

Planetary Opportunities: A Social Contract for Global Change Science to Contribute to a Sustainable Future

RUTH S. DEFRIES, ERLE C. ELLIS, F. STUART CHAPIN III, PAMELA A. MATSON, B. L. TURNER II, ARUN AGRAWAL, PAUL J. CRUTZEN, CHRIS FIELD, PETER GLEICK, PETER M. KAREIVA, ERIC LAMBIN, DIANA LIVERMAN, ELINOR OSTROM, PEDRO A. SANCHEZ, AND JAMES SYVITSKI

The global change research community needs to renew its social contract with society by moving beyond a focus on biophysical limits and toward solution-oriented research to provide realistic, context-specific pathways to a sustainable future. A focus on planetary opportunities is based on the premise that societies adapt to change and have historically implemented solutions—for example, to protect watersheds, improve food security, and reduce harmful atmospheric emissions. Daunting social and biophysical challenges for achieving a sustainable future demand that the global change research community work to provide underpinnings for workable solutions at multiple scales of governance. Global change research must reorient itself from a focus on biophysically oriented, global-scale analysis of humanity's negative impact on the Earth system to consider the needs of decisionmakers from household to global scales.

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Those concerned with the future of our planet's life-support systems face an age-old quandary. Growing and robust evidence demonstrates that humanity's ever-expanding quest to feed, house, and clothe itself is rapidly transforming the planet. The list of problems is long and familiar, including global climate change, biodiversity loss, nutrient overenrichment in some places and nutrient depletion in others, ocean acidification, and freshwater depletion. Some researchers warn that the hard limits imposed by biophysical thresholds in the Earth system will soon be breached if they have not been already, with dire consequences for humanity (Rockström et al. 2009). Others argue that many, if not most, of Earth's biophysical limits are far from being breached and that human ingenuity can find new ways to harness resources and to mitigate unintended environmental consequences (Boserup 1965, Ruttan 1977, Simon 1996). These two views bracket society's possible responses to current concerns. The first demands costly curtailment of the benefits that society derives as it alters Earth systems. The second risks complacency and a failure to face very real and challenging problems from human-induced environmental transformations.

We argue that a more meaningful reality in the Anthropocene—the current epoch of humanity's massive

impact on the planet (Crutzen 2002)—lies between these two polarized views. This middle ground forms the nexus in which scientists can contribute to one of the greatest challenges of the century: the imperative to meet the needs of all members of our species while minimizing the negative consequences for the Earth systems on which humanity and other species depend. Scientists from many arenas—including physical, biological, and social scientists—and engineers working from local to global scales need to bring together the scientific knowledge, tools, and approaches to assist society in developing solutions for pressing sustainability challenges while helping societies to advance.

We propose a scientific focus on planetary opportunities to address the middle ground. Such a focus engages the broad global change community in developing options for societal actions that increase the probability of achieving societal benefits while reducing negative outcomes for Earth systems. Indeed, the scientific community has begun conversations about such solution-oriented research (Clark 2007, NRC 2010, Reid WV et al. 2010). Critical research topics that the scientific community can likely address within a decade include improving forecasts of future environmental conditions and helping to guide the institutional, economic, and

behavioral responses to manage disruptive change. We propose a further step toward proactively focusing on solutions that are tractable and specific to particular circumstances and places.

Paradigmatic to a focus on planetary opportunities is the view that although Earth's life-support systems set the broad envelope for human survival, societies evolve, adapt to, and sometimes alter this broad envelope to overcome many biophysical constraints and to correct negative environmental consequences. For example, a long series of ingenious technologies building on millennia of incremental understanding expanded the Earth's human-carrying capacity over the last 12,000 years through plant breeding, irrigation, crop rotation, and synthetic nitrogen fixation (Ellis 2011). Through these and other human manipulations of the planet's life-support systems, a larger proportion of our species enjoys a longer life expectancy, lower infant mortality rates, and more choices and opportunities to pursue creative talents than at any time in history (Raudsepp-Hearne et al. 2010). The planet currently provides enough food for an adequate diet for the entire human population of over seven billion people, although this cooccurs with an array of environmental challenges, including nitrogen runoff, biodiversity loss, and altered climate. That nearly one billion people remain undernourished without access to this food is not the result of biophysical limits but of social and institutional failures to implement solutions (Sanchez 2010). Applying human ingenuity to achieve greater food security, while reversing and reducing agriculture's environmental consequences, is one of the greatest challenges for the twenty-first century (Tilman et al. 2002). However, there are historical examples in which societies have met similar challenges by reversing course to avoid or overcome environmental and societal harm related to resource use and technology, such as soil-erosion-reducing windbreaks and contour plowing following the North American Dust Bowl of the 1930s (Potter et al. 2004), investments in technologies and policies to reduce air and water pollution (Tuinstra 2008), and international agreements to reduce acid precipitation and stratospheric ozone-depleting chlorofluorocarbons (Mäder et al. 2010).

