Ecology and environmental science in the universities

J. S. Singh

Solutions to the increasing environmental problems of today call for trained ecologists. Universities must create centres for ecology and environmental science for such training and for research.

Never before has the transition from one century into another meant entering a period of global crisis. The cumulative impacts of the series of environmental perturbations unleashed by the growth in human numbers and consumerism on the biosphere are collectively exceeding all but the greatest upheavals of the geological past. During the present century the human population has increased three-fold, consumption rate of fossil-fuel energy has increased 12-fold, and growth in the global economy has increased 29-fold (refs. 1, 2). In the next three or four decades human numbers will double, consumption of food and fibre will triple, energy demand will quadruple, and economic activity will quintuple[3]. The carrying capacity of Earth would be saturated by the middle of the next century. Not only do we stand to lose species and genetic strains of potential medical, agricultural, and industrial importance, but we will greatly impair natural ecological processes crucial to our well-being and destroy much of the evolutionary potential of these systems to respond to future perturbations[4].

Burgeoning problems

It is difficult to foresee all environmental problems that mankind will face in the future. However, on the basis of contemporary information, I focus on four major groups of them. I do not list them here in any order of priority because they are interdependent and synergistic.

Loss of biological diversity

We seem to be entering into a phase of mass extinction. Today we are losing at least one higher-plant species per day from tropical forests alone[1]. Estimates indicate that, from ten hot-spot localities in tropical forests (300,000 km^2) alone, some 17,000 endemic plant species and 350,000 endemic animal species could well be eliminated shortly[5]. If the present trend continues, about 25% of the total 250,000 higher-plant species will be lost in the next few decades and

Top: A dense forest with high biological diversity. *Bottom*: Overexploitation has reduced forest cover and diversity.

another 25% by the end of the twentyfirst century. Further, we can expect the demise of 20–60 animal species per plant species lost[1,6]. Mass extinctions (25–>70% of extant species each time) have occurred in the past at geologic-time boundaries, such as Frasnian/Fammennian, Ordovician/Silurian, Permian/Triassic, Triassic/Jurassic and Cretaceous/Tertiary. There were a fewer species at stake then, however. There were around 25,000 species of flowering plants some 125 million years ago, by the Late Cretaceous this number had swelled to 100,000, and today there are some 200,000 species of these plants on Earth[7]. Additionally, while the past extinctions occurred each time over a span of a million years or less, and plant species were largely spared as the general nature of vegetation remained the same on both sides of the boundary[4], the present mass extinction may well occur within a short period of about 200 years, and plants (which make up the base of the food chain) will be equally or worse affected. In India alone, it is feared that 15–20% (i.e. over 2500 species) of the total vascular flora now fall in one or the other category of threatened species[8].

Degradation of ecosystems

The rate at which ecosystem degradation has occurred globally during the present century is alarming. Significant areas have already been profoundly altered, depleted, eroded or contaminated by toxic substances[9]. Anthropogenic forcing and exploitation of already shrinking resources in future would further ravage the land, water and biota. Current estimates indicate that 3 to 15 million hectares of tropical forests[10] are being cleared per year (about 1 acre per second!). Disruption of natural vegetation and subsequent, often faulty land-use management, causes serious damage to the system. Drastic disturbances such as surface mining for natural resources disrupt ecosystems entirely. The problem of land degradation is going to be specially acute for developing countries in the face of their shrinking productive land base, polluted and meagre water resources, and increasing human and livestock populations. For India, estimates indicate that more than half of the land mass of the country is already degraded in some way, out of 143 million hectares of agricultural land 56% is degraded due to bad agricultural practices[11], and now dense forest cover has been reduced to only 11% of the geographical area[12]. The situation is frequently so bad that even cessation of abuse will no longer necessarily lead to self-correction of the natural system.

