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B. R. Ramesh
Shaily Menon
Kamaljit S Bawa

Royal Swedish Academy of Sciences

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Author(s): B. R. Ramesh, Shaily Menon, Kamaljit S. Bawa

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Report B. R. Ramesh, Shaily Menon and Kamaljit S. Bawa

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Protected areas in India have historically been established on an *ad hoc* basis with little attention to the conservation value of an area. This study focusses on a set of protected areas in the Agastyamalai region of the Western Ghats (WG), India. We examine forest loss and land-use changes in the study area from the early 1900s to 1960 and from 1960 to 1990. We use GIS to perform a biodiversity gap analysis of the protected areas in the study site. We produce a detailed map of existing floristic types and use it to generate layers corresponding to floristic species richness, zones of floristic endemism, floristically unique areas, and habitat distribution of representative endemic faunal species. These layers are combined with a map of the protected area network to highlight areas of high conservation value excluded from adequate protection. Deforestation rates are high in the study region and several areas of high biodiversity value are excluded from the highest levels of protection. We offer this method as a step toward developing a utilitarian conservation value index for assigning conservation and management priorities.

INTRODUCTION

Deforestation, forest degradation and habitat fragmentation are ubiquitous in the tropics and have grave consequences for the fate of biodiversity. Yet the causes, rates, magnitude, patterns, and trends of landscape changes in the tropics at local and regional levels are not well documented. As Tucker remarks, "many people are talking about the importance of quantifying deforestation, but nobody is actually doing the work. It's pathetic. Let's face it, in another ten years, it won't be worth doing." (1).

The few studies conducted so far at the local level are primarily concerned with the magnitude of deforestation (2, 3). Ascertaining the amount of deforestation is the first crucial step in determining the status of biota, but the fate of biodiversity depends upon the existence and integrity of protected areas. Thus, conservation planning information about landscape changes must be integrated with data on spatial distribution of biodiversity and protected areas. Gap analysis, based on superimposition of layers of data on parameters such as vegetation types, wildlife habitat, and protected areas (4) provides a powerful tool for identifying gaps in conservation. Although a few studies in the neotropics have examined the representativeness of vegetation types within protected area networks (5, 6), the approach has not been widely used for tropical regions. Here we present the results of a study on patterns of deforestation, assessment of biodiversity, and gap analysis designed to increase the effectiveness of a set of protected areas in the Western Ghats, India. Our study is unusual in the sense that it is focussed on a set of protected areas. Although it is well known that the integrity of protected areas in the tropics is being seriously compromised, to the best of our knowledge there are no quantitative data on the losses of biodiversity in protected areas.

The objectives of our study, undertaken in the Agastyamalai region of the Western Ghats, are: *i)* to estimate the magnitude and patterns of forest loss, and *ii)* to conduct a gap analysis in the study area and highlight areas of high conservation value that do not receive adequate protection.

We show that landscape changes, even in the protected areas, are occurring at a rapid rate, and that many areas of considerable conservation value are not given adequate protection. Based on our findings we examine guidelines and strategies for effective conservation of biodiversity in the area.

STUDY AREA

The forests of the Western Ghats, India, are some of the best representatives of nonequatorial tropical evergreen forests in the world (7, 8). The Western Ghats cover only 5% of the country's total land area, but contain more than 4000, or 27%, of the country's total plant species. Because of its geographic isolation during the late Tertiary and subsequent evolution, the Western Ghats is one of the richest centers of endemism in India. Nearly 63% of India's arborescent evergreen taxa are endemic to the Western Ghats (9). The number of endemic plant species in the Western Ghats is estimated to be 1500 (10). The high levels of biodiversity and endemism have earned the area the status of one of the biodiversity 'hotspots' of the world (11).

The region of the WG south of the Palghat Gap contains 87% of the total endemic species of the WG and 37% of this total are endemic to this region alone (9). South of the Palghat Gap, the duration of the dry season is 2–3 months especially on the western slopes, and there is a steep increasing gradient in length of dry season from west to east. This contributes to high rates of endemism and species richness in this region. Some of the species (*Humboldtia unijuga, Hopea utilis, Gluta travancorica, Bentinckia codapanna*, etc.) have restricted distribution but are common, and others (*Taraktogenos macrocarpa* and *Dysoxylum ficiforme*) are widely distributed but rare (8). This region has been referred to as the main center of endemism in India. The southernmost region of the Western Ghats, between 77°34' E and 8° 21'–8° 58' N, is called the Agastyamalai region and contains some of the least fragmented forest tracts in the southern Western Ghats (12). At least 150 localized plant endemics are found in the Agastyamalai region (13).

The study area covers 1657 km^2 and includes an elevation range of 100 to 2000 m. Precipitation on the western (windward) side is between 2000 and 5000 mm. Rainfall decreases rapidly toward the east from 2000 to 900 mm. The dry season lasts only two to three months on the western side and increases up to six months towards the east. The mean temperature of the coldest month in the study area ranges from 13.5° to > 23°C in the west and 16° to > 23°C to the east (14).

The study area (Fig. 1) contains four Wildlife Sanctuaries (Kalakad-Mundanthurai, Neyyar, Peppara, and Shendurni) and six contiguous Reserve Forests (Kolathupuzha 1 and 2, Yerur, Pallod 1 and 2, and Kottur). Of these, only Kalakad-Mundanthurai Sanctuary lies within Tamil Nadu state; the remaining sanctuaries and forests are in Kerala state. Reserve Forests (RF) were created in India under the Forest Act of 1878 for the protection and management of timber resources. Subsequently, the level of forest product utilization from some of these

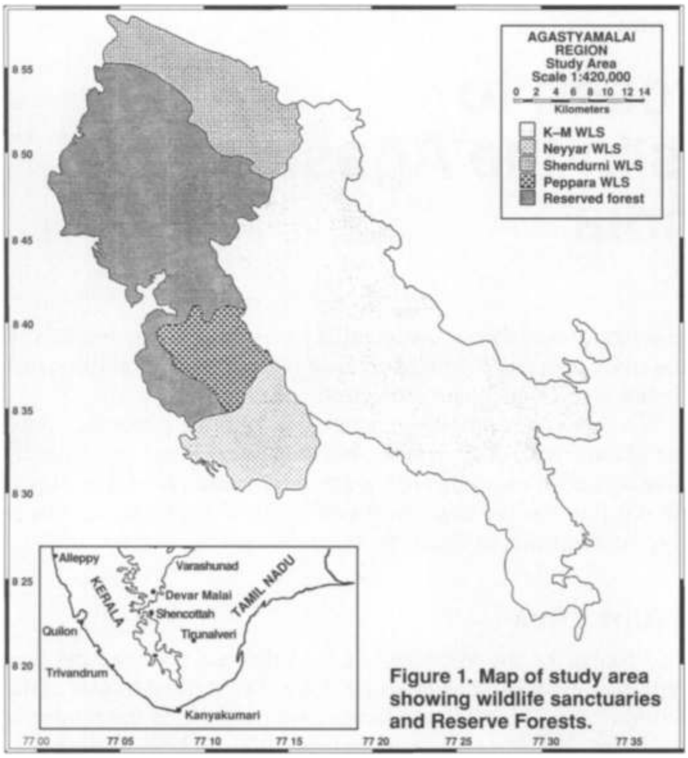

Figure 1. Map of study area showing wildlife sanctuaries and Reserve Forests.

