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# Future directions in human-environment research

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ABSTRACT

Human-environment research in the 21st century will need to change in major ways. It will need to integrate the natural and the social sciences; it will need to engage stakeholders and citizens in the design of research and in the delivery of science for the benefit of society; it will need to address ethical and democratic goals; and it will need to address a myriad of important theoretical and methodological challenges that continue to impede progress in the advance of sustainability science.



## 1. Introduction

Sustainability encompasses social sustainability, environmental sustainability, economic sustainability, as well as institutional[1] sustainability (Charles, 1994; Goodland, 1994; NRC, 1999b). The expansion of research on sustainability from the environmental dimension to the social, economic, and institutional is one of the important changes taking place in human-environment research. It began during the past decade and will be more fully implemented in the next ten years. This is a major task, from both research and policy considerations, and one that needs to question business-as-usual and find new paradigms unencumbered by assumptions about unfettered growth and development (e.g., D'Alisa et al., 2015). Neither *sustainability* nor *sustainable development* are straightforward terms and there is much to question in them, which makes the definition of and search for sustainability very much local and regional processes, rather than a national or global one, if one is to address these different pressing problems from the stakeholders' perspectives. Sustainability science is fundamental research, but it will also have to be concerned with how to implement science for the benefit of local people. The goal ultimately is to improve society's capacity to use the earth in ways that simultaneously meet the needs of the human population today and in the future. It must do so while sustaining the environmental foundations of our life support systems, and substantially reducing poverty, hunger, and inequities in access to resources (Clark, 2007; Moran, 2010; NRC, 1999a).

According to Levin (2006), socioeconomic systems are, in fact, ecological systems characterized by familiar processes such as exploitation, cooperation, and parasitism, and ecological systems are economic systems in which competition for resources are central and in which individuals seek what is best for them, but which have emergent properties that have evolutionary and systemic consequences. Thus, they are complex, adaptive systems in which patterns at the macrolevel emerge from interactions and selection processes at many lower levels of organization. Complexity theory can shed light on the interactions of these human-environment systems, by focusing not only on its structurally complex characteristics but also on the management of the use of resources in such systems. Such management needs to be adaptive in its goals and approaches, seeking system sustainability and system self-organization—since without the latter, the former is simply unattainable (Norberg and Cumming, 2008).

Human-environment research is at its foundation about sustainability science and sustainability research, and progress has been made in how such work ought to go forward. It is a good time to reflect upon some of the new directions of human-environment research, and assess which future directions are most needed. What we see is a growing convergence between the natural and social sciences, and stakeholder engagement in the production of the science that can ensure that the investments result in public

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[1] Institutions in this context are understood as rules and norms that govern society.

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benefit. This fundamentally changes the scientific enterprise, and scientists need to be trained in new ways, and learn to practice their science in a way that the public understands and supports.

## 2. Toward transdisciplinarity and integrative science

### 2.1. Training of researchers needs to change

There is an urgent need to develop theories and methods for a science of sustainability based on the fundamental interactions between people and the biophysical environment. This call for new research implies a profound level of transdisciplinarity (Brown et al., 2010), and a multiscale, multinational, and multi-temporal integrative science that brings together the physical, biological, and social sciences, including institutional analysis and governance (Kaneshiro et al., 2005; Orr, 2002). Transdisciplinarity is a challenging process, characterized by the tackling of complexity, non-linearity, reflexivity, context-specific negotiation of knowledge, and a fusion of knowledge beyond disciplines. Because such research runs counter to traditional disciplinary-based approaches that have shaped the education and training of citizens, including scholars, the first order of business is to develop the capacity to speak across the disciplinary divides, understand the assumptions of others across the table, have a systems' perspective, and work to comprehend the complexity of human-environment systems rather than seek to simplify them. Scholars studying sustainability need to work together to formulate questions, propose innovative approaches, collect data, develop data analyses that are not disciplinary but transdisciplinary in nature, and interpret the results in ways that are truly integrative and democratic—a call for citizen-engaged science. From many quarters, from the Millennium Ecosystem Assessment to Future Earth, there is a call for engagement of the non-academic community into all stages of research from identifying problems to defining methods, gathering data, analyzing, interpreting and disseminating the data. Citizen science (Boyd, 2014) is a way to encourage participation, empower citizens and democratize knowledge. It is a new way to do science, as it presumes a degree of engagement of different stakeholders in the design of the goals of the science—rarely done until now—in environmental research. It is a new, challengine frontier and one that we must embrace as we go forward in the 21st century.

