Studying human responses to environmental change: Trends and trajectories of archaeological research

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Abstract

Environmental archaeological enquiry has a long and vibrant history. Many of the same questions have persisted in archaeological dialogues over the past century. In particular, the effects of environmental change on demographic patterns, health, and societal stability are among the most pervasive questions being addressed by anthropological research. These studies have limitations, however. For example, evaluations of the complex relationships between environmental variables and human responses are only just beginning to emerge in anthropological literature. This goal requires high-resolution paleoclimate datasets and the use of quantitative modelling rooted in evolutionary and complex systems theory. This paper serves as a broad review of advances in environmental archaeological enquiry associated with environmental change and human response. I argue that the future of archaeological questions concerning human-environmental connection requires a re-evaluation of causality and the incorporation of complex systems approaches to address human responses to external pressures.

Keywords: climate change, human-environmental interaction, environmental modelling, paleoclimate, causality, complex systems

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Changes in climate (e.g., precipitation and temperature) – and environmental change more broadly – have been hot-button issues for much of the 21st century. In the past, environmental changes have led to various responses by human populations. Many times, people change locations and exploit new resources, and in particularly dire situations, we adapt through technological innovations. Because ecological conditions are such an integral part of humanity's survival, it is no wonder that archaeologists have long been interested in the relationship that humans have with their environment (e.g., Boas 1896, 1932; Flannery 1969, 1972; Moran 1990; Netting 1972, 1993; Rappaport 1967; Redman 1999; Steward 1955).

Some of the first research on this matter was undertaken in the 19th century by geologists and other researchers who had interests in understanding changes in past human settlement (e.g., Nilsson 1868; Steenstrup 1837, 1842; Worsaae 1849; also see Morlot 1861; Trigger 2006). Over the past century researchers have asked a wider range of questions pertaining to human-environmental connectivity and interaction. Today, these questions take on even more importance as the modern world grapples with climate change and abrupt environmental fluctuations.

Advances in methods and techniques geared towards the investigation of environmental variables during the 20th and 21st centuries have permitted for the assessment of many key questions in anthropology concerned with human-environmental relationships (e.g., Kintigh et al. 2014). Throughout the history of anthropology, as new and interesting methods and datasets have been developed, these questions have been addressed in different ways. Nevertheless, limitations remain. Anthropologists have long struggled with developing comprehensive high-resolution datasets with which we can compare very localized environmental events to societal responses. Building from this point, a secondary challenge for scholars is determining a way to establish definitive interconnections between environmental events and human responses and vice versa. Theoretical and methodological developments made over the past several decades have begun alleviating aspects of these challenges.

One of the fundamental limitations of most studies on the relationship between environment and human survivability is the 'correlation limitation' – i.e., most studies can only display certain associations between environmental changes and human responses but are yet to establish causal relationships between environmental factors and human responses (see d'Alpoim Guedes et al. 2016; also see Contreras 2016). Kintigh and Ingram (2018, 30) emphasize an important point:

> to make an argument for [environmental conditions causing cultural transitions], one cannot simply point out the temporal coincidence. Causal arguments must rely on additional lines of evidence (e.g. for dietary stress, conflict) that support a much more strongly contextualized argument linking the climatic and cultural events, and they must consider other climatic episodes of comparable magnitude, and their associated cultural contexts, that did not result in transitions.

As I demonstrate below, researchers have long struggled with this challenge. However, recent studies have made some strides in this particular area using quantitative computer models and new theoretical approaches.

Throughout archaeological history, there have been many different lines of questioning pertaining to human-environmental interactions. In what follows, I trace the historical trajectories of environmental archaeological research, paying attention to the methods and theories employed for addressing environmental questions. Next, I discuss the trends and trajectories of environmental archaeological research in the 21st century. Finally, I offer some potential future directions for archaeological research focusing on human-environmental interaction. Specifically, I argue that the incorporation of complex systems theory into environmental archaeological research is a necessary step for improving our understanding of the effects of environmental conditions on human societies and vice versa. This body of theory can provide greater insight into what affects the resilience of human systems and help to address issues of causation (i.e., the ‘correlation limitation’) in human-environmental studies. Furthermore, I assert that archaeological research must become integrated with other disciplines to make the greatest impact.

