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Ecology in India: Retrospect and Prospects

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INTRODUCTION

It is a privilege for me to deliver the Professor R. Misra Birth Centenary Lecture 2010. Professor Ram Deo Misra (1908–1998) was among the few who are able to establish an entire subject across a country. He has been rightly called 'Father of Ecology in India'. Today, ecology in India owes its presence in all Indian universities to the foresight and untiring efforts of R. Misra who contributed to its development and growth at a time when, as a subject, ecology was much maligned and absent or ignored in teaching curriculae in the country. He trained numerous young researchers by organizing training courses and influenced many more through his lectures. Thus he fostered ecology to become a major discipline for teaching and research in traditional university departments. I had the opportunity of being associated with him for many years; in fact he shaped my career and that of numerous others. There are no words to describe his dedication and commitment to ecology and his benevolence. In this address, I will briefly deal with how the discipline of ecology took roots in India, and will recount some of the major researches which have helped us in understanding the nature of Indian ecosystems and the ecological processes. I am certain that this account will remain incomplete and I apologise in advance for omissions. I shall also endeavour to place before you the possible and desirable future course of development in the subject. For further information following sources may be referred to: Singh (1991), Singh and Singh (1995) and Mohan Ram (2010).

EARLY HISTORY

Although 'Ecology' is a relatively young branch of biological sciences, as a philosophy or view point its roots lie in antiquity as evident from frequent references to conservation and balance of nature in our Vedic and Pauranic literature. As a science, however, it began developing around the first decade of the twentieth century, although floristic accounts had begun to accumulate following the establishment of Botanical Survey of India in 1889 and faunal accounts following the establishment of Bombay Natural History Society (BNHS) in 1883 (in fact BNHS was the only major organization concerned with wild life studies until the establishment of Wildlife Institute of India in 1982). Initially, European foresters working at the Forest Research Institute, Dehradun (established in 1906) contributed to the ecological literature; for instance, in 1911 R.S. Hole described ecology of forest grasses, and in 1916 he considered environmental effects on the regeneration of *Shorea robusta*. Basic information on the biology and regeneration of trees accumulated rapidly, leading to the publication in 1921 of the two volumes of a monumental book 'Silviculture of Indian Trees', written by R.S. Troup. H.G. Champion proposed the first ever classification of Indian forests in 1936 which was later revised by Champion and S.K. Seth in 1968. Between 1938 and 1942, N. L. Bor published several papers on the vegetation of different parts of India.

By 1920 faculties in some colleges began to be attracted to ecology. The dramatic seasonal changes in the structure and composition of vegetation of the Gangetic Plains, led W. Dudgeon, of Ewing Christian College, Allahabad, to propound the concept of 'seasonal succession' in 1920. At the Allahabad Agricultural Institute, in 1921, L. A. Kenoyer began to study the forest formations in the central Himalaya, and in 1925 Dudgeon and Kenoyer visualized a multiple climax; for example, while describing the forest vegetation of Tehri-Garhwal, they regarded *Pinus roxburghii* and *Cedrus deodara* forests as edaphic climaxes occurring within a 'Broad-leaved Sclerophyll Climatic Climax' of oaks. As early as 1922, W.T. Saxton of Madhavlal Ranchodlal Science Institute, Ahmedabad, had visualized "mixed formations in time". The influence of altitude-and climate on plant performance was reported by S.R. Kashyap, who gave an account of the alpine vegetation in his General Presidential Address to the 19^{th} Indian Science Congress at Bangalore in 1932.

The years 1936-37, which marked the return to India of F.R. Bharucha, and of R. Misra, after their postgraduate studies abroad, proved a milestone from where onwards ecology in India showed sustained development and continuous diversification. Bharucha completed his Doctoral work at the Montpellier University with J. Braun-Blanquet, and Misra at the Wray Castle, U.K. with W.H. Pearsall, FRS. Bharucha and Misra made significant contributions to the teaching of ecology, and established vigorous university centres of ecological research. Their students continually established themselves at other locations.

