

Editorial

# Meeting the challenges of the anthropocene: Towards a science of coupled human–biophysical systems

## 1. Coupled human–biophysical systems

We have entered an unprecedented era with regard to the impact of human actions on the Earth's biophysical systems. Humans have always acted in ways that affect their surroundings (Turner et al., 1990), but only recently have anthropogenic drivers become major factors at the planetary level (Steffen et al., 2004). We have appropriated half the planet's land surface for human uses, eliminated 90 percent of the big fishes in the oceans, severely depleted the earth's stratospheric ozone layer, and increased atmospheric concentrations of carbon dioxide by more than a third relative to pre-industrial levels. The impacts of human actions on biophysical systems have become so broad and deep that many observers now speak of human-dominated ecosystems (Vitousek et al., 1997) and argue that we have entered a new planetary era best described as the Anthropocene (Crutzen and Stoermer, 2000). As the name suggests, the defining feature of this era is the emergence of human action as a critical force in a range of biophysical systems. One consequence of this development is that any attempt to explain or predict the behavior of large biophysical systems can no longer succeed without addressing human actions as a central concern.

We also must recognize that biophysical forces exert a powerful influence on humans and their social systems. While advanced technologies and economic prosperity have cushioned affluent societies from many of the impacts of resource scarcity and environmental disturbances, we are far from immune. Much of the world's population lives in extreme poverty and lacks access to the most basic necessities (e.g., safe drinking water and sanitation), leaving these communities highly vulnerable to changes in resource availability and biophysical threats. Even wealthy countries cannot escape the consequences of global environmental changes, such as rising sea levels, violent storms, and health hazards resulting from climate change (Diamond, 2005; Linden, 2006; Confalonieri and McMichael, 2006).

Human and biophysical systems are coupled: human actions affect biophysical systems; biophysical forces affect human well-being, and humans respond in turn to these forces. As environmental problems of the Anthropocene

elevate the importance of understanding the nature of this interactive relationship, new challenges for scientific enquiry are emerging. Efforts to understand basic properties and processes of natural systems without regard to anthropogenic drivers are increasingly of limited use. Moreover, the management of human systems without regard for the role of underlying biophysical systems cannot succeed in the long run. The challenge before us is to develop a science of coupled human–biophysical systems.

## 2. Scientific responses

The observation that human and biophysical systems are linked is not novel. Our aim here, however, is to argue that business as usual in scientific endeavors will not produce answers to the most urgent questions about coupled systems. In order to meet the challenges of the Anthropocene, we need to develop models and methods that are capable of illuminating the interactions between biophysical forces and anthropogenic drivers. Two scientific responses to this need are possible: one that is easier to pursue but somewhat limited and another that is more difficult but essential if we are to succeed in addressing our most pressing environmental problems.

The first we characterize as *partial equilibrium analysis* in parallel with the conventional use of the term in economics. Partial equilibrium analysis assumes changes in one side of a coupled system and proceeds to analyze the consequences for the other side using familiar disciplinary methods. Thus, we can make assumptions about future trends in anthropogenic emissions of greenhouse gases (GHGs) and analyze the probable impacts of resultant changes in the Earth's climate system (e.g., sea level rise, desertification, changed disease vectors). Conversely, we can make assumptions about climate changes and evaluate the consequences for social welfare (e.g., impacts on agricultural productivity, migration, health). The former procedure treats the anthropogenic driver—emissions of GHGs—as exogenous; the latter treats the biophysical force—climate change—as exogenous. Such partial equilibrium analyses may prove adequate for many purposes.

For instance, an analysis of the probable impacts of a changing climate on socioeconomic systems may suffice to trigger efforts to mitigate climate change or to adapt to its effects. Current examples include the European Union's Emissions Trading Scheme (EU-ETS), the effort of California to take the initiative in addressing climate change at the state level, and indications of shifting policies in the insurance industry triggered by the onset of climate change. Partial equilibrium analysis is often a necessary step, moreover, when building toward the second approach.

Because the two sides of coupled systems are highly interactive, we cannot explain—much less predict—the behavior of these systems without treating both sides as endogenous. We characterize this approach as *general equilibrium analysis*, where again the meaning of the term parallels conventional usage in economics. In the case of climate change, mounting evidence indicates that anthropogenic emissions of GHGs affect climate and that resultant climate changes will affect human welfare. But establishing these links is not the end of the story. Human systems are reflexive: individuals and societies learn from past experiences and anticipate future occurrences when making current choices. Already, as described above, behavioral adjustments and policy initiatives have emerged in response to climate change. While the adequacy of these adjustments and policies as solutions to the problem of climate change is debated, we can predict that continued climate change will trigger more far-reaching responses in the future. The point is that our models need to account for such endogeneity in order to diagnose the scale and scope of environmental problems and to propose effective solutions.

General equilibrium analysis is not straightforward. Identifying key linkages and specifying the mechanisms that generate feedbacks pose formidable challenges. The dynamics of coupled human–biophysical systems often feature tipping points, emergent properties, and pervasive uncertainty. Reflexive behavior can even exacerbate problems instead of solving or alleviating them, as exemplified by self-fulfilling prophecies that trigger fishing derbies, runs on banks, and even macro-level fluctuations leading to business cycles. To date, efforts to analyze the interactive character of coupled systems are in their infancy, as illustrated by studies of the carbon-climate human-system (Field and Raupach, 2004). Thus, addressing growing environmental problems will require the continued use of partial equilibrium analysis, in addition to an enhanced capacity to understand fully endogenized coupled systems through general equilibrium approaches.

