Does forest type classification reflect spatial dynamics of vegetation? An analysis using GIS techniques

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The existing methods of classification of forest vegetation rely more on the structure and composition of tree vegetation with little information derived from other layers. We suggest that any classificatory process of forest vegetation should consider the spatial dynamics of all the three layers namely, tree, shrub and herb. In this paper we have attempted to offer an objective method of classifying the vegetation at all the three layers utilizing GIS and multivariate statistical tools. Unlike the existing techniques, our method views the forest as a continuously changing mosaic of vegetation and not as an assemblage of discrete patches. Our study suggests that understanding the spatial dynamics of vegetation at one layer may not reflect that at others. Further, as an alternate to the existing methods, we also develop a continuum map of biodiversity of the forest that offers the conservation value of each patch, an element that is not conveyed in the existing classificatory processes.

THE classification of forest and forest ecosystem is a primary requirement for managing forest resources. Historically, forests were being classified on the basis of canopy structure and composition, dominant species of vegetation, topographic and soil features depending on the user groups. There have been several attempts to develop generalized techniques to classify forests of India[1,2] and that of the whole world[3,4], based on vegetation and climate. Recent studies have adopted these methods, often with certain modifications.

These generalized classifications are mostly based on the structure and composition of the canopy layer with little emphasis on those at the shrub and herb layers and aim at a broad scale classification of forests. Consequently, these classifications may not reflect the spatial dynamics of vegetation at lower layers. Further, they fail to identify small scale vegetation heterogeneity and demarcate forests into large discrete units that are assumed to be internally homogeneous. In other words, these classifications imply that forest ecosystems are an assemblage of discrete types that are homogenous at all layers. Though there are few attempts such as Braun Blanquet[5] system that classifies forest vegetation based on the units of vegetation association, these methods are mostly judgement-based and do not incorporate the information on the species in proportion to their relative abundance at different layers; rare species that might otherwise be very important in forest structure and functioning are seldom considered in these classifications.

Here we report an approach we followed to classify the vegetation at BRT Sanctuary, Chamarajanagar District, Karnataka. Using Geographical Information System (GIS) and multivariate statistical tools we have attempted to arrive at an objective classificatory method that considers the local heterogeneity and the composition of species at tree, shrub and herb layers with an emphasis that any classification process should reflect the dynamic interactions and associations among species at different layers of vegetation.

Another drawback of the existing methods is that they do not reflect the biodiversity value of forests, an important component for the management and conservation of the forests. A few studies which did attempt to construct conservation value maps of the forests using the species richness, also treated forest ecosystems as assemblages of patches of discrete conservation values[6,7]. But the conservation value of a forest is more likely to be a gradually changing parameter than an abruptly shifting mosaic across space. We have therefore attempted to develop a continuum picture of the forests based on biological diversity of different layers.

BRT Wildlife Sanctuary is located in Mysore district (77°–77°16′E and 11°47′–12°9′N) with an area of 540 km^2. The forest types of BR Hills can be broadly categorized into five types[8] (Figure 1 *a*): deciduous forest (61.1%), scrub jungle (28.2%), evergreen forest (6.5%), savanna (3.4%) and shola (0.8%, high altitude stunted montane cloud forest) which together contain over 800 species of plants including trees, shrubs and herbs[8–11]. The terrain is highly undulating with 600 m above mean sea level (MSL) at plains of Yelandur, Kollegal and Chamarajnagar to 1800 m above MSL at Honnameti and Seematti peaks. The sanctuary harbours several large