ECOLOGY TAKES-OFF AND DIVERSIFIES

R. Misra pioneered ecological studies on low-lying lands, ravines, ponds, and herbaceous plant populations during the period 1937 and 1946. He laid the foundations of both field and experimental ecology in India, and in the process established the oldest, actively continuing centre of ecology research and teaching at the Banaras Hindu University (BHU). Amongst the significant observations made during this early phase are the occurrence of the alternation of hydrosere and xerosere in low-lying areas, relating the changes in species composition of the successional stages to habitat changes brought about both by autogenic and allogenic influences and the first experimental report of population differentiation in plants. Through a series of elegant experiments, it was shown that *Lindenbergia polyantha* and *L. urtaecifolia* are ecotypes dependent upon available calcium in soil. This study was a precursor of the autecological researches which were conducted later at many centres. Misra integrated the habitat adaptations with varying genotypic and phenotypic plasticity of plants in response to environmental conditions.

Misra moved to Saugar University in 1946, and soon a strong centre emerged there for researches on synecology of forests and grasslands. There developed new perspectives on sociology of plant communities and their edaphic control. Notable products from this centre, who established new centres elsewhere later, are S.C. Pandeya, L.P. Mall and M.C Joshi. A full paper in 'Plant Ecology' at the postgraduate level, for the first time anywhere in India, was introduced at this University in 1947. G.P. Mishra, a student of Mall, continued at Saugar. Products of this centre, J.S. Rathore, S. Bhatnagar among others, also contributed to the establishment of the 'Environmental Biology Department' at Rewa. M.C. Joshi, who completed doctoral work with Misra in 1958, made significant contributions to desert ecology at the Birla Institute of Technology and Science, Pilani.

While working at the Royal Institute of Science, Bombay, Bharucha introduced the methodology of Zurich-Montpellier School of vegetation analysis in this country. He contributed extensively in the 1940s and the 1950s to the understanding of the eco-physiological aspects of diverse communities such as grasslands, deserts, calcicolous association and nitrophilous plants. The work of the Bombay School radiated to the Indian Grassland and Fodder Research Institute (IGFRI) at Jhansi, and the Central Arid Zone Research Institute (CAZRI) at Jodhur, through K.A. Shankarnarayan and Y. Satyanarayan, and to French Institute, Pondicherry (founded in 1955), through V.M. Meher-Homji, who from 1960 onwards got involved with extensive vegetation cartography and bioclimate mapping, together with P. Legris, P. Blasco and J.P. Pascal, and later elucidated the nature of Shola grasslands. He made notable contributions in the area of phytogeography. More recently, B. R. Ramesh, working at this Institute, has provided vegetation classification at a very fine scale for the Western Ghats. The investigations at Bomaby were continued by S.B. Chaphekar (a student of B.S. Navalkar who in turn was a student of Bharucha) on the urban environment and effects of air pollution on plants. Chaphekar later moved to Pondicherry in 1985 where he joined hands with Meher-Homji in developing the 'School of Ecology' at the Pondicherry University.

K.A. Shankarnarayan established ecological research both at the IGFRI and CAZRI. He co-authored the monumental book *The Grass Cover of India* with P.M. Dabadghao in 1973. P.S. Pathak and V. Shankar, both from the Varanasi School, joined IGFRI in the early 1970s and expanded studies on grazing land vegetation. At IGFRI, the response of grassland vegetation to grazing, burning and fertilizer applications have been studied in great detail.

R. Misra returned to BHU in 1955, and soon built a strong school in ecology, attracting students from all parts of the country. He, over the next two decades, fostered ecology to become a major discipline for teaching and research in traditional departments of colleges and universities and thus laid the strong foundations of the subject in India. Early focus of this school was on ecological life history of herbaceous plants, especially population differentiation. Amongst the notable contributions made at that time include ecotypic differentiation associated with soil calcium in *Euphorbia thymifolia* (P. S. Ramakrishnan), photoperiodic response of distinct *Xanthium strumarium* populations (V. Kaul), conservation value of plants (R.S. Ambasht) and wall flora (C.K. Varshney).

In 1956, during the Indian Science Congress Session at Bombay, R. Misra and G.S. Puri (a noted forest ecologist who returned to India in 1948 after completing doctoral work with W. H. Pearsall) founded the 'International Society for Tropical Ecology', and the journal 'Tropical Ecology' began to be published since 1960 (Volume 51 published in 2010).

