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Sustainability Science

Robert W. Kates, William C. Clark, Robert Corell, J. Michael Hall, Carlo C. Jaeger, Ian Lowe, James J. McCarthy, Hans Joachim Schellnhuber, Bert Bolin, Nancy M. Dickson, Sylvie Faucheux, Gilberto C. Gallopin, Arnulf Gruebler, Brian Huntley, Jill Jäger, Narpat S. Jodha, Roger E. Kasperson, Akin Mabogunje, Pamela Matson, Harold Mooney, Berrien Moore III, Timothy O'Riordan, Uno Svedin

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Research and Assessment Systems for Sustainability
Environment and Natural Resources Program

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The Research and Assessment Systems for Sustainability Program seeks to foster the design and evaluation of strategies with which the next generation of national and international global environmental change programs might more effectively integrate and support its research, assessment and decision-support activities. In particular, we intend to catalyze and contribute to three interrelated lines of work: 1) broadening the science-defined agenda for studying global environmental change to engage more explicitly the socially defined agenda for sustainable development; 2) deepening a place-based, integrated understanding of social and ecological vulnerability to global change; and 3) exploring the design and management of systems that can better integrate research, assessment and decision support activities on problems of global change and sustainability. The program seeks to contribute to the evolution of strategies for pursuing these goals through collaboration among a small, international set of leading scholars and program managers involved in the production, assessment, and application of knowledge relating to global environmental change.

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ABSTRACT

The world's present development path is not sustainable. Efforts to meet the needs of a growing population in an interconnected but unequal and human-dominated world are undermining the Earth's essential life-support systems. Meeting fundamental human needs while preserving the life support systems of planet Earth will require a world-wide acceleration of today's halting progress in a transition toward sustainability. A significant response to this challenge has begun to emerge as a new field of sustainability science. This paper, written by a group of leading natural scientists, social scientists, and policy analysts from around the world, outlines the core questions of the field, the extensions of existing research strategies that will be required to address those questions successfully, and the institutional innovations that will be needed to develop an integrated system of research, assessment and decision support adequate for the task at hand.

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SUSTAINABILITY SCIENCE

The world's present development path is not sustainable. Efforts to meet the needs of a growing population in an interconnected but unequal and human-dominated world are undermining the Earth's essential life-support systems.[1] The extraordinary complexity of the challenges that lie ahead is suggested by today's emerging interactions among global environmental changes and the profound transformations underway in social and economic life. These include such diverse alterations of the earth as climate warming, land transformation, and loss of biological diversity, together with social transitions including a population that is growing more slowly, while aging and urbanizing; an economy that is globalizing while increasing both wealth and inequality in the face of persisting poverty; and a system of resource utilization that in the energy, manufacturing and agricultural sectors is making more with less even as it increases its overall demands on the earth to unprecedented levels.[2]

Meeting fundamental human needs while preserving the life support systems of planet Earth will require a world-wide acceleration of today's halting progress in a transition toward sustainability. A significant response to this challenge from the scientific community has begun to emerge from various global and regional programs of environmental research,[3] from the World's Scientific Academies (including individual reports from the African, Brazilian, and United States academies),[4] from independent networks of scholars and scientists,[5] and from the recent Friibergh workshop on sustainability science.[6] Above all, a response has begun to emerge from science itself and the growing recognition across many disciplines of the need for synthesis and integration – needs that are being reflected in many new multidisciplinary research efforts and institutions.[7] These various scientific efforts to promote the goals of a sustainability transition – meeting human needs while preserving the life support systems of the earth[8] – are leading to the emergence of a new field of sustainability science.

CORE QUESTIONS FOR SUSTAINABILITY SCIENCE

Sustainability science focuses on the dynamic interactions between nature and society. Substantial understanding of those interactions has been gained in recent decades through work in environmental science that includes human action on the environment and environmental impacts on humans, work in social and development studies that seeks to account for environmental influences, and a small but growing body of interdisciplinary research.[9] But we urgently need to move beyond these beginnings to shape a better general understanding of the rapidly growing interdependence of the nature-society system.