As we move forward, and project a future for human-environment research, we need to ensure that, regardless of discipline, the training we offer students is inclusive of expertise in both natural and social sciences, with an emphasis on the constraints of disciplines to find solutions to human-environment problems, and the capacity to work with different temporal and spatial scales. Business-as-usual in education and training is one of the obstacles that stands in the way of making major advances in human-environment research, since environmental problems do not belong to or respect disciplines but rather need to be addressed with comprehensive and inclusive approaches. Then, one must transform the educational enterprise by changing the structures within which people learn. How to do so will not be easy, as departments have a strong hold on the behavior of its members, and universities very often do not incentivize work across departments except rhetorically. Some departments and disciplines are more resistant than others to this need. The rise of bioengineering and biomedicine is a start, as are programs in sustainability science, and it is only a matter of time before serious integration of sciences will take place. Innovative leadership is needed to make this happen. Fortunately, we already see signs of organizations and networks breaking with tradition. Arizona State University, for one, did away with traditional disciplinary boundaries, and created new programs such as the School of Sustainability and the School of Human Evolution that bring together a variety of disciplines to address major concerns of our times. Michigan State University (MSU), through the Environmental Science and Policy Program is providing faculties and students the opportunity to work together without a whiff of disciplinarity. In Europe, important efforts are advancing in this regard: the Integrative Research Institute on Transitions in human-environment Interactions at Humboldt University in Berlin; the Institute of Social Ecology in Vienna; and several departments at Swiss universities are advancing integration outside disciplinary boundaries. The Vienna School of Social Ecology has proposed a robust approach to society-nature interactions as another useful new paradigm (e.g., Fischer-Kowalski and Haberl, 2007; Haberl et al., 2007; Krausmann et al., 2012; Singh et al., 2013). Worldwide, there are networks of academics and practitioners such as the Resilience Alliance studying resilience, adaptability, and transformability of social-ecological systems. More efforts such as these are needed to redefine the boundaries of education.

It is also crucial to develop theoretical frameworks to study complex human-environment relations. Ostrom (2009: 419) recognized that "ecological and social science have developed independently and do not combine easily," and that each discipline uses its own terminology and its own set of concepts to describe human-nature relations. She recognized the need to establish a common framework for human and environmental interactions—what she describes as the social-ecological framework (SES)—aiming to facilitate a dialogue across disciplines, organize findings, do comparisons among social-ecological systems, and study the same systems over time. The SES framework is continually updated by Ostrom's colleagues and others who have recognized its usefulness (e.g., McGinnis and Ostrom, 2014) and used for different settings that go from water and irrigation systems (Meinzen-Dick, 2007) to protected areas (Dumyahn and Pijanowski, 2011). Researchers are adapting the SES framework to include more environmental variables (Epstein et al., 2013; Vogt et al., 2015), give more attention to the context in which the SES is embedded (Torres et al., 2015; personal communication) and apply it to large ecosystems (Cox, 2014).

### 2.2. The scope of the research is now broader

Part of the challenge of citizen science and integrative science is that there are important differences and unequal relations between stakeholders—for example, between North and South, urban and rural areas, big industries/infrastructure projects and citizens—in defining what are the most pressing problems of sustainability (Clark, 2003; Martínez-Alier, 2002). In other words, stakeholders vary in what they want from scientists, and it will be a challenge to listen to the various stakeholders, and not just the ones who are louder or better funded to be present at the table. Environmental quality is linked to human equality and human health. As shown by Torras and Boyce (1998), countries with more civil and political rights, higher levels of literacy, and better income distribution have higher environmental quality than countries with more unequal income distribution and fewer rights. These findings have been replicated across U.S. states and their counties (Agyeman et al., 2002).

