Critical perspectives on historical collapse

Karl W. Butzer[a,1] and Georgina H. Endfield[b]

[a]Department of Geography and the Environment, University of Texas, Austin, TX 78712; and [b]School of Geography, University of Nottingham, Nottingham NG7 2RD, United Kingdom

Historical collapse of ancient states or civilizations has raised new awareness about its possible relevance to current issues of sustainability, in the context of global change. This Special Feature examines 12 case studies of societies under stress, of which seven suffered severe transformation. Outcomes were complex and unpredictable. Five others overcame breakdown through environmental, political, or socio-cultural resilience, which deserves as much attention as the identification of stressors. Response to environmental crises of the last millennium varied greatly according to place and time but drew from traditional knowledge to evaluate new information or experiment with increasing flexibility, even if modernization or intensification were decentralized and protracted. Longer-term diachronic experience offers insight into how societies have dealt with acute stress, a more instructive perspective for the future than is offered by apocalyptic scenarios.

complexity | social-ecological resilience | multicausality

Current Visions of Collapse

The breakdown of historical states or societies (1) has drawn attention since the 18th century, with shifting explanations that reflected prevailing intellectual climates (2). An early, macrohistorical mode gave way to biological analogs or the overriding significance of technological progress. However, two world wars of unspeakable brutality reawakened millennialist anxieties, more recently compounded by growing fears of exponential population growth, environmental deterioration, and global climatic change. In this spirit of crisis, some authors have searched for alarming, futuristic scenarios in historical digests. However, an increasing number of scientists has begun to counter this sometimes chaotic discourse with sophistication, to suggest more measured estimates for change or to steer attention to the desirability of remedial action. Diverse efforts are underway to model social response and offer simulated predictions of short- or long-range environmental change.

In particular, concern with climatic change, global environmental change, and sustainability has stimulated the formation of formal or informal programs and working groups to address environment–society relationships and their implications for sustainability. These include International Council of Science-sponsored efforts such as Past Global Environmental Change, the Integrated Land Ecosystem–Atmosphere Processes Study, and a newly minted Program on Ecosystem Change and Society.

Related groups and programs focus on land-use change (3–5), resilience (6–8), vulnerability (9, 10), and sustainability (11). Apart from the underlying need for institutional funding, such organizational strategies serve to draw attention to a new generation of directed, collaborative research (12) and help sketch alternative thematic agendas for cross-disciplinary interaction. Together, such programs have fostered a series of research themes and concepts, relevant for and, in many cases addressing, societal collapse.

These themes and concepts include complexity and network theory, historicity and legacies, tipping elements and points, and associated path-dependent relationships of coupled systems. Through paleoenvironmental and historical research, various international science programs seek to identify the dynamics that stimulate societal adaptations to such elements, so as to provide insight into the resilience of past societies that arguably may be of use to contemporary and future societies.

The challenge remains to develop an outline for comprehensive, integrated models that convincingly explicate past socio-ecological interactions, or that capture the broader, dynamic principles cross-cutting human–environmental systems while also accounting for the finer-resolution evidence and complex outcomes that they entail. Unfortunately there are insufficient empirical, rather than simulated, data on the nature of societal response to cross-disciplinary inputs, triggers, or tipping points. The public is confronted by metanarratives of global change or by semipopular works that suggest oversimplified causal correlations. Such hypotheses can readily be misunderstood as facts. Historical examples should instead be carefully selected to study the societal implications of predicted, future environmental scenarios (13).

Other difficulties arise when normative environmental systems are coupled with human systems that emphasize information, technology, and social organization. Human groups and individuals introduce cognition, information, and communication as powerful variables in dealing with values, attitudes, and decision making (14–17), so that culture, perception, and behavior condition how societies will interact with their environments or define their priorities. Scientific advances in simulating the physical outcomes of climatic change seem to be more advanced than the modeling of social response to that change (18, 19). This may reflect the profound complexities of social analysis (20, 21) and the lack of unanimity among the physical and social sciences or humanities in regard to concepts, assumptions, legacies, validity, and contingencies. These issues pose difficult problems for model designs to simulate coupled systems.