Human-environmental research in archaeology: historical trends

The first interest in the environment as a factor in human development is visible in the 19th century (Figure 1). At that time, geologists and antiquarians were interested in understanding changes in prehistoric settlement patterns (see Trigger 2006). Excavations and stratigraphic data collected led some researchers to try and construct ideas about what elements comprised prehistoric environments (e.g., Steenstrup 1837, 1842). Basic principles like stratigraphic superposition allowed researchers to identify features of past environments – particularly in well preserved areas like bogs – and gain a basic understanding of the types of fauna and flora that were present in the distant past. Understandings were limited, however, as no robust proxy datasets were yet developed, nor were there systematic records of environmental variables. Nevertheless, stratigraphy allowed researchers to determine relative changes in environments through time, and such techniques are still used for environmental studies today (e.g., Huckleberry et al. 2018). By the turn of the 20th century several researchers used the environment to address questions concerning settlement histories, cultural and biological evolution, human land-use, and human diversity (e.g., Boas 1912; Dart 1925; Huntington 1924; Osborn 1916; Sears 1932; Steward 1937; also see Trigger 2006).

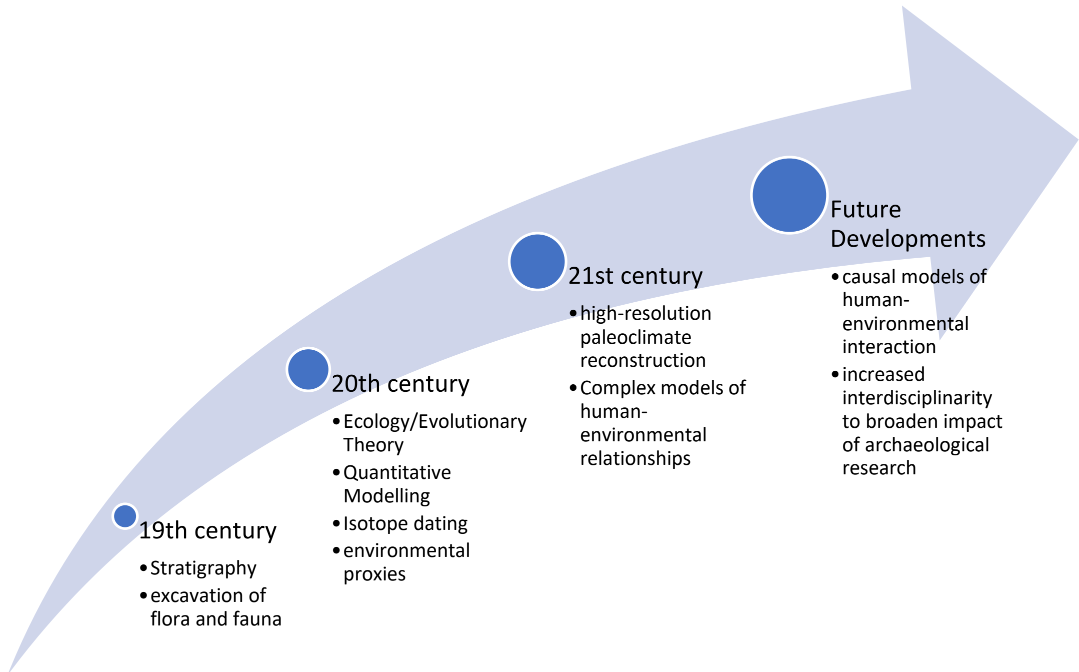

Figure 1: Developments in Methods and Techniques for Studying Human-Environment Interaction.

Much of the earliest literature concerns itself with establishing timelines of human cultural phases. The geological principles of stratigraphy and superposition were dominant in establishing lengths of occupation, and the presence of certain materials – especially metals – were used to establish cultural chronological sequences (Morlot 1861). In these endeavours to determine timings of cultural succession, investigations also led to conclusions that humans were severely altering their environments. The loss of pine trees as recorded in the peat bogs in Denmark was used as an indicator of vegetative shifts from pine to oak that also corresponded with certain technological changes associated with the stone and bronze ages (Morlot 1861; Steenstrup 1842). While it is now understood that changes in these vegetative populations are the result of more complicated hydrological phenomena and are not merely anthropogenic, these early researchers began to realize that humans could have severe environmental impacts.

In addition to the basic questions of time, many other enquiries that are still investigated today were first brought up by many archaeologists during the 19th century. For example, questions concerning animal domestication were investigated by examining changes in the skeletal morphology of species like dogs through stratigraphic layers; this led researchers to the conclusion that these changes represent the first instances of domestication (Morlot 1861). Additional studies of sheep bones point to similar conclusions and present relative dates for the beginnings of animal domestication in specific parts of the world (Steenstrup 1842). Geologic research also gave archaeologists insights into changing coastal zones through time, and changes in mollusc assemblages provided insights into changing salinity levels in certain areas (Morlot 1861). As such, the foundations for environmental archaeology were already well established by the end of the 19th century, even if in a limited manner.

