Documenting diversity: An experiment

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Complex natural systems such as soils, groundwater, and populations of disease vectors like mosquitoes exhibit a great deal of variation in space and time. Documenting such variation is essential for good management of environmental resources; it can also provide for students and teachers excellent opportunities for first hand scientific observations. This article describes such an experiment, focusing on inventorying and monitoring of biodiversity of the Western Ghats. Initiated in early 1994, this experiment involves a network of over 20 undergraduate colleges collaborating with ecologists at the Indian Institute of Science in Bangalore. Experience gained so far in this programme suggests that such field research could serve as a valuable teaching device, as well as generate useful inputs for decentralized management of natural resources at the panchayat and district levels.

COMPLEXITY and diversity are the new frontiers of science. The focus is now on systems like climate, and on the extent to which it will change as a consequence of an increase in the concentrations of greenhouse gases. It is on the diversity of life, and on the rate at which this is being eroded through manifold human impacts. It is on contagious diseases like AIDS and on understanding how these spread as a result of human social behaviour. The most significant challenges before science today lie in understanding complex systems with a great diversity of behaviours in space and time[1–3].

This shift in focus to complex, diverse systems has important implications for a country like India. Biologists have identified India as one of the top twelve megadiversity countries of the world; harbouring an estimated 500,000 out of some 10 to 30 million species of living organisms[4]. Indian monsoon circulation is amongst the most variable in the world, and is suspected to drive the El Nino-La Nina oscillations. India harbours amongst the culturally most diverse societies in the world, with shifting cultivators and artisanal fisherfolk coexisting with shrimp acquaculturists and software engineers[5]. So India offers a wealth of fascinating, complex, diverse systems for our scientists to work on. There are interesting new facts to be discovered about these systems and we are placed in an advantageous position to do so.

This is not the case when dealing with relatively simpler physical, chemical systems. Such systems are more universally accessible for investigations. In consequence, relatively readily accessible facts tend to be already known, and discovering new facts calls for elaborate, expensive experimental set ups, highly purified, expensive chemicals. As citizens of a relatively resource poor country Indian scientists are at a disadvantage in working with such simpler systems. But India with its large numbers of trained men and women could be at a considerable advantage and make significant contributions worthy of it, if our scientific community purposefully addresses the challenge of working at the new frontiers of science; of complex, diverse systems.

Science as a process

Admittedly we are far from geared to take on this challenge. One of our main shortcomings is the system of science education[6]. Any worthwhile system of science education should teach science as a process; a process of discovering new facts, organizing them in appropriate systems, making new predictions on the basis of such understanding and going out to look further for yet more new facts in the light of these predictions. But our current system of science education tends to treat science as a collection of facts, to be memorized by rote and reproduced at the time of examinations. This is in part inevitable in teaching about simpler systems of physics and chemistry, for in these contexts new facts are so hard to come by. Given the difficulties of properly equipping the laboratories in our teaching institutions, students have very limited opportunities of familiarizing themselves at first hand with even the known basic facts, let alone explore new facts. So science education ends up as an exercise of learning facts by heart from books, with little contact with the real world. This is not a system conducive to producing scientists equipped to explore new frontiers.

In the study of complex, diverse systems, in contrast, new facts are all around us and these are facts both of

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scientific interest and of practical value. The West Coast of India receives as much as 3000 mm of rain in many places. Yet many coastal villages and towns experience acute scarcity of drinking water in the summer. Moreover, more and more such places find brackish sea water encroaching on the ground-water aquifers supplying their drinking water wells. It is important to understand the water cycle in these tracts, the relationship between surface run-off and percolation to the ground-water aquifer, the role of vegetation, soils and rock structure play in this context, the interplay between the freshwater aquifer and the sea water[7]. The pertinent facts change from locality to locality, from season to season, from year to year. So they need to be continually monitored everywhere, interpreted in the proper theoretical framework and used to predict when and where water scarcities will develop. To take another example, India's west coast abounds in a diversity of medicinal herbs as well as a diversity of medicinal uses of these herbs by the various tribal, rural communities and in systems such as Ayurveda, Siddha and Yunani. Populations of many of these herbs are being decimated today through overharvests by agents of pharmaceutical companies, and through destruction of their habitats in many different ways. It is important to document the various reported uses of these herbs, to assess their efficacy, to monitor the status of their populations. These facts also vary from locality to locality, from year to year. They have important practical applications in terms of commercial production of pharmaceuticals, of providing readily accessible health care to large numbers of our people, of maintaining long term viability of the populations of these species[8].

