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Institutions, Science, and Technology in the Transition to Sustainability

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ABSTRACT

This chapter explores the implications for a transition to sustainability of understanding the Earth as a complex, interdependent system in which human perturbations produce effects (with corresponding feedbacks to humans) that occur at multiple temporal and spatial timescales. Such an approach poses obstacles but also offers opportunities to better understand how human perturbations influence the Earth system and how to govern those perturbations and our human responses to the corresponding feedbacks. This chapter examines how existing human institutions, and globalization, contribute to environmental impacts on the Earth system and also evaluates efforts of alternative institutions to incorporate science and technology into the policy process in ways that will facilitate a transition to sustainability. Major institutional reforms will be needed for existing institutions to use science and technology effectively in the service of sustainability. They will need, in particular, to improve the integration of science into the policy-making process and the integration of policy concerns into scientific research in ways that help science provide more policy-relevant knowledge to those making economic and policy decisions without undercutting its scientific validity. These are complex tasks that will require many institutions to make dramatic changes in how they operate. Experiences with existing institutions that have been relatively successful at making such changes are used to illustrate the argument.

INTRODUCTION

Making existing patterns of human behavior sustainable poses the most challenging task currently facing humanity. The ability to use science and technology effectively in that enterprise — and to understand the possibilities and limitations of that ability — will be a necessary, though not sufficient, condition for success in moving social, political, and environmental relations toward sustainability. As the rest of this volume clarifies, scientists have begun to develop an understanding of the Earth system as consisting of a set of complex, dynamic, and interdependent processes and components that operate on multiple temporal and spatial timescales. A major insight of that growing understanding has been that humans, that is, the human component of the Earth system (the anthroposphere), are having an increasing impact on the other components of that system (the atmosphere, biosphere, hydrosphere, and lithosphere) and that those impacts are generating an increasing number of feedbacks to the anthroposphere that many humans consider undesirable. Many natural scientists already recognize that viewing the Earth as a system improves our understanding of the state, trends, and dynamics of that system and its component parts. An Earth system approach, however, also offers insight for social science understandings of factors that hinder the social ability to govern human perturbations of, and responses to, the Earth system. Indeed, the obstacles to effective governance can be seen as directly related to two major insights of an Earth system perspective, namely, that the system is characterized by *complex, interdependent processes* within and among system components and that those processes include *multiple temporal and spatial timescales*. As developed in the rest of this chapter, these characteristics *pose obstacles to the creation of policy-useful knowledge* and *inhibit effective governance of human perturbations and responses*. In this chapter we delineate the ways in which existing social systems illustrate these Earth system characteristics among humans and between humans and the environment (i.e., within the anthroposphere and between the anthroposphere and other Earth system components) and explore the successes and failures of social institutions to overcome the obstacles to effective governance posed by the Earth system.

HUMAN IMPACTS ON A COMPLEX, INTERDEPENDENT SYSTEM

Human action has been transforming the Earth for centuries (Turner et al. 1990). In some historical cases, human impacts on the environment have been sufficiently large to cause the demise or relocation of tribes, communities, and whole societies. Generally, however, human impacts have been small, local, and diverse. Increasingly, humans are altering the environment in large, global, and homogenous ways that produce impacts at the Earth system level. Numerous factors undoubtedly contribute to this shift toward human impacts occurring at the Earth system, rather than local environmental, level. Two particularly important contributors are population and globalization, with the former explaining why human impacts are increasingly large and global and the latter explaining why they are increasingly homogenous.

A wide range of global-scale environmental problems now illustrate that human environmental forcings or "signals" have begun to rival or surpass the magnitude of natural variation or "noise." Such global-scale human impacts do not replace but instead overlay an increasing number of local-scale impacts. Natural systems appear increasingly unable to absorb aggregate human perturbations in ways that allow re-equilibration at either prior states of the system or states that humans would consider desirable. If we have not yet reached the carrying capacity of the Earth, we certainly have exceeded the carrying capacity of certain components as evidenced by the decline of aquifers worldwide and the collapse of most top predatory fish species (Postel 1999; Myers and Worm 2003). This shift reflects not only increases in population, affluence, and technology but also deeper drivers and structures such as markets, government policies, and the political contexts that operate at different temporal and spatial scales to encourage and constrain human choices (Ehrlich and Holdren 1972; Commoner 1972; Waggoner and Ausubel 2002).

