

## Tropical Ecosystems into the 21st Century

**WE ENDORSE THE ECOLOGICAL SOCIETY OF America's (ESA) call to shift its primary focus from the study of undisturbed ecosystems to interdisciplinary studies of human-influenced ecosystems for the betterment of human societies (1, 2). At the 2004 annual meeting of the Association for Tropical Biology and Conservation (ATBC) in Miami, Florida, we released a report ("Beyond Paradise: Meeting the Challenges in Tropical Biology in the 21st Century"), which also makes a plea for an interdisciplinary, participatory, and socially relevant research agenda to study and conserve human-impacted as well as pristine tropical ecosystems (3, 4). Here, we highlight the similarities and differences of the ESA and ATBC reports.**

The ATBC report, like that of ESA, recognizes the increasing impact of humans on tropical ecosystems. Since 1980, 288 million hectares (21%) of tropical forest areas have been deforested, while the population in tropical countries has nearly doubled. Rapid economic growth in several tropical areas exacerbates pressures on tropical forests. A unique feature of tropical regions is that millions of rural people rely on local ecosystem goods and services, often paying a high opportunity cost to maintain biodiversity.

Tropical research thus must be rooted in a more inclusive set of social values. Conservation must become part of the larger agenda of sustainable and equitable development, with the development needs of local communities receiving the same consideration as preservation goals. At the same time, interdisciplinary approaches that accord respect to alternative knowledge systems will be needed to address the effects of human activities on tropical ecosystems, the social drivers of ecosystem degradation, and the social responses to the conservation of those ecosystems. Furthermore, tropical biology will have to increasingly incorporate policy-oriented research to mitigate threats to biodiversity.

The critical knowledge needed to usher tropical ecosystems through the environmental transformations of the 21st century must focus on three components. First, human impacts on tropical ecosystems will increase dramatically. Tropical forest conversion, the effects of climate change, nutrient deposition, spread of alien species, and extraction of ecosystem products on the structure and functioning of undisturbed and managed ecosystems must be understood. The second component pertains to social drivers of change and social responses to conserva-

tion. Conflicts and continued poverty around protected areas suggest that existing approaches to conservation lack understanding of links between maintenance of diversity and human well-being. The third component, understanding the structure and function of tropical ecosystems, including cataloging tropical diversity, is fundamental to comprehend and mitigate consequences of the biodiversity loss in human-impacted ecosystems. The equal emphasis in the ATBC report on the study of pristine and human-impacted systems (distinct from the "synthetic" ecosystems described in the ESA report) stems from the uniqueness of tropical ecosystems. The latter contain substantial amounts of undescribed biodiversity, espe-



### Letters to the Editor

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cially in forest canopies and soils, and tropical ecosystems harbor 65% of the world's 10,000 endangered species.

The ATBC proposes four broad recommendations for immediate action. First, research institutions, biological collections, scientific journals, and information infrastructure in the tropics must be strengthened and multiplied by forging partnerships among institutions and collaborators. Second, society must support an expanded system of field stations that are electronically linked, include relatively pristine areas and human-impacted landscapes, and generate and apply knowledge to conserve and sustainably use tropical nature through local networks or coalitions of government agencies, academic institutions, non-government organizations, and policy-makers. Third, completing the inventory of existing life is basic to human welfare, especially in tropical regions of mega-diversity. Traditional biology must be combined with advanced technologies to rapidly develop new ways to assemble, organize, and disseminate information about diversity of life in the tropics. Fourth, interdisciplinary research by implementing cross-disciplinary training programs in biology and social sciences should be encouraged to address complex issues that lie at the interface of science and society.

Both the ESA and the ATBC statements, along with reports from other programs (e.g., Millennium Ecosystem Assessment, DIVERSITAS), demonstrate an exciting convergence of interests by tropical biologists, conservationists, and social scientists. This convergence should engender support from international environmental development agencies, national agencies, and private donors for linked studies of ecological and social systems. Such support is critical to understand tropical ecosystems and enhance the welfare of human societies that depend on them.

