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Beyond Paradise—Meeting the Challenges in Tropical Biology in the 21st Century[1]

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ABSTRACT

Tropical ecosystems support a diversity of species and ecological processes that are unparalleled anywhere else on Earth. Despite their tremendous social and scientific importance, tropical ecosystems are rapidly disappearing. To help tropical ecosystems and the human communities dependent upon them better face the challenges of the 21st century, tropical biologists must provide critical knowledge in three areas: (1) the structure and functioning of tropical ecosystems; (2) the nature and magnitude of anthropogenic effects on tropical ecosystems; and (3) the socio-economic drivers of these anthropogenic effects. To develop effective strategies for conservation, restoration, and sustainable management of tropical ecosystems, scientific perspectives must be integrated with social necessities. Three principles for guiding tropical biological research are suggested: (1) broadening the set of concerns; (2) integration of biological knowledge with the social sciences and traditional knowledge; and (3) linking science to policy and action. Four broad recommendations are proposed for immediate action in tropical biology and conservation that are fundamental to all biological and social disciplines in the tropics: (1) assemble and disseminate information on life's diversity in the tropics; (2) enhance tropical field stations and build a worldwide network to link them with tropical field biologists at their field sites; (3) bring the field of tropical biology to the tropics by strengthening institutions in tropical countries through novel partnerships between tropical and temperate zone institutions and scientists; and (4) create concrete mechanisms to increase interactions between tropical biologists, social scientists, and policy makers.

RESUMEN

Los ecosistemas tropicales mantienen una diversidad de especies y procesos ecológicos como ningún otro en la tierra. A pesar de su gran importancia a nivel social y científico, los ecosistemas tropicales están desapareciendo rápidamente. Para ayudar a estos y a las comunidades humanas que dependen de ellos a encarar mejor los desafíos del siglo 21, los biólogos tropicales deben proveer información crítica en tres áreas: (1) la estructura y funcionamiento de los ecosistemas tropicales; (2) la naturaleza y magnitud de los efectos antropogénicos sobre los ecosistemas tropicales; y (3) las fuerzas socio-económicas de esos efectos antropogénicos. Para desarrollar estrategias efectivas para la conservación, restauración y manejo sostenible de los ecosistemas tropicales, las perspectivas científicas deben ser integradas a las necesidades sociales. Tres principios para orientar la investigación en biología tropical son sugeridos: (1) ampliación del grupo de interés; (2) integración del conocimiento biológico con las ciencias sociales y el conocimiento tradicional; y (3) enlazar la ciencia con las políticas y la acción. Para una acción inmediata en biología tropical y la conservación, se proponen cuatro recomendaciones amplias que son fundamentales a todas la disciplinas biológicas y sociales en los trópicos: (1) recopilar y diseminar información sobre diversidad biológica en los trópicos; (2) mejorar las facilidades para la investigación en los trópicos (estaciones biológicas) y construir una red mundial que las una con los biólogos tropicales;

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(3) apoyar el campo de la biología tropical fortaleciendo las instituciones de los países tropicales a través de la colaboración con instituciones y científicos de zonas templadas; y (4) crear mecanismos concretos para incrementar la interacción entre biólogos tropicales, científicos sociales y tomadores de decisiones.

