Inventorying, monitoring and conserving India's biological diversity

Madhav Gadgil

An International Convention on Biological Diversity has come into force on 29 December 1993; India ratified and joined it on 18 February 1994. All countries party to the convention are committed to undertake identification and monitoring of the components of biological diversity important for its conservation and sustainable use, and to institute measures for *in-situ* conservation, with special efforts to involve indigenous people and local communities as partners in these efforts. The relevant provisions of the Convention primarily contained in Articles 7 and 8 and Annex I are reproduced in Appendix. Of course, India has for long been engaged in a variety of initiatives in all these contexts, ranging from activities of the Botanical and Zoological Surveys and National Bureaus of Plant, Animal and Fish Genetic Resources to a network of protected areas covering well over 4% of the land surface as well as marine ecosystems such as the Gulf of Mannar. But the scale and scope of activities that the Convention calls for, and the country's own economic interests dictate in view of the new regimes of national sovereignty over genetic resources, patenting of life forms and the substantial promises of biotechnology are quite unprecedented. Moreover, the effort must now widen its focus in several ways: from concern primarily with vertebrates, flowering plants and cultivated crops to a whole range of lesser known smaller invertebrates, lower plants and wild relatives of crop plants; from concern primarily with protected areas to the entire landscape, waterscape and seascape of the country; from reliance on traditional taxonomic practices to use of new techniques like DNA fingerprinting and remote sensing coupled to the computerized information systems, from concern primarily with preservation to conservation along with sustainable use, from an activity largely in the hands of a technocracy to one involving people of the country as a whole.

We must also address another challenge. India, along with China, Mexico and Brazil is amongst the few biodiversity-rich countries with very high levels of scientific capabilities, whether in taxonomy, molecular biology, remote sensing or software engineering. In the present day context of the world coming together we must therefore not only develop the relevant scientific methodologies, skills and programmes for ourselves, but share them especially with other biodiversity-rich countries of Asia, Africa and Latin America.

It is indeed appropriate to set before us the following five major objectives:

(i) Organize a conservation science that will aid in effective conservation action within the country;
(ii) Involve a wide cross-section of the Indian academic community, not only taxonomists and ecologists, but also computer scientists and social scientists, not only surveys and research institutions, but also schools, colleges, universities and NGO's, in such conservation science-oriented activities;
(iii) Develop conservation science as an effective device for involving masses of people in a scientific culture;
(iv) Encourage in India development of conservation science-related enterprises such as software for multimedia biodiversity data bases or chemicals for DNA fingerprinting;
(v) Deploy Indian expertise in conservation science especially in other biodiversity-rich developing countries thereby generating substantial additional resources for Indian conservation science.

A group of Indian biologists recently got together for a 3-day period beginning 9 March 1994 to address themselves to these five objectives at the behest of the Ministry of Environment and Forests of the Government of India. In a meeting sponsored by the Jawaharlal Nehru Centre for Advanced Scientific Research on the campus of the Indian Institute of Science in Bangalore this group of 30 included scientists from the Botanical and Zoological Surveys of India, National Botanical Research Institute, G. B Pant Institute of Himalayan Environment and Development, Tropical Botanical Garden and Research Institute, Salim Ali Centre for Ornithology and Natural History, Wildlife Institute of India, Indian Institute of Science, Universities and colleges located in Aligarh, Bangalore, Madurai, Pasighat (Arunachal Pradesh) and Patna, Karnataka Forest Department and NGO's such as Kerala Sastra Sahitya Parishat (KSSP) and Federation for Revitalization of Local Health Traditions. This article is based on the collective wisdom generated at this meeting

The challenge

Inventorying and monitoring biodiversity is in itself an immense task; ensuring its conservation in the face of multifarious pressures is mind-boggling. But these are challenges that can and must be turned into important opportunities. First consider the magnitude of diversity of living entities. There are in the world somewhere between 10 and 30 million species of sexually reproducing organisms, each of whose members is probably unique in its genetic constitution. There are at the least tens of thousands of species of lower asexual organisms, and we understand very little of the extent of their genetic variation. Life flourishes in our part of the world, and India would harbour at least 2%, more likely 5–8%, of this variation commensurate with its share of the land and oceans on the earth. That means of the order of 500000 species, only about 20% of which are as yet described, and considerable genetic variation within each species. If we are to attempt to document this in terms of traditional taxonomic effort, coupled to some modern chemotaxonomy or DNA fingerprinting, the task is simply hopeless. So while such work must go on, ever more vigorously, we have to decide on a strategy of sampling this taxonomic diversity.