Globalization has, since the sixteenth century but particularly in its current phase, magnified the impacts that changes in population, affluence, technology, markets, policies, and other drivers of environmental damage have on the Earth system (Chase-Dunn et al. 2000). It has led to profound development changes that, in turn, have produced profound environmental and health impacts (Schaefer 2003). The flow of goods, services, capital, information, ideas, and people has expanded exponentially. Western — particularly American — culture, life-styles, material desires, and perspectives spread with increasing speed through numerous channels. These and other processes captured by the notion of globalization generally have reduced the collective diversity of socio–politico–economic systems. Most countries have power sectors based on fossil fuels, transportation sectors based on automobiles, agriculture sectors based on mono-cropping, and consumer preferences that look increasingly similar despite previously diverse cultures. Without engaging the question of whether globalization's net effects on the environment are positive, current patterns of globalization certainly have many negative environmental impacts. Globalization has propagated consumer culture and generated increased demand for both raw materials and end-use commodities, although at different rates across regions and sectors. It has spread new technologies that may decrease the resources used to produce those commodities but does so only in those rare cases in which regulations ensure that prices for environmental resources reflect environmental externalities. In those settings in which globalization has increased affluence, its direct negative effects of increased consumption (and relocation of environmentally intensive activities) have been only partially offset by indirect declines in birth rates or improvements in technology.

The tendency for globalization to homogenize preferences, even while many cannot satisfy those preferences, may contribute most to Earth system stresses by decreasing the diversity of human behavior patterns causing consumption of particular resources or production of particular pollutants to be higher than they would be in a more behaviorally diverse world. A global preference for particular foodstuffs, products, or building materials focuses demand previously distributed over a variety of resources onto a relatively few resources, each of which will be more likely to collapse under the weight of that demand. If human- and livestock-powered transportation systems in China, India, and most African countries transition to fossil fuels (China and India have already begun), the lives of people in those countries will improve even as the burden placed on the Earth's atmosphere grows. Cultural homogenization, for example, by causing increasing consumption of protein from particular types of fish, such as salmon and tuna, transforms what might otherwise be local shortages into global collapses of certain fisheries. The increasing movement of people and goods also converts previously local problems into Earth system problems. Global distribution of particular products (let alone hazardous waste) implies that their disposal introduces any associated pollutants into a wide array of different ecosystems. Ships and airplanes intentionally and inadvertently introduce invasive species into habitats throughout the world, converting local pests into ubiquitous threats. In addition, both human and animal diseases spread around the globe at increasingly rapid rates (e.g., AIDS, SARS, and mad cow disease).

The effects of aggregate human behaviors on the Earth system, as well as the impacts and feedbacks of those effects on humans, prove increasingly difficult to understand or predict because of the complex, interdependent nature of the Earth system. Inputs from the anthroposphere to other components of the Earth system (hydrosphere, atmosphere, biosphere, and lithosphere) enter a system in which neither the impacts and feedbacks nor their causes can be straightforwardly identified. The wide range of inputs from the anthroposphere are themselves complex and interdependent. Human behaviors influencing global climate range from power generation and cement production to rice farming and livestock cultivation producing carbon dioxide, methane, and other chemicals and aerosols. Those influencing the fate of fish stocks involve not only intentional catch but also inadvertent by-catch, municipal and agricultural runoff, oil and chemical spills, and loss of habitat. Even if the Earth system itself were not dynamic, complex, and interdependent, we should not expect such a range of human forcings to produce linear and predictable effects on that system. Yet, even without clear models we can predict that the level of such forcings have become sufficiently large to place the system in a "no-analogue" situation, one likely to include numerous feedbacks that humans consider undesirable.

Impacts of perturbations of a complex, interdependent system can appear at temporal and spatial scales that bear little relationship to that of the initial perturbation:

- Current stratospheric ozone loss above the Antarctic is the result of releases of chlorofluorocarbons at the Earth's surface decades ago. Likewise, if all fossil-fuel use were to cease today, past emissions would have effects on the Earth system for decades if not centuries.

- Although nuclear power plants have been operating for only half a century, storage of uranium will alter environmental conditions for millennia.
- The killing of even a few individuals can push the population of an already threatened species over the brink to permanent extinction.

In these illustrations, the separation of cause from effect lies in the nature of the environmental processes involved, whether the absorption rate of certain chemicals or the recruitment rate of certain species. However, social, political, and economic forces often exacerbate the natural processes that separate causes from effects. Humans "solve" many environmental problems simply by displacing them: moving hazardous waste to distant repositories, dumping sewage into rivers or oceans, or disposing of atmospheric pollutants captured in catalytic converters or smokestack scrubbers in landfills. Globalization fosters a range of other, less self-conscious, distancings of cause and effect by reducing the awareness of both consumers and producers of the environmental effects of their consumption and production decisions: Europeans sitting in teak-paneled boardrooms rarely envision denuded southeast Asian forests, Americans eating salmon rarely see the "deserts" beneath fishpens in Norway, and those drinking their morning coffee or evening tea rarely know what pesticides were used or biodiversity lost to enable their consumption.

FOSTERING A TRANSITION TO SUSTAINABILITY

If the Earth system is characterized by complex, interdependent processes in which causes and effects are often distant temporally and spatially, then fostering a transition to sustainability proves particularly challenging. Success in that endeavor will require the creation of knowledge about the Earth system that is useful for governance and for promoting effective governance of human perturbations and responses of the system.