RESUMO

Os ecossistemas tropicais abrigam uma diversidade de espécies e de processos ecológicos sem paralelo em qualquer outro lugar da Terra. Apesar de sua tremenda importância social e científica, os ecossistemas tropicais estão desaparecendo rapidamente. Para ajudar os ecossistemas tropicais e as populações humanas que dependem deles a melhor enfrentar os desafios do século 21, os biólogos tropicais precisam gerar conhecimentos cruciais em três áreas: (1) a estrutura e o funcionamento dos ecossistemas tropicais; (2) a natureza e a magnitude dos efeitos antrópicos sobre os ecossistemas tropicais; e (3) as diretrizes sócio-econômicas destes efeitos antrópicos. Para se desenvolver estratégias efetivas para a conservação, restauração e manejo sustentável dos ecossistemas tropicais, as perspectivas científicas tem que ser integradas às necessidades sociais. Três princípios norteadores da pesquisa em biologia tropical são indicados: (1) ampliar o conjunto de interesses; (2) integrar o conhecimento biológico com o conhecimento tradicional e as ciências sociais; e (3) unir ciência com política e tomada de decisão. Quatro amplas recomendações são propostas para ação imediata na biologia tropical e conservação e que são fundamentais para todas as disciplinas biológicas e sociais nos trópicos: (1) organizar e disseminar informação sobre a diversidade biológica nos trópicos; (2) consolidar as estações de pesquisa de campo nos trópicos e construir uma rede mundial para ligar estas estações e os biólogos tropicais atuando nelas; (3) levar o campo da biologia tropical para os trópicos pelo fortalecimento das instituições nos países tropicais e através de novas parecerias entre estes países e seus cientistas com os cientistas e as instituições de países da região temperada; e (4) criar mecanismos concretos para aumentar as interações entre os biólogos tropicais, os cientistas sociais e os políticos tomadores de decisão.

Key words: biodiversity; biological research; conservation; social science; sustainable development; tropical ecosystems; tropical forests.

Tropical ecosystems support a diversity of species and ecological processes unparalleled anywhere else on Earth. People in the tropics and in other parts of the world benefit enormously from the products and services provided by tropical ecosystems. Hundreds of millions of people in tropical regions need local ecosystems to sustain traditional and contemporary livelihoods and to meet basic needs for medicines, food, and clean water. Tropical ecosystems are critical elements of the hydrology of many of the world's largest rivers. Tropical forests significantly regulate carbon and nutrient budgets throughout our biosphere. The extraordinary complexity and species richness of nature in the tropics has inspired scientists to formulate a new understanding of evolutionary and ecological principles (von Humboldt & Berg 1854; Bates 1864; Wallace 1869, 1870; Janzen 1983; Hubbell 2001; for review, see Chazdon & Whitmore 2002). The astounding diversity of life in tropical ecosystems stimulates scientific research—research that has taken on new urgency with the growing awareness that these ecosystems are critical to humanity's survival.

Despite their tremendous social and scientific importance, tropical ecosystems are rapidly disappearing. During the last two decades (1980–2000), 288 million hectares, or 21 percent of the area covered by tropical forests in 1980, have been deforested (FAO 2001). This trend and its drivers show no sign of easing.

Species loss in the tropics is difficult to quantify, but biologists estimate that the rate of species extinctions due to human activity is one to two orders of magnitude greater than the natural background rate over the last several million years (Kerr & Burkey 2002, Singh 2002, Dirzo & Raven 2003). Biodiversity is not evenly distributed, but is overwhelmingly concentrated at elevations below 800 m, coinciding with the area of greatest human impacts. Even moderate human modification (*e.g.*, high-grading) can have extremely strong negative impacts on tree demography and the organisms that are dependent on intact forest or a particular tree species. In biodiversity hotspots, the majority of which are in the tropics, up to half of the species are threatened with extinction (Myers *et al.* 2000). Availability of many important ecosystem products and medicinal plants is declining, thereby affecting the livelihoods and health of those dependent upon them—including residents of non-tropical regions. Changes in the functioning of critical ecosystems, whether due to loss of keystone species or disruption of vital processes, threaten their regulatory functions. Many of these losses and changes are not easily reversible and legacies of human disturbance can persist for centuries (Chazdon 2003, Willis *et al.* 2004). This transition is occurring at a time

when we still have much to learn about the functioning of these ecosystems and their current and potential benefits to humankind.

