

Synthesis

Toward an Integrated History to Guide the Future

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ABSTRACT. Many contemporary societal challenges manifest themselves in the domain of human–environment interactions. There is a growing recognition that responses to these challenges formulated within current disciplinary boundaries, in isolation from their wider contexts, cannot adequately address them. Here, we outline the need for an integrated, transdisciplinary synthesis that allows for a holistic approach, and, above all, a much longer time perspective. We outline both the need for and the fundamental characteristics of what we call “integrated history.” This approach promises to yield new understandings of the relationship between the past, present, and possible futures of our integrated human–environment system. We recommend a unique new focus of our historical efforts on the future, rather than the past, concentrated on learning about future possibilities from history. A growing worldwide community of transdisciplinary scholars is forming around building this Integrated History and future of People on Earth (IHOPE). Building integrated models of past human societies and their interactions with their environments yields new insights into those interactions and can help to create a more sustainable and desirable future. The activity has become a major focus within the global change community.

Key Words: *agency; anthropocene; backcasting; causality; contingency; holistic approach; integrated history; long-term perspective; resilience; social and ecological systems*

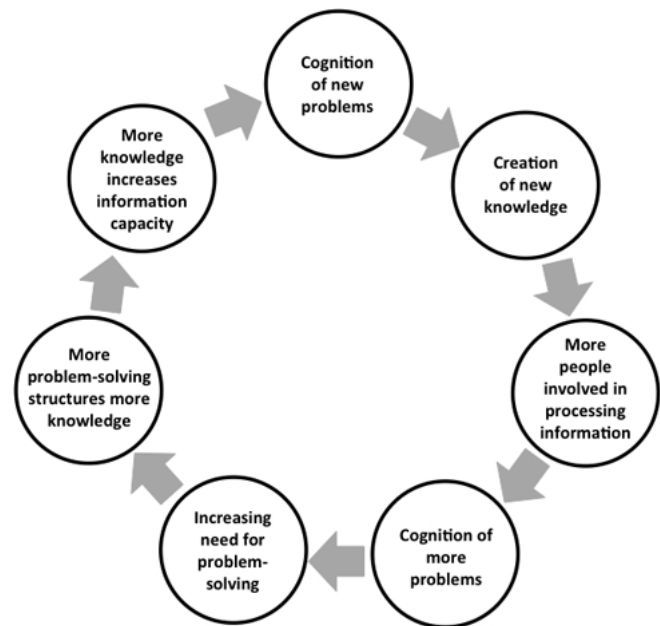
INTRODUCTION

In the past, humans have often devised solutions to perceived challenges by isolating those challenges from their wider context, and this dissociation has led to cascades of unanticipated consequences. The invention of the internal combustion engine led to the increased use of fossil fuel, atmospheric pollution, a society dependent on a limited resource, global climate disruption, and the opening up of the Arctic to further oil exploration, etc. Our challenges in the domain of security result from centuries of extractive and hierarchical global relations, along with religious intolerance and racism, which have exacerbated political, religious, and cultural differences and obscured our shared humanity. The current challenges in global economics derive from the isolation of finance and commerce from the broader economy of nature and society.

SOCIETY'S NEED FOR A DIFFERENT KIND OF KNOWLEDGE

How have we come to this point? Figure 1 shows this process, as one where the knowledge of the social-ecological system (of which we humans are part) has expanded rapidly, as have our technical prowess, the speed of change, the extent of interactivity among people, and the complexity of the challenges that we face.

Fig. 1. The process of knowledge creation.



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In the last two hundred years, this process has accelerated many times faster than ever before (McNeill 2001), so that humans now influence the environment at a global scale (Crutzen and Stoermer 2000, Steffen et al. 2007). The increase in our knowledge about the dynamics of, and our role in, the environment has not been able to keep pace with the increase of the unknown impact of our actions on that environment because the former is directly related to the (relatively small) number of dimensions that we recognize at any one time, whereas the latter concerns the (almost infinite) number that we do not. If our knowledge may have increased geometrically, the unknown is more likely to have increased exponentially (Westley et al. 2011).^[1]

As a result, we urgently need new approaches. These approaches need to combine several changes in perspective that, taken together, fundamentally modify our understanding of the social-ecological processes we are currently observing around us. Some of the most important ones are summarized here.

- The “reductionist” approach, developed in the sixteenth and seventeenth centuries, has been adequate for simple physical, chemical, and even biological systems, underpinning many of the fundamental advances of the Scientific Revolution. However, in the broader context of environmental and societal systems, it has been inadequate, setting the stage for the deluge of unanticipated consequences noted above that seem now to overwhelm us. We urgently need to develop and implement a holistic approach that focuses from the outset, and throughout the whole research process, on the whole complexity of the challenges facing us, rather than decomposing them. As part of that move, we need to break down the “great wall of dualism” (Evernden 1992:90) that has led to the current disconnect between the natural sciences on the one hand and the humanities and social sciences on the other.
- The twentieth century social sciences, driven by an increasing reliance on precise, quantitative measurements that have only been available for the last two centuries, have often overlooked long-term historical constraints and legacies in favor of short-term, often transient, dynamics. They are thus overlooking the complex dynamics that are only observable over the very long term (centuries, millennia, or even longer periods), or excluding from consideration second-order dynamics (that is, changes in the nature and manifestation of change itself), such as shifts in boundary conditions. Moreover, short-term empirical models encompass only a small subset of all conceivable system states and provide a perspective that is highly biased toward the current state of the system. Perhaps most importantly, such models by definition cannot handle the supercreativity of which humanity is occasionally capable.

