data sets from IRS 1C/1D LISS-III have been used effectively in mapping the homogenous plant colonies of *Hippophae rhamnoides*, in the Spiti region of India with prior knowledge of their occurrence, and the vegetation types of the area using remote sensing techniques (Roy et al. 2001). IRS 1C/1D of LISS-III FCC has been used for stratification of *Ephedra gerardiana* in the complex terrain conditions of Lahul and Spiti district (Porwal et al. 2003). Lewis (1994) attempted to relate classified Landsat MSS imagery to vegetation composition on Barrow Island, Australia. However, a few studies have reported on the use of hyper spectral image data for differentiation of species (Franklin 1994; Martin et al. 1998) as well as discrimination of conifer species (Gong et al. 1997) and several tropical species (Cochrane 2000).

Thus it is necessary to develop an approach to combine habitat characteristics and species composition (robust field survey) with spectral (hybrid classification) properties to delineate habitat type and disturbance pattern at landscape scale. This would help the biologist to make predictions about the extent of the impending danger to a particular habitat/species. In the present study, we have developed an approach for tropical forest habitat through the use of remote sensing and intense phytosociological data for determining habitat pattern and change at landscape scale. Later, the identified evergreen habitats were modeled using a customized package (Bio-CAP) to identify the level of habitat fragmentation and disturbance to delineate conservation zones for the sustenance of biodiversity.

Study area

The study was conducted at the KMTR covering ca.186 km^2, a part of Tirunelveli hill region (8°30′ N–8°37′ N latitude and 77°18′ E–77°25′ E longitude) located in the southern WG, southern India (Fig. 1). KMTR was designated as a Tiger Reserve in 1988 following the merger of two previously protected areas, the Kalakad Wildlife Sanctuary (established in 1971) and the Mundanthurai Wildlife Sanctuary (established in 1962; Johnsingh 2001). The reserve presently covers an area of approximately 900 km^2 and spans an altitudinal gradient from about 100–1,867 m. Geologically, the rocks are granitoid gneiss and the terrain is undulating. The mean annual ambient temperature in the evergreen forest is 22.5°C (range 15–30°C). The mean annual rainfall is about 3,000 mm from the southwest (May–August) and northeast monsoons (October–December), (Pascal 1982).

The type of vegetation varies along the elevation gradient. The foothills harbor scrub vegetation up to an altitude of 200 m. Dry teak forest, composed of stunted, thin-poled teak (*Tectona grandis*), occurs between 200 and 300 m, mixed deciduous forest up to 750 m, semi-evergreen forest up to 850 m, and wet evergreen forest from 920 to 1,500 m, beyond which high-altitude grasslands occupy the hill top (Parthasarathy 1999). There are savanna woodlands adjacent to mixed deciduous and semi-evergreen forest tracts from 400 to 920 m; in some places up to 1,400 m. Ground fire occurs in savanna woodlands during the dry months of March–May. A detailed floristic account of the forest types of KMTR already exists (Ganesh et al. 1996; Parthasarathy 1999; Giriraj 2006). These forests are classified as Tirunelveli hill-top forests and as *Cullenia–Mesua–Palaquium* series (Pascal 1988). KMTR forest is rich in

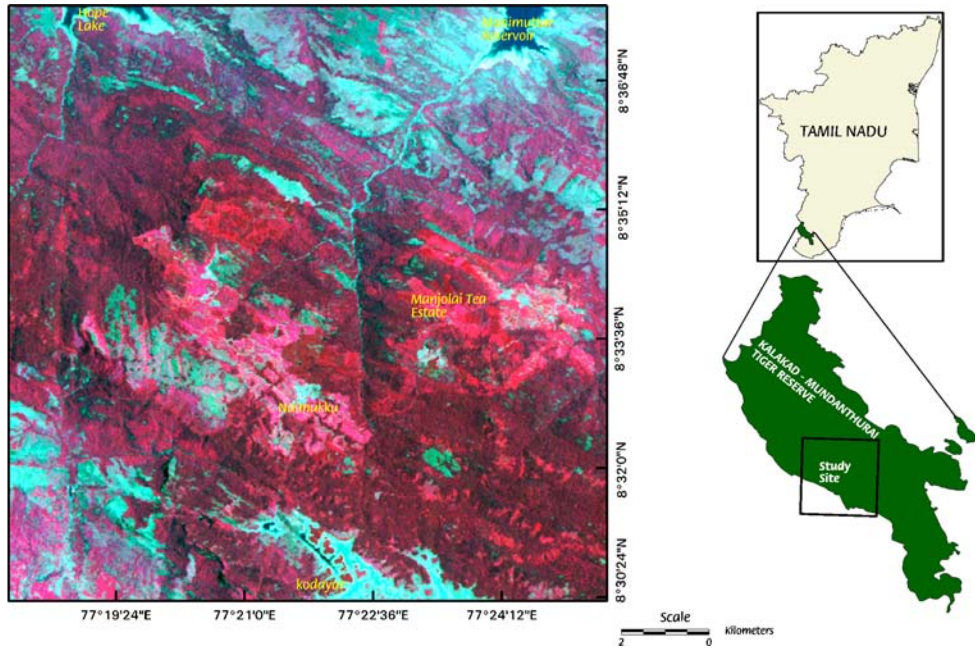

Fig. 1 Satellite imagery (IRS-P6 LISS III, 2004) of the study area and *right side* highlighting the study site within the Kalakad-Mundanthurai Tiger Reserve, Southern Western Ghats, in Tirunelveli and Kanyakumari district of Tamil Nadu state, southern India

