Environmental Reconstruction in Archaeological Science

Introduction

Environments are the totality of biological and physical variables that impinge upon an organism. Most archaeological research requires some knowledge of the environmental contexts in which humans or our ancestors made decisions, performed activities, and engaged with each other and their surrounding world. Therefore, many, if not most, archaeologists require some knowledge of past environments to address questions about past societies.

Whether driven by climate, population dynamics, disturbances, or other agents, environments are constantly changing, thereby altering organism-environment relationships. Humans and other organisms may alter properties of their environments through their decisions, movements, consumption, and other behaviors. Such alterations can have long-term evolutionary legacies (Odling-Smee et al. 2003). To disentangle these relationships and understand their consequences, archaeologists must take advantage of environmental reconstructions.

Definition

Archaeologists cannot directly observe past environments. Rather, they must reconstruct properties of past environments on the basis of indirect evidence or proxy data. Environmental reconstruction is the process through which archaeologists assemble relevant evidence from biological, geological, historical, or archaeological sources to infer properties of past environments. These reconstructions can be qualitative or quantitative and are constructed from archaeological and non-archaeological records. Reconstructions often emphasize properties of the local or regional biological communities but may also focus on inferring properties of past climates.

There are diverse strategies for reconstructing paleoenvironments in archaeological research. Projects might include environmental archaeologists or paleoenvironmental specialists as part of the research team or utilize a wealth of paleoecological reconstructions that have been produced by other scientists. For example, publicly available paleoclimate datasets can be accessed through the National Oceanic and Atmospheric Administration’s Climate Data Center (www.ncdc.noaa.gov/paleo/paleo.html). Within the NOAA web portal, climate reconstructions as well as databases for charcoal, pollen, speleothems, and other proxy records are available. Regardless of the particular research strategy, all interpretations of past environmental data rely on the strength of stratigraphic and chronological control over the contexts from which the material has been collected and on uniformitarian assumptions that provide environmental meaning for biogeophysical data.

Biological Sources of Environmental Information

Biological proxy data used to reconstruct past environments broadly conforms to one of three types: (1) indicator taxa, (2) assemblage analysis, and (3) biophysical responses. Indicator taxa are used to reconstruct particular environmental properties – usually microclimatic properties – on the basis of the presence or absence of particular taxon that has a narrow range of suitable habitat conditions. Insect remains (e.g., Coleoptera or beetle remains) have proven extremely useful in reconstructing rapid, microclimate changes (Lowe & Walker 1997; Egan & Howell 2001). In other cases, indicator taxa may be used to identify the timing of human impacts, particularly in island environments (Redman 1999), based on the presence of translocated species.

Plant, animal, and palynomorph assemblages are used qualitatively to identify particular ecological communities by comparison to modern analogs. Paleoecological assemblage analysis can be used to reconstruct the structure and composition of biotic communities, or it can be used for climatic inferences. For example, the movement of biotic communities identified in pollen assemblages is a proxy for climatic shifts by using their modern climatic tolerances as a basis for analogy. Quantitative reconstructions convert the proportions of taxa represented in the paleoecological assemblage to proportions of those taxa within the ancient environment. The taphonomy of these assemblages means that this process is never straightforward (see “Key Issues” below). However, when one can control for taphonomic processes, quantitative algorithms or transfer functions convert quantitative paleoecological assemblage data for quantitative paleoenvironmental reconstructions.

In addition to looking at the presence or absence of a particular taxon, or the proportions of associated taxa in an assemblage, paleoecologists also measure the biophysical responses of individual organisms. Perhaps the best-known technique for analyzing biophysical responses in environmental reconstruction is dendrochronology – the study of precisely dated annual growth structures in woody plants (Speer 2010). The principle behind biophysical response analysis is that organism growth is affected by the most limiting factor in the environment. For example, in semiarid environments, moisture is the key growth-limiting factor. Therefore, patterns of standardized ring widths from trees growing in such environments can be used to quantitatively reconstruct past moisture patterns.

Geological Sources of Environmental Information

Sediments and soils are geological archives from which biological proxies may be collected, but they also serve as proxy records themselves. Geological proxy data are derived from the stratigraphy, morphology, mineralogy, and chemistry of landforms, soils, and sediments. Soils are the dynamic products of physical, chemical, and biological processes that alter sediments at and near the surface of the earth (Holliday 2004). Distinctive features of soils are reflective of the environments under which they formed. Specifically, soils are a product of the (1) climate, (2) biota that live in and on them, (3) topography, (4) the bedrock or sediment that is the parent material for soil formation, and (5) the time over which the other factors have been allowed to operate. These processes are not static. As a result, soils are often palimpsests of the processes that have acted upon them during the course of their formation.