Today, societies have not fully embraced technologies, policies, and actions sufficient to avoid global climate change, ocean acidification, and a massive loss of biodiversity and are only beginning to recognize and remediate the global leakage of nutrients into water bodies from excessive fertilization and the accelerated transfer of undesired species through rapidly expanding transportation networks. How can global change science assist social decisions that address these and other global problems in which biophysical and human systems are intertwined through forcings, responses, and feedbacks?

Research on the interface between science and decision-making illustrates the need for continual engagement and critical attention to spanning the boundaries between policymakers and researchers (Reid RS et al. 2009). Key to this

engagement is the recognition that scientific analyses are only a part of a larger realm of economic and political influences on decisions (Lawton 2007). Within the realm of the science-policy interface, science is relevant if the scale of analysis matches the scale of decisionmaking. Global-scale analyses (e.g., Foley et al. 2011) seek to influence policies at a global scale but are less effective in influencing policies and implementation at national to local scales. Global scientific assessments (e.g., MA 2005, IPCC 2007, McIntyre et al. 2009, Perrings et al. 2011), global models, and analyses of global trends are necessary starting points but are insufficient unless they are coupled with finer-scale research to inform local needs and potential solutions. For example, the last few decades of research and practice in conservation underscore the utility of global-scale priority setting (Myers et al. 2000) but also reveal the inability to effectively implement long-term solutions without the full engagement of local communities (Adams et al. 2004). Top-down solutions for reducing tropical deforestation (Phelps et al. 2010) or for enhancing food security (Sanchez and Swaminathan 2005) do not assure success without bottom-up efforts to identify solutions appropriate to particular places. Research to identify effective modes of engagement between scientists and decisionmakers working at different scales of governance (e.g., international, national, state, and community) and analyses (e.g., global, watershed, patch) is an important frontier (figure 1; Cash et al. 2006).



Figure 1. Decisionmakers at multiple scales of governance respond to many social, political, cultural, and economic factors in addition to scientific analyses. Global-scale studies may influence decisions at international scales but can only be effective at influencing finer-scale decisions if they are coupled with finer-scale analyses.

Current circumstances open critical research spaces for a solution-oriented focus on planetary opportunities. Nearly all population growth in the next several decades will occur in urban areas of the developing world (Grimm et al. 2008). Prosperity created from economic activity in urban areas raises living standards and increases demand for resources. Although urbanization creates pollution, usurps agricultural land, and disconnects people from nature, it also creates unprecedented opportunities for human innovation and economies of scale to improve livelihoods by increasing access to food and other resources, for enabling efficient modes for energy use and transportation, for reducing waste and pollution abatement, and for allowing more efficient use of space and other resources. Long-lasting decisions about urban infrastructure are currently taking place, and the time is ripe for input from the global change research community to inform efficient flows of water, energy, nutrients, and wastes to support urban populations and to identify the design of institutions that promote sustainable decisions. Some city leaders in both the developed and developing world have already come together to develop plans for energy-efficient and climate-resilient development (Rosenzweig et al. 2010).

A second critical research space is based on the premise that landscapes and seascapes can be managed to support multiple functions simultaneously in order to harmonize agricultural production with biodiversity, carbon sequestration, and other ecosystem services (Turner 2010). Understanding multilevel institutional structures needed to realize these management strategies is also increasing (Daily and Matson 2008, Ostrom 2010). An example in which this has already succeeded is the management of land use within watersheds to provide clean water for urban areas such as New York and Quito (Postel and Thompson 2005). The southern Amazon offers another example in which cropland expansion shifted to already-cleared lands and away from new forest clearings toward the end of the 2000s, although continued monitoring is needed to determine whether this shift is long lasting (Macedo et al. 2012).