Creating Useful Knowledge

Complexity and interdependence introduce considerable uncertainty into our understanding of how (and which of) our behaviors as well as production and consumption systems are driving the Earth system to a no-analogue state, what the effects are, and how to respond to any negative feedbacks, either by reducing the levels of our perturbations or adapting to them. At a basic level, such systems prove analytically challenging because much, though not all, of modern "Western" science is based on a model that posits that we can "hold everything else constant" to identify and isolate the influence of one variable on another. Although such a position seems reasonable for understanding some elements of the system, it quickly becomes unreasonable for understanding the Earth system or even major components of it. In such complex, interdependent systems, change in even a single variable or parameter is likely to produce changes in many other variables, making *ceteris paribus* assumptions untenable. This conclusion is reinforced when many perturbations are changing simultaneously, as is the case for current human inputs to the Earth system. If many variables in a system are changing and each has causal links to numerous other variables, then untangling true cause-and-effect relationships becomes impressively difficult. Each cause has multiple effects, and each effect has a multitude of interacting causes. Even if there were perfect descriptive knowledge about the array of variables in the system, uncertainty would arise because of the practical and inherent obstacles to properly understanding and modeling the relationships among those variables. Generating knowledge about such systems that can improve governance of human perturbations of those systems requires changes to how scientific research is conducted as well as to how it is communicated.

Understanding the Earth system requires scientists to adopt more interdisciplinary, synthetic, and holistic approaches. As the Intergovernmental Panel on Climate Change (IPCC) reports have made clear, the net effect of human use of fossil fuels depends not only on the direct effects of introducing carbon dioxide and other greenhouse gases into the atmosphere but also on indirect and interactive effects on such processes as the uptake of carbon in trees and the ocean and increased global albedo due to increased vaporization of water. The global scientific community has begun to develop programs that foster research approaches that can address such problems. Some operate across a range of environmental issues, such as the International Geosphere–Biosphere Programme and the Scientific Committee on Problems of the Environment, whereas others have taken more targeted approaches, such as the Scientific Committee on Oceanic Research and the International Council for the Exploration of the Sea. All these programs recognize that deciphering the complex linkages even within single components of the Earth system requires collaboration across scientific disciplines. Increasingly, these and similar efforts have recognized that a full understanding of the Earth system requires the involvement of social as well as natural scientists, a fact institutionally evident in the form of the International Human Dimensions Programme on Global Environmental Change, projects such as the Global Carbon Project or Global Environmental Change and Food Systems, and the IPCC's inclusion of a wide range of social scientists in its work in all three working groups. Both scientists and funding agencies increasingly realize that understanding the dynamics of complex systems to foster sustainability always requires cooperation among natural and social scientists to integrate understandings of ecosystem functioning and human perturbations, and can often benefit from "place-based" research conducted "in ways particularly relevant to state and local decision makers" (Matson et al. 2003; NOAA 2003).

Complexity poses unique obstacles not only to understanding much Earth system science but also to communicating scientific findings effectively to both government policy makers and individual economic and political decision makers. First, the complexity and interdependence of the system introduce fundamental uncertainties. Making claims about how such systems work, predictions about their future states, or policy recommendations about how humans should interact with them have inherent and inescapable uncertainties that arise simply from the complexity of the systems. This does not imply that scientists cannot make claims, predictions, or recommendations but rather that they will need to do so based on consensus and probabilities more often than on proofs and confidence intervals. Economic and political decisions often cannot be delayed until scientific certainty is achieved; scientists can better inform those decisions by learning to communicate the often-large areas of agreement among scientists rather than highlighting remaining areas of disagreement. For example, the 1995 IPCC report's claim that "the balance of evidence suggests that there is a discernable human influence on global climate" illustrates that careful wording can allow scientists to reflect current science accurately while still raising public awareness more effectively than with other wordings. Groups like Seaweb and the Aldo Leopold Leadership Program help train scientists to communicate more effectively with the public and policy makers (Seaweb 2003; Aldo Leopold Leadership Program 2003).

Making environmental science truly useful to those who must change their behaviors and clarifying the factors driving those behaviors will require, however, deeper changes. It requires more than just "doing good science" and learning how to communicate it effectively. Research must be interdisciplinary because the things being studied require the expertise of various disciplines. If research is to influence policy and behavior, it must also be participatory. Improving the uptake of science and technology into decision making requires increasing stakeholder participation in the scientific process and increasing scientific participation in the policy process. Stakeholders who participate in scientific research tend to be more willing to accept the findings that flow from that science and use it in their decisions (Clark et al. 2002). Stakeholder participation can improve science by providing scientists with access to proprietary corporate data or sophisticated local knowledge regarding trends and causes. Involving stakeholders also increases their capacity to understand scientific findings as well as recommendations and is likely to build their commitment to sustainability as a goal. It also helps scientists to learn from stakeholders. Stakeholder participation makes science more influential by making it more salient, legitimate, and credible to the multiple audiences who must incorporate it into their decisions if a transition to sustainability is to occur (Clark et al. 2002). Broadening participation in science as well as decision making tends to produce decisions that are perceived as more legitimate and in which the problems and risks of both action and inaction are better understood, making successful implementation more likely (Fiorino 1996). Over the long term, "coproduction" of knowledge by scientists, policy makers, environmental managers, and stakeholders can increase the collective commitment to sustainability, to incorporating local concerns into science, and to incorporating science into decision making (Jasanoff 1996). In many countries, a crucial preliminary step will require strengthening civil society in both material and ideological ways so that citizens both can and want to participate meaningfully in scientific and decision-making processes. In too many parts of the world, people still lack the opportunities or the desire to participate in social, economic, and political arenas at a local and national level, let alone at the global level. Of course, successfully increasing participation in science will require avoiding scientific conclusions being dictated by economic or political pressures and will require that psychological processes of "group think" do not lead to the dismissing of important alternatives or blindness to potential nonlinearities and surprises.

