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Human–Environment Interactions

Learning from the Past

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ABSTRACT

Largely from the perspective of paleoenvironmental science, this chapter addresses the issue of how past records of human–environment interactions can provide valuable information for deriving strategies for sustainable management of human-dominated landscapes. It contrasts the different approaches to learning from the past in the sciences and humanities and suggests a simple typology of the different types of learning: trajectories and baselines; spatiotemporal variability and scaling; process responses; and complex system behavior. It argues that there are three research priorities requiring further effort and international organization: (a) the development and testing of theory that pertains to human–environment interactions; (b) the integration and regionalization of case studies and time series; and (c) the simulation of future human–environmental interactions using tools and frameworks that allow testing against historical records. Key questions are identified and shown at the end of each subsection.

> Without a knowledge of our history, we cannot understand our present society, nor plan intelligently for the future (McCullagh 1998, p. 309).

INTRODUCTION

This discussion paper[1] attempts a brief review of the ways in which useful information about human–environment interactions can be gained by studying the past. It is essentially the personal view of an environmental scientist whose perspective has evolved through a career dealing with the reconstruction of past environments from the analysis of sediments. Thus, while it attempts to cover

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[1] Parts of the paper are drawn from Dearing (2006) and Dearing et al. (2006a, b).

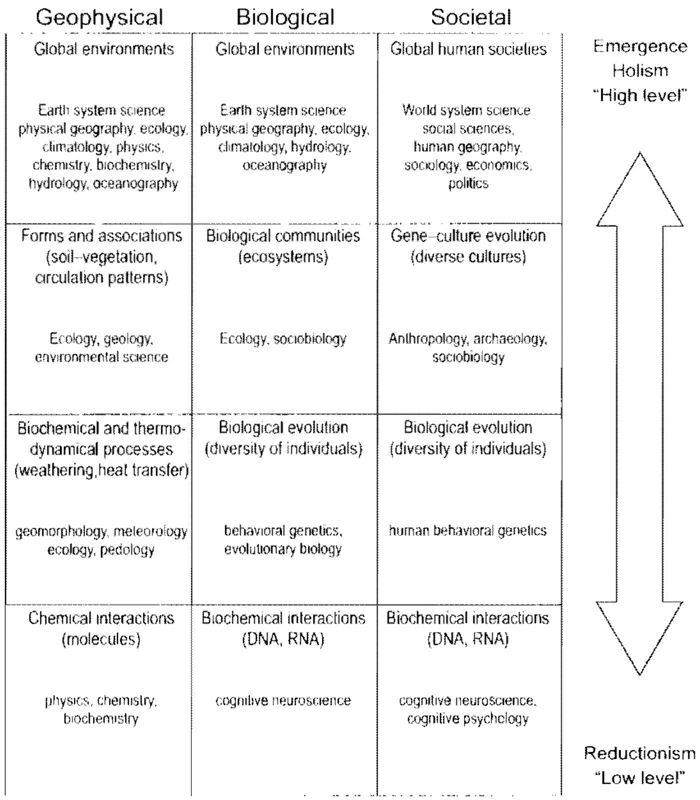
diverse approaches to the study of Earth and world systems, it is biased toward the physical sciences. Its primary aim is to draw out a few categories of "learning from the past" for discussion, focusing particularly on common and contrasting modes of learning across disciplines. Key questions are identified at the end of each section. My starting point is to consider the different approaches taken by the humanities and natural sciences in terms of dealing with history, and hence past human environment interactions.

Nature of Truth

The natural scientist reading essays and accounts of the philosophy of history cannot fail to be impressed with the tradition of intense debate about the accuracy and completeness of historical information, and the striking influence that certain historical theories have had on culture and politics. For some world philosophies, such as Marxist and Popperian, the central tenet is the value that can be placed on historical knowledge itself. In contrast, the philosophical debate about the development of the physical world appears to be far less. The environmental equivalent of the sociopolitical Grand Theories might exist in the form of Darwinian evolution and Milankovitch's orbital cycles, but these are today far less contested. Does this difference essentially stem from the perceived subjectivity or intractability of human views and actions contrasted with the objectivity of factual records of past environments? Is historical information about human actions intrinsically more unreliable and, thus, debatable? From the perspective of the humanities, McCullagh (1998) reviews methods and attitudes of assessing the truth of historical information, considering the constraints of evidence, culture and language, cultural relativism, and postmodern insights. In some ways the similarities between disciplines are clear. Both the historian and the paleoecologist have to interpret raw materials: both need to know the contexts; there may be alternative interpretations. Further, each may argue that the material should not be viewed as a literal record but one that is presented according to the authors' beliefs, data and information sampling and availability, and data processing. What perhaps is different, and surprising to some environmental scientists, is the degree of theorizing and philosophizing of approaches. For example, Collingwood's constructionist theory of history (in Gardiner 1959), in which the inadequacy of historical information demands (re)constructions rather than descriptions, is viewed as not so much a theory in the paleosciences but as a logical, rational, and dominant *modus operandi*. Clearly, there is general acceptance that sometimes there is a need for different treatments of truth, for example as "coherence with existing beliefs" in the humanities or as "consensus reached by rational enquirers" in both the humanities and environmental sciences (McCullagh 1998). Are there, however, other reasons that divide attitudes to history than simply the different levels of enthusiasm for philosophical argument?