The Global South has a very different point of view from the North. They are countries with medium human development indicators or low human development. Until very recently they have been agrarian based, and dependent on the Global North for access to capital and technology, and the North depends on them as a source of raw materials, including energy. Perhaps most important, the Global South is young compared to the Global North, which is aging rapidly and concerned with immigration flows

swamping their societies (Ekedegwa Odeh, 2010). Clearly, bridging this gap will have to involve reducing both hunger and poverty, changing consumption levels of goods and energy, and reducing the amount of waste produced in the North, while better meeting the basic needs of people in the South, including peace, while protecting the earth's life-support systems and biodiversity.

The environmentalism of the poor, described by Martínez-Alier (2002), goes beyond South-North relations and calls for a "dematerialization" of the economy in general—one step beyond the discussions about decarbonization of the economy. Martinez-Alier describes environmentalism of the poor as the poor, and very often rural populations in general, defending the environment against, for example, the imposition of big infrastructure projects, large-scale industries, and global economy demands for goods and services. He also considers "biopiracy in agriculture" as a growing phenomenom that describes how peasants all over the world have had their seeds and knowledge appropriated for free, only to have this knowledge and the "improved" seeds protected by patents without receiving any benefits (2002:8). The author also criticizes the commercialization of shrimp produced in shrimp farms at the expense of the tropical mangroves and livelihoods of rural coastal communities. Martinez-Alier points out that there is a lack of fair valuation techniques that can really value the cost of this enterprise vis-à-vis its environmental and social costs. He also signals that large cities are unsustainable because they create ecological footprints that are larger than their physical area, and thus harder to monitor. Many of these disparities have created social movements around the world, and more questions than answers around the topic of development and sustainability.

South–North inequality and the growing disparities between rich and poor—not only at the national level but also at the local level—can be seen by looking at how many poor people are confronted with the pollution and degradation from the activities of the rich. Thus, the poor end up with the environmental "bads" whereas the rich enjoy the environmental "goods" in the form of higher incomes and lives in cleaner neighborhoods distant from the sites of production. Additionally, the poor do not have access to the decision-making and policy-making processes to change their living conditions or to claim justice (Agyeman et al., 2002). *Environmental justice* has become a field of study of all these global disparities and an essential research topic when thinking about sustainability. Sustainability should be inclusive, fair, equitable, and able to provide "social needs and welfare and economic opportunity … integrally related to environmental limits imposed by supporting ecosystems" (Agyeman et al., 2002: 78). Nowadays there are efforts to create a Global Atlas of Environmental Justice (Temper et al., 2015), an initiative that aims to show that the political ecologies of these struggles are more interconnected and transnational every day.

## 3. Priorities in human-environment research

### 3.1. Institutions

Improving our understanding of how social institutions affect resource use was identified as one of the eight "grand challenges in the environmental sciences" (NRC, 2001) over a decade ago and has been repeatedly identified as a top priority (e.g., DeFries et al., 2012; NRC, 1999a, 2005a). Institutions create contexts and rules that shape the human activities that drive climate change and that shape the realistic possibilities for mitigation and adaptation. The challenge we face is understanding how human use of natural resources is shaped by "markets, governments, international treaties, and formal and informal sets of institutions that are established to govern resource extraction, waste disposal, and other environmentally important activities" (NRC, 2001: 4). Very sensitive to the topic of institutional sustainability, is the topic of how to manage natural resources. For years it was accepted that only the market, private property owners, or the state could manage these resources in a sustainable way to avoid tragedies of the commons. Ostrom (1990) showed that local communities were able to manage their resources without depleting them. Moreover, she also found that the state, private owners, and the market were not always successful at managing those resources. The research of the commons has made clear that there are no institutional panaceas to manage natural resources (Baland and Platteau, 1996; Ostrom, 2009; Ostrom et al., 2007).