During the early 1960s, the Varanasi School began studying grasslands (J. S. Singh) and forests (K. P. Singh) in ecosystem perspective emphasizing primary production. The work on production ecology coincided with the launching of the 'International Biological Programme' in 1964, and in fact, the first few IBP related studies were published by BHU researchers. The first MAB research programme in India was launched by Misra at Varanasi in 1975. Thus Misra played a key role in the International Biological Programme as well as the UNESCO's MAB Programme.

The Varanasi School was subsequently joined by D.N. Rao who had completed Doctoral work in 1967 with F. LeBlanc in Canada. D.N. Rao contributed extensively to air-pollution effects particularly that of fluoride, SO_2 and cement dust on higher plants. K. C. Misra, after completing his doctoral work with R.T. Coupland in Canada, joined this group in the early 1960s.

S.C. Pandeya moved from Sagar to establish a centre at the Saurashtra University, Rajkot, in 1969, furthering investigations on forests, on semi-arid grasslands and croplands, and in genecology of grasses. Careful field and experimental studies including chromosome morphology and number analysis led to the discovery of 25 climo-edaphic ecotypes of *Cenchrus ciliaris* and nine of *C. setigerus* distributed over arid to semi-arid regions of western India. Work of this centre radiated to Madurai Kamraj University through K. Paliwal who contributed to ecophysiology of trees. L.P. Mall established another centre at Vikram University, Ujjain, in the early 1960s, dealing mainly with grassland vegetation and plants of stressed ecosystems including mangroves. P.S. Ramakrishnan (now at Jawaharlal Nehru University, New Delhi, since 1985) moved from Varanasi first to Panjab University at Chandigarh, continued working on ecotypic differentiation and then moved to Northeastern Hill University (NEHU), Shillong, where he contributed vigorously to the ecology of shifting cultivation. V. Kaul moved to Kashmir University, Srinagar, in 1962, and developed a group of workers on lake ecosystems, D.P. Zutshi prominent among them. Currently, Zafar Reshi and his group at the Kashmir University are adding to our knowledge on the ecology of invasive flora through field and experimental studies.

J.S. Singh moved to Kurukshetra University in 1968 and to Kumaun University in 1976, where viable ecology centres were established. Extensive studies on productivity, nutrient cycling, forest hydrology, ecosystem recovery, and application of remote sensing techniques were taken up which had a national and international impact. He returned to BHU in 1985, and the leadership of the centres at Kumaun and at Kurukshetra was assumed by S. P. Singh and S. R. Gupta, respectively.

The work of Varanasi School also radiated to Jaipur through B. Gopal (now at JNU since 1986). Gopal, in subsequent years, made outstanding contributions to wetland ecology and reported that very rapid decomposition occurs in submerged plants (as in, *Najas graminea*, *Ceratophyllum echinatum*, *Utricularia* sp.) and the floating leaves of several other plants (for example, *Nymphoides* sp., *Nymphea* sp., *Imomoea aquatica*). Free-floating plants (such as, *Spirodela* sp., *Salvinia* sp., *Eichhornia crassipes*) decompose more slowly. Extremely slow decomposition occurs in emergent plants.

The Centre for Ecological Sciences (CES) at the Indian Institute of Science, Bengaluru, has grown out of the work initiated by Madhav Gadgil at the Institute since 1973. Gadgil made original contributions in population biology, conservation biology, documentation of the tradition of protection of sacred groves, policy research and careful scientific recording of over-exploitation of forest resources. He tried to understand ecology of India in historical context.

A CROSS-SECTION OF SIGNIFICANT STUDIES

It is not possible to deal with the entire gamut of ecological researches conducted by a large number of individuals and organizations. Therefore, only a cross-section of studies, with particular emphasis on those conducted in the universities, are mentioned here to provide a glimpse of the variety of research topics investigated. Key players are also named where possible.