Policy responses to the loss of tropical biodiversity are increasing. For example, the Convention on Biological Diversity proposed in 1992 (www.biodiv.org) recognizes the global significance of biodiversity and the need to safeguard our natural heritage, especially in developing countries. It has been ratified by all but a few nations, the United States among those who have not ratified it. The Convention has three objectives: conservation of biodiversity, sustainable use of biodiversity, and equitable sharing of the benefits of biodiversity. Pursuit of these objectives has led to additional international treaties on protection of genetic resources, biodiversity conservation, and sustainable development.

Significant shifts in our understanding of tropical ecosystems, the status of these ecosystems, and the socio-political context for conservation decisions have created increased demand for data and guidance from tropical biologists. Recognizing the expanding scope of their profession, tropical biologists recently initiated a broad-based effort to review the state of their field and to explore the changes needed in both the priorities and practice of tropical biology.

ESTABLISHING RESEARCH PRIORITIES

In the past, tropical biologists tended to work individually or in small groups, and formally defined their collective research needs and priorities only rarely. In 1980, a group of scientists defined priorities in tropical biology for the first time and produced a report titled "Research Priorities in Tropical Biology" (National Research Council 1980). The report (hereafter, NRC 1980 Report), commissioned by the NRC, was drafted by a committee of 14 scientists from five countries with 21 advisory biologists that represented ten other countries. The document has influenced research and research funding priorities for over two decades. Many of the recommendations of that Report remain relevant (Table 1) but other aspects are no longer relevant and do not capture the changes that have since taken place. Major shifts are now required in the overall approach to and priorities for research as a result of significant changes in our understanding of tropical ecosystems, in the status of these ecosystems, in the technologies available, and in the socio-political context in which decisions about these ecosystems are being made.

In 2000, tropical biologists from around the world initiated a broad-based effort to review the state of tropical biology and to explore opportunities for future advances in their field. Spearheaded by the Association for Tropical Biology and Conservation (ATBC), the largest professional society for tropical biologists, a process to articulate research priorities in tropical biology was formally launched at an international conference in Bangalore, India ("Tropical Ecosystems; Structure, Diversity, and Human Welfare;" July 2001) and continued through workshops and retreats in Washington, D.C. (February 2002, 2003), Panama (August 2002), and Aberdeen, Scotland (July 2003). Over 150 tropical biologists participated in these discussions via multiple communication pathways established to maximize the diversity of opinions and input. These pathways included open workshops at large international meetings on three continents at which scientific questions and research priorities were solicited and ranked in importance, requests for comments on drafts of documents posted on the web, intensive writing retreats and follow-up editing sessions by electronic mail, and invitations to senior scholars and tropical land managers for comments. This effort was supported by tropical research groups and funding agencies that include the Association for Tropical Biology and Conservation (www.atbio.org), the Ashoka Trust for Research in Ecology and the Environment (www.atree.org), the Smithsonian Institution (www.si.edu), the National Science Foundation (www.nsf.gov), and the British Ecological Society (www.britishecologicalsociety.org).

The participants in the meetings, workshops, and retreats discussed a wide range of topics, but confined the scope to terrestrial ecosystems and particularly to tropical forest ecosystems, which comprise the historical roots of the organizing societies. Although participants recognized the need to set research priorities in other tropical ecosystems (e.g., grasslands, coral reefs, fresh water systems), the focus of this report is on tropical forest ecosystems.

Here, we summarize the deliberations and recommendations that resulted from these efforts (see also Bawa *et al.* 2004). We briefly review the current state of the science of tropical biology and highlight opportunities for future advances. First, we outline research priorities in tropical biology and conservation. We then define the principles and framework needed to achieve broad goals. Fi-

TABLE 1. *Research Priorities in Tropical Biology: The National Research Council 1980 Report.*