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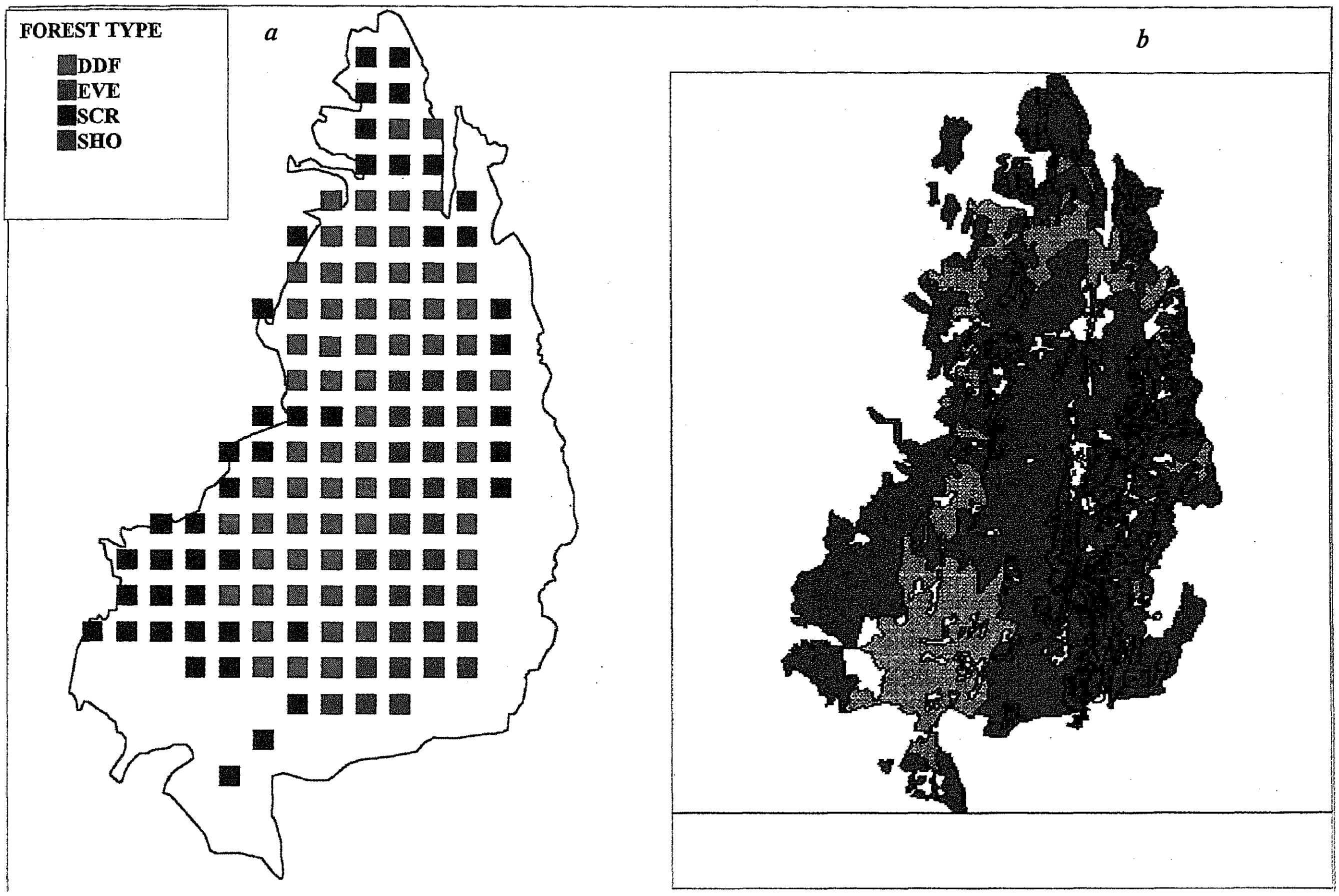

Figure 1 *a*. The study site and the location of grids within the BRT sanctuary. The sampling sites were located in the centre of each grid. Note that in predominantly agricultural areas, the sampling was not done. The colours of the grids indicate the type of forest vegetation referred to in the legend box: SCR = Scrub; DDF = Dry deciduous forests; EVE = Evergreen forests; SHO = Sholas. The inset is the vegetation map prepared from the thematic maps (interpreted from the aerial photographs; courtesy FSI and our own data from several sources). The colours of these map correspond fairly spatially to the forest types of the grids.

mammals like elephant, tiger, panther, gaur, sloth bear, spotted deer, sambar and barking deer. The forests are inhabited by an indigenous, hunter-gatherer and shifting-cultivator tribe called 'Soligas'.

Methods

Data gathering

Entire BRT sanctuary was divided into 155 grids of 2 × 2 km (Figure 1 *a*). In each of these grids the mid point was chosen, the latitude and longitude were recorded, the forest type as per UNESCO classification was noted and a rectangular transect measuring 80 m long and 5 m wide was laid. The sampled area thus constitutes only 0.01% of the sanctuary. All the stems in the range 1–10 cm, and > 10 cm DBH were enumerated and their specific name recorded. Four transects of 1.0 × 1.0 m were laid in the corners of the rectangular transect and all seedlings and herbs in them were recorded. For the present analysis 21 grids falling in agricultural areas were removed.

