What Role will Ecology (and the ESA) Play in the Future of Earth Sciences?

Ecologists and earth scientists are facing an urgent intellectual challenge. The global scale and complexity of environmental problems have increased society's need for answers to scientific questions that span traditional disciplinary boundaries. Although both national and international organizations (the Intergovernmental Panel on Climate Change and the U.S. National Academy of Sciences, among others) have recently called for increased integration across traditional disciplines, it is not clear what role ecologists will choose to play in this disciplinary reformulation of environmental science. What is clear, however, is that ecologists (and the ESA) can offer vital leadership in this area, particularly by informing allied disciplines about the critical role of ecological processes, biological diversity, and ecosystem sustainability for understanding the biological complexity of the earth system.

Is the ESA positioned to take on broad intellectual leadership within the larger context of environmental science? We here argue that ESA must urgently address this question, with emphasis on the critical interface between ecology and the physical sciences; this was also a central question discussed at the workshop *Linking Ecological Biology and Geoscience: Challenges for Terrestrial Environmental Science*, held in Madison, Wisconsin, in August 2001. This workshop was funded by the National Science Foundation and brought together 30 scientists and managers to discuss the interface between ecological biology and geological sciences.

The emergence of biogeosciences

The disciplinary basis of environmental science is in the process of reformulation. It is now clear that some of the most vexing questions about how humans impact our natural environment fundamentally depend on processes and phenomena that span biological and physical sciences. For example, biotic diversity and complexity are intimately connected to the physicochemical environment, whereas climate and soil nutrients depend closely on biological process and diversity.

Links between ecology and physical sciences are not new; historical examples include seminal ideas by Svante Arrhenius on carbon dioxide and global climate, Vladimir Vernadsky on biogeochemical cycles, and Alfred Redfield on the co-development of organisms and nutrients in the world's oceans. What is new, however, is that biology and allied earth sciences have now developed to a point where convergence is broadly available, and where the potential for synergism is unprecedented and critical for resolving key environmental problems. Recent progress of concepts, methods (e.g., genomics, molecular biology, and isotopes), observational tools (e.g., satellites), databases (e.g., soils, vegetation, and land-use change), and computational abilities have virtually revolutionized scientific readiness and opportunities at this interface.

Our workshop discussion focused on the emerging field of "biogeosciences," which refers broadly to research that spans the intellectual interface between ecological biology and the geosciences, and that aims to understand the functions of the earth system across spatial and temporal scales. Building on basic knowledge about underlying mechanisms, biogeosciences examines basic aspects of earth system function, with particular focus on how modern human activities are influencing these functions. These efforts depend on diverse approaches that include physiological ecology, functional diversity (the link between biological diversity and ecosystem function), biogeochemistry (fluxes of matter and energy in environmental systems), and biophysics (climatic, physical, and biological interactions within the earth system). The intellectual scope reaches all the way to evolutionary biology, as exemplified by links between functional attributes of the earth system (e.g., climate, atmospheric chemistry, or global carbon balances) and the historical evolution of biological function and complexity on earth.

Obstacles and opportunities

Workshop participants agreed that the most urgent problem is the *lack of a sustained intellectual home* for the biogeosciences within most academic institutions, funding agencies, and professional societies, including ESA. Much discussion centered on how to promote and reward interdisciplinary interactions despite the traditional and discipline-based structure of many institutions. This discussion and the resulting recommendations are summarized in a white paper prepared for the National Science Foundation (NSF), available at <http://www.eeb.princeton.edu/faculty/Hedin/Hedin.html>.