Reductionism and Laws

One issue that may divide the disciplines is the level at which reductionism has played a part in explaining phenomena and formulating laws. If the natural scientist believes that factual records of past natural environments are more reliable, it may be because there are generally accepted laws for the movements of particles, matter, and energy that allow coherence between findings and theory to be established across a broad range of scales. Following Wilson (1998), we may ask whether the problems of explanation in the humanities lie with the inability to seek explanations of human actions through reductionism to the same low level as in the natural sciences (Figure 2.1). This is not to say that historically the humanities have not considered the possibility of explaining human affairs through discoverable laws—as exemplified by Hobbes' *Leviathan*,



Geophysical	Biological	Societal
Global environments Earth system science physical geography, ecology, climatology, physics, chemistry, biochemistry, hydrology, oceanography	Global environments Earth system science physical geography, ecology, climatology, hydrology, oceanography	Global human societies World system science social sciences, human geography, sociology, economics, politics
Forms and associations (soil–vegetation, circulation patterns) Ecology, geology, environmental science	Biological communities (ecosystems) Ecology, sociobiology	Gene–culture evolution (diverse cultures) Anthropology, archaeology, sociobiology
Biochemical and thermodynamical processes (weathering,heat transfer) geomorphology, meteorology ecology, pedology	Biological evolution (diversity of individuals) behavioral genetics, evolutionary biology	Biological evolution (diversity of individuals) human behavioral genetics
Chemical interactions (molecules) physics, chemistry, biochemistry	Biochemical interactions (DNA, RNA) cognitive neuroscience	Biochemical interactions (DNA, RNA) cognitive neuroscience, cognitive psychology

Figure 2.1 Hierarchies of explanatory rules in geophysical, biological, and social systems arranged in three columns from low level (reductionism) to high level rules (emergence holism). The vertical arrows show the generally accepted span of explanatory rules for each system with dotted lines suggesting possible extensions in the foreseeable future (developed from Wilson [1998] and extended by the author).

Condorcet's *Sketch*, or Tolstoy's belief that laws derive from the individual tendencies of humans—but to observe that this has not been generally successful. What is apparent is that the more successful or common use of history in terms of application has been to suppose that history has "meaning" in the sense of preordination or a hidden hand (i.e., historicism): in the sense of Hegel and Marx, to observe a certain trajectory and to speculate upon its continuation into the future (cf. Gardiner 1959). "Marxism" and "hidden hands" may be considered as outmoded concepts but, as considered below, the science of complexity suggests that we should not automatically dismiss either the opportunity to find "laws of society" or the value of studying repeated patterns of emergent phenomena, such as trajectories of civilizations (cf. Friedman, this volume).

Application of Understanding

We might also analyze the difference in influence achieved by the application of theories based on history. Political, social, and cultural theories based on history have clearly affected the structure and governance of nations, but what about the impact of scientific theory? One could argue that fewer people have been directly affected by Darwin's biological theory of evolution than by the indirect political ramifications of the derived social Darwinism. It certainly seems the case that current projections of global climate change represent the first use of scientific theory based on historical analysis and testing that engages, largely via the media, directly with the lives of a major proportion of the modern world population. Perhaps it is no coincidence that one of the most influential aspects of the climate change argument is the "hockey-stick" graph of reconstructed temperatures over the past few centuries: utilizing the power of perspective to educate and influence. However, arguments for the value of *learning from the past*, as opposed to merely *knowing the past*, are often not as clear as those pertaining to the "hockey-stick" graph or have been ignored. For example, McCullagh's (1998, p. 304) statement:

> The unique value of history lies in explaining the origin and value of all social institutions, cultural practices and technological advances we have inherited…in the past, it is indeed vital to recognize the conditions which enable them [institutions] to function as they did, in case those conditions exist today or have changed.

implies that a full description and explanation of the past (i.e., knowledge of the past) is sufficient in itself. Much research, from social history to paleoecology, has been driven by the disciplinary debates—appropriate methodologies, new techniques, and the alternative explanations—rather than the development of theory about how humans interact with their environment. In fact, we may have devoted more time and effort to describing the past than analyzing it for the lessons to be gained. Where theory has emerged, it has tended to take either a predominantly cultural or physical line with little attempt to understand fully the true nature of interaction. Moreover, social and physical sciences have now embraced the implications of complexity science. As a result, theories like environmental determinism seem outmoded oversimplifications of reality.

