Evolution of natural and social science interactions in global change research programs

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Efforts to develop a global understanding of the functioning of the Earth as a system began in the mid-1980s. This effort necessitated linking knowledge from both the physical and biological realms. A motivation for this development was the growing impact of humans on the Earth system and need to provide solutions, but the study of the social drivers and their consequences for the changes that were occurring was not incorporated into the Earth System Science movement, despite early attempts to do so. The impediments to integration were many, but they are gradually being overcome, which can be seen in many trends for assessments, such as the Intergovernmental Platform on Biodiversity and Ecosystem Services, as well as both basic and applied science programs. In this development, particular people and events have shaped the trajectories that have occurred. The lessons learned should be considered in such emerging research programs as *Future Earth*, the new global program for sustainability research. The transitioning process to this new program will take time as scientists adjust to new colleagues with different ideologies, methods, and tools and a new way of doing science.

global change programs | multidisciplinary | sustainability science

A good starting point in considering the integration of scientific disciplines is the history of the preparation for the International Geosphere-Biosphere Program (IGBP), which to a certain degree, was modeled after the International Geophysical Year that took place in 1957–1958.

In July of 1983, a workshop was convened in Woods Hole, MA that was sponsored by the US National Academy of Sciences to consider the development of a new program on the "study of whole systems of interdisciplinary science in an effort to understand global changes in the terrestrial environment and its living systems." Presentations were made on the issues to be considered for the new program: the solar–terrestrial system, oceans and atmosphere, the lithosphere, and the biosphere. It was the biosphere component that was the new addition to the physical science focus of the International Geophysical Year.

The report of this workshop (1) was presented at a colloquium sponsored by the International Council for Science (ICSU) in Warsaw in August of 1983. The ICSU General Committee at this meeting proposed that a symposium be organized for the upcoming General Assembly in Ottawa, Canada in September of 1984. The objective was to see if the international scientific community was willing to engage in the process of developing this proposed program. The results of the symposium were published by Cambridge University Press in 1985 (2).

The structure of the symposium focused on the physical systems as well as the life systems. Two threads can be identified that illustrate the emerging uneasy new partnerships that would be involved in this new integrated science effort.

One thread is the incorporation of life sciences into an effort that was to build on the strong foundation that the Earth science community had already developed in international integrated science. In respect to this first thread, there was the plea that "no discipline should become overly dominant, or should view others as playing an ancillary role. Already the Global Change proposal could be viewed as dominated by the physical, geological, or meteorological sciences, when its main goal is to preserve the global life-supporting system" (3).

The second thread is related to the neglect of the social sciences in this new program formulation. At the Ottawa symposium, there was one direct contribution on the human drivers of global change (4), but it was tacked on at the end of the program. William S. Fyfe, a geochemist from Canada, made the summary of the overall symposium, and it was his dramatic oral presentation, where he focused on the human impacts of global change, that seemed to convince the delegates at the General Assembly to embrace planning for this new initiative.

Robert W. Kates, geographer, contributed a comment to the published results of the Ottawa symposium, where he noted the lack of social scientists at the meeting who could contribute to the emerging goals of the new global change program (5). It was the sense of the organizers of the meeting, however, that the challenge of bringing the physical sciences together with the biologists was a sufficient challenge and that it would be unwise to attempt to go to the next step of incorporating the social sciences.

Kates did note in his remarks what impediments needed to be surmounted to actually make this important social–natural science link. One impediment he termed attitudinal (that is, a lack of mutual respect among the practitioners of these realms). The second impediment that he noted was structural and included the differential reward systems of these realms in relation to the problems approached. It was these sorts of structural issues that inspired Thomas Kuhn (6) to write his classic book on *The Structure of Scientific Revolutions*.

Roberta A. Miller, sociologist (7), subsequently evaluated why the obvious need for the integration of social and natural sciences in global change programs was so slow to develop. She identified three main impediments: (*i*) unrealistic expectations by the partners on what each party can deliver related to the foundations of the disparate fields, (*ii*) problems related to the nature of the data that each party can bring to bear to a given problem, and (*iii*) the tendency of one field to dominate in problem identification and program formulation. All of these problems are still extant, but in general, they are being overcome to a certain degree, although much work has yet to be done. The work by Miller (8) also noted that there is a need to deal with both the local and global scales and their interactions. Much of social science is based on the local, and global generalizations are difficult because of local cultural and institutional determinants of human behavior. How

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this information relates to the use of local knowledge is discussed below.

In the end, the ad hoc planning group for the IGBP, chaired by Bert R. J. Bolin, a climatologist, reported to the next General Assembly of ICSU in 1986, where it was decided to, indeed, launch the new program that was to be called "IGBP a study of Global Change"—with the use of the word "a" denoting that the study was not to be inclusive; indeed, it was explicitly stated that the domain of social sciences would not be embraced (9).