Mapping and classification of grids

All the grids were mapped and classified into four forest types, viz. scrub, deciduous, evergreen and shola based on (a) their vegetation composition and UNESCO method of classification, and (b) their spatial correspondence with the vegetation map prepared by French Institute and by us (Figure 1 *a*). Using the species frequency data at tree, shrub and herb layers squared euclidean distances were obtained for all pairs of combination of grids and dendrograms constructed using minimum variance technique. Grids were grouped into 8–10 clusters using similar cut-off points for all the three layers. However to facilitate comparison with four forest types, they were further grouped into four clusters based on the dendrograms. Thematic maps were developed for forest type of grids and the vegetation clusters formed at three layers. The correspondence between the forest vegetation classification and multivariate clustering technique was tested using contingency χ^2 for the independence of different categories[7]. For this a contingency χ^2 table was setup with columns of forest types and rows of vegetation clusters. The number of grids in each cell corresponding to each of the combination of

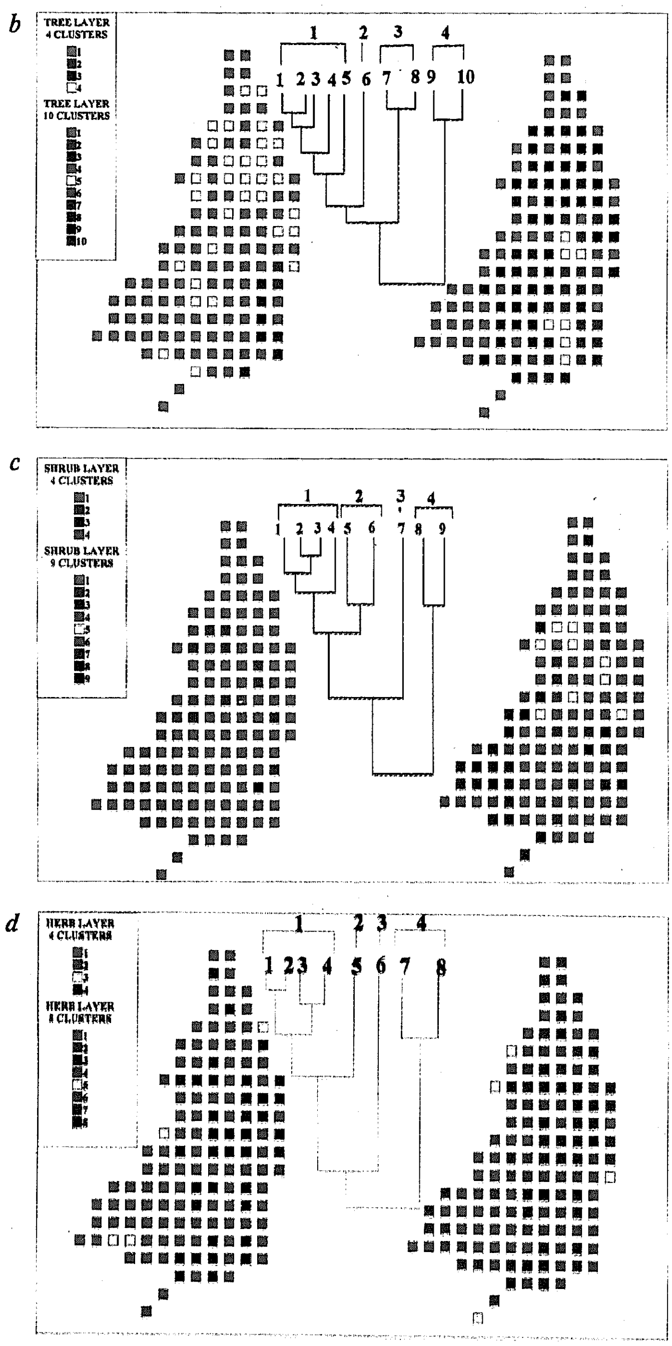

Figure 1 *b–d.* Thematic maps of the vegetation clusters of tree (*b*), shrub (*c*) and herb (*d*) layers. The map on the left in each figure represents the four vegetation clusters while that on the right represents 8–10 vegetation clusters formed based on the vegetation composition of the respective layers. The dendrogram in the middle shows a relative separation (similarity) among the clusters.

forest type and vegetation clusters were counted and contingency χ^2 value computed.

Mapping diversity

The Shannon–Weiner index values were computed for each grid separately for three layers. Using ESRI 3-D mapper for MAPINFO program, an elevation model depicting diversity index of grids was constructed. Taxonomic Avalanche Index (AI_t) was computed for tree and shrub layers using the formula given below[12].

$$AI_t = \sum_{i=1}^{n} \sum_{j=1}^{n} p_i \cdot d_{ij} \cdot p_j,$$

where p_i and p_j are frequencies of *i*th and *j*th species and d_{ij} is the taxonomic distance between *i*th and *j*th species. Taxonomic distance was considered 1 if *i* and *j* are two species belonging to same genus, 2 if they differed at genus, 3 if they differed at family, 4 if they differed at order, 5 if they differed at subclass level and 6 if they differed at class level. Avalanche index for herb layer could not be computed because taxonomic identity of some species could not yet be ascertained.

