Linking regional and landscape scales for assessing biodiversity: A case study from Western Ghats

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A broad scale classification of the Western Ghats into different types of landscapes will be a useful first step towards biodiversity assessment. Such a classification, coupled with point sampling in different landscape types could allow for efficient extrapolation of information to arrive at an estimate of the status of biodiversity in the Western Ghats as a whole. This paper attempts such a broad-scale mapping (at a 1 : 1,000,000 scale) of the Western Ghats into different landscape types, using IRS 1B imagery. For this purpose, we use the Normalized Difference Vegetation Index (NDVI) which reduces problems of scene-to-scene radiometric variability. This index is believed to be correlated to vegetation biomass, vigour, photosynthetic activity and leaf area index – and is potentially useful for classifying different types of vegetation. Our attempt is to classify at the scale of the landscapes, and not at the level of individual landscape elements (LSEs). Each landscape is a mosaic of different LSE types, and the relative distribution of these different types determines the composition of the landscape. The distribution of NDVI values was therefore taken as the basis for classification. For each 50 by 50 pixel unit constituting a 'superpixel', the four moments of distribution – mean, standard deviation, skew and kurtosis – were calculated. These superpixels were then clustered using unsupervised classification. Small patches were merged with the most dominant LSE type in the vicinity, to obtain a final set of 205 patches belonging to eleven types of landscapes. We interpret the distribution of these eleven types in terms of topography, climate, population, agriculture and vegetation cover.

INVENTORYING biodiversity and monitoring efficacy of measures for its conservation have emerged as important scientific challenges of recent years. These are also commitments for India and over 160 other countries worldwide that are parties to the Convention on Biological Diversity[1]. These are enormous tasks given the vastness of our country with its 320 million ha of landmass and 200 million ha of exclusive economic zone in the sea, the great variety of its environmental regimes, and the diversity of its 125,000 described and an estimated 400,000 as yet undescribed species of living organisms. Obviously, it would be essential to take recourse to sampling, especially in relation to periodic monitoring of changes in biodiversity to assess the efficacy of conservation measures. This is also the recommendation of the major review of the subject, the Global Biodiversity Assessment (GBA) commissioned to provide the background for launching a global effort at inventorying, monitoring, conservation and sustainable utilization of biodiversity[2]. GBA suggests that monitoring would have to be based on broad scale sampling employing remote sensing and measures at the level of the biotope and the landscape, in conjunction with point-sampling at a representative selection of localized sampling points. Data from a series of points, coupled to remote sensing should then provide information that can be extrapolated for global coverage.

We have been involved in organizing such a programme of monitoring biodiversity by combining remote sensing and field sampling approaches for the Western Ghats region of peninsular India[3]. This region comprises a mountain range running parallel to the west coast of India from 8°N to 21°N latitudes for a distance of around 1600 km. Along with a relatively narrow coastal strip, the hills that rise up to a height of 2800 m before merging to the east with the Deccan plateau at an altitude of 500–600 m, have an average width of 10[illegible] km. Biogeographically it constitutes the Malabar province of the Oriental realm, and is considered one of the 1[illegible] biodiversity hot spots of the world[4]. The challenge before us is the periodic monitoring of biodiversity of this region of about 170,000 km^2 extent.

Since the point-sampling of biodiversity would have to be based on sampling of quadrats of the order of m^2 in size, we have to traverse a total of 11 orders of magnitude to link regional level broad scale sampling with field level point sampling. The spatial scale at which remote sensing information is readily available is 10^3 m^2; this is the size of the pixel for IRS 1B-LISS [illegible] imagery with a resolution of 36.5 m × 36.5 m (ref. 5). This is the lower end of the spatial scale of individual patches covered with relatively homogeneous vegetation[illegible]

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Our programme of biodiversity assessment on the Western Ghats combined field sampling in quadrats ranging in size from 1 to 100 m^2 with mapping the coverage of different types of landscape elements in landscapes of the order of 25 km^2 (refs 7, 8). However, there is still a gap of 4 orders of magnitude, from 10^7 to 10^{11} m^2 while going from these landscapes to the Western Ghats region. Extrapolation from the scale of landscapes of 25 km^2 or so, to the region of 170,000 km^2 thus calls for definition of strata for sampling at one (or more) intermediate scales. We therefore propose defining for the Western Ghats region landscape types whose elements would be patches of the minimum size of 100 km^2. This would complement investigations of landscapes of sizes of about 25 km^2 with landscape elements with a minimum size of 1 ha, or 10 pixels of IRS 1B imagery. These intermediate strata would thus be four orders of magnitude larger; an appropriate choice for bridging a gap of four orders of magnitude. This paper then reports our investigations aimed at stratifying the Western Ghats region into around 200 patches with a minimal size of about 100 km^2 and an average size of about 1000 km^2. We end up assigning these patches to 11 distinct landscape types.