- Of critical importance in transforming our thinking has been the recognition of the importance of history in the natural sciences, especially the life sciences. There, the focus has shifted from the study of “being” to that of “becoming” (Prigogine 1980). The new emphasis on change through time fundamentally transforms the relationship between structure and process—the process becomes the (dynamic) structure. In other words, we move from a perspective in which things exist, and are from time to time transformed, to a perspective in which there is perpetual transformation. This has removed a major barrier to integrating the natural, life, and social sciences with the humanities.
- Designing such a holistic approach also requires that we find ways to simultaneously observe patterns in many dimensions, a kind of observation for which traditional Western science is not very well equipped. One way to illustrate that is by reference to the difficulty of solving the so-called Rubik’s cube. One cannot get the cube “in order” (so that each side has one homogeneous color) by dealing first with one side, then the next, and so forth. The only way to arrive at “order” is by looking at the patterns (symmetries) on all sides simultaneously and not favoring any particular one at any time. This may be the most difficult of these challenges to meet.

The need for a new approach to understanding the relationship of the past, present, and future

We conclude from this that the way may be open for a new kind of approach to social-ecological phenomena, an approach that is not only (1) transdisciplinary and (2) focused on dynamics, but that also (3) takes the very long term into account. But we go one step further; we argue for a fourth essential element that is currently missing: paradoxically *we must focus our historical efforts on the future, rather than the past*. We must concentrate on learning about future possibilities from history.

So far, in our quest for understanding, we have looked at the past to gain the insights to deal with the future. This has served us well, as we have much to learn from the past. But we have not always used the resultant knowledge to its best advantage. We have based different (often discipline-dependent) chains of cause and effect on it, which seemed to lead (more or less linearly) to the present. The future was thus negotiated between uncertain and partial extrapolations from different visions of the past, and that is clearly suboptimal. For one, this perspective does not open us to alternative historical trajectories. More importantly, this view of the past does not help us understand our relationship with the future. It views the past and the future as “foreign lands”^[2], rather than as projections in different (temporal) directions from the present: the point at which we have the ability to modify the social-ecological evolutionary process to our advantage.

Moreover, the changes that are occurring in the world around us today are so rapid and so dramatic that this approach is becoming less and less effective. Knowledge of the past is still essential, perhaps even more essential than ever, but that knowledge must be used in a new way. As a result, many are becoming aware that one cannot understand the present, let alone forecast the future, simply by looking for causality in the past through analogues and then extrapolating toward the future. We wish to unpack different ways of relating the past to the present, and extend that relationship to include the future, as sustainability is, after all, a particular way of looking toward the future.

Dearing et al. (2010) recently distinguished two different ways of relating the past to the present: an analogue and an evolutionary approach. The former is the one we have traditionally used to relate past and present (Meyer et al. 1998, Costanza et al. 2007). We did so by comparing the past and the present as different case studies and looking for differences and similarities that might help us to better understand the present—how it came about, how it functioned, where past cases may serve as lessons for our own situation, and what we might do about undesirable aspects of that situation (e.g., Glantz 1994, Landes 1998, Tainter 1998, Gill 2001, Haug et al. 2003, Diamond 2005, Jackson et al. 2009; Jackson and Hobbs 2009). Though such analogues offer insights into differences and similarities between cases and sensitize the expert, they are by definition imperfect matches with the present, especially in view of the very rapid changes the earth system (including many societies) has undergone over the last century or so (Wescoat 1991, Meyer et al. 1998). As a result, many (but not all) such comparisons between past and present have engendered “just so” stories that alert their audience to potential dangers by overstressing similarities and underlying differences between the past and the present.

A different way to use such an analogue approach, which in our opinion would be more productive, would be to compare the different cases from a systemic perspective and to distill from such comparisons an improved general insight in the structure and dynamics of such Earth systems under different conditions. In that case, each case study serves as if it were a past experiment that, if followed over at least some part of its trajectory, provides knowledge about interactions between different components of such systems under different conditions. Such knowledge may permit us—once sufficient instances have been studied and their contexts, boundary conditions, structure etc. have been brought to bear on the actual dynamics observed—to begin to outline models of the interaction of a number of the more general processes to which such systems are subject (e.g., Zhang et al. 2007). We argue that, ultimately, such comparative approaches may enhance systematic assessments of postulated generalized complex system behaviors (Hibbard et al. 2010).

An excellent example of this approach was published a few years ago as a special issue in *Ecology and Society*. There, fifteen case studies from different parts of the world were compared to try and distill some general conclusions about the underlying system dynamics, in particular from a resilience/vulnerability perspective. In the last paper in that issue, Anderies et al. (2006) conclude that a theory of the dynamics of such complex systems is still some way off, but that in the meantime the comparison gives rise to ten tentative messages that can help improve policy and management, essentially emphasizing inclusiveness (neither ecosystems nor social systems can be managed in isolation), breadth of scope (include multiple scales, multiple temporalities from very rapid to very slow), diversity (as opposed to efficiency, even at cost, because in the long term it facilitates change), dynamic management and adaptive governance (rather than top-down management), inclusion of the mental models of stakeholder groups, acceptance of vulnerability, etc.

