SPECIAL FEATURE: INTRODUCTION

Archaeology, climate, and global change in the Age of Humans

Torben C. Rick[a,1] and Daniel H. Sandweiss[b,c,1]

We live in an age characterized by increasing environmental, social, economic, and political uncertainty. Human societies face significant challenges, ranging from climate change to food security, biodiversity declines and extinction, and political instability. In response, scientists, policy makers, and the general public are seeking new interdisciplinary or transdisciplinary approaches to evaluate and identify meaningful solutions to these global challenges. Underrecognized among these challenges is the disappearing record of past environmental change, which can be key to surviving the future. Historical sciences such as archaeology access the past to provide long-term perspectives on past human ecodynamics: the interaction between human social and cultural systems and climate and environment. Such studies shed light on how we arrived at the present day and help us search for sustainable trajectories toward the future. Here, we highlight contributions by archaeology—the study of the human past—to interdisciplinary research programs designed to evaluate current social and environmental challenges and contribute to solutions for the future. The past is a multimillennial experiment in human ecodynamics, and, together with our transdisciplinary colleagues, archaeology is well positioned to uncover the lessons of that experiment.

Anthropocene | cultural heritage | human ecology | environmental change

Whether exploring popular media or scientific literature, we are constantly confronted by a planet in peril. Climate change, habitat alteration, extinction, and numerous other environmental perturbations pose significant threats to society, human welfare, and Earth's ecosystems and biodiversity. Given the scale and magnitude of climate change and other environmental challenges, researchers have emphasized the value of interdisciplinary or transdisciplinary research, including the social sciences and humanities, to evaluate these issues and search for realistic scenarios and solutions (1–3). Historical sciences such as archaeology provide important perspectives on past climate and environmental change and how past developments can inform and contextualize current and projected conditions (4–7). Consequently, research on human–environment interaction has emerged as a grand challenge for archaeology (8).

With widespread recognition that humans have altered the planet since at least the Late Pleistocene (9), archaeology is playing a growing role in global environmental research and conversations about the proposed Anthropocene Epoch, or Age of Humans (10–12). For instance, archaeological research in the American Southwest and North Atlantic provides important perspectives on the intersections of climate change and food security in the modern world (13). Integration of archaeological data with stable isotopes, ancient DNA, and analysis of climate and environmental productivity data provides perspectives on fisheries management of key species and habitats (14–17). Archaeological research and computational modeling also document the effects of drought on agriculture in China, the American Southwest, and beyond (7, 18). Debates continue about the extent and scale of past human modification of the Amazon, but past human settlement strategies and agricultural systems provide valuable insight into present and future human environmental interactions in this crucial habitat (19–21). Other studies have pooled archaeological knowledge from around the world to understand and characterize Holocene human influence on Earth's land surface and ecosystems (22, 23). There is increasing recognition that archaeological sites offer important proxy records of past climatic and environmental states that contribute data for testing models of future climate (5). Collectively, these and other studies demonstrate that archaeological sites represent a series of observation networks about changing environmental conditions and human activities through time (Distributed Long-term Observing Networks of the Past), with much potential to address modern environmental challenges (24).

[a]Department of Anthropology, National Museum of Natural History, Smithsonian Institution, Washington, DC 20013-7012; [b]Department of Anthropology, University of Maine, Orono, ME 04469; and [c]Climate Change Institute, University of Maine, Orono, ME 04469

Author contributions: T.C.R. and D.H.S. wrote the paper.

The authors declare no competing interest.

[1]To whom correspondence may be addressed. Email: RickT@si.edu or dan.sandweiss@maine.edu.

First published April 13, 2020.

Fig. 1. Topics covered in the special feature and of broad archaeological significance. (*Top*) From left to right, an eroding and threatened archaeological shell midden in California, archaeological animal remains housed in a museum collection, and modern traffic congestion and pollution; this series shows links between threatened cultural heritage, legacy/museum collections, and modern environmental and societal issues. (*Bottom*) Areas covered within each manuscript: A, ref. 25; B, ref. 27; C, ref. 26; D, ref. 29; E, ref. 28; and F, ref. 30.

This PNAS special feature brings together six globally distributed papers that demonstrate the value of archaeology within transdisciplinary research programs focused on integrating perspectives on past, present, and future climate change and related environmental challenges (25–30). These papers demonstrate cutting-edge interdisciplinary research on archaeology, climate change, and other global environmental challenges, emphasizing how archaeology provides information of value to science and society in an era of global change, while, at the same time, sounding warning bells about the ongoing destruction of this critical record (Fig. 1). Written by international teams of experts, each paper provides synthetic perspectives on how archaeology can help evaluate 1) human responses to climate change, including vulnerability and risk; 2) human environmental disturbances and management, including extinction, food security, and other issues; 3) past climate states; and 4) future directions for integrating archaeology and other social sciences into global change research.