In their seminal article, Steward and Setzler (1938) emphasize the importance of studying human behaviours within different environmental contexts; or in other words, human ecology. This, in many ways, marks the beginnings of a new form of archaeology directly concerned with ecological and environmental variables and their impacts on human and cultural development. Eventually coined ‘cultural ecology’ by Steward (1955), the first half of the 20th century sees a range of anthropological enquiry being framed within an emphasis on environmental variables (e.g., Boas 1912, 1932; Dart 1925; Huntington 1924; Kroeber 1915, 1917; Osborn 1916; Sanders 1956; Sears 1932; Steward 1937, 1955; Steward and Setzler 1938; White 1949). Central to these early studies were environmental conditions for agricultural and horticultural suitability (e.g., Steward 1937) and how food acquisition/production from various ecological conditions was either restrictive or conducive to population growth and the development of societal organization. This continues in later work where environmental zones are studied in context of population densities (Sanders 1956).

Researchers realized quite early that reconstructing climate and environmental histories required climatologists and geologists, and not merely historical documents (Huntington 1924, 19). In certain instances – particularly for long time depths delving into early modern humans – there was knowledge of some local flora and fauna that gave direct insight into environmental conditions (Osborn 1916; Steenstrup 1837). In the second half of the 20th century, improvements in environmental proxies gave rise to a slew of archaeological studies employing climatological modelling for assessing human-environmental connections – especially for addressing ideas about societal collapse (e.g., Cheptow-Lusty et al. 1998; Thompson et al. 1994; Van Geel et al. 1996). The extrapolation of broad, global-scale proxy data for applications in specific (often geographically distant) environments by many of these studies limited their validity, however, and many of these studies fall into the trap of 'deterministic' interpretations of severe climatological flux on human survival (see Erickson 1999).

Apart from the use of environmental data, some researchers relied on indirect means of assessing ecological conditions in archaeological contexts, looking at ethnographic and ethnohistoric accounts. For example, Sanders (1956) uses Spanish colonial records to make estimates of population size and settlement organization in Central Mexico. While some 'precontact' documents are consulted, the majority relies on evidence which may not be directly applicable to studies of pre-contact indigenous populations and is thus a major limitation of such an approach. Despite its problems, the incorporation of cultural information and historical records was a central argument of Steward (1955) and others and remains important today: we cannot study people without any cultural context on which to base our interpretations.

The connection between environmental and archaeology studies – especially those regarding settlement patterning – remained strong well into the mid-20th century (Trigger 2006, 373). The focus of many environmental archaeology investigations began to shift towards the incorporation of ecological principles (e.g., Flannery 1969, 1972; Geertz 1972; Harris 1966; Netting 1973, 1993; O'Connell and Hawkes 1981; Rappaport 1967; Walker et al. 2004). As such, these inquiries were directed at investigations into human behaviour and cognition, specifically human capacities for strategizing environmental exploitation and resource use (Trigger 2006, 524-525). With attention now paid to historical and cultural context via new theoretical insights of agency and practice, the question of human response to environmental stressors was now being addressed in a manner consistent with the warnings of Steward (1955). Environment was no longer the *sine qua non* to human survival; rather, it was human reactions to environment that were emphasized.

To account for human response to environmental variables, scholars begin to rely on mathematical modelling among other technological and methodological advances to study human-environmental interactions (e.g., Carneiro 1970a; Thomas 1973; Tugby 1965). Much of the archaeological literature during the second half of the 20th century dealing with environmental questions relies on the theories developed within human behavioural ecology (HBE) and Neo-Darwinian theory (e.g., Blurton Jones 1986; Dyson-Hudson and Smith 1978; Moran 1990; Neiman 1997; O'Connell and Hawkes 1981; also see Bird and O'Connell 2006; Codding and Bird 2015) and this continues to be a trend in the 21st century (e.g., Allen 2004; Bleige Bird et al. 2001, 2008; d'Alpoim Guedes et al. 2018; Lamba and Mace 2011; Robinson et al. 2019; Smith et al. 2003; Winterhalder et al. 2010; Yaworsky and Codding 2018). In such approaches, researchers have used quantitative models from population ecology and evolutionary biology to assess the rationale behind human decision-making behaviours. This research has identified some patterns that suggest environmental conditions are responsible – in part – for behaviour related to foraging practices (O'Connell and Hawkes 1981), birth spacing intervals (Blurton Jones 1986), settlement placement choice (Winterhalder et al. 2010; Yaworski and Codding 2018) and even the construction of monumental architecture (Neiman 1997). In as much as HBE has illustrated direct relationships between environmental variables and human response, it has also helped to debunk many 'deterministic' approaches to the study of human-environment relationships.