Materials and methods

Our exercise is based on the relatively inexpensive imagery generated by the Indian remote sensing satellites supplied by the National Remote Sensing Agency, Hyderabad. Images of the Western Ghats were obtained from the IRS 1B LISS 2 sensors. These images were taken in the pre-monsoon period, ranging from mid-February to mid-June, when the deciduous trees are leafless and chances of separating deciduous from evergreen forests is maximum[9]. Each LISS 2 scene covers 87 km by 74 km in area[5]. However, each scene overlaps with its neighbouring scenes, to varying extents, and hence the total effective area covered by a scene is less. A total of fifty such LISS 2 scenes covered the entire west coast, the Western Ghats as well as its foothills to the eastern side.

We did not procure multi-date data, as the expenses involved would have been too high; purchasing these 50 scenes cost us Rs 4000 per scene in 1994. While devising a methodology which can be applied on a wide scale, cost is a consideration to be taken into account. In addition to the cost factor, errors due to misregistration of scenes of the same area taken on different dates can be rather high. This may be solved only by carrying out geometric correction of the data, which would be excessively time-consuming when 50 images are involved. Due to these reasons, we selected single season (pre-monsoon) imagery for our studies.

These data were purchased in September 1994. All possible efforts were made to purchase the most recent images, i.e. those of 1994. However, persistent cloud cover often obscures the underlying areas and hence the probability of acquiring cloud-free images in the pre-monsoon period is low. For some scenes, therefore, cloud-free data of 1994 were not available and data of 1993 had to be used – in a few unavoidable cases, data of 1992 also. Of course, this means that consistent data from one year covering the entire region are not available. This is a real problem faced by investigators studying most of Southern Asia[10]. It may not however be very serious, as the landscape at a broader scale would not have changed drastically in a period of three years following the promulgation of Forest Conservation Act in 1980 (ref. 11).

From this aggregate set of fifty scenes covering the west coast, the Western Ghats as well as its foothills to the east, amounting to a total area of 170,000 km^2, we attempt to obtain information about distribution of landscape types. We face several problems in such an endeavour. The radiance measured by a remote sensor over an object is influenced not only by the interaction of that object with the incoming radiation but also by several other factors which will not stay constant from scene-to-scene, such as changes in scene illumination, atmospheric and solar conditions[12]. Because of this scene to scene variability training site data of one scene cannot be directly extended to classify another scene. Even within a scene, since the land is topographically highly variant, several training sites need to be defined[13].

Similarly, unsupervised classification of the entire data cannot be effective since classes output from one scene cannot be related to those from another. This is because a class defined by mean and variance–covariance vectors in the four-dimensional space of reflectances in one scene may correspond to a totally different type in another scene, yet exhibit the same or highly similar reflectances. Of course, these are problems which have been dealt with extensively in previous studies, which have been carried out with the intention of mapping large areas using multi-scene data. Several radiometric correction models have been proposed to improve scene-to-scene comparability[14]. These however require prior knowledge of the atmospheric and solar conditions at the time of data collection, knowledge which is not always reliably available.

The other method used to normalize data from scene to scene is the use of vegetation indices, which are believed to be correlated with leaf area index, green leaf biomass and plant photosynthetic capability[12]. The most commonly used index for vegetation studies is the Normalized Difference Vegetation Index (NDVI). The NDVI is calculated as $IR - R/IR + R$, where IR is the infrared reflectance and R the red band reflectance. It is believed to largely eliminate the scene-to-scene differences arising out of solar–target–sensor variations in geometry. The NDVI has been widely used the world over for global land cover mapping over large areas, especially with the NOAA/AVHRR sensors[15]. Errors due to atmospheric variability for the NOAA/AVHRR data have been estimated to be less than ± 10% (ref. 16). These NOAA data are, however, of coarse spatial resolution (more than 1.1 km per pixel), and may not provide correct estimations of land cover of various types. Each pixel is more likely to contain a mixture of several land cover types and should therefore be more properly interpreted as such[17,18].