Current global change shows accelerating trends in many social and physical phenomena driven by demography, technology, culture, and climate. At every point on the world's surface these drivers interact, usually in complex ways. As a global scientific community we strive to provide realistic advice and guidelines as to the optimal strategies for adaptation and sustainable management. What follows is a discussion about how we can learn about current and future human–environment interactions from the past by adopting frameworks and approaches based on historical ecology (Crumley 2006). It does not follow that understanding and explaining the past means that we can predict the future, but it does mean that we might be able to identify, justify, and rank alternative futures for humanity to work toward. Below I briefly review and exemplify different ways that this might be done. While the following sections represent epistemological categories, they are mainly for convenience: in practice, they are often combined.

TRAJECTORIES AND BASELINES

Our knowledge of world and Earth system history is highly variable in time and space. All documentary, reconstructed, and instrumental records are, to different degrees, incomplete, discontinuous, and inaccurate. For Earth systems, the growth of modern science has not been matched by the monitoring of those environmental processes and conditions that are now seen as essential for generating strategies for sustainable environmental management. Meteorological records for major regional stations and hydrological records for the largest rivers are often available for the last 100 years but more locally, and for time series of other conditions such as vegetation cover, biodiversity, biogeochemical cycles, phytoplankton populations, and atmospheric pollution, records are often nonexistent or significantly shorter. Some long documentary records provide dates of events, such as the famous phenological series from China, or semi-quantitative information such as the Nile River flood height, stretching back into antiquity, but these are exceptional. Environmental reconstruction of processes and conditions can substitute for and extend many of these records (Oldfield and Dearing 2003), but clearly, as in the case of crop yields, not all. The quality of our documented and archaeological histories of societies and culture is similar, usually becoming more generalized and more speculative as we reach back in time.

Where the issue is about the sustainability of ecosystem processes and services in the face of human pressures, past records are already being utilized to good effect in order to demonstrate antecedent change. For example, Steffen et al. (2004) summarize the acceleration of 20^{th}-century changes in several sets of human activities and impacts on the Earth system. This analysis has been extended through the Syndrome Approach (Schellnhuber et al. 1997; Lüdeke et al. 2004) to defining functional patterns of regional human–environment interactions, such as the Sahel, Dust Bowl, and Green Revolution syndromes. For specific processes, particularly for those that are important locally rather than globally, a longer timescale may reveal strongly contrasting trajectories. For example, reconstructed erosion records over the past few hundreds of years show a wide range of curve shapes: accelerating in Papua New Guinea, declining in southern Yucatán, and stationary following initial sharp rises in Michigan (Dearing et al. 2006a). These records in themselves provide a basis for defining a typology of current trends (in this case, for soil erosion) that can contribute to any evaluation of modern sustainable land-use practices. The reconstructed trajectories for a single region, southern Sweden (Figure 2.2), show the diversity of human and environmental "parallel histories" available from a rigorous analysis of documentary, archaeological, instrumental, and sedimentary records (Berglund 1991).

Perhaps the simplest application of studying trajectories is to use past conditions as a goal for the management of the present. This type of analysis has become an increasingly common part of environmental regulation, where there is often a demand to identify and describe a "baseline" or "pre-impact" condition that can be used as a reference condition or rehabilitation target. Such demands commonly exist for air pollution, nature conservation, biodiversity loss, forest management, fire suppression, and water quality (e.g., EC Water Framework Directive). The concept of "reference conditions" is now particularly well-developed in studies of lake water quality where the chemical and biological status of a lake prior to recent human impact can be inferred from the lake sediment record (Battarbee 1999). This approach is more difficult to apply in terrestrial ecosystems. For example, Bradshaw et al. (2003) review the paleoenvironmental evidence for the role of grazing mammals on forest structure and conclude that no pre-impact baseline for contemporary management targets actually exists within the Holocene period. One common, and sometimes controversial, conclusion from this kind of analysis is that selecting a pre-impact or natural condition is not straightforward; it may even be unrealistic.

Key question: Can we characterize the nature of change in a region by using the trajectories of "parallel histories" to generate typologies of change in human environmental states?