Environmental pollution and contamination

Estimates indicate global sulphur dioxide (SO_2) and nitrogen-oxide (NO_x) emissions to be 65 million and 20 million tons of S and N respectively for 1980, and 205 million and 65 million tons of S and N respectively for the year 2030 (ref. 13). Increases in these anthropogenic gases as well as in carbon monoxide (CO), methane (CH_4), and non-methane hydrocarbons in the troposphere have implications also for tropospheric concentrations of phytotoxic oxidants, such as ozone and hydrogen peroxide[13]. The acid-rain problem, thus far primarily confined to Europe and North America, is now causing concern in other regions as well, including China[14]. India cannot expect to remain unscathed. Few would be aware that ambient SO_2 levels in the industrialized Gangetic Plains are now similar to those of the industrialized regions of Europe and the northeastern US[15]. Calculated loading rates of trace metals, such as Cd, Cu, Ni, Pb, Cr, Zn, and Hg, in air, water and soils demonstrate that human activities now have major impacts on the global and regional cycles of most of the trace elements[16]. There is significant contamination of freshwater resources[17] (as well as artificial eutrophication of lakes and reservoirs) and an accelerating accumulation of toxic metals in the human food chain. (See also ref. 18 for a survey of pollution problems.)

Global change

Increase in atmospheric abundance of radiatively important trace gases, such as carbon dioxide (CO_2), nitrous oxide (N_2O), CH_4 and chlorofluorocarbons (CFCs), is occurring at a high rate. There are unmistakable evidences that this increase in greenhouse gases is going to raise global temperatures, to disturb rainfall pattern, and to cause sea-level rise within the next few decades[19]. At the same time, decreasing concentration of ozone in the stratosphere is resulting in increased UV radiation on Earth. Thus, within a few decades, Earth is likely to be much warmer; mean global temperatures would have increased by 2–4.5°C; sea levels would have risen by 30–50 cm, inundating vast coastal areas and causing ingress of salinity inland; UV radiation harmful to most organisms would have increased[20]; and warmer sea temperatures would affect the monsoon pattern of circulation, which was established over India some 11 million years ago, increasing the frequency of extreme events. Certain biomes (major regional ecological communities) will begin to migrate or begin to be reconstituted[21]. The consequences of these global-change phenomena are many, and alarming.

Responsibilities of the Indian university system

Two major roles of a university, *inter alia*, are generation of knowledge and creation of trained manpower who can use this knowledge for improving quality of life and society. Few would disagree that the environmental problems of the future are going to overwhelm all other challenges. Indian universities can hardly ignore their responsibility of conducting research to resolve these problems and of imparting education to equip the society to face them effectively.

My target in this article is the non-vocational higher-education system in the universities. It is the higher-education system that is expected to yield the analytical and theoretical precepts leading to the evolution of 'anticipate and prevent' strategies, as opposed to 'react and cure' strategies which should arise from the technological institutions. I am also not concerned here with the exoteric incorporation of environment-related courses in other disciplines (e.g. environmental biology, environmental geology), which is useful, though, for generating environmental awareness and gives a new perspective to the disciplines concerned. Further, I consider the current proliferation of newspaper-veneered and ready-with-advice-on-any-problem environmental scientists encouraging but not reassuring

Resolution of the problems listed above is not possible without a thorough understanding of ecological principles, and therefore appropriately trained ecologists (both generalists and specialists) will be required increasingly. The new generation of ecologists will require the capability to *predict*, *plan* and *manage* the environment and resources[22]. Training for such ecologists cannot be accomplished in traditional university departments designed for compartmentalized teaching of plant or animal science. The ecology and environmental science courses will have to be interdisciplinary and, often, transdisciplinary in nature. Universities will therefore have to create linkages between departments in order to bring together a combination of necessary disciplines, in the form of centres for ecology and environmental science.

These centres should, however, have a critical mass of full-time teaching faculty of their own in addition to the borrowed expertise from the other, pre-established departments, and should be entrusted with the task of teaching all ecology courses, and at all levels, in the university. They should have long-range integrated research programmes dealing with perceived local problems, and in this way can participate in regional development. For example, a centre can adopt a degraded ecosystem of the region and can concentrate its efforts on restoring it.