wildlife, particularly mammals, reptiles, avifauna, and insects (Ramakrishnan et al. 1999; Johnsingh 2001). The forest represents habitats for the endangered (IUCN—International Union for Conservation of Nature) species such as the Tiger and the Nilgiri Tahr.

Material and methods

Cloud-free IRS LISS-III satellite data of March 2004 covering path and row 101/68 was acquired from the National Remote Sensing Agency, Hyderabad. The satellite data was rectified to a scale of 1:50,000 with reference to the Survey of India maps using geometric rectification software of ERDAS IMAGINE 8.5. The initial objective was to delineate evergreen communities using species database and spectral based approach. In the first stage we prepared broad forest types—evergreen, semi-evergreen, moist deciduous, dry deciduous, dry evergreen, plantation and other land cover classes using maximum likelihood algorithm of supervised classification (Lillesand and Kiefer 1994). The classified vegetation type was validated with ground inventory plots and found to be 80% accurate (IIRS 2002). In the second stage, we masked the evergreen forest type and did unsupervised classification for its different spectral characters. Further, systematic stratified sample plots (0.1 ha) at 2-km interval totaling 47 sample points were carried out in the delineated five unidentified spectral classes during March–April 2004. Information of species, like name, girth (girth at breast height above 30 cm), and height were measured. Topography information was derived from Shuttle Radar Topography Mission (SRTM) digital elevation model and vegetation parameters like canopy cover, canopy strata, and tree height were estimated visually. We characterize the edge species as species on the edges of the habitat, invasive and deciduous species. The collected herbarium specimens were identified using available literature (Gamble and Fischer 1915–1935; Pascal and Ramesh 1987). For calculating H' we used the Shannon index using the following formula:

Shannon-Weaver index $H' = -\sum p_i \log_2 p_i$ (Shannon and Weaver 1949) where p_i is the proportion of ith species.

Species patterns across different sample points were assessed using cluster analysis. The data on 2,691 individuals and 115 species, collected from 47 plots of evergreen forests were clustered using Ward's method (minimum variance clustering) based on species density using Statistica 5.0 (1995). Finally, information on species assemblage (species co-occurring in a given area) coupled with topographic factors was correlated with spectral classes to delineate four evergreen communities over study area. To determine the accuracy of the thematic evergreen habitat map, an accuracy assessment was carried out. The Kruskal–Wallis test was used to compare species and the spectral clusters because the variances were not equal among areas sampled even after the data were transformed (Sokal and Rolf 1995). The test was carried out using the software package of SPSS/PC + (SPSS 1988).

Landscape analysis

A number of landscape metrics (or indices) that describe the landscape configuration and composition are in use either for individual patches or for the whole landscape (McGarigal and Marks 1994). In the present study, landscape analysis was carried out using Bio_CAP customized package (Bio_CAP 1999). Bio_CAP, a geospatial semi-expert package was developed using geographic information system (GIS) package (Arc/Info), Image Processing (ERDAS) and C/C++ for biological richness (BR) assessment. Landscape ecological indicators (i.e., fragmentation, patchiness, porosity, interspersion and juxtaposition) were calculated using Bio_CAP, wherein a user grid cell of $n \times n$, where $n = 250$ m was moved with the spatial data layer and given a criterion of deriving the number of patches within the grid cell. The iteration was repeated by moving the grid cell through the entire spatial layer. The output layer that contains the normalized data of the patches per cell was scaled between 0 and 10. Baseline details on roads and settlements were used to create a 2.5-km buffer (i.e., influence zone around the source of disturbance). Vegetation cover-type map was used as the input layer to derive fragmentation, patchiness, porosity, interspersion and juxtaposition for calculating the disturbance index (DI). Field-derived information was assigned to vegetation-type map to derive EU, *H'*, and BD maps.