The data available with us, in contrast, had a resolution of 36.5 m by 36.5 m, much higher than that of the NOAA–AVHRR. This meant that each of our scenes was covered by 5.75×10^6 pixels – of which a part may be covered by sea, but the rest was still a large number – too large to use as a basis of classification when 50 scenes are involved. Pixel size, therefore, needed to be increased by merging adjacent pixels and thus decreasing resolution. For this purpose we decided to merge 50 pixel by 50 pixel adjacent units so that we obtained larger-scale pixels, or superpixels, of the resolution of 1.8 km. For each such superpixel, the average NDVI of all the 2500 pixels it contains is calculated.

However, each of these larger superpixels was actually composed of 2500 smaller pixels, and information about the structure and pattern of the landscape it covers, 1.8 by 1.8 km^2, is contained in the pattern of distribution of these 2500 values – information that would not be available while using only low-resolution imagery, like NOAA imagery. Therefore, in addition to the mean, the remaining three moments of distribution – standard deviation, skew and kurtosis – which also describe the distribution of these 2500 values, were calculated for these superpixels. Each superpixel was therefore characterized by four values, which describe the distribution of NDVI values of all the 2500 pixels which it contains.

These LISS 2 scenes overlap to some extent, in order to allow for shifting of position of the image, which often happens. The details of the overlap were taken from Kasturirangan *et al.*[5]. It has been our personal experience that, at the outside, errors in positioning do not exceed 20–30 km, i.e. around 10–15 superpixels, and since we had a total of more than 50,000 superpixels, we assumed that mispositioning of scenes could be ignored. For all LISS 2 scenes then, assuming no mispositioning of images, overlapping segments were removed from the borders of the scenes and the scenes which fall under a single path were joined vertically.

A total of seven paths were present in the data purchased. For each of these paths, its position with respect to its neighbours is not known. This was manually ascertained by identifying an easily discernible landmark such as a river on images belonging to two adjacent paths, the paths were then joined together at such points. By this process, a composite vegetation index map of the entire west coast of India, the Western Ghats and its foothills was obtained.

These data contained several pixels which covered sea areas, which were to be removed. From a visual display of the data, it was seen that all sea water superpixels had mean NDVI values of less than – 0.1, whereas almost all land superpixels had mean NDVI values greater than – 0.1. All superpixels with NDVI means less than – 0.1 were therefore omitted from further analysis. There were a remaining 51,834 superpixels, covering about 170,000 km^2, which were then classified using the GRASS 4.1 software as described below[19].

To begin with, all data with NDVI means less than – 0.1 were masked out (i.e. excluded from further analysis) in GRASS. The remaining land superpixels, each described by four values (mean, standard deviation, skew and kurtosis of 2500 pixel NDVIs), were then subjected to unsupervised classification. The procedure followed thus used the values of these four moments as equivalent to values of reflectances in four bands. The classification algorithm, specified in the GRASS 4.1.5 software, uses input parameters set by the user on the initial number of clusters, the minimum distance between clusters, and the correspondence between iterations which is desired.

Initial cluster means for each band are defined by giving the first cluster a value equal to the band mean minus its standard deviation, and the last cluster a value equal to the band mean plus its standard deviation, with all other cluster means distributed equally spaced in between these. The first pass through the clustering algorithm then assigns each pixel to the class which it is closest to, distance being measured as Euclidean distance. All clusters less than the user-specified minimum distance are then merged. New cluster means are calculated for each band as the average of intensity values in that band for all pixels present in that cluster. Pixels are then again reassigned to clusters, and this process repeated until the correspondence between iterations reaches a user-specified level (here specified as 98%).

The initial number of clusters was specified as 20 and the minimum distance between clusters for merging is defined as zero (in the absence of any information on actual intercluster distances, it was thought best to play safe and not specify any distance). After several iterations, the difference between iterations dropped to < 2%. Iterations were then stopped and the image classified into a resultant 14 clusters.