SPATIOTEMPORAL VARIABILITY AND SCALING

Ideally, reference to historical points should not assume static environments but rather dynamic systems. Thus, one important type of analysis is to define an envelope of spatial and temporal variability. The paleoenvironmental sciences routinely reconstruct past frequency and magnitude time series to compare with

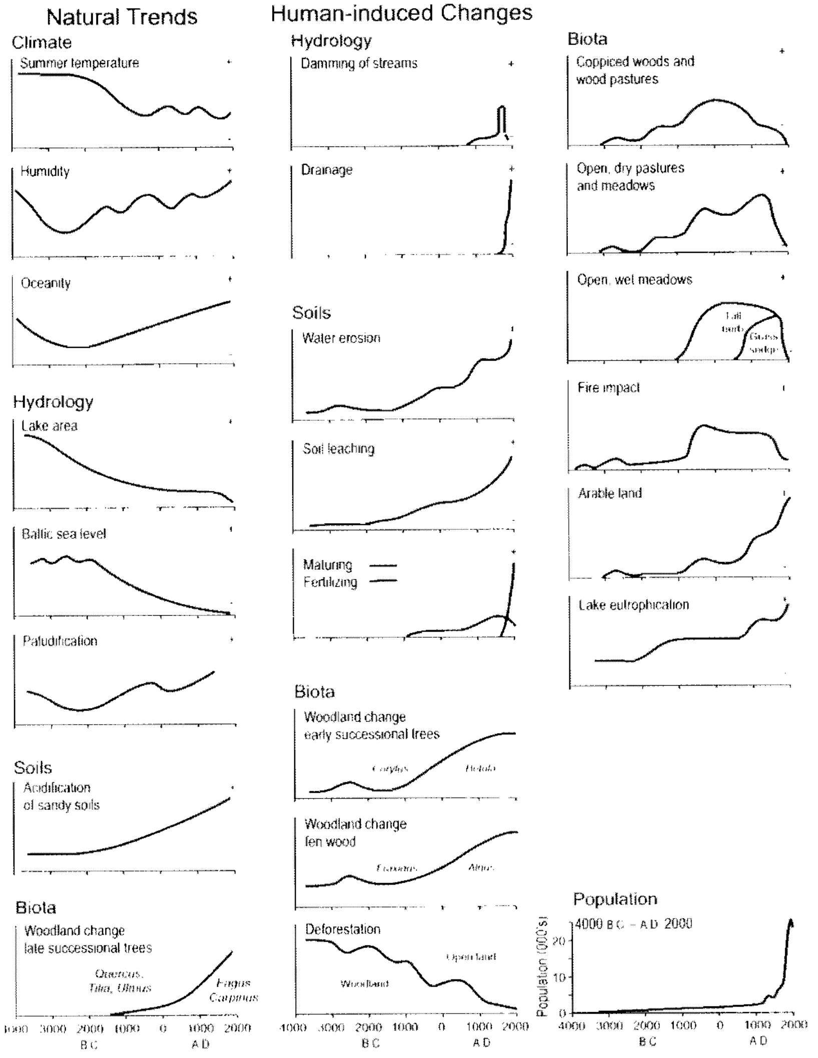


Figure 2.2 Parallel histories: trajectories of human actions and environmental conditions over the past 6000 years for southern Sweden (Berglund 1991).

modern conditions. For example, Nott and Hayne (2001) demonstrate that the recurrence interval of "super-cyclones" along the Great Barrier Reef is an order of magnitude shorter than had previously been calculated, using the period of instrumental measurements. Compiling separate time series from different sites provides an alternative way of observing spatiotemporal variability. For example, historically reconstructed fire data are now routinely used to define optimum fire suppression strategies (Swetnam et al. 1999).

However, the problem of scaling is one that lies central to linking local case studies to global processes. Ecological variability tends to increase as spatial and temporal scales become smaller, and our understanding of the controlling factors on the variability is often significantly modified by the scale of observation (e.g., Levin 1999). For time, there is the issue of defining the timescale that is relevant to the problem of concern. Over what timescales are the effects of soil conservation measures observed? Which particular flood frequency in the past resonates with climatic variation and which with the history of deforestation? In terms of space, the upscaling of cumulative local changes to the global system and the downscaling of projected impacts at a continental scale (e.g., from global climate models to local environments) present some of the greatest challenges to Earth system science. Most of our knowledge about the past comes from case studies with little uniformity in terms of spatial scale. It therefore seems sensible to promote the integration of human–environmental responses to "uniform" impacts in case studies across spatial gradients in order to generate new understanding about spatial scaling. For example, Dearing and Jones (2003) compiled past lake sediment accumulation rates in a number of catchments to calculate the effects of catchment size on the magnitude of erosional response to disturbance. Their data exhibit a spatial scaling control that seems to transcend other environmental factors, like climate. Still, examples of this sort of spatiotemporal scaling using paleodata are uncommon.

Key question: How best to integrate case studies within a region in order to gain new metadata for spatial and temporal controls on process responses?