This taxonomic diversity is further organized into communities of interacting organisms that differ greatly from one ecosystem such as a temporary pond to another, for instance, humid forest on a hill top. Mosaics of wide variety of ecosystems make up specific landscapes. Thus a typical Western Ghats landscape may include human habitation, paddy fields, betelnut orchards, eucalyptus plantations, scrub savanna, patches of humid forests with different degrees of canopy cover, streams, swamps and ponds plus barren rocky outcrops. That landscape would differ markedly from the landscape of the Deccan plateau, the Coromandel coast, Gangetic plains, the desert near Jaisalmer or the coral islands of Lakshadweep. Even similar landscapes, for instance, of hilly humid forest tracts of Kerala and Meghalaya may harbour quite different sets of organisms. Indeed several islands of the Andaman-Nicobar chain harbour species found nowhere else in the world. We can now document much of this landscape level variation at a very gross level of several hectares using remote sensing coupled to geographical information systems. But with India's 320 million hectares of land mass and 202 million hectares of exclusive economic zone in the sea, that too is an immense task, requiring some appropriate sampling of the spatial diversity as well.

There is yet another important consideration and this is the great variation in relationship of people to biodiversity and to ecosystems. Annex I of the biodiversity convention lists categories that should be focused on. These include ecosystems and habitats of species and biological communities and genes and genomes that are of social, economic, cultural or scientific importance. The perception of this significance varies greatly amongst different segments of the society. For local communities with limited market access, a wide range of local ecosystems and biodiversity resources are of high value for the quality of their life. For outsiders, the only resource of value from that locality may be pine resin or eucalyptus pulpwood. Only a highly decentralized system of recognizing values of various ecosystems and biodiversity elements could then do justice to such tremendous variation.

A significant beginning in the direction of such decentralized monitoring of ecosystems has already been made by the Panchayat level resource mapping programme in the state of Kerala. In this programme, jointly initiated by the Centre for Earth Science Studies in Trivandrum and the KSSP, villagers map the landscape and waterscape of their localities on cadastral maps on the scale of 1:7000. These maps then serve as the basis for identifying problems like soil erosion or groundwater depletion and carefully working out locality-specific development interventions. Bharatiya Gyan Vigyan Samiti (BGVS), an all-India NGO involved with post-literacy programmes has now begun extending this activity to districts such as Purulia in West Bengal outside the state of Kerala as well. KSSP and BGVS have also experimented successfully with organizing village level information on local medicinal plants as part of literacy programmes. Combining these two approaches one can visualize a nationwide village level programme of mapping of the natural and man-made habitats on the scale of a hectare or so, and inventorying some elements of biodiversity such as cultivars and wild relatives of cultivated plants and medicinal plants in each type of habitat present in the village.

Sampling habitats

Satellite imagery, including that generated by our own IRS has in theory resolution down to less than a hectare; but in practice can be used to identify landscape elements in the size range of 10 ha or so, as well as much narrower linear elements like streams and roads. Fully automated programmes of identification of such elements are possible, but would inevitably lead to serious errors, such as a gorge being identified as a ridge, or a tea garden as rain forest as happened with an early effort of mapping the Silent Valley forest by NRSA. But an interactive programme of field-based ground truthing combined with semi-automated identification can lead to a reasonably reliable classification of all the land and water surface of the country into landscape patches on the scale of a few hectares. Ideally this should bring together highly sophisticated organizations such as the National Remote Sensing Agency or the Space Application Centre and Remote Sensing Groups from Indian Institutes of Technology at Bombay or Kharagpur with a massive decentralized programme of generating the training sets for the identification exercise from the Panchayat level resource mapping programme sketched above. That is how science could begin to involve our country's masses and acquire a new and higher level of vigour.