At BHU, K.P. Singh demonstrated the significant role of tree fine roots in dry tropical forests, although the fine roots constitute only about one-third of the total below-ground biomass, they account for about three-fourth of the below-ground net production. His group has shown that the conversion of natural forest into bamboo savanna does not affect the magnitude of primary production but alters its distribution with greater allocation of production occurring below the ground. Continued soil nitrogen loading in dry tropical forest leads to increased soil macroaggregates and greater aggregate stability. J.S. Singh and A.S. Raghubanshi and their team have shown that the vegetation of the dry tropical forest is characterized by a patchy distribution of individuals, species and communities. The α-diversity and its components decreased with increasing intensity of anthropogenic disturbance. This group has made intensive studies on the nutrient cycling, diversity, and plant functional types of the dry deciduous forests. Dry tropical forests which occur on nutrient-poor soils showed several strategies of nutrient conservation, e.g. nutrient immobilization by litter microbes, tree fine roots and herbaceous ground flora, substantial withdrawal of nutrients from the senescing leaves and the efficient nutrient cycling mechanisms which enable these remnant forests to withstand the tremendous biotic pressure. Studies suggested that microbial immobilization may be the main source of nutrients for the plants and may lead to nutrient conservation by reducing nutrient loss. Structure and functioning of savanna ecosystem derived from deciduous forest has been studied in detail. Conversion of natural ecosystem from forest into savanna and croplands reduced the soil organic matter level and the proportion of water-stable macroaggregates. Ecological processes during restoration of mine spoil were quantified. Investigations on the ecology of alien invasive species such as *Lantana camara* and *P. hysterophorus* were carried out in detail in natural and derived systems. In dry tropical forests, *Parthenium hysterophorus* showed a differential response to different soil types; and these phenotypically plastic traits contribute to its invasiveness. Another study on the impact of *P. hysterophorus* on agroecosystems indicated that changes in soil pools and processes are season and crop-dependent. The invasion of the dry deciduous forest of northern India by *L. camara* threatens the survival of many species as was demonstrated by the demographic instability of tree species at different levels of lantana cover. Madhoolika Agrawal (a student of D.N. Rao) has made significant contributions in the field of air pollution, soil pollution and global climatic change effects. Studies conducted around Varanasi showed adverse impact of air pollution of urban origin on crop yields. Effects of global environmental changes on plants with particular reference to enhanced ultraviolet-B radiation and elevated CO_2 have been worked out. The extent of contamination of food chain by heavy metals through atmospheric deposition and irrigation by treated and untreated sewage water has been extensively worked out in and around Varanasi.

Significant studies on vegetation analysis, net primary production, nutrient cycling, the relationship between nutrient cycling and replacement of oak forest by pine forest, and of energy flow between forest and agroecosystems were initiated by J.S. Singh at Kumaun University. At this centre, pioneering studies on Himalayan vegetation, both terrestrial and aquatic, from tropical to alpine, with major emphasis on forest ecosystem processes and on applications of ecology to the solution of environmental problems were made by S.P. Singh. Of particular interest are analyses of plant adaptation and ecosystem level responses to the characteristically seasonal monsoon climate, consequence of leaf phenology and properties on forest structure, primary productivity and turnover of nutrients and dry matter, the effects of economic and societal factors on ecosystem structure and functioning, general biology of the region and flow of ecosystem services from one region to another.

With the input of researchers from Kumaun University, Govind Ballabh Pant Institute of Himalayan Environment and Development (U. Dhar and associates), and G.S. Rawat (of Wildlife Institute of India) we have elaborate information on the structure and diversity of the vegetation, protected area network and plant resources of the western Himalaya.

At the Kurukshetra University, J.S. Singh had started studies on net production of grasslands, with emphasis on methodology. Subsequently, under the leadership of S.R. Gupta, significant contributions were made on biomass and carbon dynamics of successional grasslands. Through a comparison of carbon input in net primary productivity and carbon output in soil respiration, S.R. Gupta showed that about 35% of decomposing plant organic matter in ungrazed grassland was conserved as new organic matter over the annual cycle. Accumulation of this energy may provide a motive for succession to a woodland under protection from grazing. Studies of Gupta's group also showed that in these grasslands, plant species composition and soil conditions influenced diversity of arbuscular mycorrhizal (AM) fungi, aggregate organic matter content and C/N ratio, biomass production, microbial activity, and soil carbon storage. The contribution of this group on soil and root respiration, litter decomposition, ecological rehabilitation of sodic soils, nitrogen transformations in soils, carbon and nitrogen dynamics in tree plantations and agroforestry systems, and diversity of AM fungi in conservation tillage systems are noteworthy.