Results and discussion

Are forest types distinct and spatially discrete? The percolation effect

We tested the correspondence of forest types with the similar number of clusters formed based on the vegetation composition of grids (Figure 1 *a, b, c, d*). Clusters based on the vegetation did show a great degree of correspondence with the forest types. The assortment of grids into different vegetation clusters at tree and shrub layer was dependent on forest type (contingency χ^2 for trees = 46.2, $p < 0.01$; for shrubs = 37, $p < 0.01$). However, at the herb layer, the grids assorted into vegetation clusters independent of their forest type (contingency $\chi^2 = 1.68$, NS). Most of the scrub forest, for instance, contained vegetation type of clusters I and IV (Figure 1 *a; b*) that represent dominance of *Anogeissus latifolia* and *Chloroxylon swietenia* species (Table 1). Thus clusters I and IV of tree vegetation can be considered as scrub vegetation-dominant cluster. Such dominance of specific vegetation clusters in a forest type could be identified for other layers of vegetation as well. However, these signal clusters of a specific vegetation type percolated often substantially into areas otherwise assigned to other forest types. For instance, tree vegetation of cluster I was found in the areas of dry deciduous and also in evergreen patches. Similarly vegetation type of cluster I of shrub layer dominant in dry deciduous and scrub forest was also found in evergreen and shola patches.

At the herb layer, the vegetation composition of different forest types was more overlapping; vegetation of both clusters I and IV, for instance, was found in all the four forest types. This percolation effect is more evident from the association of frequency of species among the forest types and vegetation clusters (Table 2). Thus the forest types neither appear to be very distinct in their composition nor are they spatially discrete. There is a process of percolation of certain components of vegetation of a given forest type into others and the extent and intensity of this percolation differ at different layers. This is also evident from the degree of similarity among the four forest types (Table 3).

The prevailing classification methods obviously have recognized these problems and for this reason the forest types are further sub-divided into a number of subtypes in order to accommodate the variations within each. But such a subdivision has become more subjective and could never be an exhaustive process. Especially, at small spatial scales, the vegetation composition could always exhibit local heterogeneity such that the generalized classification becomes futile for local management of forest resources.

Percolation of a specific vegetation complex (cluster) of a given forest type to other areas was visible even when we classified grids into more number of clusters (compare the right side diagram of Figure 1 *b*, *c*, *d* with the forest types in Figure 1 *a*). We have assessed this by the similarity (correlation) between the forest type and clusters in the frequency of different species in them. The frequency of species of scrub forest showed significant association with those of cluster 1 and 3 of tree vegetation (Table 2). These clusters also showed significant similarity in their species composition with dry deciduous forest. Similarly vegetation type of cluster 1 of shrub layer showed strong association with that of scrub and dry deciduous forests and also of evergreen patches. Thus it appears that the forest at BRT is not a canvas of discrete vegetation types with abrupt spatial transition occurring among them and that the local heterogeneity in vegetation composition occurs much more frequently than implied by forest type categories.

Does tree vegetation reflect spatial dynamics?

Our results suggest that spatial structuring of tree vegetation need not always reflect the shrub and herb layers.

Table 1. Species composition (only 10 dominant species shown here) of different forest types of BR hills

Deciduous forest		Evergreen forest	
Species	Density per ha.	Species	Density per ha.
Anogeissus latifolia	114.11	*Persea macrantha*	79.76
Terminalia crenulata	47.98	*Litsea deccanensis*	64.29
Emblica officinalis	33.47	*Syzigium cumini*	47.62
Kydia calycina	28.22	*Verpis bilocularis*	35.71
Grewia telaefolia	21.37	*Xeromphis spinosa*	35.71
Pterocarpus marsupium	14.92	*Bischofia javanica*	29.76
Xeromphis spinosa	12.10	*Mallotus philippinensis*	26.19
Ougenia ogenensis	9.27	*Viburnum punctatum*	25
Tectona grandis	8.87	*Cinnamomum zeylanica*	23.81
Dalbergia latifolia	8.06	*Basella alba*	23.81
Avalanche index	3.73	Avalanche index	3.75
Range	0–4.93	Range	0–5.03
Shannon–Weiner index	0.73	Shannon–Weiner index	0.8
Range	0–1.26	Range	0–1.17
Scrub forest		Shola forest	
Anogeissus latifolia	37.80	*Cinnamomum zeylanicum*	121.88
Chloroxylon swietenia	9.88	*Litsea deccanensis*	59.38
Dalbergia lanceolaria	8.14	*Flaucourtia indica*	59.38
Strychnos potatorum	8.14	*Wendlandia thyrosa*	59.38
Emblica officinalis	4.65	*Syzigium cumini*	46.88
Cassine paniculata	4.07	*Actinodaphnae* sp.	40.63
Bowsalia serrata	4.07	*Mallotus phillipinensis*	31.25
Flaucourtia indica	4.07	*Litsea* sp.	31.25
Erythroxylon monogynum	3.49	*Persea macrantha*	31.25
Tectona grandis	3.49	*Ligustrum parrotti*	25.00
Avalanche index	2.25	Avalanche index	3.95
Range	0–4.48	Range	0–4.43
Shannon–Weiner index	0.36	Shannon–Weiner index	0.87
Range	0–1	Range	0.6–1.08