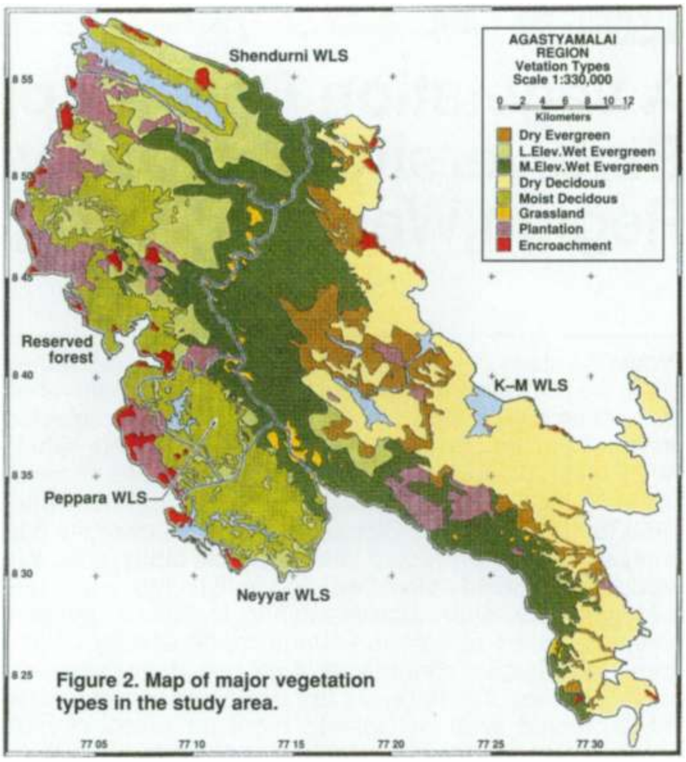

Figure 2. Map of major vegetation types in the study area.

RFs was reduced and on the basis of the importance of their biological resources, several of these were upgraded to the status of Wildlife Sanctuaries (WLS) and National Parks (NP). For the purposes of this study, we consider WLS as areas receiving higher levels of protection for biodiversity conservation, and RFs as managed areas with lower levels of protection.

METHODS

CAMRIS (Computer-Aided Mapping and Resource Inventory System), a vector-based GIS software, was used for spatial data analysis in this study. Maps were digitized on a Summagraphics digitizing tablet.

Time Series Change in Forest Cover

The extent of forest cover in the study area for the early part of the century was obtained from the Survey of India maps (at scales of 1:253 440) based on surveys conducted from 1909–1928. A vegetation map of Cape Comorin (15) at 1:1 000 000 published in 1961 by the French Institute, Pondicherry provided data on the distribution of forest cover and land-use types for the middle part of the century.

Data on forest cover and vegetation distribution for the 1990s were obtained from studies in the field, satellite imagery, and Forest Department records. These data were collected as a part of the project of the French Institute, Pondicherry, to publish the 1:250 000 scale Forest Map of South India (16). Survey of India topographic maps at 1:50 000 scale were used to obtain base information such as topography, Reserve Forest and plantation boundaries, and for selecting sites for field stations. Working plan maps of the Forest Department were consulted to update boundaries of the Reserve Forests and plantations. Landsat TM and IRS (Indian Remote Sensing) satellite images were consulted in the form of false color composite hardcopies at 1:250 000 scale. Areas of different spectral reflectances were marked and the vegetation types were identified from the field component of the study. Thus, the boundaries of each vegetation or forest type was delineated using satellite imagery. A total of 70 field stations were selected in the study area. At each station the structure of the forest was visually estimated and a detailed floristic list was compiled by identifying species of individuals within a radius of 0.5 km (0.785 ha) around the station center. The floristic list enumerated trees, shrubs, and some herbs. Changes in vegetation type between stations were noted.

Changes in forest cover and land-use types between the early part of the century (1920), mid-century (1960), and the latter part of the century (1990) were estimated by comparing the maps corresponding to the three time periods.

Gap Analysis of the Protected Area Network and Indices of Biodiversity

The major vegetation types occurring in the study area in 1990 are shown in Figure 2. Detailed spatial distribution of floristic data (not shown in figures) obtained for the 1990s were used as a basis for generation of the following layers: floristic species richness, zones of floristic endemism, unique habitats, and endemic faunal (mammal and bird) habitats. The methodology used for the generation of each layer is described below.

Layer 1: *Floristic Species Richness* (Fig. 3)

We listed the total number of species corresponding to each floristic type obtained from the field stations. To generate the floristic species richness layer, each floristic type was assigned a value corresponding to the number of species in that type. We grouped types into four classes: <50 species, 51–100 species, 101–150 species, 150–200 species.

Layer 2: *Floristic Endemic Zones* (Fig. 4)

Data values related to floristic (tree) endemism were assigned according to the percent of endemic species out of the total number of endemic tree species in the Western Ghats. We obtained a total of 126 endemic woody shrub and tree species for our study area. There are a total of approximately 310 endemic shrubs and trees in the entire Western Ghats (9). We counted the number of endemic woody shrubs and trees in each floristic type in our study area and calculated the percent out of 310. The results were grouped into the following four zones of endemism: nonforest areas which included plantations and grasslands, no endemics, low endemism (1–8%), medium endemism (9–16%), and high endemism (17–24%).