For example, the use of social theory within HBE (e.g., costly signalling) has allowed for the understanding that decisions are often partially related to environmental resources but are equally (and sometimes more so) affected by social customs and cultural traditions (e.g., Bliege-Bird et al. 2001; Smith et al. 2003; Sosis and Alcorta 2003). Furthermore, the quantitative rigor of many HBE models illustrates that in many instances, the assumed causal relationship between environmental conditions and human response is misconceived, giving way to a re-evaluation of hypotheses and a further exemplification that environment does not determine human behaviour outright.

Improvements in dating techniques in the second-half of the 20th century permitted for the use of artefacts and ecofacts, including shells, pollen, and sediments for dating archaeological deposits and understanding changes in environmental conditions (e.g., Chepstow-Lusty et al. 1998; Leyden 1985; Matteson 1960; Thompson et al. 1994). Similar work using isotope data has continued in the 21st century and has allowed researchers to understand the first instances of human occupation of various parts of the world, as well as the immediate impact of humans on ecological systems (e.g., Burney et al. 2004; Cañellas-Boltà et al. 2013; Hunt and Lipo 2006; Roberts et al. 2016). This trend towards isotope studies of past environmental conditions has permitted for the detection of human-environment interactions even in the absence of actual artefacts signalling human occupation. In this way, we can now begin to understand even the most small-scale impacts of humans on ecological systems. This is a breakthrough in our ability to address the degree of impact that humans have had on our environmental surroundings.

Environmental Archaeology in the 21st Century

Environmental archaeology today is very much focused on environmental change and its effects on human systems. In the age of research on the 'Anthropocene', it has been emphasized that human-environmental relationships are extraordinarily complex and require interdisciplinary analyses to fully grasp the nature of human-environmental interactions (e.g., Douglass et al. 2018). Recent literature emphasizes that there are many dimensions to which the environment and humans influence one another, and archaeologists have largely focused on the influence of environment on demographic patterns, health and disease transmission, and societal (in)stability.

The linkage between environmental conditions and demographic patterns has been a focal point of research both within archaeology and anthropology as a whole. Biological anthropological research has demonstrated that hominins first begin their migration out of Africa in an environmental context of warming temperatures and changing ecologies (Fleagle and Gilbert 2006; Jablonski 2005). The extension of the geographical range of modern humans was also limited by extreme environments (such as the cold climates of northern Europe). For example, geological and archaeological evidence suggests that migration into the Americas was limited by sea levels during the Holocene (see Dixon 2001). However, modern humans managed to overcome some of these environmental challenges through our cognitive abilities, and technological innovation permitted for enhanced adaptation to a wider range of environmental conditions (Fleagle and Gilbert 2006; Hoffecker 2017). Even the development of essential societal components like food storage were based in a background of environmental conditions (Testart 1982).

Environmental connections to demographic patterns have been incorporated directly into questions concerning the rise of social complexity. For example, Carneiro's (1970b) notion of 'environmental circumscription' directly links the growth of populations and the establishment of chiefdoms and states to the availability of resources and a population's ability to control those resources. This idea has since been quantitatively analysed using computer modelling (Gavrilets et al. 2010) and illustrates the complex nature of societal emergence, collapse, and environmental variables. Of course, there are contradictory hypotheses regarding Carneiro's ideas (e.g., Feinman and Carballo 2018) who emphasize collective action and other strategies above warfare and environmental pressures. Computer simulations of 'societal complexity' also show mixed results depending upon the framework used (Gravilets et al. 2010; Turchin n.d.), illustrating that the causes for such phenomena are varied and multitudinous. Any attempts to identify a primary or sole driver of change – whether they are environmental or otherwise – are inherently missing large parts of the problem.

Studies by archaeologists, anthropologists, and other researchers alike have investigated how different interactions with our environmental surroundings impact our health (e.g., Armelagos et al. 1991; Cohen and Armelagos 1984; Cook 1979; Crosby 1976, 1976; Jablonski and Chaplin 2012; McNeill 2004; Wolfe et al. 2007). By understanding how our environmental surroundings impact our well-being, studies regarding health and environment have made substantial impacts, not just within anthropology, but medicine as well (e.g., Kawachi and Wamala 2007; Patz et al. 2005; Watz et al. 2015). As such, the questions that have guided anthropology in the realm of human-environmental interactions are now spreading into interdisciplinary projects that can have real and visible impacts on the wellbeing of contemporary populations because of our understanding of the past.