New departments of ecology and environmental science can be established in selected universities. It is encouraging that some schools/departments of environmental science have already come up. However, they still remain largely multidisciplinary, maintaining discipline-oriented style and content of teaching and solving problems within disciplines. Sectoral research activity results in a diffusion of effort and monetary resources, and in redundancy of results. Disciplinarians tend to look at an environmental problem with the bias of their own discipline. Ecology, on the other hand, has grown by internalizing the different disciplines of natural and, more recently, social sciences[23]. I feel that environmental science has to be strongly biocentric; the holocoenotic environment (i.e. the life-support system) is the object and ecology is the science that deals with it. Ecology therefore must be at the core of any environmental-science programme.

I summarize below the areas that should be focused on in training and research in this preparatory stage.

Ecosystems analysis and modelling, i.e. analysis of ecological processes at the ecosystem level, to understand the functioning of ecological systems in relation to perturbations, so that mechanistic ecosystem modelling can be pursued.

Conservation and evolutionary ecology, for the protection of biological diversity and the translation of theoretical advances into concrete recommendations for management so as to ensure symbiotic man–nature interactions, and to understand the biological equipment of species which enables them to survive stresses.

Restoration ecology, for the restoration of degraded ecosystems and of biological productivity, diversity and stability or resilience of impacted ecosystems.

Ecology of global change, specially to assess the magnitude and likely impact of climatic and associated changes on species and ecosystems, and to develop the capability to take advantage of positive effects and mitigate negative effects through management.

Ecological biotechnology, for producing transgenic organisms and devising biological systems—including micropropagation of stress-tolerant, fast-growing plants—that can be useful in environmental restoration, waste recycling, detoxification, biological control, etc., and to assess the ecological risk of planned introduction of genetically engineered organisms into the environment.

Ecological economics, for integrating the study and management of nature and economics, so that the cost of damage done to the air, water, soil and biota and that of restoring this damage can be articulated in redifining progress and development goals and in recalculating GNP.

An institute of ecology

The advanced curriculum should not be just an entombment of knowledge, but rather a structure wherein knowledge is *communicated* and *used*[24]. There is a need to integrate advanced teaching programmes of ecology and environmental science with ongoing long-range, site-specific and/or problem-specific research programmes: advanced teaching and research should snugly fit into each other[22]. *Predictive capability* must be developed. Sustained experiments at various scales are called for. Expertise is required to extrapolate from processes studied at small scales and to observe the various phenomena of interest directly at large scales. Integrative form of scientific analysis is required and this in turn requires a thorough knowledge of the fundamentals (ecological processes) as well as the tools (computer modelling, remote sensing, etc.). Modelling studies require an efficient, interactive data bank. A coordinated network of sites is needed for observing short- and long-term trends in ecological processes and for conducting comparative experiments and total-system studies.

This approach to teaching and futuristic research goals calls for an institute of ecology. It is here that India has a particular responsibility because of a relatively well-developed scientific infrastructure and because many environmental problems transcend national boundaries, generally for the whole of South Asia and particularly for the Indian subcontinent[22]. World ecologists, in 1960, founded the International Society for Tropical Ecology (ISTE) and sited its headquarters at the Banaras Hindu University (BHU) in India with the assumption—rearticulated by the ecologists at the 1987 ISTE symposium—that a regional institute of ecology would emerge[25]. Earlier, in 1975, UNESCO's Programme on Man and Biosphere (MAB) regional meeting had also recommended setting up of a national institute of tropical ecology at BHU[26], which has the longest tradition of teaching and research in ecology in the region.

Such an institute, with long-range research programmes on permanent study sites, can be linked with various ecology centres in universities and research institutions for multidirectional information flow. India is endowed with a great diversity of climate and life zones, which represent all possible ecological conditions in South Asia.

