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POLICY FORUM: ENVIRONMENT AND DEVELOPMENT

Sustainability Science

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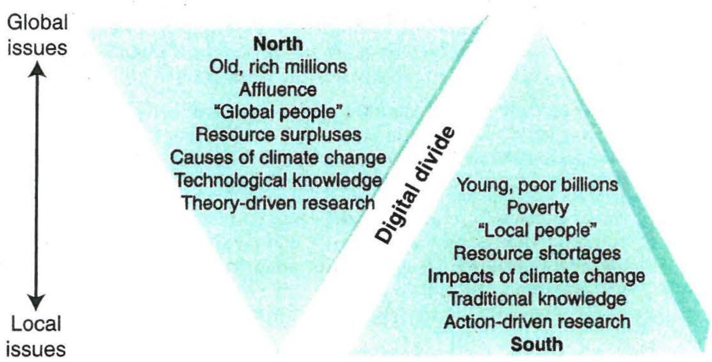
Meeting fundamental human needs while preserving the life-support systems of planet Earth is the essence of sustainable development, an idea that emerged in the early 1980s from scientific perspectives on the relation between nature and society (*1*). During the late '80s and early '90s, however, much of the science and technology community became increasingly estranged from the preponderantly societal and political processes that were shaping the sustainable development agenda. This is now changing as efforts to promote a sustainability transition emerge from international scientific programs, the world's scientific academies, and independent networks of scientists (*2*).

Core Questions

A new field of sustainability science is emerging that seeks to understand the fundamental character of interactions between nature and society. Such an understanding must encompass the interaction of global processes with the ecological and social characteristics of particular places and sectors (*3*). The regional character of much of what sustainability science is trying to explain means that relevant research will have to integrate the effects of key processes across the full range of scales from local to global (*4*). It will also require fundamental advances in our ability to address such issues as the behavior of complex self-organizing systems as well as the responses, some irreversible, of the nature-society system to multiple and interacting stresses. Combining different ways of knowing and learning will permit different social actors to work in concert, even with much uncertainty and limited information.

With a view toward promoting the research necessary to achieve such advances, we propose an initial set of core questions for sustainability science (see the table on page 642). These are meant to focus research attention on both the fundamental character of interactions between nature and society and on society's capacity to guide those interactions along more sustainable trajectories.



Sustainability science within a divided world.

Research Strategies

The sustainability science that is necessary to address these questions differs to a considerable degree in structure, methods, and content from science as we know it. In particular, sustainability science will need to do the following: (i) span the range of spatial scales between such diverse phenomena as economic globalization and local farming practices, (ii) account for both the temporal inertia and urgency of processes like ozone depletion, (iii) deal with functional complexity such as is evident in recent analyses of environmental degradation resulting from multiple stresses; and (iv) recognize the wide range of outlooks regarding what makes knowledge usable within both science and society. Pertinent actions are not ordered linearly in the familiar sequence of scientific inquiry, where action lies outside the research domain. In areas like climate change, scientific exploration, and practical application must occur simultaneously. They tend to influence and become entangled with each other (*5*).

In each phase of sustainability science research, novel schemes and techniques have to be used, extended, or invented. These include observational methods that blend remote sensing with fieldwork in conceptually rigorous ways, integrated place-based models that are based on semiqualitative representations of entire classes of dynamic behavior, and inverse approaches that start from outcomes to be avoided and work backwards to identify relatively safe corridors for a sustainability transition. New methodological approaches for decisions under a wide range of uncertainties in natural and socioeconomic systems are becoming available and need to be more widely exploited, as does the systematic use of networks for the utilization of expertise and the promotion of social learning (*6*). Finally, in a world put at risk by the unintended consequences of scientific progress, participatory procedures involving scientists, stakeholders, advocates, active citizens, and users of knowledge are critically needed (*7*).

Institutions and Infrastructure

Progress in sustainability science will require fostering problem-driven, interdisciplinary research; building capacity for this research; creating coherent systems of research planning, operational monitoring, assessment, and application; and providing reliable, long-term financial support. Institutions for sustainability science must foster the development of capacities ranging from rapid appraisal of knowledge and ex-

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perience needs in specific field situations, through global operational observation and reporting systems, to long-term integrated research on nature-society interactions in key places and regions of the world.