Social Science Agenda for Collapse

Without downplaying the importance of hard science and modeling in studies of collapse, it can be argued that socio-cultural and political processes need greater attention. We therefore suggest a broader, integrative definition: *Societal collapse represents transformation at a large social or spatial scale, with long-term impact on combinations of interdependent variables:* (*i*) environmental change and resilience; (*ii*) demography or settlement; (*iii*) socio-economic patterns; (*iv*) political or societal structures; and (*v*) ideology or cultural memory.

These are intrinsic properties rather than a shopping list. They encompass energetic structures and flows, but equally so have cultural and psychological dimensions that are grounded in human perceptions, values, and solidarity. Temporal parameters are relative, because the interactive cluster of processes waxes and wanes in shifting constellations as a transformation begins, climaxes, and concludes, with or without obvious discontinuities. Such a definition of collapse calls for a genuinely interdisciplinary field of analysis, one that pays explicit attention to social and

Author contributions: K.W.B. and G.H.E. designed research; K.W.B. performed research; and K.W.B. wrote the paper.

The authors declare no conflict of interest.

[1]To whom correspondence should be addressed. E-mail: karl.butzer@austin.utexas.edu.

humanistic issues, which should be more than an afterthought.

In pursuing such a line of research, analytical case studies are particularly productive. If based first and foremost in empirically grounded data, from specific areas, case studies can be examined inductively and deductively. For example, the 1930s Dust Bowl phenomenon on the Great Plains has been reexamined many times (22–26), with an explicit historical model by Robert Kates, to arrive at increasingly closer approximations of perceptions, issues, and processes. Renewed attention to good heuristic exemplars is integral to scientific investigation, and in the case of historical collapse also provides occasion to examine how societies dealt with crises to avoid breakdown.

In addressing the issues and nature of historical collapse, the articles of this Special Feature rely heavily on case studies that specifically draw from archaeology, anthropology, economics, and geography, as well as the geological and biological sciences. However, the cross-disciplinary fields of interaction are much broader and directly intersect with overarching concepts such as environmental history, land-use change, institutional structures, resilience, and sustainability. A consistent component is scale, in both space and time.

Importance of Direct, "Insider" Information

Over the span of the Holocene, telling evidence of social–ecological change is commonly provided by archeological survey and geoarcheological evidence (27) for settlement discontinuities. The number, density, or size of settlements can decline or shift to new concentrations. Archeological inventories may change, or whole landscapes may be abandoned (28–30). When resettlement takes place, new archaeological components often dominate, and few older loci may be reoccupied. Settlement shifts or discontinuities are common enough in the Neolithic, Bronze Age, or Iron Age records of Europe (31) and typically take place over centennial time scales. Change may represent partial or complete *archeological succession*, with some shifts rapid or even catastrophic and others marked by a measure of *evolutionary continuity*. Human impact may have effected environmental modification, or biotic evidence may record a shift to the exploitation of new habitats or resources, accompanied by changing adaptations or more complex patterns of resilience, in line with new, inferred vulnerabilities. External parameters can also shift, as a result of climatic anomalies, invasion, or epidemic disease—beyond the ebb and flow of endogenic change, and driven by new opportunities or priorities, famine disasters, or feedbacks reflecting adjustments to land access and land use.

Such shifts or discontinuities in the prehistoric record may well have been traumatic or even catastrophic at some scale, but the archaeological record often lacks the necessary sensitivity to detect this, even when regional depopulation is apparent. That indeterminate picture improves when the archaeological record acquires a much larger palette of criteria, such as socially differentiated architectural sites, suggestive of more complex and stratified communities, especially if there is evidence of concentrated craft production, exploitation of mining resources, hints or better of exchange networks, and nested hierarchies of larger and smaller sites with possible economic differentiation. Enter the concept of the *city*—highlighted by special economic, political, or religious prestige or control (27).

