Contours of conservation – A national agenda for mapping biodiversity

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Despite the world-wide concern over the rapid rate of loss of biodiversity, there seems to be little clarity on what, where and how to conserve biodiversity. In this paper, we call for a national approach to prioritize the conservation needs through an hierarchical integration of the biological and spatial elements of conservation. The proposed approach seeks to independently map the biological and spatial elements of conservation and then to integrate them to arrive at country-wide maps for conservation – what we refer to as *contours of conservation*. These atlases shall provide a composite map of the spatial structuring of the biological and spatial (habitat) elements for conservation, suggest priorities and guide appropriate allocation of national conservation efforts. In essence, they can assist in evolving a holistic national conservation plan. We present here the salient steps involved in mapping these elements and propose that a national agenda be drawn-up for the development of the country-wide biodiversity atlases and contours of conservation.

THE last couple of decades have witnessed an unprecedented concern over the loss of biodiversity the world-over. The concern has been justifiably so on the tropical forests of the world, which though cover only 7% of the earth's land surface, contain more than 50% of all known species[1]. These forests are one of the most seriously threatened and the biological resources in them are being depleted at a faster rate than in any other forests[1]. Assuming current rates of deforestation, it is estimated that by 2010, the tropical forests of the world would have lost between 33 and 50% of their species[2]. India, one of the 12 mega-diversity countries of the world, harbours an estimated 500,000 out of 10 to 30 million species of living organisms[3,4]. The forests of peninsular India alone contain an estimated average of 4.09 species of seed plants per 1000 sq km and is next only to that of southern Africa[5]. Though no precise estimates of the loss are available for India, it is conjectured that, because of the extremely high rates of deforestation and fragmentation, a substantial portion of the biodiversity may well have been lost, even before it is completely documented.

What and where to conserve: An unanswered question

Even as this realization prompts us to indulge in conservation activities, the efforts seem to suffer from a lack of direction and clarity on issues of what and where to conserve. We do not have a consensus list of all that needs to be conserved; 'we are still not clear at all as to how best to conserve biodiversity or, to be more precise, which elements of it (and where), and for which purposes'[6]. At present, conservation strategies depend excessively on independent programmes and plans such as 'just set aside a preserve', 'tiger reserve hypothesis', 'hot-spot identifications', and establishment of *ex situ* and *in situ* gardens, with little or no co-ordination among them. None of these approaches is holistic and cannot adequately address all the conservation needs. For example, the 'just set aside a preserve' approach suffers from being arbitrary and *ad-hoc*. It is clearly not the most feasible nor an ever-lasting solution to check the loss of biodiversity. In recent years, the 'tiger reserve hypothesis' has been argued to serve the cause of conservation following the assumption that these reserves may in fact protect far more biodiversity than what the reserves are actually meant for. However, such reserves far from being practical in all places may in fact contribute to the acceleration of loss of species, occurring outside the reserves.

Myers[7,8] identified areas of exceptional species richness and endemicity on the global scale and referred them as 'hot-spots' of diversity. Though identification of the hot-spots does focus conservation efforts to these areas, it is increasingly felt that such an approach may have had a deleterious effect on the maintenance of biodiversity in other areas not regarded as 'hot-spots'. For example, it has been argued that identification of a few tropical countries (such as Ecuador, India, Indonesia and Madagascar) as megadiversity centres has led to the relative neglect of biodiversity in the temperate regions of the world which houses nearly 60,000 species[6,9,10]. In India, the Western Ghats with its species-rich evergreen forests, is regarded as an hot-spot area[9,10]. Though this has justifiably led to an increased emphasis on the conservation of the forests of Western Ghats, it has also contributed to the systematic neglect of the drier forests of the Eastern Ghats (a chain of hills on the eastern coast of the country from Tamil Nadu to Orissa) along with those of the Vindhyas, Satpuras and the Aravallis[11]. It is argued that these forests at least deserve to be recognized as 'warm-spots of biodiversity"[11]. Similarly the establishment of *ex situ* and *in situ* gardens that aim to conserve diversity of specific groups of organisms is also rapidly losing relevance and these approaches are outmatched by the magnitude of the loss of biodiversity. *Thus despite the overriding concern for conserving biological resources, there does not seem to be sufficient clarity on what, where and how to conserve.*