Understanding and Reshaping the Science–Policy Interface

Using science and technology to foster a transition toward sustainability also requires building on experience to understand the processes and factors that foster (or inhibit) their incorporation into the policy realm. Contrary to common conceptions that either scientific knowledge is straightforwardly applied to policy problems or that policy makers simply ignore science to pursue political and economic goals, the interface between science and policy often involves a complex interchange reflecting the differing science and policy cultures, including differing relationships to information, institutional constraints, and a fundamental divide between environmental and economic concerns (Keely and Scoones 1999; Jasanoff and Wynne 1998).

Making science useful to policy makers requires bridging the gap that separates their differing cultures. The curiosity many scientists have to answer "basic research" questions is one which demands long-term investments with payoffs in knowledge that are often both uncertain and far off in the future. Government policy makers and economic decision makers, on the other hand, face nearer-term pressures in which both action and inaction may involve costly consequences. In policy making, views are more likely to be determined by political and economic power rather than truth and quality of research methodologies. Political constituencies often want economic or environmental solutions adopted before scientists can confidently say what consequences different policies imply. Economic decision makers — from fishers and farmers to corporate CEOs — often face market decisions about whether to go fishing, what crop to plant, or what power source to install long before anything close to full knowledge is available. Current political and economic contexts in most countries mean pro-environment decisions involve large costs for the decision maker's family, constituency, or stockholders in the short term, regardless of whether they are beneficial to other actors at some point in the future (Behn 1986). Scientists can, and appropriately often do, examine the status and trends of phenomena that occur at global and decadal scales. For instance, both technical capabilities and/or inclinations constrain impact and adaptation researchers to create large-scale models that can make predictions only at very low spatial and temporal resolution (e.g., general circulation models; see Carter et al. 1999, p. 29). However, such models often lack the resolution to guide water managers, farmers, transportation planners, and others making decisions that involve environmental, but also economic and political, considerations that are quite place- and time-specific. Likewise, elected politicians face re-election at intervals often shorter than five years and narrow and urgent constituency concerns that regularly re-emphasize how "all politics is local" (O'Neill and Hymel 1995). Such differences often breed misunderstanding and mistrust with scientists viewing policy makers as "ignoring the science" and policy makers and other end-users viewing scientists as unconcerned about "real everyday issues" (Lemos et al. 2002).

Such barriers are neither ubiquitous nor insurmountable. Indeed, science can fit quite effectively into policy- and decision-making processes when researchers and policy makers engage in the mutual construction of knowledge and understand the constraints posed by the institutional contexts in which it operates (Shackley and Wynne 1995). Researchers at the International Institute for Applied Systems Analysis in Austria have worked closely with diplomats negotiating limits on acid precipitants in Europe and North America to develop models that address the policy issues at the center of the negotiations with state-of-the-art natural and social science modeling techniques (VanDeveer 1998; Botcheva-Andonova 2001). Scientists have extended models of El Niño Southern Oscillation (ENSO) patterns to help ministries of agriculture, water, fisheries, energy, and health devise strategic plans for crop planting, dam releases, fish quotas, and similar concerns (International Research Institute for Climate Prediction 2002). Especially over time, such efforts at "coproduction" of knowledge can reduce the barriers that often lead scientific information to be ignored, rejected, misunderstood, or misused if the context-specific character of the science–policy gap is understood (Jasanoff 1996; Lemos et al. 2002). Rather than assuming and reinforcing a linear sequence in which scientific consensus must precede policy action, a more appropriate model may be one of "a policy stream and a problem stream running parallel to one other, each occasionally feeding the other and moving it along" (Betsill and Pielke 1998).