This effort requires inputs from a serious ecological effort at a hierarchical classification of the landscape elements of the entire country. The different hierarchical categories may then go as: (i) forest, (ii) canopy cover class 40–60%, (iii) deciduous, (iv) Terminalia-Anogeissus-Tectona series, or (i) scrub-savanna, (ii) srub cover class 10–20%, (iii) predominantly thorny, (iv) Acacia-Zizyphus series; or (i) wetland (ii) perennial (iii) size class 5–10 ha, (iv) Eutropic, no floating weeds. Some attempts along these lines have been made by NRSA in its wasteland maps, or the French Institute of Pondicherry in its vegetation maps. We will have to build on these to generate a classification powerful enough to cover the entire country.

Given such a classification we can devise a scheme of sampling the different landscape elements of the country for generating an inventory and for monitoring biodiversity changes. Such a sampling scheme would need to take into account the following factors: (i) Extent of similarity of the different landscape elements in their biodiversity complements, as well as contribution to the quality of human life. The sampling should attempt to cover as wide a diversity of elements as possible. More unique elements such as mangrove forests would then be sampled more intensively. (ii) Levels of biodiversity and contribution to quality of life. The sampling should give higher weightage to the more important elements such as coral reefs. (iii) Rarity: Rarer elements such as the few surviving patches of Deccan thorn forest may be sampled at higher rates. (iv) Rates at which particular types of elements are being transformed into other less diverse or important types. Emphasis should be on the more critically threatened elements such as wetlands of Brahmaputra valley. (v) Feasibility of maintaining diversity or contribution to the quality of life. Emphasis should be on elements that could be managed more effectively to maintain or enhance their diversity levels or contributions to quality of human life, for instance high altitude pastures in Himalayas.

This would not be a programme of one-time sampling of different habitat elements, but a continuing component of the monitoring programme. It should be linked to a geographical information system-based computerized information system. Development of such a system, perhaps based on object oriented data bases could be an important challenge that India's vigorous software industry could profitably take up.

Sampling taxa

The major focus of biodiversity inventorying effort thus far has been on preparing lists of species, mostly of a few well-known groups of organisms such as flowering plants and birds at the level of regions such as states and districts, and less frequently smaller localities like a National Park. As suggested above, the focus in space should now shift to sampling of more carefully selected landscape elements and in time the sampling should be repeated at some defined interval to monitor changes. At the same time, it is impossible to adequately sample all taxa in any given sampling locality and careful selection of taxa should be made based on considerations of (a) representativenes, (b) ecological significance, and (c) human significance.

Representativeness should be viewed along three dimensions – phylogeny or evolutionary lineages, habitat preference and functional role. Biotechnological applications in the future would be looking for as many distinctive genes as possible. Since each distinctive evolutionary lineage is presumably based on some set of distinctive genes, it would be useful to bring in as many evolutionary lineages as possible within the gamut of the proposed sampling programme. Such a sampling strategy should be grounded in the phylogenetic trees constructed on the basis of molecular information. This would have some immediate implications. For instance, archaebacteria are an evolutionarily very distinct lineage which has hardly been investigated. It must find a place in our sampling scheme. Secondly, the major taxa should be classified in terms of their occupation of all major habitats such as ocean sediment, open sea waters, rocky intertidal zone, muddy intertidal zone, swamps, deep soils, rocky outcrop and so on. We should so select the taxa that we have representation of those occupying all the variety of habitats. Thirdly, any given organism plays a distinctive ecological role such as anaerobic decomposer, detritus feeder, primary producer, sit-and-wait predator, active carnivore and so on. We would have to prepare a proper inventory of all such roles the members of different taxa play and then ensure that our sampling strategy leads to an adequate representation of the groups playing various roles.

Apart from ensuring representation of different evolutionary lineages, habitat occupancy and functional role, we might like to enhance representation of taxa with attributes of some special interest. Four such deserve mention, namely, keystone resources, indicators, endemic and rare taxa. Keystone resources are those taxa whose presence promotes the presence of a number of other taxa in a biological community. Thus in tropical forest biomes there are periods of year with very low availability of fleshy fruits for fruit-eating birds and mammals like barbets, fruit bats and monkeys. Several species of *Ficus* which fruit in such pinch periods may be critical for the persistence of the frugivore species, and have therefore been termed keystone resources. However, given our very limited knowledge of community interactions it is doubtful if we can effectively identify such keystone resources in thousands of contexts in which they may occur. There is in my mind a very similar problem with the notion of indicator taxa. These are considered to be taxa particularly sensitive to erosion of diversity from biological communities. Thus lichens are known to rapidly disappear with atmospheric pollution. This really amounts to a bioassay of environmental change and not necessarily of changes in overall diversity levels. It is therefore open to doubt whether either keystone or indicator taxa could be identified to effectively help in devising more meaningful sampling or conservation strategies.