Conceptual Diagram for the Emerging Program—The Road Map Is Set

During the decade of the 1980s, a parallel program was being developed by the US National Aeronautics and Space Administration on Earth system science. This planning culminated in the landmark reports led by Francis P. Bretherton (meteorologist) entitled *Earth System Science. Overview* (10) and *Earth System Science: A Closer View* (11).

A compelling part of the Bretherton Report was a captivating overview or conceptual framework of how the Earth system functions. Two views of this framework were published in the 1988 report: one was a view of global change over thousands to millions of years, where such processes as plate tectonics and solar variability are the main drivers, and the other was a view over decades to centuries, where human activities are an important driver of the physical climate system and biochemical cycles (Fig. 1).

The conceptual framework for the developing IGBP adopted a streamlined version of the Bretherton decades to centuries model, emphasizing the need to build the bridges between the climate systems and biogeochemistry (Fig. S1). The human drivers were left out of the initial configuration of this new program as prescribed by Bolin's planning group.

Beginnings of Natural and Social Science Interactions in Global Change Research

Despite the poor start in integrating social and natural science in the early days of the global change programs, positive moves were being made in several directions. Unlike the global programs that were focusing primarily on the natural sciences, some of the national global change programs incorporated social sciences into their national research programs; this incorporation happened with the development of the US Global Change

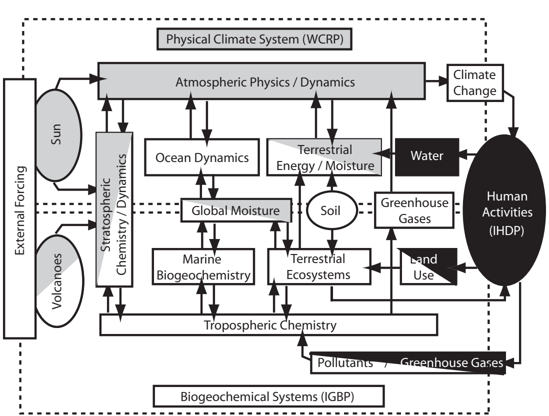

Fig. 1. A conceptual model of the functioning of the Earth system in time scales of decades to centuries where human forces have become prominent (if not dominant) (11).This figure was an important driving force for the conceptualization of subsequent Earth system research programs that are identified (World Climate Research Programme, IHDP, and IGBP) in this simplified version of the Bretherton Diagram from the National Center for Atmospheric Research.

Research Program, where there were several pathways proposed to address this issue. In a 1988 report (12), four key areas were proposed for inclusion in the program. These areas were the social elements that were most related to the climatic, biogeochemical, and biological drivers of change. The areas designated were (*i*) global land use change, (*ii*) industrial metabolism, (*iii*) usable knowledge of global change, and (*iv*) institutions for management. As the preparation proceeded in the development of the US program (13), two priorities were identified: land use and industrial metabolism.

The social science community, through the International Social Science Council (ISSC) and their Human Dimensions Program initiative (HDP), started efforts to launch an independent global change program. At the 16th General Assembly of the ISSC in 1986, a resolution was adopted to form an ad hoc committee to explore the possibility of developing a program that would be complementary and supportive of the emerging ICSU IGBP.

A proposal for the new effort was, in turn, presented to the 17th General Assembly of ISSC in Barcelona, which was accepted, and a Standing Committee on Human Dimensions of Global Change under the leadership of Harold Jacobson was established (14). International meetings were held to develop a specific program with the following research components:

- Social dimensions of resource use;
- Perception and assessment of global environmental conditions and change;
- Impacts of local, national, and international social, economic, and political structures and institutions;
- Land use;
- Energy conversion and consumption;
- Industrial growth; and
- Environmental security and sustainable development.

This proposal was accepted at the 18th ISSC General Assembly in 1990 (15).

Additional work on developing this program was taken on by a working group of the Consortium for International Earth Science Information Network (16) led by William Kuhn. The Consortium for International Earth Science Information Network group proposed a conceptual framework parallel to global change programs for the social sciences termed a Social Process Diagram (Fig. S2), which included the interactions among population, economic systems, production systems, political systems, and human behavior. In contrast to the Bretherton diagram, where the social dimension was a small side box in the Social Process Diagram, global environmental changes was the small side box.

However, the initial attempt to have a parallel effort to the IGBP for the human dimensions as the Human Dimensions Program (HDP) failed for complex reasons. There were two separate and competing international program offices of the International HDP, one in Barcelona and one in Geneva. Funding was an issue. The ISSC was not a strong organization at that time, and interactions with the ICSU were weak.

Then, in 1996, HDP was reborn. Eckart Ehlers, a geographer, critical to this rebirth, obtained the resources and a home for the program in Bonn, Germany. The program was renamed as the IHDP on global environmental change, and the original seven HDP priorities were reduced to just three: (*i*) institutional dimensions of global environmental change, (*ii*) industrial transformation and global environmental change, and (*iii*) human security and global environmental change (17). ICSU became a joint sponsor of this program together with the ISSC.