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2. M. A. Palmer *et al.*, *Science* **304**, 1251 (2004).
3. K. S. Bawa, W. J. Kress, N. M. Nadkarni, S. Lele, *Biotropica*, in press.
4. ATBC's report (available at <http://www.atbio.org/>) is based on an international effort initiated in 2000 to review the state of tropical biology and to explore opportunities for future advances in the field. We thank over 150 tropical biologists who participated in the discussions from 2000 to 2004. A. Fiala and A. Das helped in locating statistical figures and sources of information. This report has been prepared with the support of tropical research groups and funding agencies, including the Association for Tropical Biology and Conservation ([www.atbio.org](http://www.atbio.org)), the Ashoka Trust for Research in Ecology and the Environment ([www.atree.org](http://www.atree.org)), the Smithsonian Institution ([www.si.edu](http://www.si.edu)), the National Science Foundation ([www.nsf.gov](http://www.nsf.gov)), and the British Ecological Society ([www.britishecologicalsociety.org](http://www.britishecologicalsociety.org)).

## Changing Strategies in Science Education

AS J. HANDELSMAN *ET AL.* NOTE IN THEIR Policy Forum "Scientific teaching" (23 Apr., p. 521), recent educational research has shown that a variety of active-learning strategies are superior to the teaching methods that many of us experienced in our own training. That is, the traditional approach of lecturing to a room full of students seems to be less effective than engaging these students in the process of thinking about the information.

A particular challenge, which was not noted by Handelsman *et al.*, is reorienting our role in the training of secondary science teachers—indeed, in training teachers throughout the K–12 enterprise. In general, the science courses through which K–12 teachers learn their science are taught by scientists. It is incumbent upon us as scientists to ask ourselves how well we serve as role models for the teachers we train.

In general, we tend to teach the way we were taught ourselves. It is only after we become more comfortable with our teaching expertise, and more comfortable in our other roles as scientists, that some of us may begin to investigate alternate pedagogical approaches. The same can be said for the students whom we teach. If we instruct our future K–12 teachers by the traditional approach of lecturing about

scientific facts, we may expect that they will use the same methods in their own classes.

But science is not the memorization of facts. It is an ongoing, investigative endeavor. It requires thinking deeply about subjects, and continuously assessing whether the data support the current understanding. Actually doing science requires a world view that is quite different from that which we portray in our classes.

As scientific literacy has declined, we have considered a variety of ways to address it. One very important effort has been the development of the National Science Education Standards (1, 2). Built into the Standards is the expectation that the teaching of science should be realigned to match more closely the doing of science. That is, K–12 instruction should, wherever possible, use methods of active learning and of inquiry-based learning. The typical response to reading this, I suspect, will be "good, that is as it should be."

Thus, we have a paradox. We applaud the Standards' exhortation to teach science as an investigative endeavor and to use inquiry-based methods where possible. Yet, we, ourselves, tend to teach the way we were taught and use didactic lecturing—through which we train future K–12 teachers the avoidance of inquiry-based methods. Consequently, it is exceedingly difficult for K–12 teachers to incorporate inquiry-based teaching into their courses. This realization suggests that it is essential that we move our own teaching methods into the current century, pay attention to the educational literature, and use active learning, problem-based learning, and inquiry-based learning in our own classes.

Handelsman *et al.* have offered recommendations for how we might improve the Culture of Science to put greater weight on the teaching enterprise. I suspect, however, given the vast inertia of our scientific and educational systems, that a single Policy Forum will be insufficient. It will be necessary to give educational innovations the same degree of attention that we give to basic research. Given the prestige and wide readership of *Science*, I ask that a new section of the journal be created to discuss teaching issues. We need open and frequent discussion of this tremendously important issue.