Biosphere reserves to cover distinct ecoclimatic zones have been and are being established. Some of these reserves, coupled with certain areas that experience rapid changes owing to intense anthropogenic forcing, could serve as permanent research sites for the institute. Operating within the university system, the institute can have more latitude and establish effective links with other centres of importance within and outside the South-Asian region for collaborative training and research with international funding from UNESCO, the South Asian Association for Regional Cooperation (SAARC), World Bank, the Food and Agriculture Organization (FAO), the United Nations Environment Programme (UNEP), etc. The six disciplines outlined earlier should be the focus of research at the institute, which can also have a flexible programme of degree, diploma and certificate courses on selected topics of environmental concern to the South-Asian region. The Ministry of Environment and Forests, together with the University Grants Commission, could be the nodal agency for the institute, with active support from the Department of Science and Technology (DST), Department of Space (DoS), Department of Biotechnology (DBT) and the Council of Scientific and Industrial Research (CSIR).

The proposal of reorganizing non-vocational higher education to create centres of ecology and environmental studies, and to establish an institute of ecology, will probably encounter resistance owing to (i) the inertia of the system, (ii) the faith of the academia in existing disciplines and system, (iii) uncertainty of employment generation, (iv) interdisciplinary and interinstitutional rivalries, and (v) lack of funds. I shall leave this article open-ended and let the readership, including policy makers and those concerned with funding of science, react to the possible factors of resistance. Much will depend, however, on the way we set national priorities in dealing with the burgeoning environmental concerns.

1. Myers, N., *Global and Planetary Change*, 1990, **2**, 175.
2. *World Resources Report*, World Resources Institute, Washington, DC, 1989.
3. *Our Common Future*, World Commission on Environment and Development, Oxford University Press, Oxford, 1987.
4. Ricklefs, R. E. *et al.*, *Global and Planetary Change*, 1990, **2**, 159.
5. Myers, N., *Environmentalist*, 1988, **8**, 187.
6. Raven, P. H., *We Are Killing Our World: The Global Ecosystem Crisis*, MacArthur Foundation, Chicago, 1987.
7. Knoll, A. H., in *Extinctions* (ed. Nitecki, M. H.), University of Chicago Press, Chicago, 1984, pp. 21–68.
8. Jain, S. K., in *Tropical Ecosystems: Ecology and Management* (eds. Singh, K. P. and Singh, J. S.), Wiley-Eastern, New Delhi, 1991, pp. 69–80.
9. Brinck, P., Nilsson, L. M. and Svedin, U., *Ambio*, 1988, **17**, 84.
10. Bouwman, A. F., *Land Use Policy*, Butterworth, London, 1990, pp. 154–164.
11. Sivaramakrishnan, K., in *Perspectives on Environment and Ecology in India* (eds. Singh, J. S. and Singh, K. P.), International Society for Tropical Ecology, Varanasi, 1987, pp. 87–95.
12. Madhavan Unni, N. V., in *Space and Forest Management*, 41st AIF Congress, Dresden, Germany, 1990, pp. 49–69.
13. Oppenheimer, M., *Climatic Change*, 1989, **15**, 255.
14. Zhao, D. and Sun, B., *Ambio*, 1986, **15**, 2.
15. Graedel, T. E. and Crutzen, P. J., *Sci. Am.*, 1989, **261**, 58.
16. Nriagu, J. O. and Pacyna, J. M., *Nature*, 1988, **333**, 134.
17. Khoshoo, T. N., Environmental priority in India and sustainable development, presidential address, 73rd session, Indian Science, Congress Association, 1986.
18. Sharma, A. K., Impact of the development of science and technology on environment, presidential address, 68th session, Indian Science Congress Association, 1981.
19. Grantham, R., *Trop. Ecol.*, 1989, **30**, 157.
20. Raghubanshi, A. S. and Singh, J. S., *Trop. Ecol.*, 1991, **31**, 1.
21. Peters, R. O., in *Biodiversity* (ed. Wilson, E. O.), National Academy Press, Washington, DC, 1988, pp. 450–461.
22. Singh, J. S., *Nature*, 1991, in press.
23. Misra, R., *Proc. Natl. Sci. Acad.*, 1985, **B51**, 641.
24. Mayer, W. V., *Biol. Int.*, 1990, **20**, 8.
25. Singh, J. S., Singh, K. P. and Ambasht, R. S., *Curr. Sci.*, 1988, **57**, 872.
26. UNESCO, *Programme on Man and Biosphere (MAB), Regional meeting on integrated ecological research and training needs in tropical deciduous and semideciduous forest ecosystems of South Asia*, MAB report series no. 35, 1976.