Such interdisciplinary research has allowed for great strides in understanding societal responses to environmental change (see Dong 2018). Archaeology and anthropology play a major role in this research because our discipline allows us to look to past people's ideas and innovations to cope with identical issues in today's world. Additionally, many studies that attempt to grapple with such environmental-human connections ultimately require anthropologists and archaeologists, because in research without such input, deterministic arguments begin to emerge for a range of arguments, most notably that of collapse of societies (e.g., Büntgen et al. 2011; Diamond 2005). Archaeology has grappled with determinism – environmental and otherwise – throughout its history (see Trigger 2006) and has become adept at challenging these types of conclusions – particularly through quantitatively and theoretically rigorous frameworks which incorporate social, cultural, and environmental variables. Thus, anthropology provides fundamental benefits to the study of human-evnrionmental connectivity and can contribute to contemporary situations.

Recently, archaeologists have refocused their attention on human responses to climate change and environmental degradation, but now explicitly look at how past experiences can inform contemporary responses to similar threats (e.g., deMenocal 2001; Hsaing et al. 2013; Kennett and Marwan 2015; Ortloff and Kolata 1993; Redman 1999; Redman et al. 2007; Thompson et al. 1994; Van Geel et al. 1996; Weiss 1997). One recent study utilizing mathematical modelling demonstrates how environmental changes caused the breakdown of irrigation infrastructure in the Cambodian city of Angkor (Penny et al. 2018). By modelling rates of erosion with various environmental conditions (including event magnitude as suggested by

Kintigh and Ingram [2018]), the researchers illustrate how unstable climatological conditions have adverse effects on human systems. This is just one example of how environmental modelling is informing archaeologists to the relationship between environmental conditions and human survivability beyond simple correlations (also see Armit et al. 2014; Hsaing et al. 2013; Lamba and Mace 2011).

This refocus on climatological and environmental changes has culminated in the study of a new geologic epoch, the Anthropocene (Crutzen and Stoermer 2000; Earlandson and Braje 2014; Lane 2015), which epitomizes the study of human impacts on environmental surroundings. Although studies of environment and its effects on people is nothing new (see for example Huntington 1924), these new studies are directly contributing to a broader literature on sustainability, health, environmental justice, and public policy regarding this issue (e.g., Mentaschi et al. 2018; Patz et al. 2005; Redman et al. 2007; Scheffer et al. 2012; Schleussner et al. 2016; Tainter 2014; Weiss and Bradley 2001).

Central to much of this new research is the concept of resilience (see Davies et al. 2018; Walker et al. 2004). Resilience research has contributed to the understanding of how a system can respond to and withstand external and internal stressors. Within anthropology, resilience theory has resulted in an increased understanding of how human actions can contribute to a loss of adaptability, but also how we can recognize these behaviours and potentially correct these issues in the present (e.g., Burger et al. 2012; Costanza et al. 2007; Hegmon et al. 2008; Turck and Thompson 2016). Ultimately, addressing contemporary issues concerning environmental change are unlikely to be solved without an understanding of resilience theory and the contributions made by archaeological research.

As has been emphasized for decades of anthropological work, our research must seek to improve our understandings of modern phenomena and make impacts beyond the field itself (*sensu* Steward and Setzler 1938, 10). It is for this reason that questions concerning human-environment interaction have remained such a vital part of anthropological and archaeological research. Studies of this nature have far-reaching implications well beyond academia and can impact policies that can improve contemporary society (e.g., d'Alpoim Guedes et al. 2016; Redman et al. 2007). There are some who question the nature of how applicable archaeological research can be on the modern world (see Lane 2015), and our field certainly has its limitations. However, by collaborating between our subfields and looking to other disciplines altogether (e.g., computer science, geology, environmental science, public health, etc.) we can work to produce research that has real impacts to modern day communities. For environmental archaeologists, specifically, such collaborations can provide important insights to a world facing greater threats from environmental change.

This kind of impact requires the focusing of questions and dissemination of information directly to the public in ways that can be explicitly incorporated into public policy. We are in a unique position to be able to address the question of how the past – in terms of both innovations and adaptations to environmental instability/change – can help to direct our responses to similar changes in the present. These steps are vital to ensuring that our knowledge in this particular area can evoke real change in our world and by extension help to limit hardships and disasters that have occurred before and are likely to repeat themselves. This notion of public engagement is not isolated to this line of archaeological enquiry alone, however, and has been the subject of a movement towards inclusive forms of anthropology (e.g., Harrison and Schofield 2009; Gould 2007; Little and Shackel 2014; Merriman 2004).