Table 2. Correlation between the species frequency of different forest types and the clusters formed using multivariate statistics. Values in parentheses indicate the sample size

	Scrub		Deciduous		Evergreen		Shola	
Cluster	Level I	Level II	Level I	Level II	Level I	Level II	Level I	Level II
Trees								
1	0.81(48)		0.47(95)		−0.18(104)		−0.27(84)	
2	−0.17(103)		−0.06(121)		0.83(81)		0.52(77)	
3	0.44(63)	0.40(121)	0.84(84)	0.73(133)	0.04(92)	0.49(121)	−0.18(70)	0.18(121)
4	0.08(61)		0.30(84)		−0.03(80)		−0.11(61)	
5	−0.15(66)		0.004(96)		0.78(74)		0.21(53)	
6	−0.09(50)	−0.09(50)	0.05(85)	0.05(85)	−0.02(76)	−0.02(76)	0.26(53)	0.26(53)
7	−0.17(62)	−0.16(68)	−0.10(96)	−0.10(98)	0.44(75)	0.67(75)	0.9(46)	0.78(50)
8	−0.14(61)		−0.08(93)		0.75(74)		0.49(50)	
9	0.87(77)	0.87(80)	0.94(88)	0.94(88)	−0.04(115)	−0.04(113)	0.49(50)	−0.08(99)
10	0.85(51)		0.92(84)		−0.07(83)		−0.13(62)	
Shrubs								
1	0.267(172)		0.68(168)		0.48(153)		0.09(151)	
2	−0.02(129)		0.24(133)		0.64(95)		0.21(80)	0.25(184)
3	−0.05(118)	0.77(189)	–	0.78(187)	0.62(86)	0.46(185)	0.86(66)	
4	0.95(106)		0.025(134)		−0.07(159)		−0.04(144)	
5	0.08(123)	0.09(123)	0.69(124)	0.70(124)	0.15(112)	0.154(112)	−0.05(103)	−0.05(104)
6	0.06(93)		0.39(118)		0.08(89)		−0.03(67)	
7	−0.02(102)	−0.02(102)	−0.04(125)	−0.04(125)	0.34(89)	0.34(89)	0.93(63)	0.93(63)
8	0.99(96)	0.99(96)	0.59(130)	0.59(141)	−0.06(132)	−0.02(141)	−0.04(117)	−0.04(121)
9	0.98(92)		0.59(124)		−0.06(112)		−0.05(90)	
Herbs								
1	0.88(182)		0.28(241)		−0.01(190)		−0.02(176)	
2	0.65(167)	0.93(290)	0.36(239)	0.68(285)	0.07(179)	0.37(273)	0.07(165)	0.36(274)
3	0.13(173)		0.49(219)		0.21(126)		0.18(111)	
4	0.33(266)		0.91(253)		0.94(197)		0.93(197)	
5	0.56(154)	0.56(154)	0.21(233)	0.21(233)	0.08(141)	0.08(141)	0.09(122)	0.09(122)
6	0.87(154)	0.87(154)	0.23(226)	0.23(226)	−0.02(121)	−0.02(121)	−0.03(106)	−0.03(106)
7	0.47(164)	0.41(234)	0.91(223)	0.92(246)	0.96(133)	0.98(195)	0.92(119)	0.93(199)
8	0.39(233)		0.91(244)		0.98(187)		0.94(191)	

Table 3. Similarity among the vegetation types. The values are correlation coefficients for the frequency of species at the tree, shrub and herb layers respectively. The numbers in the parentheses are n values