Soils that retain properties from ancient but no longer active soil-forming factors are paleosols. Paleosols may be buried soils if they are no longer a part of active soil-forming processes due to subsequent burial. They may also be relict soils if they have been exhumed by subsequent erosion or were never buried. Properties of paleoenvironments may be inferred from soil chemistry (e.g., macronutrients, isotope composition), mineralogy, (macro-) morphology, and micromorphology (Holliday 2004; Goldberg & Macphail 2006).

In addition to serving as contexts for the accumulation of biological materials (see above) and as parent materials upon which soils may form, sediments may also be used to generate environmental proxy data. For example, the thickness of rhythmic variations in lake deposits (i.e., varves) can be used as a proxy for winter precipitation in some environments (Lowe & Walker 1997). Chemical sediments are minerals that are formed when ions precipitate out of solution. Chemical sedimentary proxies include evaporite minerals in paleolakes, laminated carbonates in speleothems, and biogenic carbonates in corals. Speleothems have become particularly attractive for paleoclimatic reconstructions, wherein the width of laminated bands and their isotopic composition appear to record varying amounts and sources of precipitation. Some speleothems may preserve annual or quasi-annual banding and can often be dated directly using the uranium decay series (Lowe & Walker 1997).

Geomorphology, the study of landforms and their origin, is one of the oldest approaches to reconstructing past environments. Certain landforms only develop as a consequence of particular sedimentary processes that occur under certain climatic conditions (e.g., moraines will only form along the margins of an active glacier). Anachronistic landforms indicate paleoenvironmental conditions that contrast with contemporary ones. Stratigraphic relationships between landforms also preserve evidence of environmental changes and their relative chronology (Goldberg & Macphail 2006).

Historical Sources of Environmental Information

Historical records are a valuable source of paleoenvironmental information for certain times and certain places. Like other records, historical documents are subject to varying forms of bias in their formation. Unlike biological, geological, and archaeological biases, which are taphonomic (see “Key Issues” below), biases in historical documents originate with the author of the documents. Recorder reliability, motivation, and conflicts of interest must always be taken into consideration when interpreting historical documents. However, historical observations can yield invaluable clues to the structure and composition of past environments (Russell 1997). Seemingly mundane, economic observations of planting and harvesting dates, for example, have been used to reconstruct paleotemperature changes (Egan & Howell 2001). Visual depictions of past landscapes and biota, which include rock art, landscape paintings, and early photographs, and ancient maps are also sources of information on past environments. Maps and written records of historical property surveys, for example, are samples of past forest composition that have been used for semiquantitative reconstructions of species changes in recent centuries (Russell 1997; Eggan & Howell 2001).

Archaeological Sources of Environmental Information

Archaeological sites are archives for biological and geological proxies linked directly to human-related environmental contexts. Care is required in the use of these records because the unique formation processes of paleobiological assemblages at archaeological sites affects the relevance of archaeological proxy data for landscape reconstructions (Dincauze 2000). Archaeological deposits are particularly valuable for paleoenvironmental reconstructions because they provide opportunities for age control through archaeological cross dating. Archaeological deposits are also locations of anthropogenic sedimentation that may bury paleobiological remains that might not otherwise be preserved (Lyman & Cannon 2004).

Historical Background

By the middle of the nineteenth century, Charles Lyell and Louis Agassiz demonstrated that the Earth had great antiquity. Their writings also indicated that the Earth had experienced climates and biota that were extinct or were no longer representative of contemporary environments. Ultimately, it was the stratigraphic relationship between Paleolithic artifacts and Ice Age deposits, landforms, and biota that unequivocally demonstrated the antiquity of human cultures in Europe and North America (Meltzer 2009).

The late nineteenth and early twentieth century was a period of methodological development in the study of ancient environments. Much of this initial work was dedicated to chronology, including Gerard De Geer's pioneering varve chronology that estimated the duration of the Holocene epoch and the development of dendrochronology by A. E. Douglass (Speer 2010). The study of pollen assemblages extracted from the varves described by De Geer was used to generate the first four-part environmental subdivision of the Holocene, now known as the Blytt-Sernander periodization (Lowe & Walker 1997). Although Douglass recognized that variability in ring width was related to past climates, it was not until the 1960s that the potential of tree rings as quantitative proxies for annually resolved paleoclimate reconstructions was developed (Speer 2010).