For urban societies there may also be documentary sources that help identify collapse of a group of towns or an *archaic state*. Urban centers in the Near East reach back into prehistoric times in the case of proto-literate, high cultures or "civilizations." Investigation can move beyond archaeological survey to unravel the successive horizons of settlement mounds, with the preferred assistance of geoarchaeological research (32). House floors, former streets, and community or monumental structures can be studied at the microlevel to identify different kinds of sediments that accumulate during settlement growth or decline, until the time of abandonment or deliberate destruction (14, 33, 34). On a wider scale, transport of urban sediments to adjacent streams may allow testing of relationships between occupation histories and regional degradation or environmental change. Explanations for discontinuities or collapse become more tangible.

Although some written sources become available for parts of the Near East toward 3000 B.C.E., they initially are very fragmentary or thematically limited. In conjunction with later recording of oral traditions, they offer a skeletal framework of changing dynasties but, until late in the third millennium, little by way of explanation for or perceptions of change (35, 36). For example, the demise of the Akkadian Empire is incompletely documented by coeval sources. Instead, changes have to be inferred from younger texts or chronicles that were ideologically tailored with respect to an idealized role of the "good ruler." Although the conventional canons of Near East historiography are complemented by phenomenally rich archaeological and artistic records, initial reconstructions of administrative structures and social changes depend to some degree on anthropological models. Even with multiple lines of convergent evidence and social science sophistication, a possible diagnosis of protohistoric "collapse" must rely on a fragmentary data set. This explains the significance of the insider perspective for later societies that do have a complex written record (37), as was the case in Egypt, Colonial Mexico, or Cyprus.

Dating, Timing, and Correlation

Reliable time frames are as much a problem in identifying collapse as are records that include direct narratives (38, 39). In a specific case study, the criteria to date key information on environmental variability, depopulation, political simplification, or social resilience may simply be inadequate to integrate or to correlate with other sites or outlying regions.

The collapse of the Akkadian Empire in Mesopotamia or of Old Kingdom Egypt illustrates the problem. Accurate calibration of Accelerator Mass Spectrometry (AMS) dates for the mid to late third millennium B.C.E. is tenuous, given the irregularities of the calibration curve (40). Attempted calibrations may have a range of some 300 y, with multiple intercepts. On the other hand, chronological reconstructions from regnal years are beset by problems of incomplete, incorrect, or illegible records or elite accounts for individual reigns, in addition to periods with an uncertain number of short-term rulers. No generally accepted chronology has been established for Mesopotamia before ≈2100 B.C.E. For example, within the Syrian site of Tell Brak a very large body of isotopic dates—for three distinct archaeological levels that represent successive ruling administrations—are indistinguishable (41). In Egypt, the Old Kingdom dynasties seem to be reasonably well dated, but the subsequent First Intermediate Period is not (42). As a result it is uncertain which Egyptian dynasties or rulers correlate with which Akkadian kings, let alone how either region interdigitated with events in the Aegean world or Indus Valley. The ancient capital of Akkad has not yet been found and is probably dispersed deep in alluvial deposits of the Euphrates River, whereas events referred to in the chronicles can be difficult to relate to actual places, let alone scientifically excavated sites.

It is a stretch to correlate the reputed collapse of several Near Eastern civilizations (supposedly around 2200 B.C.E.) across western Asia and beyond when in fact major events are imprecisely dated within 2 or more centuries. Such temporal uncertainty also does not warrant the use of proxy climate records from distant oceans or continents to explain sociohistorical processes proceeding apace in Mesopotamia or Egypt.

Implementing a Social Science Agenda

The research articles of this Special Feature constitute an alternative framework to a metanarrative-driven understanding of historical human–environment relationships and collapse. These empirically grounded articles represent four continents and come from many distinct environments, addressing a wide range of global variability and resilience. They span different time ranges, so as to offer a spectrum of contextual factors and issues, with cumulative contributions to a repertoire of ideas.