PROCESS RESPONSES

Causation, explanation, and insight are often derived through inductive reasoning using corroborative, correlative, and converging lines of evidence from parallel sets of records. This may involve, for example, the use of instrumental and documentary records to provide independent data for external forcings, like climate and human activities, and the use of paleoenvironmental or historical data for response records. This also applies to postulated human–environment interactions from local to global scales. For example, the strength of Ruddiman's recent theory (2003) that global climate was affected by early human impact rests to a large extent on visual correlations between independent data for forest regrowth driven by epidemics and minima in the CO_2 ice record. Learning from the past in this context is often implicit: through past records we learn about the functioning of the system in question for which the present is simply the latest point in time. An exception is the use of analogs, where it is assumed that a past set of conditions closely resembles a present state, or projected future state. Deevey (1969, p. 40) stated that "where time is required for an experiment there's no substitute for history," arguing that the power of historical perspectives included learning from analogs of modern conditions. This line of argument has also been convincingly used by archaeologists and anthropologists to demonstrate the multidirectional nature of human–environment interactions: the vulnerability of past human societies and civilizations to natural climate change or events contrasted with the self-imposed impacts on support systems arising from unsustainable practices and positive feedback (e.g., Redman 1999; Diamond 2005). Such case studies clearly demonstrate the interrelatedness of human actions and biogeophysical processes, and can serve to dismiss the notion of absolute environmental determinism. They are strong conveyors of messages about unsustainable practices and the vulnerability of human society. However, we should be cautious in using them as analogs to inform the construction of mitigation or adaptation strategies to current and future stresses because the decision-making processes in past case studies can usually only serve as a basis for speculation. In this sense, Collingwood (in Gardiner 1959) saw history as a sequence of actions where the job of the historian was the study of the "thoughts" behind the actions. May (1973) took this idea further by analyzing the role of history on 20th-century U.S. foreign policy from the documented viewpoints of the crucial actors. He showed that foreign policy is often influenced by what history apparently teaches or portends, but that it makes wrong decisions because the past is an inappropriate analog for the present. Analogs are also used erroneously, as when trajectories are extrapolated into the future without qualification, or used selectively to support a moral judgment.

Overall, the task of understanding human–environment interactions through an inductive cause-and-effect paradigm may not be realistic simply because of the inability to understand the cognitive processes behind individual human actions (Wilson 1998). In this sense, the real value of inductive cause–effect "explanations" based largely on correlation lies with their generation of testable hypotheses.

Key question: How can we maximize our understanding of human–environment interactions through analysis of parallel historical records?

COMPLEX SYSTEM BEHAVIOR

Although cause–effect explanations remain a dominant mode, the view from complexity science argues against simple causative explanation. Open, dynamic systems are expected to behave nonlinearly with respect to external forcings and their internal organization (e.g., Phillips 1998; Levin 1999; Scheffer et al. 2001). External forcings may exert their influence through the transgression of thresholds, there may be time lags in a process response, and perhaps most importantly a modern system is not separated easily from its past: we should expect that it has been conditioned or sensitized by past events, or bears the legacy of past forcings and responses. Complexity science also predicts that systems may exhibit emergent phenomena: forms and structures that have evolved merely through a network of process interaction within a set of boundary conditions. Understanding the complexity of current systems in these terms is a high priority if we are to avoid environmental surprises at local and global levels (e.g., Amsterdam Declaration 2002).

If the formalization of complexity through mathematics is relatively new, the ideas are certainly not. Throughout the history of philosophy, one common observation from critics of historicism is their frequent allusion to the need to understand interactions between individuals, thus rejecting holism. Popper (1957, p. 18) argues that holistic studies of groups do not lead to an understanding of culture, "for if social structures…cannot be explained as combinations of their parts or members, then clearly it must be impossible to explain new structures by this method." Similarly, Tolstoy states: "Only by taking infinitesimally small units for observation (the differential of history, that is, the individual tendencies of men) and attaining to the art of integrating them (that is, finding the sum of these infinitesimals) can we hope to arrive at the laws of history" (in Gardiner 1959, p. 174). This raises the issue of how to integrate Earth and world systems. Essentially, do we have appropriate methodologies that can combine the natural laws of the physical world with approaches to the study of society that have largely excluded "historicism" as a mode of explanation? One approach may be to embrace more fully the new "physics of society" (Ball 2004) and utilize historical records more imaginatively to help define Tolstoy's "laws of history." In this sense Ball (2004) presents an optimistic view on the application of network and complexity theory to understanding social change—from the aggregation of individual actions to produce group behavior, through the emergence of scale-free societal properties, to the modeling of colonization and political action by national powers. The central point to be made is that long timescales of observation often enable, uniquely, complex phenomena and nonlinearities to be identified—certainly for environmental systems perturbed by human actions (e.g., Tainter 2000). In some cases high-resolution environmental time series (which include implicitly the actions of humans) may be amenable to mathematical tools that identify certain kinds of system behavior, like self-organized criticality (e.g., Dearing and Zolitschka 1999).