	Deciduous	Evergreen	Shola
Scrub	0.76(96)	−0.12(120)	−0.17(80)
Tree	0.61(151)	−0.04(157)	−0.04(142)
Shrub	0.56(270)	−0.02(215)	−0.03(202)
Herb			
Deciduous	–	−0.02(120)	−0.08(105)
Tree	–	0.17(160)	−0.01(148)
Shrub	–	0.87(243)	0.04(202)
Herb			
Evergreen	–	–	0.49(82)
Tree	–	–	0.50(101)
Shrub	–	–	0.96(128)
Herb			

Table 4. Correspondence among clusters formed at different layers. The values in each cell are the χ^2 values. The values in parentheses indicate degrees of freedom

	Shrub layer	Herb layer
Tree layer	153.87(72)*	90.46(63)
Shrub layer		113.79(56)*

*Indicates significance at $p < 0.05$.

Clusters based on tree vegetation showed correspondence with those based on shrub but were independent of those at herb layer (Table 4). Herb layer showed a greater spatial homogeneity than shrub and tree layers. In fact, the distribution of vegetation composition of herb layer occurred entirely independent of both the forest types and tree layer composition. Thus it appears that existing classificatory methods typifying the forests

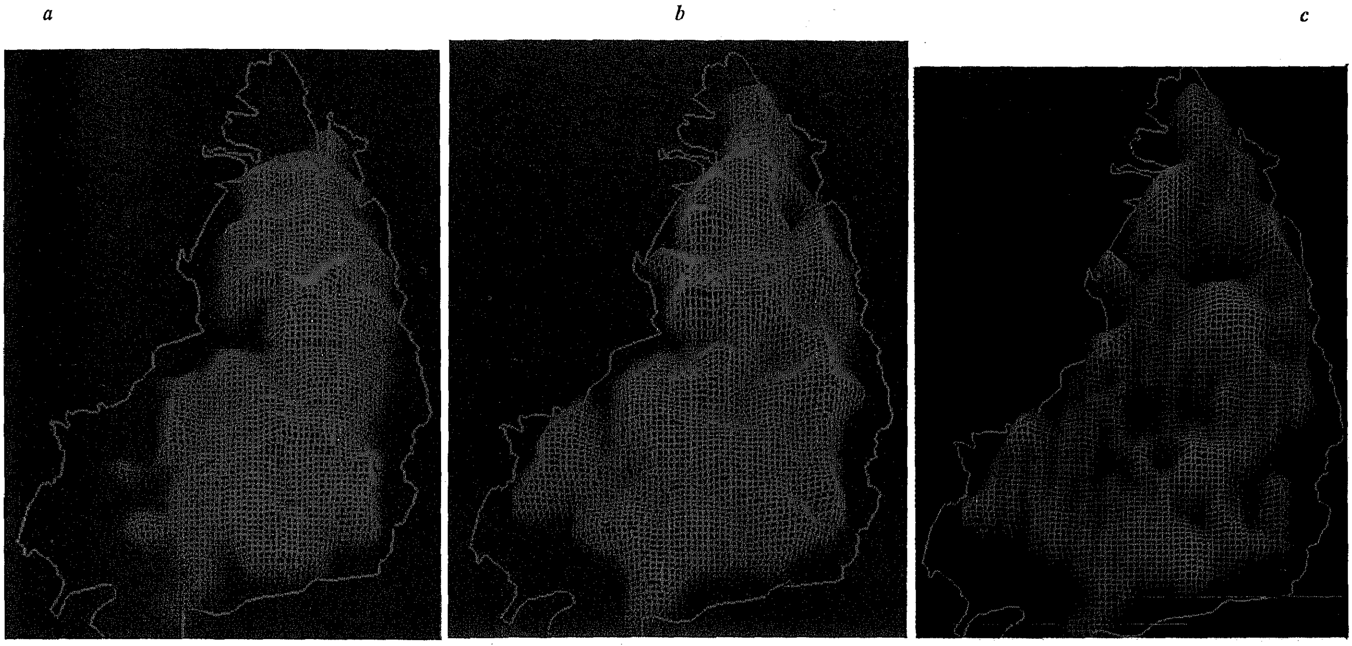

Figure 2 *a–c*. 3-D maps of the Shannon–Weiner index values of tree (*a*), shrub (*b*) and herb (*c*) layers at BRT. 3-D maps were developed based on the contours extrapolated from the diversity index values at each sampling point. The elevations are only relative within each map.

