Sustainability or Collapse:
What Can We Learn from Integrating the History of Humans and the Rest of Nature

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Abstract

What is the most critical problem facing humanity at the beginning of the 21st century? Global pandemics, including AIDS? Global warming? Meeting global energy demands? World-wide financial collapse? International terrorism? The answer is all of these and more. We live in an increasingly global system in which our most critical problems surpass regional and national borders. But because humans can influence the future, we cannot fully predict it. However, if we can adequately understand the past, we can use that understanding to *create* a better, more sustainable and desirable future. An emerging consensus is that simple, deterministic relationships between environmental stress, (for example, a climatic event), and social change are inadequate. Extreme drought, for instance, has triggered both social collapse and ingenious management of water through irrigation. Human responses to change may in turn feedback to the climate and ecological systems, producing a complex web of multidirectional connections in time and space. Integrated records of the human-environment system over millennia are needed as a basis for understanding the past and forecasting future changes.

We live in an increasingly global system in which our most critical problems go well beyond regional and national borders. When past civilizations collapsed, they were relatively isolated from other parts of the world. Today, in our interconnected global system, massive social failure in one region threatens the entire system. Can the current global system adapt and survive the accumulating, highly interconnected problems it now faces? Or will it collapse like Easter Island, the Classic Maya, the Roman Empire and other past civilizations, but on a larger scale? What can we learn from these past civilizations (and especially the ones that did NOT collapse) to help guide our current global society toward sustainability? To answer this question requires a new, more integrated, transdisciplinary understanding of the history of how humans have interacted with the rest of nature, how we currently interact, and what the options are for future interactions. Our phrasing of the previous sentence is quite deliberate. “Humans and nature” implies that humans are separate from nature, while “humans and the rest of nature” implies that humans are a part of nature, not separate from it. We emphasize “history” because much discussion of human-environment interactions has lacked a temporal dimension and as such is 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. If we continue to operate in ignorance or denial of this integrated historical understanding, we run the very real risk of going the way of the Easter Islanders. 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

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 climate context and the less obvious interactions which shaped and mediated these events (Figure 1). The capability to integrate human history with new data about the natural history of the earth at global scales and over centuries to millennia has only recently become possible. This integrated history could not have been accomplished even 10 years ago, and is a critical missing link that is needed in order to provide a much richer picture of how (and why) the planet has changed in historical times. Such an integrated history will advance research from various perspectives of the earth's history and possible futures and can be used as a critical shared data set to test integrated models of humans in natural systems.

Socio-ecological systems are intimately linked in ways that we are only beginning to appreciate (1-7). Furthering this research agenda poses great methodological challenges. Events can be plucked from the past to prove 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 evident in the figure. For example, water extraction 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 represented on such a graph. One challenge in linking human and environmental change is the development of a new integrated analytical modeling paradigm that reveals the complex web of causation, while allowing important emergent properties and generalities to rise above the details. Only with such a paradigm can we survey the past and test alternate explanations rigorously. To develop the integrated understanding we seek, a project of the global change research community has been initiated titled: "Integrated History and future of People On Earth (IHOPE)[1].

Long-term Goals of the IHOPE Project

The IHOPE project has three long-term goals:

1. Map the integrated record of biophysical and human system change on the Earth over the last several thousand millennia, with higher temporal and spatial resolution in the last 1000 and the last 100 years.

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[1] A first step toward the development of such an integrated history and future took place at a Dahlem conference in Berlin, Germany; June, 2005. IHOPE-Dahlem assembled an interdisciplinary group of 40 top scholars from a range of natural and social science disciplines with the goal of identifying mechanisms and generalizations of how humans have responded to and impacted their environment over millennial (up to 10,000 years ago), centennial (up to 1000 years ago), and decadal (up to 100 years ago) time scales as well as a glimpse of the future of the human-environment system. The IHOPE Dahlem Workshop was the kickoff event for a series of coordinated interdisciplinary research projects around the world that will allow us to learn about the future from the past.

2. Understand the socio-ecological dynamics of human history by testing human–environment system models against the integrated history.
3. Based on these historical insights, develop credible options for the future of humanity.

To achieve the ambitious goals of IHOPE multiple scientific challenges must be met. This includes linking disparate disciplinary approaches, cultures and models across the sciences and humanities, development of an appropriate information infrastructure to link such disparate information, and developing a common understanding and approach.

Evolution of the Human-Environment Relationship

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 feedback to the climate and ecological 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 (8-9).

