Kamaljit S. Bawa of the University of Massachusetts, Boston, USA is known for his work on the reproductive biology of trees of the tropical forests of Central America. Of late, he has been interested in the conservation and management of biodiversity in the tropics, especially India. In this comment to Padmanaban's article on "Indian biology research at cross roads" (Curr. Sci., 1992, 63, 509–511), Bawa identifies a different pattern of hierarchy of thrust areas in biology. Arguing that Padmanaban's article is restricted to only one of the layers in such a pattern, he suggests that there are several other areas that need more thrust in India.

—Editor

Indian biology research at crossroads—Another perspective

Kamaljit S. Bawa

A critical assessment of the status of Indian science[1] has been long overdue. For a number of years, India has boasted the third highest number of scientists in the world, and until recently the government's expenditures in research and development as a percentage of GNP have steadily increased. It is thus natural to examine the impact of Indian scientists in various fields and to ascertain if science, as practiced in India, can meet the challenges of the future as well as the needs of the society, which, despite being economically disadvantaged, has so generously endowed scientific research.

Here I evaluate the assessment of Indian biology made by Padmanaban in his article, Indian biology research at cross roads[2]. In any assessment, in order to get the right answers, it is important to ask the right questions; it is my contention that Padmananban's article does not ask all the right questions. His review is confined to molecular and cellular biology. Moreover, the article does not identify factors that limit progress. Thus, it is unlikely to offer a prescription for moving the Indian biology forward, which I assume was the *raison d'être* for the collection of articles in *Current Science*. I first argue that Padmanaban's article does not fully define the central issues of biology. I then describe the fields in which Indian biologists can make unique contributions. After briefly reviewing the past and present research of Indian scientists in areas other than molecular and cellular biology, which are covered by Padmanaban, I examine factors that limit the progress of Indian biology. Finally, I examine the outlook for the future and discuss changes that will be needed for Indian science to move ahead.

Central issues

Many biologists would disagree with Padmanaban's statement that the fundamental questions in biology relate to the evolution, organization and expression of the gene. One could argue that the central problem in biology remains the origin, evolution and maintenance of organic diversity. After all, the greatest scientific revolution—the Darwinian revolution—was about the evolution of organic diversity. The evolutionary underpinnings of the diversity of life still occupy a center stage in biology and bind all biological subdisciplines. The structure and expression of the gene remains a central issue inasmuch as life on earth has a hierarchical organization. However, the gene is only one level of organization, and while for molecular biologists it might be the most important level, other levels of organization, including molecules, cells, tissues, organs, individuals, populations, species, communities, and ecosystems, also provide interesting opportunities to gain insights into the natural world. Padmanaban recognizes these opportunities when he mentions a few areas of biochemistry and cell biology. However, he overlooks whole fields of biology, such as biogeography, ecology, epidemiology, ethology, evolution, physiology, comparative morphology, systematics, toxicology, and genetics. Not only are these subdisciplines central to understanding contemporary issues in biology, but it is in some of these areas that Indian scientists have excelled in the past. Internationally, each of these subdisciplines is as vigorous as molecular biology, and some of them have been acquiring more and more importance as we come to grips with the problems of environmental degradation.

In the context of environmental degradation, few biologists would deny that conservation of biodiversity is one of the most pressing issues of our time. With the unprecedented loss of biodiversity at all levels of biological organization, the science of conservation biology has recently emerged as one of the most important and vibrant subdisciplines of biology. It is well known that tropical forests harbor one-half to two-thirds of all species that exist on earth, and that many of the contemporary extinctions are occurring in the tropics as a result of deforestation and habitat alteration. India, as Padmanaban also admits, has a rich fauna and flora. The country ranks among the top ten with respect to the number of species in many taxonomic groups of plants and animals[3]. India also has an extremely high rate of deforestation. Thus, for countries like India, conservation biology is much more central to research in biology than perhaps any other subdiscipline. Even outside India, with at least three species becoming extinct every day at the global level[4], no biologist can claim that 'the gene is still occupying the central stage' in biology.