At the North Eastern Hill University, studies on shifting cultivation practised in Meghalaya, Mizoram and Nagaland, along with the traditional custom of maintaining sacred groves, were conducted by P.S. Ramakrishnan and his group. O.P. Toky and others provided an excellent account of successional changes during the fallow period of shifting cultivation. This group's contribution has expanded our ecological knowledge on shifting cultivation in the north-east India. Notwithstanding the adverse impact on natural forest ecosystems, shifting agriculture was shown to be highly energy efficient compared to terrace cultivation so much so that net gain to the farmer under a 30 year Jhum cycle may be more than twice of terrace cultivation. Analysis of indigenous ecological knowledge systems through a socio-ecological approach has also been the focus of research of P.S. Ramakrishnan, K.G. Saxena (now at JNU) and K.S. Rao (now at Delhi University). Population ecology of weed and forest tree species was the focus of research of R.S. Tripathi who has pioneered studies on the ecology of invasive species in the country. He has made productive contributions to the understanding of reproductive strategies of weeds, regeneration ecology of forest trees, ecology of degraded ecosystems, agro-ecosystems and agro-forestry systems, and biodiversity. Analysis of degraded as well as undisturbed forest ecosystems with a focus on nutrient cycling has been a core area of research of H.N. Pandey. His efforts to link plant diversity with ecosystem functioning is worth mentioning. S.K. Barik and his group are actively engaged in ecosystem research, conservation ecology and carbon dynamics studies following quantitative approaches. Researches on agroecosystems have been pursued by A. Arunachalam in Arunachal Pradesh. U. Shankar is engaged in mapping of plant diversity at landscape level.

C.R. Babu's group at the Centre for Environmental Management of Degraded Ecosystems (CEMDE), University of Delhi, for the last two decades has been pursuing successful action-oriented research on ecological restoration using biological inputs: grasses, legumes, different functional groups of microbes, and soil invertebrates. Researchers of CEMDE have studied the taxonomy, biology and ecology of lantana with a view to finding out the correct taxonomic identity of the weedy populations and the invasive characteristics that enable it to overcome all methods used to contain it, and to evolve an effective management strategy (cut rootstock method) to control it. Inderjit has demonstrated that allelochemicals released from roots and foliage of invasive species could inhibit the growth of associated crop species by interfering with their physiological and biochemical pathways. He has also discovered that exotic invasive plants could accumulate high concentrations of a generalist soil pathogen that creates a negative feedback for native plant species that are more sensitive to the pathogen than the invader itself.

At the Department of Ecology and Environmental Sciences, Pondicherry University, N. Parthasarathy and his group have been working on biodiversity of tropical wet and dry evergreen forests in Western and Eastern Ghats and in Coromandel Coast region for the last two decades, and have established a variety of long-term ecological research plots where changes in species abundances are being monitored. These studies have led to quantification of forest diversity and information on short-term biodiversity changes particularly in response to disturbances. The work of this group on lianas is especially commendable. P. Davider's group has conducted studies on ecology of pollination and seed dispersal of wild plants of the Western Ghats and tropical dry evergreen forest in southern India, and on Island biogeography in the Andaman Islands. At the same department, M.V. Reddy has worked on the spatio-temporal variations of decomposer soil epigeal arthropods, and belowground microarthropods and earthworms and their role in plant litter decomposition and in ecosystem services such as soil amelioration and nutrient cycling across different land uses.

At CSE, in the Indian Institute of Science, Bengaluru, R. Gadagkar has made significant contributions on animal behaviour, especially on the social biology of *Ropalidia* which has been published as a book summarizing 20 years of research on eusociality of this wasp. R. Sukumar has done pioneering work on human-elephant conflict in India. He has set up a number of plots including a 50-acre unit in Mudumalai, for long-term research on the dynamics of tropical forest communities in relation to climate, fire and impact of elephants and human disturbances. Parameters such as mortality, recruitment, phenology, growth and dispersal mechanisms of these vegetation communities are being studied systematically.