Down to earth

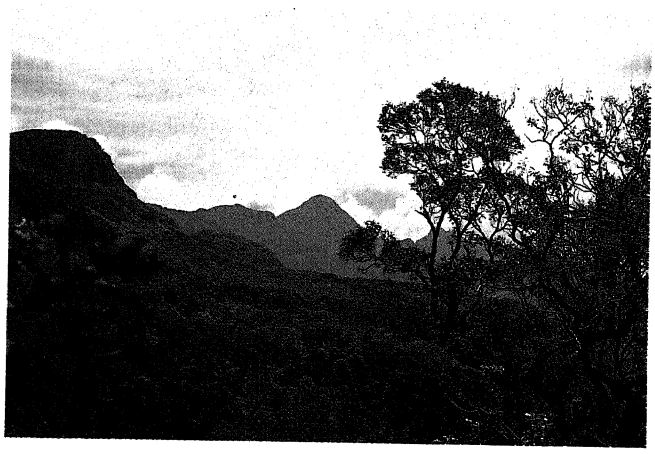
These are just two of the many, many examples of how the study of behaviour of water, rocks, soils, microbes, plants, animals, human groups would generate new facts of scientific interest, and with practical implications. Surely involving science students, and of course, teachers as well, in a process of discovering, interpreting and predicting on the basis of such new facts observed first hand would be the best way of training practising scientists for India. The difficulty of course is that such a system of training scientists cannot be organized in a routine, unimaginative, centralized fashion. Moreover, the training students receive through such a process cannot be assessed through routine, unimaginative, centralized examinations. It would therefore call for more initiative, more effort on the part of teachers and administrators. It would also mean much less scope for private coaching in which many teachers are involved today. So there would undoubtedly be some inertia and some vested interests against implementing such proposals. But the students, unless they get away with copying at the exams, would stand to gain in every way. For now their effort would go into making first hand scientific observations, interpreting new data in place of learning dead, seemingly irrelevant facts by heart. The process would not only help produce a scientific manpower and womanpower that can work far more competently on real life problems, but the process would generate information that would be of use in tackling real life problems of relevance to the society.

Biodiversity

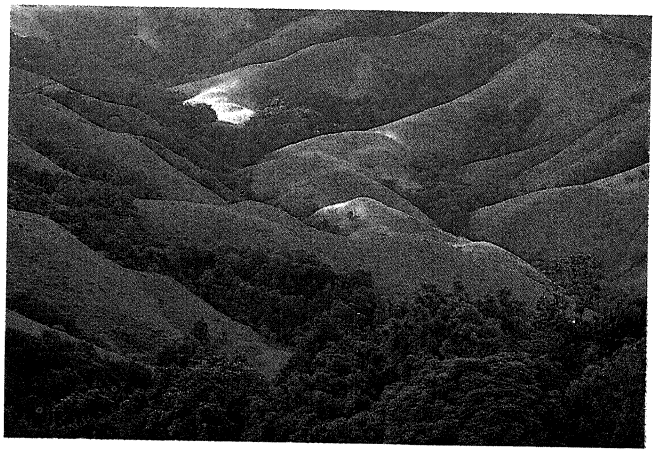
The fact that such a process can generate information of social relevance means that the society would be more readily willing to fund this type of science education. I would like to discuss here a concrete example of how such funds can be available, and can be put to use to generate activities of both educational and practical value for science teachers and students. The activities pertain to inventorying and understanding on-going changes in the levels of biodiversity of living organisms. Such an understanding of levels, distribution and dynamics of biodiversity has assumed considerable significance over the last decade for two reasons[9]. Firstly, recent developments in molecular biology now make it possible for us to move genes across completely unrelated organisms – from mammals to yeasts, from bacteria to insects. This has added an entirely new dimension to the possibilities of putting genetic resources to human use, so that organisms once thought of as totally insignificant may now be put to use and result in large commercial gains. Along with this have come the possibilities of patenting of living organisms and their products[10]. Thus Japanese have applied for a patent on the digestive enzymes of an Australian frog that broods its young in its stomach. Perhaps these enzymes hold clues to the treatment of stomach ulcers. Japanese also reportedly import from the west coast of India insectivorous plants belonging to the genus *Drosera*; they may be developing some applications based on their unusual enzymes. Along with such technological developments and opening up of commercial possibilities has come the realization that the world's heritage of biological diversity is being rapidly eroded and requires urgent action for conservation.