Summary and Recommendations
Biological Inventory
The international effort in completing an inventory of tropical organisms should be greatly accelerated, especially during the next 25 years.
Tropical Ecosystem Studies
Tropical ecosystems should be investigated in depth at places selected because they are representative, diverse, and capable of experimental manipulation and because of scientific and societal importance. These studies should investigate both natural and experimentally manipulated ecosystems and should emphasize solutions to problems in areas of general ecological interest.
Studies of Tropical Aquatic Systems
We believe that tropical freshwater systems should be studied much more intensively than at present in view of their scientific and economic importance.
Monitoring Forest Conversion
National schemes for monitoring the rates of conversion of tropical moist forests and other tropical vegetation types should be encouraged and, when appropriate, aided by competent international bodies.
Five-Year Schedule
During the 5-year period 1980–1985, we call for the following actions as matters of extreme importance for the attention of all the nations of the world: ● At least double, in constant dollars, the funds now devoted to biological inventory in the tropics. ● Increase by at least 50 percent the number of professional systematists engaged in studies of tropical organisms. ● Initiate operations in at least the basic four ecosystem sites mentioned, establish a center for the study of tropical plant physiological ecology, and complete the installation of their physical facilities. Complete the basic studies of mineral cycling and the basic biological and soils inventories at each ecosystem site. ● Initiate or expand major comprehensive studies of the structure and functioning of the Amazon, Orinoco, and Purari rivers and their major branches; of Lakes Valencia and Maracaibo; and of the Sudd, the Pantanal of Mato Grosso, the *varzea* of the Amazon Basin, and the delta and backwaters of the Orinoco. The basic 5-year studies we have outlined should be completed in all these cases well before 1990, and studies of other subjects should be initiated in the period 1986–1990. ● Fund national monitoring and international reporting of the rates of conversion of tropical vegetation types, especially tropical moist forest.

nally, we present recommendations for meeting the current and future challenges faced by tropical biologists.

TROPICAL BIOLOGY IN THE 21ST CENTURY

A major transformation has occurred in the relationship between humans and tropical ecosystems over the two and a half decades since the NRC report was published. The NRC 1980 Report focused primarily on the research priorities of biological scientists working in the tropics. Today, if tropical biologists are to help tropical ecosystems and the human communities dependent upon them better face the challenges of the 21st century, the development of biological knowledge must be complemented by and integrated with research in the social sciences. Understanding of the factors that drive anthropogenic stress in the tropics, how these stresses play themselves out through tropical ecosystems to affect human well-being over space and time, and which social arrangements or factors can alleviate these stresses must be developed in an interdisciplinary manner to inform policy and action for conserving, restoring, and enhancing the values of tropical ecosystems (Tables 2–4).

Knowledge component 1. Basic research on tropical ecosystems: description, maintenance, and function.—Understanding the diversity, maintenance, and functioning of tropical ecosystems is the foundation of biological research in the tropics. Yet, after a century of work in these regions, our knowledge about tropical forests is still incomplete due to the complex and diverse nature of these ecosystems. Few issues are of greater importance to the scientific enterprise than to complete the catalogue of life and its natural history on earth (Wheeler *et al.* 2004). Approximately equal numbers of species of trees can be found in just one-half square kilometer of tropical rain forest in

TABLE 2. *Research issues and questions pertaining to* Knowledge Component 1. Basic Research on Tropical Ecosystems: Description, Maintenance, and Function.

Examples of topics on tropical diversity and ecosystems currently being addressed by tropical biologists include:
Describing Tropical Diversity
• Levels and patterns of genetic and species diversity in poorly known regions of the tropics, in poorly known groups (*e.g.*, epiphytes, fungi, and microorganisms), and in little explored habitats (*e.g.*, soils, forest canopy).
• Factors and processes that explain the current patterns and distribution of tropical diversity at the population and species levels.
• Influence of history and spatial heterogeneity on genetic and species diversity.
Origin, Patterns, and Maintenance of Tropical Diversity
• Factors that explain the relative abundances and species richness over time and space.
• Role of biotic interactions in the structure and functioning of tropical ecosystems.
• Origin and maintenance of diversity in natural and human impacted landscapes.
Functioning of Tropical Ecosystems
• Relationship between biodiversity and ecosystem functioning in different habitat types.
• Relationships among soil biodiversity, nutrient cycling, and productivity.
• Relationship between ecosystem structure and ecosystem services, particularly watershed and pollination services.