Each cluster was identified as a landscape type – there are therefore 14 landscape types identified initially in this analysis. The number of landscape types of course depends upon the input parameters specified while clustering. We were satisfied with an input value of 20 types of landscapes, which subsequently converged to 14, as this is an adequate number of landscape types which will allow us to stratify the region. It is also not so large so that interpretation becomes difficult. The size and shape of patches of these clusters was then calculated using the software FRAGSTATS 2.0 and a histogram of the frequency distribution of patch sizes plotted[20]. It was found that there were a total of 12,164 patches of various landscape types in this map, several of them small in size.

This is too large a number of patches to be investigated at this scale. Our purpose requires reducing these to a number around 200, so that a programme of field sampling could be organized in each patch. Some method is therefore required to merge very small patches with larger ones. To this end we used the following algorithm: first each patch of size 1 superpixel was merged with the class to which most of its neighbours belong. Subsequently, for all patches which are two superpixels in size, this algorithm was repeated. This process was continued until all patches smaller than 30 superpixels in size, i.e. of about 100 km^2 in extent were merged with their most prominent neighbour, and only 205 patches finally remained. In this process, three of the classes which were present only in small-sized patches disappeared from this map, leaving a final set of eleven classes. For each class, the average mean NDVI, standard deviation, skew and kurtosis values of all its member superpixels were calculated. Average patch size and shape were also calculated. The patch shape index compares the shape of the patch to that of a circular patch of the same area. A large shape index then means that the patch is more elongated.

The distribution of each of the eleven classes present in the final resultant map was then compared with maps of the Western Ghats topography, rainfall, temperature, forests, crops and population, in order to interpret the distribution of each of these classes with respect to all these parameters. The relief map and forest cover map were taken from the Census Atlas National Volume and the rainfall, temperature, crops and population pressure distribution were taken from the Irrigation Atlas of India[21,22]. The information on forest cover has been supplemented by comparisons with the forest maps brought out by the Forest Department of India and the vegetation maps of the French Institute, which contain information on the distribution of forest as well as non-forest types such as scrub, crops and plantations[23-27].

Results

A total area of 170,000 km^2 along the west coast and Western Ghats of India was classified into fourteen vegetation types using the four moments of distribution of the NDVI. This classified map was subjected to a patch merging algorithm in order to merge each patch smaller than 30 pixels with the most abundant class in its neighbourhood, to obtain a new map (Figure 1). A total of 205 patches were obtained, belonging to a final eleven classes. This map contains certain errors in location due to the fact that the images do not contain totally accurate information on geographical location – hence, errors in location of an area can be as much as 20–30 km in either direction – however, in classifying a total area of 170,000 km^2, such errors are not a very serious defect.

Analysis of patch size distributions, both for the original classification (Figure 2) and the classification after patch merger has been carried out (Figure 3), reveals that these distributions are highly skewed. Figure 4 shows that maximum area is occupied by the landscape types which have intermediate vegetation index values, whereas landscape types with very low and very high mean NDVI values occupy very small fractions of the total area.

It is difficult to directly correlate each type of landscape derived from this analysis with easily discernible types on the ground, such as evergreen forests or agricultural areas. This is because the scale of this analysis is such that each patch covers a mixture of several ecosystem types – in other words, it is classification at the landscape scale, not at the ecosystem or habitat scale. However, comparisons with relief maps, rainfall and temperature maps, maps of crop distribution, forest type distribution, distribution of other types such as plantations and other non-forest types, and population pressure on arable land have been made for each of the eleven types of landscapes. We have numbered the landscape types in ascending order of mean NDVI. These are described below. Table 1 summarizes the various attributes of these 11 landscape types.

Landscape type 1 is distributed in the southeast part of the Ghats, in the foothills of the Ghats to the leeward side. Rice, millets and oilseeds are the crops grown in this area, and the natural vegetation of this area is tropical dry deciduous forest. However, large parts appear to have been converted to open areas with palmyra trees planted in between. This landscape type therefore appears to correspond to a largely open area, planted with palmyra trees, rice, millets and oilseeds in parts. The landscape is highly heterogeneous, as is demonstrated by the high average standard deviation.

Landscape type 2 is present in the middle portion of the Ghats, near the crest. Rice and millets are planted in this area. Natural vegetation in this area is tropical moist deciduous forest. However, it has been largely degraded in this area, and it now mostly consists of open areas planted with rice and millets, as is shown by the low average NDVI and high standard deviation.