It is possible to define rare and endemic taxa with a higher degree of confidence, although even in these cases our stock of knowledge is exceedingly limited. Rare taxa are those with very low population levels either because they have a very restricted geographical range (such as the Nilgiri Langur confined to southern Western Ghats), maintain rather low population densities everywhere (such as the King Vulture) or occur in very restricted habitats (such as the tree species *Myristica fatua* characteristic of swamps in evergreen forests of southern Western Ghats). We may want to specially include such rare taxa in diversity monitoring programmes. The major limitation, of course, is that such information is available only in the case of a few well-known groups of organisms such as birds, mammals and flowering plants. This difficulty also applies to endemicity. An endemic taxon is one with a restricted distribution. Thus a national endemic is one wholly limited to India or a regional endemic one restricted to a defined region such as South Asia. Given that countries now have national sovereign rights over their biodiversity resources, taxa entirely confined to our political limits surely are of interest. However, we may, through appropriate co-operative arrangements with neighbouring countries be able to take good advantage of regional, not just national endemics. Furthermore many more taxa of invertebrates and lower plants of which we know so little are likely to have far more restricted distributions and hence be endemic in comparison with better known vertebrates and higher plants. Focusing on known national endemics may then be only of limited significance.

To flesh out this abstract scheme will require a careful look at firstly the taxonomic diversity of organisms in terms of evolutionary affinities, habitat preference and ecological role and secondly at the availability of taxonomic expertise within the country. The latter is clearly woefully inadequate given the magnitude of the task before us. For instance, we do not have a single taxonomist specializing in soft corals – a group of organisms of great interest to the pharmaceuticals industry. An immediate task would then be to prepare a biodiversity expert database for the country on the pattern of the first rate information system on mangrove ecosystems developed at the Dr M S Swaminathan Research Foundation in Madras. Such a database would permit us to identify major lacunae in terms of both taxonomic groups and geographical coverage of the country.

How may we then proceed to bridge the gaping holes that such an exercise would uncover? One approach could be to pour in a lot of money, train thousands of young biologists and then employ them in centralized agencies such as Botanical and Zoological Surveys of India. But our experience of such centralized institutions under state patronage is not a very happy one. An alternative could be to tap the talent of the tens of thousands of master's degree holders in botany, zoology, microbiology who are employed in the several thousand undergraduate colleges distributed throughout the country. These college teachers have adequate background and sufficient free time to cultivate serious taxonomic expertise if we create the right conditions. After all two of India's leading taxonomists, T. N. Ananthakrishnan and Cecil J. Saldanha have worked for most of their lives in undergraduate colleges. We may then think of devising special training programmes to train such biology college teachers who voluntarily come forward in specially identified taxonomic groups and then give them special grants to develop adequate facilities in their colleges and to travel to major herbaria or museums during their vacations. Such a decentralized programme of nurturing taxonomic expertise will have several advantages. First, it will save enormous travelling expenses incurred by scientists working in centralized agencies. Secondly, if a college teacher ceases to be active, his or her special research support can be terminated: something that is not possible with a scientist employed in government institutions. Finally, these taxonomic experts can work in close touch with the barefoot ecologists involved with the Panchayat level bioresource mapping programmes suggested above.

Human concerns

Human societies have been interested in biodiversity in part for its own sake, but much more significantly for its contribution to human welfare. The latter may be viewed in three ways. Biodiversity may contribute to human well-being through its commercial application, be it in modern pharmaceutical industry, or through fabrication of cane furniture by rural artisans. It may supply commodities used outside of market framework, be it as food or herbal medicine. Thirdly, it may enhance the quality of human habitat through aesthetic, social, cultural, scientific value.