Science also can foster sustainability policy by engaging the politically convenient predilection to treat scientific uncertainty as an always-appropriate basis for political or economic inaction. As already noted, uncertainty is fundamental and inherent to environmental science in general and Earth system science in particular. Inaction is surely the appropriate response to some forms of uncertainty. However, politicians usually prefer inaction because it maintains the status quo distribution of economic and environmental costs and benefits, and scientific uncertainty simply provides political cover to continue "business as usual." The introduction of the precautionary principle in national law and international treaties shows some progress is being made on this front. Indeed, the case of stratospheric ozone illustrates the ability to set policy at the global level despite considerable scientific uncertainty about the status and causal mechanisms of the problem — here science raised public awareness and reinforced political "momentum that had already been established" and also helped identify cheap alternatives to CFCs (Betsill and Pielke 1998, p. 165). Solid science, appropriately communicated, still enters and must operate within a political context. In the ozone case, action was not triggered by scientific insights alone but by U.S. leadership and industry cooperation that reflected the pressures of domestic actors rather than international pressures (Betsill and Pielke 1998, p. 166). The ability to reach agreement on the Kyoto Protocol of the United Nations Framework Convention on Climate Change (FCCC) also suggests that scientists can communicate science that contains fundamental (but not central) uncertainties in ways that do not preclude policy action. A more pessimistic scenario is evident, however, in the regulation of many international fisheries, which reinforces the notion that the communication of science is important but its acceptance depends on the mechanisms by which different actors negotiate common action given their competing interests. Despite advice from their scientific bodies, most international fisheries commissions have regularly failed to adopt scientifically informed quotas that would prevent overexploitation (Stanford Fisheries Policy Project 2000; Myers and Worm 2003; Peterson 1993). Successful scientific advice in contentious contexts, like fisheries, must simultaneously avoid too lax recommendations that fail to constrain behavior and too stringent ones that political and economic pressures prevent decision makers from adopting (Alcock 2001). Although more careful analysis is needed to confirm this conclusion, the choice to have scientists work closely with policy makers (as in the acid precipitation and ENSO cases just mentioned) appears to improve the incorporation of science into policy by making it more salient and understandable to policy makers without undercutting its scientific credibility (Clark et al. 2002). How science is incorporated into policy making has immense consequences for the interests of different stakeholder groups, and thus changing the role of science will be a highly contentious and political process.

Networking among producers and users of scientific information can build on specific knowledges and identify the inadequacy of existing management strategies for environmental problems, as well as better alternatives at regional, national, and global scales (Keely and Scoones 1999). In many countries and often internationally, politicians and scientists control most major decision points, with the general public and concerned citizens often treated paternalistically with respect to scientific complexities (Lemos et al. 2002). Such a technocratic approach is likely to be ineffective in the many cases in which social and political considerations, rather than technical principles, are central to sustainability decisions. Consider two research groups that built competing actor networks to support their divergent scientific positions on biodiversity conservation in Kenya (Cussins cited by Keely and Scoones 1999, pp. 21–22). One group used field experiments to support their claim of a relationship between the elephant concentrations and biodiversity loss, a claim that was contested by the other group. The former validated their claims by reference to the conventions of international scientific practice whereas the other validated theirs by reference to the perceptions of local stakeholders well-informed about local conditions. Although both groups had built strong links with stakeholders, the latter group's view was more widely accepted because it had built a broader network and had developed arguments that were more attractive to key local stakeholders. Such involvement of stakeholders in scientific enterprises engages social, economic, and political sectors in working for sustainability in ways that reverse the disaffection caused by the many cases in which policy makers rely on technical arguments to escape responsibility for politically difficult decisions (Keely and Scoones 1999).

Any successful governance for sustainability will be based on changes in the behavior of billions of people and on changes in the structural factors that constrain or foster certain behaviors such as markets, government policies, as well as production and marketing strategies of corporations. Inducing such changes is likely to be both easiest and most effective if scientific information is not only scientifically credible but is also perceived by lay publics and stakeholders as salient or relevant to their decisions and as having been produced through a fair and legitimate process that took their concerns and knowledges into account (Clark et al. 2002). The acceptance and incorporation of science into the policy process is likely to be fostered by decision-making processes that expect and welcome an active, more equitable and respectful interplay of scientists, key political and economic actors, and stakeholders so that a wide spectrum of knowledges and perspectives can be taken into account.

Effective Institutions for a Transition to Sustainability

Taking sustainable development seriously requires institutions that strive simultaneously toward environmental protection and improvement of human welfare (WCED 1987). This requires surmounting the traditional barriers that separate the governance of economic, social, and environmental affairs. Although what happens in the marketplace influences nature and vice versa, human governance has often been ignorant of or insensitive to these connections. Social, political, and economic relations among humans constitute a complex, interdependent system in its own right, and globalization within that system sets off dynamics in the anthroposphere that are often as dynamic, multi-causal, and poorly understood as those in the natural sphere of the Earth system.

