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Understanding Human–Landscape Interactions in the “Anthropocene”

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Abstract This article summarizes the primary outcomes of an interdisciplinary workshop in 2010, sponsored by the U.S. National Science Foundation, focused on developing key questions and integrative themes for advancing the science of human–landscape systems. The workshop was a response to a grand challenge identified recently by the U.S. National Research Council (2010a)—“How will Earth’s surface evolve in the “Anthropocene?”—suggesting that new theories and methodological approaches are needed to tackle increasingly complex human–landscape interactions in the new era. A new science of human–landscape systems recognizes the interdependence of hydro-geomorphological, ecological, and human processes and functions. Advances within a range of disciplines spanning the physical, biological, and social sciences are therefore needed to contribute toward interdisciplinary research that lies at the heart of the science. Four integrative research themes were identified—thresholds/tipping points, time scales and time lags, spatial scales and boundaries, and feedback loops—serving as potential focal points around which theory can be built for human–landscape systems. Implementing the integrative themes requires that the research communities: (1) establish

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common metrics to describe and quantify human, biological, and geomorphological systems; (2) develop new ways to integrate diverse data and methods; and (3) focus on synthesis, generalization, and meta-analyses, as individual case studies continue to accumulate. Challenges to meeting these needs center on effective communication and collaboration across diverse disciplines spanning the natural and social scientific divide. Creating venues and mechanisms for sustained focused interdisciplinary collaborations, such as synthesis centers, becomes extraordinarily important for advancing the science.

Keywords Human impacts · Human–landscape interactions · Human adaptation · Landscape change · Interdisciplinary research · Anthropocene

Introduction

Humans have dramatically altered Earth's landscapes, and landscape change has affected human conditions, behaviors, and decision-making options. But, despite the importance of human–landscape interactions to the sustainability of societies, ecosystems, and physical landscapes, many of the connections and potential feedbacks between Earth's surface systems and human systems remain largely unexplored and poorly understood (NRC 1999; Steffen and others 2002; Young and others 2006). The 2010 workshop, *Landscapes in the "Anthropocene:" Exploring the Human Connections*, sponsored by the U.S. National Science Foundation (NSF) and held at the University of Oregon, brought together geomorphologists and related Earth-surface scientists with social and behavioral scientists and engineers in an effort to meet this challenge. The goals of the workshop were to exchange analytic perspectives, identify key questions, and develop a common conceptual framework for investigating human–landscape systems and anticipating how they might evolve in the future. Because increasing human impacts are changing Earth's surface at unprecedented rates and because human society depends on Earth's surface for resources and ecosystem services, such efforts are critical for producing the new knowledge required for mitigation, environmental restoration, and social adaptation. In this article, we outline the need for greater focus on landscapes, summarize the key outcomes of the workshop, and discuss research needs and challenges that provide a basis for a roadmap forward for integrated, interdisciplinary human–landscape research.

The Importance of Landscapes

The many important values of natural landscapes to human societies—through the supporting, provisioning, regulating, and cultural services of the natural environment—have been recognized internationally (Millennium Ecosystem Assessment 2005; Killeen and others 2012). Because life and human society depend on the provision of basic environmental services, including those of food production and water regulation, the ability to anticipate and predict changes to landscapes is important to all of humanity. Prediction allows unwanted changes to be minimized, planned for, or avoided. A citizen's idea of landscape is likely to be a wide-angle view of an outdoor scene, either natural or rural, to which the viewer may attribute spiritual, sentimental, economic, or aesthetic value. To an Earth scientist, the same landscape appears as a dynamic system involving different forms of matter and sets of processes while, to an ecologist, the landscape may represent a set of habitat patches or a snapshot in time of an ecological system. In recent decades, environmental management and environmental policies have emphasized the biological aspects of landscapes, and scientists, environmental managers, and the public have largely embraced goals that foster biodiversity and avoid losses of species (e.g., Hahs and others 2009). In addition to the attention given to biodiversity, the physical and hydrological aspects and functions of Earth's surface merit additional emphasis, and the social, cultural, political, and economic factors affecting human–landscape interactions in environmental management merit more complete understanding and integration into the science of landscape change. It is critically important to better understand landscapes as integrated with, not separate from, human systems and to combine and extend research perspectives from many disciplines across the social and natural sciences and engineering to improve the ability to predict and manage landscape change.