Generating adequate scientific capacity and institutional support in developing countries is particularly urgent as they are most vulnerable to the multiple stresses that arise from rapid, simultaneous changes in social and environmental systems. Efforts to increase scientific capacity will take place within a context of very different funding patterns (involving philanthropic foundations, businesses, and governmental and intergovernmental bodies), environmental concerns, and research orientations. The difficulties of the situation are aggravated by resource and knowledge differences and a deepening digital divide (see the figure on page 641). However, the opportunity to bridge this information gap rapidly and to share knowledge and new technologies with even the most remote and disadvantaged communities may be realized in the next few decades.

Some of the new infrastructure needs can be met with Internet-oriented systems that link interdisciplinary research teams across regions and users of scientific information with the scientists who provide it. A few institutions with wide-ranging global capabilities are needed as well. However, a comprehensive approach to capacity building will have to nurture these global institutions in tandem with locally focused, trusted, and stable institutions that can integrate work situated in particular places and grounded in particular cultural traditions with the global knowledge system. Examples of such arrangements are few, but our experience includes such diverse examples as global ENSO (El Niño–Southern Oscillation) forecasting and decision support systems in Africa, scientific support for the Convention on Long-Range Transboundary Air Pollution in Europe, the Yaqui Valley study of land-use change in Mexico, the Sustainable Cities Ph.D. program with its focus on Los Angeles, and mountain development in the Himalayas. In the Himalayan study, for example, local institutional teams including natural and social scientists from five countries (China, India, Nepal, Pakistan, and Bangladesh) plus the International Centre for Integrated Mountain Development (ICIMOD) focus on the effects of globalization on the fragile ecosystems and economies of their common mountain region. In particular, they have been identifying the coping strategies to meet the challenges and harness the opportunities offered by the globalization process (*8*).

CORE QUESTIONS OF SUSTAINABILITY SCIENCE

How can the dynamic interactions between nature and society—including lags and inertia—be better incorporated into emerging models and conceptualizations that integrate the Earth system, human development, and sustainability?

How are long-term trends in environment and development, including consumption and population, reshaping nature-society interactions in ways relevant to sustainability?

What determines the vulnerability or resilience of the nature-society system in particular kinds of places and for particular types of ecosystems and human livelihoods?

Can scientifically meaningful "limits" or "boundaries" be defined that would provide effective warning of conditions beyond which the nature-society systems incur a significantly increased risk of serious degradation?

What systems of incentive structures—including markets, rules, norms, and scientific information—can most effectively improve social capacity to guide interactions between nature and society toward more sustainable trajectories?

How can today's operational systems for monitoring and reporting on environmental and social conditions be integrated or extended to provide more useful guidance for efforts to navigate a transition toward sustainability?

How can today's relatively independent activities of research planning, monitoring, assessment, and decision support be better integrated into systems for adaptive management and societal learning?

Core questions. For background references underlying these questions, see supplementary material (*10*).

Next Steps

In the coming years, sustainability science needs to move forward along three pathways. First, there should be wide discussion within the scientific community—North and South—regarding key questions, appropriate methodologies, and institutional needs. Second, science must be connected to the political agenda for sustainable development, using in particular the forthcoming "Rio + 10" conference: The World Summit on Sustainable Development that will be held in South Africa in 2002. Third (and most important), research itself must be focused on the character of nature-society interactions, on our ability to guide those interactions along sustainable trajectories, and on ways of promoting the social learning that will be necessary to navigate the transition to sustainability. It is along this pathway—in the field, in the simulation laboratory, in the users' meeting, and in the quiet study—that sustainability science has already begun to flourish (*9*).

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Supplementary Material

Supplemental Table 1. Core Questions of Sustainability Science
1. How can the dynamic interactions between nature and society—including lags and inertia—be better incorporated in emerging models and conceptualizations that integrate the Earth system, human development, and sustainability *(1)*?
2. How are long-term trends in environment and development, including consumption and population, reshaping nature–society interactions in ways relevant to sustainability *(2)*?
3. What determines the vulnerability or resilience of the nature–society system in particular kinds of places and for particular types of ecosystems and human livelihoods *(3)*?
4. Can scientifically meaningful "limits" or "boundaries" be defined that would provide effective warning of conditions beyond which the nature–society systems incur a significantly increased risk of serious degradation *(4)*?
5. What systems of incentive structures—including markets, rules, norms and scientific information—can most effectively improve social capacity to guide interactions between nature and society toward more sustainable trajectories *(5)*?
6. How can today's operational systems for monitoring and reporting on environmental and social conditions be integrated or extended to provide more useful guidance for efforts to navigate a transition toward sustainability *(6)*?
7. How can today's relatively independent activities of research planning, monitoring, assessment, and decision support be better integrated into systems for adaptive management and societal learning *(7)*?

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