Ancient Environmental and Climatic Change in Global Context

Paleoscientists from many disciplines work to reconstruct ancient environmental and climatic change, but it is archaeologists who put humans into the picture. Learning how our ancestors responded contextually to change, sometimes called human ecodynamics (31), expands our understanding of human history and offers lessons for the present and future.

Many of the papers in this special feature focus on human ecodynamics during the Holocene (25–27) and/or reconstruct past climate regimes from archaeological data (27). These studies recognize that climatic and environmental change do not explain all aspects of change in human organization, behavior, demography, or distribution, but each one provides examples in which people responded to changing conditions. Often, these responses are tied to changing availability of fresh water, usually extended droughts. Petraglia et al. (26) document several multicentennial droughts in eastern and northern Arabia and their relation to changes in human demography and trade.

One of the common adaptive responses to climatic change by ancient peoples was high mobility linked to low population densities and foraging and/or pastoral lifeways; examples in these papers include Madagascar (25) and northern Arabia (26). As many of the authors point out, dense, urbanized global populations preclude the kind of mobility documented earlier in the Holocene. Nevertheless, large-scale, climate-driven migration is increasing (32); archaeology shows us that this is a human response deeply embedded in our history, and a closer look at past examples may offer lessons on more or less successful strategies despite the tremendous disparity in scale.

Other archaeologically recovered climate mitigation strategies may also prove useful. Douglass and Cooper (25) provide the example of house structures in the Caribbean. Prehistoric houses were semipermanent and built of a combination of labor-intensive, hurricane-resistant components and perishable, easy-to-replace materials. Reconstruction was relatively easy. Modern houses in the region are often maladapted, being built of hard materials that are expensive to replace and dangerous in hurricanes and earthquakes. In northern Arabia, oasis water management systems beginning as much as 7,000 y ago allowed continuous occupation across the severe 4.2-ka drought (26), an event so extreme and so globally visible that it has recently been made the division between the Middle and Late Holocene (33).

Humans have both actively shaped and inadvertently recorded past environments. Sandweiss et al. (27) emphasize the underutilized contributions of archaeological climate proxies to paleoclimate reconstruction (their SI Appendix, table S1 lists both natural and archaeological climate proxies). In their case study of Holocene El Niño frequency variation, Sandweiss et al. review problems with natural proxies for the Peruvian coast (the heartland of El Niño) and the historical precedence and value of archaeological proxies in recognizing and delineating this variation.

Preserving the Past and Creating a Legacy for Tomorrow

Archaeologists have increasingly demonstrated the value of the archaeological record to help contextualize present-day environmental and social issues (8). However, the archaeological record itself has come under increasing threat from climate change-induced storms and sea level rise that cause erosion; the spread of development and urbanization which destroy the nonrenewable archaeological record; and looting (illegal collecting/excavation), especially in areas fraught with conflict (34–36). Focused on the study of material remains or objects, archaeology is a discipline that inherently builds collections that need to be cared for indefinitely by museums, repositories, or other facilities. These legacy collections are invaluable resources for science and society, but are also under threat from lack of funding, space, and other variables.

Two papers in this special feature tackle these issues of the disappearing past and the challenges of using, building, and caring for archaeological legacy collections, heightening these issues for a broad interdisciplinary audience (28, 29). The global coastal archaeological record provides key insight into the historical ecology of fisheries, long-term marine climate change (e.g., El Niño), and other variables, but, from Scotland to Florida, Maine, and beyond, these sites are disappearing, often before scientists or the general public learn about their value for understanding the interconnections between the human past, present, and future (28). Dawson et al. (28) chronicle these issues, documenting what is lost to science with the destruction of nonrenewable archaeological resources and demonstrating the value of engaging the public through citizen science to be stewards of this record of global cultural heritage. Citizen science remains underutilized in the field of archaeology, but it has tremendous potential for gleaning information from a record threatened by climate change and other anthropogenic perturbations.