A growing body of evidence and experience suggests that the needed understanding must encompass the interaction of global processes with the ecological and social characteristics of particular places and sectors.[10] The regional character of much of what sustainability science is trying to explain means that relevant research will have to learn how to integrate the effects of key processes across the full range of scales from local to global.[11] It will also require fundamental advances in our ability to address such issues as the behavior of complex self-organizing systems, the responses, some irreversible, of the nature-society system to multiple and interacting stresses, and the options for combining different ways of knowing and learning so that social actors with different agendas can act in concert under conditions of uncertainty and limited information.

With a view toward promoting the research necessary to achieve such advances, we propose in Box 1 an initial set of core questions for sustainability science. These are meant to complement the core questions of existing global change programs by focusing 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.

Box 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?[12]
2. How are long-term trends in environment and development, including consumption and population, reshaping nature-society interactions in ways relevant to sustainability?[13]
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?[14]
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?[15]
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?[16]
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?[17]
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?[18]

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 (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 usable knowledge within both science and society. Given the magnitude of these challenges, it is clear that incomplete knowledge, and limitations in our ability to utilize it, will permanently challenge sustainability science as it tries to link research to action and to reconcile scientific excellence with social relevance.

What does this mean for the organization of the scientific fabric? It means, in particular, that sustainability science research must be created through processes of co-production in which scholars and stakeholders interact to define important questions, relevant evidence, and convincing forms of argument. The pertinent actions are not ordered linearly in the familiar sequence of scientific inquiry, where action lies outside the research domain. Rather, these are combined in entangled patterns relating to the problem to be tackled and the practical constraints of inquiry. The climate change issue illustrates this entanglement. In it, all stages of scientific exploration and practical application (e.g., predictive models *and* preventive action, scenario exploration of the future *and* impacts analysis of the past, government review of science *and* scientists commenting on policy) are occurring simultaneously and influencing each other.[19]

In each single stage of sustainability science research, novel schemes and techniques have to be used, extended or invented. Spanning the large range of spatial scales involved may require the construction of "macro-scopes" that blend remote sensing with ground-truth in conceptually rigorous ways.[20] The problem of mismatch between the time scales of action and those of classic scientific hypothesis testing, publication, and international assessment or review might be reduced by systematic use of networks to organize expert judgment.[21] The challenge of complex outcomes from multiple stresses may be addressed by integrated place-based models that employ semi-qualitative representations of entire classes of dynamical behavior rather than seeking to predict exact trajectories into the future.[22] Inverse approaches that start from outcomes to be avoided and work backwards to identify relatively safe corridors could eventually circumvent many difficulties in standard environmental assessment and cost-benefit accounting.[23] Finally, new methodological approaches for decisions under a wide range of uncertainties in natural and socio-economic systems and their inertia are becoming available.[24]

The new quality of sustainability science makes explicit the character of social learning that was implicit in the scientific enterprise since its beginnings.[25] In a world put at risk by the unintended consequences of scientific progress, social trust in scientific knowledge claims and institutions cannot be taken for granted. Participatory procedures involving scientists, stakeholders, advocates, active citizens and users of knowledge are needed to transform knowledge claims into trustworthy, socially-robust, usable knowledge about the realities which matter in social and environmental change and in the transition to sustainability.[26] In addition, scientists will need to be increasingly sensitive to shifts in patterns of governance that could assist their endeavors.

INSTITUTIONS AND INFRASTRUCTURE

The scientific infrastructure needed to effect a transition to sustainability must build upon and evolve in concert with existing institutions that have served the scientific community during this recent quarter century of remarkable progress. However, major inadequacies and institutional barriers in these existing systems will require innovative means to ensure that urgent research questions relating to interactions of nature and society are addressed. Progress in sustainability science will require the fostering of problem-driven, interdisciplinary research; building capacity for this research, particularly in developing countries; creating coherent systems of research planning, operational monitoring, assessment and application; and providing reliable financial support for all of these endeavors over the long term. These institutions for sustainability science must foster the development of capacities ranging from rapid appraisal of knowledge and know-how 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 in order to enhance resilience in regions that are most vulnerable to the multiple stresses that arise from rapid, simultaneous changes in social and environmental systems. Existing and novel funding mechanisms involving philanthropic foundations, businesses, and governmental and intergovernmental bodies should be explored to support these endeavors.