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 or vulnerability 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 centre 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, changes of 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 European 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 years 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. 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.

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, in climatic and many other ways, for centuries into the future.

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 US, and subsequent collapse as a polity) discontinuities. Variations in the growth rate of CO_2 in the atmosphere occur 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/NZ) following World War II and which has continued into this century (10,11). 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, 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 thresholds and triggering abrupt changes. Transitions to new energy systems will be required. There is a growing disparity between wealthy and 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 when a society is resilient to perturbations (e.g. climate change) and there are circumstances when a society is so vulnerable to perturbations that it will be unable to cope (1, 5). 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. Although the future will differ from the past, 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.

The fundamental question we ask is: *how the history of human-environment systems generate useful insights about the future*? In trying to gain insights from the past, tests of alternate models 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 both numerical data and historical narratives and the understanding of how to combine them. 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 various scales have also been developed (12, 13). Rather any single approach having intrinsic advantages, comparing, synthesizing and integrating the results from different modeling approaches is a more robust strategy, paralleling the use of multiple working hypotheses. Developing an integrated historical narrative and data base will allow testing of alternate models, more rapid evolution of paradigms, and better answers to questions about the degree to which the future is predictable vs. contingent.

It has been said that if one fails to understand the past, one is doomed to repeat it. IHOPE takes a much more "hopeful" and positive attitude. If we can *really* understand the past, we can *create* a better, more sustainable and desirable future.

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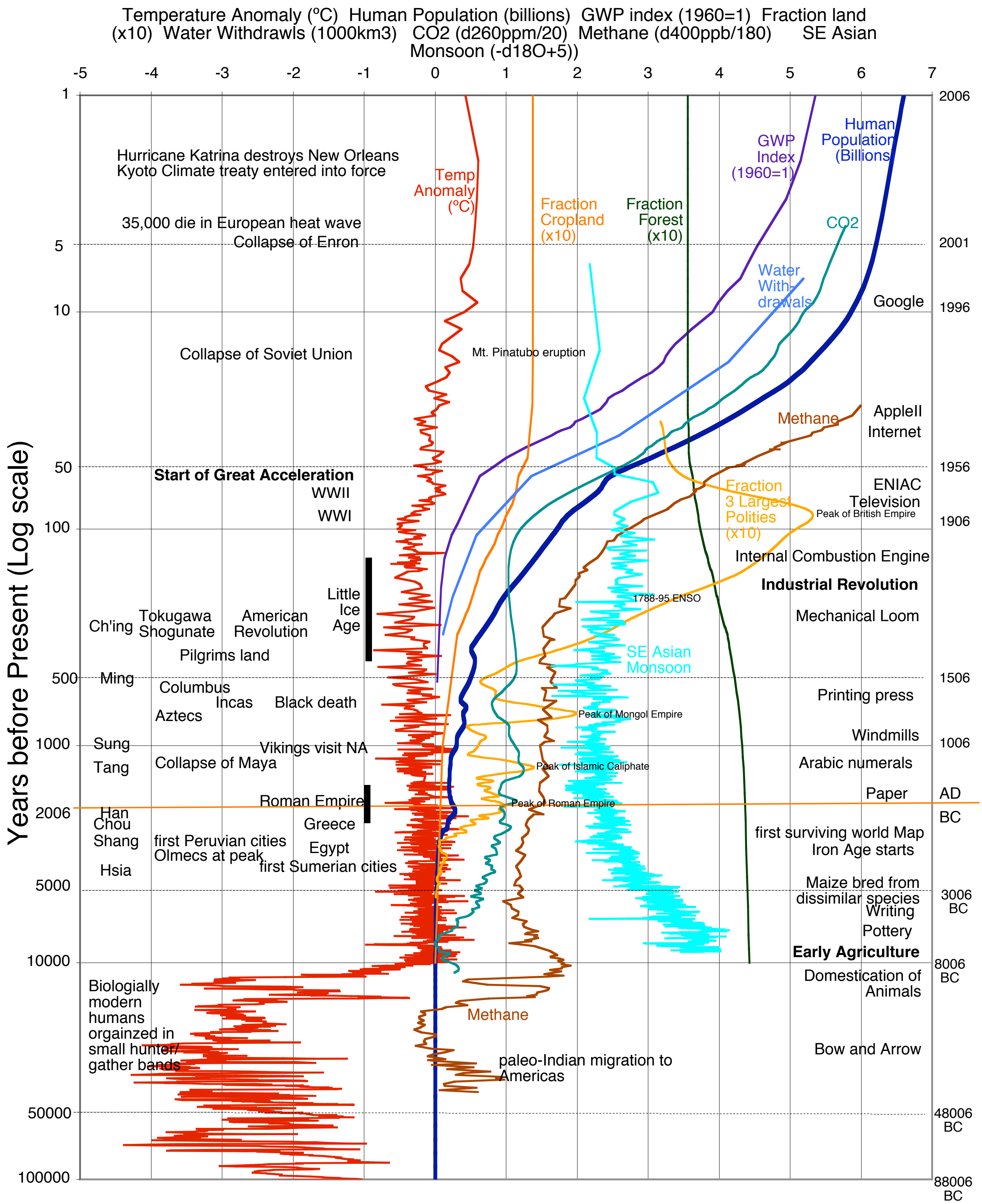