### 3. The governance filter

To bring knowledge to bear on the challenges of the Anthropocene, it is also essential that we consider the role of governance systems treated as institutional filters mediating between human actions and biophysical pro-

cesses (Fig. 1). Work dealing with resource management has focused traditionally on regulating the impacts of the volatility of biophysical systems on human welfare. What is new is the need to regulate the impact of human actions on large-scale biophysical systems. In other words, the vector connecting human systems to biophysical systems in Fig. 1 is growing increasingly important. Also highlighted in the figure is the governance filter, which consists of the sets of rights, rules, and decision-making procedures that are created by humans to guide actions, including those that may have disruptive impacts on biophysical systems (e.g., emissions of GHGs) (Young, 1999). Governance systems also provide mechanisms, such as insurance schemes and emergency assistance programs, that can help cushion the impact of biophysical forces on human welfare in both the short term (e.g., hurricanes, tsunamis) and the long term (e.g., climate variability). As Fig. 1 makes clear, the emerging challenge is the demand for governance that can manage both of these relationships simultaneously.

Rights and rules can be both part of the problem and part of the solution in managing coupled human–biophysical systems. Severe depletions of resources arising from the tragedy of the commons (Hardin, 1968), for example, are attributable in large measure to the absence of effective rules limiting the use of natural resources or environmental services (e.g., use of the atmosphere as a repository for GHGs) (Baden and Noonan, 1998). Yet governance systems can address a wide range of environmental problems by influencing the behavior of key players. The introduction of a cap-and-trade system has played an important role in reducing acid rain arising from sulfur dioxide emissions in the United States (Tietenberg, 2002), and a number of countries are now experimenting with trading systems directed for the most part to emissions of carbon dioxide (Kruger and Pizer, 2004).

The performance of governance systems is highly sensitive to contextual factors, such as the fit between ecological and jurisdictional boundaries and the interplay between discrete systems of rights and rules (e.g., the provisions of the climate regime and those of the world trade regime) (Young, 2002). In the absence of a clear understanding of the relevant biophysical and socioeconomic systems, governance systems can generate unforeseen, unintended, and undesirable consequences. Furthermore, because specific governance systems tend to

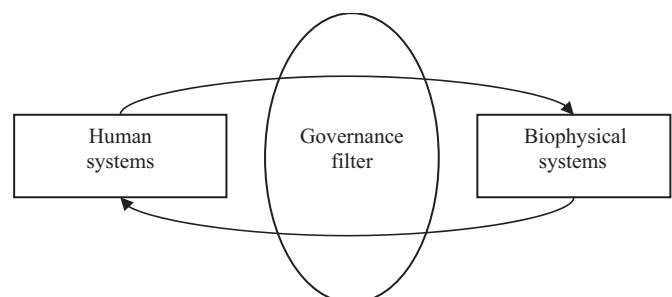


Fig. 1. Coupled human–biophysical systems.

favor the interests of some participants over others, efforts to (re)form these institutional arrangements are sensitive to the structure of power or influence in human societies and virtually always involve hard bargaining. For instance, the European Union was able to initiate an Emissions Trading Scheme to meet Kyoto Protocol obligations in part because of the discontinuation of coal production in Great Britain and reductions in German emissions arising from reunification in 1990. Similarly, the Russian Federation finally ratified the protocol in part due to the expectation of being able to sell excess allowances—so-called “hot air” arising from economic decline following the collapse of the Soviet Union.

#### 4. The way forward

The knowledge required to manage today’s human–environment interactions needs to go beyond natural science research in which human actions are treated as exogenous or largely ignored, and social science research that fails to consider the impact of biophysical forces. We need to promote efforts that create a science of coupled systems with both biophysical and socioeconomic elements fully endogenized. Partial equilibrium analysis in which each side takes into account drivers emanating from the other is a useful and necessary first step. But we must also work toward general equilibrium analysis in which the interactive dynamics become a focus of analytic attention. Success in meeting the challenges of the Anthropocene, such as the impacts of climate change, will require a sustained and creative effort to develop methods for analyzing coupled systems, while also making use of sophisticated governance systems to guide interactions toward desirable outcomes.

The perspective that we advocate has important consequences for the conduct of science. It requires that we wrestle with questions concerning the training of students to meet the challenges of the Anthropocene. Beyond the familiar tradeoff between breadth and depth, we need to find ways to foster greater integration across traditionally distinct disciplines or fields. There will always be an important role for single-investigator projects initiated from the bottom up. But the effort to understand the behavior of complex and dynamic systems creates incentives to build larger research teams and to design and conduct initiatives that involve collaboration among scientists in different institutional settings. It is encouraging that many of us are already involved in collaborative projects of this sort under the auspices of the international global change research programs. Another encouraging sign is that an increasing number of funding agencies, such as the US National Science Foundation and the European Science Foundation, are placing greater emphasis on the coupling of human and biophysical systems in scientific

endeavors. We hope these trends continue to gain strength and that the result is an enhancement of transnational scientific networks that deemphasize traditional distinctions among disciplines and build toward a greater understanding of coupled human–biophysical systems.

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