Context and Significance

The "Anthropocene"

Humans have altered Earth's surfaces throughout history (Sauer 1956; Butzer 1990; James 2011). People have modified land cover through agriculture and urban development, thereby changing hydrologic, biogeochemical, and biologic processes. Mining and construction have altered the form of the land surface (Hooke and others 2012), and industrial and agricultural practices have chemically altered water and soil. Dams and levees built for flood control, water supply, and hydroelectric power production interrupt sediment movement along rivers and change landscapes and human activities (e.g., Goldsmith and Hildyard 1986; Kondolf 1997; Graf 2001; Pizzuto 2002; Schmidt and Wilcock 2008). Beyond effects to physical landscapes, human activities have also affected atmospheric processes and climate, which in turn, affect social and biophysical processes on Earth's surface (Vitousek and others 1997). The effects of people on landscapes are likely to increase as human population grows to exceed 10 billion inhabitants later in this century (United Nations 2010). Environmental impacts of the human population and its resource consumption and disposal have intensified to the extent that the term "Anthropocene" has emerged in the scientific literature to signify a new geologic era (Crutzen and Stoermer 2000) dominated by human activity (Steffen and others 2007; Zalasiewicz and others 2008). A proposal to name Anthropocene as a formal geologic epoch (Zalasiewicz and others 2008; Williams and others 2011) is currently in development for consideration by the International Commission on Stratigraphy (Zalasiewicz and others 2011).

The challenges confronting the Anthropocene are increasingly global in scale. One measure of the global human impact on landscape—the conversion of land to urban uses—is not only related to population and per-capita GDP, but also to political and economic factors that vary geographically (Seto and others 2011). Human activities have become globally interconnected and intensified through new technology, capital markets, and systems of governance (Folke and others 2005). Interactions between global social change and global environmental change may amplify or dampen one another through feedback mechanisms, which ultimately may shape both societal coping capacity and ecosystem resilience (Young and others 2006). Periods of abrupt environmental change, especially related to climate change, are expected to increase in frequency, duration, and magnitude (Steffen and others 2004). Yet, at the same time, the apparent reduction of the capacity of the environment to sustain societal development (Diamond 2005) increases the vulnerability of human populations to harm in many places around the globe (Kasperson and others 1999). Understanding, predicting, and responding to rapidly changing processes on Earth's surface is thus among the most pressing challenges of our time.

Scientific Developments

Historically, Earth scientists have studied human impacts to the landscape primarily from the perspective of humans as external drivers of change (c.f., Thomas 1956; Goudie 2000; James and Marcus 2006). Thus, in relation to river landscapes, research has emphasized adjustments in fluvial systems (e.g., Rhodes and Williams 1979) following urbanization, deforestation, mining, and flow regulation by dams. As individual studies have accumulated, the scales, persistence, and variations in process responses have become better known (James and Marcus 2006). Knowledge of how landscapes have changed following human impact has been important for developing theories for landscape change and informing management and restoration. Still, this approach has not been sufficient to capture the full range of interrelationships among landscapes increasingly affected by multiple human-caused stressors. It has also not fully acknowledged the iterative effects of landscape change on people (Steffen and others 2002; Egan 2006). For example, human responses to landscape change include mitigation and adaptation strategies that often result in further modification of Earth's surface (e.g., Cooke 1984; Nordstrom 1994). The development and implementation of policy also shape and facilitate societal feedbacks, which are critical to slowing or reversing undesired landscape changes and increasing the sustainability of human life, life of other species, and social systems. Effective transformation of scientific understanding into policy requires understanding social processes and may entail building the capacity to implement policy (Folke and others 2005; Mitchell and others 2006).