Table 5. Correlation among the diversity indices (Avalanche and Shannon–Weiner indices) of tree, shrub and herb layers ($n = 134$). The Avalanche index values for herb layer were not computed and hence the corresponding correlation values are not provided

	Shannon index (tree)	Shannon index (shrub)	Shannon index (herb)	Avalanche index (shrub)
Shannon index (tree)		0.08	0.33*	0.04
Shannon index (shrub)			0.13	0.87*
Shannon index (herb)				0.11
Avalanche index (tree)	0.89*	0.02	0.28*	0.04

*Significant at $p < 0.05$.

have limited value in understanding the spatial dynamics of vegetation at different layers and, understanding the vegetation dynamics at one of the layers namely, tree or shrub or herb need not reflect that in other layers. For this reason, we propose that forests need to be mapped based on the vegetation composition at all the three layers. A comprehensive picture of spatial dynamics of forest vegetation could emerge only when we have maps of vegetation at all these layers.

Mapping diversity. (i) *Species diversity distribution*. The spatial distribution of species diversity (Shannon–Weiner index) was not strongly linked to the forest types. At tree level, though the species diversity was greater along evergreen and shola patches, parts of deciduous and scrub forests also showed high diversity (Figure 2 *a*). At shrub layer, the correspondence was much weaker (Figure 2 *b*). Certain grids in the scrub patch showed almost and often more species diversity than the evergreen patches. The lack of association between forest type and the diversity of a grid was more apparent in the herb layer diversity map (Figure 2 *c*). Thus classifying forests on the basis of species diversity might offer an entirely different picture of the forests (Figure 2 *a–c*). It helps recognizing that unlike implied in the classical forest classifications diversity of forests is continuous and spatial variation occur independent of forest types. Further, there was a poor correlation among species diversity of the three layers (Table 5), suggesting that our understanding of any of these layers might be of limited value in reflecting the diversity at other layers.