DI was computed by adopting linear combinations of defined parameters on the basis of probabilistic weightages.

$$\mathrm{DI} = \int \{\text{Fragmentation, patchiness, interspersion, porosity, biotic disturbance, buffer, juxtaposition}\}.$$

BR at landscape level is determined as a function of ecosystem uniqueness (EU), *H'*, edge category (EC), terrain complexity (TC), and DI. The main parameters like EU, *H'*, and information on edge habitats come from phytosociological data as well as the species list from the IUCN category for RET species. The weights of the number of species present in different vegetation types were added to derive relational weights, which provided input to estimate the BR index. Weightages were given in accordance with species richness—high weightage for high species richness. TC was derived using elevation information obtained through the digital elevation model. BR values were scaled to five qualitative grades.

$$\mathrm{BR} = \int \{\text{Ecosystem uniqueness, species diversity, edge category, terrain complexity and disturbance index}\}$$

Results

Vegetation type distribution

The results on vegetation type based on digital classification of IRS LISS-III satellite data are presented in Table 1. Out of the total study area ca. 186 km^2, four evergreen complexes constitute 68.17 km^2 (36.63%) of the area. A majority of the evergreen forest lies in the gradient of 1,100–1,400 m altitude and 20–40% slope contributing to 26.85 km^2 (14.43%). Grassland covers 15.35 km^2 (8.5%) and is mainly in the areas of Kudrivetti and Manjamparai region. Edges of the evergreen patches are surrounded by orchards mainly tea and coffee constituting an area of 15.97 km^2 (8.58%). The occurrence of reeds (*Ochlandra* sp.) in the disturbed evergreen forests was digitally classified covering an area of 8.89 km^2 (4.78%). Moist and dry deciduous forest covering 27.41 km^2 (14.73%) was noticed in the areas of Mundanthurai plateau and lower Kodayar region.

Table 1 Vegetation and land cover distribution for the part of Kalakad-Mundanthurai Tiger Reserve, Southern Western Ghats (Tamil Nadu), southern India

Sl.	Vegetation type	Area (sq. km)	Area (%)
1	Evergreen	68.17	36.63
2	Semi evergreen	13.76	7.39
3	Moist deciduous	16.92	9.09
4	Dry deciduous	10.49	5.64
5	Dry evergreen	11.05	5.94
6	Semi evergreen with reeds	14.64	7.87
7	Reeds	8.89	4.78
8	Teak	2.02	1.09
9	Scrub/shrubs	2.32	1.25
10	Grassland	15.35	8.25
11	Orchards	15.97	8.58
12	Fallow/barren	2.57	1.38
13	Water	3.94	2.12
Grand total		186.10	100.00

Species richness

Based on field data from 47 sample points of 0.1 ha, species-distribution pattern in these evergreen forests showed a total of 236 species from 153 genera distributed in 54 families with a stand density of 621 stems ha^{-1} from 2,920 individuals (Table 2). The Shannon diversity index showed a high species heterogeneity of 6.62 *H'*. Genera having maximum number of species include *Diospyros* (15 species), *Syzygium* (7), *Litsea* (7), *Garcinia* (5), *Drypetes* (5) and *Cinnamomum* (5) and five major families include Euphorbiaceae (27 species), Lauraceae (25), Ebenaceae (15), Rubiaceae (11) and Meliaceae (10). A total of 83 endemic species distributed across 25 families was recorded. Fifteen species have been identified based on the IUCN-RET category for the present study.

Cluster analysis

Cluster analysis was carried out to assess the species assemblages in the complex evergreen forests using species distribution data from 47 plots. A maximum cluster linkage distance of 2.1 was used to regroup the 47 sample plots into five different clusters. The regrouped five clusters are shown in Fig. 2. While regrouping, the plot identity in terms of location is also kept in mind such that possible species assemblages pertaining to characteristic topographic complex could be observed. Accordingly, five major clusters as shown in the Table 3 representing species composition/individuals were observed. Some of the clusters include *Agrostistachys meeboldii*, *Aglaia bourdillonii*, *Cullenia exarillata*, *Gomphandra coriacea*, and *Myrisitica dactyloides* making up 77 species of 971 individuals, and *Mesua ferrea* L., *Mangifera indica*, *Xanthophyllum flavescens*, *Heritiera papilio*, and *Knema attenuata* accounting for 116 species of 526 individuals. Similarly, the three major clusters unique to elevation-slope complexes indicate the variability in species distribution pattern.

Species similarity was studied as a function of the species presence/absence data for the five clusters and it varies between 27 and 56%. Between clusters of C1 and C4 the similarity seems to be 52% whereas for clusters C2 and C3 showed 56%, contrastingly clusters C2 and C5 showed 27% of species similarity. It indicates that the species in these clusters are restricted in its distribution pattern.

Table 2 Enumeration of phytosociological data for the evergreen forest carried out in the Kalakad-Mundanthurai Tiger Reserve, Southern Western Ghats (Tamil Nadu), southern India

Area sampled (0.1 ha)	47
Tree	
Species richness	236
No. of genera	153
No. of families	54
Shannon-Weaver index *H'*	6.62
Total stems	2,920
Stand density ha^{-1}	621
Basal area m^2 ha^{-1}	51.76
No. of endemic species	83
No. of edge species	70
Shrubs	19
Herbs	15
Climbers/epiphytes	22

Biological and topographical characters of the clusters

Characterizing the clusters with biological and topographic factors helped in delineating the evergreen habitats. Assemblage C1, which has 77 species with a stand density of 809 stems per ha, had canopy closure of >80% with all its canopy strata distributed in the range of 1,100–1,400 m having 20–40% slope (Table 4). Contrastingly, cluster C4, which had 131 species with a stand density of 579 stems per ha, has 60–80% canopy closure with the presence of 2–4 canopy strata distributed in the high altitude of 900–1,400 m and >50% steep slope. The cluster C3 and C5 in the altitude of 700 m–1,300 m are at 10–30% slope having 57–116 species a stand density of 538–584 stems per ha.