Visionary leadership in the biogeosciences requires professional organizations, universities, and federal agencies to more broadly recognize the scholarly and societal value of interdisciplinary science. Funding agencies can play a particularly important role in promoting interdisciplinary interactions (an observation not lost upon university administrators), but many agencies are struggling with how to support emerging fields that cut across disciplines, including biogeosciences. The committee identified fragmentation of leadership and resources across administrative boundaries as the central reason why the current "piecemeal" model of funding does not offer the sustained vision and creativity that is needed at present. Although programs such as *Coupled Biogeochemical Cycles* (a component of *Biocomplexity in the Environment* at the NSF), and the *Large Scale Biosphere–Atmosphere Experiment in Amazonia* (NASA) have been important, they address only limited time horizons, and only certain aspects of the required integration. Core programs such as *Ecosystem Studies* (NSF) have traditionally linked biology to the physical sciences, but are also

more limited in scope and context than the broad and evolving intellectual home called for by workshop participants. The workshop participants urged the NSF and other funding agencies to develop permanent homes for biogeosciences based on joint and balanced representation from biology and the geosciences.

Stronger support for the biogeosciences within educational institutions will allow faculty and researchers to dare to take risks and be innovative—not only in research, but also in graduate and undergraduate training and curricula. Although training and educational programs are critical (and offer an opportunity for funding agencies to promote links across disciplines), these must be anchored in real commitments to interdisciplinary-based learning. Training of the next generation of leaders in environmental science demands curricula that link biological and physical understanding—a palpable challenge for university administrators as well as faculty. Along with this new challenge comes the inevitable tension between providing a broad education in environmental science, while at the same time training students in the key disciplinary skills and depth of knowledge required for future careers. There is considerable room for experimentation and development of novel educational models.

Challenges to the Ecological Society of America

We believe that the ESA must develop a clear vision for integrating research across ecological and physical sciences, and for promoting interdisciplinary education as a rule (rather than an exception) within the earth sciences. With the advent of new interdisciplinary journals such as *Ecosystems*, the potential for a new *JGR-Biogeosciences* journal, and the increasing leadership shown by the American Geophysical Union in promoting interdisciplinary research (the AGU recently established a new *Biogeosciences* section), many workshop participants felt that ESA is in danger of losing members to other societies, and readers to other journals. Of even broader significance is the question of how ESA can proactively inform allied fields about the critical importance of considering the organization of biological process—from genes to ecosystems—in any effort to develop integrated understanding of the earth system. "Interdisciplinary" is fashionable today for good scientific reasons, and although ecology needs to thrive on its own terms, it must also take responsibility for providing information and intellectual leadership to allied disciplines.

What steps might ESA take to address the above concerns? A first step is to create a new *Biogeosciences* or *Biogeochemistry and Ecosystem Ecology* section. Such a section can serve as a focal point for discussing how to engage allied scientific fields, educators, decision makers, and managers of science. A second step is to develop joint efforts between the ESA and the AGU (or other allied organizations) to stimulate interactions and communication between societies, possibly led by designated "liaisons" from each organization. Such efforts ought to include joint sponsorship of symposia and workshops at annual meetings, focused on developing common intellectual platforms to guide future research directions, and interdisciplinary education at undergraduate and graduate levels. A third step is to develop a conference series that specifically targets interdisciplinary links between ecology and other fields, possibly following the highly successful model of Chapman Conferences (convened by the AGU). A sustained series of such conferences—with an appropriate name such as "Hutchinson conferences"—could serve as a sustained think tank for exploring contributions of ecology (and the ESA) within a variety of scientific, educational, and policy questions. A fourth step is to promote the publication of biogeosciences research in ESA journals. It is clear that building a bridge between ecology and the physical sciences depends on encouraging members (and nonmembers) to submit interdisciplinary papers to the ESA journals, and to foster the view of ESA journals as leading the conceptual integration of ecology within the broader environmental sciences.

Will ESA engage these new developments, or miss the proverbial boat? We believe ESA can (and should) play a leading and proactive role in this pursuit of some of the most challenging and intellectually broad questions of our times. The issue at hand, however, is what the ESA membership can (and will) do *now* to set the course for such vision and leadership—locally within our own community, and globally with allied disciplines, educators, policy makers, and funding agencies. By taking a more active interdisciplinary role, the ecological community, guided by strong leadership from ESA, can ensure that the "bio" in biogeosciences is firmly grounded in sound, high-quality, and innovative ecological research.

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