Landscape type 3 is present mainly along the eastern side of the Ghats, and is prominently found at the two highest spots in the Ghats – the Nilgiri hills and the Anaimalai hills. The natural vegetation is of the montane wet evergreen forest type, and the moist deciduous type. Crops grown in these areas are rice, millets and oilseeds. The landscape in the Nilgiris and Anaimalais is a complex of shola forests, which are evergreen forests, and montane grasslands, with plantations of Eucalyptus also present in the Nilgiris. In other patches, the vegetation is a mixture of moist deciduous forests, dry deciduous forests and open spaces.

Landscape type 4 is found distributed along the entire length of the Ghats. Towards the northern end, it is distributed in the eastern and western parts, whereas as one moves southwards, it is found mostly at the eastern foothills of the Ghats. This type is therefore not associated with any specific altitude range but is found distributed

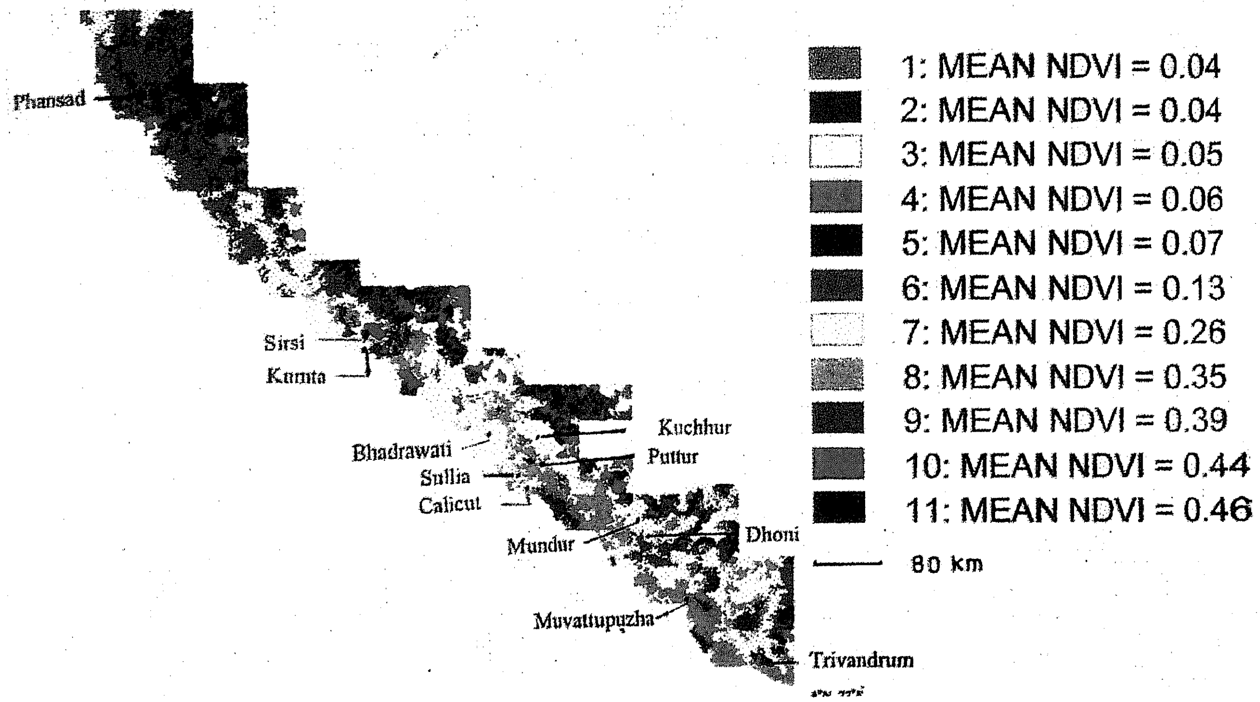

Figure 1. Geographical distribution of 205 patches of 11 landscape types derived by unsupervised classification based on normalized difference vegetation index (NDVI) from IRS 1B data for 1992–94 for the West Coast-Western Ghats region.