Elements for conservation

Basically, the elements that demand conservation attention can be classified broadly under two categories, namely (i) the biological elements and (ii) the spatial and other habitat features. These elements and their interactions together provide a mosaic of conservation priorities. Though occasionally these elements could be inter-linked, it is possible to identify distinct and hierarchical units under each of them. For instance, the biological elements that demand conservation could be specific genes, the relatives of certain species, the species *per se* in an ecosystem, a set of taxonomically related species, species related through their functional or economic value, and the whole biota. Similarly, the spatial elements that demand conservation could be unique micro- and macro-habitats, ephemeral zones, sensitive patches of the ecosystems, unique forest types and the whole ecosystem as such. At present, conservation efforts, if any, are mostly *ad-hoc* and are independently directed towards these elements, often in proportion to the importance claimed by the group having allegiance to these elements. While every element worthy of conserving deserves attention, it is important to identify the overlaps and prioritize the elements through co-ordination and intense interactions among the interest groups. This would not only avoid redundancy in the conservation activities, but also focuses attention to the most important issues from an otherwise ad-hoc approach and hence makes conservation a cost-effective exercise.

Mapping the conservation elements of the country

In this paper, we propose a national approach for mapping and integration of the various biological and spatial elements of conservation so as to prioritize the conservation needs. We suggest that strategies to conserve the biodiversity of the country should be based on development of country-wide maps for conservation – what we refer to as *contours of conservation.* These maps which would result from integrating data from various layers and of different elements provide a composite map of the spatial structuring of biodiversity for the country and can guide national conservation efforts. In other words, just as we are systematically preparing maps depicting the physiognomy of our country, we should also aim to develop maps depicting the *biognomy* or the *biodiversity profiles* of our country for a sound national conservation strategy and for an appropriate allocation of resources to the conservation activities. We suggest a bottom-up approach for developing these biodiversity atlases and contours of conservation and suggest that they could be done in three steps, namely (i) mapping the biological elements for conservation, (ii) mapping the spatial (habitat) elements for conservation and (iii) mapping the contours of conservation. We describe below these steps with examples of the efforts made at our centre and elsewhere.

Mapping the biological elements for conservation

Geographical distribution of biological elements to be conserved. After Vavilov[12] identified the centers of crop diversity, there have been several attempts to map the spatial distribution of biological elements including economic trees, endangered plant and animal resources, etc. These efforts have been accelerated in the recent past, due to th availability of remote sensing and GIS mapping sot wares. However, a primary requirement of any such mapping process is the need to identify the units of biological resources that demand conservation. These units can be arranged as a hierarchically accumulating but independent layers into which data can be added on indefinitely at all the levels and updated periodically. Table 1 lists the different elements and layers to be considered for this purpose and the corresponding maps that need to be prepared.

At our centre, we have been developing maps at three of these hierarchies, namely genetic conservation maps

Table 1. Biological elements for conservation and the conservation maps to be developed

Biological units to be conserved	Maps to be developed	Purpose
Genes	Genetic conservation maps	Conservation of genetic diversity
Species	Species conservation maps	Conservation of species
Groups of species (related taxonomically or functionally)	Species richness conservation maps	Identifying the red spots
Biodiversity	Biodiversity conservation maps	Identifying the hot spots

(e.g. for *Phyllanthus emblica*[13] and *Terminalia* sp.), species conservation maps (e.g. for bamboos, sandal wood) and species richness maps or red-spots for *Dalbergia* (Figure 1), Dipterocarps (Figure 2), orchids (Figure 2, inset), ants[14], and leaf hoppers. Such maps are also being prepared for medicinal plants[15], root grubs[14], birds and tiger beetles.