Scores of museums, repositories, and research laboratories around the world maintain some level of archaeological collections. As St. Amand et al. (29) demonstrate, these legacy collections are also under threat, like the sites from which they came. Lack of funding, space, and, often, awareness of their value by those outside of archaeology (or sometimes within) poses threats to the care and maintenance of these collections. Nonetheless, working with legacy collections is of great value to archaeology and interdisciplinary science, with much to offer to research on the social dimensions of climate and environmental change (29). Continued site destruction often means that legacy collections are the only remaining source of paleoclimatic and human ecodynamic information in locales where the sites once existed. Working with legacy collections is also an important ethical approach to research. Many indigenous communities around the world advocate working with legacy collections in lieu of or in addition to additional excavation. If we are to continue to demonstrate the value of archaeology for addressing contemporary issues and challenges, we need to work to preserve both the rapidly eroding archaeological record and the legacy collections that have been built from those sites.

Using the Past to Look to the Future

Increasingly, archaeologists look to the future, drawing on the unparalleled long-term record of human–environmental interactions to provide context and guidance for future environmental conditions, scenarios, and planning. The papers in this special feature illustrate some of the best examples of this research, providing regional and global examples of past human response to or influence on environmental change from the Arabian deserts to Africa, the Caribbean, Peru, Australia, and the United States of America (25–27). They also demonstrate the value of using existing archaeological collections and building new collections for future research of societal significance, an endeavor that is highly ethical but difficult to fund (29). Just as we are continuing to expand the interdisciplinary research and applicability of archaeological research, the very record that we depend on for research is extremely vulnerable to climate change, a nonrenewable resource that is akin to losing volumes of history books that have never been read (24, 28, 34, 37).

Despite significant challenges, the future for archaeological contributions to interdisciplinary global research is unlimited. In their paper, Rockman and Hritz (30) look to the future and highlight the value of archaeological perspectives for illuminating the human condition, and documenting the ways that archaeology can engage with contemporary global change and climate research. They demonstrate how archaeology can help define the limits and challenges of societal responses to climate change through evaluating aspects of human experiences and memory evident in the archaeological record. Indeed, the responses of society to climate change remain one of the greatest challenges of our time, and archaeology has a role to play in helping address and, we hope, transcend this issue.

A key step forward in the coming years is to use these interdisciplinary archaeological examples to engage policy makers, other scientists, and the public. Archaeological involvement in the Intergovernmental Panel on Climate Change and other national and international groups remains relatively limited, but is growing (30). A key direction is continued collaboration across disciplines, fostering open dialogue and recognition that the human past provides a roadmap for how we got to the present and signposts for where we would like to go in the future.

1 W. Mauser *et al.*, Transdisciplinary global change research: The co-creation of knowledge for sustainability. *Curr. Opin. Environ. Sustain.* **5**, 420–431 (2013).

2 P. Holm, V. Winivarter, Climate changes studies and the human sciences. *Global Planet. Change* **156**, 115–122 (2017).

3 A. Jorgenson *et al.*, Social science perspectives on drivers of and response to global climate change. *WIRES Clim. Chan.* **10**, e54 (2019).

4 M. J. Hudson, M. Aoyama, K. C. Hoover, J. Uchiyama, Prospects and challenges for an archaeology of global climate change. *WIRES Clim. Chan.* **3**, 313–328 (2012).

5 D. H. Sandweiss, A. R. Kelley, Archaeological contributions to climate change research: The archaeological record as a paleoclimatic and paleoenvironmental archive. *Annu. Rev. Anthropol.* **41**, 371–391 (2012).

6 R. Van de Noort, *Climate Change Archaeology: Building Resilience from Research in the World's Coastal Wetlands* (Oxford University Press, 2013).

7 J. A. d'Alpoim Guedes, S. A. Crabtree, R. K. Bocinsky, T. A. Kohler, Twenty-first century approaches to ancient problems: Climate and society. *Proc. Natl. Acad. Sci. U.S.A.* **113**, 14483–14491 (2016).

8 K. W. Kintigh *et al.*, Grand challenges for archaeology. *Proc. Natl. Acad. Sci. U.S.A.* **111**, 879–880 (2014).

9 N. L. Boivin *et al.*, Ecological consequences of human niche construction: Examining long-term anthropogenic shaping of global species distributions. *Proc. Natl. Acad. Sci. U.S.A.* **113**, 6388–6396 (2016).