The evolutionary view of the past focuses on instances in which the present remains continuously and strongly connected to the past (Carpenter 2002). These connections address processes that operate over longer time scales than the examples mentioned above, are repeated regularly, and/or involve time lags, contingencies, emergent effects, or past legacies that are integral to the functioning of the contemporary and future system. By integrating observational, documentary, and reconstructed data, such studies provide a perspective that is critical to understanding all the elements of contemporary system dynamics, including the second order dynamics that are continuously modifying the boundary conditions within which such systems operate. Moreover, long time series of data and information may be the only way to confirm complex system behavior (e.g., alternative steady states, the adaptive cycle, contingent and emergent properties, and feedback mechanisms) in real-world systems. And, finally, this approach is much better suited to deal with the no-analogue situation that we presently face with respect to sustainability of humans in the Earth system.

Integrating past, present, and future

To move beyond this distinction between analogue and evolutionary approaches requires us to come to grips with yet another dimension of the relationships between past, present, and future: the differences in our use of the concept of time that are (mostly) implicit in the various ways we use the past to improve our understanding of the present and our anticipation of the future.

Our perception of the past is very different in nature from our perception of the future. Whereas we see and conceive the past by reducing the number of dimensions we observe in the present into a more or less coherent narrative in terms of causalities and certainties, we conceive of the future by amplification of the number of dimensions experienced in the

present, describing it in terms of alternatives, possibilities, and probabilities.

Western science, ever since the fourteenth century, has emphasized the need to solidify as much as possible the relationship between observations and interpretations. Thus, these interpretations linked the phenomena investigated to what was already in existence at the time they were observed, rather than to what was still to come (and therefore could not be observed). This kind of (natural) history seems to have been the predominant explanatory paradigm, at least until the eighteenth century (cf. Girard 1990). It necessarily emphasized the explanation of extant phenomena in terms of chains of cause and effect and (much later) an emphasis on feedback loops, in both cases linking the progress of processes through time to their antecedent trajectory.

The long-standing emphasis in science on linking present to past has therefore resulted in an approach that is essentially reductionist, achieving a sense of “reality” or “truth” by simplification. In particular, it has emphasized thinking about “origins” rather than “emergence”, about “feedback” rather than “feed-forward”, about “learning from the past” rather than “anticipating the future”. The inevitable corollary of that tendency is the fragmentation of our world view that we now see as one of the main handicaps in our attempts to understand the full complexity of the processes going on around us, and which has been institutionalized in the way academia is structured.

But it is, in our opinion, also responsible for much of the analogue way of using the past, in the sense that the “ex post” approach (relating the present to the past) is contradictory to the way time impacts on any kind of dynamics, which is essentially “ex ante” (moving from the past to the present and the future). This contradiction seems to have been resolved by disconnecting present and past, using an ex ante perspective on time for the past itself (looking at how things emerge in the period of the past studied), but relating our understanding of the past to the present in an ex post manner (i.e., looking for the origins of modern phenomena rather than their emergence).

The evolutionary approach presented by Beddoe et al. (2009), Dearing et al. (2010), and Caseldine and Turney (2010) does, to an extent, develop the ex ante perspective and is therefore better suited to understanding how the past engendered the present. But we will need to push the envelope further if we are to fully develop our capacities of anticipation. We need to find ways to not only juxtapose ex post and ex ante approaches to the present, but to combine them in an iterative process of interaction, so that we may move, artificially, backward and forward in time between past and future, via the present.

Integrating past, present, and future in this manner conflicts with our usual scientific approach because science is traditionally question-driven and aims to be “value-free”. It poses a question about the present, which generally takes the

following forms: “Why is it that?” or “Why are things this way, and not another?” And the answers to such questions lead to other, similar, questions, all of which contribute to knowledge, but only within a certain, often very restricted, paradigm. The new approach to building toward the future that we advocate here goes about things in a fundamentally different manner. It first outlines a number of possible trajectories from the present into the future that are compatible with our understanding of the past dynamics that have brought us to the present, and then asks the following question: ‘What is the future result we desire?’ Next, it attempts to approach that result by asking ‘What do we need to do to achieve that?’ It is solutions-focused. It looks at the inherent possibilities while trying explicitly to avoid what appears unsustainable, yet acknowledging that striking that balance will never be easy and will always involve both uncertainties and values (Table 1).

THE ROLE OF MODELS

Models are, in the words of the British historian R. G. Collingwood (1946) “tools for thought”—virtual or material tools that represent certain aspects of a reality that interest us, and that we can manipulate to gain different perspectives on that reality. But in the sixty years since that definition was coined, the rapid development of computing has placed at our disposal a set of such tools that we could never have imagined in Collingwood's time. These models can represent very complex dynamics in ways that allow us to look at them both ex post and ex ante. Such tools are now commonly used in a wide range of disciplines, including the natural, life, environmental, and economic sciences, and in contexts that range from academia to all the major financial and economic institutions such as the IMF, the OECD, governments, and the defense establishments of many countries, etc. They are the basis for all kinds of economic forecasting but are also at the core of much of climate science and a growing number of sustainability-related projects, such as the MEDALUS and ARCHAEMEDES programs of the European Union's research directorate (Brandt and Thornes 1996, van der Leeuw et al. 1998), the Millennium Ecosystem Assessment (2005), etc. Yet their power has not yet been fully exploited in the historical and archaeological sciences and has therefore not very frequently been brought to bear on the very long term.

We want therefore to first present examples of dynamic models that strive to integrate the first three dimensions outlined above: (1) transdisciplinarity, (2) describing dynamics, and (3) integrating the very long term. We will then discuss ways in which such models could be focused on the future, and end with a summary of advantages and disadvantages of this approach.

There are currently a limited, but growing, number of successful examples of this kind of model, spanning up to a thousand years. We will briefly describe two of the most successful and thought-provoking published examples: one for the early agricultural societies in part of the southwestern

Table 1. Integrating natural and human history.