Geographers Join the Fray

Jacobson, as the leader of the HDP effort, was a political scientist. He was more or less alone in his field in seeing the importance of a focus on global change as a driving force for this discipline and related social science disciplines. A major disciplinary force that was preadapted for global change research was geography. These scientists, by training, bridged social and natural sciences and had a strong spatial focus; furthermore, they had a cadre of scientists with strong leadership attributes. The senior of these scientists was Gilbert F. White. White's very distinguished career covered many areas. He was a President of the Scientific Committee on Problems of the Environment (SCOPE) during the period of 1976–1982. Gilbert trained two students, Ian Burton and Robert Kates, who went on to become his colleagues and also became engaged in efforts to build bridges between natural and social scientists in global change research. The strong commitment of geographers in pushing engagement in global change research farther included Roger E. Kasperson (former chair of the Stockholm Environment Institute), Billie Lee Turner II (major driver in the establishment of the IGBP Land Cover and Land Use Change program), and Roland J. Fuchs (Director of the Global Change System for Analysis, Research, and Training). Diana M. Liverman, a geographer, became one of the first chairs of the US National Academy of Science Committee on the Human Dimensions of Global Change. As noted, Eckart Ehlers, a German geographer, was the first chair of the scientific committee of the IHDP.

Climate Assessments—An Early Test of Natural Science–Social Science Interactions

The first large-scale interaction between social and natural scientists in global change research and assessment came with the run up to the Intergovernmental Panel on Climate Change assessment process.

The dramatic impacts that climate variability had on human populations led to the development of the World Climate Program, which was initiated in February of 1979 under the aegis of the World Meteorological Organization. One of the goals of this new subprogram, called the World Climate Impact Program (WCIP), was "advancing our understanding of the relation between climate and human activities." This program called for "an integration of climatic, ecological and socio-economic factors entering into complex problems of vital importance to society, such as availability of water, food, and energy" (18). (The WCIP was subsequently subsumed by the formation of the Intergovernmental Panel on Climate Change).

SCOPE undertook an authoritative review of the methodology of climate impact assessment as called for by the WCIP (19). The work by Kates (18) addressed the challenges involved in such assessments that would, by their nature, involve two different science realms—the natural and the social (the latter science being younger, without consensual theory, and with a much smaller experimental base on issues related to global environmental change).

The work by Kates (18) described the kinds of integrated models that would be needed to capture the varying degrees of social/natural science interaction in climate impact relationships (Fig. 2). As Kates (18) notes, "It is easier to draw schematics than to describe what actually occurs. Variables described as climatic variation or societal variation are themselves products of the underlying processes of nature and society" (18). Over 20 y after this pioneering conceptual work (19), truly integrated climate change models are still not well-developed.

IGBP Begins to Incorporate Social Science and Build Partnerships

Not long after the beginnings of operation of the IGBP, there were efforts to build bridges with the social science community. One of the first efforts grew out of the IGBP program on Global Change and Terrestrial Ecosystems. This program was building models of vegetation change as related to biophysical drivers but lacked input models of land use change, which of course, were driven, to a large extent, by human actions. A joint project was initiated by IGBP and HDP to fill this void—Land Use Land Cover Change (LUCC) (20). This task was not easy. One of the impediments to progress in global change studies was that many areas of social science focused on local case studies to the exclusion of generalizing studies across regions. This result was analogous to the early gap between ecological studies and climate change studies—an enormous discrepancy in the scale of interest and conceptual development. An early report by the US National Committee on the Human Dimensions of Global Change encouraged the adoption of remote-sensing technology in social science studies as a way forward on the scaling issue (21).

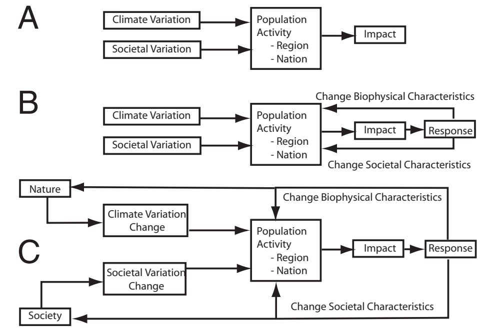

Fig. 2. Conceptual diagrams of the interactions between society and nature in response to climate change impacts (53). (*A*) Basic model structure, (*B*) interactive model with some feedback, and (*C*) interactive model with feedbacks to populations as well as driving variables. Modified from ref. 53.

The LUCC program undertook extensive metaanalyses of case studies globally on the drivers of land use change, such as deforestation and cropland development. The synthesis of the results of this innovative effort was published in 2006 (22). An example of the output from this program was the unpacking of the complex interactions between indirect and direct drivers of deforestation.

Richard H. Moss played a critical role in the development of the interface between the natural and social sciences in the formative years of the IGBP as well as subsequent to those years. In this position, among other things, he worked to develop the land cover project along with Billie Turner (20).