Four spectral classes delineated using unsupervised classification

Delineation of evergreen forest using unsupervised classification and linking with biological and topographical characters of the clusters helped in differentiating (Fig. 3) four spectral classes, namely 900–1,400 m with >50% slope, 1,100–1,400 m with 20–40% slope, 900–1,300 m (<20%), 700–1,300 (>30%), and finally, 400–800 m with <20% slope. Area-wise evergreen habitat (S2) contributed to 26.85 km^2, followed by S4 (18.7 km^2) and the least by S3 contributing to 8.6 km^2. The identified evergreen habitats were thoroughly checked in the field with GPS points. The overall accuracy stands at 72% with a kappa statistics of 0.70 (Table 5). Using these data, a final map was brought out covering the four evergreen sub-groups and other vegetation and land cover classes (Fig. 3).

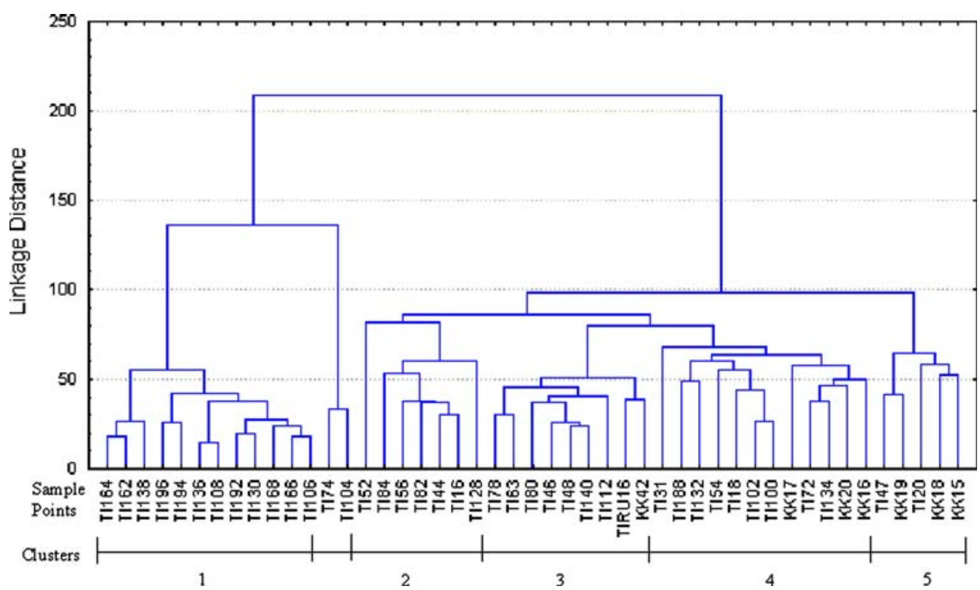

Fig. 2 Species association using cluster analysis based on Ward's method with Euclidean distance for the all sample points (4.7 ha having 115 species with 2,691 individuals)

Table 3 Comparative evaluation of species and spectral clusters and Kruskal–Wallis test to determine significant differences among evergreen groups in the Kalakad-Mundanthurai Tiger Reserve, Southern Western Ghats (Tamil Nadu), southern India

Sl.	Clusters		Plots	Topography		Species	Individuals	Species assemblages	Significance
	Species	Spectral		Elevation (m)	Slope				
1	C4	S1	12	900–1,400	> 50	131	695	*Litsea floribunda, Cullenia exarillata, Tricalysia apiocarpa, Eugenia calcadensis, Symplocos racemosa*	$P < 0.001$
2	C1	S2	12	1,100–1,400	20–40	77	971	*Agrostistachys meeboldii, Aglaia bourdillonii, Cullenia exarillata, Gomphandra coriacea, Myristica dactyloides*	$P < 0.001$
4	C3	S3	9	700–1,300	10–30	116	526	*Mesua ferrea, Mangifera indica, Xanthophyllum flavescens, Heritiera papilio, Knema attenuata*	$P < 0.01$
3	C5		5	900–1,300	< 20	57	269	*Acronychia pedunculata, Schleichera oleosa, Macaranga peltata, Alstonia scholaris, Symplocos macrocarpa*	
5	C2	S4	7	400–800	< 20	99	421	*Dimocarpus longan, Hopea parviflora, Strombosia ceylanica, Kingiodendron pinnatum, Syzygium mundagam*	$P < 0.01$

