Diagnostic analysis of conservation zones using remote sensing and GIS techniques in wet evergreen forests of the Western Ghats – An ecological hotspot, Tamil Nadu, India

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Abstract. This study highlights spatial characterization of evergreen forests of the Western Ghats – an ecological hotspot in Tamil Nadu, India – using remote sensing and GIS-based analysis in conjunction with ground-based phytosociological data. The evergreen forests of Tamil Nadu are distributed in four distinct hill ranges, Nilgiri, Anamalai, Palni and Tirunelveli, having different topographic, bioclimatic and disturbance levels. The evergreen forests in these four hill ranges are characterized for their uniqueness in terms of patch characteristics and phytosociology. A vegetation type map was prepared using IRS LISS III satellite data and was used to study the patch characteristics in terms of patch size, number, shape, porosity and landcover diversity (LD). The phytosociological characteristics, namely species richness, diversity, similarity and community assemblages, were studied using ground data collected from 95 sample points of 0.1 ha size. Patch size and number revealed distinct intactness and disturbance levels in these four hill ranges. Evergreen forests in the Tirunelveli hills comprising 216.09 km^2 are distributed in 306 patches, and in the Palni hills, with 285 km^2, forests are distributed in 1029 patches, indicating a high level of fragmentation. LD, indicating the spatial heterogeneity of landcover, was very high in the Nilgiri hills and low in the Tirunelveli hills. The spatial analysis helped to delineate homogenous large patches of evergreen forest, which can be adopted for appropriate conservation strategies. A total of 342 tree species belonging to 4490 stems were evaluated for phytosociology. Only 15–28% of similarity in terms of species distribution was found across the hill ranges. Conjunctive analysis of patch characteristics and species distribution showed high species richness in less fragmented evergreen forests and *vice versa*. The study identified the areas of prioritization in terms of ecorestoration and conservation based on patch and phytosociological characteristics.

Introduction

India possesses a rich flora of flowering plants (17,000 species) with a high degree of endemics (33.5%). The vegetation in the Indian sub-continent is distributed mainly in four distinct geographical zones, *viz* the Himalayas, Vindhyans, Western and Eastern Ghats. The Western Ghats spread over a total area of 160,000 km^2 containing eight national parks and 39 wildlife sanctuaries. The region represents a

characteristic bioclimatic context involving monsoon-influenced climate and orography-induced elevation regimes. This north–south running biogeographical system exhibits contrasting vegetation formations to that of the Western and North East Himalayas. The Western Ghats represent unique taxonomic hierarchies, remnant ecosystems and strong endemic associations. The sholas, mangroves, dry evergreen, swamps, reeds and riverine belts, etc. represent the unique repositories of diverse genomes. This mega-diversity region has been the source of exquisite timber and non-timber resources yielding invaluable medicinal, aromatic, food and other industrial products apart from harboring huge wilderness ecotourism potential. Of the 4000 species of flowering plants in the Western Ghats, 1500 species are endemics (Nayar 1989). The Agasthyamalai hills in the southern end of the Western Ghats in south India are known for their high species diversity, harboring 2000 flowering plant species with 7.5% endemism (Henry et al. 1984).

The Western Ghats are considered as one among the 25 biodiversity hotspots of the world (Myers et al. 2000). Such luxuriant vegetation compositions, evolved over geologic time scales, have witnessed various land use practices depending upon the resource demand and ingress of human dimension. This has induced considerable alteration in the Western Ghats biogeography, bringing commercial agriculture, commercial forestry, hydropower, mining and biotic pressures inside the forest ecosystems. In view of this, concerted efforts are made to study and understand the complex biodiversity pattern of the Western Ghats vegetation and assess the impacts to assist in developing appropriate conservation strategies. Several studies are conducted on vegetation distribution pattern, taxonomic association and also the impact of various natural and anthropogenic activities on biodiversity.

Previous studies

Pascal (1982b, 1982c, 1984) and Ramesh and Pascal (1997) prepared vegetation type maps of the entire Western Ghats region using satellite data, ground-based phytosociology and bioclimatic data. Permanent plots of varied size were used in biodiversity rich areas of the Western Ghats to understand the structure and functional patterns of biodiversity. Pascal and Pelissier (1996) reported the detailed structure and floristic composition of tropical evergreen forest using a 28 ha permanent plot at Uppangala, Kodagu district, Karnataka. Based on the data collected from this permanent plot, Pelissier (1998) and Pelissier and Goreaud (2001) showed that spatial patterns of vegetation are related to dynamic processes, which depend on both exogenous and endogenous factors of vegetation. In another study, a permanent plot of 30 ha size was established for long-term ecological research on biodiversity of tropical evergreen forests of Varagalaiar, Anamalais, Western Ghats, Tamilnadu (Ayyappan and Parthasarathy 1999). Changes in woody composition, abundance and forest stand structure were investigated in three different sites of Kalakad National Park, Western Ghats, Tamilnadu, using three 1-ha plots (Parthasarathy 2001). The dynamics of tropical dry deciduous forest in Mudumalai sanctuary, Nilgiris, was studied using a 50 ha permanent plot (Sukumar et al. 1998). Herb species diversity of the Western Ghats was studied for different

vegetation types using 500 quadrants scattered over 15 different sites (Harish and Utkarsh 1999).

In addition, phytosociological studies in conjunction with wildlife biology, habitat losses and disturbance impact were also done at different parts of the Western Ghats (Sukumar et al. 1992; Chandrashekara and Ramakrishnan 1994; Parthasarathy and Karthikeyan 1997; Parthasarathy 1999; Jha et al. 2000; Devy and Davidar 2001; Dutt 2001; Ganesh and Davidar 2001; Johnsingh 2001). Information on distribution of endemic and rare, endangered and threatened species was also reported by several organizations (Ahmedullah and Nayar 1987; Nayar 1996; Ramesh and Pascal 1997; Subbarayalu and Velmurugan 1999). Using satellite and aerial photographs, the entire Uttara kannada forest type and growing stock maps were prepared on 1:25,000 scale along with the physiographic characterization of slope, aspect and drainage maps. In addition, a systematically selected ground inventory was carried out in about 620 field plots of 0.1 ha to describe the forest structure and volume for the entire district (Dutt and Udayalakshmi 1994). The application of remote sensing data IRS 1B in linking regional and landscape scales for assessing biodiversity in the Western Ghats was studied (Nagendra and Gadgil 1998; Nagendra 2001a).

Relevance of the present study

The studies conducted in the region are mainly confined to understanding the structural and functional properties of different forest types in a specific bioclimatic region, local specific wildlife habitats and forest mensruation, etc. The effects of variability in bioclimate, topography and anthropogenic factors on spatial pattern of landcover and species diversity have not been studied much. Studies along these lines would help to understand the vegetation responses and organization to various bioclimatic and disturbance regimes. In this regard, the study of forest landscapes in terms of their patch composition and configuration is considered as one of the important pieces of information (O'Neill et al. 1988; Peters and Goslee 2001). Large-scale gradients in landscape heterogeneity can be related to broad-scale patterns in the environment. For example, spatial variation in climate, topography and soil were found to be strongly related to latitudinal gradients in richness of landcover types across the American continent (Wickham et al. 1995). The pattern and changes in forest types over the last two decades in three landscape level physiographic provinces of the state of Alabama, USA were studied (Parresol and McCollum 1997). The study found that spatial patterns of landscapes are useful to quantify human impact, predict wildlife effects and describe various landscape features.

The patch characteristics on type, number, shape, size, heterogeneity and boundary characteristics in a landscape matrix indicate the spatial organization of vegetation types, biotic disturbance, availability of nutrients, amount of energy flow and habitat suitability (Turner 1989; Li and Reynolds 1993; Ritters et al. 1995). While the discussion of the effect of patch area on community structure has been extensive, the implication is that larger patches generally hold a greater number of

species than smaller patches (Laver and Haine-Young 1993). It was reported that small fragmented patches experience lesser density of population and increase in the risk of extinction (Farina 1998). Brokaw and Scheiner (1989) have provided data, which indicate that differences in gap sizes lead to variations in species composition. Whitmore (1975), as cited by Forman and Godron (1986), remarked that plant species composition and community structure varied according to the shape of open gaps in Malaysian tropical rain forest. Landscape connectivity is a measure of how spatially contiguous a landscape matrix is. Connectivity can exert strong influences on ecological processes, such as the movement and dispersal of organisms, the use of resources by animals, gene flow, and the spread of disturbance (Pearson 1993).