Layer 3: *Unique Areas* (Fig. 5)

The layer on unique areas was based on field surveys and knowledge of the restricted distribution of different ecosystems and species. Uniqueness was determined at two levels: ecosys-

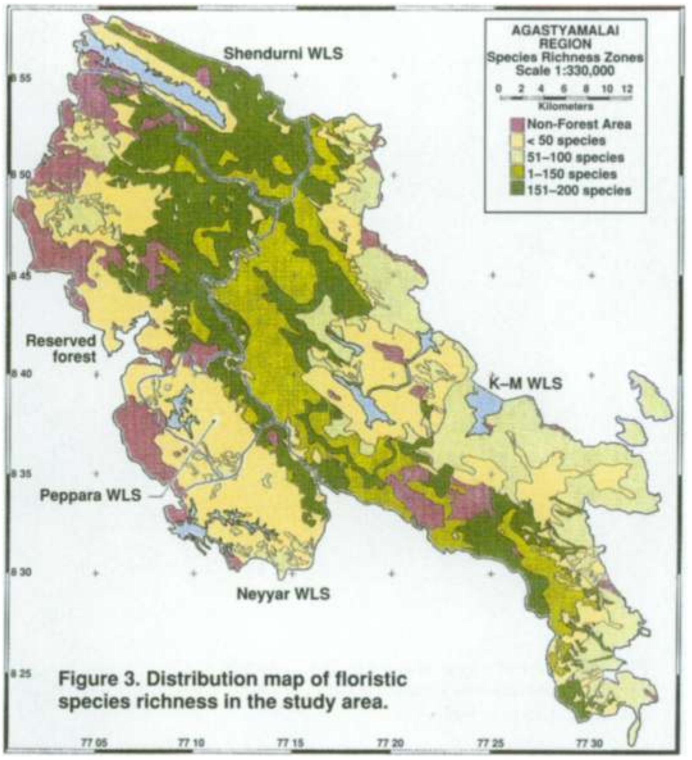

Figure 3. Distribution map of floristic species richness in the study area.

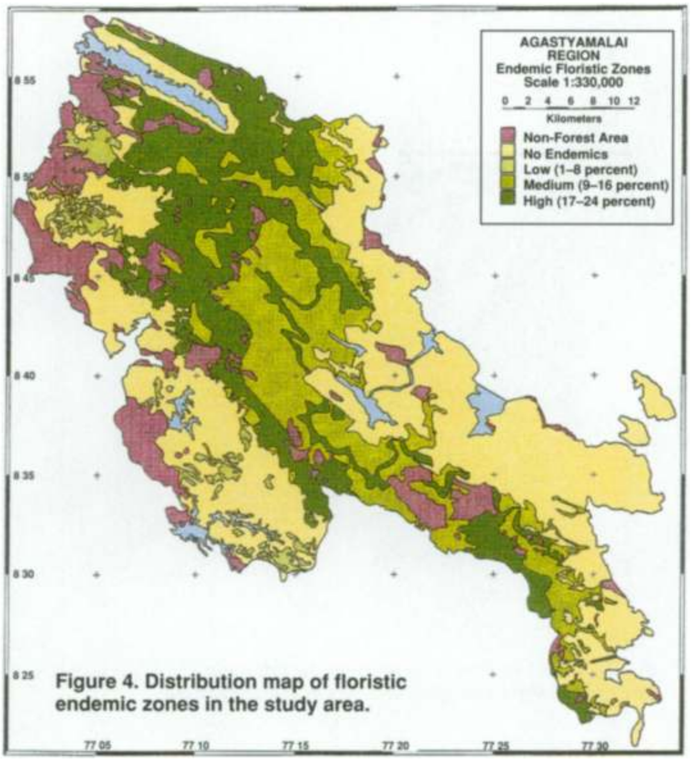

Figure 4. Distribution map of floristic endemic zones in the study area.

tem and floristic. *Myristica* swamps are the unique areas at the ecosystem level. These swamps are found only in poorly drained regions with very long rainy seasons (7). The characteristic feature of this swamp ecosystem is the abundance of trees belonging to the Myristicaceae family. *Myristica fatua var. magnifica* is confined to such swamp habitats. Other *Myristica* species found here are *Gymnacranthera canarica, Myristica dactyloides*, and *Knema attenuata*. These species develop stilt roots with pneumatophores; some stilt roots sprout 6 m above the soil. The undergrowth is dominated by Aroideae and Zingiberaceae. *Myristica* swamps are found only in Kerala and a few occur in the North Kanara district of Karnataka where they are more disturbed. Many potential swamps have been converted into rice fields, oil palm, and teak plantations. Those shown in Figure 5 are remnant patches surrounded on either side by eucalyptus and teak plantations. Although these remnant patches have undergone further fragmentation they are the best representative of this ecosystem in the entire Western Ghats.

Unique areas at the floristic level are the *Hopea racophloea* and *Humboldtia decurrens* facies, the *Nageia wallichiana* facies, and the *Hopea utilis* facies (17). *Hopea racophloea* and *Humboldtia decurrens* are the facies of low elevation in the Dipterocarp forests between Pallod RF and Shendurni WLS. In the study area this facies has the highest number of species (270) compared with all other vegetation types. *Humboldtia decurrens*, a cauliflorous tree, is endemic to this region. This area represents one of three distinct populations of *Hopea racophloea* in the Western Ghats (17). In the *Cullenia exarillata* dominated forests of the medium elevation, *Nageia wallichiana* and *Aglaia bourdillonii* form distinct facies above 1000 m. *Nageia wallichiana* is the only gymnosperm tree in the Western Ghats and the study site is the core area for this species. Some pockets have been recorded around Periyar and Anamalai region. *Aglaia bourdillonii* along with other species like *Garcinia travancorica, Syzigium microphylla, Symplocos nairii*, and *Eugenia floccosa* are local endemics. The *Hopea utilis* facies forms a transition between the wet and dry evergreen forests. This species is locally endemic and found nowhere else in the Western Ghats.