Recognition of such interactions has prompted new concepts for examining complex environmental systems (Pfirman and AC-ERE 2003; NSF AC-ERE 2005) that reflect two-way couplings and nonlinear relations (e.g., Murray and others 2008; Corenblit and others 2011; Chin and others 2013). Inclusion of social processes in these concepts is not simple, however, as they encompass human actions, the networks through which humans interact, and the institutions in which they operate. Nonetheless, a more complete and useful treatment of human impacts on landscapes requires consideration of such factors because they influence both the original impact and the potential responses and feedbacks within the landscape system. In other words, people influence whether a dam is built or how a city is developed, and human systems need to manage and adapt to the environmental changes (Dietz and others 2003), such as loss of sediment to coastal areas or increases in flood frequency caused by these activities.

Researchers have increasingly articulated the need for new integrating concepts and approaches for understanding human-dominated environmental systems (e.g., Stern and others 1992; Kinzig 2001). Grimm and others (2000) issued a call to action for ecologists to integrate their science with that of social scientists to achieve a more useful and realistic understanding of the natural world in general and ecology in particular. Lubchenco (1998) also emphasized the increasingly close connections between ecological systems and human health, the economy, social justice, and national security. Van de Leeuw and Redman (2002) stressed the role of archeology in revealing long-term and slow-moving processes in socio-nature studies. More recently, synthesis has been advocated as a mode of research needed to bring together diverse datasets, disciplines, and cultural perspectives (Carpenter and others 2009). For climate science, the U.S. National Research Council (NRC 2007) concluded that the integration of human dimensions is necessary to address societal impacts of climate change and management responses. NSF has also recently called for increased collaboration between the geosciences and the social and behavioral sciences (NSF 2009).

At the NSF, efforts have accelerated to infuse social sciences into the Long-Term Ecological Research Network (LTER) (Redman 1999; Redman and others 2004; LTER 2007) and other environmental observatories (Vajjhala and others 2007). Increasing incorporation of social sciences in examining human–environmental systems is also reflected in NSF's Biocomplexity in the Environment competition (Michener and others 2001) and later in the Dynamics of Coupled Natural and Human Systems program. The Urban Long-Term Research Areas program (ULTRA) supports study of the interaction between people and natural ecosystems in urban settings, and, more recently, the Science, Engineering, and Education for Sustainability (SEES) initiative supports interdisciplinary scholarship needed to address complex problems and facilitate the move toward global sustainability (Killeen and others 2012). These efforts parallel developments elsewhere around the world, including the ecohydrology program of the United Nations Educational, Scientific, and Cultural Organization (Lemos and others 2007), as well as the recent scientific initiatives of the European Science Foundation (ESF 2010a, b).

But, despite calls for more interdisciplinary work linking human activity with landscape systems, much of the emphasis to date has focused, not explicitly on landscape systems, but on linking human activity with ecosystems (e.g., Redman and others 2004) or with atmospheric processes and climate (e.g., Steffen and others 2007). Literature on social–ecological systems has also grown rapidly (e.g., Lew and others 1999; Walker and others 2004; Folke 2006), as have the number of case studies for coupled human and natural systems that emphasize ecological phenomena (e.g., Liu and others 2007a, b). Concepts developed for urban–ecological systems explicitly incorporate human decisions, cultural institutions, and economic systems (Grimm and others 2000; Pickett and others 2001; Alberti and others 2003).

Although knowledge gained from studies of social–ecological and human–climate systems can inform research on human–landscape systems, what is needed now are new approaches for investigating human–landscape systems in which geomorphic and societal processes are central. Whereas, ecological systems involve organisms, organic matter, and nutrients, the operation of geomorphic systems depends on thresholds of erosion and sediment transport, which may trigger policy and institutional responses that differ from those for ecological systems. For example, catastrophic geomorphic change, such as that caused by flooding, typically leads to significant governmental intervention and assessment of the effects of land-use change on geomorphic processes (e.g., Interagency Floodplain Management Review Committee 1994). Slow-onset landscape changes, such as soil degradation or the loss of soil water-storage capacity, create more insidious problems by remaining unrecognized until they reach crisis proportions. Distinct questions, datasets, and frameworks are therefore required for developing a predictive understanding of integrated human–landscape systems that emphasizes geomorphic phenomena and the consequent interactions, responses, and feedbacks among social, physical, and biological systems.