The importance of spatial heterogeneity to species diversity has been well documented, and is most closely related to beta species diversity (Whittaker 1960, 1972). The extension of these ideas to landscape diversity is more recent, and several studies have linked measures of alpha and beta species diversity with landscape diversity (Romme 1982; Lapin and Barnes 1995). The diversity of the trees and shrubs was found to be higher on plots with the greatest geomorphological heterogeneity, indicating an important connection between landscape diversity and species diversity (Burnett et al. 1998; Nichols et al. 1998).

With reference to the Western Ghats, a few attempts were made to link landscape, vegetation type and species association. On broad-scale mapping of the Western Ghats (1:1,000,000 scale), 205 patches belonging to 11 different landscape types consisting of topography, climate, population, agriculture and vegetation cover were delineated using IRS 1B data (Nagendra and Gadgil 1998). The nature and the extent of forest degradation and its causes have been intensely debated using meso-scale analyses of forest condition in the region of the Western Ghats (Lele et al. 1998). The relationships between forest fragmentation and density of large mammals, effect of shape of patches of evergreen forest on the lion-tailed macaque population were studied (Krishnamurthy and Kiester 1998; Prasad et al. 1998). Landscape complexity and plant diversity prospect zones in parts of Uttara Kanada in the Western Ghats were mapped through spatial analysis of patch characteristics (Udayalakshmi et al. 1998). However, the evergreen forest in the Western Ghats, constituting 2.71% (7064.61 km^2) of the total forest area, harboring nearly 60–70% of the species richness and 15% of the endemic species (Dutt et al. 2002), is yet to be extensively studied. Hence, in prioritizing the areas of conservation and biodiversity value, characterization of evergreen ecosystems in terms of landscape parameters, phytosociology, endemism, economic value, abiotic and biotic disturbance assumes greater importance. The current study focuses on characterizing evergreen forest of the Western Ghats of Tamil Nadu distributed across four different hill ranges with varied topography, bioclimate and disturbance levels using remote sensing and GIS analysis.

Study area

The Western Ghats, also known as Sahyadris, extend about 1600 km starting in the

north from the Tapti river, Maharashtra and going down to Kanyakumari, Tamil Nadu in the south. These hill ranges run parallel to the west coast having predominantly two aspects, *viz.* western and eastern, hardly 40 km away on average from the shore line. The southern portions of these hill ranges are largely covered in the states of Kerala (western aspect) and Tamil Nadu (eastern aspect), with the ridgeline separating the states. Eastern aspects of Tamil Nadu experience steep gradients of rainfall and temperature due to the receding effects of the southwest monsoon coming from the west coast and the distribution patterns of the northeast monsoon. On the other hand, western aspects in Kerala receive rainfall from the southwest monsoon.

Therefore, bioclimatic patterns in the eastern and western aspects are different due to the spatial and temporal distribution of the southwest (June–September) and the northeast monsoon (November–December), and also due to the degree of physiographic variations. Mean annual rainfall and number of rainy days are relatively high in the western aspects compared to the eastern aspects. The number of dry months is low in the western aspects (Pascal 1982a). In addition, the western and eastern aspects experience a different degree and kind of biotic pressures within and around the evergreen forest, in fragmentation levels and in the mechanism of the protection methods used. Because of the variations in the bioclimatic characteristics and biotic pressures, the spatial organization of the vegetation types as a landscape mosaic differs across these two aspects (Ramesh et al. 1997).

Therefore it is required to understand the landscape characteristics and vegetation distribution pattern more holistically with reference to each aspect. The eastern aspects of the Western Ghats of Tamil Nadu are chosen for the present study, covering seven districts, namely Nilgiri, Coimbatore, Dindigul, Madurai, Virudhunagar, Tirunelveli and Kanyakumari. These districts distinctly fall under four major hill ranges, namely Nilgiri (Nilgiri hills), Coimbatore (Anamalai hills), Dindigul and parts of Madurai (Palni hills) and Virudhunagar, Tirunelveli and Kanyakumari (Tirunelveli hills). The study area lies between 8–11° N latitude and 77–78° E longitude.

The study area includes major wildlife sanctuaries covering an area of about 2266.68 km^2, namely Kalakad–Mundanthurai, Indira Gandhi National Park, Nilgiri Tahr, Mudumalai, etc. According to Champion and Seth (1968), the evergreen forests in these hill ranges belong to tropical evergreen forest category (1A) with four sub-types, *viz.* giant evergreen forest (1A/C1), southern hill top tropical evergreen forest as (1A/C3), west coast tropical evergreen (1A/C4) and Nilgiri sub-tropical hill forest (8A/C1).

Physiography and climate

The evergreen landscapes in the four hill ranges are quite distinct from each other, both in terms of physiography and climatic patterns. The spatial variability in the rainfall observed ranges from 1000–5000 mm with the number of dry months ranging from 1 to 5. The mean temperature of the coldest month varies from <13 to >23 °C (Table 1). The occurrence of evergreen forest ranges between altitude 500–2490 m. Major peaks include Anaimudi (2695 m) of the Anamalai, Doddabetta

Table 1. Physiographic and bioclimatic variation seen in different hill ranges in the Western Ghats of Tamil Nadu, India.

Hill range	Altitude (m)		RF (mm)		T (°C)		DS	RD
	Min.	Max.	Min.	Max.	Min.	Max.		
Nilgiri	700	2490	900	>5000	<13	23	2–5	85–92
Anaimalai	690	1997	900	5000	16.0	>23	3–4	66–102
Palni	869	2396	900	1600	<13	<23	1–5	44–92
Tirunelveli	500	1280	1200	5000	13.5	23	3–5	89–92

RF – annual average rainfall, T – mean temperature of the coldest month, DS – dry season in months, RD – number of rainy days.

(2637 m) of the Nilgiris, Agasthyamalai (1868 m) of Tirunelveli, and Vembadi (2068 m) of the Palni hills.

Geomorphology and pedology

The Western Ghats is an archean age formation, represented by gneiss and granites. The Nilgiri hills consist of a great mass of foliated gneiss rock termed charkonite. The Anamalai hills consist of metamorphic to igneous types of rocks. The Palni hills consist of plutonic rocks. The rocks are entirely charnockites, bluish granite, though broad bands of feldspars and quartz cross the gneissic foliations. In the Tirunelveli hills the geological formation is, for the most part, from the archean age, represented by gneisses and granites. The outer slopes of the hills are subjected to heavy wash on the surface due to scanty growth of vegetation. The soil on the slopes is chocolate colored, sandy loam, which is rich in organic matter and supports vegetation. The soils in the valley are clayey in nature. The topsoil varies in thickness from a few mm to 90 cm. The soils contain a high amount of iron and aluminum oxides and are porous up to 1 m in thickness. The outer slopes of the hills are subjected to heavy wash on the surface due to scanty growth of vegetation. In the upper reaches of the hills where the moist evergreen forests are, the soil is mostly loamy. In the valleys and low-lying areas the soil is fairly deep.

Methodology

Forest type classification using satellite data

IRS 1C/1D LISS III data of January–March (1997–1998) covering path/rows, *viz.* 99/66, 100/66, 100/67, 100/68, 101/66, 101/67 and 101/68 were acquired from the National Remote Sensing Agency, Hyderabad with cloud-free data. The satellite data were rectified with reference to 1:250,000 SOI topographical maps using geometric rectification software of ERDAS 8.4 Imagine analysis. The RMS error within a pixel is maintained by ensuring the well-defined GCPs (Ground Control Points) distributed evenly over the entire scenes. Prior to the classification of each scene for different vegetation types, various spectral classes observed on the image

were marked and ground verified to utilize during the training set selection. Likewise, all the spectral classes were assigned to training sets and all the geometrically corrected images were classified. After the completion of classification, misclassified areas were observed and reclassified considering small areas of interest (AOI) or through interactive editing for improved accuracy. The classification improvements were also followed through examination of confusion matrix of the training sets and wherever the classes were overlapping, training sets were recreated before launching the classification. The maximum likelihood algorithm was used to classify all the scenes. The individual classified scenes were mosaiced to form a continuous area, ensuring a seamless type map between the scenes. The classes helped in delineating forest types *viz.* evergreen, semi-evergreen, moist deciduous, dry deciduous, dry evergreen, sholas, grasslands, scrubs, reeds and different types of plantations, etc. The classified vegetation map was validated by verification on ground and found to be 80–85% accurate. The output details on vegetation and landcover classification were generated with an output pixel resolution of 62.5 m, compatible to 1:250,000-scale mapping.