	Natural history	Human history	Integrated history for the anthropocene?
Domain	Nature	Society	Environment (social-ecological interactions)
Time scale	Longer time scales	Shorter time scales	Integrated time scales
Focus	Causality	Human agency Contingency	Causality and agency interacting, envelope of contingency
Goal	Interpreting the past from the present Looking for origins in terms of natural laws	Interpreting the present from the past Looking for origins in terms of causal chains	Integrating past, present, and future Looking for emergence (in the systems sense) to understand the present and generate a better future
Process	Description, observation, and experimentation lead to explanation	Description, critique, analysis, and interpretation lead to insight and understanding	Description is the basis for modeling and understanding dynamics of the social-ecological system
Tools	Natural science discourse Palaeoenvironmental sciences, prehistoric archaeology Conceptual frameworks	Narrative and statistical discourse Classical and historic archaeology and documentary history Case studies as unique trajectories	Multiple discourses Integrated history of people and the environment Use case studies embedded within conceptual frameworks to generalize

United States (Kohler et al. 2007) and the other for the complex agricultural societies of the Near East and the transition to urbanism (Wilkinson et al. 2007).

A dynamic model of early agricultural society in the southwestern United States

The early agriculture model is an agent-based model (ABM), in which individual households are represented by agents, so that populations can interact and learn as households as well as groups. They operate in a virtual landscape that represents as closely as possible the real landscape of southwest Colorado at the time. The aim of the project was twofold: (1) to understand the co-evolution between these populations and their environments over a period of some seven hundred years, including the ways in which techniques and cultural characteristics have transformed that environment, and (2) to understand these societies as they are represented in the archaeological record, that is, to use the model as a tool to scientifically interpret various aspects of the archaeological record. Specifically, the project focuses on two questions: what drives the two cycles of colonization, growth, and depopulation in the area, and how can we explain the movement of people from small hamlets into larger community centers in each cycle. These questions are identical to those we pose ourselves about the present—the rise and fall of civilizations and the growth of urbanism.

We will leave the reader to go through the various building blocks of the model—estimates of productivity of various soils for maize under different climatic and hydrological circumstances; water availability, seasonality, and dependability; site location and size, demography and degree of aggregation; exchange of different materials between settlements; the role

of hunting and gathering under different circumstances, etc.

The model itself is one of household resource (game, maize, water, firewood, exchanges, etc.) use under the impact of both changing local environmental conditions (soils, elevation, water, climate, etc.) and the human use of those resources. Decisions about resource use balance the different kinds of resources in such a way that calories and proteins, water and firewood are at all times sufficient for the household. When they threaten to become insufficient, the household will move location to a point where more ample resources are available or can be captured at lower cost.

But the decision making of the individual households does not only change with circumstances; the model also includes cultural changes, that is, changes in the ways people are thinking about the decisions they have to make. In that sense, this model is a prime example of an effort to bring the environmental and the social and cultural dynamics together in the fulcrum where they actually meet: human perception and decision making. To do so, the model assumes a “belief space” that can change as a result of household experiences and their successes and failures. It includes situational, normative, topographic, historical (or temporal), and domain knowledge so that, for example, an agent has access to knowledge about the distribution of current agricultural production and topography, distribution of rainfall over the preceding period, and various agricultural techniques.

Finally, the model takes exchange into account. Exchange in societies such as these is not random. It is here modeled as occurring in three different kinds of networks—a kinship network, an economic network, and a hub network. The kinship network evolves as the system keeps track of births,

partnerships, and deaths, including the formation of new individual households by offspring of other households. As is ethnographically known for such networks, the exchange between households is generalized—the households do not keep track of these exchanges, assuming reciprocation over the long term, so that there are temporary imbalances in the exchanges. The economic network is driven by the desire to exchange things that are not directly available to one of the two parties involved in immediate exchange for something the other party does not have, so that there are no imbalances in this system. Exchange decisions in this system are thus essentially based on differences of availability. Exchanges in this network can give rise to debt and therefore affect households' social status and credibility and thus the connectivity of a household to other households. Those households that do well in the kin-based and/or economic network can hoist themselves socially higher and become members of the hub network—the network of those who are central to the community because of their wide network of exchange partners.

An important property of this model is the fact that by modeling exchanges in the networks, the society is not only modeled as a population of individual households, but also as a dynamically evolving society in which individual households participate differentially. And, in fact, that aspect of the model gives us one of the most interesting insights into the evolution of the system over the long term: the fact that over the period concerned, we can distinguish three cycles of growing interaction between households, followed by a breakdown of these exchange networks. Such breakdowns appear at least in this model to be the result of fluctuations in the availability of resources, because as resource availability diminishes, debt increases, so that fewer participating households are still trusted in the economic exchange network, which therefore decreases in size (number of nodes).

But over and beyond that, what is the use of this kind of modeling for the understanding of the long-term socioenvironmental dynamics of societies? First of all, we can use this approach to look at the dynamic interactions over the very long term of a much larger number of variables and processes than we can in any kind of traditional historical approach. In fact, we can in this manner build complex dynamic systems with emerging characteristics, and thus begin to develop the *ex ante* perspective on the dynamics involved. Secondly, we can experiment with the dynamics, in that we can change certain parameters or feedback loops that determine, for example, environmental conditions. Thirdly, we can experiment with the human responses to these changing circumstances, and in particular we can evaluate choices made against the options that may have been available but were not chosen, and thus have the agents learn from their mistakes. Fourthly, we can elicit some of the unanticipated consequences of human decisions and actions upon the

environment by looking at the long-term consequences of these actions. But most importantly, we can do all of these things for the same set of phenomena, so that we can really come to grips with their shorter- and longer-term dynamics, the contexts in which these played out, and the alternative scenarios that might have, but did not, occur.