Efforts to increase scientific capacity will take place within a context of very different funding patterns, environmental concerns, and research orientations, aggravated by a deepening digital divide (see Figure 1). But the opportunity to rapidly bridge this information gap, and to share knowledge and new technologies and their benefits to even the most remote and disadvantaged communities, is a real possibility for the early decades of this century. 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. But a comprehensive approach to capacity building will have to nurture in tandem with these global institutions many 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: mountain development in the Himalayas,[27] global ENSO forecasting and decision support systems in Africa,[28] scientific support for the Convention on Long-Range Transboundary Air Pollution in Europe,[29] the Yaqui Valley study of land-use change in Mexico,[30] and the Sustainable Cities Ph.D. program with its focus on Los Angeles.[31]

NEXT STEPS

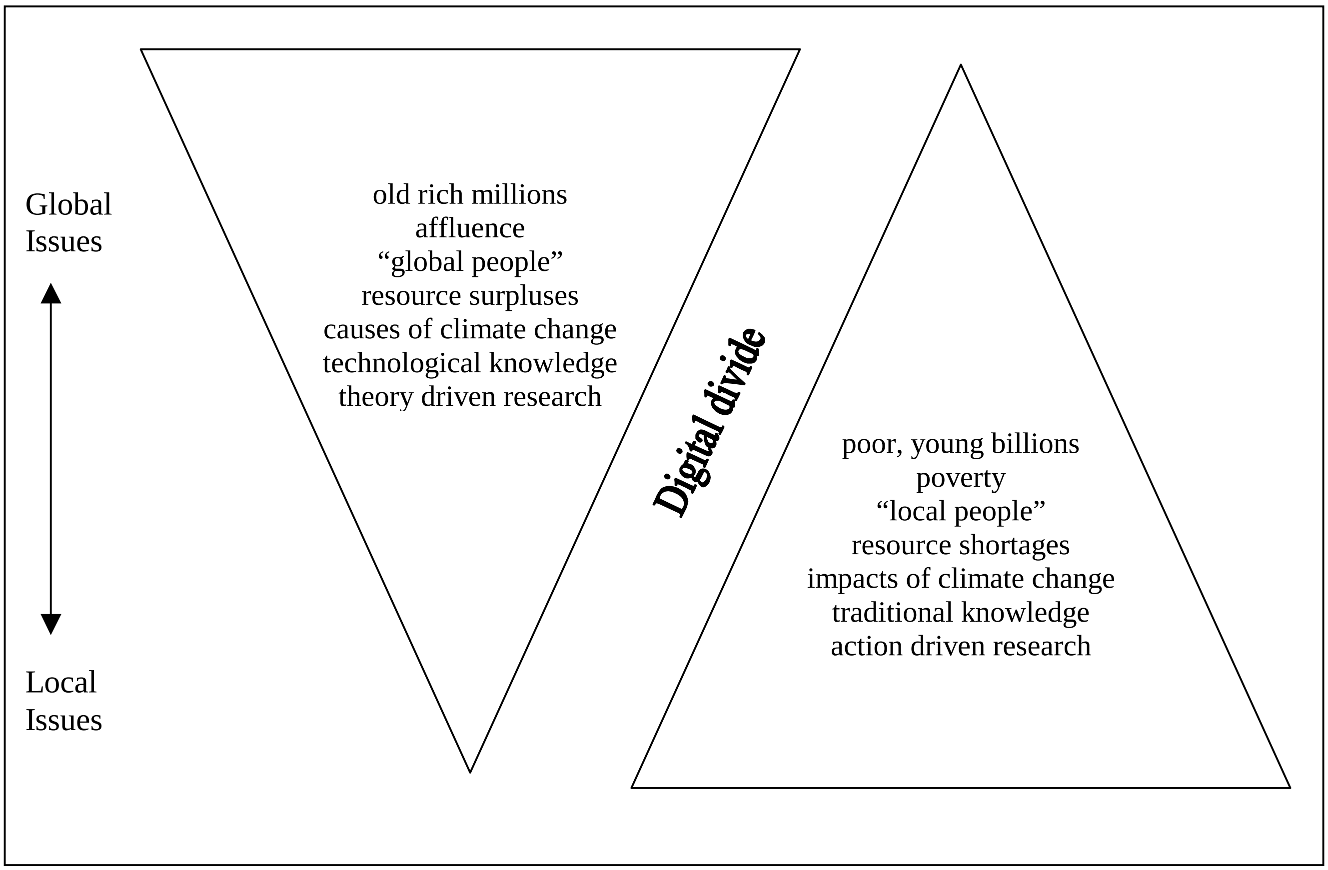
In the coming years, sustainability science needs to move forward along three pathways. First, there should be wide discussion within the scientific community, North and South, of the particular novelty of the approach, its key questions, appropriate methodologies and institutional needs. Meetings of scientific academies and scholarly communities need to advance discussions of content, systems of inquiry, and infrastructure support for sustainability science. International environmental research programs and many regional and national affiliates are undertaking reviews, planning exercises and institutional experiments to consider refocusing or broadening their programs. The World Academies of Science have made a commitment to generate, share, and disseminate science in support of a transition towards sustainability. Consultations in Africa, Asia, Europe, Latin America, and North America will consider the place of sustainability science in regional centers and local research efforts. Following such an extended period of consideration and reflection on the substance and strategy of sustainability science, attention should be given to required institutional innovations and ways of achieving them.[32]