Landscape metrics

A number of landscape metrics (or indices) that describe the landscape configuration and composition are in use, either in terms of individual patches or of the whole landscape (McGarigal and Marks 1994). In the present study the following landscape metrics are studied.

Patch size and number
Once the type classification was prepared using satellite data, it was vectorised in the GIS domain to characterize the patches. The information on patch size and patch number was extracted from the vectorised classified data for each hill range. A minimum window of 3×3 pixels was set for patch analysis.

Patch shape
A simple measure of patch shape is the perimeter-to-area ratio. This measure is often standardized so that the most compact possible form, either square or circle, is equal to 1. A higher perimeter value indicates an increase of edge effect, an ecologically undesirable influence on most species populations and communities.

Porosity (PO)
Porosity is the measure of number of patches or density of patches within a particular type, regardless of patch size (Forman and Godron 1986):

$$PO = \sum_{i=1}^{n} C_{\mathrm{pi}}$$

where C_{pi} is the number of closed patches of the ith cover class.

Landcover diversity (LD)
Based on the information generated on the number of landcover types (landcover heterogeneity) and their abundance in each window, LD (Shannon–Wiener index) was calculated. Starting from a window size of 250–2500 m with an increment of two pixels, the number of landcover types present in each window was calculated using the 'block variety' function in the GRID module of the Arc-Info GIS.

Phytosociological data

Sampling approach
The spatial layer generated on evergreen forests using IRS LISS III multi-spectral satellite data was used for distribution of sample points across four hill ranges. A total of 95 sample points (0.01% of the total evergreen area) were chosen for phytosociological data collection. The sample points were randomly distributed, covering different elevation and bioclimatic regimes. Distribution of evergreen forest in the Western Ghats is classified into three elevation regimes, i.e. low, medium, and high (Ramesh et al. 1997). Out of the 95 sample points in four hill ranges, 11, 38, and 46 points were laid in low, medium and high elevation regions respectively, keeping in view the extent of distribution of evergreen forest. The ground sampling was only intended to broadly assess the species diversity pattern across the different hills and not to understand or relate the species composition and organization against specific bioclimatic/topographic variables.

The geographic coordinates of the sample points were generated and using the hand-held GPS, the locations for the field plots were reached. 0.1 ha plots were laid on the ground at the corresponding location. The fieldwork was conducted from March 1999 to April 2001. Tree girths were measured at 1.3 m from the ground. The collected specimens were identified using various regional Floras (Gamble and Fischer 1915–1935; Pascal and Ramesh 1987; Matthew 1999). Specimens identified were confirmed in the herbarium of the Botanical Survey of India, Coimbatore, and the Rapinat Herbarium, Tiruchirapalli. Nomenclature of species follows the Flora of Tamilnadu (Nair and Henry 1983; Henry et al. 1987) and the Flora of the Palni hills (Matthew 1999).

Phytosociological analysis
Standard procedures were adopted to generate information on the following measures of phytosociology. Individuals having $\geq$30 cm girth were considered for phytosociological analysis.

Sørensen similarity index
The percentage similarity of the species occurring in different hill ranges was calculated using the Sørensen similarity index:

$$\text{Sørensen similarity index} = \frac{2C}{A+B}$$

where C is the sum of common species and A and B are the sum of the species occurring in two different hill ranges.

Importance value index (IVI)
The floristic structure was studied using the IVI of Curtis and McIntosh (1950). This index is generally calculated as the sum of the relative frequency (rF), relative density (rD) and relative basal area (rBA) for each species.

Diversity index
Species diversity was calculated based on the Shannon–Wiener index for the richness of the given site:

$$\text{Shannon–Wiener index } H' = -\sum p_i \log_2 p_i$$

where p_i is the proportion of the ith species.

Species accumulation curves
The average species accumulation curves (no. of species vs. individual) were plotted from randomly shuffled samples in order to remove the effect of the sample order on the species accumulation curve and produce a smooth curve. The curves were drawn using the EstimateS software (Colwell 1997) involving the Chao2 estimator. The Chao2 estimator is a non-parametric species richness estimator (Chao 1987), using the observed number of species, species with only one individual (singletons) and with two individuals (doubletons) in the following formula:

$$S_{\text{Chao2}} = S_{\text{obs}} + \frac{Q_1^2}{2Q_2}$$

where S_{obs} is the number of species observed in the pooled quadrant samples, $Q1$ the number of singletons in the pooled quadrant samples, and $Q2$ the number of doubletons in the pooled quadrant.

Cluster analysis
Cluster analysis was done to assess the species association pattern across the four hill ranges. The data on 4151 individuals and 172 species collected from 95 plots of evergreen forests were clustered using Ward's method (minimum variance clustering) based on species density in each plot using STATISTICA for Windows (StatSoft 1995). Ward's method of clustering works on the underlying principle that at each stage of clustering, the variance within clusters is minimized with respect to the variance between clusters. Within-group variance is defined as the sum of squares of the distances between sampling units within the centroid of the cluster. At each clustering cycle, the two sampling unit clusters whose fusion results in the minimum increase in variance (relative to the variance within each cluster taken separately) are joined. This method is regarded efficient in identifying the closest relationship (Ludwig and Reynolds 1988). This resulted in clustering of plots having higher similarity in terms of species association.

Table 2. Vegetation and landcover distribution in different hill ranges in the Western Ghats of Tamil Nadu, India.

S. no	Types	Nilgiri hills	Anaimalai hills	Palni hills	Tirunelveli hills	Total area (km^2)
A	*Phenological types*					
1	Evergreen	138.86	197.50	285.86	216.09	838.31
2	Semi-evergreen	113.94	167.11	110.48	254.22	645.76
3	Moist deciduous	132.81	295.52	626.89	551.57	1606.80
4	Dry deciduous	430.59	550.27	816.92	552.82	2350.60
5	Dry evergreen	–	–	–	76.29	76.29
6	Sholas	145.70	2.62	6.58	–	154.90
7	Grassland	438.71	134.13	283.30	81.11	937.25
	Subtotal	1400.62	1347.15	2130.04	1732.10	6609.91
B	*Other landcover types*					
8	Shrubs	197.84	558.36	1624.41	1474.34	3854.95
9	Ochlandra	–	–	49.87	45.53	95.40
10	Teak	6.55	1.08	1.57	18.99	28.20
11	Orchards	664.71	100.70	215.98	108.86	1090.25
12	Agriculture	245.55	1216.82	1307.13	1198.77	3968.29
13	Fallow/barren	3.22	4163.39	7194.85	8055.16	19416.62
14	Water	22.54	30.35	76.63	143.96	273.48
	Grand total	2541.04	7417.85	12600.48	12777.71	35337.09

Results

Vegetation type distribution

The results on vegetation type based on digital classification of IRS LISS III data are presented in Table 2. Vegetation and landcover images for parts of the Palni and Tirunelveli hills are given in Figure 1. The forest types covered 6609.91 km^2, of which dry deciduous forests constitute 35.56%. The Dindigul district covered larger proportions of evergreen forest, 225 km^2, followed by Coimbatore with 167.11 km^2. Semi-evergreen forests are predominant in the Tirunelveli district, covering 178.34 km^2. The distribution of dry deciduous forests is uniform all over the districts. Grasslands covering 937.25 km^2 are largely distributed in the Nilgiri and Palni hills. Sholas are predominantly distributed in Nilgiri. It was estimated that evergreen forests constitute around 9.91–14.66% of the total area under four phenological forest types, as shown in Figure 2. The percentage area covered by evergreen forest is lowest in the Nilgiri hills (9.91%) and maximum in the Anamalai hills (14.66%).