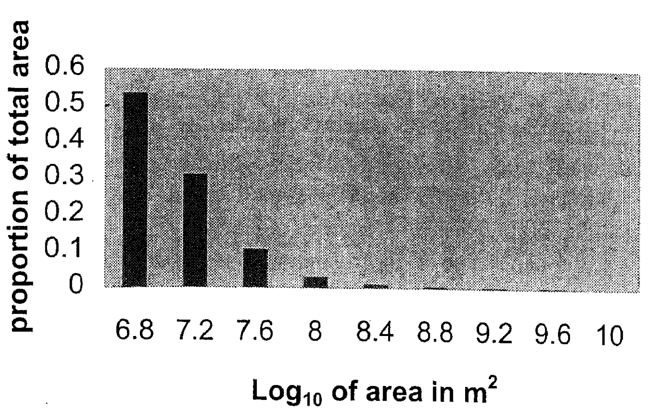

Figure 2. Frequency distribution of sizes of 12,164 patches of 14 landscape types with a minimum patch size of 3.33×10^6 m^2.

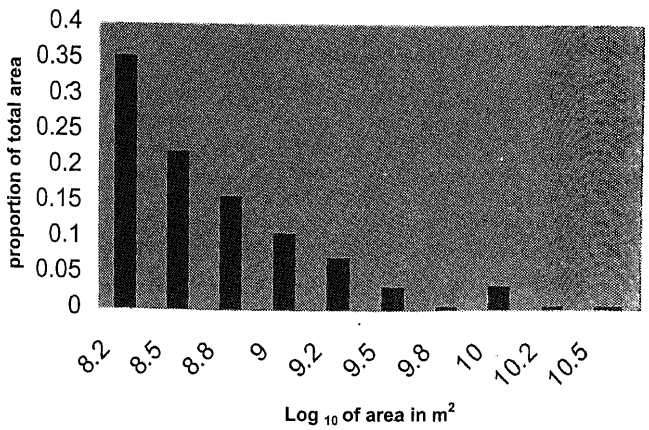

Figure 3. Frequency distribution of sizes of 205 patches of 11 landscape types with a minimum patch size of 99.9×10^6 m^2.

from the coast to the crest of the Ghats. Natural vegetation is mostly dry deciduous in the north, and moist deciduous in the south. In the north, the forested area has been largely replaced by tree savanna, shrub savanna and open land complexes, and in the south by open land with scattered palmyra trees. In some parts, rice, millets and occasionally oilseeds also are planted.

Landscape type 5 is found distributed along the entire length of the Ghats, more towards the eastern side although in the north a few patches are found distributed near the west coast. The bioclimatic regime, the natural vegetation as well as patterns of managed land use of this landscape type are very similar to those of landscape type 4.

Landscape type 6 is also distributed over the entire length of the Ghats, although in the north it is mainly distributed towards the west coast, while in the south it is distributed more in the eastern foothills of the Ghats. Natural vegetation in this area is moist and dry deciduous forest. In the north, moist deciduous forests and dry deciduous forests exist in patches, but large stretches of open area with millets, cotton and rice are also present. To the south, largely open land exists with scattered palmyra trees and millets, oilseeds and rice planted, in addition to some patches of dry deciduous forest.

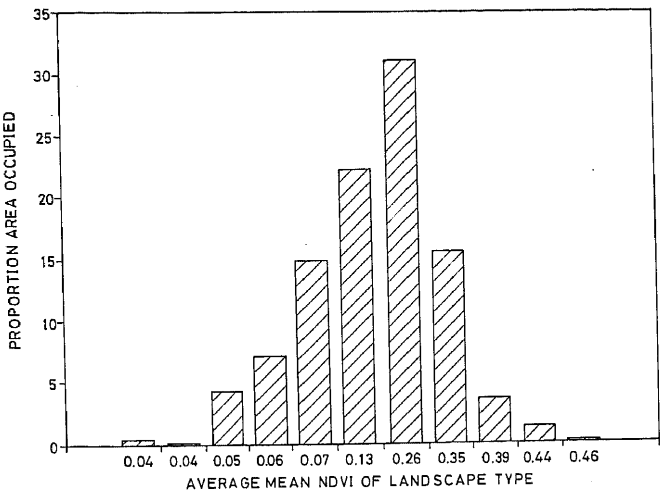

Figure 4. Frequency distribution of normalized difference vegetation index for the 205 patches of 11 landscape types.