Borneo or Ecuador compared to the entire four million square kilometers of north temperate forest that covers Asia, Europe, and North America. Plants are one of the better known groups of organisms on the planet with 300,000 described species. Yet, as many as 50,000 species remain to be discovered and the great majority of these unknown species reside in tropical forests. Estimates of the diversity of life in the canopies of tropical forests indicate that tens of thousands of arthropod species (insects, mites and spiders) that live only in the crowns of tropical trees are still unknown to science. Even less is known about the diversity of species-rich tropical fungi and microbial life.

Biodiversity has been most extensively described at the species level, but must be studied at a variety of scales including genes, populations, communities, and ecosystems, We can neither comprehend nor mitigate the consequences of the loss of biodiversity and its effects on ecosystem functioning in human impacted ecosystems without an understanding of diversity and its role in regulating critical processes in natural ecosystems. Thus, tropical biodiversity presents three broad areas of investigation for science: (1) describing the diversity; (2) understanding its origin and maintenance; and (3) understanding the functioning of ecosystems, and the link between diversity and ecosystem functioning (Table 2). The study of biotic interactions will be critical for sustaining both natural and constructed ecosystems and landscapes in the tropics. Collaboration and syntheses across these three themes will lead to new theories and predictive science, as well as providing a foundation for more applied areas of conservation and management of tropical ecosystems. Living diversity, particularly tropical diversity, has no substitute. Genomics and genetic engineering can enable us to construct new genotypes to suit many human needs, but it is the biotic interactions in nature that ultimately determine the maintenance of diversity.

Knowledge component 2. Impacts of human activities on tropical ecosystems.—Humans have evolved in concert with their environments and are an integral part of nature. However, people now have an overwhelming impact on natural tropical ecosystems. The rate of deforestation is high and increasing. Habitats that were previously contiguous are becoming increasingly fragmented. Invasive introduced species pose increasing threats to the structure and functioning of many ecosystems. Climate change has already altered the distribution of biodiversity, ecological processes, and ecosystem functions. There is compelling evidence that these patterns will be exacerbated in the future. As human populations in many tropical regions continue to grow rapidly, and as consumption of materials and the emission of pollutants by people everywhere increases, the negative impacts of anthropogenic activities on tropical ecosystems will undoubtedly become more severe. Globalization may further increase deleterious consequences of human impacts because the drivers and effects of change are decoupled in space and time.

Priorities include an understanding of a multitude of human impacts on tropical ecosystems and responses of ecosystems to human interventions as well as management strategies designed to conserve and restore ecosystems (Table 3).

TABLE 3. *Research issues and questions pertaining to* Knowledge Component 2. Effects of Human Activities on Tropical Ecosystems.

Aspects of anthropogenic effects on tropical diversity and ecosystems currently being addressed by tropical biologists include:
• Effects of changes in land use and land cover, economic globalization, invasive species, genetically modified organisms, habitat fragmentation, pollution, and resource use on the composition, structure, and functioning of tropical ecosystems.
• Feedbacks of tropical ecosystems to local, regional and global climate regimes, particularly the role of tropical forests in the global carbon budget; role of tropical ecosystems as indicators of climate change.
• Relative impacts of conservation and restoration strategies such as protected area networks, controlled harvesting, controlled burning, and selective breeding or careful (re-) introduction of species on tropical ecosystems.