Modeling the development of Early States in Mesopotamia

This model, like the last one, is an agent-based model, but here each agent is actually an individual as a member of a nested set of households and other social configurations. Moreover, it differs from the last one in subject matter and information available for the model, as well as in the software used (the Dynamic Information Architecture System, an object-based system developed by the Argonne National Laboratory in the United States). The systems modeled here are much more complex both in structure and in their relationship with the environment. At the same time, this model has actual social, geographical, written historical, and archaeological data available as input, so that it can take account of contemporary observations about society and the natural environment, and not only of extrapolations from modern observations. Finally, it also asks different questions (Wilkinson et al. 2007:175-176), including the following:

- How and why did third and fourth millennium BC cities in S. Mesopotamia grow to a greater size and complexity than those of rain-fed N. Mesopotamia?
- What was the dynamic trajectory of such settlements through time?
- How did the resultant cities respond to a capricious natural environment, and were they able to grow, survive, or decline under a range of social, environmental, and economic stresses?

These questions are again closely related to the ones we ask ourselves from a modern sustainability perspective, as well as from that of the long-term urban dynamics that are now dominating the settlement pattern of human populations.

This model essentially builds on input data concerning the geography, hydrology, settlement pattern, and sectors of the economy as the preceding one. However, it models some of these in much more detail because of the availability of written data: the size range of households and component families, the agricultural calendar, additional requirements for feast days, multiple sources of fuel, etc. Other data are either reconstructed from Roman data (mortality data and life tables) or have been taken from ancient Mesopotamian archives (real estate, field sizes and agricultural techniques, including seeding rates, irrigation, fertilizing, etc.). But the lack of precise, annual hydrological data means that, in other respects, this model is not quite as detailed as the southwestern United States example.

To us, this model is a particularly good example of the kinds of models that we should be working toward, because the richness of the written and archival, as well as the archaeological data it integrates makes this a model that moves us yet further toward the integration of sociocultural and environmental dynamics into a single nonequilibrium model.

Two versions of the model are constructed for Northern and Southern Mesopotamia, respectively. In the former, agriculture is rain-fed, in the latter irrigation-based. Here, we will focus on the Northern Mesopotamian case, which is the best-developed to date. I leave it to the reader, again, to look into the details of the inputs and structure of the model, as these are not the subject here. The processes addressed are demographic and kinship-based behaviors, subsistence-based behaviors, and exchanges of labor and commodities, and in this the model resembles the southwestern United States model greatly. The advantages summarized for that model do of course also hold for this model, but in what seem like major differences, this model (1) takes explicitly into account some of the many different process speeds that are always interacting in a complex systems model (Wilkinson et al. 2007:197-198), and (2) has so much more information about social and technical customs, detailed social dynamics, etc., that the model is able to drill down to individual instances of behavior in individual households and assess their impacts.

The first of these capabilities opens the way to modeling the shifts in risk spectra that occur as a society interacts for a longer time with its environment. In such circumstances, as people deal with frequently occurring challenges by finding solutions to them, they inevitably trigger unintended consequences that will manifest themselves over different timescales. Ultimately, these unintended consequences may “collide” in time and cause important changes. This is an essential element of the study of any society over the very long term. The capability to include dynamics at different time scales, therefore, is a major step forward.

The other novel characteristic, richness in social information, is very useful for us from the perspective of understanding the interaction between process and events that inevitably control the historical trajectory of a society because it enables us to experiment with different scenarios that reflect complex combinations of environmental as well as social stresses at the level of the individual household or settlement. Thus, the model identifies “tipping points” in the evolution of the system, phases in which an “abrupt and vivid” change occurs as a hidden resource threshold (such as the number of plow teams per settlement, insufficient manpower at harvest time, etc.) is reached or the demography very suddenly changes (for example, due to an epidemic).

Scenarios focused on the future

Although these two models are indeed able to replay history and therefore enable us to envisage various ex ante scenarios

and to see these play out experimentally, the main purpose of these models has been to generate a better understanding of the past, rather than help improve ways to deal with the future. The following model, however, explicitly has improving the future as one of its purposes. As a Complex Systems model, it is particularly suited to this task, as it has the capacity to show us robust, but counter-intuitive, system behavior. It is one of a substantive and rapidly growing number of such exercises that comes out of the “adaptive management” school, where the model is used to derive alternative management strategies and help identify the strategy that best suits certain desiderata. It is used here to point out how such approaches, extended over the long-term time scales that were the subject of the last two models, can actually improve our insights into the future, especially when they also involve spatial scales from the largest to the smallest.

The aim of this exercise is to answer, at least to some extent, the following question: “To what extent can proactive national, regional, and local responses to climate change and other global drivers shape future outcomes, at least at these sub-global levels, when forces of global change are beyond national, regional, or local control?” (Bohensky et al. 2011). The geographical area about which this question is asked is the Great Barrier Reef, one of Earth’s environmental treasures, for which no comprehensive future analysis has yet been done that downscales global climate change projections to the scales at which responses are likely to emerge.