Wade (1994), Ostrom (1990), and Baland and Platteau (1996) formulated a list of conditions that may facilitate the sustainable use of natural resources in common-property situations: for example, the importance of locally devised access and management rules and the presence of unique ones (e.g., only Baland and Platteau said rules need to be simple and easy to understand). Agrawal (2002) synthesized and complemented these results with other empirical evidence that led to a unique list of conditions to enable communities to manage their resources in a sustainable way. Agrawal (2002: 53) explains that "this list of factors can be only a starting point in the search for a compelling theorization of how these factors are related to each other and to outcomes" and claims that in the future it may be necessary to focus "on configurations of conditions that contribute to sustainability." The author is also very clear that this list of factors represents a methodological challenge for scholars in the future, but one that needs to be tackled.

Closely related to the topic of natural resource management is the question of how users of natural resources, and citizens in general, will behave when resources become more scarce either as a result of climate variation such as droughts or caused by other users. Studies are exploring this question using different methodological approaches that go from economic experiments (Blanco et al., 2015) to surveys (Cinner et al., 2011) and ethnographic work (Trawick, 2002). Shah et al. (2012: 682) found that "scarcity creates its own mindset, changing how people look at problems and make decisions"; the authors explain that scarcity leads to behavior that is short-term minded, inefficient, and risk prone (e.g., asking for loans that are impossible to pay) and to neglect other problems by creating a shift in attention. The authors describe it as "cognitive load" that prevents people from making good decisions. Thus, it is crucial to investigate the institutions needed to facilitate the management of resources under scarcity scenarios.

Another promising, but increasingly challenged, approach is the use of payments for environmental services (PES). While this, on the face of it, would seem to provide a solution to the challenges of sustainable development, a number of scholars point to several problems such as how the payments can crowd out existing environmental values, which will not return once the payments stop (Lopez et al., 2013). Another problem seems to be that many PES schemes make demanding requests for land title and delivery of quantitative information to those paying, which favors the already well-off rather than those most in need. How to build resilience in communities to better handle climate change, and the complex interactions between local communities and ecosystem services that others wish to pay for is another growing area of research (Biggs et al., 2015).

The research agenda on institutions includes also documenting the institutions shaping these activities from local to global levels, understanding the conditions under which the institutions can effectively advance mitigation and adaptation goals, and improving the understanding of the conditions for institutional innovation. It is crucial to support institutions that promote justice and equity among different social groups, but also to improve the ways

to measure them (e.g., initiatives such as ecological footprint analyses). Fundamental research on resource institutions holds the promise of identifying more realistic behavioral models for designing responses to climate change.

### 3.2. Consumption

To advance the frontiers of human-environment research we also need to improve our understanding of what drives **environmentally significant consumption** (NRC, 1997; Stern, 2000) —consuming energy, materials, water, and information. Research on environmentally significant consumption illuminates a fundamental human driver and builds understanding needed for effective mitigation responses. Part of the research agenda includes individual and household-level behavior (e.g., what motivates consumption). We need to understand links among economic consumption, resource consumption, and human well-being, including the potential to satisfy basic needs and other demands with significantly less resource consumption, and the responsiveness of consumers to efforts to change their behavior through information, persuasion, incentives, and regulations. Another part of the research agenda concerns decisions in business organizations that affect environmental resource consumption, whether by the organizations themselves, by marketing to ultimate consumers, or through the structure of product and service chains.

A powerful mechanism influencing consumption decisions is the creation of infrastructures that favor or disfavor certain practices, lifestyles, or consumption patterns (e.g. Bolton and Foxon, 2015). A great many of the changes that must be implemented to achieve a sustainable planet run into pre-existing models of infrastructure governance that are very short term in perspective and fail to prioritize the future. Some of the elements necessary for a diminished impact from the energy-producing sector need to include greater flexibility in modes of energy production (biofuels, solar, geothermal) to complement fossil fuel and nuclear sources. The success of Ontario, Canada, in eliminating electricity-generating coal plants from the entire province, just 12 years from the time the government announced its intention to do so, should give abundant reason to be hopeful, and provide elements for research to understand how and why Ontario was so successful in achieving its goal (Marshall, 2013).