There have been several previous attempts in developing species richness maps[16–18]. The IUCN Plant Conservation Programme is identifying several hundred major centres of plant diversity world-wide[4]. The utility of such maps would however, depend upon the extent to which the spatial distribution pattern of species correspond across taxa. Prendergest *et al.*[19] showed that within Britain, the spatial distribution patterns of species frequently do not coincide for higher taxa. However, Williams and Gaston[20] reported that correspondence in spatial distribution patterns across taxa is broadly true within continents. In our own study, the spatial distribution patterns of species such as *Dalbergia*, orchids, endangered plants, dipterocarp, ants, root grubs and birds largely corresponded to the traditionally known major areas of biodiversity, namely the Western Ghats and the Eastern Himalayas (Figures 1 and 2; see also Ali and Ganeshaiah[14]). However, several other studies show that such overlap is not always forthcoming. For example, in north America, the hot-spots for freshwater fishes occur in the drainages of the eastern US while for the birds it is in northern Mexico[21]. In Australia, the hot-spot ranges for members of Proteaceae is in south western and eastern parts of Australia, while that for Chenopodiaceae it is in the arid regions of central Australia[22]. In Madagascar, where one of the most thorough studies on mapping the biodiversity has been conducted, spatial distribution patterns of different species of rare butterflies, reptiles and lemurs are strikingly different. Thus in these cases, different protected areas may have to be chosen for the different taxa to conserve the maximum biodiversity. However, such taxa-centric approach to conserve the biodiversity may not always be feasible nor even desirable for reasons mentioned above.

An important consideration in developing the maps of biodiversity is the choice of the scale. Though it may be a matter of convenience and sometimes constrained by the available data, it is important to realize that mapping at one scale (such as local, regional, national and global scales) may not have significance at the other. Several earlier studies have mapped species in grids of 50,000 sq km[21]; we have been mapping the distribution in grids of 10,000 sq km. Perhaps, one of the best data sets are by Prendergast *et al.*[19], who have mapped the biological elements in Great Britain in grids of 100 sq. km area. Obviously, mapping at larger spatial scales, though easier, has implications for conservation

