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Evolution of the human-environment relationship

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Introduction

A full understanding of the challenges facing humanity requires knowledge of the evolution of the roles of technology, population expansions, cultural mores, climate, disease and warfare in changing human attitudes and responses through time. This is especially the case if the past is to be used in more sophisticated ways than as a simplistic analogue of projected future conditions. We also know that assessment of the sensitivity or vulnerability of modern landscapes and ecosystems to future human activities and climate can be greatly improved by knowing the rates and directions of past trajectories in key processes such as land cover, soil erosion and flooding, observing how thresholds have been transgressed and deducing the natural or pre-impact patterns of environmental variability. Already, such knowledge is leading to the improved formulation of resource management strategies.

The present nature and complexity of socio-ecological systems are heavily contingent on the past; we cannot fully appreciate the present condition without going back decades, centuries or even millennia. As we are witnessing today with global warming, current societal actions may reverberate, in climatic and many other ways, for centuries into the future. As such, there is the real danger that our visions of the future are becoming unconstrained by knowledge of what has already occurred, at least in part because information about human-environment interactions in the historical past has not been well organized for this purpose or properly utilized. If we continue to operate in ignorance or denial of this integrated historical understanding, we run the very real risk of mirroring the paths of the Easter Islanders, the Classic Maya or the Roman Empire. But if we can adequately learn from our integrated history, we can create a sustainable and desirable future for our species.

Integrating Human and Natural History

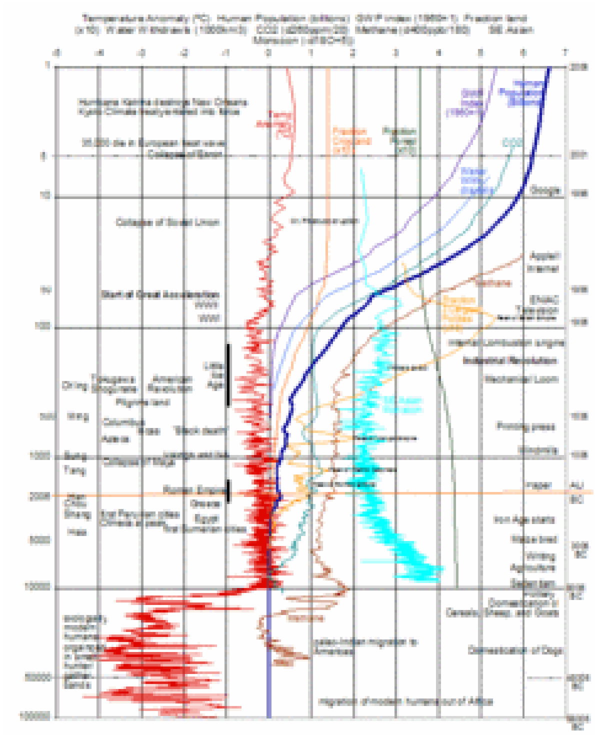

Figure 1. Selected indicators of environmental and human history.

While this depiction of past events is integrative and suggestive of major patterns and developments in the human-environment interaction, it plots only coincidence, not causation, and must, of course, be supplemented with integrated models and narratives of causation. In this graph, time is plotted on the vertical axis on a log scale running from 100,000 years before present (BP) until now. Technological events are listed on the right side and cultural/political events are listed on the left. Biologically modern humans arose at least 100,000 yrs BP and probably more than 200,000 – 250,000 yrs BP, but sedentism (and later agriculture) did not start until after the end of the last ice age and the dramatic warming and stabilization of climate that occurred around 10,000 yrs BP, at the Pleistocene/Holocene boundary. Northern Hemisphere temperature can be reconstructed for this entire period from ice core data, combined with the instrument record from 1850 until the present. Human population fluctuated globally at around 1 million until the advent of agriculture, after which it began to increase exponentially (with some declines as during the black death in Europe) to a current population of over 6 Billion. Gross World Product (GWP) followed with some lag as people tapped new energy sources such as wind and eventually fossil fuels. Atmospheric carbon dioxide (CO_2) and methane (CH_4) closely track population, GWP and energy use for the last 150 years. The start of the "Great Acceleration" after WWII can be clearly seen in the GWP, population, and water withdrawal plots. The plot for "SE Asian Monsoons" shows the long-term variability in this important regional precipitation pattern. Patterns in land use are shown as the fraction of land in forest, cropland, and in the "three largest polities". This area in large "polities" or sovereign political entities has increased over time, with significant peaks at the height of the Roman, Islamic Caliphate, Mongol, and British empires. Currently the three largest polities are Russia, Canada, and China, together covering about 32% of the land surface. At the peak of the British empire in 1925, the 3 largest were Britain, Russia, and France, together covering about 53% of the land surface before the independence of British and French colonies.