As explained by Vlek and Steg (2007), in rich countries, the level of wealth has not increased the general subjective well-being of their populations; people are buying more luxury goods that at the same time create big environmental damages. The authors argue that research needs to be done so people can get gratification in a sustainable way, showing the importance of advancing and expanding knowledge of **environmental psychology.**

From the consumer, citizen, and activist side there is a need to advance understanding of the motivations behind **environmentally responsible behavior** (**ERB)** at the private and public levels. Awareness and concern for the environment has been growing but this has not been reflected in more ERB (Scannell and Gifford, 2010). Private ERB refers to activities that one does in the private sphere such as recycling, composting, or turning off lights. Public ERB entails organization for collective public change thus presumes active participation and active citizenship (Chawla and Cushing, 2007). Both private and public ERB are important; human-environment research should contribute to understanding how to promote these two, acknowledging the fact that public ERB is likely to have a greater impact by influencing larger publics.

Citizens have double responsibilities: to consume responsibly as individuals and households, and to become engaged in their communities to bring about change in how the larger society makes choices about the uses of nature. The former is necessary to strengthen the moral foundations of our relations to the environment—a necessary but not sufficient condition to achieve sustainability. The latter is necessary to ensure that our actions affect the larger society: by participation in groups and organizations that protect the environment, by voting for candidates who show commitment to environmental conservation, and to address the pathways to the well-being of present and future generations. As described by Orr (2002: 1459) "sustainability … is constituted by a series of public choices that require effective institutions of governance and a well-informed, democratically engaged citizenry."

It is crucial to advance research that aims to change personal and social norms, such that pro-environmental behavior becomes the norm. As discussed by Kinzig et al. (2013), this shift in social norms is not easy to accomplish; however, governments may use different policy instruments to bring about such behavior modification. The role for scholars is to help in the design of effective policies, which includes assessments of both intended and unintended effects of these policies on personal and social norms. There is a need to understand the institutions- behavior link.

### 3.3. Decision making

Human response to climate change depends on decision making (e.g., NRC, 1992, 1999a, 2005a). Anticipating or guiding human system responses to both perceived risks and opportunities related to climate change and its experienced and expected impacts requires a sophisticated understanding of how people and organizations handle incomplete and uncertain scientific information and incorporate, ignore, or reinterpret it in decision making. The research agenda includes attention to individual cognition, risk judgments, and decision making in groups, organizations, and social institutions (e.g. Kahneman, 2003, 2011; Kahneman and Tversky, 2000; Kahneman et al., 1982).

### 3.4. Climate change in context

Improving our understanding of socioeconomic change as a context for **climate change impacts** and responses is another research priority. Assessing possible human-system impacts of and responses to climate change calls for understanding changes in other driving forces affecting those systems over the time horizon of interest in future climates. Examples include demographic change, economic change, and institutional change. Three situations are particularly high priorities: technological change, land-use change, and urbanization.

One of the most significant and most difficult socioeconomic changes to project beyond a period of one or two decades is *technological change*, which may or not reduce the rate of climate change, reduce some of its impacts, or offer alternatives for adaptation to those impacts. Key practical applications of such research include projecting the rate of implementation of technologies for carbon sequestration, seawater desalination, efficient cooling technologies for buildings, and finding ways to speed implementation of desired technologies. Fundamental research seeks improved understanding of what determines rates of technological innovation and adoption. The research agenda includes studies of the roles of incentives, aspects of organizations that might develop and implement new technology, institutional forces promoting or resisting change, and the potential of both transformational and incremental change (Geels, 2005).

A second kind of change, often key to connecting human dimensions with earth-system modeling, is *land-use change*, which reflects interactions between human and natural systems. This has been a robust area of research, led by the Land Use and Land Cover Change Program (LUCC) and then by the ongoing Global Land

Project (GLP). These projects have been concerned with the coupling of human and environmental systems as they influence land use and land cover and the ecosystem services derived from them. GLP has recently become a core project of Future Earth (2015). A huge challenge is posed by this evolution in the study of land use, since a major focus of Future Earth projects is on the co-design and co-production of knowledge with stakeholders. Much remains to be done as one goes forward in learning how to involve stakeholders and produce a science that is relevant to social needs while remaining cutting edge as a science (Pahl-Wostl et al., 2013).