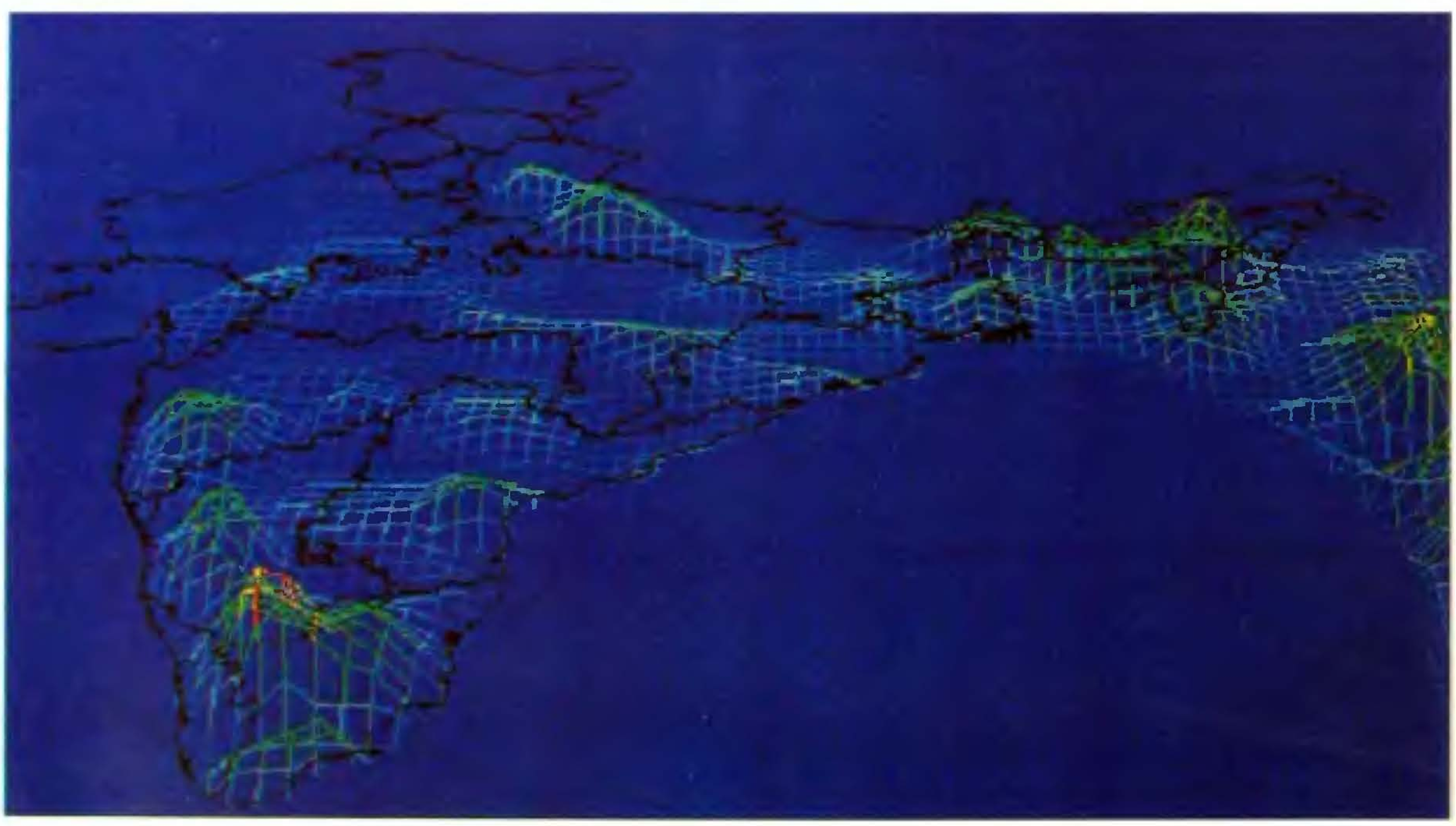

Figure 1. Hypsographic view of the species richness of Dalbergias. Data on the geographic occurrence of different species of *Dalbergia* (45 species) were obtained from Thothathri[35], the latitude and longitude were assigned for each record and mapped. The density of species in each grid of the size 1° × 1° was computed, and contours for the density obtained. Based on the contour data, the three-dimensional view was constructed using suitable GIS software (see Ali and Ganeshaiah, this issue, for details).

planning that would be coarser compared to mapping at smaller scales.

Integration of species distribution data and preparation of biodiversity atlas. An important task after preparing the various hierarchies of maps of the biological elements is to evolve an algorithm to integrate these spatial distribution data such that a new and composite biodiversity atlas of the country can be developed. Integration of such data would be useful in generating predictive distribution maps and in identifying the factors regulating these distributions. However, spatial integration of the distribution data from different groups demands an altogether new algorithm and a novel calculus[23].

One of the approaches towards integration of data across species involves the use of higher taxon richness index[21,24–27]. The principle behind using this index is that it enables differentiating pixels or areas with say three species of the myna birds from those containing three diverse species of birds such as a myna, a drongo and a wood-pecker. On just the species richness count, both the pixels would be similar while at a higher taxon richness level, the pixel with the three different bird species will be weighted more for conserving biological diversity. Higher taxon richness has been used in mapping the spatial distribution of biodiversity[20,28]. In fact WORLDMAP, a GIS-based software, offers a graphical tool for establishing priority areas on the basis of maximum biodiversity as established by evaluating taxonomic distinctiveness of the species within a region[6].

Recently, Ganeshaiah *et al.*[25] developed a novel quantitative index, called the 'Avalanche index', that combines the properties of the conventional diversity index along with the taxonomic distance among the species. It also facilitates computation of a composite index score irrespective of the taxonomic affiliation of the species (including across the plant and animal kingdom). Using this index, Murali *et al.*[29] (this issue) have developed a biodiversity map for the vegetation data for BR Hills,