The opening Perspective [including supporting information (SI), available online] by Butzer (2) argues that a plausible cause for sociopolitical breakdown should be grounded in direct, insider information, drawn from internal histories. Case studies from Old and New Kingdom Egypt record how economic decline, corruption, insecurity, or war precondition a state for concatenations of declining productivity, recession, and possible climatic perturbations. With low resilience, cascading devolutionary feedbacks can then destabilize a system through famine, internal conflict, and political simplification, eventually leading to subsistence crises, breakdown of the social order, and civil wars. However, with high societal resilience, buffering feedbacks may instead lead to the emergence of military leaders, support by new elites, a reaffirmation of the "cosmic" order, and ideological shifts that allow reconstitution of the state. In effect, multiple interactive thresholds led to different "regime shifts" (see ref. 43) in Old vs. New Kingdom Egypt.

Expansion of these case studies to include Islamic Mesopotamia, Egypt's Fayum Oasis, and Axum (Ethiopia) (ref. 2 and its SI) adds experience on irrigation failure or demographic decline in the wake of ethnic change, climatic anomalies, or environmental degradation. Although the many interlinked inputs, triggers, and feedbacks can precondition or lead to breakdown, environmental change was subordinate to internally driven processes, rather than the primary cause of devolution. Cognition, values, and priorities are critical, so that the conceptual model proposed (figure 1 in ref. 2) not only emphasizes environmental resilience but also the role of leadership, elites, and ideology for either breakdown or reconstitution. These historical examples of cyclical collapse were not "abrupt" but mainly played out over centennial rather than decennial time scales.

In a strictly archaeological setting, Rosen and Rivera-Collazo (44), with the help of good paleoecological data, show the utility of adaptive cycles from resilience theory (45). The authors suggest that the abrupt, cold-climate oscillation at the end of the Pleistocene (the Younger Dryas, ≈12,900–11,600 cal. B.P.) delayed the transition to food production in the open woodlands of the southern Levant. In response, resilient foraging groups reorganized to implement earlier, successful strategies, exploiting a broader spectrum of resources (identified by plant and animal residues), in combination with greater mobility. Later in the cycle, a greater investment in prime, high-yield foods narrowed the resource spectrum and decreased mobility. However, hunting pressures eventually reduced the availability of large game, favoring a belated shift to food production. Multidisciplinary archaeology can indeed develop useful models for prehistoric times.

The Maya Collapse (≈750–900 C.E.) is controversial, with explanations ranging from long-distance teleconnections to arguments centered on different environmental responses in various regional, ecological contexts, originally including tropical forests and woodland. As noted by Luzzadder-Beach et al. (46), this process spanned time and distance. Complex proxy data indicate several drier periods, linked to major transitions in human adaptation or response. However, during the Terminal Classic, collapse was pervasive, even in perennial wetlands that should have been less affected by drought. Dunning et al. (47) address the different rates of Maya population recovery from such recurrent droughts and environmental degradation. In some areas long-term environmental changes required development of new adaptations, whereas elsewhere cultural factors may have delayed repopulation, including the reconsecration of abandoned lands (*kax*) before reoccupation as cultivated space (*kol*). As in the Levant, cyclic growth and decline involved both environmental and cultural resilience, but given its diversified criteria, the Maya record is more complex.

Two other articles offer insights on resilience and social transformations in the far North Atlantic realm, as based on survey, excavation, and a battery of analytical techniques, applied to multiscale comparative analyses of examples from Medieval Iceland and Greenland. Dugmore et al. (48) assess differences of social transformation, sustainable practice, environmental change, isolation, mobility, and choices about subsistence and social organization. Under what circumstances can population levels not be maintained? How did divergent adaptations benefit Iceland and the Greenland colonies with the onset of the Little Ice Age (LIA)? This informs on the consequences of locational choices for settlements, with respect to subsistence and external connectivity. High-resolution correlation of tephra layers from Iceland, by Streeter et al. (49), shows that plague-related depopulation on Iceland was followed by reduced pastoral impact on the soil balance, which eventually may have improved environmental resilience in the face of the LIA. The North Atlantic articles illustrate the effectiveness of comparative analyses of large datasets from an expanded range of variables. They go well beyond the singular emphasis of abrupt climatic change, by teasing out the role of systemic resilience and niche specialization.