Because of the many uncertainties involved in looking toward the future of this particular system (and in that respect this situation resembles most archaeological or other long-term ones), the results of the work are formulated in terms of four scenarios, rather than forecasts, projections, or predictions. Each of these, in keeping with a tradition started in the 1990s, outlines a different societal attitude to change—from (1) a defensive one that excludes change, (2) one that admits change as far as it may occur due to the operation of current dynamics, in terms of individuals and markets, without any structural changes, and (3) one that does include cooperation aimed at reform, thus instantiating structural changes imposed from the highest level considered in the model, to (4) the most visionary one, which is supposed to provide the highest quality of life (dependent on the authors and the cases studied), by implementing the greatest transformation.

As has by now become our usual procedure, we leave it up to the reader to study the details of this approach (inputs, structure of the models used, etc.) in the original publication. Suffice it here to say that the authors considered the drivers of climate change, mitigation, and adaptation to be essentially determined by the underlying world views and values related to societal development and the concomitant use of resources to achieve those visions. And in keeping with the management support goal of the exercise, the scenario choices focused to

an important extent on how they affected the provisioning, regulating, supporting, and cultural services provided by the ecosystems concerned.

In this case, the four scenarios deal with two possible worlds, an empty one and a full one, at each of two levels, the world and Australia, as the purpose of the exercise was to study the relative impacts of the world dynamics versus the dynamics in Australia. The empty world follows the mainstream model of development based on ideas that have been inherited from a world in which resources were plentiful, populations relatively low, and built capital was the constraining factor. In the full world, built capital dominates, and the development model reconceptualizes the nature and purpose of the economy so that the focus is on social and environmental wellbeing rather than only material wellbeing.

One of the most interesting results from our perspective is the implications for the four kinds of capital involved: natural, social, human, and built. The two extreme scenarios (here called “trashing the commons” and “best of both worlds”) result in the predictable outcomes reflected in their names. In the second case, all kinds of capital increase, albeit to a different extent, whereas in the first one most kinds of capital decrease, except population and the built environment. But the two others give us some important insights. In the “free rider” scenario (an empty Australia in a full world, in which Australia does nothing about its environment but profits from what other nations do) as well as in the “treading water” scenario (a full Australia in an empty world, in which Australia has an active policy of mitigation in a world that does not), natural capital is seriously diminished, but there are major differences in social capital (which is generally reduced in the former and enhanced in the latter, especially democracy) and in human capital (where education and health are improved in the latter and reduced in the former). Overall, the treading water scenario proves to be considerably better for total wellbeing than the free riders, implying that local measures can overcome much of the negative effect of the global situation, but not vice versa! From the perspective of ecosystem services, we find that in the trashing the commons scenario, all natural ecosystems and the services they provide decrease, whereas intensive agriculture and urbanization increase. In the best of both worlds scenario, land area coverage stays more or less the same. Both the intermediate scenarios are essentially destructive of the environment, albeit to somewhat different degrees.

Where do these examples lead us?

What should we conclude from this last example for the management of the Reef environment in Australia? If Australia does nothing to mitigate climate impact locally and regionally, it will be dependent on what happens elsewhere, and therefore not able to assess risks and uncertainties, which means that there can be no longer-term planning. Proactive approaches, on the other hand, do not only improve ecosystems

services, but also improve the predictability of the future and thus reduce risk and uncertainty. But another important conclusion is the following: that it clearly is not easy to address global environmental change at the regional level, although that is the level at which the impact of such change is most clearly felt. We must therefore devote more effort and attention to the cross-scale interactions. That in turn confirms the importance of the Panarchy approach proposed by the Resilience Alliance (Gunderson and Holling 2002).

But to truly understand a system like this one, as the authors state (Bohensky et al. 2011), one must also be able to work across temporal scales, as we have seen in the archaeological examples above. In the absence of doing so, one misses some of the long-term dynamics of such systems because they cannot sufficiently clearly be observed over short time scales. Such long-term dynamics are both natural (such as tectonics in areas that have frequent small shocks, or erosion and similar phenomena) and cultural (as in the case of the aggregation–disaggregation phenomenon in the southwestern United States case). Moreover, one cannot, over short time scales, observe the change of change—the impact of changes on the dynamics of change itself—emergence of new feedback loops, for example, or shifts in the interaction patterns between processes of different kinds. Finally, scenarios built on a basis of observations over relatively short time scales take legacy effects into account that have not been observed or analyzed.

Examples such as the archaeological ones above have their own disadvantages because they do not (yet) sufficiently take spatial differentiation (whether natural or as a result of human impact) into account or, for that matter, the manifold ways in which spatial differences in landscape and exploitation enable the emergence of societies and ways of life because they allow combinations of resources to emerge. In our opinion, it is clear, therefore, that long-term, detailed models of past dynamics will have to evolve so as to include multiple spatial scales, and that they can then serve as a useful basis for the kinds of scenario analyses that we have presented in the third example.

IHOPE

That is what the IHOPE project is all about (Hibbard et al. 2010): using cross-scale models of the long-term dynamics of major kinds of societal systems to gain better insights in the systemic dynamics of those systems, in order to become more familiar with what the future might bring. To do this most effectively, we are comparing several instances of each of a number of societies that differ in size and complexity, such as the small-scale tribes of Australia, the somewhat larger, but still relatively small-scale societies of the prehistoric southwestern United States, the Maya cities in Guatemala and Yucatan (which are interesting because their history encompasses a major tipping point when they move from the highlands to the lowlands), the Roman Republic and Empire, and others.