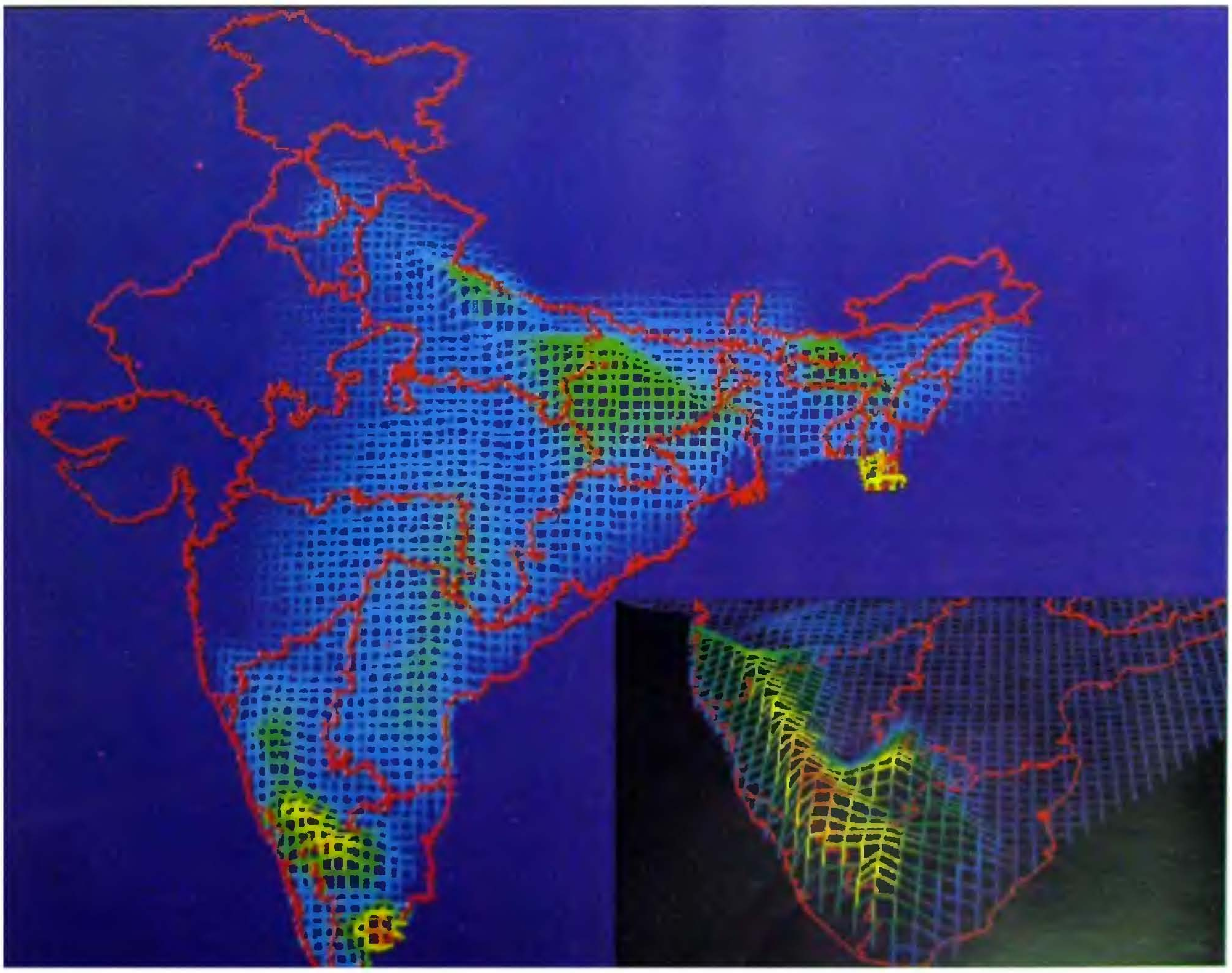

Figure 2. Hypsographic view of Dipterocarp members in India and orchids in south India (inset). Data on the distribution of species (30 species of dipterocarps[36] and 140 species of orchids[37]) was obtained from diverse sources, monographs, etc. and plotted as mentioned in Figure 1.

Karnataka. Clearly, such maps offer a holistic view of the disparate vegetation elements occurring in the BR Hills and helps focus our conservation efforts to areas of high biodiversity. At our centre, we are attempting to develop such biodiversity atlases for the country by integrating the spatial distribution patterns of various biological elements. While we are aware that they may not be complete at any rate, the open-ended feature of such maps permits a continuous improvement.

Mapping the spatial or habitat elements for conservation

Equally important as mapping the biological elements but perhaps the most difficult task would be to map the spatial elements that need to be conserved and thence to develop the *habitat conservation maps*. Unlike for biological elements, there are far too few attempts to map the spatial elements. This is probably because of the demanding task of defining the criteria to be considered while developing these maps. Nevertheless it is possible to list a set of important issues that should be the prime drivers for constructing such maps. For example, the uniqueness of the micro- and macro-habitats (such as Myristica swamp, river spray zones), sensitiveness of habitats (the forest peripheries that are in continuous interaction with the human activities), the ecological significance and the biological value of the habitats, etc. could be some of these criteria. The hierarchical units and the maps that need to be developed for spatial elements are given in Table 2.

It should be noted that even these layers are gradually cumulative and are open ended in that they could be continuously improved by adding data at any level. There are several independent attempts at mapping such spatial elements both at local and regional scale[30]. We have been mapping areas of rapid changes in the land use cover at BR hills (Figure 3). Based on the major vegetation types, Gadgil and Meher-Homji[31] identified 43 different vegetation types in the country and have analysed the extent to which they still persist as forest formation. Using normalized difference vegetation indices (NDVI), Harini and Gadgil[32] (this issue) have attempted to classify the entire Western Ghat forest into different landscape types. An integration of all such databases with suitable algorithms would provide valuable inputs to develop the forest conservation maps. Further, they would be extremely useful in stratifying the landscape such that redundancies can be reduced and the conservation efforts can be spread more appropriately.