Millennium Ecosystem Assessment and the Askö-Beijer Institute—Other Tracks Building Social Science–Natural Sciences Interactions

The Millennium Ecosystem Assessment (MA) was a big step forward in bringing the natural and social science communities together in an assessment effort to evaluate the current status and trends of ecosystems through time. The construction of the conceptual framework (23) and the execution of the products of the assessment (24) were collaborative efforts between these communities. The assessment centered on the proposition that ecosystems deliver benefits to society that contribute to human wellbeing. The natural and social sciences, thus, were welded together in all components of the project. The policy response assessment (25) and particularly, the multiscale assessments (26) most heavily engaged the social sciences, because they dealt in depth with the full range of societal responses from institutions and governance, economics and incentives, social and behavioral responses, and knowledge and cognitive responses as well as technological responses. The effectiveness of the responses that were assessed was also considered.

Given the past history of interactions of the social and natural science communities, it was feared that there would be a difficult path ahead in executing the MA, but this result did not prove to be the case. As Karl-Göran Mäler (27), an economist, recently noted, "only a couple of decades ago . . . these two groups were quite hostile to each other, in this case ecologists accusing economists for being responsible for the increasing human encroachment into the natural environment (pollution, destruction of habitats, etc.) and economists replying that ecologists should stay where they belong, studying nature and not trying to build a new economics" (27).

Much of the mistrust between the ecologists and economists was minimized, because cooperation between these groups was increased through a series of workshops organized by the Beijer Institute of the Royal Swedish Academy of Sciences under the leadership of Karl-Göran Mäler in 1993 on the Swedish island of Askö. Many seminal papers on the interface between the environment and economics were crafted at these meetings. Some of those scientists involved in these workshops subsequently became involved in the MA. However, there is still much work to be done to include macroeconomists, sociologists, behavioral scientists, and many other social scientists to develop further the knowledge base for global environmental change.

Gradual Natural Science–Social Science Integration Within the Natural Science Global Change Programs

As some of the pioneering global change social scientists hoped (I. Burton, R. W. Kates, and W. C. Clark), there was an increasing integration of social science activity within the natural science programs in addition to the noted LUCC program of IGBP. In the following section, we show how this process proceeded within the ICSU-UNESCO Global Environmental Change (GEC) program on biological diversity, DIVERSITAS, as an example. These developments were proceeding in parallel to the developing IHDP, where there was still little crosstalk with the GEC programs.

Biodiversity emerged both as a new scientific field and a global issue in the late 1980s, and it became a globally important policy issue with the establishment of the Convention on Biological Diversity in 1992. The work by Loreau (28) analyzes how the concept of biodiversity successfully brought together taxonomists (focusing on the global decline of global species diversity), ecologists (seeking to understand the functional consequences of biodiversity changes in ecosystems), conservation biologists (discussing how to best protect endangered species in nature reserves), and more recently, economists (exploring new ways to value biodiversity).

Over the past three decades, the field moved from a focus on systematics and taxonomy (1970–1980s) to include a view of biodiversity's role in ecosystem functioning throughout the 1990s (29). This move brought the field closer to Earth System Science. In the early 2000s, DIVERSITAS and the MA placed biodiversity within the context of ecosystem services and human wellbeing. This path began to bring social scientists into the program; it had already started with the publication of the Global Biodiversity Assessment (30), which had three chapters dedicated to the human dimensions by lead authors who were members of the DIVERSITAS Scientific Committee.

The most recent development of the DIVERSITAS strategic plan is building a new biodiversity science that can determine what changes in biodiversity and ecosystem services are detrimental to society, suggest solutions for avoiding or mitigating these changes, and suggest ways to enhance the capacity of our social–ecological systems to support biodiversity and ecosystem services under global change (DIVERSITAS strategic plan 2012–2020) (31). The development of this new plan by the Scientific Committee of DIVERSITAS included biodiversity scientists as well as sociologists, economists, and environmental policy experts; it included discussions and establishment of bridges with the IHDP community.

DIVERSITAS, teaming up with IHDP, has been the prime mover in the development of the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES). These two programs, bringing together the natural and social sciences, have shown the need for such collaboration for addressing human needs within a dynamic coupled socioecological system necessary for this critical international agreement.

Attempts for a Fuller Integration of the Global Change Programs—Amsterdam Declaration

The integration of natural and social sciences in global environmental research and assessment is gradually becoming a reality. This integration can be seen in the threads of activity coming from many directions. The ICSU global change programs have been directly working to more integration at their operational level. In 2001, there was a major shift to more direct integration of the separate programs. At an open science conference cosponsored by all of the ICSU GEC, it was stated in the meeting summary (the Amsterdam Declaration) that

> [a] new system of global environmental science is required. This is beginning to evolve from complementary approaches of the international global change research programmes and needs strengthening and further development. It will draw strongly on the existing and expanding disciplinary base of global change science; integrate across disciplines, environment and development issues and the natural and social sciences; collaborate across national boundaries on the basis of shared and secure infrastructure; intensify efforts to enable the full involvement of developing country scientists; and employ the complementary strengths of nations and regions to build an efficient international system of global environmental science.