Landscape type 7 is found distributed both to the east and west of the entire Ghats, and in some sense forms the matrix of this map. It is therefore difficult to define it as belonging to any particular topographic range, temperature range or rainfall regime. Natural vegetation is of the wet evergreen forest type, and extends to moist deciduous on the foothills at the leeward and windward side. Most of the evergreen forests of the Ghats fall within this class. Millets, cotton and rice are grown in the north. Millets and oilseeds are grown in the south. The natural vegetation still exists in pockets, but has largely been replaced by woodland to savanna-woodland, tree savanna to grass savanna, thickets and scattered shrubs. Arecanut, coconut, coffee and other miscellaneous plantations exist in this area. This landscape therefore appears to be a complex of patches of evergreen and deciduous forests along with degradation stages of this vegetation as well as several tree plantations, rice and millet cultivation, and is present along large stretches of the Ghats.

Landscape type 8 is present mostly in the western part of the Ghats, and absent in the northernmost stretches. It appears to prefer the coastal areas, but does enter the windward foothills of the Ghats also. The natural vegetation is evergreen. Large patches of natural forest have been cleared, and rice, tapioca, and coconut planted – these LSE types intermingle with disturbed and secondary evergreen and semi-evergreen LSE types.

Landscape type 9 is absent in the northern stretches of the Ghats – in the central and southern parts, it appears in small patches distributed either in the west coast, or the western foothills of the Ghats. The natural

Table 1. Summary of the attributes of the 11 landscape types

Land scape type	Total area (km^2)	No. of super-pixels	Mean NDVI	Mean SD	Mean skewness	Mean kurtosis	Mean patch area (km^2)	Mean shape index	Altitude range (m)	Mean daily temperatures (°C)	Annual rainfall (mm)	Persons per ha arable land
1	714	220	0.04	11.38	2.60	0.05	238	1.99	300–600	22.5–25.0	1000–2000	2–4
2	143	44	0.05	18.29	2.68	0.05	143	1.51	> 1350	20.0–22.5	2000–4000	2–4
3	6915	2136	0.05	7.74	1.61	5.77	461	2.49	600–1350	22.5–25	1000–4000	6–8
4	11,744	3623	0.05	5.63	1.22	0.06	367	2.55	0–2800	20.0–27.5	1000–4000	0–4
5	24,702	7625	0.07	4.17	0.87	0.07	537	3.01	0–2800	20.0–27.5	1000–4000	0–4
6	36,960	11,405	0.13	3.02	0.55	0.08	924	3.49	0–600	22.5–27.5	2000–4000	0–2
7	51,900	16,017	0.36	2.18	– 0.04	0.12	2595	3.91	?	?	?	6–12
8	25,830	7971	0.46	3.19	– 0.66	0.10	1230	4.0	0–600	20.0–25.0	2000–4000	8–16
9	5856	1808	0.49	5.13	– 1.21	0.09	366	2.75	0–600	22.5–25.0	2000–4000	8–12
10	2151	663	0.49	9.13	– 1.89	0.07	239	2.31	0–2800	22.5–25.0	2000–4000	8–12
11	104	32	0.56	18.80	– 2.27	0.07	104	1.5	> 600	20.0–22.5	4000	0

?, Difficult to define.

vegetation is evergreen and semi-evergreen. The landscape consists of evergreen and disturbed semi-evergreen forests along with moist deciduous forests and woodlands to savanna-woodlands. Rice, tapioca, coconut, millets and oilseeds are also grown in this area.

Landscape type 10 is found mainly associated with type 9, and contains the same mixture of LSE types. However, the average standard deviation of this type is much higher than that of type 9, and therefore this landscape is probably much more heterogeneous.

Landscape type 11 is present in a single small patch. The natural vegetation is evergreen, and the high mean vegetation index combined with the fact that population pressure is low and no crops are grown, probably means that natural forest largely exists in this area, although the high standard deviation suggests that degraded parts or clearings exist interspersed with the forested areas.