Since 1878 British colonial and Cypriot postcolonial governments enacted environmental policies based on the premise of ongoing deforestation and degradation of a fragile Mediterranean ecosystem (i.e., coupled system degradation). According to Harris (50), this narrative is based on inaccurate assumptions and interpretations that oversimplify the goals of government, fail to recognize the difference between degradation and change, and scapegoat the pastoral lifestyle and its presumed environmental impact. Archival and field research instead underscore the environmental and societal resilience of "degraded" areas and the effects of changing economic, political, and social contexts. This case study of natural resource management and environmental resilience (see ref. 43) illustrates that what the colonial government viewed as unsustainable was, in all probability, sustainable.

The Special Feature concludes with Endfield's (51) archivally based study of resilience and adaptive response in colonial Mexico. She marshals archival documentation to argue that although much of human history can be viewed through an ontogenetic lens of emergence, florescence, and decline, intersecting with extreme events or natural disasters, to do so would obscure the specific socio-economic, cultural, political, and background environmental contexts that helped shape them. The interactions between the environment and society influence how regional livelihoods may be vulnerable to disruption. However, her detailed case analyses also inform on the degree to which different societies and groups can develop institutions and cultural coping strategies to deal with environmental changes at different scales, to show that vulnerability to change can lead to an improved understanding of risk (10). Environmental crises could therefore challenge but also improve societal resilience, increasing opportunities for learning and innovation, to broaden the repertoire of adaptive responses (17, 52). Collapse is not an inevitable result of transformations, although the transformations themselves offer opportunities to examine the complex structure of social interactions.

Overall, the case studies present six examples of collapse in response to mainly societal, interacting factors (cascading feedbacks), in which climatic or ecological change was no more than a coagency, with a single case of significant degradation (Axum). Some five examples without collapse illustrate different facets of environmental or societal resilience. This set of supporting articles cuts across ecological variability and time to articulate complementary insights about multicausality, rather than single-factor environmental explanations. The environment is of course critically important for sustainability, but such interrelationships are filtered through a web of complex social responses. Rather than assemble an anthology of historical collapse, the Special Feature highlights multicausality, resilience, unpredictability, and how societies cope with crises.

Societal collapse raises productive questions about diachronic coupled systems. Such issues would include the following: why collapse is important, how common it is in the historical record, whether it is inevitably linked to environmental disasters, or whether it offers precedents to correct contemporary outcomes or devise solutions for the future. Perhaps the most trenchant would be how societies have avoided collapse by revitalizing a common will to overcome adversity, drawing from both old experience and new information to revise or develop collective strategies for survival. Voluntary transformation can be painful, but it does offer hope for reconstitution and recovery. The case studies developed in this Special Feature suggest that optimal solutions ultimately are cognitive and collaborative. However, solutions to acute crises of sustainability cannot be devised or implemented if remedial response is modeled with stereotypic assumptions about human behavior.