Research issues in conservation bio-

logy are well defined[5–7], and for India. Singh has highlighted a number of research areas in biodiversity in an article also published in a recent issue of *Current Science*[8] as a part of this plea for educational institutions to pay more attention to environmental sciences. India also has a long, rich tradition of human use of biodiversity. This use provides a framework for the country's biologists to undertake important research in sustainable use of natural resources. Sustainable agriculture and forestry are contingent on the maintenance of biodiversity; thus, the research on various facets of biodiversity offers opportunities for closer ties among biologists, agricultural scientists and foresters. The incorporation of human ecology, with its varied and challenging problems, into the mainstream of biology further increases the options for undertaking exciting research which contributes to the resolution of fundamental problems on the one hand and the betterment of the human condition on the other.

Potential for unique contributions

Innovation and uniqueness are key elements of advances in science. India possesses a unique biota, the evolution and ecology of which has been scarcely explored. Moreover, with increasing human population and development activities, India's biota faces novel threats. These threats provide biologists with the opportunity to develop innovative solutions to the sustained management of natural resources. By resolving issues related to evolution, conservation, and sustained utilization of biotic resources, Indian scientists can make unique contributions to the field of environmental biology, which includes all of the subdisciplines listed in the preceding section. It is also important to note that research in environmental biology is less expensive than that in molecular biology, yet it affords the opportunity for fundamental discoveries as well as applied work that is of immediate value to the society. This does not imply that the current emphasis on molecular biology by Indian biologists and the government is misplaced. In fact, recent developments in molecular biology and biotechnology have revolutionized the field of molecular evolution and have spawned such new subdisciplines as molecular ecology. Molecular biological techniques can aid in addressing many critical issues in the conservation of genetic resources, wildlife management, and epidemiology of subtropical and tropical diseases. Indeed, these techniques are being applied to answer questions concerning utilization and management of genetic resources at places like the Indian Bureau of Plant Genetic Resources and the M. S. Swaminathan Research Foundation, but a full realization of the potential offered by molecular biology and biotechnology would require new institutional mechanisms and a fresh outlook on the part of molecular biologists and environmental scientists. Padmanaban also outlines several unique opportunities in bacteriology, parasitology, and insect pests that can lead to advances in basic and applied research at the same time.

Contemporary Indian biology

Padmanaban has already given some examples of noteworthy research in the fields of molecular and cellular biology. I have argued that Indian scientists have a rich tradition and an exciting future in other areas of biology, notably environmental biology, including such diverse fields as behavior, biogeography, ecology, evolution, genetics, conservation biology, population biology, paleontology and systematics. Indian biologists have in the past made excellent contributions to the areas of genetics and evolution, comparative morphology, cytogenetics and evolution, paleontology, genetics and plant breeding, and ecology, to cite a few. Outstanding work in these and other areas, viz. ecosystem ecology, ecosystem ecology and shifting agriculture, biodiversity and human ecology, chronobiology, plant reproductive biology, ecology of social insects, animal ecology, theoretical biology, plant evolution, plant breeding and genetics, still continues. Nonetheless, the relative contributions of Indian biologists to major developments in biology on the international scale remain slim.

Constraints on progress

One of the major constraints limiting progress, as Rao explains[9], is the underfunding of science. Although India has an adequate number of scientists, facilities for research are poor. For example, I have highlighted opportunities for research in several areas of environmental biology. The conduct of such research requires good facilities for field work, which are largely nonexistent in India. For instance, the vastness of the existing infrastructure notwithstanding, there is not a single well-equipped field station in the country to which the scientists from all institutions have free access at all times of the year.

Increased funding alone is not likely to improve the quality of biological research in India. There are several other maladies, which the scientists who participated in the debate about Indian science do not adequately discuss. First, research in India is largely a government enterprise. While the federal and state governments overall have done a credible job in providing resources for scientists, power in federal and state governments is highly centralized. This centralization and red tape, another byproduct of government bureaucracies, stifles innovation and ideas and is particularly detrimental to the development of young scientists. Centralization of power also extends to government institutions and universities, as well as research laboratories.