The layer on unique areas contains two classes: Unique areas (comprising *Myristica* swamps, *Hopea rachophloea* and

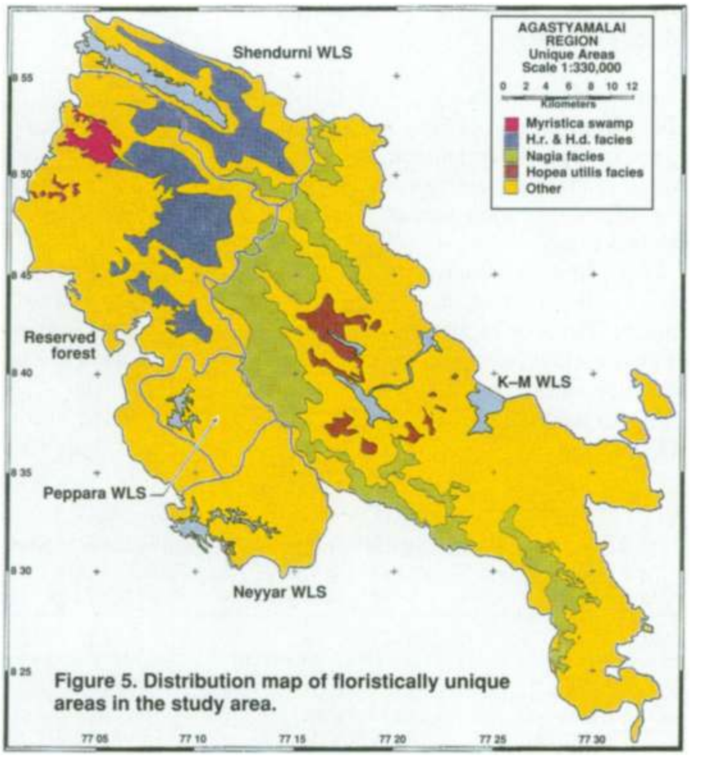

Figure 5. Distribution map of floristically unique areas in the study area.

Humboldtia deccurrense facies, *Nageia* facies, and *Hopea utilis* facies) and Other.

Layer 4: *Endemic Faunal Habitat* (Fig. 6)

The layer on representative endemic faunal habitats was created by assigning data values to each floristic type based on the number of endemic mammalian and bird species found in a particular type. A list of the mammal and bird species and their habitat types is provided in Table 1 (18, 19, and information from recent fieldwork by Kumar (mammals) and Kannan (birds) (pers. comm.). Only mammal and bird data were used because relevant details on the habitat preferences of other vertebrate classes such as reptiles and amphibians are not available in the literature. The layer on endemic faunal habitat has the following 5 classes: No

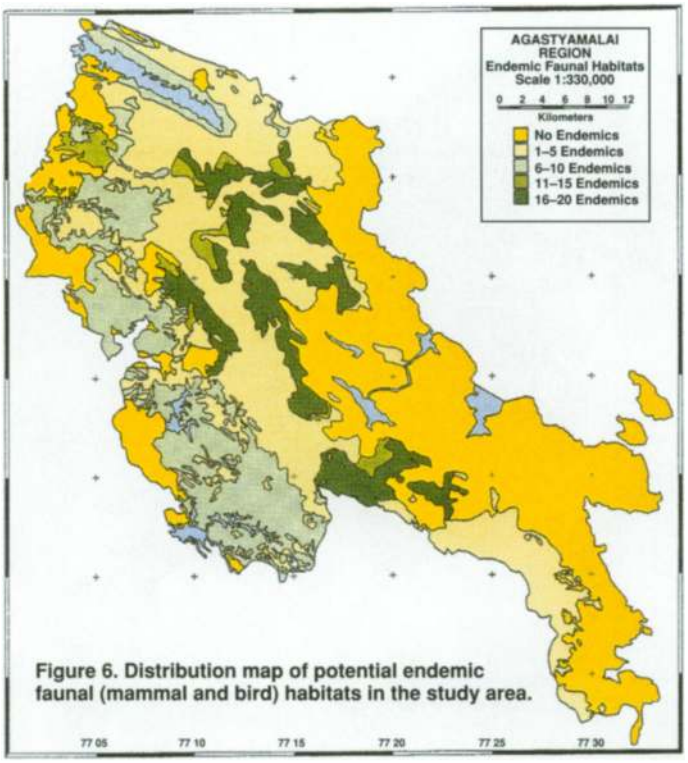

Figure 6. Distribution map of potential endemic faunal (mammal and bird) habitats in the study area.

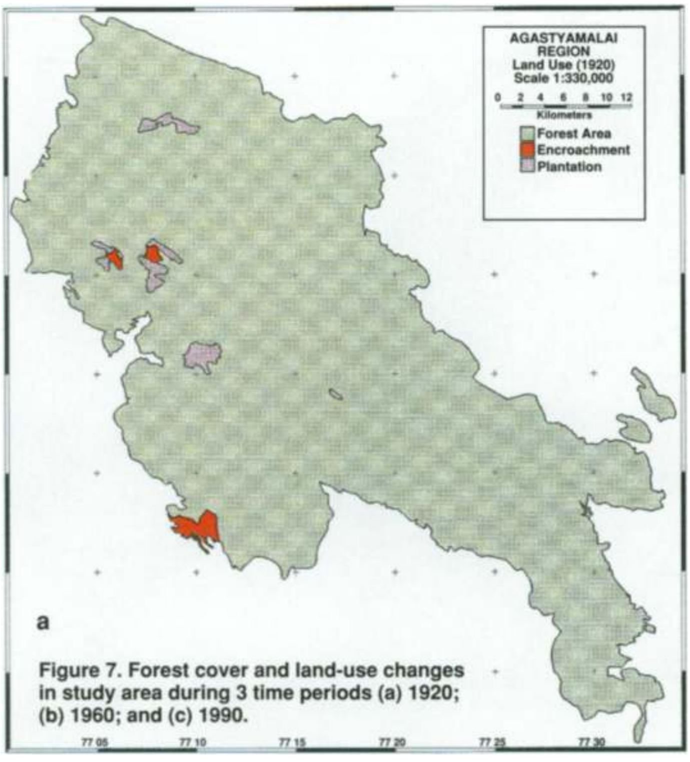

Figure 7. Forest cover and land-use changes in study area during 3 time periods (a) 1920; (b) 1960; and (c) 1990.

endemics, 1–5 endemics, 6–10 endemics, 11–15 endemics, and 16–20 endemics.

Conservation Values

The information in each of the layers (floristic species richness, zones of floristic endemism, floristically unique areas, and endemic faunal habitats) was combined to yield a composite picture of conservation values. Two methods were employed to achieve this.

In the first method, the percentage of each WLS and RF covered by the different classes in each of the four layers was calculated. The sum of the percentages for the highest class in each of the four layers was divided by four to obtain an index of conservation value for each protected area.