Landscape parameters

The patch size and distribution in four different hill ranges are given in Table 3. In the Palni hills patches of <50 ha and 100–500 ha constitute 35.85% (931 patches) and 35.23% (43 patches), respectively, of the total evergreen area. In the Anamalai hills, 24.39 and 38.4% of the area is occupied by patches of less than 50 ha and >1000 ha, respectively. In contrast, the Tirunelveli and Nilgiris hills were found
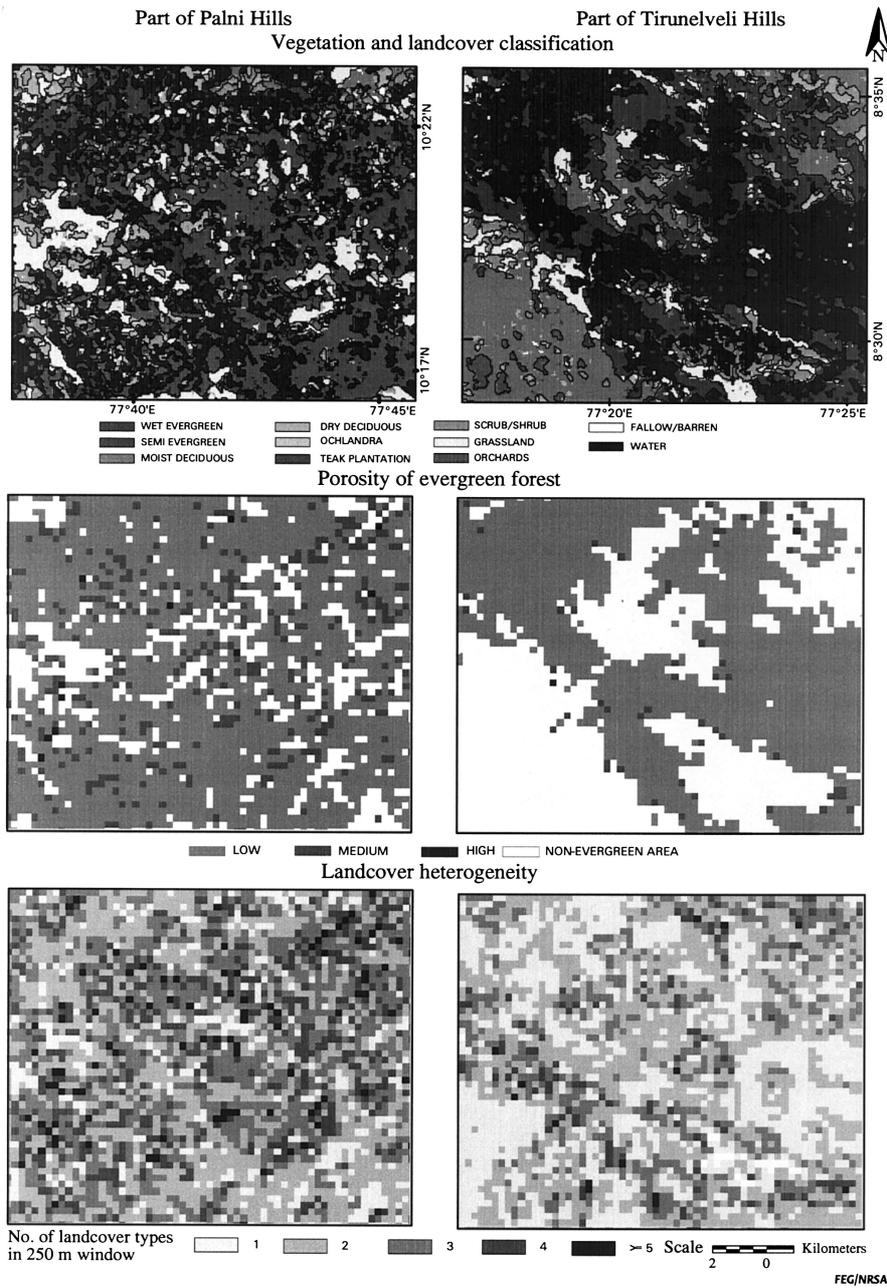
Part of Palni Hills   Part of Tirunelveli Hills
Vegetation and landcover classification

WET EVERGREEN   DRY DECIDUOUS   SCRUB/SHRUB   FALLOW/BARREN
SEMI EVERGREEN   OCHLANDRA   GRASSLAND   WATER
MOIST DECIDUOUS   TEAK PLANTATION   ORCHARDS

Porosity of evergreen forest

LOW   MEDIUM   HIGH   NON-EVERGREEN AREA

Landcover heterogeneity

No. of landcover types
in 250 m window   1   2   3   4   > 5   Scale   Kilometers

FEG/NRSA

Figure 1. Vegetation and landcover classification, porosity and landcover heterogeneity seen in two different hill ranges in the Western Ghats of Tamil Nadu, India.
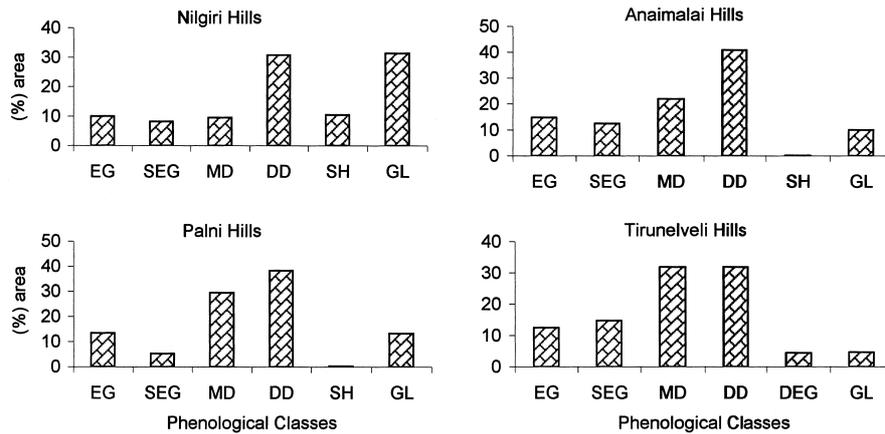
Figure 2. Distribution of different phenological classes seen in different hill ranges in the Western Ghats of Tamil Nadu, India.

Table 3. Patch characteristics of evergreen forests in different hill ranges in the Western Ghats of Tamil Nadu, India.

S. no.	Characteristic	Nilgiri hills	Anaimalai hills	Palni hills	Tirunelveli hills
1	Area (km^2)	138.86	197.50	285.86	216.09
2	Number of patches	193	473	1029	306
3	Patch density	1.39	2.39	3.60	1.42
4	Landcover diversity	2.75	2.16	2.45	2.02
5	Patch size (ha)				
	<50	14.39[a] (165)[b]	24.44 (438)	35.85 (931)	12.10 (263)
	50–100	6.59 (12)	6.2 (17)	13.64 (51)	7.12 (23)
	100–500	23.08 (12)	11.15 (11)	35.23 (43)	12.72 (10)
	500–1000	0.00	19.72 (5)	6.86 (3)	8.64 (3)
	>1000	55.93 (4)	38.49 (3)	8.42 (1)	59.41 (7)
6	Perimeter/area ratio				
	<0.015	27.97 (54)	14.80 (70)	16.62 (171)	24.51 (75)
	0.016–0.025	60.62 (117)	61.73 (292)	57.34 (590)	55.88 (171)
	>0.025	11.40 (22)	23.47 (111)	26.04 (268)	19.61 (60)
7	Porosity				
	1–3	95.59	88.81	83.42	93.95
	4–6	4.35	10.77	15.91	5.94
	>7	0.05	0.42	0.67	0.11

[a]Non-bracketed number indicates % of evergreen forest. [b]Bracketed number indicates number of patches.

with a predominance of larger patch sizes. Especially in the Tirunelveli hills, it is found that 59.41% of the area is covered by seven patches. The results revealed that the distribution of patches could be categorized into three different patterns, namely larger areas covered by a number of small patch sizes (Palni hills), large areas of big and small patches (Anamalai hills), and large areas with a few big patch sizes (Tirunelveli hills), as clearly seen in Figure 1.

The perimeter-to-area ratio of the evergreen patches is given in Table 3. In the Palni and Nilgiri hills, a tendency towards higher perimeter–area ratio was observed. The area with a ration >0.025 is 26.04 and 23.47% in Palni and Anamalai, respectively. More complex shapes have increasingly higher ratios.