Temperature Anomaly (ºC) Human Population (billions) GWP index (1960=1) Fraction land (x10) Water Withdrawls (1000km3) CO2 (d260ppm/20) Methane (d400ppb/180) SE Asian Monsoon (-d18O+5))
Years before Present (Log scale)
-5 -4 -3 -2 -1 0 1 2 3 4 5 6 7
1
5
10
50
100
500
1000
2006
5000
10000
50000
100000
2006
2001
1996
1956
1906
1506
1006
AD
BC
3006 BC
8006 BC
48006 BC
88006 BC
Hurricane Katrina destroys New Orleans
Kyoto Climate treaty entered into force
35,000 die in European heat wave
Collapse of Enron
Collapse of Soviet Union
Mt. Pinatubo eruption
Start of Great Acceleration
WWII
WWI
Little Ice Age
Ch'ing
Tokugawa Shogunate
American Revolution
Pilgrims land
Ming
Columbus
Incas
Black death
Aztecs
Sung
Tang
Vikings visit NA
Collapse of Maya
Roman Empire
Han
Chou
Shang
Greece
first Peruvian cities
Olmecs at peak
Egypt
first Sumerian cities
Hsia
Biologially modern humans orgainzed in small hunter/ gather bands
paleo-Indian migration to Americas
Temp Anomaly (ºC)
Fraction Cropland (x10)
Fraction Forest (x10)
GWP Index (1960=1)
Human Population (Billions)
CO2
Water With-drawals
Methane
Fraction 3 Largest Polities (x10)
1788-95 ENSO
SE Asian Monsoon
Peak of Mongol Empire
Peak of Islamic Caliphate
Peak of Roman Empire
Methane
Google
AppleII
Internet
ENIAC
Television
Peak of British Empire
Internal Combustion Engine
Industrial Revolution
Mechanical Loom
Printing press
Windmills
Arabic numerals
Paper
first surviving world Map
Iron Age starts
Maize bred from dissimilar species
Writing
Pottery
Early Agriculture
Domestication of Animals
Bow and Arrow

Figure 1. Selected indicators of environmental and human history (raw data and sources are given in supplementary information). 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 40,000 yrs BP and probably more than 100,000 yrs BP, but agriculture did not start until 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 CO_2 and Methane 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.

Supplementary Information (to be posted on the web site)

What do we need to know?

Several key questions and directions for further research emerge from this initial synthesis, including:

1. What are the long term trajectories extending into the future, and the strength of past and current interactions? The analysis of socio-ecological systems around a range of time scales from millennial through centennial and decadal and into the future provides a rich basis for a deeper understanding of human-environment interactions. For example, in the millennial timescale, humans move from hunter-gathers to agriculture and civilizations, developing a stronger ability to manipulate nature, at least at the local and regional level. But the reverse direction of the human-environment relationship – impacts of natural environmental variability and change on human societies – was stronger and, for the most part, dominated the relationship. By the centennial timescale, the two-way interactions between humans and the natural world, especially at larger spatial scales, had become more balanced. The imprint of humans at large regional scales was now clearer and the first signs of significant global impact were appearing. The Great Acceleration – the rapid expansion of human activities and impacts since about 1950 - carries this trend dramatically forward. We are now a global geophysical force that rivals the great forces of nature in many aspects. A feature of the Great Acceleration that points towards the future evolution of socio-ecological systems is the fundamental role of technology in mediating the interactions between humans and the rest of the natural world.