In the second method, the four layers were converted into a 2000 x 2000 celled grid (cell size = 1354 m^2) and grid algebra was performed on the four resultant grids. For the purposes of grid algebra, the classes in each layer were given values from 0 to 40 in increments of tens. For example, in the species richness layer, values were assigned as follows: Nonforest areas = 0, < 50 species = 10, 51–100 species = 20, 101–150 species = 30, and 151–200 species = 40. For the layer on unique areas, all unique areas were assigned a value of 40 and other areas were assigned a value of zero. All nonforest areas and zones of no endemism were assigned values of zero. The assigned value for every grid cell corresponding to each layer was added to generate final conservation values. The minimum possible final value for any grid cell was 0 and the maximum possible value was 150. These conservation values were reassigned into five classes: Low (10–30), Low-Medium (40–60), Medium (70–90), Medium-High (100–120), and High (130–150) to obtain a final map highlighting areas of high conservation values.

Table 1. List of endemic bird and mammal species used in faunal habitat analysis (1, 25).

Species	Common name	Habitat type
Mammals		
Funambulus tristriatus	Jungle-striped squirrel	Evergreen forests
Macaca silenus	Lion-tailed macaque	Medium elevation evergreen forests
Trachypithecus johnii	Nilgiri langur	Medium elevation evergreen forests, Plantations
Martes gwatkinsi	Nilgiri marten	Medium elevation evergreen forests
Viverra civettina	Malabar civet	Low elevation evergreen forests, Moist deciduous forests
Paradoxurus jerdoni	Brown palm civet	Evergreen forests
Hemitragus hylocrius	Nilgiri tahr	Grasslands, rocky outcrops
Birds		
Anthus nilghiriensis	Nilgiri pipit	High altitude grassland, rocky outcrops
Nectarinia minima	Small sunbird	Low and medium elevation semi-evergreen and evergreen forests
Muscicapa albicaudata	Nilgiri verditer flycatcher	Wet evergreen forests
M. pallipes	White-bellied blue flycatcher	Wet evergreen forests, Moist deciduous forests, Cardamom plantations
M. nigrorufa	Black and Orange flycatcher	Medium elevation wet evergreen forests, Cardamom plantations, Ochlandra mosaics
Brachypteryx major	Rufous-bellied shortwing	Medium elevation wet evergreen forests
Garrulax jerdoni	Travancore white-breasted laughing thrush	Medium elevation wet evergreen forests, Ochlandra mosaics
Psittacula columboides	Blue-winged parakeet	Low and medium elevation evergreen forests, Moist deciduous forests
Columba elphinstonii	Nilgiri wood pigeon	Low and medium elevation wet evergreen forests
Galerida malabarica	Malabar crested lark	Grassland
Pycnonotus priocephalus	Grey-headed bulbul	Low elevation semi-evergreen and Moist deciduous forests, Disturbed fragments, Ochlandra mosaics
Schoenicola platyura	Broad-tailed grass warbler	Medium elevation ochlandra mosaics, Grassland
Harpactes fasciatus	Malabar trogon	Moist deciduous forests, Evergreen forests
Batrachostomus moniliger	Ceylon frogmouth	Evergreen, Bamboo forests, Moist deciduous, and Thick secondary forests
Ocyceros griseus	Malabar gray hornbill	Evergreen forests, Moist deciduous forests
Megalaima rubricapilla	Crimson-throated barbet	Evergreen forests, Moist deciduous forests
Turdoides subrufus	Rufous babbler	Thickets and secondary jungle, Edges of evergreen forests

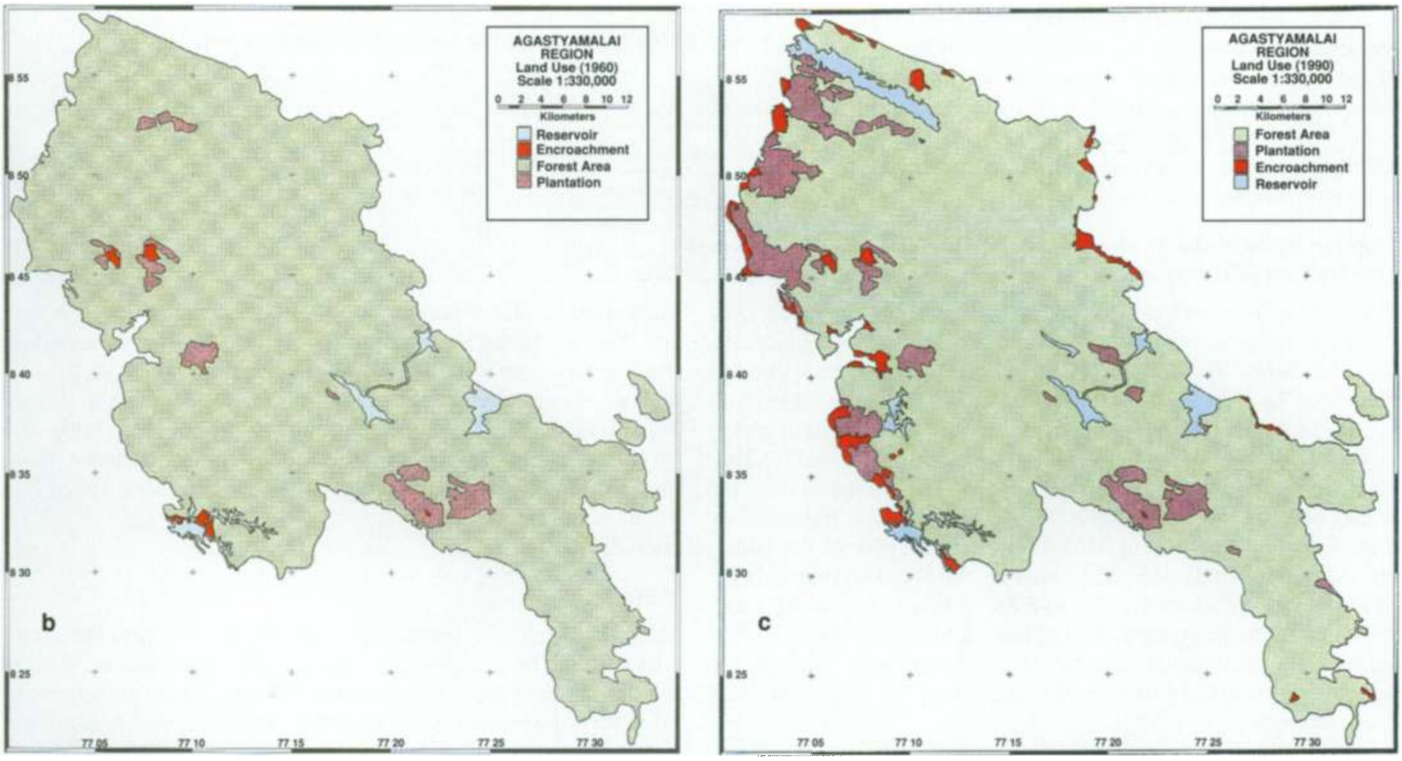

Table 2. Forest cover and landuse changes in study areas during 3 time periods.