A High-Priority Initiative

Recognizing the importance and urgency for accelerating understanding of human–landscape systems, the NRC (2010a) recently recommended the development of a high-priority research initiative, The Future of Landscapes in the "Anthropocene." Outlined in the report, *Landscapes on the Edge: New Horizons for Research on Earth's Surface*, this initiative requires full participation from social, behavioral, and economic sciences in collaboration with the geosciences, biological sciences, and engineering to meet the grand challenge of predicting "How will Earth's surface evolve in the Anthropocene?" Another 2010 NRC report (NRC 2010b), *Strategic Directions for the Geographical Sciences,* called for large-scale collaborations between researchers with diverse areas of expertise, including the social, behavioral, and economic sciences, to increase understanding of the human role in environmental change, along with other important challenges of the twenty-first century. The NRC recommended workshops as a first step to jump-start development of interdisciplinary initiatives; the workshop reported in this article was held for that purpose.

The Science of Human–Landscape Systems

Clearly emerging from the 2010 workshop was the need to recognize the interdependence of hydro-geomorphological, ecological, and human processes and functions in understanding human–landscape systems in the Anthropocene. A new and more complete science of human–landscape systems is needed that is both disciplinary and interdisciplinary (Fig. 1). Research questions relevant to human-caused landscape change, framed from individual disciplinary perspectives, enable advances in theory in those fields. At

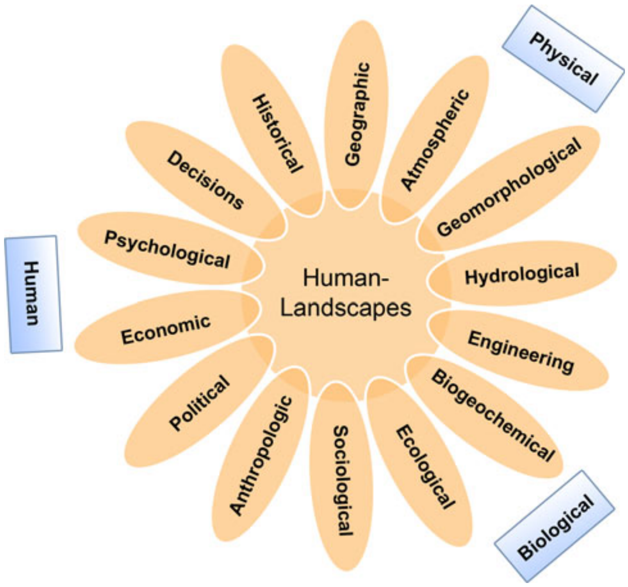

Fig. 1 The science of human–landscape systems. Perspectives and expertise contributed by individual disciplines (*petals*) and interdisciplinary interactions (*center*) advance the science

the same time, they contribute to the core science of human–landscape systems, in which synergism and collaboration across disciplines enable multi-faceted questions to be addressed. In other words, a more complete understanding of human–landscape systems requires interdisciplinary collaboration, which enables the sum of understandings of landscape to be greater than its parts.

Key Questions

To frame key questions from individual disciplinary perspectives that can contribute to interdisciplinary collaboration in integrated human–landscape research, workshop participants first gathered in small groups with others of their home disciplines. Disciplines represented by the 50 participants included anthropology, climate science, ecology, economics, engineering, geography (human and physical), geomorphology, hydrological science, policy science, and sociology. The following questions, which emerged from these groups, are presented here as examples of key disciplinary questions:

Anthropology: How do societies adapt to changes on Earth's surface, such as to land eroding due to agricultural activity? What cultural variables affect how people value their natural resources and environment, and underlie decision making?

Climate science: How can we improve models of land-surface characteristics that are closely coupled with human activity? How can simulations of climate history in various locations be improved to provide baseline data for predicting future climates and perturbations on Earth's surface?

Ecology: What common currency can be used to relate environmental goods and services to other aspects/frameworks of economic and political systems? How predictable are response variables, given that the trajectory of the recovery may be different from that of the impact?