KNOWLEDGE COMPONENT 3: SOCIAL DRIVERS OF TROPICAL ECOSYSTEM DEGRADATION AND SOCIAL RESPONSES FOR CONSERVATION, MANAGEMENT, AND RESTORATION.—The continuing loss and degradation of tropical habitats is a clear indication that society is not adequately responding to the crisis of biodiversity and habitat loss in the tropics. Part of this lack of response has to do with major gaps in our understanding of the roots of this crisis as well as its likely human impacts. Tropical biologists must include in their research agenda the linkage between sustainable use of tropical diversity and human well-being. Providing concrete evidence of the positive relationship between human well being and tropical natural ecosystems can increase the motivation and support for conservation. Improved understanding of the complex drivers of change both inside and outside of protected areas will contribute to devising better governmental policies and civil society actions for conservation and sustainable use (Table 4). There is thus a need to include human-dominated landscapes in tropical biological research (Daily *et al.* 1998, 2000). This will result in enhanced efforts to add diversity to agricultural pools, to increase the prospect of conserving biodiversity in undisturbed landscapes, and to practice reconciliation ecology (Rosenzweig *et al.* 2003).

PRINCIPLES FOR ADVANCING TROPICAL BIOLOGY AND CONSERVATION

Tropical biologists face complex and multiple challenges in the 21st century. Priorities must concentrate on the documentation and understanding of tropical diversity and its function, the curtailment of habitat degradation, and the engagement of civil society in the conservation, management, and restoration of biodiversity. To advance these and other priorities and to meet contemporary challenges in science and society, tropical biologists are urged to expand the scope of their activities and broaden their approaches. The primary activities of tropical biologists and scientists must continue to be the expansion of knowledge of tropical diversity and ecosystem function. At the same time tropical biologists must actively assist in translating this knowledge into action plans to halt habitat degradation, to preserve species in disturbed habitats, and to use all tropical landscapes sustainably. Now, more than ever, scientific perspectives must be integrated with social necessities. Such socially relevant research on tropical ecosystems would be based on three principles: (1) broadening the set of concerns; (2) integration of biological knowledge

TABLE 4. *Research issues and questions pertaining to* Knowledge Component 3: Social Drivers of Tropical Ecosystem Degradation and Social Responses for Conservation, Management, and Restoration.

Examples of social science issues, sustainable development, and restoration in tropical systems currently being addressed by biologists include:
• Linkage between human well-being and the structure and functioning of tropical ecosystems across regions, communities and time; economic and non-economic "valuations" of these linkages and changes in these values over time and space.
• Role of traditional knowledge and community-based management in conservation of tropical ecosystems.
• Effect of over-consumption, poverty, property regimes, migration, and macro-economic policies on degradation of tropical ecosystems.
• Relative effectiveness of conservation paradigms and policies, management and governance regimes, and restoration efforts in curtailing habitat degradation while improving the welfare of local communities.

with the social sciences and traditional knowledge; and (3) linking science to policy and action.

Principle 1. Develop broader values and concerns for a socially oriented biology.—Tropical research must be rooted in a more inclusive set of values and concerns than in the past. Tropical biologists have always been aware of societal needs in developing countries and will have to continue to be sensitive to the diversity of values and concerns in society, particularly the concerns of the poor and underprivileged communities that often live in or close to areas of high tropical biodiversity. Rural people throughout the tropics rely on local ecosystem goods and services to sustain their livelihoods. Often they pay a high opportunity cost for maintaining biodiversity, whereas those calling for conservation experience a much higher material standard of living in urban centers. Hence, conservation must be seen as part of the larger agenda of sustainable and equitable development of tropical countries.

This conservation ethic will also require tropical biologists to demonstrate a concern for the diversity and functioning of human-dominated or 'disturbed' ecosystems as well as their more traditional concern for pristine or slightly disturbed ones. Most tropical wildland ecosystems today are impacted by humans, contain substantial amounts of biodiversity, and retain many attributes of natural ecosystems. The study of such ecosystems has important implications for local human welfare as well as the eventual fate of the surrounding, less disturbed ecosystems.

Principle 2. Adopt interdisciplinary and participatory approaches in science and conservation.—Tropical biologists will require interdisciplinary and participatory approaches to address the issues that relate to the effects of human activities in tropical ecosystems, the social drivers of ecosystem degradation, and the social responses to the conservation of those ecosystems. Biologists will have to collaborate extensively with social scientists, and 'pure' biologists must coexist with interdisciplinary hybrids such as ethnobiologists, economic ecologists, conservation biologists, and ecological anthropologists. Simultaneously, tropical biology research must become more participatory, involving local communities and according respect to alternative knowledge systems—even while not necessarily agreeing with them—in addition to modern scientific knowledge. Partnership with local communities may be an important key to the success of conservation and restoration efforts.