Human history has traditionally been cast in terms of the rise and fall of great civilizations, wars, specific human achievements, and extreme natural disasters (e.g. earthquakes, floods, plagues). This history tends to leave out, however, the important ecological and climatic context and the less obvious interactions which shaped and mediated these events (Figure 1). Socio-ecological systems are intimately linked in ways that we are only beginning to appreciate. Furthering the research agenda on such systems poses great methodological challenges. Events can be selectively chosen from the past to support almost any theory of historical causation. While Figure 1 puts a range of environmental indicators and historical events together on the same graph, it can show only coincidence, not causation. The causal links are more complex and not self-evident. For example, water availability is related to complex developments resulting from social organization, engineering and climate (see the Roman Empire period on Figure 1). While we use the timeline to illustrate the parallels between human and environmental change, the complex web of causation that resulted in the sequence of events depicted cannot be easily represented on such a graph.

Human societies respond to environmental (e.g., climate) signals through multiple pathways including collapse or failure, migration and creative invention through discovery. Extreme drought, for instance, has triggered both social collapse and ingenious management of water through irrigation. Human responses to change may in turn alter feedbacks between climate, ecological, and social systems, producing a complex web of multidirectional connections in time and space. Ensuring appropriate future responses and feedbacks within the human-environment system will depend on our understanding of this past web and how to adapt to future surprises. To develop that understanding, we need to look at multiple time and space scales.

At millennial timescales different cultural elements (social and political structure, traditional practices, and beliefs, to name a few) enable or constrain responses. Even global-scale events (climate change, major volcanic activity, etc.) do not affect all regions at precisely the same time or with the same intensity. Models (conceptual and computational) of how societal characteristics and environmental conditions affect the resilience of socio-ecological systems are needed. Processes important for the study of resilience, vulnerability, or sustainability include: the degree of rigidity of social, economic, and political networks; the diversity of biophysical resources and of human resourcefulness; the development of complexity, costliness and ineffectiveness in problem-solving; and the cyclical expansion/contraction and geographical shift in the center of accumulation with periodic declines and “dark ages” when external limits to social reproduction are reached. Simple, deterministic relationships between environmental stress, (for example, a climatic event), and social change are inadequate. Organizational, technological and perceptual mechanisms mediate the responses of societies to environmental stress, and there are also time-delays to societal responses.

More recent changes in the human-environment relationship, such as accelerated globalization and global environmental change, have deep roots in humanity’s relationship with nature over the past millennium. While we often associate the term “global change” with the greenhouse gas warming evident in the last decade, socio-ecological changes at continental and global scales were put in motion over at least the past 1000 years (e.g. many European landscapes looked much like they do today far earlier than this). Important phenomena include a rise in human population, the strengthening of nation states, the global transfer of inventions and values, the beginning of industrialization and the rise of global communications, and associated with these the dramatic modifications of land use and biodiversity, hydrological and energy flows, and key ecological processes.

The last 1000 year period is also interesting because it's a period when broad swings in temperature as well as clusters of extreme weather events arguably changed the trajectory of history. The fourteenth century in Europe saw the end of the Medieval Warm Period. Particularly during the period from 1315–1317 Western Europe witnessed a combination of rainy autumns, cold springs, and wet summers that led to crop failures and a dramatic slowdown in urban expansion. These early Europeans were further subjected to the last major locust invasion (1338), the "millennium flood" (1342), and the coldest summer of the millennium in 1347. From 1347 to 1350 the "Black Death" devastated populations. The clustering of extreme events in the fourteenth century fundamentally undermined social order and was a key factor in a major wave of anti-Semitic pogroms and systematic discrimination. In the same period, agricultural land was abandoned and forests increased. Many would argue that it also led to the end of the feudal system, improved land and employee rights and, through the enlightenment period, paved the way for the modern age. The Little Ice Age affected food availability in many parts of Europe, leading to the development of technological, economic and political strategies as ways to reduce vulnerability. The exceptional 1788-1795 ENSO event reverberated around the world in places as far afield as the first British colonial settlement in Australia, the Indian monsoon region, Mexico and western Europe (13). Thus, the present nature and complexity of socio-ecological systems are heavily contingent on the past; we cannot fully understand the present condition without going back centuries or even millennia into the past. An important implication is that societal actions today will reverberate for centuries into the future in climatic and many other ways.

Turning to the more recent past, the 20th century witnessed several sharp changes in the evolution of socio-ecological systems, at both global (two world wars and the Great Depression) and regional (e.g. the failure of Soviet farming, its reliance on grain from the U.S., and subsequent collapse as a polity) discontinuities. Variations in the growth rate of carbon dioxide (CO_2) in the atmosphere occurred in response to both climatic controls over land-atmosphere-ocean fluxes (for example, CO_2 increases more rapidly in El Niño years because of climate effects on terrestrial ecosystems) and political events (the growth rate slowed during the 1970s oil shock and after the breakup of the Soviet Union because of changes in fossil fuel use). The 20th century also marks the first period for which instrumental records of many environmental parameters have become available and for which detailed statistical records of many human activities have also been collected.