The project was initiated at a Dahlem conference in 2005 (cf. Costanza et al. 2007) and has since constituted teams in Australia, North America, Africa, and Europe, with emergent participation in the project from colleagues studying the Arctic, southeast Asia and island societies in the Pacific Ocean. It is currently sponsored by both the IGBP (under the AIMES program) and IHDP and has its administrative home at the Stockholm Resilience Center (Hibbard et al. 2010).

One current activity of the project is building an integrated dynamic systems/agent-based model of the Maya civilization. The model includes the dynamics of the biophysical system—climate, water, vegetation, primary production, etc.—integrated with the human system—demography, settlements, agriculture, trade, technology, institutions, etc.—to replicate the dynamics of the civilization over three major drought cycles and its ultimate collapse. Running model simulations through time shows the spread of human settlement across the landscape. A number of functions for rainfall, net primary productivity, and agricultural suitability are calculated by the cell-based landscape and changes based on assumptions about climate cycles that influence rainfall. Demographic models interact with spatial data to grow agricultural crops and drive migration and further settlement. Settlements are linked via a trade network, and the provision of ecosystem services, agriculture, and trade combine to provide overall human wellbeing. The system is then simulated through time and under comparative scenarios to examine under what conditions the system maintains sustainability, or in turn collapses or reorganizes. The model is evaluated based on its ability to generate outcomes consistent with the body of archeological evidence, in this case the ability to generate the regional settlement pattern of lowland Mayan cities, the location of cross-Yucatan peninsular trade routes via El Mirador, Tikal, and Calakmul, and the ascendancy of coastal cities in the post-classic period. The model allows the investigation of a range of scenarios, including altering the frequency and severity of droughts; the sophistication of trade technology by land, canoe, and marine routes; and the impacts of random shocks such as volcanic eruptions.

We expect that IHOPE will encourage the development, testing, and use of other integrated, dynamic models of the types described to help us better understand the past as a means to creating a sustainable and desirable future. By building such multiscale models of the dynamics of different kinds of societies, and comparing them from the perspective of their structuration as well as evolution over time in different environments, we will gain a much improved insight in scales of socioenvironmental dynamics that we have thus far not been able to grasp, and thus to improve our decision making about our future, which is seeing currently such dramatic changes in the breadths of the temporal and spatial scales involved.

Responses to this article can be read online at:

<http://www.ecologyandsociety.org/vol16/iss4/art2/responses/>

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LITERATURE CITED

- Anderies, J. M., B. H. Walker, and A. P. Kinzig. 2006. Fifteen weddings and a funeral: case studies and resilience-based management. *Ecology and Society* 11(1): 21 [online] URL: <http://www.ecologyandsociety.org/vol11/iss1/art21/>
- Beddoe, R., R. Costanza, J. Farley, E. Garza, J. Kent, I. Kubiszewski, L. Martinez, T. McCowen, K. Murphy, N. Myers, Z. Ogden, K. Stapleton, and J. Woodward. 2009. Overcoming Systemic Roadblocks to Sustainability: the evolutionary redesign of worldviews, institutions and technologies. *Proceedings of the National Academy of Sciences USA* 106:2483-2489. <http://dx.doi.org/10.1073/pnas.0812570106>
- Bohensky, E. L., J. Butler, R. Costanza, I. Bohnet, A. Delisle, K. Fabricius, M. Gooch, I. Kubiszewski, G. Lukacs, P. Pert, and E. Wolanski. 2011. Future makers or future takers? A scenario analysis of climate change and the Great Barrier Reef. *Global Environmental Change* 21:876-893. doi:10.1016/j.gloenvcha.2011.03.009 <http://dx.doi.org/10.1016/j.gloenvcha.2011.03.009>
- Brandt, C. J., and J. B. Thornes. 1996. *Mediterranean desertification and land use*. Wiley & Sons, New York, New York, USA.
- Carpenter, S. R. 2002. Ecological futures: building an ecology of the long now. *Ecology* 83:2069-2083.
- Caseldine, C. J., and C. Turney. 2010. The bigger picture: towards integrating palaeoclimate and environmental data with a history of societal change. *Journal Of Quaternary Science* 25(1 SI):88-93. <http://dx.doi.org/10.1002/jqs.1337>
- Collingwood, R. G. 1946. *The idea of history (revised edition 1994)*. Oxford University Press, New York, New York, USA.
- Costanza, R., L. J. Graumlich, and W. Steffen, editors. 2007. *Sustainability or collapse? An integrated history and future*