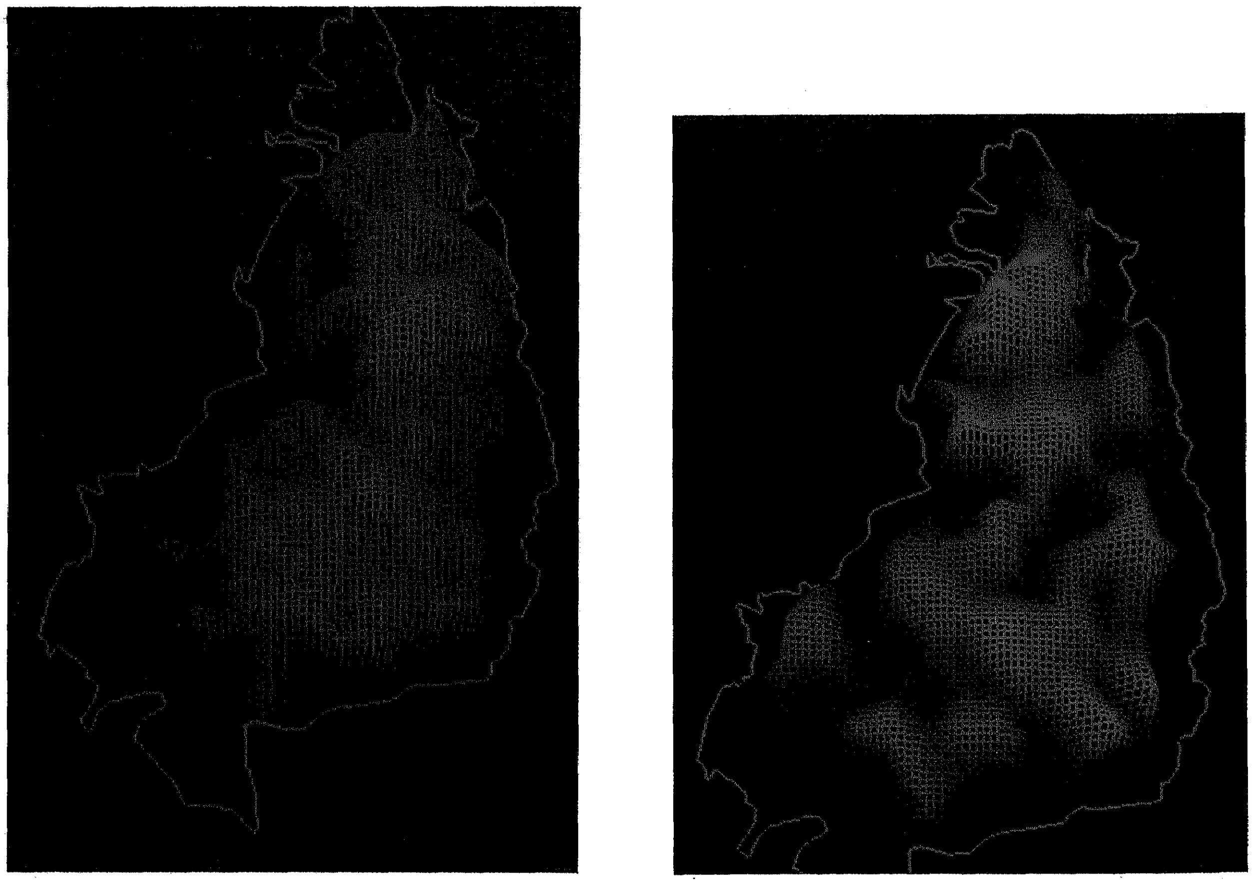

Figure 3 *a–b*. 3-D maps of the Avalanche index values of tree (*a*) and shrub (*b*) layers at BRT. 3-D maps were developed based on the contours extrapolated from the Avalanche index values at each sampling point. The elevations are only relative within each map.

(ii) *Taxonomic diversity distribution*. In addition to species richness and frequency, Avalanche index considers the taxonomic distance among species as well. In this sense it offers information on taxonomic diversity. The Avalanche index distribution of BR hills followed almost similar pattern as that seen for species diversity (Figure 3 *a*, *b*). This is because the two were highly correlated at both tree (0.891) and shrub (0.87) layers. Though the taxonomic diversity was high along the evergreen and shola patches, certain patches of scrub and deciduous forests showed more taxonomic diversity than evergreen vegetation. This may be because though the scrub and deciduous patches may not be as species-rich as the evergreen are, certain areas have species from a wider taxonomic groups. This enhances their taxonomic diversity and probably for this reason, often other studies have suggested that scrub and deciduous forests are taxonomically as diverse as certain evergreen patches are (Ganeshaiah *et al.*, ms in preparation).

Thus species and taxonomic diversity can be more profitably used to develop a continuum map of forest vegetation. Taxonomic diversity map in particular can combine the data on diverse groups of organisms such as flora, fauna and micro-organisms and in this sense these diversity maps offer more meaningful spatial perspective of forest, that are no more dependent only on vegetation. Such maps also reflect the conservation value of the forest, view the forest as a continuum of changing biota, and recognize local heterogeneity. In this sense, construction of conservation maps as done here would offer spatially a better perspective than those suggested earlier[6,7]. However, suitable algorithms need to be developed for such a purpose.

Conclusions

Traditional methods of classifying the forests imply that forest can be viewed as an assemblage of discrete types and that the spatial transition from one type to the other occurs abruptly. In other words, forests are viewed as jig-saw puzzles. Though such borders between forest types are more for convenience than to represent the ground reality, unfortunately, resource management practices do not recognize this limitation. Recognizing these difficulties, different methods are suggested to classify forest vegetation based on dominant species and 'associations' amongst species. All such attempts essentially underline a need to develop better techniques of forest classification that are both objective and recognize the continuous change in species composition.

Our work suggests that with the new tools of mapping and multivariate statistics, it should be possible to develop forest vegetation clusters at different layers namely tree, shrub and herb. The resolution of such maps of course, would be an inverse function of the scale at which the data on vegetation composition could be gathered. In any case, such a classification based on the hierarchical clustering of the sampling sites offers information that could be used for diverse purposes. In fact, accompanying a forest map with dendrograms of forest vegetation clusters could become a regular practice of packaging the maps. Such packages with dendrogram offer the users certain liberty to classify the forest and develop maps to the desired level of complexity. In this sense, they retain the simplicity of the existing methods but also offer detail spatial dynamics of vegetation when required. Such packages should now be possible with the recent developments in statistical techniques and associated computer technology to use them. Our work also suggests that mapping the diversity of forest ecosystem could be a novel and useful way of viewing the forest vegetation. The diversity maps help in formulating conservation plans for the forest ecosystems.

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MEETINGS/SYMPOSIA/SEMINARS

International Conference on Environment and Bioethics

Date: 14–16 January 1999
Place: Chennai

Topics include: Health ethics and environment; Biodiversity and environment; Philosophy of environment ethics; Bioethics and bioresources; Bioethics and education.

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Symposium on Biomonitoring and Ecoconservation

Date: 14–16 November 1998
Place: Bareilly

Topics include: Biodiversity and ecoconservation; Toxicology – Animals, plants and men; Case studies – Impact assessment and environmental health; Waste utilization and recycling; Immunosuppressant and immunotoxicology; Impact of hazardous chemicals on the ecosystem; Environmental biotechnology.

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