International convention

These two-fold developments, a realization of tremendous value and a concern with long term conservation, have recently resulted in an International Convention on Biological Diversity (CBD) initiated at the Rio Earth Summit in June 1992 and in force since December[11] 1993. CBD, for the first time recognizes the sovereign rights of all countries over their biodiversity resources,

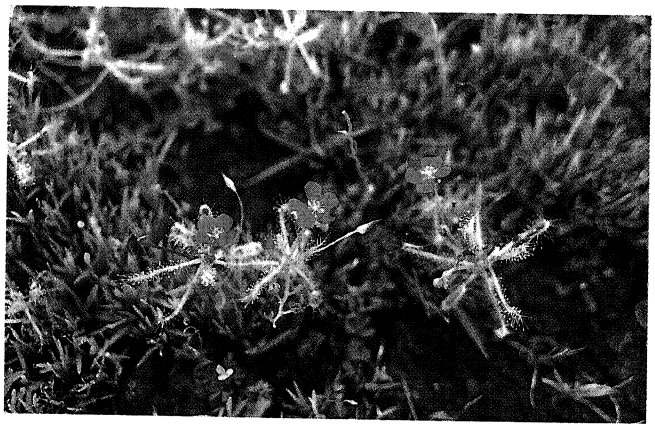


Agastyamalai – A view of Agastyamalai hills in Thiruvananthapuram. These hills are known for high levels of biodiversity, a good number of which are endemic to the Western Ghats. Photo: M. D. Subash Chandran.



Typical shola vegetation of Western Ghats. Photo: N. A. Madhyastha.

Acrocarpus fraxinifolius – Buttressed base of an immese sized tree *Acrocarpus fraxinifolius* at Narasimharajapura Range, Chikmagalur district. Photo: M. D. Subash Chandran.



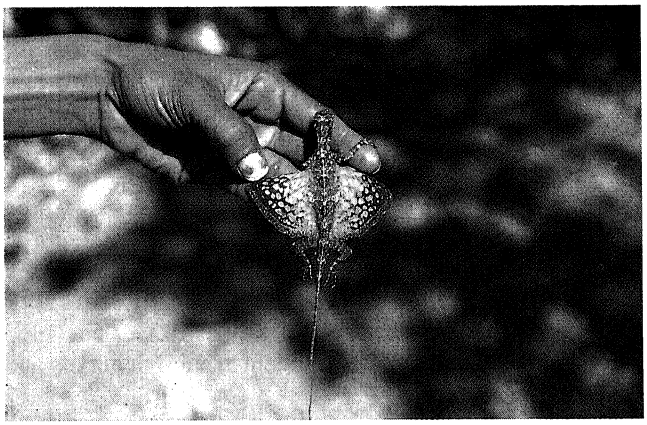
Drosera indica – an insectivorous plant growing during the rainy season along the exposed laterite hills of coastal Uttara Kannada. Photo: M. D. Subash Chandran.

commits all parties to the convention to facilitate access to their resources, and in return promises the countries of origin of such resources favourable treatment in terms of transfer of technology and of financial resources. CBD commits countries to prepare proper inventories of their biodiversity resources, to monitor their fate, to organize adequate information systems for such resources, and to take steps to conserve them[12,13]. CBD also recognizes the role of indigenous communities in conservation and sustainable use of biodiversity resources and enjoins member countries to share benefits of utilization of biodiversity resources with these indigenous communities.