The idea of historical contingency has also been a common and long-running theme in the humanities and natural sciences. Whether it is Tolstoy's first method of history, whereby a series of continuous events is selected and examined ("even though there can be no beginning to any event"), Stephen J. Gould's impassioned view on the uniqueness of evolutionary paths, or the current web site (http://www.cooperative research.org/index.jsp) which describes the perceived timeline of actions and events that led to the 9/11 terrorists attacks (in the view of the web compiler now stretching back to the Russian invasion of Afghanistan in 1979), the idea that the present is conditioned by the past is an enduring one. However, while the potential value of history in defining the importance and existence of contingent processes is self-evident, the approach to be taken is not. Certainly, it seems sensible that we should not follow Churchill's view that "the farther backward you can look, the farther forward you are likely to see." Otherwise we should fall into the trap posited by Bertrand Russell in his tongue-in-cheek argument (Russell 1934) for the cause of the Industrial Revolution in terms of the chain of world events that starts with the migration of the Turks out of a desiccating Central Asia, and the fall of Constantinople. But how far back do we look?

For recent studies of ecological systems in North America, Foster et al. (2003) provide many examples of how modern ecosystems are a product of past cultural history. In some, human actions from decades past still reverberate into the present system; in others, the sensitivity of the present system to current forcings has increased because of past impacts since the times of the European pioneers. Three aspects of contingency should be highlighted here. First, the concept of *inertia*, which describes a process that once underway will not be halted without conditions changing, like demographic growth, the atmosphere–ocean system, or forest succession. Second, *emergence*, describing the appearance of a macroscale form from coevolving interactions operating at a microscale—from local cultural landscapes, to regional and world social structures such as Friedman's (2006) cyclical hegemonies, and Tainter's (2000) organizational problem-solving. Third, *conditioning*, where a past change to a system makes a particular impact more likely (e.g., deforesting land makes the fluvial system more sensitive to the same amount of rainfall than it was previously). An ability to distinguish between these facets of contingency and to define them for key environmental situations seems highly desirable.

Key question: How do we determine how far back in time our studies should cover in order to capture the important elements of contingency and emergence that are relevant to understanding today's socioenvironmental systems?

BEYOND MARX AND MILANKOVITCH: DEVELOPING AND TESTING THEORY

Learning from the past should include the development of theory, as already mentioned, but this seems quite deficient with respect to human–environment interactions. It might be argued that separate elements and processes contained within human environment interactions, such as culture, economics, climate and ecology, are already relatively well founded on theory. However, the opposing argument made here is that there is a lack of fundamental theory (i.e., that which generates laws or axioms) pertaining to the complexity of multidirectional interactions between human spheres and the physical environment at all scales. What should these theories encapsulate and enable? Well, the whole issue of defining sustainable management, including system sensitivity, impact assessments, and societal vulnerability seems to be a prime candidate. How do the common properties and dynamics of real socioenvironmental systems translate to the languages of energetics, complex system dynamics, and "the physics of society"? How does the sensitivity of a socioenvironmental system change with spatial scale? How does the pattern of networked interactions define stability and resilience? What are the relationships between real systems, operating far from "natural" or "equilibrium" states, and sensitivity to perturbations? How do we embed the value of common property regimes for sustainability in theoretical terms? In developing new socioenvironmental theory, can we build on and reconcile current research trends: the social theory of adaptive capacity and vulnerability (e.g., Pelling 2003); world system analysis (Hornborg and Crumley 2006); ecological dynamics (e.g., Levin 1999; Pahl-Wostl 1995) and the formal mathematical approach advocated in Earth system analysis (e.g., Schellnhuber and Wenzel 1998)?

Historical information may provide the vital perspective and insight that inspires new theory, but it also serves to test theory and hypotheses. Therefore, advancing testable theory about balanced human–environment interactions rather than about either biophysical or social phenomena should not only be viewed as a scientific priority, but may also be the route to reducing the constraints imposed by methodological differences. Where paleoenvironmentalists have worked together with environmental historians within an historical ecology framework, the potential to support or refute conjectures about the causes of environmental change is clear. Reconstructing parallel histories of social, climate, and natural environmental change provides a methodology in which circular argument is minimized and deductive hypothesis-testing maximized. One example of its success is in understanding the anthropogenic causes of surface water acidification. Surface water acidification was recognized as a major problem in the U.K. and elsewhere from the early 1980s. A lack of long-term instrumental data for precipitation acidity and water quality meant that there were a number of alternative theories as to its causes. These included industrial emissions, but also the effects of forestry and long-term natural biogeochemical cycling. Different lake records were compiled (Battarbee et al. 1985), which allowed post hoc scientific control for certain variables, such as geology and the absence or presence of coniferous plantations. These records showed that increased precipitation acidity caused by industrial emissions of sulfur and nitrogen oxide gases over 100–200 years was the only plausible explanation. These findings contributed significantly to government decisions in the U.K. and elsewhere to introduce sulfur emission reduction policies.