Recently a geospatial database on vegetation types of India has been prepared by P.S. Roy (Indian Institute of Remote Sensing, Dehradun) using IRS satellite data in conjunction with climate, topography, edaphic and field enumerated data on species composition, physiognomy, structure and disturbance, collected over 20,000 geospatially located field sample plots. The database has been developed through a collaborative effort of 21 Institutes and 61 scientists over a period of 12 years. It provides spatial information on 113 vegetation types consisting of natural, semi-natural and managed formations. At the University of Agricultural Sciences (UAS), Bengaluru, K.N. Ganeshaiah and R. Uma Shankaar are documenting biodiversity and developing a comprehensive plant database.

Wild life biologists, such as R. Chellam, A.J.T. Johnsingh, Y.V. Jhala, and Jamal Khan, among others, working at the Wildlife Institute of India or elsewhere have significantly contributed in the area of ecology and conservation of a variety of wild life.

Science-based NGOs have also contributed substantially to our ecological knowledge. For example, Ankila Hiremath and her group at the Ashoka Trust for Research in Ecology and the Environment (ATREE) have studied the processes underlying patterns of spread of lantana in the Western Ghats, and H. Nagendra of the same organisation has related patterns of landscape change to human-environment interactions. At the Nature Conservation Foundation, Mysore, C. Mishra has worked on reducing human-wildlife conflict in the high-altitude areas of Himachal through community-based conservation, M.D Madhusudan on links between cattle grazing and coffee in the Western Ghats, A. Dutta on foraging and nesting ecology of hornbills in Arunachal Pradesh and T.R.S. Shankar Raman and others on the restoration of rainforest in the Western Ghats. BNHS has conducted commendable long term ecological studies in the wetlands of Bharatpur, Bhitarkanika, Point Calimere with particular reference to birds. U. Karanth of the Centre for Wildlife Studies, Bengaluru, has studied the prey - predator relationships and habitat partitioning in coexisting predators in Bandipur - Nagarhole National Park.

FUTURE PERSPECTIVES

As evident from the foregoing, ecology has taken firm roots in India, data on many of the characteristics of major ecosystems and species have been collected but in a relatively fragmented and short-term manner. Although data will continue to be collected as India has a big land area and is characterised by huge diversity of habitats and environmental conditions, attempts need to be made at consolidation and meaningful synthesis so that unanswered questions can be identified. Also problems being faced by humans in this Anthropocene era, such as environmental degradation and climate change, loss of biodiversity and increasing ecological footprint relative to living planet index and sustainable development, etc., are huge and complex, and indeed need the attention of ecologists. Role of ecologists in contributing to the solutions for these problems is beset with several constraints that have to be overcome. There is a lack of total system perspective and integrative approach, long-term data and experiments on ecosystem properties, predictivity due to deficient capability of mathematical modelling of ecological processes, integration with social sciences, understanding of sustainability parameters, and communication skill. These lacunae are not unique to India, however. I address some of these in the following paragraphs for future perspectives.

Let me begin by citing one of the most comprehensive global study of the state of ecosystems i.e. Millenium Ecosystems Assessment (http://www.millenniumassessment.org). The assessment provides a state-of-the-art scientific appraisal of the condition and trends in the world's ecosystems and the services they provide, as well as the scientific basis for action to conserve and use them sustainably. Based on the outcomes of MEA, ICSU-UNESCO-UNU (2008) identified key knowledge gaps and prioritized research needs that should be filled through additional scientific research at global and regional scales. Regional research activities may focus on understanding the full dynamics of the relationships among drivers, ecosystems and human well-being and understanding the trade-offs among ecosystem services across spatial and temporal scales to generate information directly relevant to decision-makers.

Integrative Ecology

Holling (1998) identified "two cultures in ecology". He compared an "analytic approach" that develops its activity by expanding the existing knowledge base through experiments, with an "integrative approach" where progress is achieved through the integration of existing knowledge, from different disciplines. The integration of knowledge in programmes such as MEA has been very successful in addressing a broad range of issues using scenarios, modelling and key indicators (Quétier et al. 2007). To address concerns of integration, we have to adopt a research approach that comprises: (1) the inclusion of diverse taxa of animals, plants, and microbes; (2) the integration of individual, population, community, and ecosystem levels of organization; (3) the incorporation of more than one patch type in a heterogeneous landscape; and (4) a combination of long-term monitoring and manipulative field experiments.