India, along with 125 other countries is a party to CBD and therefore committed to developing an inventory of its biodiversity resources, monitoring their dynamics, organizing a computer-based system of such information and working out an effective strategy of conserving these resources[14]. It is also committed to documenting the knowledge and practices of conservation and sustainable use of biodiversity elements by its indigenous communities[15]. These are major challenges before India's biological, informatics and anthropological communities, challenges that can be turned into significant opportunity for injecting a new vigour into our educational and research establishments, and to contribute towards conservation of our national heritage. There is genuine social demand at the national as well as international level for addressing this challenge, and financial resources are being mobilized. What is needed is the will to organize the effort.

Profuse natural regeneration of *Xylia dolabriformis* (ironwood tree) in a protected forest planted with exotic *Acacia auriculiformis*. In most of the Western Ghats tract mere protection by fencing alone is sufficient for rapid regeneration of natural forests. Photo: M. D. Subash Chandran.

Encroachment – a common site. Photo: N. A. Madhyastha.



'Draco' – a flying lizard found frequently in the Agastyamalai area. These are being caught and sold in hundreds by greedy specimen collectors. Photo: M. D. Subash Chandran.

A network team from Bhadravathi engaged in field work in Narasimharajapura range forest of Chikmagalur district.

An immense task

The task of inventorying and conserving biodiversity is immense, for valuable elements of biodiversity are not restricted to a few pockets, in a few national parks. Wild relatives of rice, for instance, occur in numerous wetlands dispersed over the Indian countryside and wild relatives of taros and yams are to be found along road verges. The insectivorous *Drosera* plants being quietly collected and exported to Japan occur in small rain puddles on sheet rocks all along the Western Ghats. So the task must truly cover all of the country, and concern itself as much with lowly lichens and leeches, mushrooms and mayflies as with tigers and rhinoceros.

Such a task cannot be carried out in a routine, centralized fashion for the ecological systems are highly variable in space and time, and must be investigated and more importantly managed in ways sensitive to this variation. So it is necessary to organize an effective network covering the entire country. Such a network will have to be erected on two pillars; the large numbers of students and trained biologists working as teachers in undergraduate colleges throughout the country and the even larger number of practical ecologists – fisherfolk and shepherds, dispensers of herbal medicine and rat-catchers who depend on living resources for their livelihoods[14]. If mobilized such a group will not only generate valuable information, of both basic and applied interest but the process will also serve as an excellent tool of training in science.

Western Ghats

In 1993 funds for such an experiment became available to me through an award as a Pew Foundation Fellow in Environment and Conservation[16]. The foundation provides to the fellow's institution an amount of $150,000

to be spent over a four-year period in a flexible fashion at the fellow's discretion. This support has been used to organize a network of undergraduate colleges, university departments, and NGOs to investigate the biodiversity of the Western Ghats. The hill chain of Western Ghats has been recognized as one of the World's 18 Biodiversity Hot Spots, i.e. a region of high levels of biodiversity under threat of rapid loss[17]. The Western Ghats are an island of tropical humid forest at a considerable distance from the large humid forest tracts of Southeast Asia, and harbour a large number of endemic species, i.e. species occurring nowhere else in the world. Inventorying, monitoring and conserving the biodiversity of the Western Ghats is therefore an important concern.

Along with the adjoining West Coast, the Western Ghats are a region of highest levels of literacy on the Indian subcontinent. It therefore has a large number of biology teachers, certainly well over 1000, many of them Ph D holders working in undergraduate colleges. I have been in touch with several of them over the years, having organized a successful project to evaluate the impact of the Western Ghats Development Programme with the help of students and teachers of 28 colleges in Karnataka[18] in 1990–91. So when the Pew Award funds became available I invited 45 biology teachers from the Western Ghats states of Maharashtra, Goa, Karnataka, Tamil Nadu and Kerala to consider the possibility of working together on biodiversity problems of the region. We met in Bangalore from 4 to 7 April, 1994 and agreed to collaborate. A series of intensive workshops, including several on field methodology followed. This has resulted in the establishment of the Western Ghats Biodiversity Network (WGBN) functioning in a co-ordinated fashion with a common methodology jointly evolved by the whole group.