Past institutional efforts at governance have taken three different approaches to environmental protection, the first one focusing primarily on economic growth and trade. To understand how this institutional setting operates, it is useful to examine recent development patterns. Globalization, and particularly trade liberalization, has produced quite varied patterns of participation in global trade, development, and environmental impacts. Global economic growth has produced economic benefits for some sectors, regions, and people but provided fewer benefits to, and often imposed economic and environmental costs on, many others. Developed countries' share of manufacturing exports, for instance, has declined recently while their share of technology-intensive, high-value added exports have increased, allowing these countries to promote technological and institutional innovation and improve their citizens' economic welfare. They have low poverty rates and average incomes almost 40 times those of the 20 poorest countries (World Bank 2000). They have begun to "decouple" economic growth from local environmental degradation through technological, economic, and institutional transformations, even as they continue to contribute to Earth system problems (e.g., CO_2) and displace environmental and social problems associated with raw material extraction, industrial production, and waste to developing countries (Fischer and Amann 2001, p. 28). Newly industrialized countries that developed industrial bases closely integrated into the global trading system in the 1970s and early 1980s saw a drop in absolute poverty levels during the 1990s (Lo 1994; World Bank 2000, p. 3). In many developing countries, by contrast, the increase in manufacturing exports has entailed products that involve intensive exploitation of environmental and natural resources, the use of unskilled labor, and the low-skill assembly stages of transnational production chains (Fischer and Amann 2001; UNCTAD 2002). In these countries, the number of people in poverty rose from 1.2 to 2.8 billion from 1987 to 1998 (World Bank 2003). Rents from depleting natural capital are used to make debt payments, transferred to developed nations through deteriorating terms of trade, or lost to economic inefficiency and political corruption rather than being used to develop technological and human capital.

These changes have often been driven by market and systemic forces that have not been self-consciously managed. To the extent they have been governed, the dominant influences on development have been institutions and organizations focused primarily on economic issues, such as the World Trade Organization (WTO), the Organization for Economic Co-operation and Development (OECD), the World Bank, and the International Monetary Fund (IMF). After World War II, major developed country governments established these institutions to foster development, originally within a welfare paradigm and more recently within a neoliberal paradigm. GATT and WTO efforts have sought to reduce or eliminate tariffs, commodity cartels, subsidies, and regulatory standards and expand bilateral, regional, and global trade agreements to promote international trade and protect patents, copyrights, and trademarks (Schaefer 2003). Pressures from the World Bank, IMF, and developed countries have led many developing countries to adopt a broad range of structural reforms with deep implications for those governments relationships with other governments (trade and financial markets), with domestic markets (privatization and deregulation), and with citizens and workers (reduced health and education expenditures and restructured labor markets) (Gwynne and Kay 2000; Harris 2000; Schaefer 2003). These policies, however, have often also reduced expenditures on environmental protection, weakened environmental regulations, and produced increased pressures on natural resources.

The balancing of economic, human developmental, and environmental goals central to a sustainability transition is only beginning to be engaged seriously. Economic considerations consistently receive higher priority at international, regional, national, and local levels. Although many of the structures and programs of primarily economic institutions at all governance levels now incorporate environmental protection and poverty reduction as goals, these goals are rarely central to these organizations' missions and few have yet found ways to address them comprehensively and coherently. Institutional mandates and incentives generally reward a narrow sectoral focus, while cross-sectoral perspectives that might better identify and manage social and environmental issues often recieve few resources and little support (Wade 1997; Gibbs 2000; Varady et al. 2001). The greater priority given to economic over social and environmental considerations plagues the systemic level as well. Economic institutions are far more powerful and comprehensive in their coverage than are social and environmental institutions. The results of WTO dispute panels exemplify the many ways in which economic concerns receive more attention and resources as well as greater legal status and deference than social and environmental institutions. Trade liberalization has sometimes made natural resource protection more difficult in both developed and developing countries. Harmonization of regulatory standards and labeling sometimes leads to the lowering rather than raising of standards, for example, Codex Alimentarius pesticide residue levels for fruits and vegetables that are below those set by the US EPA (Schaefer 2003). Investment liberalization and deregulation have contributed to altering production location decisions of numerous corporations in ways that reflect new costs, regulations, profit considerations, and terms of market access but rarely reflect environmental impacts. As a result, many resource-intensive industries in which environmental protection involves large cost shares have moved to countries of low environmental standards (Varady et al. 2001; Schaefer 2003).

A second set of institutions has had mixed results when they have sought to address needs crucial to human development without examining obvious and directly related environmental dynamics within a complex Earth system. For example, the International Maize and Wheat Research Center (CIMMYT) was created in the 1960s to promote agricultural productivity and the "Green Revolution" via governmental subsidies and investments in infrastructure and marketing that strongly promoted the use of pesticides, fertilizers, and hybrid seeds. The Green Revolution boosted agricultural productivity that supported growing populations in many developing countries and, together with international trade, benefited consumers worldwide by increasing year-round availability of a variety of products at lower prices. These economic gains were accompanied by social and environmental costs, including (a) erosion and decreased fertility of soils, (b) increased ineffectiveness of pesticides against pests, (c) sterility, pesticide poisoning, and other health risks to farmers, and (d) increased disparity between wealthy farmers and poor peasants (Wright 1986; Simonian 1988). Similarly, efforts by the World Health Organization, the UN Food and Agricultural Organization, and developing country health agencies designed to promote the use of certain pesticides, whether to eradicate mosquitoes or to protect crops, initially produced significant health and economic benefits to local populations. In what has become a recurring pattern, however, these strategies became less effective as increasing pest resistance created an "arms race" between human efforts to eradicate pests and the pests' efforts to survive (Chapin and Wasserstrom 1981). More recently, policy makers and farmers have worked with scientists to develop the alternative of integrated pest management, a strategy that did not require a full understanding of the complex relationships among crops and plants, but the far simpler recognition that those relationships are complex and that taking advantage of, rather than circumventing, those complexities was likely to be more effective.