Ecological Monitoring

Integrative ecology needs long-term data on ecosystem properties for which a meaningful ecosystem monitoring programme has to be put in place. Ecological monitoring is the process of maintaining regularly updated records of key parameters for a defined geographic area. It provides the data base necessary for implementing goal-focused project research and for computer modelling (McNaughton and Campbell 1991). In India we need to strengthen and expand systems for monitoring climate, air and water quality, atmospheric deposition, species, plant communities, and disturbance processes; of course appropriate indicators of climate change, biodiversity richness and loss, etc. for monitoring need to be carefully selected. The monitoring records eventually become the bases for determining trends in ecosystem state and dynamics over extensive temporal sequences and spatial scales (McNaughton and Campbell 1991). Indian ecology will benefit from efforts to develop and deploy networks of observation systems to gain quantitative understanding of ecosystem processes in representative systems and across gradients of land use and climate. Recent establishment of ISRO sponsored Agro-Met weather stations, energy flux and eddy covariance towers across the country are good examples in this direction, and ecologists should take the advantage of such stations.

Long-Term Ecology Experiments

Long-term studies are designed to capture the effects of the environment and biotic interactions (including human impact) in on-going ecological processes (Pickett 1991). Long-term ecological research sites (LTERs) are also required to validate mechanistic and predictive models of global change and ecological results (Pickett 1991). Even to obtain knowledge on vegetation succession, long-term permanent plot monitoring is an appropriate research tool. According to Bakker et al. (1996), the relevance of the permanent plot observations lies in: (1) separating trends from fluctuations; (2) the possibility to extrapolate beyond the time range of available observations (now often 20 to 40 years); (3) improving extrapolation to other sites (which have of course their own characteristics); (4) predicting vegetation change at future combinations of environmental factors (scenario analyses); (5) testing ecological models which are often based on assumptions not derived from solid field studies.

Since the founding of International LTER's in 1993, global long-term ecological research programmes have expanded rapidly, reflecting the increased appreciation of the importance of long-term research in assessing and resolving complex environmental issues. However, India lags behind in formal establishment of focused LTERs and immediate corrective measures should be initiated. A Scientific Committee of young ecologists (having at least 15-20 years research tenure left) need to be established to decide criteria for site selection, identify and work with partners and stakeholders to define in some detail the coordinated research that will be conducted at each site. This committee should also initiate dialogue with potential funding bodies for scientific research and donor agencies to assist with funding for the research sites. A framework for inter-site analysis and synthesis has to be provided to ensure proper coordination with current and future assessments. It is important that LTER sites should design their own field measurement programs, choosing a locally relevant research focus which should also broadly relate to the core research areas. Sites should conduct field, laboratory and theoretical investigations on their particular biome. Each site needs to address patterns and processes that extend over local to global spatial scales and operate on annual to decade to century time scales. Sites must have designated "core" monitoring datasets that have to be maintained over extended periods of time. Of course this requires long-term funding commitment.

Ecological Informatics & Databases

The exponentially increasing volume of primary data in digital form generated by automated data collection through long-term observations, experiments, simulations, sensors and satellites need to be archived and preserved so that they are available and appropriate for contemporary discovery and future re-use. Newer developments in information and communication technology are allowing us new experiences in the integration, analysis and visualization of ecological information, and are leading to development of a new field of research, ecological informatics. Adoption of standards and protocols and development of tools for collection, management and cleaning of data, geo-referencing, and modelling tools, are allowing a quantum leap in the area of ecosystem and biodiversity informatics (Bisby 2000, Canhos et al. 2004).