Economics: What are the separate economic effects of natural- and human-system drivers of human decisions that affect the landscape? What are the negative externalities associated with these decisions and how large are the external costs? How effective are different policy tools and incentives at correcting those externalities?

Engineering: What are the effects of long-term engineering projects, given that such projects reflect the culture at the time of construction, but potentially outlast that culture? How can engineering consider other processes (biological, chemical, social), in addition to the fundamentals based in the conservation of mass and energy?

Human geography: What are the effects of connectivity/networks and associated spatial autocorrelation issues on understanding management regimes and response options? What integrative techniques and approaches can spatial sciences contribute to understanding and predicting human–landscape systems?

Geomorphology/physical geography: What are the relevant timescales for addressing particular human–landscape interactions, when problems can occur over a geologic period or in a single flash flood? How can we separate human from natural signals in landscapes?

Hydrological science: What timescales of hydrological processes are most relevant to ecological and human communities? What spatial scales are appropriate, especially when addressing the fragmentation of landscapes?

Policy science: What are the constraints—social, economic, biophysical landscape processes—on human behavior, and how do we understand them to promote change in individuals, communities, and institutions? How effective is adaptive management in producing policy solutions?

Sociology: What are the broader social and political consequences of landscape change, such as the installation or removal of dams, especially when the magnitude of causes and effects are asymmetric (i.e., small change in landscape processes can produce large social change, and vice versa)? How are the risks and benefits distributed among people?

These key questions represent the work within each petal of the "flower" diagram depicted in Fig. 1, and contribute to potential interdisciplinary research for integrated human–landscape systems, represented in the center of the diagram. Articulating research questions for specific disciplines helped others grasp the broad issues and theoretical motivations of work in those disciplines. This task revealed similarities and differences among disciplines, thus helping to identify linkages and areas of overlap as well as areas of potential misunderstanding. Although not all possible disciplines were present, and these questions represent the thinking of a just a few persons per discipline, the questions exemplify the process and take the first step of communicating meaningful problems to researchers in other fields. Other articles in this issue (e.g., by Chin and others 2013; Gerlak 2013; Peterson and others 2013) elaborate upon some of these disciplinary questions—the individual petals of the flower diagram—and provide challenges from those disciplines toward advancing the science of human–landscape systems.

Integrative Linkages and Themes

As interdisciplinary groups discussed the key questions across their disciplines and determined areas of common interest, they identified integrative research themes. All the themes use the language and approach of "systems," which emerged from interdisciplinary discussion as a productive way to share and integrate concepts across disciplines of social and natural sciences, as well as a conceptual platform for modeling and predicting change. Four themes, outcomes of the 2010 workshop, are presented here as examples of cross-cutting research themes developed to advance the science of contributing social and natural science and engineering disciplines, while building a new, integrated body of knowledge. Although different, they are not mutually exclusive. Some of them are also treated in more detail elsewhere (see Jordan and others 2010; Kondolf and Podolak 2013).

Theme 1. Thresholds/tipping points: What are they, and how do they rise from interactions among hydro-geomorphologic, ecologic, and human systems? Given multiple and cumulative drivers of change, how can we infer the exact cause and effect relationships? Are thresholds predictable—i.e., are signals of irreversible change identifiable, especially where the path of response differs from the trajectory of impact?

Jordan and others (2010) called for scientists to understand environmental systems affected by human activity that might be approaching thresholds for irreversible change. Taking a broader view, Scheffer (2009) argued for applying the theory of critical transitions, in which a reduction of resilience enables a small perturbation to cause a rapid shift to a new stable state, as a way to explain and manage social and environmental systems. Examples of thresholds that affect the landscape include the points at which rainfall runoff begins to erode soil particles (c.f., Morgan and Mngomezulu 2003) or rocks begin to move in a river (Church 2002), gully initiation (Schumm 1979), and economic conditions that lead a farmer to sell land to a developer. Until the threshold is reached, incremental changes do not change the function of the system. Interventions, such as steepening a slope by excavation, removing trees from a slope, or adding water, bring a slope closer to its threshold of failure. A social/economic threshold can affect the physical landscape, while a physical threshold can affect human actions and the anthropogenic landscape.