Research methodology

This methodology involves the following elements:

1. Each team selects an area of about 25 km^2, preferably close to the location of their institution, for biodiversity studies. These study sites include examples of both relatively natural, as also human-impacted ecosystems.
2. These study sites are investigated as a landscape composed of different individual elements such as evergreen forest, moist deciduous forest, tree savanna, grasslands, ponds, seasonal streams/streamlets, habitation, etc. Initially different types of landscape elements are identified and mapped with the help of a Survey of India toposheet.
3. This landscape map is compared with a false colour composite of a satellite imagery and correspondence is established between ground truth and imagery. Certain ground control points which can be reliably located on the topographic maps and on the satellite image are identified, and ground truth ascertained in the vicinity of such points. The control points are used to correct the geometric distortion in the satellite imagery. All this information leads to generation of supervised classification of the landscape under investigation.
4. The landscape map serves to locate representative elements of each type of landscape element for an investigation of levels of species diversity in selected groups of organisms such as freshwater molluscs and insects, mosses, flowering plants, butterflies, ants, legless amphibians and birds.
5. These landscape maps are compared with information obtained on earlier status of the landscape from older topographic maps, satellite imagery, as also oral accounts of the local people to reconstruct the ecological history of the landscape.
6. Local people are interviewed to document their knowledge of occurrence and uses of various plant and animal species as also of local conservation practices. Also documented is their perception of ongoing patterns of landscape change, ongoing changes in biological communities as well as species of particular interest such as medicinal herbs, and their perception of forces driving these changes.
7. All of this information is put together to derive a picture of ongoing changes in biodiversity, forces driving such changes and of how local communities perceive these. Attempts are being made to use these as inputs for the development planning process at the panchayat, taluk and district levels to steer development on to a more environment-friendly course.

Network profile

The programme was kicked off with a 4-day methodology workshop held in field at the Integrated Rural Technology Centre of Kerala Sastra Sahitya Parishat at Mundur near Palakkad from 28 to 31 May 1994. It brought together 35 science teachers representing 27 institutions, with researchers from the Indian Institute of Science (IISc), M. S. Swaminathan Foundation (MSSF) and the Foundation for Revitalization of Local Health Traditions (FRLHT). These 27 institutions included 2 University botany departments, 20 undergraduate science colleges and 5 NGOs. Two of these NGOs were in fact channelizing funds to 2 more colleges. As Figure 1 shows the network spans the entire north–south stretch of the Western Ghats in the states of Maharashtra, Goa, Karnataka, Kerala and Tamil Nadu. It covers the elevational gradient from sea level to 1200 m; the greatest concentration being in the range of 0–600 m. The sites under investigation thus do not include higher altitudes above 1200 m. IISc, however, has a field station in the upper Nilgiris at an altitude of 2000 m, helping to fill this gap. The sites cover the rainfall gradient from 1000