These challenges posed by Future Earth lay the basis for what sustainability science research programs should look like for the next decade or more. Such programs will be built on a collaborative framework across the social and natural sciences, and with relevant elements of civil society to explore pathways to global sustainability. This integration must be based on an iterative process that involves reflection among all stakeholders, and an adaptive, flexible approach to co-design, co-production, and co-dissemination of knowledge and actions (Mauser et al., 2013)

Land use is such a central issue for climate change—related to greenhouse gas emissions, emission sinks, impacts, and responses—that it seems remarkable that a capacity does not exist to project such changes beyond a decade or two. Largely because of limitations in the ability to project demographic and economic changes over a period of more than several decades, along with changes in institutional and policy contexts, however, projections of land-use change into the mid-term and longer are essentially unavailable at present. Needed research includes decomposing component factors influencing land-use change; improving fundamental understanding of the relationships among population, land-use change, and environment; and linkages across scales (NRC, 1998, 2005b). Integrative modeling incorporating the advances from the climate change modeling community with those from the land-use modeling community remains an important research priority.

### 3.5. Other important future directions

Long-term social-ecological research (LTSER) has begun to emerge as a new field of research and combines the deep insights from the research carried out for decades in the Long-Term Ecological Research sites (LTERs), and the International LTERs, with the growing need to couple the natural science insights from rural and urban LTERs with the development of coupled human-natural systems (CHANS) and other efforts at integrating the natural and social sciences (Singh et al., 2013). This is a continually evolving area, since the challenge of integrating the insights from the natural and social sciences remains with us, and no easy pathways have emerged. Another recent effort to link CHANS across time and space has been proposed by Liu et al. (2013) and named *telecoupling*, which refers to how coupled systems are teleconnected by things like commodity trade and resultant land-use and land-cover changes at places of origin and destination of the commodities.

*Urbanization*, a third kind of change, is the shift of the world population toward cities, and the rapid expansion of urbanization across the world. Ever larger cities make use of much larger amounts of fossil fuels, emit more carbon per capita, and transform landscapes from high infiltration to low infiltration surfaces that change the earth's surface dynamics. Public health and demography are also deeply affected by urban living, with greater exposure to respiratory problems, rapid transmission of infection, and high levels of trauma from vehicular traffic and crime, moderated by greater use of force by the state. Needed research in this area includes how to reduce the footprint of cities, facilitate the creation of green spaces, reduce the environmental costs of traffic and consumption by urbanites, and construct systems of transportation that reduce emissions, while at the same time facilitate the commute of urbanites to their places of work and leisure.

#### 3.5.1. Industrial ecology

An important new direction is the development of an ecology of industrial processes. Industrial ecology refers to the study of material and energy flows through industrial systems and has increasingly become a key element in thinking about sustainability, given our growing dependence on cities and industry-based rather than agriculture-based economies (Ehrenfeld, 2004). Interest in this area began by focusing on industrial metabolism but has expanded to include life-cycle planning, ecodesign, concern with producer responsibility, and product-oriented environmental policy. Current directions seek to redirect “waste” flows into productive processes thereby achieving efficiencies and reduced pollutants (Kraines and Wallace, 2006).

#### 3.5.2. Valuing biodiversity and ecosystem services

In order to have a sustainable planet and move toward a science of sustainability, one needs to find ways to value biodiversity and ecosystem goods and services. Human economic systems inevitably weigh the value of all goods and services, and in this valuation, ecosystem goods and services have suffered, as they are often priced well below their true value. It is a form of discounting that favors polluting, high consumption, and wasteful behavior by consumers and industries. However, the values in environmental decision making should be beyond the definition of the traditional economic valuation. According to Dietz (2015), six values influence environmental decision making: self-interested values, humanistic altruism (i.e., values toward other humans), biospheric values (i.e., altruism toward other species and the biosphere), traditional values, openness to change values (i.e., considering everything as worthy), and hedonic values (e.g., gratification). These values have received much less attention than *economic* valuation but may be even more important in understanding human decisions about the environment. Research on environmental values emerged from questions about the relative importance of altruism and self-interest that were found to be relevant in studies of collective action and the commons dilemmas. There is a need to evaluate the different values as they become expressed in different contexts such as rural vis-à-vis urban areas, and in different developed and developing countries.