The sampling strategy ought to take into account these various values and specially include taxa possessing high levels of such value. It must of course be stressed that many organisms today considered insignificant may tomorrow acquire substantial value. Thus bamboos were once being eliminated as weeds by forest managers, although they have always had many subsistence uses for the rural population, and subsequently became very important as a raw material for paper industry. Nevertheless, it makes sense to pay special attention to taxa like wild relatives of crop plants and plants and animals used in folk medicine, as wild foods or by rural artisans. The sampling scheme must also focus on husbanded plants and animals. In this case it needs to go down to the level of cultivars/animal breeds.

Biodiversity also has social and cultural values attached to it. Some years ago scientists of the Botanical Survey of India discovered an undescribed species of the first Indian record of the genus *Kunstleria* in a sacred grove in Kerala. Trees of genus *Ficus* are widely regarded as sacred throughout India, as are primate species. Such taxa should receive special attention, along with habitats maintained as sacred groves and ponds.

Study parameters

The considerations outlined above would permit us to decide on where and which organisms should be sampled. We additionally need to decide more specifically on how the sampling should be carried out, how often, and what parameters should be studied in the field and with respect to selected organisms. Much of this would have to be decided upon in the context of specific taxa and ecosystems. Thus once a year sampling may suffice while investigating ant or tree species, but not in case of seasonally much more variable taxa such as butterflies or planktonic algae. By and large the sampling effort should be such as to effectively sample the overall diversity under investigation.

We also need to think of the parameters to be determined with respect to individual organisms. Should it stop with sorting into possible species or higher categories like families or even orders? Should we be content with sorting into 'operational taxonomic units', or with serious attempts at identifying and naming the taxa? Or should we link such sampling to possible programmes of utilization in the spirit of biodiversity prospecting? That would call for preparing alcohol or other suitable extracts from concerned organisms, and their screening. Finally, it may be considered appropriate to subject the taxa to DNA fingerprinting to more firmly establish their identity, although no species-specific DNA probes are known as of today. Such options should be assessed in relation to possible commercial utilization, as well as the need to establish national sovereign rights over specific organisms and the costs of organizing such investigations.

Periodic monitoring

Monitoring biodiversity change would have to include three elements: (a) relative levels of diversity in different types of landscape elements, e.g. natural deciduous forest, teak plantation, eucalyptus plantation, scrub savanna, or sorghum field (b) Rate at which one kind of landscape element is being converted into another, and (c) rate at which diversity levels are changing in a given kind of landscape element, for instance, bird diversity of natural deciduous forests, or teak plantations may be declining with time because of the increased levels of pesticide residues in the environment, or because no more dead trees are retained to furnish nesting holes.

Periodic field monitoring in conjunction with remote sensing as well as in the field should be designed to answer all these three questions, which would ultimately give a clue to the broader trends of changes in biodiversity levels. Furthermore, it would be of great value to try and reconstruct such pictures for the past few decades on the basis of ecological histories provided by knowledgeable members of local communities. Our attempts to reconstruct the ecological history of Nilgiri hills have indeed demonstrated that local people can with considerable assurance reconstruct changes in any locality over the last three decades or so. Indeed such information may only rest with people living close to earth such as river fishermen. Thus, Kaliappan, who has fished the Moyar river in the Nilgiris for the last 40 years was able to recount to us in great detail changes in the cross-section of that river, in its water flow regime, in its quality of water, and composition of the fish fauna. He could also relate the changes in fish fauna to reduction in certain habitats and increase in others in ways that were entirely convincing to the ichthyologists. But ichthyologists have looked at only a minute sample of country's freshwater streams, indigenous fisherfolk have been fishing most of them for generations. Combining this folk knowledge with modern scientific knowledge is a major challenge before the genius of the Indian scientific community.

Assigning values

The programme sketched above ought to result in an optimal use of scientific effort coupled to tapping folk ecological knowledge to reconstruct ongoing changes in the landscape and waterscape of India, and in the biodiversity that it harbours. One needs to assign values and arrive at priorities before this information base can be translated into a conservation strategy. One step in such an exercise would be to assign values to individual elements of biodiversity. These elements may range from an enormous banyan tree – perhaps the country's largest, a population of musk deer in Nanda Devi Biosphere Reserve, or a cultivar of finger millet in Ananthpur district of Andhra Pradesh. The values might be assigned on one or more of the following kind of criteria:

(a) *Taxonomic distinctiveness*: *Gnetum ula* a climber of Western Ghats which is only one of two gymnosperm species on Western Ghats may be valued more on grounds of taxonomic distinctiveness than a vine of wild pepper, *Piper nigrum*.