While this article was in press, the Ecological Society of America, recognizing that many of the environmental problems that challenge human society are fundamentally ecological in nature, came out with a multiauthor report on sustainable biosphere initiative (*Ecology*, 1991, **72**, 371), which focuses on the necessary role of ecological science in the wise management of Earth's resources and the maintenance of Earth's life-support systems. This document proposes three research priorities for the nineties: (i) global change, (ii) biological diversity, and (iii) sustainable ecological systems. The report presents a detailed ecological research agenda, and should be read by all those interested in ecology and environmental science.

J. S. Singh is in the Department of Botany, Banaras Hindu University, Varanasi 221 005.

The problem of conserving amphibians in the Western Ghats, India

R. J. Ranjit Daniels

Habitat distruction and hunting for dissection specimens have taken their toll. But there may be other, subtle factors causing loss of amphibian populations.

Amphibians are probably the best indicators of environmental health of all vertebrates. The amphibian skin is extremely sensitive to changes in external temperature and humidity. Being easily permeable, the skin makes these creatures comparatively more susceptible to the adverse effects of aquatic, terrestrial and air pollutants. Moreover, the fact that the skin has to be moist for normal gas exchange limits the available habitats that amphibians can invade. Therefore any change in local amphibian populations should alarm conservationists[1].

Some of the well-known causes of amphibian decline in the tropical countries are direct exploitation by man for the frog-leg trade, large-scale habitat destruction, and heavy use of fertilizers and pesticides in agricultural and forest lands. There are other, less publicized ways of amphibian destruction going on in many parts of the tropics. India is no exception, and unless some of these aspects are brought to light, it, like any other developing tropical country, would be blamed for letting its amphibians disappear primarily through habitat destruction.

Habitat destruction has indeed caused considerable damage to the overall amphibian fauna of India. The Western Ghats have felt the hard hands of humans ever since the European invasion a few centuries ago. Few would have known that the Western Ghats are the richest in amphibian species for the entire tropical Asia[2]. Including 13 of the 15 species of Indian caecilians (limbless amphibians), there are nearly 120 species of amphibians hitherto reported from the Western Ghats. At least 60% of these are considered endemic to the area and more species are being discovered from this hilly region. For instance I recently collected from parts of the southern Western Ghats a species of tree-frog of the genus *Polypedates* (earlier *Rhacophorus*). Experts from the Zoological Survey of India could not separate this species from *P. cruciger*, which has been considered endemic to Sri Lanka[3]. There can be more such examples. However, many new species of amphibians may not remain to be discovered if habitat destruction continues at the present pace in the Western Ghats.

Ecology

In my experience with amphibians in tropical forests of the Western Ghats and of Panama in Central America, the moist evergreen forests contribute the most to the local amphibian diversity. They include terrestrial, arboreal and aquatic species in the community. It is also apparent that the forest canopy is primarily responsible for maintaining a majority of the species round the year. It regulates the local understory temperature, the wetness of soil and leaf litter, the amount of light reaching the ground, and the perinneality of streams. All amphibians are sensitive to these environmental factors, which even influence their behaviour. For instance, while there are amphibians that are strictly nocturnal, such as some of the tree-frogs, many are opportunistic, switching between being nocturnal and being diurnal depending on the environmental conditions. The terrestrial frog *Eleutherodactylus fitzingeri* in Panama can be found active during both day and night within canopied forests. However, it is seen in forest clearings and near buildings only during the night. There are similar examples among Indian frogs too. I have seen the narrow-mouthed frog *Microhyla ornata* under logs and stones during the day in open habitats, and active in litter in closed evergreen forests even during the dry season in the Western Ghats. Species of frogs and toads show clear shifts in niches depending on the surrounding environmental conditions. Toads (*Bufo* spp.) retreat into crevices and holes during the day in hot, open areas but rest exposed on litter within canopied forests. The bronzed frog (*Rana temporalis*) moves about considerably and even ascends bushes as high as one metre above the ground during the night but stays close to water between rocks during the day. For an amphibian it is the surrounding temperature (which should ideally be 20–30°C) and the relative humidity (which is 50–75% even during dry seasons within canopied forests) that matter. Hence forest amphibians such as *Bufo parietalis* and *Rhacophorus malabaricus* die when the surrounding temperature goes beyond 34°C and the relative humidity drops below 40%.