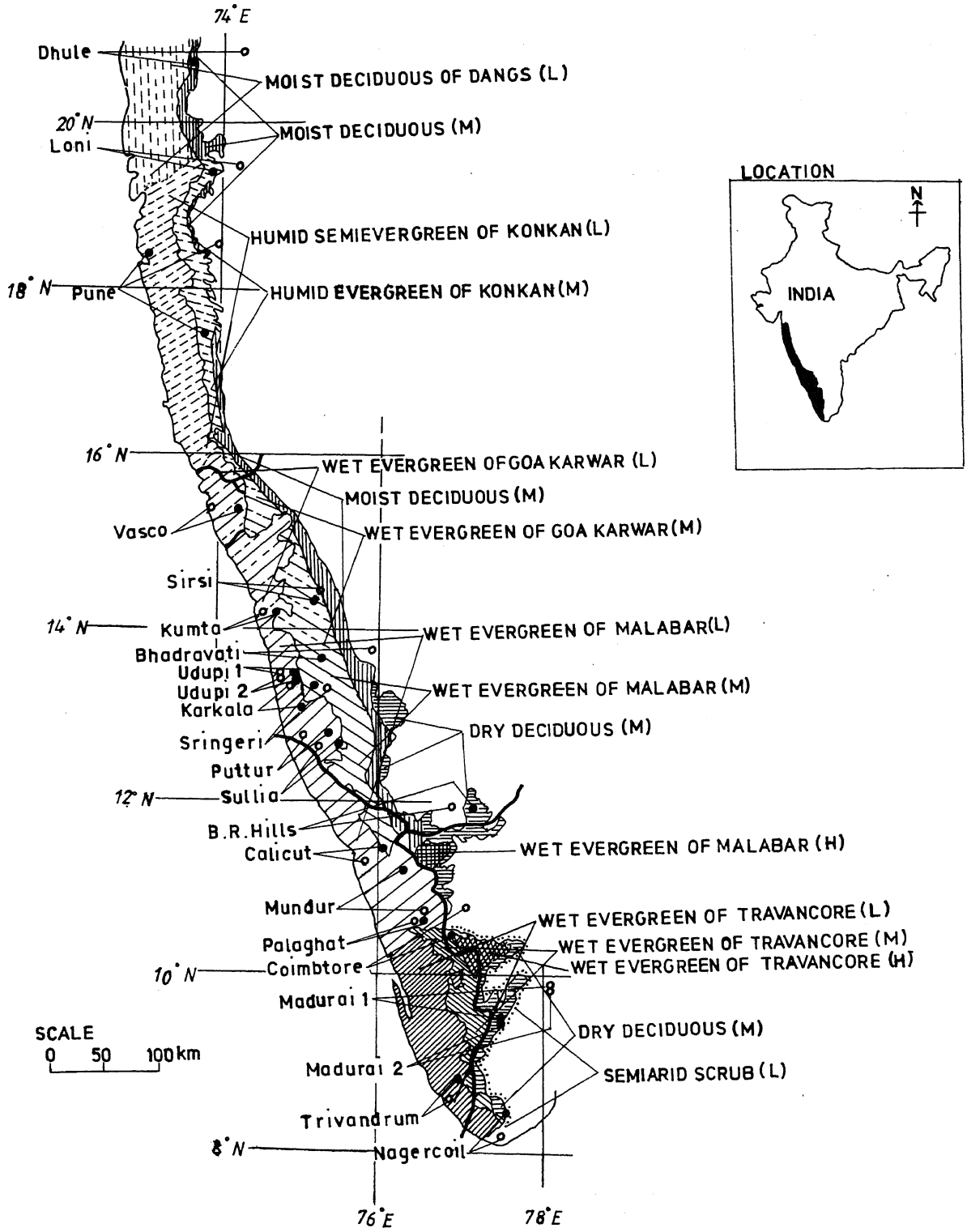


Figure 1. Study sites of the Western Ghats Biodiversity Network members in relation to the distribution of vegetation types. Open circles refer to the headquarters of the member institution, filled circles to the study sites. The letters L, M and H in brackets following the vegetation type refer to low (0–600 m), medium (600–1200 m) and high (above 1200 m) elevation zones.

to 6000 mm a year, as also over 3 to 8 dry months a year. The vegetation types investigated by the network span wet evergreen forests and various cultivations through moist and dry deciduous forest and scrub, leaving out only the high altitude sholas and grasslands; these are being studied through IISc's field station.

The actual study sites range from a distance of 10 to 200 km from the location of the institution involved; the median distance being 40 km. Most study sites are considerably impacted by human interventions; all of them however do retain some tracts of forest vegetation with near-natural composition. The landscapes are intricate mosaics of patches and linear elements. For our purpose only those above 2500 m^2 in size are recognized. These have been assigned to 45 types of terrestrial and 10 types of aquatic elements. The study sites are mosaics of several individual patches, belonging to 4 to 20 types. Of these scrub, disturbed moist deciduous forest and tree savanna are most widespread, occurring in 60% of the study sites; 5 other element types occur in only one site each.