Table 4 Vegetation structure, topographic factors for the four evergreen habitats for the Kalakad-Mundanthurai Tiger Reserve, Southern Western Ghats (Tamil Nadu), southern India

Species clusters	Plots	Vegetation structure				Topographic factors	
		Species	Stand density (ha^{-1})	Canopy closure (%)	Canopy strata	Elevation (m)	Slope (%)
S4	12	131	579	60–80	2–4	900–1,400	> 50
S1	12	77	809	> 80	3–4	1,100–1,400	20–40
S3	9	116	584	> 80	3–4	700–1,300	10–30
S5	5	57	538	60–80	3–4	900–1,300	< 20
S2	7	99	601	60–80	2–4	400–800	< 20

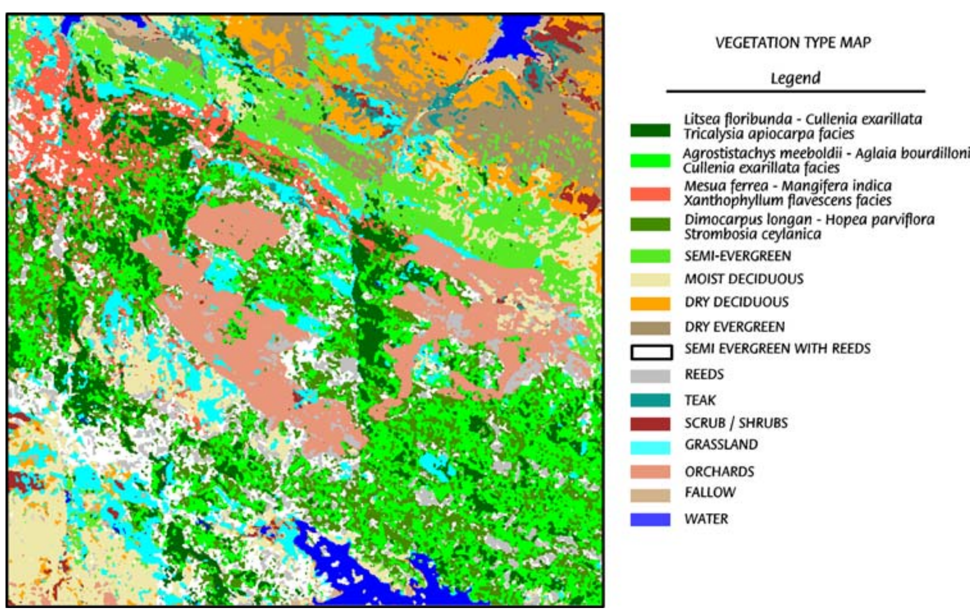

Fig. 3 Spectral and species-based mapping of four different evergreen habitats were overlaid with other vegetation and land-cover classes for the part of Kalakad-Mundanthurai Tiger Reserve, Southern Western Ghats (Tamil Nadu), southern India

Comparative evaluation of species and spectral clusters

The spectral class S1, i.e., high altitude–high slope, at 900–1,400 m and > 50% slope are with the species assemblages of cluster C4 having predominantly *Litsea floribunda*, *C. exarillata*, *Tricalysia spherocarpa*, *Eugenia calcadensis*, and *Symplocos racemosa*. Significant differences ($P < 0.001$ level) were found for the groups be-

Table 5 Area statistics and its accuracy assessment for the Kalakad-Mundanthurai Tiger Reserve, Southern Western Ghats (Tamil Nadu), southern India

Class	Area (sq. km)	UA	PA
S1	14.1	80	100
S2	26.85	80	99
S3	8.6	60	60
S4	18.7	66.8	80
Total	68.2		
Overall accuracy (%)		72	
Kappa statistics		0.70	

UA user's accuracy (%), *PA* producer's accuracy (%)

tween S1–C4 and S2–C1 using the non-parametric Kruskal–Wallis test (Table 3). The spectral class S2, i.e., high altitude–moderate slope at 1,100–1,400 m and 20–40% slope is in the C1 cluster possessing large composites of *A. meeboldii*, *A. bourdillonii*, *C. exarillata*, *G. coriacea*, and *M. dactyloides*. Similarly the clusters of C3 and C5 are in the spectral classes of S3, and the cluster of C2 is in the spectral class of S4 (Table 3). Significant differences ($P < 0.01$) were found among the groups of S3–C3/C5 and S4–C2.

Species richness of the five evergreen complexes is in the range of 57–131 species with a diversity (H') of 4.7–6.25 (Table 6), as compared to the other evergreen habitats zones of 1,100–1,400 m where the diversity of shrubs seem to be quite high ($H' = 11$). Interestingly, the habitats of 700–1,300 m showed maximum climber species ($H' = 11$) and a high basal area of 71.02 m^2/ha.