	Landuse type (change) km².				Annual deforestation rate	
Year	Encroachment	Plantations	Reservoir	Forest	% of study area	% of forest cover
1920	11	20	0	1626		
					0.07	0.07
1960	4 (−7)	46.4 (+26.4)	19.6 (+19.6)	1579 (−47)		
					0.31	0.33
1990	46 (+42)	132 (+85.6)	56 (+36.4)	1423 (−156)		

Total study area = 1657 sq. km.

RESULTS

Time Series Change in Forest Cover

The extent of forest cover and various land-use types within the study area during 1920, 1960, and 1990 are shown in Figures 7a, b, and c, respectively. The total forest area was 1626 km^2 (98.1% of the study area) in 1920, 1579 km^2 (95.3% of the study area) in 1960, and 1423 km^2 (85.9% of the study area) in 1990. Table 2 shows the change in forest cover during the three time periods. Forest loss in the study area between 1920 and 1960 was 47 km^2. This loss represents 2.9% of the forest cover with an annual deforestation rate of 0.07% during the 40-year period. From 1960 to 1990, 156 km^2 of forest were lost. This represents a loss of 9.9% of the forest cover with an annual deforestation rate of 0.33%. During the 30-year period, 85.6 km^2 were lost to plantations, 42 km^2 were replaced by encroachments, and 36.4 km^2 were lost to reservoirs.

Patchiness in Distribution of Vegetation Types in the Study Area

Vegetation types in the WG closely follow bioclimatic variations. The decisive factors are total rainfall, length of the dry season, and minimum temperature (7). Wet evergreen forests occur at both low and medium elevations and comprise 634 km^2 (38% of the study area and 45% of the forest cover.) The eastern counterpart of the low elevation wet-evergreen forest, is the dry-evergreen forest which occurs in areas where rainfall is between 1200–1500 mm and the length of the dry season is 4–5 months. The study area contains 118 km^2 of dry-evergreen forests (7.1% of the study area and 8.3% of the forest cover.) Moist deciduous forest occurs on the western side where the rainfall is between 2000–3000 mm. It forms a total of 277 km^2 (16.7% of the study area and 19.5% of the forest cover). Its counterpart on the eastern side is the dry deciduous forest comprising a total of 359 km^2 (21.7% of the study area and 25.2% of the forest cover).

Apart from total extent of the various vegetation types, the patchiness in their distribution (Table 3) is an important consideration in deforestation studies. Although medium elevation wet-evergreen forest has an areal extent of 457 km^2 in the study area, its distribution is in the form of one large contiguous patch of almost 440 km^2 and 14 other patches of much smaller area and rather high P/A (perimeter to area) ratios. In fact, medium elevation wet-evergreen forest is the most compact of the different vegetation types in the study area, probably due to its location at the core of the study area at higher altitudes and farther away from human influence. The low elevation wet evergreen forest (total area 177 km^2) is much more patchily distributed. It occurs in 45 patches, the largest of which is 80 km^2. The majority of the patches have very small areas and high P/A ratios. Similarly, dry-evergreen forests occur in 33 patches, moist deciduous forests in 40 patches, and dry-deciduous forests in 22 patches, respectively.

K-M WLS lies on the eastern side of the crest of the Western Ghats and contains dry-deciduous and dry-evergreen forests. An isolated forest patch floristically similar to low elevation wet-evergreen forests occurs within this sanctuary in the moist valley of the Tambaraparani river to the east of the Agastyamalai peak. However, it differs from its counterpart by the presence of locally endemic species such as *Palaquium bourdillonii*, *Diospyros humilis*, *D. barberi*, *Memecylon subramaniamii*, and *Garcinia rubroechinata*.

Table 3. Patchy distribution of vegetation types in the study area.

Vegetation type	Area (km^2)	Number of patches	Number of patches with P/A < 15 m ha^{-1}
M. El. wet-evergreen forest	457	15	1
L. El. wet-evergreen forest	177	45	2
Dry-evergreen forest	118	33	0
Moist-deciduous forest	277	40	1
Dry-deciduous forest	359	22	2
Grassland	19	36	0

Gap Analysis of the Protected Area Network and Indices of Biodiversity

The results from method one are shown in Table 4, which lists the area and percentage under each class. Among the sanctuaries, Shendurni WLS obtained the highest conservation value index (38.8%). Nearly 60% of Shendurni WLS is covered by wet evergreen forests with high levels of species richness and endemism (55% each). The bulk of *Hopea racophloea* and *Humboldtia decurrens* facies are confined to this area alone. The conservation value index of RF is 24.1% which is higher than that of other WLS except Shendurni. Nearly 60% of the western side of the study area is covered by the Reserve Forests. Almost 44% of RF is covered by evergreen forests including fragments and 28% represented by deciduous forests. Although fragmented, the best preserved *Myristica* swamps are restricted to this area. Almost 26% of the RF is covered by plantation and encroachment.

The output from the grid analysis (method two) gives a visual picture of the distribution of areas of different conservation values (Fig. 8). In general, the results agree with that obtained by the previous method. Once again, Shendurni WLS displays a high extent of areas of high conservation value (shown in green). The RF have the next highest proportion of areas with high conservation values followed by KM WLS. By contrast, both Neyyar and Peppara WLS are poorer in conservation value.

DISCUSSION

Deforestation

Microlevel rates of forest loss, such as those within the study area, should be examined in the context of deforestation rates in other parts of the country. Several workers have attempted to estimate deforestation rates for the entire country and individual states. However, these estimates are widely disparate. For ex-

Table 4. Indices of biodiversity and conservation values in each protected area.