2. How connected are our activities? Another way of looking at these trends in the human-nature relationship is to contrast the connectivity of humans to nature with the size and power of the "human enterprise". One end point is represented by hunter-gatherers, who are strongly connected to nature but are small in numbers and have a weak capacity to impact the natural world at large scales. Agrarian societies evolving into the early civilizations represent an interesting mid-point, in which the human enterprise had become large enough and active enough to significantly impact the natural world at more than local scales. On the other hand, early human civilizations still retained a strong connection to the natural world through their direct and visible reliance on ecosystem services for their success and well-being. The other end point is the current highly technological, globalizing society, which is less connected to nature than ever before but also more numerous and economically powerful than ever before. The human enterprise has grown to enormous size and strength. It can (and does) insulate people from both the direct knowledge and experience of the ecosystem services on which we all still ultimately depend and from the many global-scale impacts of the burgeoning human enterprise on the natural world.

3. What are the fast/slow controls on adaptive cycling? Insights can also be obtained from examining the evolution of socio-ecological systems from a particular time perspective, but in a broader context. For example, a particular strength of the millennial-scale analysis is that it addresses the importance of the long-term evolution of societies.

The analysis is able to go beyond shorter-term historical cycles to multiple completed cycles of the rise, spread and eventual decline of civilizations. This raises some intriguing questions that would not necessarily arise from examining shorter time scales. How do societies re-organize after a decline or collapse? What are some of the more important "slow processes" (c.f. resilience perspective in the next section) that are barely discernible at shorter time scales but can dramatically affect the success or failure of socio-ecological systems? Are there particular points in the evolution of socio-ecological systems at which slow processes flip from being adaptive to being destabilizing?

4. Given contingency, what are the key antecedent controls on modern and future system states? Finally, examining socio-ecological systems across multiple time scales can identify the antecedents further back in time of major phenomena that occur in a particular era or time. A good example is the Great Acceleration (ca. 1950 to the present). The phenomenon is well described from a decadal perspective but the antecedents, especially in the socio-economic sphere (e.g., globalization, fossil fuel use, increased information flow, etc.), go well back into the centennial timeframe. Examining the Great Acceleration from a longer time perspective also uncovers the still-born Great Acceleration of the late 19th and early 20th centuries. Most of the ingredients for an acceleration of the human enterprise were apparent, but the decline and collapse of many countries and regions in the 1915-1945 period due to economic depression and world wars delayed the phenomenon for a half-century. On the other hand, this could also be interpreted from a resilience perspective as two adaptive cycles of the modern, globalized socio-ecological system.

Common themes across time scales

Several common themes are also emerging from this initial synthesis, including:

1. There is a general movement away from simple causality or cause-effect paradigms as a credible explanatory framework. Multiple cases studies have revealed diverse social responses to similar climate changes. There is a strong consensus that we are dealing with complex, adaptive, integrated, socio-ecological systems that often defy simple cause-effect logic in their behavior. Complex systems may exhibit multiple interactions between apparent drivers and responses where the direction and strength of interaction are not necessarily explicable in terms of simple, direct and linear causative links; there may be internal dynamics that drive system changes. Studies therefore will need to encourage the use of concepts from complexity science, including linear and nonlinear dynamics, feedback, thresholds, emergence, historical contingency and path dependence, and the application of nonlinear simulation tools, spatially explicit and agent based models to simulate relevant phenomena (c.f. Young et al. 2006)

2. A dichotomy often arises between explanatory power and predictive success. Could anyone have predicted the collapse of the Classic Maya civilization a century before it occurred? Could anyone in 1900 have predicted the evolution of human societies, especially their relationship to the natural world, through the 20th century? In both of these (and other) cases, we have impressive explanatory power in describing what

unfolded, but that does not yet translate into an ability to predict the future trajectories of complex socio-ecological systems. In fact, our increasing ability to influence the future makes it more difficult to predict it. A better way to look at it is that we can use a deeper understanding of the past to help us *create* a better future, rather than to *predict* the future.

3. While human actions often succeed in reducing specific risks, these efforts also created qualitatively new risks at a larger spatial scale and/or a longer timeframe. The notion of "risk spirals" points to a dangerous positive feedback loop. As human societies become more complex and interconnected at every scale, it becomes more costly to deal with shocks from the natural world and, ironically, in the process of making themselves more complex, societies inadvertently and (often) unknowingly change their interaction with natural systems in ways that make these systems more vulnerable to abrupt changes or extreme events.