A total of 83 endemic species comprising 1,117 individuals belonging to 25 families were enumerated, and a total of 70 edge species making up 486 individuals recorded from 32 families. The endemic as well as edge species were compared with different clusters (Table 6). Of the 131 species and 695 individuals, 45 endemic species of 288 individuals and 40 edge species of 156 individuals are found in high altitude–high slope areas. Contrastingly, the high altitude—moderate slope areas had 77 species with 971 individuals and a high percentage of endemism consisting of 32 species and 362 individuals with least EC of 12 species and 38 individuals.

Landscape analysis

Fragmentation–DI–BR

Different levels of forest fragmentation were assessed for the four evergreen habitats and are given in Table 7. Low-level fragmentation in all the habitats ranged between 11 and 21% and moderate level of fragmentation between 73 and 80%. All the evergreen habitats showed least level of high fragmentation at 6–8%. The lesser level of high fragmentation is primarily due to the higher level of protection, with most of these high fragments being areas of plantation within the habitat.

Table 6 Comparison of species richness, diversity pattern, endemic species and its disturbance traits within the four evergreen habitats, Kalakad-Mundanthurai Tiger Reserve, Southern Western Ghats (Tamil Nadu), southern India

Sl.	Species clusters	Topography		Species richness				Species diversity	Basal area m^2/ha	Endemic		Edge		Intactness/neighborhood
		Elevation (m)	Slope (%)	T	S	H	C	H'		Species/total species	Individuals/total individuals	Species/total species	Individuals/total individuals	
1	S4	900–1,400	> 50	131	8	8	10	6.25	38.29	45/131	288/695	40/131	156/695	Edged with grassy/rocky slope, intact
2	S1	1,100–1,400	20–40	77	11	8	5	4.70	63.85	32/77	362/971	12/77	38/971	Edged with other evergreen type, porous with reeds
4	S3	700–1,300	10–30	116	4	4	11	5.92	71.02	48/116	236/526	27/116	59/526	Edged with semi-evergreen, plantations, porous with abundant reeds
3	S5	900–1,300	< 20	57	0	0	1	4.64	24.49	15/57	45/269	20/57	131/269	Edged with other evergreen type, plantations, porous with reeds
5	S2	400–800	< 20	99	3	6	6	5.36	46.71	45/99	187/421	20/99	101/421	More edges and fragmented

DI map was prepared using fragmentation, patchiness, porosity, juxtaposition, interspersion, and road/village information. Indicative levels of disturbance are seen only in 12% of the area, while low and moderate levels of disturbance were seen in 29 and 54% of the area, respectively. Around 11–31% of the evergreen complexes come under indicative zones. Nearly 29% of the area comes under low disturbance indicating large levels of intactness. On the other hand, 54% of moderately disturbed areas indicated fragmented ecosystems and high level of disturbances due to the presence of a large number of orchards intermixed within the forest types.

Table 7 Landscape analyses based on forest fragmentation, disturbance, and biological richness as seen in Kalakad-Mundanthurai Tiger Reserve, Southern Western Ghats (Tamil Nadu), southern India

	S1	S2	S3	S4
Fragmentation (%)				
Low	21.10	18.50	13.55	11.47
Moderate	73.39	76.22	79.17	80.12
High	5.51	5.29	7.27	8.40
Disturbance index (%)				
Indicative	15.76	11.50	31.20	16.11
Low	40.49	40.35	32.41	38.44
Moderate	41.87	47.56	34.95	45.20
High	1.88	0.59	1.44	0.25
Biological richness (%)				
Low	0.53	0.41	15.71	1.06
Moderate	0.00	35.23	64.49	50.17
High	74.93	48.75	19.80	35.36
Very high	24.54	15.61	0.00	13.41

S1 900–1, 400 m, > 50% slope; *S2* 1, 100–1,400 m, 20–40% slope; *S3* 700–1, 300 M, < 20% slope; *S4* 400–800 m, < 20% slope

Biologically rich areas were identified using combined landscape metrics and ground inventory (Fig. 4). Forty-seven percent of the areas showed high BR, with unique ecosystems, species diversity and biodiversity value. Eleven percent of the area showed very high BR constituting high altitude–high slope complexes at 900–1,400 m and > 50% slope. The areas at 1,100–1,400 m with 20–40% slope showed high BR because of the presence of a large number of endemic species and high percentage of local variance in its distribution. On the other hand, deciduous systems showed least BR, possibly due to lesser diversity and absence of EU.

Discussion

Environmental surrogates are represented by assemblages of species based on the assumption of a stratified random distribution among patches of suitable habitats. Species are assemblages of populations that are often distributed across a landscape of habitat types. These populations have specific adaptations to regional environmental conditions (Murthy et al. 2006). Populations are being lost at a much higher rate than are species (Hughes et al. 1997), resulting in the loss of novel adaptations to unique habitats that are necessary to meet future environmental changes. One strategy for conserving the maximum amount of adaptive variation is to preserve populations that occur along environmental gradients, thus preserving the full range of populations across habitats, as well as the unique traits of those populations (Smith et al. 2001). In this context, accounting for the spatial distribution of populations, species, and communities assumes importance and tools