In 1937, American anthropologist Julian Steward advocated that archaeologists understand each culture – and culture change over time – in its ecological context. This position ultimately became influential for the generation of "new" archaeologists in the 1960s and 1970s. In the late 1940s and early 1950s, the pioneering excavations of Grahame Clark at the Mesolithic site of Star Carr contributed to the changing perspectives of Anglophone archaeologists from an emphasis on culture history and artifact taxonomy to the ecological and economic study of past societies. The Star Carr project, as well as the research of Robert Braidwood in Iraq, demonstrated the value of interdisciplinary collaborations in both fieldwork and analysis that produced environmental reconstructions at appropriate scales and resolutions for addressing human-environment research questions (Fagan 2001).

By the 1970s, quantitative analysis of pollen assemblages was being used to track the geographic patterns of dispersal and migration of plant taxa after deglaciation as well as to identify paleoenvironments that have no modern analog (Lowe & Walker 1997; Egan & Howell 2001). By this time, quantitative methods were developed to transform tree-ring width measurements and statistically calibrate them to historic climate observations to retrodict annual climate properties over multiple centuries or longer (Speer 2010). In recent decades, techniques for collecting starch grains and plant opal phytoliths from soils and sediments and the increasing accessibility of mass spectrometers have improved the range of independent proxies for environmental reconstruction. Analyses of light isotopes (carbon, nitrogen, and oxygen) from bones and shells to reconstruct paleoenvironments and paleo-diets have also become more commonplace (Dincauze 2000).

Key Issues

All environmental reconstructions rely on the interpretation of proxy records. Therefore, it is critical that all paleoenvironmental studies are conducted with explicit concern for (1) how the proxy records form or the taphonomy of the proxies and (2) the nature of the space-time relationships between proxies and their related environmental variables. Mismatches in spatiotemporal scale can undermine comparative analyses. Variance in the spatiotemporal scales and resolutions of archaeological and environmental records will become increasingly salient as global-, hemispheric-, and continental-scale environmental records are used by archaeologists to understand their local or regional archaeological records.

- Taphonomy, Spatiotemporal Scale and Resolution, and Lagged Responses
  All biophysical and geological proxies must be interpreted with an understanding of how the record formed. Some

biological remains, particularly some wind-borne pollen grains, can be transported great distances before they are deposited. Others, such as microfaunal remains from archaeological contexts (Dean 2005), are unlikely to move far from where they lived. In the case of palynological analyses, the nature of the sedimentary basin has implications for the spatial scale at which the assemblage is representative. Large lakes trap airborne pollen from a larger area than small lakes (Lowe & Walker 1997). Pollen from alluvial deposits originates primarily from the alluvial watershed but may be also contain pollen reworked from older deposits and wind-borne pollen from wider areas. Pollen of some taxa travels further than others and postdepositional weathering may add further bias by differentially degrading pollen (Egan & Howell 2001).

Similar issues are pertinent for the temporal scale and resolution of sedimentary proxies. Discontinuous sampling of sediments for analysis can affect the inferred timing of paleoenvironmental changes. In the case of episodic records (e.g., sedimentary charcoal records), discontinuous sampling may entirely miss key events. Additionally, the size of the sampling interval in continuous samples limits the temporal resolution of the resulting record in ways that vary based on the rate of sediment accumulation. Bioturbation and pedoturbation may homogenize materials of different ages, further reducing the precision and resolution of proxies derived from such records.

The issue of scale and relevance is important for paleobiological records from archaeological sites, as well. Whether they represent food remains or not, small mammals are less likely to be transported long distances from their habitat by ancient hunters than large mammals, thereby making them more reliable proxies for local paleoenvironments (Dean 2005). Cultural formation processes further complicate the interpretation of paleobiological archives from archaeological deposits (Schiffer 1996). Because of differentiation in taphonomy, scale, and resolution, care must be taken when comparing environmental reconstructions using different proxies from different contexts.

Finally, different biota will respond to paleoclimate changes at different rates, related to their mobility and lifespan. Mobile and short-lived insect populations respond much more quickly to climate changes (Paleoentomology: Insects and Other Arthropods in Environmental Archaeology) than long-lived and immobile tree species that must rely on seed dispersal to "migrate" to new environments (Lowe & Walker 1997). The nature of the temporal response to environmental stimuli is the lagged response for a particular proxy. Lagged responses affect the temporal resolution and precision of paleoecological proxies and must be considered in the course of building environmental reconstructions.