The porosity levels of evergreen forest are shown in Table 3 and Figure 1. Porosity levels were scaled as low, medium and high. The percentage area within these classes clearly shows that the evergreen forest of the Anamalai and Palni hills is more porous in comparison to the other two hills. The area with low porous conditions in the Palni hills is 83.42%, whereas in other hills it is found to be around 95%.

LD was calculated at different window sizes for the four hill ranges, as given in Figure 3. The Nilgiri and Palni hills are found to have a higher LD compared to other hill ranges. In addition, the rate of increase in LD progressed up to the 1375 m window in the Nilgiri and Palni hills, whereas in the Anamalai and Tirunelveli hills it flattened at the 625 m window. Beyond these window sizes the diversity value did not show much variation, even at the window size of 2500 m. At the maximum window size of 2500 m, the highest diversity of 2.75 H' was found in the Nilgiri hills, and the lowest diversity of 2.02 H' was found in the Tirunelveli hills. The low and high levels of landcover heterogeneity in the Tirunelveli and Palni hills, respectively, are shown in Figure 1.

Phytosociological analysis

The data on phytosociological parameters of the four different hill ranges are presented in Table 4. A total number of 125 species with 1062 stems in the Nilgiri hills (531 ha^{-1}), followed by 168 species with 1444 stems in Tirunelveli (578 ha^{-1}), 134 species of 943 stems (377 ha^{-1}) in the Anamalai hills and 101 species with 1041 stems (416 ha^{-1}) in the Palni hills were recorded. The species accumula-
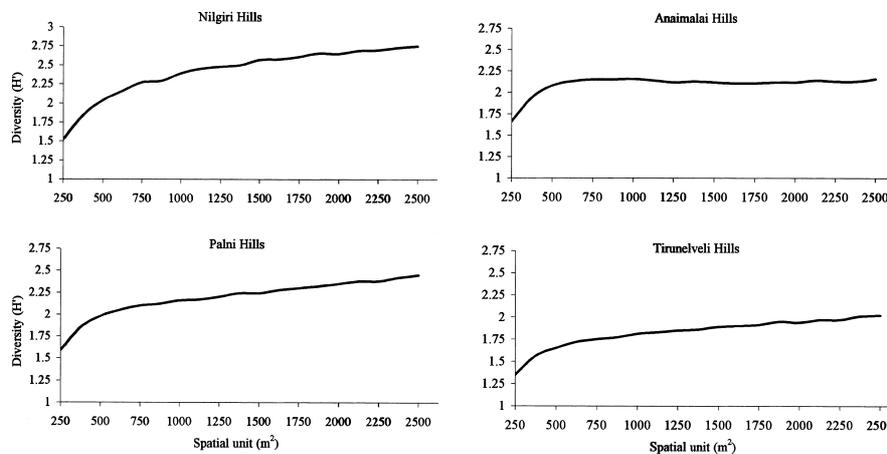

Figure 3. Landcover diversity of different hill ranges in the Western Ghats of Tamil Nadu, India.

Table 4. Phytosociological data of evergreen forests of different hill ranges in the Western Ghats of Tamil Nadu, India.

S. no.	Parameters	Nilgiri hills	Anaimalai hills	Palni hills	Tirunelveli hills
1	Total sampled area (ha)	2.0	2.5	2.5	2.5
2	Species richness	125	134	101	168
3	Total stems	1062	943	1041	1444
4	Stand density (ha^{-1})	531	377	416	578
5	Shannon–Wiener index (H')	5.75	6.18	5.79	6.28
6	Species Similarity Index (%)				
	Nilgiri hills	–	16	11	12
	Anamalai hills		–	28	21
	Palni hills			–	11
	Tirunelveli hills				–

tion curve showed different flattening levels in the hill ranges. The species accumulation as a function of number of individuals is given in Figure 4. All the hill ranges, except the Tirunelveli hills, show a tendency towards flattening of the curve. The increment in species accumulation is quite high in the Anamalai and Tirunelveli hills compared to the Nilgiri and Palni hills.

Species similarity between different hill ranges was studied using species presence/absence data. Of the species recorded, 16% are found similar between the Nilgiri and Anamalai hills. Palni and Anamalai hills, the closest hill ranges, have only 28% common species. The Tirunelveli hills, located in the southern part of the Western Ghats, showed similarity around 11–21% with the other three hill ranges (Table 4). Interestingly, the first 10 predominant species recorded in the Tirunelveli hills have no predominance in the other hill ranges. This indicates that their distribution is strongly localized. In the Tirunelveli hills *Cullenia exarillata* Robyns (32.06), *Hopea utilis* (Bedd.) Bole (9.99) and *Mesua ferrea* L. (9.84) are found as
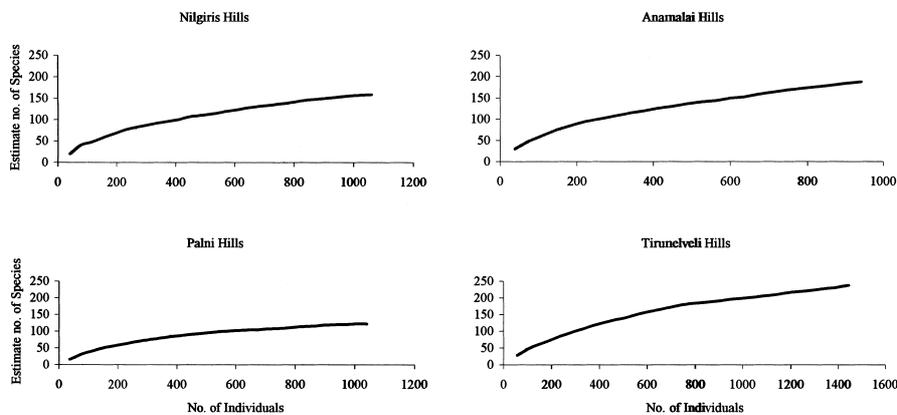

Figure 4. Species–individual curves generated using the Chao2 estimator across different hill ranges in the Western Ghats of Tamil Nadu, India.

Table 5. Predominant species in evergreen forest of different hill ranges in the Western Ghats of Tamil Nadu, India.