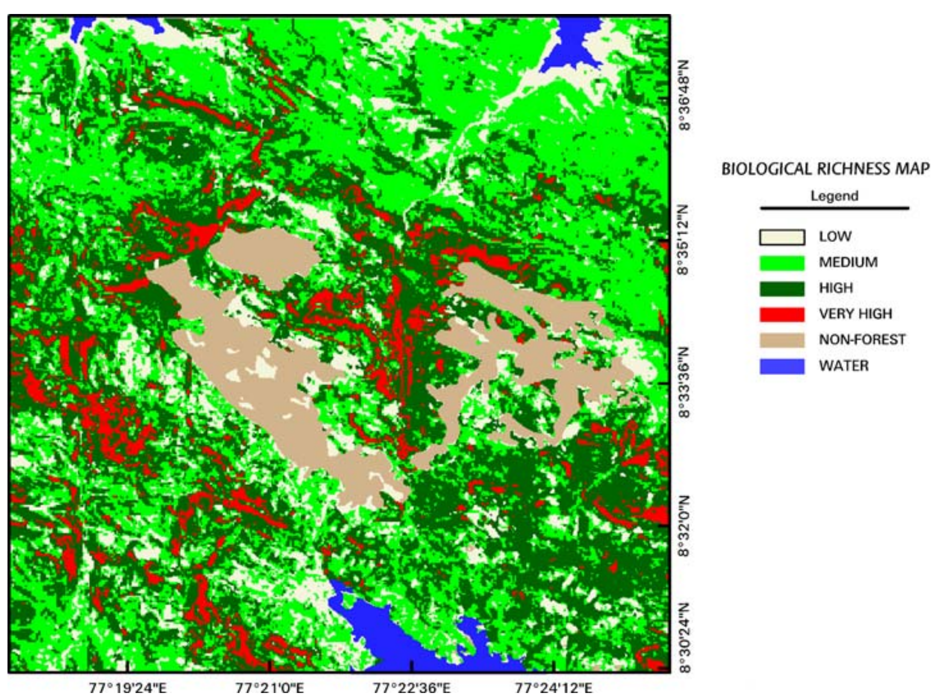

Fig. 4 Biological richness map based on fragmentation, disturbance level and ground inventory for the part of Kalakad-Mundanthurai Tiger Reserve, Southern Western Ghats (Tamil Nadu), southern India

like remote sensing and GIS have a great potential to map micro and macro habitats to understand the vegetation distribution (Murthy et al. 2006).

Habitat mapping using remote sensing and GIS

A range of environmental variables is seen to characterize a given species or forest type when it is not appreciably modified by humans (Skidmore 1989). Patterns of species distribution on the ground have been shown to be associated with the distribution of environmental variables such as topography, rainfall or soil type (Bauer and Peterson 2005; Irfan-Ullah et al. 2007). The distribution of these spatially variable parameters is often analyzed best through remote sensing data (Debinski and Humphrey 1997; Van Horssen et al. 1999). Researchers in Yellowstone National Park used Landsat and a GIS to categorize habitats a priori and then determined the relationship between remotely sensed habitat categories and species distribution patterns (Debinski et al. 1999; Giriraj 2006).

In the present study we characterized the spectral properties of evergreen complexes using hybrid classification and linked them with species assemblages obtained using cluster techniques. Out of the five species assemblages identified using cluster analysis of the plot data in conjunction with the elevation and slope data, the clusters in the range C3 and C5 could not be distinguished spatially using the spectral data (S3). An overall accuracy of 72% was observed between the species assemblages and the spectral clusters. The results for these spatially delineated plant communities would be useful in analyzing the diversity patterns, endemism, and disturbance level in the area in relation to each plant community.

Species richness and diversity

A total of 236 tree species and 2,920 individuals from 47 sample points and Shannon diversity between 5.8 and 6.3 *H'* were enumerated for the present study. The observed high level of Shannon diversity may be due to large level of micro-variability occurring as a result of bioclimatic, topographic, and disturbance factors. Similar conditions of high diversity and large number of rare species were reported in Costa Rica (Lieberman et al. 1996), Amazonian forest (Ulh and Murphy 1981), Sabah, Southeast Asia (Newbery et al. 1992) and Uppangala, Central WG, India (Pascal and Pelissier 1996).

Further, the species richness of 131 species with 579 stand density in 1.2 ha in the elevation-slope range of 900–1,400 m and $>50\%$ slope is comparable with other high species richness areas viz., 198 species of 1.81 ha in Sepilok, Sabah (Nicholson 1965); 214 species in 1 ha in Mulu, Sarawak (Proctor et al. 1983); 244 species in 2 ha in Pasoh, Malaysia (Manokaran and Kochummen 1987) and 307 species ha^{-1} in Amazonian Ecuador (Valencia et al. 1994). The forest stand density of 809 stands ha^{-1} in these zones is higher than that of the Courtallum reserve forest, WG (482 stems ha^{-1}), which also harbors a tropical wet evergreen forest (Parthasarathy and Karthikeyan 1997) and that of Uppangala sites (610 and 635 stems ha^{-1}) of Karnataka (Pascal and Pelissier 1996). In comparison with the wet evergreen forest across the tropics, the tree diversity ranges from 20 species ha^{-1} in Rio Xingu, Brazil (Campbell et al. 1992) to 307 species ha^{-1} in Amazonian Ecuador (Valencia et al. 1994). Thus, zones of 1,100–1,400 m elevation ranges in the KMTR region with 64 species ha^{-1} and elevation-slope range of 900–1,400 m and $>50\%$ slope with 114 species ha^{-1} represent high species diversity zones in the tropics of India.