- Human Impacts on Ancient Environments

Beyond descriptive accounts of past environments, scientists reconstruct paleoenvironments to identify causes of environmental changes. Testing causal explanations involves chronological comparisons of hypothetical cause and response variables. Demonstrations of correlation are not sufficient to infer causation, however. It is necessary to demonstrate that (1) changes in the causal factor precede the response and (2) to specify the mechanisms by which the hypothesized causal factor would drive the observed changes. The causal mechanism should be amenable to testing with additional paleoenvironmental or archaeological data.

Human impacts on ancient environments have long been controversial, but they have never been more visible in the academic literature than they are today (Redman 1999). Scientists recognize that humans, like all organisms (Odling-Smee et al. 2003), impact their environments (Redman 1999; Dincauze 2000) and that the likelihood of ancient human impacts is high, albeit variable in space and time. This does not necessitate that all environmental changes on human timescales were caused by ancient societies, however. Attribution of anthropogenic causes to environmental degradation in the past is particularly challenging because it is often used for political purposes. In light of the far-reaching implications and visibility of some human-environment impact narratives, archaeologists should be particularly careful to be rigorous, explicit, and precise in their use of paleoenvironmental, paleoclimatic, and archaeological evidence.

The interpretive challenges and political pitfalls of human-impacts research are well illustrated by the decades-old debate concerning the mass extinctions in the Late Pleistocene. The apparent chronological correlation between the colonization of North America and Australia and the extinction of most large terrestrial fauna has been used to implicate human predation or "overkill" as the cause of the extinctions. Beyond poorly resolved chronologies (Grayson 2007), however, there is very little direct evidence to support direct predation or "overkill" as a mechanism. Alternative explanations of climate-driven or human-induced habitat changes are also plagued by poor chronological resolution and poorly supported evidence for the causal mechanisms.

A novel study by Gill et al. (2009) demonstrates the value of using multiple, independent proxies at appropriate temporal and spatial scales to identify the relationships between key processes and test alternative hypotheses of "overkill" and climate change as causes of the extinction. Gill et al. (2009) estimated mega-herbivore biomass through a palynological proxy (the dung fungus Sporormiella), infer past vegetation communities through pollen assemblages, and use micro-charcoal as a proxy for biomass burning. By measuring each proxy from the same samples, the authors built robust estimates of the temporal associations between proxies for key response and causal variables. These records indicate that herbivore populations began declining 1,000 years before major changes in fire activity and vegetation occurred. Therefore, climate-driven habitat change and fire-driven habitat change can be excluded as causal factors because both vegetation and fire activity postdate the decline in herbivore populations. Even with the uncertainty of the radiocarbon chronology for these cores, the relative relationship of events is securely known because of the stratigraphic relationships between the samples. In the absolute chronologies, the decline in herbivore populations precedes the archaeological evidence for local human populations, thus rejecting the "overkill hypothesis" (Meltzer 2009).

- Scale Mismatches in Environmental Analysis
  The abundance of paleoclimatic reconstructions at the continental to hemispheric scales offers a wealth of analytical opportunities for reconstructing human-environment relationships. Careless comparisons of coarse-grained archaeological chronologies with hemispheric climate reconstructions, however, can lead to spurious conclusions. Given chronological uncertainties in archaeological datasets, one can find a reconstructed climate change that will roughly correlate with the culture change of interest. If the large-scale climatic phenomenon cannot be demonstrated to have local environmental impacts that affected the lives of human residents, however, such correlations are meaningless. For example, the Younger Dryas Chronozone was a period when many, but not all, Northern Hemisphere paleoclimate records indicate rapid cooling before the onset of the Holocene. It has been suggested that environmental changes during the Younger Dryas transformed Paleoindian cultures across North America, although given environmental variability across the continent, it is unlikely that it could have done so uniformly (Meltzer & Holliday 2010).
  Mismatches in scale must be carefully considered in large-scale meta-analyses that combine local records into regional- or continental-scale aggregates to identify emergent properties. Such meta-analyses reduce variance between records, thus enhancing the shared signal between them, presumably because of shared causal factors acting at the same spatial scale. With few exceptions, human activities are time transgressive and variable in space. Any influence that human activities may have had on local records would likely be removed from records aggregated in this way. Although archaeological records could be similarly aggregated at a large spatial scale, mismatches in the representativeness of meta-records from archaeology and paleoecology could lead to spurious conclusions.
  A recent effort to compare meta-analyses of charcoal records and radiocarbon-dated archaeological sites in the Australasian region illustrates the problems of mismatched scales and resolutions. Although both the aggregated fire history and archaeological datasets cover overlapping areas, the ecological zones represented by each dataset are not precisely the same (e.g., the western semiarid interior is well represented in the archaeological record and poorly represented in the fire record). When both datasets are aggregated, the lack of apparent correlation between the records led the authors to suggest that aboriginal Australians must have had no impact on past fires (Mooney et al. 2011). This conclusion is inconsistent with historical, ethnographic, and other paleoecological observations and is not warranted by the analytical methods because the datasets are mismatched in spatiotemporal scale. Such meta-analyses are likely to become more common in the future. Collaboration with archaeologists that includes appropriate scalar relationships between the datasets and their relevance to particular research questions will improve the quality of such endeavors.