Second, Indian scientists by and large receive poor training in graduate schools. During the last three decades, the number of colleges and universities offering post-graduate degrees have mushroomed without a concomitant increase in the number of well-qualified scientists who could add rigor and depth to post-graduate training. Although poor training may be ultimately attributable to inadequate funding, lack of strategic planning is also an important factor.

Finally, biology is a vast subject. The exploration of all frontiers in life sciences can consume considerable resources. With limited funding, priorities must be defined. Even in the 'affluent' West, it has become commonplace for professional societies and national academies to develop research agendas. A lot of research in India focuses on trivial problems, is limited in scope, and covers subjects that have been investigated elsewhere. This problem in part stems from poor training of the country's

scientists, and in part from lack of overall direction.

Outlook for future

India may lack material resources, but its 850 million people constitute one of the best reservoirs of brain power available. This power must be unleashed to improve the quality of Indian science. Infusion of additional funds, as Rao argues, would enhance scientific activities; however, several other steps must be taken to fully capitalize the talents of India's scientists.

Decentralization of power in universities, research laboratories, and other scientific establishments must be accelerated. The juniormost scientists must have as much freedom and access to resources as the seniormost scientists in a given unit. Red tape must be reduced so that scientists can devote more time to scientific research. Decentralization and reduction of red tape will not be easy. The country's institutions mirror the culture of the society in which they are embedded. Thus unless there is overall decentralization, the freedom and flexibility so critical for creative activity will remain a dream for the vast majority of Indian scientists.

Cogent research agendas must be developed for various subdisciplines of biology. This cannot be done by individuals. Groups of scientists with common interests should review priorities in their respective fields. The development of research agendas must be based upon the unique opportunities offered by India's diverse biota and the wide range of interactions between India's people and living organisms. The Department of Science and Technology has recently taken initiatives to identify key areas for research[10]. These initiatives should be strengthened, and the research priorities they identify should be made widely known.

The quality of Indian science will ultimately depend upon the type of graduate and post-graduate training that Indian scientists receive. There must be a systematic review of the post-graduate programmes throughout the country to determine their deficiencies and how these might be remedied. The country's top-notch research institutes should play a leading role in enhancing the capability of other institutes. Moreover, the government can take active steps in involving Indian expatriates in training young scientists at little or no cost. In fact, the mere elimination of red tape would encourage Indian expatriates not only to participate on their own in Indian science, but also to bring more resources into the country.

An additional problem is the lack of accountability. Science in India is largely a government enterprise, and as in other public sector ventures, there is very little accountability in scientific and academic institutions. Scientists, in order to receive continuous support, must be held accountable for the resources invested in their work.

Finally, the quality of Indian scientific journals must be improved[11]. The scientific journals mirror the aspirations of scientists and set the standard to be followed. The quality of papers published in most Indian scientific journals is extremely poor. Such papers create the illusion of productivity. Worse, they set bad standards for young scientists. Professional associations and societies must review the current publication practices of their journals.

Epilogue

Rao's editorial[9] raises two issues: inadequate funding for Indian science and the balance between pure science and technology in a country like India. I have argued that the infusion of funds alone cannot raise the standards of Indian science, and unless the standards are raised, a good case for additional funding would be difficult to make. The debate about pure science and societal needs is widespread even in the more affluent Western world, and it is appropriate for Rao to raise the issue in the context of Indian science. Fortunately, biologists in India have access to unique organisms and to interesting interactions between human populations and the rapidly vanishing wildlands and biota. Moreover, the increasing pressures from human societies for a better environment pose novel challenges in the fields of public health, agriculture, forestry, and conservation and sustained management of natural resources. In order to fully realize the potential offered by the circumstances, Indian biologists should develop concrete research agendas in various subdisciplines that offer opportunities for innovative research. Some of this research would require new mechanisms for collaboration among molecular and environmental biologists and even social scientists. In order to improve the overall standard of research in India, science must be decentralized, graduate and post-graduate training of scientists improved, and the quality of scientific journals enhanced.

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