Human-environmental research in archaeology: trajectories for future studies

Researchers have made great strides in improving how we study past environments (Figure 1), and theoretical and methodological innovations in the 20th century, specifically, have allowed for unprecedented improvements in developing quantitative models of environmental phenomena. In a recent review of environmental archaeology literature over the past 15 years, Carleton and Collard (2019) conclude that there has been a spike in environmentally focused studies, specifically those focusing on environmental change and paleoclimate reconstruction. In reviewing the literature included in this article, which is inherently focused on research covering these topics, there is a noticeable increase in article quantity over time as well as the incorporation of developments from complex systems theory and paleoclimate reconstruction (see Figure 2). While not exhaustive, this illustrates an important shift which is beginning to take place within environmental archaeology.

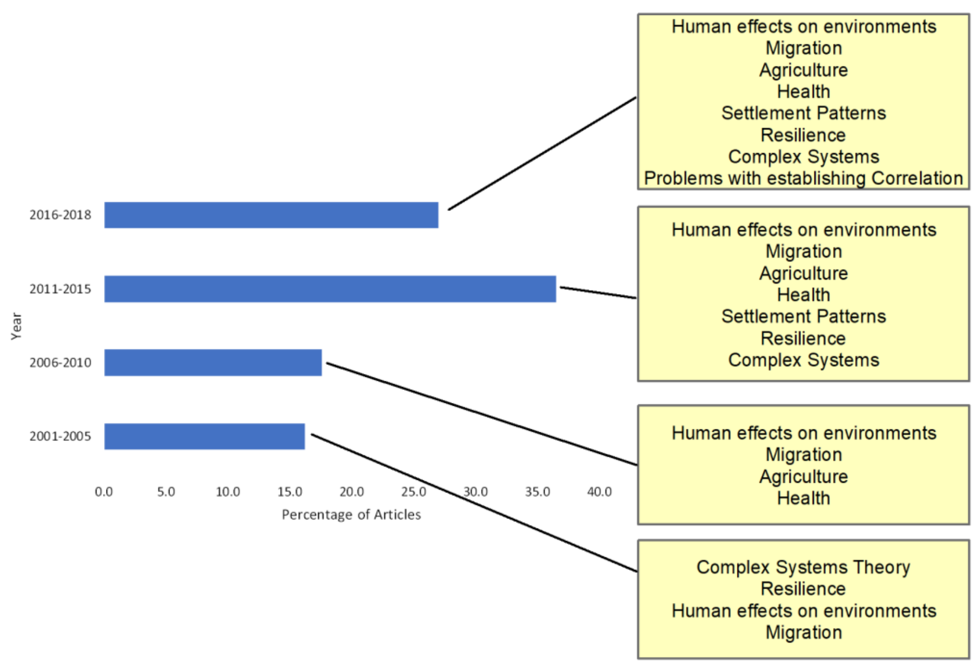

Figure 2: Shows the temporal breakdown of articles referenced in this paper in their contributions to the study of archaeological questions concerning human-environmental

interactions. The number of articles is trending upwards, with the number of major themes and foci following suit. The upward trend in environmental archaeological research conforms with prior studies by Carlton and Collard (2019) and Dong (2018).

One of the trends identified which presents one of greatest challenges for researchers is demonstrating causality between environmental variables and human response, and vice versa. How can we develop causal arguments for social changes via environmental alterations? We must develop robust models via explicit and sufficient theory (*sensu* Lewontin 1974). Returning to Kintigh and Ingram (2018), we must account for more than temporal coincidences between two events. Causality requires empirical association, temporal priority of the independent variable, and accuracy by accounting for confounding variables (Chambliss and Schutt 2006; also see Contreras 2016). To establish causal linkages, we must avoid *post hoc, ergo propter hoc* arguments and remember that no phenomenon ever has one single cause. As such, we must be able to differentiate between ultimate and proximate causation and understand that in most instances we will be looking for proximate causes; for social change is extraordinarily complex, and thus finding the 'one true cause' is impossible. *Sine qua non* arguments regarding societal change and external factors are antithetical to how such systems work, and when these systems span through diverse geographic and environmental regions, the complexity of change increases even further. As such, studying causal relationships between environmental and human interaction requires the inclusion of a multitude of different variables – including political, economic, and social factors on top of environmental contexts – to determine associations and proximate relationships between environmental and social changes.

New methods and techniques are also needed to better understand how environmental conditions affect societal development. Importantly, we need high resolution proxy datasets to understand not merely general climatic conditions, but highly localized situations as well.