A second pathway is to reconnect science to the political agenda for sustainable development, using in particular the forthcoming “Rio + 10” conference.[33] The idea of sustainable development emerged in the early 1980’s from scientific perspectives on the relationship between nature and society. Over the last 15 years, however, with few exceptions, science and technology have not been active partners in the societal and political process of sustainable development. Scientists helped construct an agenda for science but had little impact on subsequent action.[34] Ten years later the emergence of sustainability science offers a more pertinent opportunity to help guide nature-society interactions along sustainable trajectories throughout the globe.

A third is research itself, currently underway across the continents, in groups small and large, on the character of nature-society interactions, on improving 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 will flourish.

FIGURES

Figure 1. Sustainability Science within a Divided World. A cartoon-like view of the sharp contrast in both perceptions and realities of resource distribution between countries of the "North" and "South." The research of the "North" is global in orientation, theory-driven, and draws upon technological knowledge. The much smaller research effort of the "South" is local in orientation, action-driven, and draws upon traditional knowledge. The socio-economic, environmental, and knowledge dichotomies are exacerbated by the deepening "digital divide."



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[4] See the World's Scientific Academies' *Transition to Sustainability in the 21st Century* (Tokyo Summit of May 2000), http://interacademies.net/intracad/tokyo2000.nsf/all/sustainability_statement; C. E. Rocha-Miranda, ed., "Transition to Global Sustainability: The Contributions of Brazilian Science" (Academia Brasiliera de Ciências, Rio de Janeiro, 2000), http://www.abc.org.br/eventos/trabsim99_en.htm; the African Academy of Sciences' Tunis Declaration: Millennial Perspective on Science, Technology and Development in Africa and its Possible Directions for the Twenty-first Century (Fifth General Conference of the African Academy of Sciences, Hammamet, Tunisia, 23-27 April 1999), http://www.unesco.org/general/eng/programmes/science/wcs/meetings/afr_hammamet_99.htm; the United States National Research Council, Board on Sustainable Development, *Our Common Journey: A Transition Toward Sustainability* (National Academy Press, Washington, D.C., 1999), http://www.nap.edu/catalog/9690.html. To these reports from Academies of Science should also be added a remarkable series of *Annual Reports* by the German Advisory Council on Global Change (WGBU), http://www.wbgu.de/wbgu_publications.html.

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[6] The Sustainability Science Workshop took place on October 10-14, 2000 at Friibergh Manor, Örsundsbro, Sweden. All of the authors of this article were workshop participants. It was hosted by the Swedish Council for Planning and Coordination of Research and made possible by financial contributions from the Swedish Council, the David and Lucile Packard Foundation, the Office of Global Programs, U.S. National Oceanic and Atmospheric Administration and other U.S. Global Change Agencies, and the U.S. National Science Foundation. The Organizing Committee included William C. Clark, Robert Corell, Bert Bolin, Robert Kates, Jane Lubchenco, John Schellnhuber and Uno Svedin. Further information on the workshop and its follow-up are tracked in the Sustainability Science Forum, http://sustainabilityscience.org.

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[8] The major documents addressing a sustainability transition employ a variety of conceptualizations, but nearly all define the transition in terms of these two major goals. See the analysis in National Research Council, Board on Sustainable Development, “Our common journey,” in *Our Common Journey: A Transition Toward Sustainability* (National Academy Press, Washington, D.C., 1999), pp. 21-58, http://www.nap.edu/catalog/9690.html.

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