- of people on Earth. MIT Press, Cambridge, Massachusetts, USA.
- Crutzen, P. J., and E. F. Stoermer. 2000 The "anthropocene." *IGBP Global Change Newsletter* 41:17-18.
- Dearing J. A., A. K. Braimoh, A. Reenberg, B. L. Turner II, and S. E. van der Leeuw. 2010. Complex land systems: the need for long time perspectives to assess their future. *Ecology and Society* 15(4): 21. [online] URL: <http://www.ecologyandsociety.org/vol15/iss4/art21/>
- Diamond, J. 2005. *Collapse: how societies choose to fail or succeed*. Viking Books, New York, New York, USA.
- Evernden, N. 1992. *The social creation of nature*. Johns Hopkins University Press, Baltimore, Maryland, USA.
- Gill, R. B. 2001. *The great Maya droughts: water, life and death*. University of New Mexico Press, Albuquerque, New Mexico, USA.
- Girard, R. 1990. Innovation and repetition. *SubStance* 62/63:7-20. <http://dx.doi.org/10.2307/3684663>
- Glantz, M. H., editor. 1994. *Drought follows the plow: cultivating marginal areas*. Cambridge University Press, Cambridge, Massachusetts, USA. <http://dx.doi.org/10.1017/CBO9780511608308.009>
- Gunderson, L. H., and C. S. Holling. 2002. *Panarchy: understanding transformations in human and natural systems*. Island Press, Washington, D.C., USA.
- Hartley, L. P. 1953. *The go-between*. Hamish Hamilton, London, UK.
- Haug, H. G., D. Günther, L. C. Peterson, D. M. Sigman, K. A. Hughen, and B. Aeschlimann. 2003. Climate and the collapse of Maya civilization. *Science* 299:1731-1735. <http://dx.doi.org/10.1126/science.1080444>
- Hibbard, K. A., R. Costanza, C. Crumley, S. van der Leeuw, S. Aulenbach, J. Dearing, J. Morais, W. Steffen, and Y. Yasuda. 2010. *Developing an integrated history and future of people on Earth (IHOPE): research plan*. IGBP Report No. 59. IGBP Secretariat, Stockholm, Sweden.
- Jackson, S. T., J. L. Betancourt, R. K. Booth, and S. T. Gray. 2009. Ecology and the ratchet of events: Climate variability, niche dimensions, and species distributions. *Proceedings of the National Academy of Sciences USA* 106(suppl. 2):19685-19692. <http://dx.doi.org/10.1073/pnas.0901644106>
- Jackson, S. T., and R. J. Hobbs. 2009. Ecological restoration in the light of ecological history. *Science* 325:567. <http://dx.doi.org/10.1126/science.1172977>
- Kohler T. A., C. D. Johnson, M. Varien, S. Ortman, R. Reynolds, Z. Kobti, J. Cowan, K. Kolm, S. Smith, and L. Yap. 2007. Settlement ecodynamics in the prehispanic central Mesa Verde region. Pages 61-104 in T. A. Kohler and S. E. van der Leeuw, editors. *The model-based archaeology of socionatural systems*. School of Advanced Research Press, Santa Fe, New Mexico, USA.
- Landes, D. S. 1998. *The wealth and poverty of nations: why some are so rich and some so poor*. W. W. Norton, San Francisco, California, USA.
- McNeill, J. R. 2001. *Something new under the sun*. W. W. Norton, New York, New York, USA.
- Meyer, W. B., K. W. Butzer, T. E. Downing, B. L. Turner II, G. W. Wenzel, and L. Westcoat. 1998. Reasoning by analogy. Pages 217-289 in S. R. Raynor and E. L. Malone, editors. *Human choices and climate Change. Vol. 3. The tools for policy analysis*. Battelle Press, Columbus, Ohio, USA.
- Millennium Ecosystem Assessment. 2005. *Ecosystems and human well-being: synthesis*. Island Press, Washington, D.C., USA.
- Prigogine, I. 1980. *From being to becoming*. W. H. Freeman, San Francisco, California, USA.
- Steffen, W., P. J. Crutzen, and J. R. McNeill. 2007. The anthropocene: are humans now overwhelming the great forces of nature? *Ambio* 36:614-621. [http://dx.doi.org/http://dx.doi.org/10.1579/0044-7447\(2007\)36\[614:TAAHNO\]2.0.CO;2](http://dx.doi.org/http://dx.doi.org/10.1579/0044-7447(2007)36[614:TAAHNO]2.0.CO;2)
- Tainter, J. 1988. *The collapse of ancient societies*. Cambridge University Press, Cambridge, Massachusetts, USA.
- Van der Leeuw, S. E., and the ARCHAEOMEDES Teams. 1998. *The ARCHAEOMEDES project: understanding the natural and anthropogenic causes of land degradation and desertification in the Mediterranean Basin*. Office for Official Publications of the European Communities, Luxembourg.
- Wescoat, J. L. 1991. Resource management: the long-term global trend. *Prog Hum Geogr* 15(1):81-93.
- Westley, F., P. Olsson, C. Folke, T. Homer-Dixon, H. Vredenburg, D. Loorbach, J. Thompson, M. Nilsson, E. Lambin, J. Sendzimir, B. Banarjee, V. Galaz, and S. E. van der Leeuw. 2011. Tipping towards sustainability: emerging pathways of transformation. *Ambio, in press*.
- Wilkinson, T. J., M. Gibson, J. H. Christiansen, M. Widell, D. Schloen, N. Koutchoukos, C. Woods, J. Sanders, K.-L. Simunich, M. Altaweel, J. A. Ur, C. Hritz, J. Lauinger, T. Paulette, and J. Tenney. 2007. Modeling settlement systems in a dynamic environment. Pages 175-208 in T. A. Kohler and S. E. van der Leeuw, editors. *The model-based archaeology of socionatural systems*. School of Advanced Research Press, Santa Fe, New Mexico, USA.
- Zhang, D. D., P. Brecke, H. F. Lee, Y.-Q. He, and J. Zhang. 2007. Global climate change, war, and population decline in

recent human history. *Proceedings of the National Academy of Sciences USA* 104:19214-19219. <http://dx.doi.org/10.1073/pnas.0703073104>

^[1] And even where, over the past couple of decades or so, we have accelerated our scientific knowledge base to a point where we *do* know enough to propose changes at local (e.g., acid rain, use of pesticides) and global scales (e.g., climate change mitigation), there is a disconnect between the science and the prevailing and “accepted” social trajectories based on growth, so that such proposals are not implemented.

^[2] cf. L. P. Hartley's famous phrase: “The past is a foreign country: they do things differently there”, in his novel *The Go-Between* (Hartley 1953).