Research advances of a discipline depend on the availability of diverse and rich databases from multiple public and private sources, and their openness to easy recombination, search, and processing (Canhos et al. 2004). We are entering in an era when global species databases in the form of comprehensive index of all known plants, animals, fungi, and microorganisms are being constructed by accessing a distributed array of taxonomic indexes (Bisby 2000). Global Biodiversity Information Facility (GBIF), the European Network for Biodiversity Information (ENBI), Inter-American Biodiversity Information Network (IABIN) are some of the biodiversity related databases which provide open access. We in India need to develop such databases for biodiversity and other ecosystem benchmark parameters. In India, NRSA, NCL, ATREE and UAS are active in this direction (Jeeva Sampada and IBIN are good starts in this direction), but data generated by universities and research institutions are yet to be standardized and archived in open accessible databases so that concept reviewers, modelling community and decision makers can use them meaningfully. Lack of common methodology, absence of cross laboratory calibrations and different frequency and units of measurements make most of the Indian ecology and environment research data hard to use and interpret. We need national standard methodologies for ecological and environmental parameters; this is one aspect which MoEF and other central organisations should take on urgent basis.

Ecosystem Modelling

Enhancing predictive capacity is one of the most important future endeavours for Indian ecologists. We need to develop and use models to formulate testable hypotheses, forecast change, inform research priorities, and integrate information from monitoring systems, observation networks, and experiments. Mechanistic, quantitative simulation modelling, should be a core component of long-term ecological research (McNaughton and Campbell 1991). These models need to address the system level linkages between drivers, feedbacks, ecosystem services, economic valuation and human wellbeing indicators.

Human Dimensions and Sustainability Science

There is still a major divide between social sciences and natural sciences. Ecology can bridge this gap. There is a need to initiate coordinated research to understand the dynamics of the relationship between humans and ecosystems (ICSU-UNESCO-UNU 2008). Such an initiative should enhance understanding of: (a) the nature of interactions among drivers; (b) the relative influence of ecosystem change on human well-being; (c) interactions among ecosystem services; (d) cross-scale (temporal and spatial) interactions of drivers, services, and responses; (e) how ecosystem services and human well-being outcomes can be modified by changes in policies or management; and (f) how to model the relationship between humans and ecosystems at local, regional and global scales.

Biosphere reserves in India are one of the potential areas where ecologists can focus initially for the study of relationship between humans and ecosystems. These are natural systems which do not exclude people but rather encompass ecosystems, people, ecological services, and both adverse as well as beneficial actions of people on the environment. These biosphere reserves are also ideal sites for LTERs in India.

As human interaction with the natural environment is increasing immensely and day by day, we need to refocus ecology towards research that ensures a future in which natural systems and the humans they include coexist on a more sustainable planet. Sustainability science is a field of research which deals with the interactions between natural and social systems, and with how those interactions affect the challenges of sustainability. It has emerged in the 21st century as a new academic discipline (Kates et al. 2001). The core of this discipline is the concept of sustainability which means meeting the needs of present and future generations while substantially reducing poverty and conserving the planet's life support systems. Thus, sustainability science addresses the fundamental character of interactions between nature and society, and society's capacity to guide those interactions along sustainable trajectories (Kates et al. 2001). Sustainability science, therefore, seeks real world solutions by breaking down artificial disciplinary gaps between the natural and social sciences through the creation of new knowledge and its practical application to decision making (Clark and Dickson 2003, Palmer et al. 2005). Emergence of Sustainability Science as an important research domain provides Indian ecologist fraternity an opportunity to open dialogues with social scientists, and the emerging wisdom will be possibly more useful for policy makers in contrast to hard science conclusions published in traditional ecology journals. Therefore, our new ecological research priorities should include (a) promotion of research that integrates global and local perspectives in a place-based framework for understanding the interactions between environment and society; (b) focus on a limited set of understudied questions, those that underpin the understanding of those interactions; and (c) promotion of more efficient use of existing tools and processes that link knowledge and action (National Research Council 2002).

Strengthening Communications

At the end, I would like to address the issue of communicating ecology with common public and policy makers. Despite producing an enormous amount of new information, ecologists are often unable to convey knowledge effectively to the public and to policy-makers. Unless the discoveries of ecological science are rapidly translated into meaningful actions (what has been termed Translational Ecology, Schlesinger 2010), they will remain quietly archived while the biosphere degrades. Therefore, we have to communicate results and uncertainties in formats useful and accessible to policy makers and resource managers. We (as individuals and as institution) should also recognize public outreach as an appropriate and important professional endeavour. This is so important that Pace et al. (2010) have suggested that such efforts towards communicating science to the common public and policy makers should be considered in merit evaluations.

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