| S. no.	Nilgiri hills	IVI	Anamalai hills	IVI	Palni hills	IVI	Tirunelveli hills	IVI
1	*Litsea laevigata*	20.46	*Syzygium densiflorum*	19.15	*Syzygium densiflorum*	15.41	*Cullenia exarillata*	32.06
2	*Turpinia nepalensis*	14.91	*Palaquium ellipticum*	15.19	*Xantolis tomentosa* var. *elengioides*	15.22	*Hopea utilis*	9.99
3	*Hydnocarpus pentandra*	12.71	*Olea dioica*	8.69	*Syzygium lanceolatum*	14.67	*Mesua ferrea*	9.84
4	*Syzygium arnottianum*	11.97	*Litsea glabrata*	8.60	*Litsea glabrata*	13.57	*Pterospermum xylocarpum*	9.33
5	*Syzygium hemisphericum*	10.95	*Artocarpus hirsutus*	7.74	*Phoebe wightii*	11.17	*Schleichera oleosa*	6.37
6	*Meliosma simplicifolia*	10.70	*Persea macrantha*	6.99	*Cinnamomum verum*	10.04	*Myristica malabarica*	5.70
7	*Syzygium cumini*	10.48	*Bischofia javanica*	6.68	*Michelia niliagirica*	9.67	*Symplocos macrocarpa*	4.98
8	*Litsea floribunda*	8.69	*Agrostistachys borneensis*	6.67	*Eurya nitida*	9.20	*Artocarpus heterophyllus*	4.97
9	*Persea macrantha*	7.50	*Schefflera venulosa*	6.58	*Persea macrantha*	9.01	*Macaranga peltata*	4.87
10	*Syzygium montanum*	6.77	*Mallotus stenanthus*	6.02	*Neolitsea scorbiculata*	8.44	*Holigarna arnottiana*	4.71
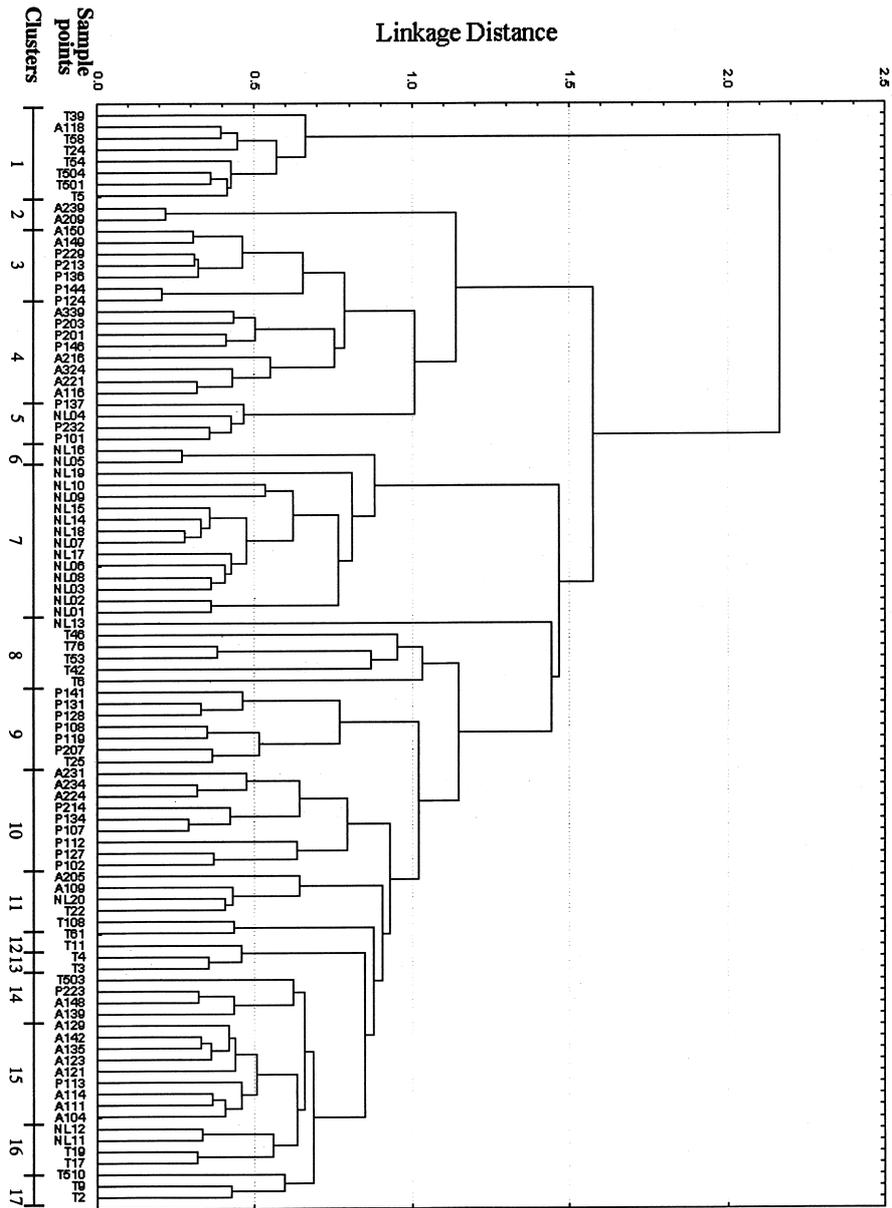
Figure 5. Species association using a cluster technique based on euclidean distance of four different hill ranges in the Western Ghats of Tamil Nadu, India.

predominant species (Table 5). In Anamalai the flora is largely composed of *Syzygium densiflorum* Wall. ex Wt. & Arn. (19.15), *Palaquium ellipticum* (Dalz.) Baillon (15.19), *Olea dioica* Roxb. (8.69); in the Palni hills dominant species

Table 6. Unique species clusters of the different hill ranges of evergreen forest in the Western Ghats of Tamil Nadu, India.

Cluster	Hill range	Species association	No. of individuals	No. of species
1	Tirunelveli	*Cullenia exarillata – Drypetes oblongifolia – Palaquium ellipticum – Schefflera racemosa – Nageia wallichiana*	386	54
2	Nilgiris	*Litsea laevigata – Turpinia nepalensis – Syzygium arnottianum – Saprosma glomerata – Euodia lunu-ankenda*	514	59
3	Palni	*Phoebe paniculata – Celtis timorensis – Beilschmiedia wightii – Xantolis tomentosa var. elaegonidae – Alseodaphne semecarpifolia*	223	49
4	Anamalai	*Persea macrantha – Palaquium ellipticum – Artocarpus hirsutus – Harpullia arborea – Isonandra stockii*	352	72
5	Palni	*Syzygium densiflorum – Pentapanax leschenaultii – Eurya nitida – Rhododendron nilagiricum – Rapanea capitellata*	303	46
6	Tirunelveli	*Hopea utilis – Eugenia mooniana – Aglaia roxburghiana – Syzygium mundagum – Hopea parviflora*	199	29
7	Tirunelveli	*Mesua ferrea – Polyalthia coffeoides – Holigarna arnottiana – Hopea utilis – Dipterocarpus indicus*	156	27

include *Syzygium densiflorum* Wall. Ex Wt. & Arn. (15.41), *Xantolis tomentosa var. elengioides* (A.DC.) Vajr. (15.22), and *Syzygium lanceolatum* (Lam.) Wight & Arn. (14.67).

Cluster analysis was carried out to assess the species association in evergreen forests using species distribution data from 95 plots. A maximum cluster linkage distance of 0.8 was used to regroup the 95 sample plots into 17 different clusters. The regrouped 17 clusters are shown in Figure 5. While regrouping the plot identity in terms of hill location is also kept in mind, such that possible species assemblage pertaining to each hill range could be observed. Accordingly, as shown in Table 6, seven major clusters representing species composition/individuals pertaining to four hill ranges were observed. However, the remaining clusters represent a common species pool arising out of all the four hill ranges. The cluster *Cullenia exarillata* Robyns – *Drypetes oblongifolia* (Bedd.) Airy Shaw – *Palaquium ellipticum* (Dalz.) Baillon – *Schefflera racemosa* Harms – *Nageia wallichiana* (Presl) O. Kuntze constituted 386 individuals consisting of 54 species. The species cluster of *Mesua ferrea* L.– *Polyalthia coffeoides* (Hook. f. & Thoms.) Benth. – *Aglaia elaeagnoidea* (A. Juss.) Benth. – *Syzygium mundagam* (Bourd.) Chithra – *Hopea utilis* (Bedd.) Bole – *Dipterocarpus indicus* Bedd. was found with 27 species of 156 stems. These two clusters, with distinct species association and dominants, are only seen in the Tirunelveli hills. Similarly, around five major clusters unique to different hills are found, indicating the variability in species distribution pattern. The remaining species clusters were found common to all the hill ranges.

Discussion

Patch characteristics

Patch characteristics of evergreen forests in terms of size, proportion, shape and context were found to be different in the four different hill ranges studied. The variation in the physical environment, *viz.* climate, soil, topography, and other landform features may lead to heterogeneous spatial distribution of resources like water, nutrients and light, resulting in the formation of vegetation patches of different character (Burnett et al. 1998; Nichols et al. 1998; Kolasa and Rickett 1991; Peters and Goslee 2001). In addition, naturally occurring and human-created disturbances also play a vital role in the patch formation and characteristics (Platt 1975; Fuller et al. 1998). The four hill ranges in the study area are quite different in their bioclimatic conditions in terms of rainfall pattern, temperature, number of dry months, humidity, etc. (Table 1). In addition, animal grazing, trampling, digging, fire, forest cutting, pests, cultivation and urban development are also prevalent in different degrees in all the four hill ranges. The extent of forest and commercial plantation activity, protection and conservation measures followed in the area also vary in degree and kind.