Theme 2. Time scales and time lags: How do time scales of geomorphological, hydrological, and ecological processes relate to those of behavioral and institutional processes? How do time lags within physical, biological, cultural, political, and economic systems interact to influence observed and predicted system states?

A time lag between landscape change and its effects can complicate efforts to link cause with effect. In the Copper Basin of Tennessee, 150 years of copper-mining-induced deforestation and soil erosion were followed by reforestation, but the response of the land to rainfall remains more like that of a denuded landscape than a forest (Harden and Mathews 2000). Legacy effects of anthropogenic change to the landscape have been noted by numerous researchers, including Walter and Merritts (2008) who, centuries later, found that streams in Pennsylvania and the Mid-Atlantic States continue to show the effects of colonial-era dams. Likewise, the effects of cultural and economic changes may be slow to become visible in the landscape, and changes, such as loss of soil fertility, might not be noticed until they disrupt social or economic systems.

Theme 3. Spatial scales and boundaries: How do physical boundaries compare with cultural and political boundaries? Do human-made boundaries produce environmental signals, and vice versa?

This theme is rich with possibilities for interdisciplinary investigation, as boundaries are part of the discourses of human and natural systems. Boundaries—perceived, regulatory, cultural, political, or physical—delineate everything from social norms to drainage basins. Environmental management that spans political boundaries, such as management of a landscape to ensure the quality and quantity of water, requires cross-boundary cooperation and shared understandings of problems and solutions. Studies of edge and core locations, and of the interrelationships between boundaries of different drivers of a complex system, have the potential to advance theory in multiple disciplines. Some anthropogenic boundaries (e.g., the border of Haiti and the Dominican Republic, the fenced edge of a protected area, or the edge of an irrigated field) produce clear environmental signals, but many landscape-related boundaries are less obvious and more dynamic.

Theme 4. Feedback loops: In human–landscape systems, how can feedback loops be identified and tightened to slow or reverse degradation, especially when coupling is weak, or when coupling is driven by a threshold response? How can coupling be managed to promote greater resilience in desired system states toward a sustainable Earth?

The strength of coupling (connections) between loss of environmental quality and human action to reverse the trend depends, not only on the strength of the signal, but also on such social factors as priorities, willingness to act, and recognition of cause-and-effect relationships. Tightening feedback systems to increase awareness, knowledge, and action in the short term can avoid greater impacts in the long term. Exploration of feedbacks, which has only begun to characterize these linkages, has potential to transform approaches to the study of human–landscape systems. For example, Blaikie and Brookfield (1987) showed that land degradation can be both a cause and an effect of rural poverty.

Pressing Needs and Challenges

Having developed interdisciplinary research themes with potential to advance the science of human–landscape systems, the next step was to consider what would be needed to successfully implement these and other interdisciplinary themes. Workshop participants identified three specific needs: (1) common metrics, (2) new ways to integrate disparate types of data, and (3) new ways to synthesize and scale up the results of research, from local case studies to farther-reaching theory and models.

First, *common metrics* for describing and quantifying human, geomorphological, and biological systems would allow comparisons between the conditions of biophysical and human systems. For example, a metric to quantify resilience would make possible comparisons of resilience among human and hydro-geomorphological systems (e.g., MacKinnon and Derickson 2012). Developing and testing usable common metrics is an urgent first step toward interdisciplinary advances for human–landscape systems. The new study required to develop and test the effectiveness and utility of potential metrics, and to establish protocols for defining metrics and other indicators should provide interesting research opportunities for interdisciplinary collaboration.

Second, a critical need exists for *integrating data* and developing *integrative methodologies*. Particularly important is the need to merge spatially extensive data from remote sensing with local-scale, field-based data. Developing systematic methodologies for analyzing relationships across disciplines will also require integrating qualitative methods and conceptual models with quantitative methods and models (see Zvoleff and An 2013; Lach 2013). The need for this type of integration is not unique to studies of human–landscape interactions; rather, it applies to many other interdisciplinary research themes.