(b) *Endemicity*: Nilgiri tahr, an ungulate species restricted to southern Western Ghats may be valued more than the Himalayan tahr which also occurs in neighbouring countries.

(c) *Rarity*: The relatively rare *Bentinckia* palm from southern Western Ghats may be valued more than the widespread palm species *Phoenix sylvestris*.

(d) *Threatened status*: Liontailed macaque, threatened by the fragmentation of its rain forest habitat may be valued more than the widespread and more adaptable bonnet macaque.

(e) *Economic potential*: *Artocarpus hirsutus*, a wild relative of jackfruit may be valued more than another tree species, say *Holigarna arnottiana*, of evergreen rainforest.

(f) *Cultural value*: *Ficus* species may be specially valued because of their widespread sacred status.

Specific landscape elements may be valued in terms of the value of biodiversity elements they harbour along with other ecosystem services or human values they may be assigned. Thus a forest swamp may not only harbour important endemic species like *Myristica fatua*, but may also be important in regulating stream flows. It may be additionally valued as part of a sacred forest site.

Such value assignment would permit the information on on-going changes in the country's landscape and waterscape and in biodiversity levels to be translated into an assessment of the significance of such changes. Such an assessment would point to contexts in which the changes are nothing to be worried about and others in which they are leading to serious erosion in biodiversity levels, or in ecosystem services or in contribution to quality of human life.

Designing a conservation strategy

This information would then be the basis of designing a conservative strategy. The strategy must of course pay attention not only to what changes must be arrested and what promoted, but also what is feasible in practice. One may apply the triage principle developed in the Second World War to make the final choices of action in this context. The triage principle addressed the wounded who needed treatment. The first category was those not very seriously wounded who would survive without special medical care, the second those wounded seriously with a good chance of survival given medical care and the third wounded so seriously that there was little chance of survival even with special medical care. Conservation action may similarly focus on those habitats or taxa whose loss would be significant, but whose preservation is still a practical proposition, is not too hopeless.

Conclusion

I have tried to set down above a whole range of methodological and organizational issues based on what I have been able to gather together of the wisdom of my scientific peers, as well as of the tribals, fisherfolk, herders and farmers in many parts of the country. This whole endeavour of documenting and conserving the immense riches of the country's biodiversity offers unparalleled opportunities for developing a vigorous, people-oriented culture of science while taking good care of our precious heritage. I can only hope that this article would serve to catalyse a vigorous debate in the country on how we would meet this significant challenge of the day.

ACKNOWLEDGMENTS I am grateful to the authorities of the Ministry of Environment and Forests who induced me to undertake this exercise, and especially to T N. Khoshoo, the Chairman of the committee. I am grateful to the following participants at the discussion meeting whose collective wisdom was distilled above: J. R. B Alfred, T. N. Ananthakrishnan, P. C. Bhattacharjee, R. J. Ranjit Daniels, Darshan Shankar, V. Dhar, R Gadagkar, K. Gopinath, A J. T. Johnsingh, N. V. Joshi, K. S Murali, V. Nagaraja, V. Nanjundiah, N. J. Pillai, M. K. Prasad, S. N. Prasad, P. Pushpangadhan, A. R. Rahmani, S Rajendran, B. A Razi, B C. Sabata, C. J. Saldanha, A R. K. Shastri, K. G. Sivaramakrishnan, R. K. Sinha, R Sukumar, R. Uma Shaankar, D. K. Upreti and D K. Ved.

The Ministry of Environment and Forests, Government of India, Indian Institute of Science and the Jawaharlal Nehru Centre for Advanced Scientific Research have financially supported this effort.

Appendix. Convention on biological diversity (5 June 1992)

Article 7. Identification and monitoring

Each contracting party shall, as far as possible and as appropriate, in particular for the purposes of Articles 8 to 10