1. Tainter JA (2000) Problem solving: Complexity, history, sustainability. *Popul Environ* 22:3–41.
2. Butzer KW (2012) Collapse, environment, and society. *Proc Natl Acad Sci USA* 109:3632–3639.
3. Clark WC, Dickson NM (2003) Sustainability science: The emerging research program. *Proc Natl Acad Sci USA* 100:8059–8061.
4. Turner BL, 2nd, Lambin EF, Reenberg A (2007) The emergence of land change science for global environmental change and sustainability. *Proc Natl Acad Sci USA* 104:20666–20671.
5. Dearing JA, Braimoh AK, Reenberg A, Turner BL, II, Van der Leeuw S (2010) Complex land systems: The need for long time perspectives in order to assess their future. *Ecol Soc* 15:21.
6. Nelson DR, Adger WN, Brown K (2007) Adaptation to environmental change: Contribution of a resilience framework. *Annu Rev Environ Resour* 32:395–419.
7. Redman CL, Kinzig AP (2003) Resilience of past landscapes: Theory, society and the longue durée. *Conserv Ecol* 7:14.
8. Gil-Romera G, et al. (2010) Interpreting resilience through long-term ecology: Potential insight in Western Mediterranean landscapes. *Open Ecol J* 3: 43–53.
9. McLaughlin P, Dietz T (2007) Structure, agency and environment: Toward an integrated perspective on vulnerability. *Glob Environ Change* 18:99–111.
10. Endfield GH (2008) *Climate and Society in Colonial Mexico: A Study in Vulnerability* (Blackwell, Oxford, United Kingdom).
11. Turner BL, II (2010) Vulnerability and resilience: Coalescing or paralleling approaches for sustainability science*? Glob Environ Change* 20:570–576.
12. Janssen MA, Schoon ML, Ke W, Börner K (2006) Scholarly networks on resilience, vulnerability and adaptation within the human dimensions of global environmental change. *Glob Environ Change* 16: 240–252.
13. Meyer WB, et al. (1998) Reasoning by analogy. *Human Choice and Climatic Change*, eds Rayner S, Malone EL (Batalle Press, Columbus, OH), Vol 3, pp 217–290.
14. Butzer KW (1982) *Archaeology as Human Ecology: Method and Theory for a Contextual Approach* (Cambridge Univ Press, New York).
15. Adger WN (2000) Social and ecological resilience: Are they related*? Prog Hum Geogr* 24:347–364.
16. Liu J, et al. (2007) Complexity of coupled human and natural systems. *Science* 317:1513–1516.
17. Folke C (2006) Resilience: The emergence of a perspective for social-ecological systems analyses. *Glob Environ Change* 16:253–267.
18. Costanza R, et al. (2007) Sustainability or collapse: What can we learn from integrating the history of humans and the rest of nature? *Ambio* 36:522–527.
19. Wainwright J (2010) Climate change, capitalism, and the challenges of transdisciplinarity. *Ann Assoc Am Geogr* 100:983–991.
20. Crooks A, Castle C, Batty M (2008) Key challenges in agent-based modeling for geo-spatial simulation. *Comput Environ Urban Syst* 32:417–430.
21. Loule MA, Carley KM (2008) Balancing the criticisms: Validating multi-agent models of social systems. *Simul Model Pract Theory* 16:242–258.
22. Miewald RD (1978) Social and political impacts of drought. *North American Droughts*, ed Rosenberg NJ (Westview, Boulder, CO), pp 79–101.
23. Worcester D (1979) *Dust Bowl: The Southern Plains in the 1930s* (Oxford Univ Press, New York).
24. Bowden MJ, et al. (1981) The effect of climate fluctuations on human populations: Two hypotheses. *Climate and History: Studies in Past Climates and Their Impacts on Man*, eds Wigley TML, Ingram MJ, Farmer G (Cambridge Univ Press, Cambridge, United Kingdom), pp 479–513.
25. Butzer KW (1983) Human response to environmental change in the perspective of future global climate. *Quat Res* 19:279–292.
26. Cunfer G (2005) *On the Great Plains: Agriculture and Environment* (Texas A&M Univ Press, College Station, TX).