10 B. D. Smith, M. A. Zeder, The onset of the Anthropocene. *Anthropocene* **4**, 8–13 (2013).

11 T. Braje, Earth systems, human agency, and the Anthropocene. *J. Arch. Res.* **23**, 369–396 (2015).

12 E. Ellis *et al.*, Involve social scientists in defining the Anthropocene. *Nature* **540**, 192–193 (2016).

13 M. C. Nelson *et al*., Climate challenges, vulnerabilities, and food security. *Proc. Natl. Acad. Sci. U.S.A.* **113**, 298–303 (2016).
14 J. M. Erlandson, T. C. Rick, Archaeology meets marine ecology: The antiquity of maritime cultures and human impacts on marine fisheries and ecosystems. *Annu. Rev. Mar. Sci.* **2**, 231–251 (2010).
15 I. McKechnie *et al*., Archaeological data provide alternative hypotheses on Pacific herring (*Clupea pallasii*) distribution, abundance, and variability. *Proc. Natl. Acad. Sci. U.S.A.* **111**, E807–E816 (2014).
16 E. J. Reitz, Continuity and resilience in the central Georgia Bight (USA) fishery between 2760 BC and AD 1580. *J. Archaeol. Sci.* **41**, 716–731 (2014).
17 T. C. Rick *et al*., Millennial-scale sustainability of the Chesapeake Bay Native American oyster fishery. *Proc. Natl. Acad. Sci. U.S.A.* **113**, 6568–6573 (2016).
18 R. K. Bocinsky, T. A. Kohler, A 2,000-year reconstruction of the rain-fed maize agricultural niche in the US Southwest. *Nat. Commun.* **5**, 5618 (2014).
19 C. R. Clement *et al*., The domestication of Amazonia before European conquest. *Proc. Biol. Sci.* **282**, 20150813 (2015).
20 D. Piperno, C. McMichael, M. Bush, Amazonia and the Anthropocene: What was the spatial extent and intensity of human landscape modification in the Amazon Basin at the end of prehistory? *Holocene* **25**, 1588–1597 (2015).
21 D. Piperno, C. McMichael, M. Bush, Finding forest management in prehistoric Amazonia. *Anthropocene* **26**, 100211 (2019).
22 L. Stephens *et al*., Archaeological assessment reveals Earth's early transformation through land use. *Science* **365**, 897–902 (2019).
23 R. Hooke, Land transformation by humans: A review. *GSA Today* **22**, 4–10 (2012).
24 G. Hambrecht *et al*., Archaeological sites as Distributed Long-term Observing Networks of the Past (DONOP). *Quat. Int.*, 10.1016/j.quaint.2018.04.016 (2018).
25 K. Douglass, J. Cooper, Archaeology, environmental justice, and climate change on islands of the Caribbean and southwestern Indian Ocean. *Proc. Natl. Acad. Sci. U.S.A.* **117**, 8254–8262.
26 M. D. Petraglia, H. S. Groucutt, M. Guagnin, P. S. Breeze, N. Boivin, Human responses to climate and ecosystem change in ancient Arabia. *Proc. Natl. Acad. Sci. U.S.A.* **117**, 8263–8270.
27 D. H. Sandweiss *et al*., Archaeological climate proxies and the complexities of reconstructing Holocene El Niño in coastal Peru. *Proc. Natl. Acad. Sci. U.S.A.* **117**, 8271–8279.
28 T. Dawson, J. Hambly, A. Kelley, W. Lees, S. Miller, Coastal heritage, global climate change, public engagement, and citizen science. *Proc. Natl. Acad. Sci. U.S.A.* **117**, 8280–8286.
29 F. St. Amand *et al*., Leveraging legacy archaeological collections as proxies for climate and environmental research. *Proc. Natl. Acad. Sci. U.S.A.* **117**, 8287–8294.
30 M. Rockman, C. Hritz, Expanding use of archaeology in climate change response by changing its social environment. *Proc. Natl. Acad. Sci. U.S.A.* **117**, 8295–8302.
31 B. Fitzhugh, V. L. Butler, K. M. Bovy, M. A. Etnier, Human ecodynamics: A perspective for the study of long-term change in socioecological systems. *J. Archaeol. Sci. Rep.* **23**, 1077–1094 (2019).
32 G. J. Abel, M. Brottrager, J. Crespo Cuaresma, R. Muttarak, Climate, conflict and forced migration. *Glob. Environ. Change* **54**, 239–249 (2019).
33 International Commission on Stratigraphy, International Chronostratigraphic Chart. http://stratigraphy.org/ICSchart/ChronostratChart2018-07.pdf. Accessed 20 March 2020.
34 J. M. Erlandson, Racing a rising tide: Global warming, rising seas, and the erosion of human history. *J. Island Coast. Archaeol.* **3**, 167–169 (2008).
35 S. Pollock, Archaeology and contemporary warfare. *Annu. Rev. Anthropol.* **45**, 215–231 (2016).
36 G. Hambrecht, M. Rockman, International approaches to climate change and cultural heritage. *Am. Antiq.* **82**, 627–641 (2018).
37 T. McGovern, Burning libraries: A community response. *J. Conserv. Manag. Archaeol. Sites* **20**, 165–174 (2018).