A third set of institutions have directly and explicitly addressed environmental problems. Transboundary environmental problems of all types have been addressed through hundreds of bilateral, regional, and global institutions that have quite varied success in mitigating these problems (Mitchell 2003). The effects and effectiveness of most environmental agreements have yet to be carefully analyzed. To date, research has identified considerable variation in their effectiveness. Agreements on stratospheric ozone depletion, dumping of wastes in the North Sea, and dumping of radioactive wastes globally are some of those that have been judged as quite influential; those addressing the world's natural and cultural heritage, tropical timber, and many fisheries have usually been judged as less effective (Miles et al. 2001; Victor et al. 1998; Brown Weiss and Jacobson 1998). Such judgments of these and other agreements depend considerably on the criteria used to evaluate effectiveness and on the analyst's skills in estimating what would have happened without the agreement. Considerable research is currently underway to understand the design features of, and conditions under which these international environmental institutions are effective at altering behavior. Yet, research into how well they do at incorporating scientific information, let alone at designing governance structures that respond to the complex, interdependent, and multi-scale nature of Earth system problems, is still in its infancy (Clark et al. 2002).

Designing governance to better control our perturbations of, and guide our responses to, the Earth system is likely to require significant changes from current policy approaches in at least three ways. First, environmental policies have often failed when based on a reductionist rather than system perspective. Effective governance requires policies developed in recognition that, if not precisely how, changes in one behavior and its drivers may initially produce intended and desirable outcomes through direct causal relationships but may subsequently produce unintended and undesirable feedbacks that offset those improvements or create unforeseen problems in arenas previously considered “unrelated.” Besides unexpected but undesirable outcomes that have been part of the Green Revolution and pesticide control, consider that chlorofluorocarbons were initially welcomed as a solution to the health hazards of earlier refrigerants (such as ammonia and propane) and only later were proved detrimental to the global ozone layer. Prospectively, the complex set of interactions of pollutants in the atmosphere suggest (as noted by Crutzen and Ramanathan, this volume) that local air pollution policies requiring the reduction of aerosols (such as sulfates and black carbon) may exacerbate the problem of global warming because aerosols reflect sunlight and modify cloud properties in ways that counteract global warming. Like integrated pest management, marine reserves and protected areas are illustrative of new approaches being developed that recognize, in this case at a local level, that the best strategy for protecting complex environmental systems involves eliminating perturbations of some portions of those systems that can serve as buffers for the rest of the system.

The characteristics of human perturbations of the Earth system raise major hindrances to effective governance. The temporal and spatial distance between causes and effects, discussed above with respect to uncertainty, also raises political obstacles to mitigation or adaptation initiatives. First, most existing governance structures do not recognize the need for, nor do they facilitate, policy making in the face of the inherent and fundamental uncertainty of complex systems. We can draw lessons from rare cases of success such as the incorporation of precautionary principle language into institutional mandates at local, national, and global levels. The ability to regulate or ban an activity before the evidence of harm is conclusive, as illustrated in global regulation of ozone-depleting substances and national regulation in Europe of genetically modified foods, becomes particularly crucial in an Earth system in which evidence of harm may not be available until it is too late to take remedial action. Such strategies demand a willingness to incur immediate and clear costs to avert unclear and uncertain risks, a strategy that has yet to become commonplace in most of the world.

Second, the social concomitant of gaps between causes and effects is that those reaping the economic or other benefits of a behavior are not the same as those experiencing the environmental costs of it. Environmental problems are often assumed to involve tragedies of the commons in which all actors benefit from their own engagement in an activity but are harmed if others also do so. Displacement of environmental costs onto future generations or onto people in other regions or countries involves, however, a more malign social problem:

those engaged in an activity have little reason to stop unless they become concerned about the victims of that activity or those victims have the ability to punish or reward them. Spatial displacement of environmental problems generally imposes environmental costs onto the least enfranchised and least powerful of the world's population, whether in poor communities or in developing countries. Temporal displacement moves environmental costs onto future inhabitants of the planet whose voices and concerns can only be expressed through the actions of current inhabitants concerned about those future inhabitants. Global markets can obscure the economic impacts of consumer choices and of location decisions by corporations. Yet, alternative market mechanisms are being developed based on new relationships among consumers, labelers, and certifiers that clarify causal impacts and promote fairer terms of trade and better health and environmental standards for workers and consumers. Certified organic agriculture, silviculture, aquaculture, green manufacturing, and voluntary regulations under the International Organization for Standardization (ISO) offer alternative models that may facilitate the transition to sustainability but reflect several competing and paradoxical aspects.[1]