The Indira Gandhi wildlife sanctuary (Anamalai), Kalakad–Mundanthurai wildlife sanctuary (Tirunelveli) and Nilgiri Biosphere (Nilgiri) constitute the larger part of these evergreen forests. Less disturbance was found in these areas due to a higher

level of protection and large areas of high rainfall conditions amenable for evergreen formation, which might be the reasons for the formation of patches of larger sizes. It is interesting to note that the contiguous patches of >1000 ha of evergreen forest with less porosity cover >50% of the area in the Tirunelveli and Nilgiri hills. The focused priority on conservation of these patches may be helpful to sustain the biological diversity, as these patches of evergreen forest provide unique habitats for various endemic plant species and wildlife. These patches may be large enough to allow the natural disturbance regime to operate, maintain characteristic species composition, support mosaics of community formations, sustained successional patterns and system function (Pickett and Thompson 1978). However, considering the degree of spatial distribution of small-sized patches across the different bioclimatic and topographic regimes, phytosociological studies in the small-sized patches also assume greater priority to understand the landscape more holistically.

The patch dynamics and biotic exchanges among patches, which determine the ecosystem structure and function, are of major concern in the conservation and management of forest ecosystems (Lewin 1984; Nagendra 2001b). In this connection the spatial organization of the patches as identified in this study can form a baseline for continuous monitoring and assess the changes in habitat conditions in the study area. Hobbs (1987) and Hobbs and Huenneke (1992) also emphasized the importance of temporal satellite data to generate information on various landcover types and analysis on patch characteristics in GIS to understand landscape diversity changes and its relation with species diversity patterns.

The Palni hills, which have a larger evergreen area, were found with an increased number of patches and lesser size distribution, indicating the fragmentation of the ecosystem. A shift towards higher perimeter–area ratio evidently exhibits the degree of edge available for larger disturbances in the evergreen system. The evergreen forests were also found to be more porous in nature in Palni, indicating the ingress of endogenous and exogenous factors making the landscape more heterogeneous. The lack of protected areas in the Palni hills and a large number of orchards and commercial plantations may be the causes for higher fragmentation, area–perimeter ratio and landcover heterogeneity. Patch shape, orientation and heterogeneity influence the edge to core ratio and edge habitat, affecting the distribution of edge- and core-preferring species. Some of the edge-preferring species like *Mallotus tetracoccus* (Roxb.) Kurz, *Clerodendron viscosum* Vent. and *Glochidion ellipticum* Wight, and core habitat species like *Palaquium ellipticum* (Dalz.) Baillon, *Mesua ferrea* L. and *Drypetes oblongifolia* (Bedd.) Airy Shaw, etc. are examples observed in the present study. Forest patch size, shape and neighborhood, therefore, influence within patch species diversity and composition (Carlton and Taylor 1983; LaGro 1991). Hence intense phytosociological studies in the fragmented evergreen ecosystem of the Palni hills, having varied patch sizes and shapes, may help to understand the species diversity pattern in association with landscape heterogeneity. In the fragmented forest ecosystems the preservation of a 'minimum dynamic area' or areas large enough to contain multiple patches in various stages of disturbance or recovery is considered very important, as internal recolonization among the patches can contribute to the characteristic species composition and system function (Pickett and Thompson 1978; Hobbs 1987; Saunders et al. 1991). Therefore, with the level
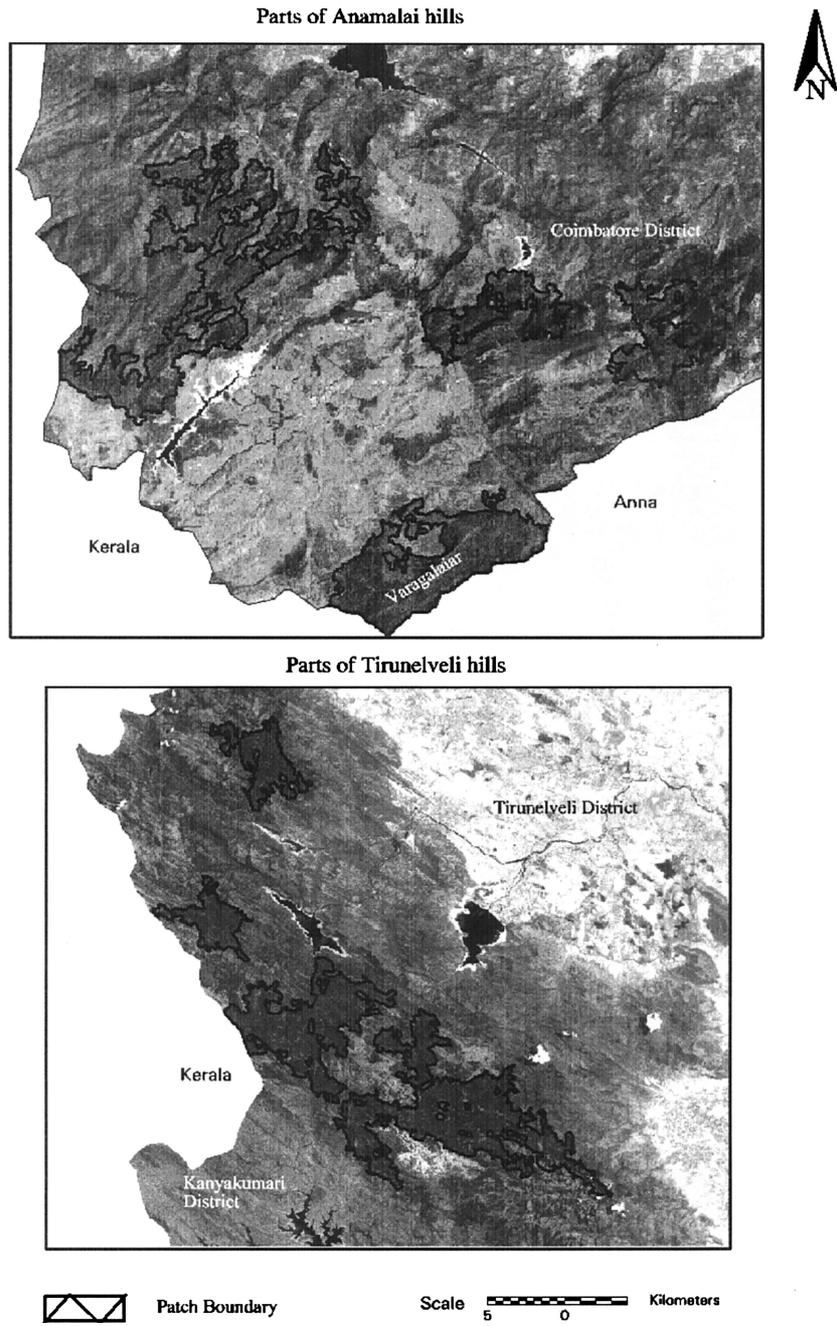
Parts of Anamalai hills

Parts of Tirunelveli hills

Figure 6. Large evergreen patches (>1000 ha) as identified using IRS LISS III satellite data in the Western Ghats of Tamil Nadu, India.

Table 7. Patch, phytosociological and zone characteristics in different hill ranges in the Western Ghats of Tamil Nadu, India.

S. no.	Hill range	Patch characteristics		Phytosociological characteristics			Zone characteristics: conservation zones identified and characteristics
		Fragmentation of evergreen forest[a]	Landcover diversity (H')	Species richness	Stand density (ha^{-1})	Diversity (H')	
1	Palni	3.60	2.45	101	416	5.79	Highly fragmented and high landcover diversity zones with less species diversity
2	Nilgiri	1.39	2.75	125	531	5.75	Less fragmented and high landcover diversity zones with moderate species diversity
3	Anaimalai	2.39	2.16	134	377	6.18	Moderately fragmented and less landcover diversity zones with high species diversity
4	Tirunelveli	1.42	2.02	168	578	6.28	Less fragmented and less landcover diversity zones with high species richness diversity

[a]Determined using number of patches/total area.

of fragmentation of natural evergreen forests in the Palni hills as seen in Figure 1, it is pertinent that these fragmented minimum areas of evergreen forests are identified and grouped as larger units of conservation, using spatial modelling techniques involving remote sensing and intense ground-based phytosociological information.

Species richness and diversity

In the present study, using remote sensing data, the evergreen forests are delineated and the sample points are randomly distributed across the different bioclimatic regimes in all the four hill ranges. This has helped to compose a baseline database on species richness and diversity patterns accounted across the bioclimatic regimes. The species similarity across hill ranges is on the order of 15–28%. The differences in the species similarity and diversity across the different ecosystems are normally caused largely by infrequent species. However, in the present study the first 10 predominant species (based on IVI value) of the Tirunelveli hills were also found to be different from the other four hill ranges. The cluster analysis of all the plots showed four major clusters with distinct species association confining to each particular hill. This indicates the divergence and uniqueness of these four ecosystems studied.