27. Butzer KW (2008) Other perspectives on urbanism: beyond the disciplinary boundaries. *The Ancient City*, eds Marcus J, Sabloff JA (Sackler Symposium, School for Advanced Research Press, Santa Fe, NM), pp 77–94.
28. Potter TW (1979) *The Changing Landscape of South Etruria* (Elek, London).
29. Jameson MH, Runnels CH, Van Andel TH (1994) *A Greek Countryside: The Southern Argolid from Prehistory to the Present Day* (Stanford Univ Press, Stanford, CA).
30. Marcus J (1998) The peaks and valleys of ancient states: An extension of the dynamic model. *Archaic States*, eds Feinman GM, Marcus J (School for Advanced Research Press, Santa Fe, NM), pp 59–94.
31. Milisauskas S, ed (2002) *European Prehistory: A Survey* (Kluwer, New York).
32. Butzer KW (2008) Challenges for a cross-disciplinary geoarchaeology: The intersection between environmental history and geomorphology. *Geomorphology* 101:402–411.
33. Rosen AM (1986) *Cities of Clay: The Geoarchaeology of Tells* (Univ of Chicago Press, Chicago).
34. Beach TP, Luzzadder-Beach S (2008) Geoarchaeology and aggradation around Kinet Höyük, an archaeological mound in the Eastern Mediterranean, Turkey. *Geomorphology* 101:416–428.
35. Shaw I (1999) *The Oxford History of Ancient Egypt* (Oxford Univ Press, London).
36. Franke S (1995) Kings of Akkad: Sargon and Naram-Sin. *Civilizations of the Ancient Near East*, ed Sasson JM (Simon & Schuster Macmillan, New York), II, pp 831–841.
37. Butzer KW (2005) Environmental history in the Mediterranean world: Cross- disciplinary investigation of cause-and-effect for degradation and soil erosion. *J Archaeol Sci* 23:1773–1800.
38. Lentz DL, Hockaday B (2009) Tikal timbers and temples: Ancient Maya agroforestry and the end of time. *J Archaeol Sci* 36:1342–1353.
39. Hunt TL (2007) Rethinking Easter Island's ecological catastrophe. *J Archaeol Sci* 34:485–502.
40. Hornung E, Krauss R, Warburton DA, eds (2006) Ancient Egyptian chronology. *Handbook of Oriental Studies* (Brill, Boston).
41. Oates D, Oates J (2001) Archeological reconstruction and historical commentary. *Excavations at Tell Brak, Vol. 2, Nagar in the Third Millennium BC*, eds Oates D, Oates J, McDonald H (McDonald Institute Monographs, Oxbow Books, Oxford), pp 379–396.
42. Bronk Ramsey C, et al. (2010) Radiocarbon-based chronology for Dynastic Egypt. *Science* 328:1554–1557.
43. Kinzig A, et al. (2006) Resilience and regime shifts: Assessing cascading effects. *Ecol and Society* 11:20.
44. Rosen AM, Rivera-Collazo I (2012) Climate change, adaptive cycles, and the persistence of foraging economies during the Pleistocene/Holocene transition in the Levant. *Proc Natl Acad Sci USA* 109:3640–3645.
45. Gunderson LH, Holling CS (2002) *Panarchy: Understanding Transformations in Systems of Humans and Nature* (Island Press, Washington, DC).
46. Luzzadder-Beach S, Beach TP, Dunning NP (2012) Wetland fields as mirrors of drought and the Maya abandonment. *Proc Natl Acad Sci USA* 109:3646–3651.
47. Dunning NP, Beach TP, Luzzadder-Beach S (2012) Kax and kol: Collapse and resilience in lowland Maya civilization. *Proc Natl Acad Sci USA* 109:3652–3657.
48. Dugmore AJ, et al. (2012) Cultural adaptation, compounding vulnerabilities and conjunctures in Norse Greenland. *Proc Natl Acad Sci USA* 109:3658–3663.
49. Streeter R, Dugmore AJ, Vesteinsson O (2012) Plague and landscape resilience in premodern Iceland. *Proc Natl Acad Sci USA* 109:3664–3669.
50. Harris S (2012) Cyprus as a degraded landscape or resilient environment in the wake of colonial intrusion. *Proc Natl Acad Sci USA* 109:3670–3675.
51. Endfield G (2012) The resilience and adaptive capacity of social–environmental systems in Colonial Mexico. *Proc Natl Acad Sci USA* 109:3676–3681.
52. Walker BH, Holling CS, Carpenter SR, Kinzig AP (2004) Resilience, adaptability, and transformability. *Ecol and Society* 9:5.