Indices	K-M km^2	K-M %	Shendurni km^2	Shendurni %	Peppara km^2	Peppara %	Neyyar km^2	Neyyar %	RF km^2	RF %
Tree Species-Richness										
< 50 species	184.5	21.5	29.8	19.1	51.92	64.4	77.6	64.2	127.6	28.7
51–100 species	245.7	28.6	0.0	0.0	4.9	6.1	9.61	7.9	32.5	7.3
101–150 species	189.0	22.0	11.6	7.4	4.2	5.2	1.5	1.2	20.5	4.6
151–200 species	154.6	18.0	85.6	54.8	11.82	14.7	15.8	13.1	144.1	32.4
Endemism										
No Endemics	397.91	46.3	30.8	19.7	49.4	61.3	75.2	62.2	125.5	28.2
Low (1–8 percent)	0	0.0	0	0.0	6.4	7.9	9.7	8.0	31.38	7.1
Medium (9–16 percent)	262.2	30.5	11.7	7.5	4.2	5.2	1.5	1.2	20.2	4.5
High (17–24 percent)	109.2	12.7	85.7	54.9	11.8	14.6	17.9	14.8	143.8	32.4
Uniqueness										
Other areas	627.9	73.1	82.02	52.5	75.05	93.1	109.4	90.5	335.3	75.4
Hopea utilis facies	28.29	3.3	0	0.0	0	0.0	0	0.0	0	0.0
Myristica swamp	0	0.0	0	0.0	0	0.0	0	0.0	15.22	3.4
H.r. and H.d. facies	0	0.0	50.45	32.3	0	0.0	0	0.0	88.12	19.8
Nageia facies	181	21.1	7.57	4.8	0	0.0	0.4	0.3	4	0.9
Total unique area	209.29	24.4	58.02	37.2	75.05	0.0	0.4	0.3	107.34	24.1
Endemic Faunal Habitat										
No Endemics	484.3	56.4	8.95	5.7	3.17	3.9	4.66	3.9	104.7	23.6
1 – 5 Endemics	205	23.9	79.99	51.2	29.3	36.4	23.89	19.8	139.8	31.5
6 – 10 Endemics	0	0.0	28.08	18.0	35.73	44.3	75.18	62.2	108.8	24.5
11–15 Endemics	7.18	0.8	4.48	2.9	0.38	0.5	0	0.0	27.9	6.3
16 – 20 Endemics	88.78	10.3	13.13	8.4	1.83	2.3	0.46	0.4	33.1	7.4
Conservation Value Index		16.4		38.8		7.9		7.2		24.1

ample, an FAO study (20) estimated an annual deforestation rate of 0.6% between 1981–1990 for India, but another study (21) suggests that India's total forest area declined by only 0.04% annually between 1982 and 1990. Disparity in estimates from different studies results from several reasons, including differences in methodology, differences in definitions and classification of forest and land-use types, and unavailability or inaccessibility of accurate maps. Such disparities in estimates of the rate and extent of deforestation underscore the need for more careful regional or local-level studies.

For the state of Kerala, annual forest loss from 1905 to 1965 was estimated (22) to be 0.27% of the total geographic area (0.6% of the forest cover) and from 1965 to 1973 the annual deforestation rate was 1% of the total geographical area (4.8% of the forest cover.) An NRSA study for the period between 1972 and 1982 demonstrated an annual deforestation rate of 1.4% of the total forest cover in Kerala (12).

The high rate of annual forest loss in the study area (0.33% between 1960 and 1990) is very significant in light of the fact that the entire study area has been under some form of protection during that period. If this rate of deforestation continues for the next 30 years then a further forest loss of approximately 160 km^2 can be expected by the year 2020. Assuming that most of the future deforestation will occur around existing areas of human habitation (i.e. plantations and encroachment), 70 km^2 or 45% of the forest loss will occur within the Reserve Forest area.

The principal causes of deforestation between 1960 and 1990 are encroachments, which increased from 4 km^2 to 46 km^2, plantations which increased by over 85 km^2, and 36.4 km^2 of reservoirs created by hydroelectric dams.

Patchiness in Distribution of Vegetation Types

The extent of patchiness or fragmentation of forests is an important consideration in assessment of deforestation trends. Studies in other parts of the world have demonstrated that small forest patches with large P/A ratios that are close to agricultural or other nonforest lands are more readily cleared than large blocks of forests. In a study in the Philippines (23) all forest patches with P/A ratios greater than 15.0 m ha^{-1}, present in 1934, were found to have been cleared in 1988.

Patchiness is partly a natural phenomenon, controlled by factors such as climate, topography, and soil type, and partly caused by anthropogenic forces in the form of encroachments, plantations, and reservoirs. For example, in the study area, grasslands are present as small, widely distributed patches. However, most of the grasslands lie within the well-protected interior region and their patchiness is a natural phenomenon; grasslands typically occur at high altitudes on peaks exposed to the ravages of wind and frost conditions. The medium elevation wet-evergreen forests also lie within the well-protected interior of the study area and thus are less exposed to anthropogenic pressures and occur as one large patch and a few smaller ones towards the southern end where plantation activity and encroachments are present. In contrast, low elevation wet-evergreen forests and moist-deciduous forests lie along the periphery of the study area where encroachment and plantation activity are the highest and, thus, have a much more patchy distribution. In our analysis of patchiness, we examined patches of different vegetation types rather than forest patches. The former, in most cases, are surrounded by or are contiguous with forests of other vegetation types and therefore present a somewhat less serious situation. Nevertheless, small isolated patches of wet-evergreen forests within a matrix of moist-deciduous forests, encroachments, and plantations, as seen along the entire western edge of the study area, are likely to be extremely susceptible to degradation and subsequent deforestation. Continuous monitoring of these patches should be a high priority for conservation and management of biodiversity in this protected area network.

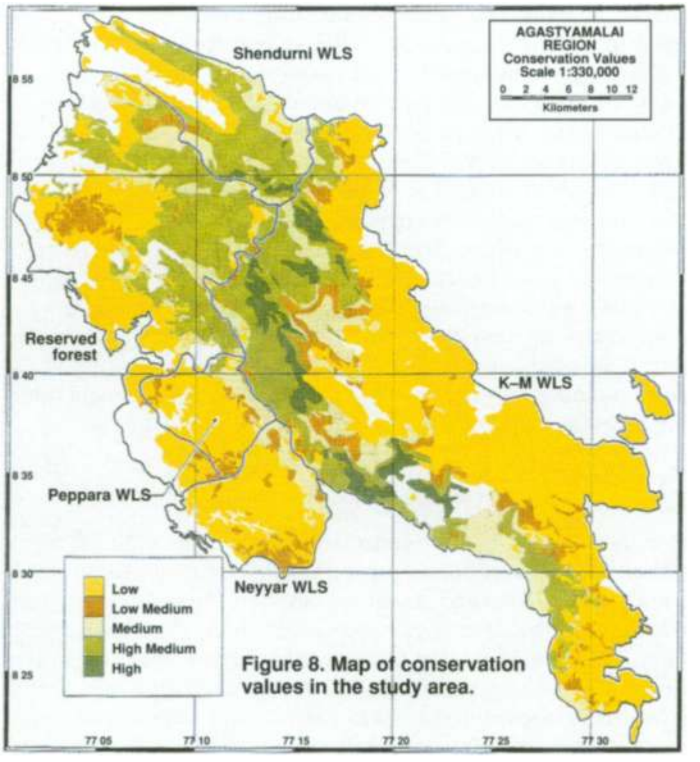

Figure 8. Map of conservation values in the study area.