Landscape ecology

Development of a standardized system of classification of landscape element types, their mapping in the field, leading to supervised classification of the satellite imagery on the basis of such a map been completed for 20 of the 27 study sites. The Regional Remote Sensing Service Centre (RRSSC) of the Space Department in Bangalore has played a key supportive role in this programme. Attributes of these landscapes are now being analysed with the help of Geographical Information System, and we should soon be able to publish a rather comprehensive study of the landscape of the Western Ghats as a result of the co-operative effort of WGBN in collaboration with RRSSC, Bangalore. The system of classification of landscape element types for this biogeographic province could be the starting point of developing a comprehensive system of this type for other parts of India as well[12].

Sampling biodiversity

Mapping of the landscape provides the context for field sampling of diversity in a variety of taxonomic groups. The attempt is to sample patches of all types of landscape elements with greater emphasis on types such as evergreen forest supporting higher levels of diversity. This sampling involves laying of quadrats of 10 m × 10 m at 40 m interval along transects 600 m long, if necessary in more than one segment in smaller patches. Birds and butterflies are sampled along the entire 600 m transect, while trees and other taxa such as ants and frogs are sampled in the quadrats. Freshwater molluscs and insects are being sampled in aquatic habitats through as yet unstandardized methodologies. Caecilians (legless amphibians) are also being sampled opportunistically in their preferred habitats, apart from quadrats.

Such sampling has progressed to varying degrees. A total of 250 transects have been laid over 25 study localities; sampling of trees has been concluded in 3000 quadrats of 100 m^2 each over these transects. Birds have been sampled along 75 transects in 15 study localities; butterflies along 90 transects in 15 localities. Some limited sampling of freshwater molluscs, fishes, mosses, freshwater insects, ants, caecilians, frogs and snakes has also been completed. Much of these data have been computerized using a common format; its analysis is now being initiated.

Practical ecological knowledge

WGBN has, from its inception, attempted to interact with and involve local communities in the exercise. An important component of the programme is to document the perceptions and knowledge of the local communities regarding the landscape over which they gather resources such as fuelwood and medicinal herbs, the status and ongoing changes in the soil, water and biological resources. This programme of community level documentation is being undertaken as a part of the larger countrywide exercise of 'Community Registers' initiated by FRLHT. Based on the field experience gained over the first year, a 4-day field methodology workshop on community register was held at Phansad Wildlife Sanctuary in Raigad district of Maharashtra in August 1995 under the leadership of K. C. Malhotra and M. K. Prasad. Following this workshop systematic case studies of 4 localities have been initiated. At a more general level such documentation continues in all localities. The use of plant poisons to collect fishes and protection to sacred *Ficus* trees is being comprehensively documented in many of the localities.

This exercise of community register includes an important component of local knowledge of changes taking place in the landscape and forces driving these changes. These changes are related to changes in levels of biological diversity deriving from habitat changes, as well as changes due to direct exploitation of biological resources. Local people are then encouraged to propose how they would like to see the processes of landscape transformation and of changes in biodiversity regulated. It is hoped to use these proposals as inputs to the decentralized processes of management of natural resources at the panchayat and district levels. It is also hoped that the documentation of the knowledge of uses of elements of biological diversity by local communities could aid in their sharing in the benefits of commercial uses of this diversity within the framework of the Convention on Biological Diversity.

Capacity building

WGBN has elicited enthusiastic participation by a number of undergraduate science teachers and students. The field work is spearheaded in some cases by committed teachers, in some other cases students are the driving force. A total of 300 students were reported to have participated in the field work; of these 206 students have been active throughout. Five of the students involved have taken up special projects on their own, on bird and butterfly communities, attributes of tree bark and local knowledge. A total of 33 teachers belonging to zoology (19), botany (10), statistics (2), computer science and economics (1 each) have participated; of these 20 have been particularly active. Seven of these active teacher participants were invited by the Museum of Natural History in London to work at their collections over a six-week period in June–July 1995. They were accompanied by one scientist each from the Botanical and Zoological Surveys of India. We are thus in the process of establishing active collaboration with the Surveys to help in identification and build systematic-biological capabilities at the colleges.