The improved development and testing of theory probably requires two new initiatives: (a) the compilation, integration, and regionalization of existing knowledge and data and (b) the continued development of dynamic models for the simulation of human–environment interactions. These are considered in the final two sections.

Key question: How can we develop new testable theory for the behavior of socioenvironmental systems that helps guide sustainable management?

INTEGRATION AND REGIONALIZATION

There are two dominant models for the integration of human–environment interactions. The first comes from the environmental sciences and emphasizes integrative studies across natural systems. This approach (cf. Swetnam et al. 1999) tries to encompass the full set of multidirectional interactions between human activities and fluvial, ecological, geomorphic, and climatic systems; effectively treating human actions, like deforestation and drainage, as *stressors* on a natural environment, not unlike climate. The objectives seek to find explanations of human actions in terms of the wider political and economic climate, but the emphasis is on the description and reconstruction of parallel histories. Less emphasis is placed on the changing nature of social and political organization, and the role of distal economic drivers, technology, disease, and climate feedback (e.g., drought and extreme cold) are essentially implicit or speculative. The Ystad Project (Berglund 1991) exemplifies this approach, describing the cultural landscape in southern Sweden over the past 6000 years through historical and scientific reconstructions at a number of sites (Figure 2.2). It describes changes in society and the landscape in order to understand human–environment interactions better through time and to provide a sound foundation for the management of the natural environment, cultural landscapes, and ancient monuments. It poses questions about the effects and spatial patterns of human influence on vegetation change set within a broad hypothesis that argues for the development of agrarian landscapes driven by technology, population, and environmental carrying capacity. The second approach treats humans in past natural environments, explicitly, as *actors* rather than stressors. This type of integration is implicit within the aims of IGBP Core Projects (e.g., LAND and LUCC) and the wider Earth System Science Partnership, but entails more ambitious integration that bridges the gaps between world systems, social science, historical ecology, and Earth system science. In this respect, the Mappae Mundi project (de Vries and Goudsblom 2003) provides a narrative that places the sustainability of humans and their habitats in a long-term socioecological perspective, as well as a foundation for future studies.

A considerable amount of historical and paleoenvironmental information already exists for many parts of the world, yet rarely is it compiled and analyzed in a form that maximizes our learning of human–environment interactions beyond the level of the case study (for an exception, see van der Leeuw 2005). One major task is therefore to produce syntheses at either national levels or for common ecosystems and landscapes that capture the current understanding of long term (100–10^2 years) ecosystem dynamics. A new initiative in the IGBP Core Project "Past Global Changes" (PAGES) will attempt to do this (http://www.liv.ac.uk/

geography/PAGESFocus5/). PAGES Focus 5 encourages paleoscience and environmental history communities to interact more effectively in order to provide a fuller understanding of landscapes and environmental systems. These integrative syntheses will act as inventories of information that can help inform contemporary studies of these ecosystems (ideally linked to other IGBP Core Projects, such as LAND, or the Long Term Ecological Research Network). A draft scheme for organizing regional syntheses shows a two-dimensional matrix defined by zonal and azonal geographical regions, and simple measures of the intensity and duration of past human impact (Figure 2.3). Such a scheme will allow us to catalog regions where sufficient information and data already exist, and to prioritize new regions where new records and syntheses are required (e.g., "fragile human landscapes," "threatened human landscapes," and "highly valued ecosystems").

Ecosystem type		← Human land-use impact →		
		Low	Medium–High	
			Recent (last 1–2 ka)	*Ancient (last 1–2)*
Zonal	Temperate mixed forest			Rhine / Eifel
	Mediterranean			SW Turkey
	Temperate grassland		Upper Midwest U.S.A.	
	Tropical moist forest			Mesoamerica
	Boreal forest	Peace River, Canada		
Azonal	Large oceanic islands		North Island, New Zealand	
	Mountains			W Alps
	Large river floodplains		Murray Darling	Lower Yangtze
	Coastal zone, peatlands, etc.			Netherlands
	Lake systems		SW Scotland	

Figure 2.3 An example of an organizational matrix for the regionalization of global case studies within PAGES Focus 5. Each cell represents a zonal region or azonal system for which high-quality (well-dated, high-resolution) multi- and interdisciplinary paleoenvironmental data (including sedimentary, archaeological, instrument, and documentary data as appropriate/available) already exist and where synthesis of information for different environmental systems (e.g., lakes, fluvial) and/or at different scales is feasible. Blank cells could be targeted for new studies, with priorities set by criteria such as high biodiversity status; fragile and/or degraded regions; projected climate and/or human impacts; pollution loadings; and regions coincident with other IGBP Core Projects (Dearing 2005; Dearing et al. 2006b).