Table 2. Spatial elements to be conserved and the conservation maps to be developed

Spatial units to be conserved	Maps to be developed	Purpose
Micro-habitats	Micro-habitat conservation maps	Identifying unique micro-habitats
Macro-habitats	Macro-habitat conservation maps	Identifying unique and important macro-habitats
Habitats and forests	Forest conservation maps	Mapping sensitive and high value forest zones
Ecosystems	Ecosystems conservation maps	Mapping national grids for conservation

Mapping the contours of conservation

Based on both, the *biodiversity atlases* (biodiversity conservation maps) and the *habitat conservation maps*, an integrated map that combines the properties of the two, needs to be developed to arrive at the *contours of conservation*. This challenging task requires serious interactions at the national level to arrive at consensus on issues such as the levels of the interacting hierarchies that need to be considered, the weightage co-efficients to be assigned for the spatial vs the biological elements, etc. Further, construction of these contour maps shall not be a one-time task, rather be an open-ended effort that can be improved as the information is accumulated. Nevertheless, the exercise would be worthwhile, because such contour maps shall incorporate the concerns of all

Figure 3. Map of BR Hills, south India showing intensive alterations in the land cover for the past two to three decades. The dark colours indicate frequent and intense changes.

the interested groups and hence could guide us in developing national plans for conservation.

A national agenda for mapping biodiversity

The contours of conservation, the biodiversity atlases and their accompanying data will have widespread application in guiding national conservation plans and in the effective allocation of scarce resources. These maps could be used to evaluate the relevance of protected areas and accordingly restructure them. Because of the strong visual outputs generated by these maps, they would serve both the generalist and specialists alike in making decisions in conservation action. Besides addressing issues related to conservation of biological diversity, these maps would help direct attention to basic issues pertaining to the distribution pattern of species. For example, the biodiversity contour maps will enable determining the anomalous distribution patterns, if any, of taxa and their implications.

Among the tropical countries, India is uniquely endowed for the development of such maps. Through both formal and informal surveys conducted over the past 150 years, there is an excellent documentation of the flora and fauna of the country. The vast network of colleges and universities and libraries across the country and their associated archives and herbaria provide rich sources of data from which the species distribution maps can be developed. However, the task of collating the information from diverse sources for the entire country and preparing the maps, is enormous and clearly cannot be accomplished by one or few groups. Rather, there is a need for a national consortium of interested individuals, scientists, institutions and NGOs to collectively search, retrieve, digitize and analyse the data before the maps can be developed for the country. At present there are few but independent groups in the country addressing these issues. Gadgil[3] and his co-workers in a collaborative programme with college teachers have embarked on an important task of monitoring the country's biodiversity. This programme aims at developing an exhaustive account of the biodiversity of the Western Ghats and to study its dynamics in various landscape types. More recently, the Indira Gandhi Conservation Monitoring Centre (IGCMC) based at New Delhi is planning to prepare spatial distribution maps of endangered plant species and tigers in order to assess the conservation threats at the regional scales. The FRLHT, Bangalore has been extensively mapping the medicinal plant resources of the country[15]. The French Institute, Pondicherry has been mapping the vegetation of the Western Ghats with particular reference to the endemic plant species[33]. Several groups are engaged in mapping the tiger and elephant populations and their habitats in the country[34]. While each of these is admirably addressing the specific issues, it is desirable that such diverse data bases be brought together, to further enrich the respective studies and to provide a holistic view for effective conservation.

We propose that a country-wide network of groups working in these and related areas be initiated to complement their respective strengths towards the common goal of mapping the country's biodiversity. One of the model programmes that can be emulated is the Environmental Resource Information Network (ERIN) established by the Australian Government[22]. The central objective of the network, started in 1989, was to 'provide geographically related environmental information of an extent, quality and availability required for planning and decision making'. Through the involvement of a score of institutions, the ERIN is involved in spatially integrating all of Australia's species information with the ultimate aim of generating biodiversity maps of the country. These maps have already been used in a number of conservation-management tasks.

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