The most remarkable phenomenon on Earth in the 20th century was the "Great Acceleration," the sharp increase in human population, economic activity, resource use, transport, communication and knowledge–science–technology that was triggered in many parts of the world (North America, Western Europe, Japan, and Australia/New Zealand) following World War II and which has continued into this century (Figure 1, 14, 15). Other parts of the world, especially the monsoon Asia region, are now also in the midst of the Great Acceleration. The tension between the modern nation-state and the emergence of multinational corporations and international political institutions is a strong feature of the changing human-environmental relationship. The "engine" of the Great Acceleration is an interlinked system consisting of population increase, rising consumption, abundant cheap energy, and liberalizing political economies.

Globalization, especially an exploding knowledge base and rapidly expanding connectivity and information flow, thus acts as a strong accelerator of the system. The environmental effects of the Great Acceleration are clearly visible at the global scale—changing atmospheric chemistry and climate, degradation of many ecosystem services (e.g., provision of freshwater, biological diversity, etc.), and homogenization of the biotic fabric of the planet. The Great Acceleration is arguably the most profound and rapid shift in the human–environment relationship that the Earth has experienced.

Towards the end of the 20th century, there were signs that the Great Acceleration could not continue in its present form without increasing the risk of crossing major thresholds and triggering abrupt changes worldwide. Transitions to new energy systems will be required. There is a growing disparity between the wealthy and the poor, and, through modern communication, a growing awareness by the poor of this gap, leading to heightened material aspirations globally—a potentially explosive situation. Many of the ecosystem services upon which human well-being depends are depleted or degrading, with possible rapid changes when thresholds are crossed. The climate may be more sensitive to increases in carbon dioxide and may have more inertia than earlier thought, raising concerns of abrupt and irreversible changes in the planetary environment as a whole.

From the past, we know there are circumstances in which a society is resilient to perturbations (e.g., climate change) and there are circumstances in which a society is so vulnerable to perturbations that it will be unable to cope. The evolutionary biologist and biogeographer Jared Diamond identifies what he considered to be the 12 most serious environmental problems facing past and future societies—problems that often have led to the collapse of historical societies:

1. Loss of habitat and ecosystem services;
2. Overfishing;
3. Loss of biodiversity;
4. Soil erosion and degradation;
5. Energy limits;
6. Freshwater limits;
7. Photosynthetic capacity limits;
8. Toxic chemicals;
9. Alien species introductions;
10. Climate change;
11. Population growth; and
12. Human consumption levels.

More importantly, Diamond, and several others before him, have emphasized that the interplay of multiple factors is almost always more critical than any single factor. Societies on the edge become brittle and lose resilience (including the ability to adapt social values to new circumstances) making them more susceptible to the impacts of potential perturbations of several kinds, including climate change, political corruption, war, and terrorism. In addition, what happens to any society is an emergent phenomenon, the result of individual decisions and conflicts in combination with environmental factors.

To make further progress, we need to construct a framework to help us understand the full range of human-environment interactions and how they affect societal development and resilience. We now have the capacity to develop this framework in the form of more comprehensive integrated models, combining approaches from geophysical, systems dynamics and agent-based models to implement approaches including simulation games and scenario analysis. Insights from modeling and analysis of the rich array of well-documented integrated historic events can be used to structure, test and further develop these models. A few examples of integrated dynamic historical simulation models now exist, including Turchin's work on historical dynamics with several case studies on everything from the rise and fall of religions to imperial expansion and dynastic cycles, and agent-based simulation models of the growth and decline of the Anasazi in the Southwestern U.S.

The fundamental question we need to ask is: *how does the history of human-environment systems generate useful insights about the future?* In trying to gain insights from the past, tests of alternate models must play a central role. While in the natural sciences, alternate models can be tested against numerical data sets, in testing models (conceptual and computational) of the human-environment system, we need to use the full range of data from numerical time series to historical narratives. We also need to develop new skills and techniques for integrating these disparate data sources of fundamentally different characters. The extent to which we can (or cannot) reproduce historical behavior in socio-ecological systems determines the confidence we can place in future projections. An array of different modeling approaches, some focused strongly on the biophysical aspects of the Earth System (e.g., General Circulation Models of climate) and others centered on socio-economic aspects (e.g., models of the global economy) have been developed for projecting Earth System behavior into the future. Integrated models at multiple spatial and temporal scales have also been developed. Recognizing that no single approach has intrinsic advantages, a strategy of comparing, synthesizing and integrating the results from different modeling approaches is probably more productive, paralleling the use of multiple working hypotheses. Developing an integrated historical narrative and database will allow testing of alternate models, more rapid evolution of paradigms, and better answers to IHOPE related questions.

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