Landscape analysis

Fragmentation accompanies habitat loss and is recognized as a serious threat to biological diversity (Saunders et al. 1991; Fielder and Kareiva 1997; Laurance et al. 1998). Analyzing landscape fragmentation (Turner and Gardner 1990; Amarnath et al. 2003) has been a common goal for landscape pattern analysis using satellite imagery. Amarnath et al. (2003), Menon and Bawa (1997), and Nagendra and Gadgil (1998) used remote sensing and GIS for biodiversity conservation following landscape ecology and spatial analysis approach. In the present study, fragmented landscapes have been identified as a function of forest and non-forest in a grid matrix to delineate areas as low to high fragments. An area of high fragmentations occurs due to the historical changes in the land cover heterogeneity prevalent in the form of reeds and semi-evergreen orchards within the evergreen systems.

Low levels of fragmentation, patchiness, porosity, and interspersion, and high levels of juxtaposition would result in an increased distance from the sources of biotic disturbance and lead to lesser disturbance areas as seen in the DI map (Roy et al. 2005). Areas nearer to habitation were observed to have high levels of disturbance. Reserved forests adjacent to habitations were under high level of disturbance. Most of the forest areas supplemented with complex terrain were seen to be under low and medium levels of disturbance. DI using BioCap for the four evergreen habitats clearly showed undisturbed habitats because of the high level of protection within the KMTR sanctuary. Lesser areas of high disturbances were quantified, due to the existence of plantations like tea and coffee, abandoned areas and remnant corridor evergreen patches on the fringes of the plantations. Moderate levels of disturbance were identified and their major causes are selective felling of timber, or burning to encourage regeneration of fodder for grazing livestock, and have a clear role in impacting the natural ecosystems (Chapin et al. 1997, 2000; Cochrane et al. 2002). Other indices like fractal dimension, contagion, connectivity also explains the process and degree of disturbance over time and measures like core area index, largest patch index, high species richness and endemism explains the complexity of the landscape and can be used as a measure for detecting biological rich areas (Zipper 1993; Baskent and Jordan 1995; McGarigal et al. 2001, 2002; Chandrashekhar et al. 2003; Roy et al. 2005; Shilpa Babar 2008, unpublished data). Other types of natural resources use such as the extraction of non-timber forest products, and individual tree cutting or burning for honey and dammar collection may have no immediately apparent impacts on natural ecosystems. The impacts of these activities may only manifest themselves over longer time scales.

Areas of BR or hotspots are related to species richness, EU, degree of TC and disturbance (Bojorquez-Tapia et al. 1995; Myers et al. 2000; Amarnath et al. 2003; Chandrashekhar et al. 2003). The four evergreen communities were found to have different levels of diversity, endemism and disturbance regimes. For instance, the very high biologically rich areas in the zones of 900–1,400 m and >50% slope had high species richness and diversity showed moderate levels of disturbance with relatively low endemism. On the other hand, high biologically rich areas at 1,100–1,400 m and 20–40% slope had less species richness and diversity, with low disturbance and high percentage of endemism. The reason could be the very low population density and inaccessibility of these areas. It was also observed that disturbance affects BR. Thus, the medium elevated evergreen habitats tend to have high species richness and endemism (Ganesh et al. 1996; Parthasarathy 1999, 2001). However, areas of BR decreased with increase in disturbance. The identified BR zones in the present study forms a framework for conservation prioritization and bioprospecting purposes.

Conclusions

It can be concluded from the above study that satellite remote sensing and statistical techniques allows identification and delineation of evergreen habitats. These evergreen communities have been related with landscape characteristics, species assemblages, microhabitats like slope, topography, endemism, and proportion of core and edge species to prioritize areas of high disturbance and conservation of biological diversity. The identified endemic habitat zones need to be intensely safeguarded by the Forest Department, so that the genuine needs of the local population and conservation interests are not sacrificed. The principal aim of this study is to develop an approach for prioritization of areas and to evaluate, justify and recommend the quality and quantity of the methods utilized for study for intensified preservation through a study of the richness, endemism, and disturbance factors. Thus remote sensing, GIS and phytodiversity database have been successfully employed to monitor and prioritize different wet evergreen communities. In the coming decades, with the improvement in technology and availability of imagery, regular monitoring of the tropical forest ecosystem would be more feasible.

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