A third example of opportunities for solution-oriented research lies in the developing agenda for an African Green Revolution. The first Green Revolution developed improved varieties of wheat and rice at the exclusion of African staple root crops and tropical maize. Moreover, institutional and political factors contributed to Africa's near exclusion from the large gains in improved agricultural productivity of the first Green Revolution. With developing institutional capacity, improvements in crop varieties, and international attention, an incipient African Green Revolution is beginning (Ejeta 2010). The research community has much to offer to apply lessons from the Green Revolution in Asia and Latin America to boost yields in Africa while minimizing unintended negative social and environmental consequences.

Geopolitical concerns about phosphorus availability offer yet another illustration of the strong coupling of local-scale solutions to global-scale problems (Cordell et al. 2009). For

millennia, traditional farmers recycled manures, including their own, in successful efforts to conserve and recycle phosphorus (Ellis and Wang 1997). Now, mined phosphorus fertilizers, large-scale livestock production, and urbanization have concentrated phosphorus to such high levels that it has become a serious pollutant in surface waters around the world. Solutions are emerging with a modern technological return to the traditional recycling of sewage and other phosphorus resources in agricultural systems, which simultaneously eliminates phosphorus pollution in surface water and limits it in agroecosystems (Cordell et al. 2009).

Many other opportunities arise for the research community to contribute to sustainable solutions: green energy systems; integrated satellite and social-networking systems to identify whether, how, when, and where interventions may be needed; understanding and simulating the complex interactions between biophysical processes and human societies; analyzing institutions and governance practices that are effective in achieving solutions; and devising efficient mechanisms for social learning based on ongoing successes and failures to move toward sustainability. As humanity uses an increasing share of the Earth's primary production and other resources (Vitousek et al. 1986, Steffen et al. 2011), the probability of harmful backlashes for the Earth system increases, and flexibility for reversing course diminishes, which reinforces the need to pursue these and other opportunities sooner rather than later.

A scientific focus on developing, evaluating, informing, and advising society on the potential pathways for sustainable development allows a rich contribution to society's ability to thrive while avoiding dangerous outcomes. The daunting and massive challenges of the day require a renewed social contract, rooted in scientifically and socially realistic possibilities for managing the planet, between global change researchers and society (Lubchenco 1998). We assert that an emphasis on global biophysical limits at the expense of a focus on realistic solutions is insufficient, as are assumptions that technologies can always solve environmental problems. For global change science to fulfill its part of the social contract, a vision of planetary opportunities needs to become a focal point for global change research, with sophisticated exploration of the synergies and tradeoffs between human and biophysical systems that will ultimately determine the success of our species and our planet's ecological heritage.

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Ruth S. DeFries (rd2402@columbia.edu) and Pedro A. Sanchez are affiliated with Columbia University, in New York, New York. Erle C. Ellis is affiliated with the University of Maryland, Baltimore County, in Catonsville. F. Stuart Chapin III is affiliated with the University of Alaska, in Fairbanks. Pamela A. Matson is affiliated with Stanford University, in Stanford, California. B. L. Turner II is affiliated with Arizona State University, in Tempe. Arun Agrawal is affiliated with the University of Michigan, in Ann Arbor. Paul J. Crutzen is affiliated with the Max Planck Institute for Chemistry, in Berlin, Germany. Chris Field is the director of the Department of Global Ecology at the Carnegie Institution of Washington, in Stanford, California. Peter Gleick is affiliated with the Pacific Institute for Studies in Development, Environment, and Security, in Oakland, California. Peter M. Kareiva is affiliated with The Nature Conservancy, in Arlington, Virginia. Eric Lambin is affiliated with Stanford University, in Stanford, California, and with the Catholic University of Louvain, in Louvain-la-Neuve, Belgium. Elinor Ostrom is affiliated with Indiana University, in Bloomington. James Syvitski is affiliated with the University of Colorado Boulder. Diana Liverman is affiliated with the University of Arizona, in Tucson.