Discussion

This investigation is a part of a programme to develop the methodology to monitor biodiversity across spatial scales spanning 14 orders of magnitude, from a quadrat on the scale of $1 m^2$ for field level sampling to the entire biosphere spanning an area of $10^{14} m^2$. We focus our investigation on a region, that of Western Ghats in peninsular India with an area of the order of $10^{11} m^2$. Our proposal is to stratify this region as a first step into 205 patches, extending in size from 10^8 to $10^{10} m^2$ with a mean of $10^9 m^2$. This we do on the basis of satellite imagery with a resolution at the scale of $10^3 m^2$, by merging 2500 pixels to create superpixels with areas of the order of 10^6–$10^7 m^2$. We attempt to normalize for the inevitable scene-to-scene variation by using the NDVI. Each superpixel is then characterized by the values of mean and three further moments of NDVI for the constituent 2500 pixels. We then cluster these superpixels on the basis of this information into 14 classes, with over 12000 patches with a mean size of 10^7–$10^8 m^2$. This is too large a number of strata to form the basis of a programme of field sampling. We therefore merge these to derive 205 patches, with a mean size of $10^9 m^2$. We have thus resorted to unsupervised classification of the satellite imagery at this stage.

These 205 patches are assigned to 11 types of landscapes. With patches of this size the landscapes are inevitably complex mosaics of a large number of landscape element types, of the order of 50–100 as defined for the entire region of Western Ghats; these elements being relatively homogeneous at the spatial scale of $10^4 m^2$. We do believe, however, that the procedure has led to identification of types of landscapes that reflect ground reality; and that it has been possible to interpret them in terms of patterns of land cover known from the Western Ghats region. These 205 patches may then represent characteristic landscape patterns that constitute an appropriate basis for organizing a programme of field sampling. Administrative divisions such as taluks and districts with areas of the order of $10^9 m^2$ and $10^{10} m^2$ respectively are another possible alternative, as are bioclimatic zones. The administrative divisions do to an extent reflect natural topographic and climatic variation, but are not directly based on natural variation. The bioclimatic zones are at the base of distribution of natural biota, as well as cultivated crops, but are losing relevance with increasing levels of human interventions. The current distribution of values of appropriately normalized vegetation index is then a very reasonable basis for stratification of the region at this spatial scale.

The 205 patches thus delineated may be an appropriate basis for setting up a programme of field sampling. We propose to do this by selecting a study landscape of a size of the order of 10^7–$10^8 m^2$ within each patch. We then suggest a supervised classification of the relevant satellite imagery in terms of constituent landscape elements belonging to some 50–100 landscape element types over the entire region. This would lead to the preparation of a landscape map with individual elements ranging between $10^4 m^2$ and $10^6 m^2$ in size. Actual field sampling through quadrats of the size of 1 to $10^2 m^2$ or so can then be organized by properly siting these quadrats amongst representative patches of different types of landscape elements. Figure 5 summarizes this overall

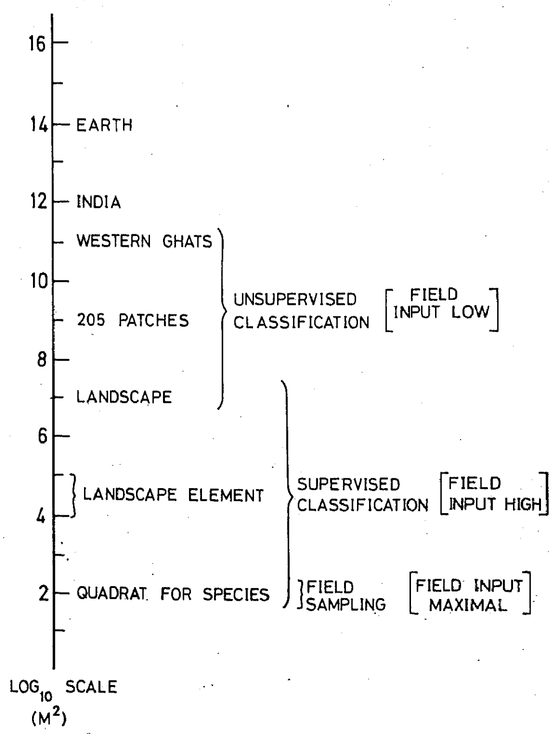

Figure 5. Proposed scheme of biodiversity investigations at different spatial scales.

proposal for linking the sampling for biodiversity at a hierarchy of different spatial scales.

Monitoring of biodiversity is a new challenge and the methodology is just beginning to be developed. Ours is then necessarily a preliminary proposal which needs to be carefully scrutinized, amended, perhaps rejected. We hope that it would nevertheless help catalyse debate and further developments in this exciting new area of scientific research.

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