Principle 3. Link science with policy and action.—The practice of tropical biology must complement "pure" or "curiosity-driven" research with more targeted action- or policy-oriented research to understand and mitigate specific threats. Such research requires acknowledging that policy-makers, activists, and the lay public are key audiences in addition to one's scientific peers, that communicating the significance of one's findings to these diverse audiences, and that getting involved in follow-up action constitute important contributions to the improvement of society for the future. On one hand, this link to policy will require changing the incentive structure within academia to reward such communication and action while, at the same time, requiring scientists to be more accepting of the opportunities presented by their multiple roles in society.

We hope that these key principles—broader values and concerns, interdisciplinary and participatory methods, and action- and policy-oriented practice—can evolve to guide the pursuit of tropical research priorities. Progress in incorporating these principles into the practice of tropical biology must be monitored, and the assessments fed back into the design of activities related to education, habitat management, and policy decisions.

RECOMMENDATIONS FOR IMMEDIATE ACTIONS

The NRC 1980 Report on "Research Priorities in Tropical Biology" made broad recommendations in four major areas of research and provided a five-year schedule of action (Table 1). Since that time, significant progress has been made in each of these priority areas; yet each area remains highly relevant today. Rather than compiling a list of discipline-specific projects and then prioritizing each of these research areas, the model developed by the NRC 1980 Report is followed here by setting out four broad recommendations for immediate action in tropical biology and conservation.

Recommendation 1. Assemble and disseminate information on life's diversity in the tropics.—An inventory and catalogue of existing life is basic to science and human welfare. A top priority for advancing tropical biology research and conservation is a complete inventory, description, and classification of the plants, animals, and microorganisms

of tropical biomes. The urgency of this task demands a marriage of traditional biology with advanced technologies to provide a new set of scientific tools and methods for the description of tropical biodiversity and to permit broad access to that information. Tropical biologists must accelerate their efforts in the inventory of species particularly in the unexplored regions and habitats around the world—which may be as close as the backyard for residents of the tropics. Tropical forest canopies and soils, two examples of these little-explored habitats, are critical to climate regulation, carbon sequestration, and nutrient dynamics, processes that extend far beyond tropical landscapes in their impact.

Field biologists conducting their work in both natural habitats and human-altered landscapes in the tropics must have immediate access to the vast store of biodiversity information contained in libraries, museums, zoos, and botanical gardens to integrate into their discoveries in the field. At the same time, the large amounts of data being collected through biotic inventories and other types of field work must be assembled, organized, and disseminated in a manner that allows easy access and integration with other data. Biodiversity informatics, including the technologies of species-recognition, offers tremendous opportunities and potential for tropical biologists to advance their research. In addition, bioinformatics provides powerful tools to aid biologists in communicating their data to policy makers and society.

Recommendation 2. strengthen tropical field stations and build a worldwide network to link them with tropical field biologists.—An expanded and well-supported system of field stations dispersed throughout the tropics linked with field researchers at their individual field sites will greatly enhance comparative and collaborative work across ecosystems, continents, and disciplines. Field sites must include not only pristine areas where tropical biologists have traditionally investigated basic research questions, but also access to adjacent landscapes that have received significant human impact. A wider concept of "field sites" will result in broadening the scope of tropical biology and the adoption of multidisciplinary approaches necessary to address critical questions on human impacts and societal responses.

To succeed in this linkage, a "mega-network" with virtual connectivity based on advanced communication technology should be developed to globally connect teams at field stations and nature reserves with individual researchers at their field sites. The network of field stations linked with biodiversity data bases (see below) and local networks of coalitions of government agencies, academic institutions, non-government organizations and policy makers can help tropical biologists to fulfill their goals.