(http://www.igbp.net/About/History/2001-Amsterdam-Declaration-on-Earth-System-Science.html).

To carry out this declaration, the GEC programs joined to establish an Earth System Science Partnership (ESSP) that includes the four programs [climate (World Climate Research Programme), Earth system science (IGBP), biodiversity (DIVERSITAS), and human dimensions (IHDP)] and launched several new cross-cutting initiatives, which included the Global Carbon Project, the Global Environmental Change and Food Systems, the Global Water System Project, and subsequently, the GEC and Human Health Program and the Monsoon Asia Integrated Regional Study (32). The preexisting Global Change System for Analysis Research, and Training program was part of this family of joint projects of the ESSP.

Additionally, there were some bilateral formal projects established among programs [for example, the cosponsored projects between IGBP and IHDP, the Global Land Project, the expanded Land–Ocean Interactions in the Coastal Zone, and the new Integrated History and Future of People on Earth program that has only recently released its research plan (33). These programs have been slow in developing, which is characteristic of these large-scale international efforts built on volunteer scientists. However, it should be acknowledged that, because IGBP was the prime driving force of these projects, there has been a natural tilt to natural sciences governance in some of these efforts.

In a relatively short time for such a complex new coalition, a review of the progress being made by the ESSP was initiated in 2007 by the parent organization (ICSU) and the International Group of Funding Agencies for global change research (IGFA). This review concluded that the ESSP structure was inappropriate in several ways to address the major global change challenges faced by society. The review noted, in particular, that the ESSP should develop more strategic thinking in addressing global challenges that require coordinated action, marshal and channel resources accordingly, and engage with the wider community and users (32). This review led to a series of actions that brings us to the present, and a new integrated international global change research program is being crafted called *Future Earth*, which is detailed below.

At the 2001 Amsterdam meeting, while the ESSP was being assembled to bring a greater integration of the independent global change programs, a parallel proposal was made to accomplish this goal. Kates (personal communication) had long been dissatisfied with the lack of integration in the global change programs between natural and social sciences and felt that the establishment of separate programs for climate, Earth system science, biodiversity, and human dimensions balkanized these areas. Over time, Kates and his colleagues offered an alternative model, which was termed sustainability science. A symposium was held at the Amsterdam meeting that has been considered the launch of this concept. A foundational paper stemming from a small meeting of international scientists sponsored by the Swedish government was published in *Science* (34), and it was the backdrop for this symposium. The symposium itself was not well-received, and it was not incorporated directly into the Amsterdam Declaration. Subsequently, however, this concept picked up considerable momentum, which is discussed below.

Sustainability Science Continued Development

Robert W. Kates and William C. Clark have been tireless champions of the sustainability science concept. While at the International Institute for Applied Systems Analysis, Clark directed a study entitled *Sustainable Development of the Biosphere* (35), which had contributions from many of those scientists involved in the developing ICSU Global Change Programs. This volume has sections on both the natural and social science viewpoints as well as policy implications. It was a pioneering contribution to the integration of disciplines that is crucial to addressing the vision of sustainable development.

Outside of the ICSU realm, the sustainability science initiative has gained considerable momentum principally from a US platform and the efforts of others who joined with Kates and Clark [notably, Pamela A. Matson (36) and Billie Turner II]. The US National Academy initially became a platform for additional development of the concept through a Board on Sustainable Development, which produced the report, chaired by Kates and Clark, entitled *Our Common Journey, a Transition toward Sustainability* (37). PNAS established a home for sustainability science by introducing a dedicated section at the urging of the President of the National Academy in 2005 (38). This establishment provided a strong platform for contributions in this research realm.

Another center of development was Japan. In 2005, the University of Tokyo established a research network for Japanese universities on sustainability science called the Integrated Research System for Sustainability Science. The United Nations University launched a journal entitled *Sustainability Science* the following year. In 2012, the International Society for Sustainability Sciences was established, with *Sustainability Science* becoming its official journal. Another indicator of the growth of sustainability science is the explosive number of publications that relate to the sustainability science paradigm (39).

In sum, the sustainability science area is gaining much momentum, more as a ground-up initiative rather than a formal international program, although it is being recognized institutionally at the national level, which was indicated by the US National Science Foundation establishing a research funding program for sustainability science.

With so much activity, it is now easier to focus on the core of this research area and its goals. As noted in the article in the sustainability science entry in Wikipedia, "[c]onsensual definition of sustainability science is as elusive as the definition of sustainability or sustainable development." Returning to the foundational work by Kates et al. (34), it is stated that sustainability science "seeks to understand the fundamental character of interactions between nature and society."