*Integrative modeling and policy initiatives* need to incorporate scientifically rigorous tools to measure environmental values in robust ways over the short, medium, and long terms so that purely short-term valuation does not trump long-term adaptive management. Additionally, more research is needed to connect these environmental values to actual behavior and not only to self-reported intentions as has been commonly done to date (Dietz, 2015: 13).

*Sustainability science* has to begin to include an ethical dimension that goes beyond the current processes required by universities for the protection of human subjects because researchers in both the natural and social sciences should be accountable to non-research stakeholder communities. Ehrlich and Kennedy (2005) pointed out different ethical questions that are not easy to address, for example the right of the current population vs. the rights of future generations when considering environmental impacts of our actions. The authors aim for the creation of a Millennium Assessment of Human Behavior that will include an ethical dimension of how we treat others and the environment. The authors' intention is to promote a cultural change in how we think about ethical responsibility to environmental goods and services. Future Earth and other international groups have taken to heart this ethical call and implemented ways to

pressure society, scientists, and policy makers to take this seriously.

As Eigenbrode et al. (2007) note, very often when integrating research across disciplines, teams may face philosophical differences that make the dialogue among them very difficult. A Toolbox dialogue method was designed to enhance the prospects for meaningful dialogue in the face of philosophical differences by researchers at MSU and the University of Idaho (O'Rourke and Crowley, 2013). This NSF-funded application of the Toolbox approach to the ethical dimensions of research accountability takes into consideration that researchers have responsibilities that very often are ignored: (1) the role of scholars as advisors of policy makers, (2) our relationship with non-human nature, (3) the definition of expertise and the importance of expert opinion, and (4) the ways scholars identify and communicate risk to society (NSF grant SBE-1338614). The **ethical dimensions of sustainability** are rarely discussed openly, and the new paradigms proposed by Future Earth and other international groups begin to move the research community in the direction of addressing these ethical obligations to both nature and society.

### 3.5.3. *Computational social-ecological research*

Scientists with a strong social science discipline background have a considerable learning curve before they can make serious contributions to understanding the climate models and other human-environment research challenges, as do natural scientists in being able to comprehend the importance of the human dimensions of climate and environmental change. More could be done to draw social scientists to human-environment research in the context of a changing climate, particularly at the pre-doctoral and early career stages. A 1992 NRC review devoted a chapter to human resource and organization issues and offered several recommendations for addressing the problem, including the creation of a transportable 5-year package of dissertation, postdoctoral, and research support. The idea would be to facilitate career advancement for social scientists working in a field outside the core of their disciplines, which could help build the community of researchers and might strengthen interdisciplinary institutions working on climate change. In a recent NRC review (NRC, 2007: 75) it was noted, "[T]he natural sciences may offer a successful model for building human dimensions capacity, especially programs to move young investigators into the arena and to support postdocs." Baby steps have been taken in this direction, but a lot more needs to be done. One needs to ensure that scientists in human-environment research have computational skills to deal with big data, mathematical modeling, and cutting-edge tools to analyze data and make them available to stakeholders. Increasingly it will be necessary to co-design and co-produce science with stakeholders, as Future Earth is nudging us to do, and to develop a new age of research where citizens' engagement with scientists is commonplace, rather than exceptional—a new social contract between stakeholders and scientists for a sustainable future (DeFries et al., 2012). This is clearly the future, an uncertain one in many ways, but the future is always unknown. By our actions we shape it each and every day. It is up to us to play an important role in shaping its direction and its eventual fulfillment.

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