Recently, Contreras et al. (2018) developed a geographically weighted approach to directly tying paleoclimate data to geographically placed archaeological data. In this ‘downscaling’ approach, proxy data are compared with modern geographically situated datasets and then masked onto a spatial surface to create a raster of paleoclimate data values. In so doing, environmental data can be directly linked to archaeological events in terms of their spatial and temporal extents and the changes of these values through time and space. While there remain issues with the extrapolation of past environmental conditions from modern data – as well as the temporal scale of the data used – the approach provides a useful way forward to tackling the problem of relating proxy data with localized cultural events.

Temporal resolution of environmental proxies has been improving in recent years, reaching resolutions into decadal spans, as well as centennial spans (Marcott et al. 2013). This resolution of proxy data has allowed for modelling of agricultural innovation and productivity on a global – as well as regional – scale (d’Alpoim Guedes et al. 2018). There are a slew of different proxies for measuring past environmental conditions, including geological, biological, terrestrial, glaciological, and historical materials. Some of the more well-known archives are lake core sediments, ice cores, and tree-rings which have been used for several decades for a range of purposes spanning from examination of stable isotopes, calculation of dry and wet seasons, and precipitation levels (e.g., Bell 1952; Bakka and Kaland 1971; Thompson et al. 1994). Others, such as diatoms and microbotanical remains, have become widely used more recently (e.g., García-Granero et al. 2015; Stoemer and Smol 1999) to understand direct effects of environmental conditions on organic life. Each of these different proxies have strengths and weaknesses and can detect different components of the past environment (see Bradley 2015 for a detailed discussion).

For example, speleothems found in caves have been used to construct annual resolution records of precipitation and have been used successfully in many places around the world (e.g., Bar-Mathews et al. 1997; Scroxton et al. 2017). These records can be directly tied to archaeological sites and cultural events due to their spatial relevance. However, these proxies can be biased to specific conditions and thus only contain records for specific seasons or time periods in which calcite was able to form (see Wong et al. 2011). In contrast, recent work using cores from coral reefs (Zinke 2009) has illustrated the potential to reconstruct extremely high-resolution precipitation and temperature records (seasonal, annual, and decadal) of more broad spatial scales. These records have been constructed for the past several hundred years and researchers believe that ancient corals in some regions may allow for these records to extend back thousands of years (Douglass and Zinke 2015). Of course, one of the limitations with corals is that they are spatially disconnected from many archaeological sites, and their interpretation is challenged by complex ocean-atmospheric relationships. However, as these studies increase, coral proxies will help in establishing a relatively continuous record of tropical ocean conditions (Bradley 2015). Especially in coastal regions today, understanding the complex dynamics between human survivability and environmental shifts is vital, as projected changes in sea-levels and temperature in the next few decades will require substantial innovation and adaptation to drastically changing coastal resources and habitat suitability (see IPCC 2018).

Because there are a plethora of proxies to choose from, each of which provides its own benefits and drawbacks (see Bradley 2015), the way forward is the adoption of multiproxy reconstructions. In such a study, a slew of environmental proxies are used conjointly to improve reconstructions, and this has been proven highly effective in paleoclimate research (Li et al. 2010). For example, de Boer et al. (2014) utilize diatoms, pollen, sediment composition and stable isotopes to investigate environmental and climatological changes in Mauritius in the Indian Ocean. Each proxy was used for a specific purpose: pollen for calculating precipitation changes, diatoms and other micro- and macro-organisms for decadal drought conditions and salinity measurements, and stable isotopes and sediment composition for centennial drought and moisture events. Because each proxy has specific capabilities (and resolutions), by combining them together, researchers can better understand short-term and long-term trends and gather more information than any single proxy can reveal on its own.

The development of robust models of human-environmental relationships are getting us closer to establishing causal links between these variables and human systems. In particular, advances in computer simulations using complex systems theory and agent-based modelling have been instrumental in improving our ability to understand the intricate interconnections between environmental and human variables. These theoretical and methodological frameworks are becoming central to many environmental archaeological studies in the 21st century (Figure 2).

Complex systems theory involves the emergence of a multitude of different actors – political systems, hierarchical organization, social connections, environmental conditions, etc. – and the dynamic interplay between these various actors (Grimm et al. 2005; Kohler 2012; Kohler and Gumerman 2000; Lansing 2003). Actors (or agents) are able to make decisions about how best to reach their goals (e.g., what kind of crops should be planted, when is the best time to go to war, what is the best way to maximize agricultural production, etc.). This process of decision making – which is central to complex systems theory – is what agent-based models attempt to capture. Another central parameter of this theoretical framework is that local interactions among different components are essential for the organization and larger-scale dynamics of the entire complex system (Wu and David 2002, 23). However, it is also necessary to look at top-down hierarchical organization – in addition to bottom-up structures –to fully grasp the dynamics of complex systems because ‘ecological systems are not sandpiles, but hierarchical patch dynamic systems with evolving structures and changing components’ (Wu and David 2002, 23).