A decade later, Kates revisits the question of what kind of science is sustainability science (40). He comes up with a definition that captures current central activity: "sustainability science is a different kind of science that is primarily use-inspired, as are agricultural and health sciences, with significant fundamental and applied knowledge components, and commitment to moving such knowledge in societal action". Thus, sustainability science is probably most easily characterized not by the particular questions that it addresses but rather, the approach that is taken to providing solutions to sustainability issues. This characterization generally means that the products can involve input from multiple partners from the technological, natural, and social sciences. The work is codesigned and integrated, and it is solutions-oriented and usually context-specific.

However, there are proponents of a more mechanistic view of what sustainability science could be. West (41), at a symposium at Potsdam, Germany, called for a "grand unified theory of sustainability" that would encompass

> a) energy, food and resource production and consumption, b) ecology, the environment, and climate change, c) human population, health, and well-being, d) the global economy, including the nature of risk and the dynamics of financial markets, and e) the social, cultural, and political institutions and organizational structures upon which the preceding depend.

He posited that the science of complex systems could offer a framework for such a development, although he doubted that such a lofty goal was indeed achievable. Attempts at bringing about such mechanistic understanding are certainly embodied in the efforts of the integrated modeling community, which was noted above.

Resilience Alliance

A somewhat parallel approach to sustainability science to integrating social and natural sciences is embodied in the Resilience Alliance that was established in 1999 (http://www.resalliance.org/). This alliance is a network of scientists and institutions that uses a conceptual framework that was first articulated by C. S. Holling in 1986 (42) and updated in 2001 (43). This framework is built on the nature of hierarchies and cyclic properties of both ecosystems and social–ecological systems and their adaptive nature. Concrete examples of resilience approaches for sustaining ecosystems and societies in the face of change were clearly articulated in a book published in 2006 by Walker and Salt (44), and the basic principles were described in a textbook by Chapin et al. (45) in 2009. An important component of this framework is developing resilience in systems to avoid crossing over irreversible thresholds (regime shifts) that move systems into a less favorable state for society. Thus, the resilience approach is an important approach to sustainability and has the same goal as sustainability science, but it is built on an overarching theory that sustainability science per se lacks.

What About Progress at the International Science Program Level Within Social Sciences?

One of the important contributions from the IHDP community over the past 10 y has been on environmental governance. The first thrust began with the work by Elinor Ostrom and colleagues under the LUCC. The governance of the commons and the role of local communities in overseeing the use of local resources in contrast to government regulations and private market instruments were a central contribution by the IHDP community over these years. Following the governance of land resources, Oran Young and others began a 10-y study on global governance, bridging the local to global spectrum. This work of IHDP's governance project contributed to the policy discussions running up to the Rio+20 summit on environmental governance and reform.

At present, the two main bodies focusing on the international research agenda of social sciences in global change are the International Social Science Council (ISSC), and IHDP, which is a program sponsored by ISSC, ICSU, and the United Nations University. Both of these entities are revising their programs to engage, to a greater degree, the full sweep of social sciences into global change research. Nearly a decade after the beginnings of the global change research programs, it was noted that (46)

> [f]or most social scientists ... it is still quite uncommon to put their research into the context of global environmental change. Despite the fact that the social and economic dimensions, i.e. demographic, social, cultural, economic, political and legal factors, play a key role in man made global change, the social sciences for long did not show any concern for global environmental change and they still are entering into these aspects somewhat reluctantly and hesitantly...There is, as yet, no "tradition" of global environmental research in the social sciences.

Framing the Issues. The ISSC and IHDP are working to lay the groundwork for building this tradition. ISSC has recently produced a report that provides a framework for social science global change research called the transformative cornerstones, (47) whereas the IHDP has developed a social sciences framework that will be useful to develop the IPBES conceptual framework (48). Although not a call for an international research program, it indicates the key social science research areas that are critical in the global change arena, and it is a call to arms of engagement.

How the problems are framed is critical to finding the solutions to solve the problems. For example, we normally see in the literature on climate change the need to find solutions to mitigate carbon emissions such that global temperatures do not increase beyond 2° and adaption measures to accommodate the 2° temperature rise. This framing of the climate problem from a deterministic and mechanical perspective by the natural sciences community leaves very little room for the social sciences to explore human dimensions issues pertinent to their research agendas. A social science framing, for example, on the same problem could be the following questions: how will world beliefs and ethics change in the midst of climate change? What are the implications for human wellbeing and equity? How can these be changed to accommodate to these increases? The former framing might mobilize the economists, which it has done, to understand the costs–benefits of mitigation and adaption measures but not necessarily mobilize the sociologists, anthropologists, and behavioral scientists. among others, who are more interested in addressing fundamental questions concerning why individuals and societies do what they do and how they might change their attitudes and behaviors.

Is this framing important? Recent studies by behavioral scientists show the use of their research in gaining a better understanding of why societies are reluctant to act even with the wealth of scientific knowledge. These reasons can vary from the perception of fear, belief that it is too big of a problem to be tackled by the individual, and agnosticism to science to just plain selfish behavior. Understanding these underlying values, beliefs, or fears is crucial for understanding and managing these behaviors in addressing climate change. Getting to the root of these global change issues needs the involvement of a wide range of social science disciplines broader than the present mix that is currently involved (48).