Recommendation 3. Bring the field of tropical biology to the tropics by strengthening institutions in tropical countries through partnerships between tropical and temperate zone institutions and scientists.—Historically, the majority of tropical biologists were born and trained in temperate regions. To sustain tropical habitats and species, tropical biologists must originate from tropical countries. Thus current training sites, research institutions, biological collections, journals and information infrastructure in the tropics must be strengthened and new ones will have to be built. This will involve substantial re-direction or augmentation of funds to tropical countries, "affirmative action" in favor of students from those regions into northern universities, and strengthening faculty exchange between the north and the south.

Many tropical countries are relatively small and have few research institutions. Partnerships between institutions in these countries and the temperate zone as well as large tropical countries institutions will be critical in fostering tropical research and building a cadre of resident tropical biologists. Tropical field stations and networks such as the Global Canopy Conservation Program, the Center for Tropical Forest Science, and the Organization for Tropical Studies can play an important role in strengthening institutions and promoting partnerships.

Recommendation 4. Create concrete mechanisms to increase interactions between tropical biologists, social scientists, and policy-makers.—Working across disciplinary barriers does not happen naturally within academia. A concerted set of activities must be initiated that introduce tropical biology to social scientists at various levels. Particularly important are training programs ("social sciences for the biologists" and "biology for the sociologist") that encourage existing and new interdisciplinary research initiatives and integrate social science components into the curriculum of tropical biology students at the undergraduate and graduate levels.

Proactively setting up platforms for dialogue among tropical biologists, civil society representa-

tives and policy makers in different sites and regions will be critical for success in addressing many issues related to human impacts and restoration of tropical habitats. Coalitions of scientists, civil society organizations and policy makers must be linked with networks of field stations. Such coalitions and networks, in turn, will encourage enterprise-based conservation, joint management of protected areas, and restoration of degraded habitats.

THE FUTURE OF TROPICAL BIOLOGY, HUMAN ECOLOGY, AND SUSTAINABILITY SCIENCE

The expertise of tropical biologists is essential to build a firm foundation of knowledge about the tropics as well as to conserve, restore, and sustainably use tropical habitats and organisms. The most important role that tropical biologists can play is to gather and analyze information related to all aspects of tropical ecosystems, ranging from the inventory of species and genes to monitoring ecological processes at the landscape and biosphere levels. When used in conjunction with new tools for communication and dissemination of knowledge, these data will be critical to the development of biologically feasible management plans and policies, to monitoring long-term change in ecosystems, and to link human welfare with integrity of local ecosystems. New knowledge must be communicated not only to other scientists, but also to local people, policy makers, and the next generation of scientists and non-scientists. As a group, tropical biologists must accelerate their contributions to the critical base of knowledge upon which public policies for the long-term support of conservation and management strategies must ultimately be built. All of these activities must be pursued within the framework of a socially aware, engaged, and active community of tropical scientists.

The expanded research agenda of tropical biology will require reallocation of existing resources that must be supplemented by new resources. In the last several years, a convergence of interests has occurred on the part of tropical biologists, conservationists, ecologists, and social scientists in pursuing a broader, socially-relevant research agenda because of the overwhelming impact of humanity on ecological systems (e.g., DIVERSITAS 2002, Millennium Ecosystem Assessment 2003, Palmer *et al.* 2004a, b). We are hopeful that this convergence of interests among scientific and social disciplines working in the tropics will be met by a broad constituency of support for additional funding from international development and environmental agencies, national agencies, and private donor agencies for the study of those biological systems most heavily impacted by humanity—none more critical than tropical systems for the welfare of human societies as well as life on Earth.

Both existing resources and additional resources can be marshalled to address critical issues in tropical biology. The convergence of interests among professional organizations, and government and non-government agencies will have to be transformed into greater collaboration and coordination than at present. Our common interest and resolve will be instrumental in fostering the networking required to achieve our goals.

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