Future Directions

Increasingly, environmental reconstructions are central components of archaeological research programs. These efforts improve our understanding of past societies, their legacies on their surroundings, and their responses to environmental changes. Environmental archaeology has an important role to play in addressing outstanding questions of human impacts on environments that have had evolutionary consequences for humans and other organisms. Recent hypotheses about the role of ancient land use affecting Holocene climates will also require archaeological testing. These are not exclusively academic endeavors. Environmental archaeology has begun to contribute to discussions about solving modern social-environmental problems. Progress on these fronts will likely continue in the foreseeable future.

- Human Contributions to Ancient Climate Change
  Human agency in global warming since the industrial era is not in dispute among scientists. Paleoclimatologist William Ruddiman (2005), however, has provocatively suggested that human impacts on Earth's climate system long predate the industrial era. Ruddiman suggests (1) that deforestation for agriculture in temperate forests altered global carbon cycling beginning 8,000 years ago and (2) that the development of paddy rice agriculture increased tropical methane releases over the last 5,500 years. These greenhouse gas emissions stabilized Holocene climates and delayed the start of the next glacial period. From an atmospheric perspective, these hypotheses explain the anomalous relationships between carbon dioxide and methane concentrations in the Holocene relative to previous interglacial periods. At present, however, these hypotheses lack sufficient archaeological support. Archaeologists will play a key role in testing the Ruddiman hypotheses in the future with important implications for contemporary policy discussions regarding global warming.

- Niche Construction and Human Biological and Cultural Evolution
  Evolutionary biologists are increasingly turning their attention to the role of niche construction as an evolutionary process. Niche construction is the process by which organisms alter the selective pressures on themselves, their descendants, and other organisms in their environment (Odling-Smee et al. 2003). All organisms affect their environments, but humans are quintessential niche constructors. Explicit study of the evolutionary legacies of human behaviors and their environmental impacts is lacking, however. In the future, archaeologists and paleoenvironmental specialists will begin to untangle the role of niche construction in hominin evolutionary history.

- Applied Research for Biodiversity Conservation or Ecological Restoration
  Modern environments are a product of their history. Land managers and conservation biologists increasingly recognize the need to understand the history of a particular landscape to ensure its sustainability in an ever-changing world. Data about the variability in structure, composition, and key ecological processes of past environments are key to this type of management known as applied historical ecology (Swetnam et al. 1999). Archaeologists have been late to recognize their importance to this field but increasingly recognize that applied historical ecology needs archaeology to understand how humans contributed to past ecological structures, compositions, and dynamics (van der Leeuw & Redman 2002). Zooarchaeologists have spearheaded archaeological research that is relevant for contemporary environmental problems (Lyman & Cannon 2004), but other environmental archaeologists are poised to contribute as well. Archaeological contributions to applied historical ecology will require increased collaboration with non-archaeologists and, in most cases, will require research designs that are driven by non-anthropocentric questions and goals. This may be an uncomfortable future for archaeologists from anthropological traditions, but by emphasizing the social dimensions that are necessary to understand social-ecological sustainability, it is distinctly anthropological. Perhaps, in the future, environmental archaeology will be recognized as a cornerstone field within applied anthropology.

Cross-References

Braidwood, Robert Biographical
Clarke, Graham Biographical
Dating Techniques in Archaeological Science
Molluscs (Isotopes), Environmental Archaeology Analyses of
Multiple Microfossil Extraction in Environmental Archaeology
North American Megafauna Extinction: Climate or Overhunting?
North American Terminal Pleistocene Extinctions: Current Views
Optical Mineralogy of Soils and Sediments in Environmental Archaeology
Pacific Island Colonisation, Environmental Archaeological Evidence of
Paleoentomology: Insects and Other Arthropods in Environmental Archaeology
Paleosols, Environmental Archaeology of
People as Agents of Environmental Change

Phytoliths, Environmental Archaeology Analyses of
Resilience in Environmental Archaeology
Soil Pollen (Plant Microfossils), Environmental Archaeology Analyses of
Star Carr, Environmental Archaeology
Taphonomy of Plant Micro-Remains in Environmental Archaeology

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