The high species richness (a total of 342 species of 4490 stems from 95 sample points of 0.1 ha) and diversity (5.8–6.3 H') observed in the hill ranges is due to the large number of infrequent species. The non-flattening of the species accumulation curve for the Tirunelveli hills could be due to the large number of infrequent species existing in various microhabitats, developed due to bioclimatic, topographic and disturbance factors. Similar conditions of high diversity and a 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 Western Ghats, India (Pascal and Pelissier 1996). In addition, the species richness reported in Tirunelveli forests (168 species with 1444 stems in 2.5 ha) is similar to that of high species richness areas, *viz.*, 198 species in 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).

A comparative evaluation with the species data collected from large-scale permanent plots in these hill ranges was also done. In the present study a total number of 168 species with 1444 stems (578 ha^{-1}) were recorded from 25 sample points of 0.1 ha in Tirunelveli. On the other hand, in Sengaltheri, a part of the Tirunelveli region, 125 species from 2673 stems (851 ha^{-1}) were recorded from 3.14-ha plots representing different disturbance levels (Parthasarathy 1999). In the Anamalai hills our study has recorded 134 species with a stand density of 943 stems (377 ha^{-1}) in 25 sample points of 0.01 ha. In contrast, from a 30-ha permanent plot laid at Varagalaiar, Anamalais, Western Ghats, 148 species with 13 393 stems (446 ha^{-1}) were reported (Ayyappan and Parthasarathy 1999). The delineation of evergreen forest and random distribution sample points across the hill ranges has

helped to account for a large number of species and analyzing the diversity with less sampling intensity.

The comparison, however, revealed less variation in the stand density but large variation in the type and number of species. High degree of spatial variability in rainfall, topography and various biotic interferences prevailing in the study area might be the reasons for the large environmental heterogeneity and local habitat formation, resulting in high species richness and diversity. Hence, further intensive sampling is necessary in order to account for the rare and endemic distribution of the species and understand the diversity pattern. In this regard the homogeneous patches of different sizes, shapes and neighborhoods identified (Figure 6), in conjunction with the bioclimatic and topographic data will facilitate identification of suitable plots of large sizes or random distribution of sample points across the different environmental gradients to assess the species richness and diversity. In the four hill ranges, the study identified 15 evergreen forest patches of >1000 ha size with small openings of semi-evergreen forest, grasslands and rocky slopes. These patches are located at varied altitudinal, bioclimatic and disturbance range levels. The study recommends these patches as the sites for biological conservation and monitoring on a long-term scale.

Conservation zones – patch and species distribution

Species diversity at any one point in a landscape is determined by multiple factors acting on multiple scales (Wiens 1989; Turner and Gardner 1991; Turner and Corlett 1996). At the landscape scale, the frequency and spatial distribution of critical habitats and resources determine species distribution patterns (Swingland and Greenwood 1983; Pearson 1993), while historical accidents, community inter-actions, and spatio-temporal variability further limit the distribution that is realized at any given time. At finer scales, populations may be separated on patches of habitat within a landscape of less suitable habitat (e.g. Arnold and Weeldenburg 1990; Merriam et al. 1991; Opdam 1991). Plant species found in a resource patch can differ from species in other patches containing different levels of resources. Hence patch characteristics and the pattern of patches within the landscape matrix influence the flows of species, structure and composition within and between landscapes. Increasing heterogeneity usually reduces the number of larger patches, thus decreasing available habitat for interior species, which often need larger contiguous areas of relatively undisturbed habitat (Debinski et al. 2001; Peters and Goslee 2001). Several studies have linked measures of alpha and beta species diversity with landscape (patch) diversity. In an important study of tropical de-forestation in the Amazon rain forest, species in patches of various sizes were compared to evaluate the importance of patch size to species number (Lovejoy et al. 1984, 1986). Large patches were richest in species and small patches were found to contain only edge conditions. The plant species richness in Rhode Island Audubon refuges was highly correlated with terrain and geomorphological characteristics (Nichols et al. 1998). Changes in landscape diversity through time were related to

fire frequency, and were hypothesized to have important effects on species diversity as well as wildlife habitat (Romme and Knight 1982).

In the present study also an attempt was made to assess the species richness and diversity pattern under different landscape conditions. The patch density of evergreen forest and LD of the entire area were taken into consideration. The low patch density indicates a smaller number of patches with large areas and *vice versa* (Table 7). On the other hand, a high LD indicates high heterogeneity of the matrix in terms of various types of landcover types surrounding the evergreen forest. Species richness and diversity in different hill ranges were compared in conjunction with these two landscape parameters. The Tirunelveli hills, which have a low patch density of evergreen forest and low LD, were found to have high species richness and diversity.

On the other hand, the Palni hills, having high patch density and LD, were found to have low species richness and diversity. The sign of impact of LD on species distribution is also observed in the Nilgiri hills, where evergreen forests of large size are present. It can be observed that the stand density is high, but the total number of species recorded is low when compared to a similar high rainfall hill range like Tirunelveli (Table 7). The decrease in number of species might be due to large-scale plantation activity, disturbances in terms of fire, tourism, and grazing around the patches of evergreen forest, affecting the edges of evergreen forest and thus resulting in probable loss of suitable habitat for edge species. This shows that the patch size and its neighborhood have a relation with the species richness and diversity at landscape level. Accordingly, each hill is characterized as a unique conservation zone having different fragmentation, LD levels, species richness and diversity pattern (Table 7). These landscape characteristics clearly show that each conservation zone requires altogether different conservation priorities and management strategies.

However, the processes relating to the patch formation, sizes, neighborhood and associated spatial patterns of the species distribution need to be understood in order to characterize the relationship between species diversity and patch parameters more deterministically. In this regard a suitable sampling design and spatial modeling using information generated on vegetation type through remote sensing, along with phytosociological data, will be of great use.

Conclusions

This study revealed that the evergreen ecosystems in four different hill ranges in the Western Ghats, Tamilnadu, are distinct from each other in their topography, climate, landscape structure and species distribution. Patch characterization through spatial analysis of a vegetation type map revealed that areas like the Palni hills are highly disturbed because of settlements, commercial plantation and tourism. Lack of protected areas in the Palni hills may be one of the reasons for the high disturbance. Protected areas like the Indira Gandhi wildlife sanctuary (Anamalai), Kalakad–Mundanthurai Tiger Reserve, wildlife sanctuary (KMTR, Tirunelveli), and

Mudumalai wildlife sanctuary (Nilgiri) are found as less disturbed sites. The presence of large homogeneous patches with suitable climatic factors (high rainfall and short dry season) in the KMTR site, covering an area of about 59.41 km^2, indicates the richness of the site. The focused priority on conservation of these patches may be helpful to sustain the biological diversity, as these patches of evergreen forests may provide unique habitats for various endemic plant species and wildlife. The spatial organization of the patches identified in the study can form a baseline for continuous monitoring and assess the changes in habitat conditions in the study area. High species richness (a total of 342 species of 4490 stems from 95 sample points of 0.1 ha) and diversity (5.8–6.3 H') is recorded in the hill ranges. A total number of 168 species with 1444 stems (578 ha^{-1}) were recorded from 25 sample points of 0.1 ha in Tirunelveli, indicating high species richness, similar to those of the rich tropical evergreen forests of the world. Species richness and diversity in different hill ranges were compared in conjunction with landscape parameters, showing that the integrity of large evergreen patches with less hetero-geneity in its neighborhood has a relation with the high species richness and diversity at landscape level. The uniqueness in species richness and diversity pattern of the four different hill ranges indicates the requirement of site-specific conserva-tion strategies. The homogenous patches of different sizes, shapes and neigh-borhoods as identified in the study are useful to identify suitable permanent plots of large sizes or random distribution of sample points across the different environmen-tal gradients to assess the species richness and diversity. The Palni and Nilgiri hills require larger ecorestoration activities with high priority. The Anamalai and Tirunelveli hills need sustained conservation strategies using detailed spatial data-bases generated through tools like RS and GIS, linked with ground-based phytosociological studies.

Acknowledgements

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