Habitat disturbance, pollution

Besides direct destruction there are many other ways of rendering a habitat unfit for amphibians. A common practice in the Western Ghats is for local villagers to enter the forests and collect all the leaf litter on the floor. These are dumped directly in their betelnut (*Areca catechu*) gardens close by or transported several kilometres away to fertilize a paddy field. Leaf litter on the floor is an important daytime refuge for both terrestrial and aquatic frogs during the dry season. While all terrestrial frogs seek the cover of moist litter during the day, even the most aquatic of frogs, *Rana hexadactyla*, often disappears under it. Some species of tree-frogs (*Philautus* spp) lay eggs in the litter and grass, where there is direct development without a tadpole stage. These frogs are common in forests where there is a thick layer of leaf litter on the floor. Hence, despite protecting habitats from logging, fire, etc., if the leaf litter is continuously harvested without any consideration of the effects, much of the amphibian life would be affected.

Tea and rubber estates are causing considerable damage to the forest ecosystem in the Western Ghats by polluting the soil and water with chemical fertilizers, pesticides and factory wastes. Clear perinneal streams are made turbid and seasonal owing to soil operations within the estates. *Ansonia ornata* (Bufonidae) and *Micrixalus saxicola* (Ranidae) are species of amphibians endemic to the Western Ghats showing a preference for clear torrential streams within evergreen forests. Though such streams are frequent along the Western Ghats, these species are very local today, restricting themselves to a few unpolluted, clear perinneal streams. Though locally abundant, populations are widely separated. The hills of the southern Western Ghats, viz., Keeriparai and Maramalai, which are contiguous with the Ashambu Hills, are some of the most affected areas, owing to the large-scale planting of rubber during the past 25–40 years. Many perinneal streamlets have dried up here owing to direct soil operations or diversion of water into estates for irrigation and factory use. Factory wastes have left the water milky and putrefying in many streams. Amphibians in these streams are certainly affected. A clear indication of this is the decline of the bronzed frog *Rana temporalis*. This species, which was very common along the southern streams 25 years ago, is locally rare or absent today. It is, however, widespread in the Western Ghats, being hardy and capable of surviving at surrounding temperatures in the range 11–36°C and low humidity (RH 10%). It is locally common such as along the unpolluted river Kunthipuzha flowing through the Silent Valley National Park.

The bronzed frog *Rana temporalis*: surviving in the Western Ghats, but for how long?

Specimen hunting

While it is science that calls for the conservation of species, it is science that is rather unconsciously destroying them. The common green frog *Rana hexadactyla* is a classic victim of destructive science. This species is being locally exterminated day after day purely through collection for biology classes. Dissecting frogs has long been a laboratory practice in schools and graduate courses. An average biology student in India handles a minimum of two dead frogs during his zoology laboratory course. This has been part of the science syllabus in India for at least the past 40 years. Where do the frogs come from year after year? No effort has been made so far to culture frogs for this purpose. Since for local boys and men it is a money-fetching business to supply frogs regularly to schools and colleges in the neighbourhood, they go rampant, collecting frogs all through the year. The criterion for collecting is large size, and the result is that the catches are female-biased, with many being gravid. Collections often include females of similar species such as *Rana tigrina* and *Rana cyanophlyctis* as well.