Strengths and weaknesses

Experience of the network over the last 18 months has helped us understand both strengths and weaknesses of the institutions involved. University post-graduate departments are very much dependent on Ph D student research and cannot readily involve in a co-operative programme of this type. NGOs, especially those dependent on one or few active individuals are also at a disadvantage. Under-graduate science colleges, can, however function very effectively in such a programme. There are of course certain limitations. Currently all such activity has to be on a voluntary basis, since no academic credit is available for such field research. Therefore, teachers and students can spend a limited amount of time in the field, and this has to be fitted in with the annual calendar so as not to interfere with the examinations. Given these limitations, their performance has been very encouraging. Two hundred students and 20 teachers who are more serious have put in about 4000 total person days of field research over the first year, i.e. 18 field days per head per annum. As the methodology gets well established, they may be able to do better, and we may expect each individual teacher and student to put in 30 days of field work per academic year. Given that there are over 6000 undergraduate science colleges in India, this could amount to a substantial contribution.

The programme started off with 20 colleges, 5 NGOs and 2 University Departments. Of these 3 colleges, 1 NGO and both the University Departments have withdrawn after completing some limited amount of work. But 17 colleges and 4 NGOs have done well and are keen on long term continuation of such a programme. We had initiated the network by contacting 45 institutions, of these 27 could be invited to actively participate because of limitation of funds. Of the 27, 21 continue, and at least 12 have performed extremely well. I believe this to be a very encouraging success rate.

Financial outlays

The investments required for the programme have been very modest. Each institution has used between 20 and 30 thousand rupees (700 to 1200 US dollars) per year to support the field work and computerization of the data. The Indian Institute of Science has provided additional support to the network with the help of 2 full time staff, training programmes and literature at the cost of some Rs 300 thousand (10,000 US dollars) per year. These modest financial outlays have yielded substantial dividends.

International programmes

India, along with 125 other countries is a party to the Convention on Biological Diversity and therefore committed to inventorying and monitoring levels of biological diversity, record this information in computerized data bases and use it to develop strategies of conserving biodiversity[12,13]. India has also agreed, as a member of the Commission for Sustainable Development, to implement decentralized programmes of integrated environmental assessment as a part of Agenda 21 (ref. 19). Programmes being undertaken by WGBN could be a useful model for organizing such activities within the country, and perhaps elsewhere in the world as well. These programmes also deal with several elements of a major international scientific effort, Diversitas, being co-ordinated through UNESCO, ICSU and IUBS[20]. It is hoped that WGBN would develop in the years to come mutually beneficial links with such international efforts.

Prospects

A great deal could and should be done to take this experiment further. We need to create in our educational system much greater flexibility to encourage original research by teachers and students, especially at the undergraduate level. Such work should be rewarded by academic credit. As argued above, field work on soil, water, biological resources could form a most valuable component of such research. Such field work needs to be promoted by greater flexibility of teaching schedule.

Institutions of higher learning and scientific agencies such as Botanical and Zoological Surveys of India need

to be encouraged to actively work with undergraduate colleges in such programmes, perhaps through award of special grants. At the same time, we need to create mechanisms for using the results of such research as inputs for a decentralized process of development planning at the Panchayat and District Levels. Programmes such as District Level Units of National Natural Resource Management System of the Department of Science and Technology and Paryavaran Vahinis of Ministry of Environment and Forests could fruitfully collaborate with such efforts.

While much thus remains to be done, there are many hopeful signs of progress in these directions, with a much greater interest in nature study amongst the younger students and a strengthening of the Panchayat Raj Institutions. We must now make serious efforts to explore these spaces, and to infuse genuine vigour in our scientific investigations, as well as efforts at taking good care of our natural heritage.

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