Unifying Methodologies and Conceptual Frameworks. For a large part of the last two decades of GEC research, much of the social sciences contribution has come from a limited subset of the social science community, such as geographers, which as stated earlier, were preadapted for working at the interface of natural and social sciences and economists. Much of the GEC research has relied on networks of researchers getting together to work on problems that they, as a discipline, have been working on within their respective organizations across the planet. Therefore, the natural tendency to work with colleagues from similar disciplinary backgrounds using common methodologies and frameworks allows easier collaboration and outputs expected from their respective disciplines and disciplinary academic journals. Many social science disciplines, however, use very different frameworks and methodologies, which entails high transaction costs in carrying out GEC research. The lack of funding for systematic multidisciplinary research calling for the full participation of the broad range of social science disciplines has hindered the development of fully interdisciplinary research with the GEC arena. One exception to the norm is the development of conceptual frameworks focusing on the economics of GEC. In a recent publication, IHDP put forward a conceptual framework, making the link between the natural and social systems through the concept of inclusive wealth and natural capital (49).

The IHDP is now working on developing a social sciences conceptual framework, which could be easily integrated with the natural sciences frameworks to provide a deeper understanding of the principle indirect drivers, such as population demographics, inequality, world beliefs, and values among others, that might be the causal factor for the direct drivers of change, such as climate change, water and land use, etc. A better understanding of these causal pathways would provide the basis for developing appropriate responses to mitigate or adapt to GEC across the different parts of the world.

Transition to a New Research Strategy—The Long Trail

Where are we now? In the last two decades, the natural and social sciences and the technological communities have become more and more engaged in understanding and to a greater extent, addressing the rising tide of the global changes that are threatening the wellbeing of societies. More attention, more resources, and more integrated efforts to maintaining global habitability are urgently needed.

As noted, the social sciences are increasingly focusing on global change issues, and there are initiatives to consolidate the work being done in a more interactive manner.

The assessment processes foster within-discipline integration as well as transdisciplinary advances among the natural and social scientists. At the same time, disciplinary programs are broadening their horizons as noted above. However, there is a drive to have a greater integration in international research programs. This task is certainly not trivial, which was observed in the development of the *Future Earth* program.

Returning to the 2008 report of the ICSU-IGFA review of the ESSP (32) and the visioning process that followed (50–52), the General Assembly of ICSU in 2011 decided

> to establish a major new interdisciplinary research initiative of 10-y duration on Earth system sustainability in collaboration with other partners of the Alliance; and
> to recognize the initiative as an Interdisciplinary Body and request that the Executive Board implement the necessary governance and support structures in collaboration with other partners of the Alliance.

ICSU and its partners the ISSC, the Belmont Forum (a high-level group of the world's major funders of GEC research) and IGFA as well as the United Nations Environment Program, United Nations Educational, Scientific and Cultural Organization, and United Nations University (together known as the Science and Technology Alliance for Global Sustainability) launched this major new 10-y initiative at Rio+20 (June of 2012). This new initiative is meant to be built on and to progressively replace the existing global change programs. It is being designed with these key characteristics in mind:

Deliver knowledge enabling countries, regions, and communities to transition to sustainability.
Build the capacity to deliver solutions.
Actively engage young scientists and developing countries scientists.
Significantly expand the involvement of social scientists and economists.
Involve stakeholders and decision-makers across governments, businesses, and civil society.

The new initiative is called *Future Earth—Research for Global Sustainability*.

A number of key lessons can be learnt from the IPBES consultative process that might be relevant for the successful establishment and implementation of *Future Earth*. These lessons relate to principles governing the way that *Future Earth* goes about implementing its research program.

The first principle is scientific credibility. Because *Future Earth* needs the active participation of a multitude of disciplines, it would need to be led by a team of highly credible scientists from the various disciplines to mobilize their respective communities.

The second principle relates to independence. Although the scientific research should adhere to the concept of codesign, the research agenda should not be influenced or dictated by vested interests in the forms of governments, private sector, or nongovernmental organizations.

The third principle relates to inclusiveness, where the process is kept open to all communities and does not become a community of like-minded individuals but encapsulates different ideologies, approaches, tools, and methodologies.

The fourth principle focuses on equity. There must be a concerted effort to include scientists from all parts of the planet and not be heavily influenced by scientists from the industrialized countries. Opportunities must be made available to allow senior scientists from the less-industrialized countries to participate with equal status. This principle is not to be mistaken with capacity-building activities to build the knowledge of scientists from the less-industrialized countries.