Another form of damage is caused directly by the scientists themselves. Massive collecting expeditions are still being undertaken by scientific institutions and museums. It is data from the tropics that they are interested in and within a short time. They are therefore resorting to short-cuts such as destructive sampling. For instance, in the recent herpetofaunal study at Ponmudi

The green frog *Rana hexadactyla*, victim of destructive science teaching.

during 1982 in which the Field Museum of Natural History, Chicago (USA), and the National Museum of Natural History, Delhi (India), collaborated[4,5], about 1500 amphibians and reptiles were collected from a small hill range (ca 80 km^2) in the Western Ghats within a short period of 6 weeks. While it is true that such studies contribute considerably to our understanding of geographical range and ecology of several species, the large-scale killing of animals cannot be overlooked. The Ponmudi study did discover two new species of frogs for the Western Ghats (*Nyctibatrachus minor* and *N. aliciae*) and added a bit of information regarding the habitat and microhabitat preferences of some amphibians. However, considering the elimination of a major population of amphibians (964 individuals) in a locality, should conservationists not be alarmed? Who knows how many generations of each species collected were nipped off by killing so many juveniles and adult females? The study period (May–June) coincided with the first rains and the breeding time of most amphibians in the Western Ghats.

Need for objective study

It is true that, in the Western Ghats as in many other parts of the tropics, habitat loss plays a significant role in the disappearnce of species, amphibians being no exceptions. However, what is more apparent and alarms conservationists throughout the world are statements like 'a few hundred hectares of rain forests are being felled per day in the tropics'. Less striking factors threatening local existence of amphibians are not always noticed. That scientists are 'perplexed' by declining amphibian populations even in 'well-protected' habitats, as Blaustein and Wake[1] put it, is due to the fact that many of the subtle factors operating within the ecosystems towards the elimination of species have not been brought to light fully. At least in the Western Ghats a few of these causes are apparent. Removal of leaf litter from the floor of otherwise intact forests, chemical pollution of water from estates upstream, and collection of specimens can play a significant role in the loss of amphibians. Destructive sampling by scientists has been a common practice though not always publicly announced. Since the Western Ghats offers the best species pool of amphibians over most of the Asian tropics, it is more susceptible to frequent destructive sampling by scientists than any other. Local populations of amphibians would soon be threatened if some of these subtle factors are not identified and controlled.

1. Blaustein, A. R. and Wake, D. B., *TREE*, 1990, **5**, 203.
2. Inger, R. F. and Dutta, S. K., *J. Bombay Nat. Hist. Soc.*, 1986, **83**, 135.
3. Morgan-Davies, A. M., *J. Bombay Nat. Hist. Soc.*, 1958, **55**, 11.
4. Inger, R. F., Shaffer, H. B., Koshy, M. and Badke, R., *J. Bombay Nat. Hist. Soc.*, 1984, **81**, 406 and 551
5. Inger, R. F., Shaffer, H. B, Koshy, M. and Badke, R., *J. Bombay Nat. Hist. Soc.*, 1987, **8**, 189.

R. J. Ranjit Daniels is in the Centre for Ecological Sciences, Indian Institute of Science, Bangalore 560 012.

Addendum

In Singh, R. P., 'Technology transfer—successes and failures', *Curr. Sci.*, 1991, **60**, 272–275 the following references had been left out.

1. Manning, G. K., *Technology Transfer: Successes and Failures*, San Fransisco Press Inc., San Fransisco, California, 1974, p. 233.
2. Mogavero, L. N. and Shane, R. S., *What Every Engineer Should Know About Technology Transfer and Innovation*, Marcel Dekker, New York, 1982, p. 154.
3. Ramesh, J. and Weiss, C., *Mobilizing Technology for World Development*, Praeger Publishers, New York, 1979, p. 234.
4. Rosenberg, N. and Frischtak, C., *International Technology Transfer: Concepts, Measures, and Comparisons*, Praeger Publishers, New York, 1985, p. 329.
5. Samli, A. C., *Technology Transfer: Geographic, Economic, Cultural and Technical Dimensions*, Quorom Books, Westpark, CT, USA, 1985, p. 296.