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## Universities and the Teaching of Science

**IN THEIR POLICY FORUM "SCIENTIFIC TEACHING"** (23 Apr., p. 521), J. Handelsman *et al.* call for reform of science teaching at research universities. It is ironic to find that the best practices for science teaching described in the article are considered innovative and noteworthy. At predominantly undergraduate colleges and universities, where teaching is a significant part of the professional lives of faculty, these approaches are now common and pervasive. It is unfortunate that the authors fail to recognize this, because there are implications for policy in higher education. More time spent on innovation in teaching typically means less time available for conducting research. For example, faculty at undergraduate colleges and universities publish about one paper every 2 years (1). Although it is noteworthy that these professors maintain modest research programs under challenging research conditions, this level of productivity is likely to be unacceptable at research universities. Indeed, administrators at research universities should be striving for greater faculty productivity in research.

The critical policy issue is not how we get research faculty to pay more attention to teaching. Nor is the critical issue how to get teaching faculty to publish more papers. The critical issue is faculty productivity and the alignment of this productivity with the various university missions. If, as the authors posit, undergraduate science education at the research universities is in need of a reform, then it may be more realistic to ask for accurate public descriptions of the strengths and weaknesses of the research university concept. Potential undergraduate students can then make informed choices about where to spend their tuition dollars.

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### Response

**WE AGREE THAT MANY INDIVIDUALS AND** programs at primarily undergraduate institutions are leaders in teaching innovation.

However, national reports and agencies indicate that the majority of undergraduates are not becoming scientifically literate members of society, and that science education reform is overdue at all undergraduate institutions, regardless of size (1-8).

On the basis of these reports, education reform should be on the agenda of all colleges and universities. As Luken points out, teaching could be construed as a conflict of interest at research universities (and vice versa at smaller colleges), but all of these institutions have multiple missions. The mission statement of most research universities includes educating undergraduate students; both research laboratories and classrooms contribute to that goal. If research universities didn't educate, they would be research institutes. Moreover, research universities already practice the effective joining of research and teaching in graduate education. It is the responsibility of research universities to prepare future faculty for careers in research and teaching. Teaching is not incidental at a research university—it's essential.

The goal of our Policy Forum was to impress upon scientists the importance of

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scientific teaching at research institutions, to provide evidence that reform is needed, and to offer examples of innovative teaching resources. We acknowledge practices of scientific teaching at small colleges, and would be interested to know of any data about teaching and learning at these schools that could be applied to research institutions. Ideally, instructors at large and small universities will work together to share results and evidence-based explanations of teaching experiences that foster student learning.

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## TECHNICAL COMMENT ABSTRACTS

### COMMENT ON "How the Horned Lizard Got Its Horns"

Salvatore J. Agosta, Arthur E. Dunham

Young *et al.* (Brevia, 2 April 2004, p. 65) purported to identify the mechanism behind the origin and maintenance of horns in horned lizards. Unfortunately, they asserted rather than demonstrated the current function of horns and failed to recognize the crucial distinction between adaptation and exaptation. As a result, the question implied in the title of their article—how the horned lizard got its horns—remains unanswered and, in the absence of an historical perspective, is unanswerable.

Full text at

[www.sciencemag.org/cgi/content/full/306/5694/230a](http://www.sciencemag.org/cgi/content/full/306/5694/230a)

### RESPONSE TO COMMENT ON "How the Horned Lizard Got Its Horns"

Edmund D. Brodie III, Kevin V. Young, Edmund D. Brodie Jr.

Our study of the effect of natural selection on the horns of horned lizards focused on current function, not historical origins of the trait as described by the phylogenetic definition of adaptation. We explain why studies of current function are important for understanding adaptation and why a purely historical perspective on adaptation is unproductively limiting.

Full text at

[www.sciencemag.org/cgi/content/full/306/5694/230b](http://www.sciencemag.org/cgi/content/full/306/5694/230b)

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