Two further aspects of international environmental change research would be addressed by these syntheses. First, a full inventory of past environmental processes and human–environment interactions within a region could make major contributions toward ranking subsystem sensitivities to particular combinations of past climate and human impact, and help to underpin other attempts to characterize functional human–environment units (Lüdeke et al. 2004; Lambin et al. 2001) where crucial long-term trajectories may be lacking. Success may require new methods for ranking the sensitivities of modern ecosystems based on long-term histories, utilizing, for example, system energetics, "distances" from pre-impact states, and rates of change in key process variables (e.g., Dodson and Mooney 2002). Second, improved ability to scale-up local case studies through coordinated regionalization will allow generalization or transfer of findings across larger geographical areas and ecosystems, giving compatibility with the scale of real and modeled environmental drivers (e.g., administrative areas, downscaled GCM outputs). An example of where this has already been attempted is the biomization of pollen diagrams (Prentice et al. 1996) used to produce global vegetation/biomass maps for chosen time periods (e.g., BIOME 6000). For some processes, it may provide the means to upscale to the global scale in order to compute new global process records, such as a Holocene record of global deforestation or sediment flux to the global coastline.

Key questions: How do we prioritize which regions or ecosystems need new and dedicated research programs to establish historical perspectives? How do we move from viewing humans as "stressors" to viewing them as "actors" in reconstructed environments?

SIMULATING FUTURE HUMAN–ENVIRONMENTAL INTERACTIONS

However powerful the insights gained from history, there will always remain gaps in the record and uncertainty with regard to narrative description and explanations. However detailed and penetrating, a full analysis of available past records will not be able to generate alternative and testable strategies for sustainable management. Enhanced levels of confidence in understanding human–environment system behavior are therefore most likely to come through mathematical simulation modeling. A key measure of the quality of our theoretical understanding of socioenvironmental systems has to be the extent to which we can simulate reality. Simulation modeling is therefore a key complement to empirical studies of human–environment interactions and may be used together with historical and paleoenvironmental data in different ways. For example, model–data comparisons are often used to isolate an individual forcing by controlling for other variables. This is a particularly valuable approach in human-interaction studies where a common issue is how to "isolate" the effect of land-use or land-cover change, forced by human actions, from the impact of climate change. However, sufficient empirical evidence now exists to show that human–environment interactions are complex and essentially nonlinear, characterized by the growth of relatively long-lived emergent phenomena at all scales: social institutions, social structures, ecosystems, and geomorphic forms. Thus, ideally, new simulation models should allow complex and macroscale emergent phenomena to arise from microscale interactions within an evolutionary framework. Such models would be run forward from the past and be validated against historical time series before simulating future systems under different scenarios of climate, environmental, and societal change: a methodology utilized in disentangling the individual and combined roles of alternative climate drivers of 20th-century global warming.

One promising approach would be to build on recent developments in spatially explicit cellular automata-type models (Dearing 2006). These models can be classified according to the level of functional rules used, the means by which and the timescales over which the model is validated, and the extent to which the activities of human agents and decision making are made explicit. As with integrating case studies, there is a logical dichotomy of approaches depending on how human actions are captured. For example, biophysical cellular models in catchment hydrology use low-level rules (Figure 2.1), long timescales ranging from decades to millennia, but with limited inclusion of human agents. Environmental changes are expressed as sequential maps or as time series of outputs from the whole catchment. In such examples, human agents are brought into play mainly as stressors to set future scenarios for hard engineering options or land-use change. In contrast, the inclusion of humans as agents makes use of high-level rules and often a restricted history. Limitations of cellular automata modeling include the constraints imposed by the simplicity of cellular models and how this simplicity has to be compromised to accommodate action-at-a-distance social processes. Beyond these problems, there are ongoing developments that are likely to see improved cellular-based modeling, through integration with GIS, macrolevel models and, in ecology, developing individual-based approaches. A recent variant of the cellular automaton approach provides a compelling spatiotemporal simulation of the global population through the Neolithic transition (Wirtz and Lemmen 2003), with validation through the archaeological record. Perhaps most headway toward the development of integrated socioenvironmental models has been gained through the development of agent-based models (ABMs), particularly among the international land-cover and land-use community (e.g., Parker et al. 2001). The emphasis in ABMs tends to be on social and economic drivers of land use rather than the coevolution of interactions between humans and environmental processes, and validation has largely come through sequential maps of land cover derived from satellite imagery since the 1960s. For example, projections of global land use for different socioenvironment scenarios by the Millennium Ecosystem Assessment (2005) utilize observed changes in global crop and forest areas since 1970 with modeled socioenvironmental scenarios until 2050. Thus, while these approaches are of great value in strategic planning, they have yet to exploit the fully reconstructed history of human–environment interactions that is often available.

Key question: How do we improve the integration of socioeconomic and biogeochemical processes within the same dynamic simulation modeling framework?

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