Environment and development

M. S. Swaminathan

The key to a better common future for mankind lies in coupling the right use of modern space and information technologies and biotechnology with ecological obligations.

The World Commission on Environment and Development (1987) called for the achievement of necessary growth rates in economic development without harm to the life-support systems of the planet, terming this *sustainable development*. This will be the theme for the UN Conference on Environment and Development scheduled to take place in Brazil in June 1992. Sustainable development involves paying concurrent attention to problems of intra- and inter-generational equity. The large volume of literature currently becoming available on this topic suggests that the problem facing us now is not so much one of discovering *what* must be done to ensure sustainability, but more importantly, learning *how* to achieve it.

In population-rich but land-hungry countries like India, China and Bangladesh, enduring food security will depend greatly on strategies to enhance crop yields. At the same time, the onward march of the green revolution will have to be on the basis of 'green' or environmentally friendly technologies. If productivity-enhancing technologies do not spread to more areas and farming systems, the poverty of small-farm families will persist, since they will have very little marketable surplus and thus will not be able to profit from the remunerative output-pricing policies of governments. Nor will it be possible to prevent the further expansion of cultivated area at the expense of forests and soils vulnerable to erosion or other forms of damage to their innate biological potential.

Both the Food and Agriculture Organization of the UN (FAO) and the United Nations Environment Programme (UNEP) estimate that an important cause of deforestation in the world is the spread of agriculture into forest lands. At the same time, population increase and growth in purchasing power make a more rapid advance in agricultural production necessary. Thus a continuous quest for technologies that can help enhance the productivity of economic plants and farm animals per unit of time, land, water and energy is essential. For example, in India, cereal production will have to increase by at least seven million metric tons per year during the present decade to meet demand, as against the average annual increase of 3.5 million tons of food grains achieved during the last two decades. In Sub-Saharan Africa where population is growing at 3.5% a year, food production will have to be more than tripled in the next 25 years to meet the needs of the growing population. Similar progress will be needed in respect of other agricultural commodities. Can such advances in agricultural production and productivity be achieved without over-exploiting land and groundwater resources and increasing the problems created by biotic and abiotic stresses?

The solution lies in ecological agriculture. A major aim of the strategy described as low-input sustainable agriculture (LISA) by the US Department of Agriculture is to ensure the long-term sustainability of *current production levels in the USA*. However, while defending the *status quo* in yield as the priority task in industralized nations, raising average yields is the urgent need in developing countries. For example, the average yield of paddy in California is about 8.5 tons per hectare, while the current average paddy yield in India is about 2.5 tons per hectare. India already has over 47% of its land area under agriculture. Every fourth farmer in the world is an Indian farmer. Less than 4% of the arable land of the country is under pastures and grazing lands, although India has over 20% of the world's farm-animal population. Unless rice yields are doubled within the next 20 years, it will be difficult to manage the national food security system without food imports. The same situation prevails in respect of wheat, sorghum, pulses, oilseeds and other food crops. So the pathways for sustainable agriculture in India will have to be based on substantial advances in productivity and not just on the maintenance of current yields and production levels, as in the US.

We thus face a paradox. On the one hand, several of the components associated with traditional green-revolution or land-saving technologies, particularly those involving the use of high doses of mineral fertilizers, chemical pesticides and heavy farm machinery, have negative ecological repercussions. While on the other hand, a continuous growth in terrestrial and aquatic productivity is a must in countries where

M. S. Swaminathan is Chairman, M. S. Swaminathan Research Foundation, 14 II Main Road, Kottur Gardens, Madras 600 085.

This article is the text of the acceptance speech delivered by the author at Los Angeles, USA, on 5 April 1991, on the occasion of the award of the Tyler prize for environmental achievement.