The transition team appointed by the Alliance for Global Sustainability will deliver an operational plan by 2013, which will be followed by an implementation phase. Thus, the time in planning will have been as long or longer than the length of the actual operation of the ESSP program that it supplants. However, no matter what form *Future Earth* takes, the interaction between social and natural science research will be stronger and more directed to problem-solving. No doubt, this interaction will be welcomed by many scientists, but others will be concerned about the place for basic research in this new construct, the maintenance of the international research networks that characterize many disciplines, and the role of the bottom-up research initiatives that have energized the volunteer armies that carry out international collaborative research and assessment activities. The new program will be codesigned by the international science leadership in collaboration with the international funding agencies and relevant users of scientific information, which could bring many new opportunities; however, as with anything radically new, there will be a period of rough patches as it rolls out. The ultimate goals are admirable, and the gap that has existed for much too long between the natural and social science communities in addressing the overshadowing global change issues individually and collaboratively will have been closed.

Time Line of Natural Science and Social Science Interactions in the Development of the Global Change Research Programs

1979. World Climate Research Program established in response to climate change threats.

1986. IGBP launched. Response to global change impacts more generally. Social sciences excluded.

1986-on. Identification of impediment to natural science–social science interaction:

i) Unrealistic expectations between disciplines.
ii) Nature of data available by disciplines.
iii) Natural scientists propose projects to social scientists without coproduction of plan.
iv) Scale of research focus dissimilar (local vs. global).
v) Academic reward systems differ among disciplines.
vi) Lack of acceptance of the value of alternate knowledge systems.

1990. HDP established by the ISSC as a parallel program to the IGBP.

1991. DIVERSITAS (biodiversity) established by ICSU (including International Union of Biological Sciences and SCOPE) and United Nations Educational, Scientific and Cultural Organization. GEC programs now include climate, Earth system science, and biological diversity.

1993. LUCC program brings some social science to IGBP.

1996. HDP reestablished as the IHDP, with ICSU being an additional new sponsor together with ISSC. The United Nations University became the third sponsor in 2006.

2002. DIVERSITAS relaunched as a GEC program.

2001. Amsterdam Open Science Conference of GEC programs form ESSP.

i) Greater integration called for "across disciplines, environment and development issues, and the natural and social sciences."
ii) Cross-cutting programs established including Global Carbon Project, Global Water System Project, and Global Environmental Change and Food Systems.

2007. Review of ESSP initiated by ICSU and International Group of Funding Agencies for Global Change Research.

2008. ESSP review released.

i) Did not review science projects per se but the structure of the overall program.
ii) "Structure input should be driven by the scientific mandate with input from users."
iii) A wide audience should be engaged, including policy and development communities.
iv) Funding inadequate for mandate.
v) Should develop a long-term vision.

2008. 29th ICSU General Assembly, Maputo, Mozambique. A committee of ICSU, the Committee on Scientific Review and Planning, takes over responsibility for ESSP future development, with proposed consultations and plans for a framework for GEC research.2009. ICSU's Committee on Scientific Review and Planning establishes a task team to plan a visioning process.

2009. Belmont Forum established to improve funding to international global change research coordination (IGFA+)

i) Called for "strengthening engagement between the (international) research funding agencies and the academic research community as represented by ICSU."
ii) "Improving coordination of early phase engagement on GCR strategies and priorities to improve codesign, coalignment, and cofunding of major research programs." The Forum has subsequently issued an international call for proposals on a couple of major global change priorities as envisioned.
iii) This group proposed, in essence, a shift from bottom-up motivated science in global change research to a codesign between scientists and funding communities.

2010. ICSU visioning report released and calls for

i) A transition from research from a natural science focus to one incorporating a broader range of sciences and humanities.
ii) More integrated inter- and transdisciplinary research approaches.
iii) The report title telegraphs a change in program focus: "Earth System Science for Global Sustainability: The Grand Challenges"—an amalgamation of natural and social sciences.

2010. Science and Technology Alliance for Global Sustainability established. A coalition of the Belmont Forum, ICSU, ISSC, United Nations Educational, Scientific and Cultural Organization, United Nations Environment Program, United Nations University, and World Meteorological Organization (observer) to support the new emerging global change research restructuring and operation.

2011. ICSU General Assembly establishes the Earth System Sustainability Initiative.
2011–2012. Transition team establishes boundaries of the new global change research; the program is now termed *Future Earth*.
2012. IGBP, DIVERSITAS, IHDP, and World Climate Research Programme convene the successful Planet Under Pressure Conference.
2012. June Rio+20 Launch of *Future Earth* program.

Parallel Efforts to Build Bridges Between Natural and Social Sciences

1993. Beginning of Askö, Beijer Institute symposia bringing ecologists and economist together to produce keystone papers at this neglected interface.
1999. Resilience Alliance established. Conceptual framework built on fostering resilience of ecological and social systems.
2001. Sustainability science. Foundational paper published. Solutions-oriented science built on codesigned integrated input from technological, social, and natural sciences.
2005. MA results published. Brought a balance of natural and social scientists together to address global change impacts on the capacity of ecosystems to deliver ecosystem services to society.

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