4. A critical aspect of any society is the trade-off between short-term production and long-term resilience or sustainability. These values are often in conflict. In general, there is a need to keep production systems well below theoretical carrying capacity to avoid a severe drop in resilience. Cultural traditions and social networks have played an important role in building long-term resilience by acting as a brake on short-term production that would damage or diminish resilience and long-term sustainability. During the Great Acceleration, many of these cultural traditions have faded and, due to competitive forces in almost all arenas of human activities, we may be adversely affecting resilience and long-term sustainability.

5. The role of feedback processes is crucial in complex socio-ecological systems (and a big reason why simple cause-effect paradigms often have little explanatory power). A potentially dangerous positive feedback loop (a "risk spiral") was mentioned above. But are there counteracting negative feedback loops that can generate increased resilience in socio-ecological systems? For example, is there a general self-regulating feature in human civilizations that acts to lessen environmental stresses when they become apparent? Are the "decelerating trends" we see now in some aspects of the contemporary human enterprise part of a self-regulating feature that will slow the Great Acceleration?

6. "Collapse" is a central concept in developing an integrated understanding of the past, and probably the most critical question facing current society, but its use needs to be refined to reflect the variety of socio-ecological responses to environmental changes. We need to differentiate between radical environmental alterations, radical institutional changes, and radical demographic losses in a region. The first or second in isolation may be better thought of as a transformation, yet when combined with the third seems to fit the term collapse.

Research challenges

To address these issues there are a set of research challenges that will need to be met regardless of the time scale or particular aspect of interest. These include:

1. Data on the behavior of socio-ecological systems vary enormously in quality, selection, interpretation, resolution, dating/chronologies, and unevenness (c.f. Costanza 2006). The amount of data rises dramatically as we approach the present, and this could easily distort analyses.

2. There is an issue regarding the balance between social and environmental data. In the longer time frames there seems to be more information on societal characteristics and less on the nature of environmental change. This makes it difficult to explore the types or characteristics of environmental variability or change to which various societies are especially vulnerable.

3. There is often a dichotomy in research approaches – reductionist v. systems-oriented – that can lead to tension within research teams and thus pose major challenges to interdisciplinary research projects. Studies need to adopt a range of alternative explanatory frameworks, embracing conventional scientific positivist approaches as well as discipline-specific protocols. However, a key issue is the evaluation of explanations and the realistic appreciation of uncertainty. How we learn from the past takes different forms (c.f. Dearing 2006): the type and range of data sources, the different disciplinary conventions and the nature of conceptual and predictive models used imply that there is no single method to determine the quality and certainty of explanations. In some contexts, it may be possible to utilize a hypothesis-testing approach, but in others the ability to falsify hypotheses may be severely restricted. In many historical studies, the use of approaches that argue from the perspective of mutual internal consistency or weight of evidence may be more appropriate.

4. In analyzing socio-ecological systems or simulating their behavior into the future, biophysical laws governing aspects of nature can give an "envelope of regularities" in projections or analyses (but complex natural systems can also have strong nonlinearities). This broad envelope of regularities can define the "environmental space" within which human societies operate, but contingent events, which are difficult or impossible to predict, often determine the trajectories of socio-ecological systems within that space and are thus crucially important to how the future will actually unfold. We need to know what the range of possibilities are, as we continue to create the future.

5. Comprehensive models of the Integrated Earth System (or humans-in-nature) are still in their infancy and have a long way to go (c.f. Costanza et al 2006). Nearly all models begin with a strong emphasis on either the natural or the human part of socio-ecological systems. There is a strong need for more balanced, hybrid approaches that can take on the research challenges outlined above. The insight, data and models generated from the close collaboration of environmental historians, archeologists, ecologists, modelers and many others will allow the construction and testing of new ideas about humans' relationship with the rest of nature. It will also allow the calibration and testing of a new

generation of integrated global earth system models that contain a range of embedded hypotheses about human-environment interactions.

We are poised to address a number of critical research and policy questions affecting the life of all humans on earth. It is fitting at this point to conclude not with answers, but with questions. The big, general questions for the IHOPE activity (consistent with the long-term goals stated earlier) can be summarized as the following:

- **What are the complex and interacting mechanisms and processes resulting in the emergence, sustainability or collapse of socio-ecological systems?**
- **What are the pathways to developing and evaluating alternative explanatory frameworks, specific explanations and models (including complex systems models) using observations of highly variable quality and coverage?**
- **How do we use knowledge of the integrated history of the earth for understanding and *creating* the future?**

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