Third, as individual studies continue to accumulate, an urgent need has emerged for *synthesis*, *generalization*, and *meta-analyses*. How can individual studies, which commonly document single small impacts, be aggregated in meaningful ways to quantify cumulative impacts? Each removal of a small dam along a river may exert a small impact, but would removal of a series of dams collectively affect the river and the lives and livelihoods of local populations in different ways? How can individual studies of local-scale issues be scaled up to regional and international scales, such as to document the global sum of small diffuse human impacts or of environmental stressors on human responses? Are studies from one area applicable to other areas? The challenges of cross-disciplinary and cross-scale synthesis are fertile ground for future research (Carpenter and others 2009).

These needs for interdisciplinary research present challenges that are institutional and infrastructural as well as thematic. Identifying common metrics, integrating data and ways of data collection, and synthesizing across studies require *effective communication and collaboration among multiple communities*. These communities include a range of natural scientists, engineers, social and behavioral scientists, scientists from different traditions, modelers, and field-based researchers. The intellectual and practical challenges of interdisciplinary research become especially evident in collaborations among biophysical and social sciences. Differences in methodological approaches often pose real and perceived gaps that must be bridged to forge scientific advances. In the case of research on Earth's surface processes, identification of colleagues across a perceived social/biophysical science "divide" for potential collaboration has also been difficult because researchers in these fields have historically worked in isolation from each other. Yet, the time has come to engage in dispassionate conversation about the future of Earth's changing landscapes and the societal effects of these changes, to create a focused effort across disciplines that can anticipate and mitigate future impacts to the environment and to society, and to incorporate changes that have already occurred into human policy and decision-making processes. Because increasing human impacts are changing Earth's surface at unprecedented rates (Vitousek and others 1997), and because human society depends on Earth's surface for resources and essential ecosystem services, such efforts are critical for transforming our approach to producing the new knowledge required for mitigation, environmental restoration, and social adaptation. A key challenge, therefore, is to develop venues and mechanisms (e.g., NRC 2004) for supporting and sustaining broad interdisciplinary work focused on human–landscape interactions.

The Way Forward

Participants of the 2010 workshop affirmed the need to meet the grand challenge ("How will Earth's surface evolve in the "Anthropocene?") posed in the NRC report, *Landscapes on the Edge: New Horizons for Research on Earth's Surface* (NRC 2010a). The NRC report highlighted the need for Earth-surface scientists to collaborate with social and behavioral scientists to advance understanding of human–landscape systems and recommended focusing on the long-term legacy of human activity on landscapes, complex interactions within human-dominated landscapes, and coupled human–landscape dynamics. The key questions and integrative linkages and themes identified, and the articulation of challenges and opportunities presented in this article provide the essential theoretical, conceptual, and practical foundations for collaboration between Earth-surface scientists and social and behavioral scientists.

A primary outcome of the workshop was recognition of the need for continued efforts to build an interdisciplinary research community that comprises social scientists in full intellectual partnership with geomorphologists and other natural scientists and engineers in the study of human–landscape interactions. Participants recognized this outcome as essential in developing the high-priority initiative, The Future of Landscapes in the "Anthropocene," recommended by the NRC (2010a). They were empowered by face-to-face discussion, which they found to be critical to the success of building community, and they placed high priority on creating opportunities for future workshops and working groups focused on specific themes. This outcome validates and supports the recommendation of the NRC that workshops are the first step toward coordination and collaboration among disciplinary fields.

Beyond workshops and working groups, the NRC also recommended the establishment of community centers to acquire the data necessary for developing new integrative and predictive models. Our human–landscape system discussions reiterated the NRC recommendation that national centers, focused on human–landscape systems, will be important for sustaining the collaborations needed to advance the science. In addition, international collaborations and international centers will expand the range of knowledge of human–landscape interactions and provide a broader range of experiences and models for environmental management. The outcomes of this workshop suggested that broadly based centers that focus on synthesis and theory-building would offer the most promising route toward transformational advances in the study of human–landscape systems. Modeling activities could form one component of the synthetic and theoretical work. Thus, the findings from this workshop support the recent call to accelerate synthesis activities in the environmental sciences (Carpenter and others 2009) and promote centers as extraordinarily effective institutional settings for advancing synthesis projects.

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