Modelling behavior can be accomplished in several ways, most commonly using ‘bottom-up’ approaches, whereby a single hypothesis is postulated and incorporated into a model and attempts to prove its usefulness in the context of limited data (Grimm et al. 2005). Alternatively, there are top-down approaches and alternative modelling approaches that seek to test competing hypotheses simultaneously to determine the most likely set of processes responsible for specific outcomes. However, studies have shown that a mix of both top-down and bottom-up approaches are needed to model ecosystem dynamics (Wu and David 2002).

Using this theoretical framework, it has become possible to model multifaceted and interwoven relationships between different components of nature and society, including those relationships between humans and environmental surroundings (e.g., d’Alpoim Guedes et al. 2016; Kennett and Marawan 2015; Penny et al. 2018). Of course, there are many datasets that are required to conduct adequate assessments of complex systems theory. For example, highly resolved cultural and social data – which is difficult to acquire for prehistoric peoples – high-resolution environmental proxies, and a clear understanding of archaeological materials in terms of chronology and sociopolitical development. The future of anthropology very much rests with these modelling approaches, as agent-based complex systems approaches models enable researchers to test hypotheses about the various processes involved in human-environmental interactions (Kohler and Gumerman 2000:14; Lansing 2003).

Conclusions

Anthropological research centred around human-environmental interactions have long struggled with developing high resolution datasets and establishing definitive relationships between environmental events and human responses. The history of environmental anthropology illustrates the various means by which scholars have thus far attempted to cope with these issues: developing a branch of theory from ecology directed at understanding human behaviours (human behavioural ecology); the creation of quantitative methods of testing these theories; the development of environmental proxies from paleoenvironmental datasets such as lake cores, ice cores, and others; and the use of computer modelling to derive causal relationships between environmental conditions and human response. As we move towards the future, we must continue making progress in the realm of quantitative evaluation of theoretically derived hypotheses and explicitly demonstrating relationships between human and environmental variables. Furthermore, we must ensure that we conduct intra- and inter-disciplinary research, making sure to place our results in both anthropological and broader societal contexts to ensure our research makes real contributions to coping with environmental change in the present.

In the age of the Anthropocene, the nature of human environmental interactions has become even more pressing due to the dangers of environmental instability (Hinkel et al. 2013; IPCC 2018). These changes threaten the livelihoods of hundreds of millions of people – especially those near coasts – as well as the archaeological record itself (Anderson et al. 2017; Erlandson 2011; Reeder et al. 2012; Westly et al. 2011). As such, archaeology will have a major role to play in understanding how people in the past coped with similar climatological changes.

With the various methods utilized by scholars over the past hundred or so years, we have been able to ask many interesting questions regarding human responses to environmental change, the linkage between environment and health, resilience and collapse within environmental contexts, and the various means by which humans have managed to use environmental resources to their advantage. As discussed previously, the future of environmental archaeological studies involves development of techniques and methods for reconstructing past environmental conditions, but they also involve creating a deeper understanding of processes that increase and inhibit resilience of human populations in times of environmental uncertainty. This requires the integration of many lines of evidence across disciplines, including ecology, anthropology, and history (see Douglass et al. 2018).

In addition to interdisciplinarity, we must also engage with other disciplines within anthropology, incorporating cultural and biological studies into research on environmental effects on populations and societies. Studies of cognition and behaviour via human behavioural ecology and other cultural anthropological frameworks have contributed greatly to the study of human-environmental interaction. Ultimately, the future of environmental archaeology – and archaeology as a whole – is trending towards increased collaboration between and among different fields

Questions concerning human-environmental relationships are important for developing modern policies relating to resource management, health, and understanding the effects that environmental change has on human societies (see Kintigh et al. 2014). By studying how people in the past have coped with these issues, we can better prepare ourselves in the present to deal with these same challenges. This represents one of the greatest challenges for archaeological and anthropological research in the 21st century. Ultimately, it will fall to the future generations of archaeologists to address the question of what the impacts of environment are on the stability of social, economic, and political systems, and furthermore to expand this discussion explicitly into the contemporary world to help cope with current and future challenges in this area.

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