Demonstrations in Seattle, Genoa, and other cities, the nongovernmental summits that paralleled the 1992 United Nations Conference on Environment and Development and the 2002 World Summit on Sustainable Development, as well as other actions by civil society groups are raising awareness of the negative social and environmental implications of free trade and economic growth. An important institutional step in providing a voice to disenfranchised actors incurring environmental harms has been taken by those institutions that directly involve nongovernmental organizations, citizens groups, and other representatives of stakeholder interests in the policy-making process. Successes with participatory democracy at the domestic level have begun to influence policy making at the international level, as illustrated by the 1998 signing of the Convention on Access to Information, Public Participation in Decision-Making, and Access to Justice in Environmental Matters. Both global and regional trade agreements include provisions and subsidiary bodies mandated to protect the environment, some doing so in relatively transparent ways that facilitate monitoring and accountability by civil society groups. Even where such opportunities do not exist or are small, local communities and grassroots organizations are being successful in pressing governments, corporations, and international organizations to increase their attention to social and environmental concerns (Wilder 2000). As with participation in science, and as is evident in recent

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[1] Certifiers of organic agriculture are constrained by contractual obligations under EU and ISO certification rules that were initially intended to give voice to national notions of social justice, environmental protection, and health. Producers receive an organic price premium, traded off, however, against production, certification and organization costs, and additional organizational burdens (e.g., new responsibilities, more work; see Muttersbaugh 2001).

experience with the Kyoto Protocol, expanding participation must involve mutual dialogue and understanding that lead to improved decisions rather than simply to compromises among the original participants of stakeholders.

Third, confronting the magnitude, diversity, and multiple scales of human impacts on the Earth system will require concerted effort at all governance levels, from international treaties to national governments to city administrations to individuals. Ensuring that scientific and technical knowledge facilitates such efforts requires long-term efforts to communicate science effectively to policy makers, as outlined above, a less arrogant attitude from scientists, as well as educating stakeholders and the general public about particular environmental problems and, more generally, improving scientific literacy. Designing models that provide resolution at various temporal and spatial scales can help policy makers to use science effectively. In addition, over the long term, processes of involving stakeholders in the coproduction of knowledge can go beyond simply improving understanding of what is known and of uncertainty to enhance the willingness and ability of communities to take action to protect the environment. Fortunately, the range of levels of environmental concern has led to institutional variation and innovation in addressing environmental problems. Despite the reluctance of the United States to commit to mitigating national emissions of greenhouse gases, many American cities and states are taking action to reduce their emissions (International Council for Local Environmental Initiatives 2003). BP (British Petroleum) is the most visible major corporation to take voluntary action to reduce corporate emissions (Browne 2002). Many national governments are going forward with unilateral actions to reduce their impacts on the Earth system rather than waiting until all contributors to the problem are ready to take action. The complexity and uncertainty of the Earth system make innovation, whether within or across institutions, central to our success at managing a transition to sustainability. Institutions must engage in self-conscious trial and error of low-likelihood-of-success but high-payoff experiments, to engage in critical evaluation of their performance against sustainability indicators, and to admit errors and failures when they occur, skills that institutions are notoriously poor at exercising (Social Learning Group 2001). This will require scientific and technological innovation as well as social innovation in more effectively incorporating both science and stakeholders into decision making.

CONCLUSIONS

Managing a transition to sustainability is a decades, indeed centuries, long task that will require human societies at all levels to improve vastly their ability to understand how their behaviors and the subsystems within which they are embedded alter the Earth system, to identify indicators that threaten sustainability, to find windows of opportunity, and to develop, adopt, and implement technologies and policies so that, over time, currently unsustainable development and behavior patterns are transformed into sustainable ones. To achieve sustainability, human institutions collectively should build social consensus regarding sustainability as a goal, find ways to identify threats to sustainability and their sources, prioritize among multiple threats and identify responses to them, and implement those responses effectively. Many existing human institutions are not primarily oriented toward environmental protection or improving the material foundations of citizenship; thus current development trajectories are unlikely to become sustainable if those institutions do not undergo dramatic change in the near- to medium-term future. The major institutional reforms needed for existing institutions to use science and technology effectively in the service of sustainability must do a better job of integrating science into the policy process and policy concerns into science, coordinating institutions across issues and across scales, promoting both scientific and policy innovation, increasing participation in both science and policy processes, and engaging more in processes of self-conscious institutional and social learning. These are large tasks that require, at least for many institutions, dramatic changes in how they operate. They constitute at least part of what is necessary but of course not sufficient if human societies are to succeed in a transition to sustainability. The question is whether human societies are up to the task.

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Back: Wolfgang Lucht, Bill Clark, Oran Young, and Ron Mitchell
Front: Alison Jolly, Gilberto Gallopin, Patricia Romero Lankao, S. Sreekesh, Ann Kinzig, and Crispin Tickell (not shown: Ottmar Edenhofer)