Gap Analysis

Comparing the three sanctuaries and the RF on the western side, we see that the RF form a block of forest between Shendurni WLS on the north and Peppara and Neyyar to the south. There are no clear or obvious biological or geographical reasons why the three areas forming WLS have been given a high level of protection or why the RF area has been excluded from adequate protection. In fact, the total evergreen forest area in the RF is 196 km^2, which is higher than that covered by the other three WLS (152 km^2). On the other hand, as a result of inadequate protection, the RF have a much larger area converted to plantation (89 km^2) compared to 9 km^2 in the WLS.

It is interesting to note that each of the WLS has some area taken up by one or more reservoirs ranging in size from 5 to 20 km^2. However, RF contain no reservoirs, thus supporting the idea that WLS have been established as afterthoughts subsequent to the construction of reservoirs. For example, in 1983 a dam was constructed across Karamana river at the base of Agastyar peak. Most of the forests in the lower reaches of the catchment including those along the margin of the reservoir were logged to make room for eucalyptus plantation. The total area deforested was 30 km^2. An area of 53 km^2 constituting the watershed of the dam was declared Peppara WLS. This area was contiguous with the previously established Neyyar WLS along the southern edge and with Mundanthurai WLS along the eastern edge. In 1984 an area of 100 km^2 around the Kallada Irrigation Reservoir in Quilon district was notified as Shendurni WLS.

Conservation Value Index

Our conservation value index is based on rather scant biological data. More information on the distribution of various plant and animal species including the distribution of wild relatives of plant and animal species of actual and potential economic importance is required to develop an appropriate index. Moreover, our index does not include the consideration of threats to biodiversity which vary across the protected area; interior areas are less threatened than peripheral areas. Thus, although the peripheral areas are biologically less diverse, they require more protection than areas of high conservation value. Our index also does not take into account socioeconomic factors such as economic, cultural, and religious importance of various habitats and species. Finally, the conservation value index has been developed to evaluate the utility of the approach towards assigning priorities for conservation and management. Ideally, such approaches should be used for large areas. The area under consideration is too small to be demarcated into zones of higher or lower importance. We believe that the entire area requires an equal degree of protection. What our analysis emphasizes is that the interior areas are biologically more diverse, but less threatened. The fate of biodiversity in such areas is subject more to natural phenomena than to anthropogenic pressures. The peripheral areas are more threatened by human impact and unless the integrity of the peripheral habitats is maintained, the whole protected area network would be endangered. The interior and peripheral zones thus require different types of management interventions for the maintenance of biodiversity.

RECOMMENDATIONS

Our recommendation for conservation strategies in the Western Ghats is that the rationale for establishment of protected areas should be revisited and should be based on the potential of various areas for biodiversity conservation. In the Agastyamalai region, specifically, the RF deserve much higher levels of protection than currently provided. This recommendation is based on a landscape approach that takes into account rates and extent of deforestation, distribution of vegetation types, patchiness of the distribution, tree species richness, uniqueness of habitats, and distribution of floral and faunal endemic species and/or their habitats.

Other studies have looked at the Agastyamalai region and proposed conservation strategies to make up the gap in protection. Rodgers and Panwar (24) proposed two areas, both under reserve forest status, for extension of the protected area network in the Agastyamalai region. The first is Ponmudi Hills with an area of 100 km^2 in Kerala to serve as a link between Shendurni and Peppara-Neyyar wildlife sanctuaries. The second is Upper Kodayar of 50 km^2 in Tamil Nadu to serve as an extension to the southern border of Kalakad wildlife sanctuary. For each of the existing and proposed protected areas they have listed the presence of significant biomes (ecosystems) and the following significant wildlife species: tiger, elephant, gaur, Nilgiri tahr, Nilgiri langur, lion-tailed macaque, rusty spotted cat, malabar civet, hornbills, water fowl, and mugger crocodiles protected in these regions. The choices in Rodgers and Panwar (24) are based on a subjective evaluation of known factors such as size, diversity of habitat, presence of rare species, long-term viability, degree of disturbance, threat, and ease of establishment. Rodgers and Panwar (24) acknowledge the disadvantage of this method in that no attempt is made to quantify the importance of these factors and suggest the alternative of an objective, quantitative scoring of a set of specific parameters. However, as they rightly point out no method would be perfect as the choice of the set of factors and their scoring in the suggested alternative would be subjective as well.

Thus, although it is not possible to have a completely quantitative scoring system, the present study has attempted to use a spatial analysis approach to provide biologically meaningful and logistically feasible conservation alternatives. Ideally, gap analysis should be carried out on a larger area such as the entire country or the entire Western Ghats in order to assess the distribution and extent of vegetation types and other indicators of biodiversity and the gaps in their representation within the existing protected area network. This study attempts to illustrate the possibilities of a vegetation-based gap analysis approach toward effective biodiversity conservation at a micro- or regional level. Detailed information such as zones of endemism and species richness may not be available or easily obtained for large areas thus justifying studies at local/regional levels. We recommend continuous monitoring of the patchiness of vegetation and the biodiversity within protected areas and the development of detailed spatial information for the management of biodiversity.

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B. R. Ramesh is a scientist at the French Institute, Pondicherry. His main fields of interest are forest ecology and mapping of vegetation and species distribution. His address: French Institute, PB 33, Pondicherry, 605001, India.

Shaily Menon is a research associate at the University of Massachusetts, Boston with research interests in biodiversity conservation and applications of GIS in conservation biology. Her address: Department of Biology, University of Massachusetts/Boston, 100 Morrissey Blvd., Boston, MA 02125, USA.

Kamaljit S. Bawa is a professor in the Department of Biology, University of Massachusetts, Boston. His research interests include conservation of biodiversity, ecology and economics of nontimber forest products, and population biology of tropical forest trees. His address: Department of Biology, University of Massachusetts/Boston, 100 Morrissey Blvd., Boston, MA 02125, USA.