*Journal of Archaeological Science: Reports 23 (2019) 968–972*

# Multi-scale, integrated approaches to understanding the nature and impact of past environmental and climatic change in the archaeological record, and the role of isotope zooarchaeology

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Keywords:
Palaeoenvironment
Palaeoclimate
Stable isotope analysis
Palaeoecology
Prehistory

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Abstract

Climatic change, and associated environmental changes, are key challenges facing the world today, and are altering the future of our planet and its inhabitants. Climatic and environmental shifts also had profound effects on human societies in the past, and archaeology has a key role in helping us understand how humans, animals and the broader ecosystem responds and adapts to environmental change. Understanding human-environmental interactions on local, regional, and global scales is therefore not only a key part of better understanding the past, but also for informing the present. A significant area to explore is the palaeoecology of archaeologically-important prey-species, both as a means of more accurately reconstructing ancient landscapes and ecosystems, but also for better understanding past human activity, landscape use and faunal resource exploitation. New biomolecular approaches, and particularly isotope zooarchaeology, have enhanced our ability to reconstruct past ecosystem dynamics, paleoenvironmental and paleoclimatic conditions, and the economic strategies that humans used to cope with them. However, the integration of multiple lines of evidence and methodologies remains the most powerful approach towards studying environmental change, resilience and adaptation in the past, not only for the benefit of archaeologists but other specialists. This special section of Journal of Archaeological Science Reports draws together papers using a range of methodologies to understand past human interactions with their environments, from Alaska, to Coastal Brazil, Europe and beyond. Studies are on a range of scales, from individual sites to big data, multi-site analyses, and encompass periods from Palaeolithic to the Middle Ages. Given the multi-faceted nature of the human past, archaeologists need to use a broad range of datasets to best understand environmental change and its impact on humans and animals. By drawing on inter-disciplinary specialisations and working alongside experts from other fields it will be possible to gain a more integrated and complete understanding of the ecological, economic, social and cultural effects of climatic and environmental changes on past populations.

## 1. Introduction

The reconstruction of past climatic and environmental change is central to modern archaeological practice and to the better understanding of past human lives and societies. Multiple methods are employed to reconstruct environmental change on a range of scales relevant to the study of the past, from site-specific to broader regional and even global archives (e.g. Moreno et al., 2014, Rasmussen et al., 2014, Stevens et al., 2014). However, beyond the reconstruction of past climatic conditions, a central tenet of archaeology should be to understand the impact of environmental changes, on broader ecosystems, on fauna, and ultimately on past human groups (e.g. Birks et al., 2015, Boivin et al., 2016, Douglas et al., 2016, Markova et al., 2015, Schwindt et al., 2016, Staubwasser et al., 2018, Weninger et al., 2009). Changes in past environments, climates, and faunal ecology had significant impacts on human populations, from the evolution of early humans, the extinction of the Neanderthals and the global dispersals of modern humans (e.g. Finlayson and Carrión, 2007, Giampoudakis et al., 2017, Levin, 2015, Melchionna et al., 2018, Obreht et al., 2017, Petraglia et al., 2019, Staubwasser et al., 2018, Timmermann and Friedrich, 2016), to the origins of agriculture, the formation of early states and beyond (e.g. Butzer, 2012, Lucquin et al., 2018, Richerson et al., 2017, Zeder, 2011). In this way, environmental changes, and the response of archaeological populations to those shifts, have shaped the course of human history.

Climate change is also a problem facing the world, and Archaeology, today. Recent research in the Arctic and elsewhere has highlighted that loss of permafrost, global warming, increased storminess, and coastal erosion are proving a threat to archaeological, ecological and environmental records (Hollesen et al., 2017, Hollesen et al., 2018, Howard et al., 2008). As well as being a casualty of contemporary climate change, Archaeology, also has a clear contribution to make to modern climate change debates (Mitchell, 2008, Van de Noort, 2015). After all, understanding the nature and extent of environmental and climatic changes in the past, and how societies respond to such changes, may be crucial to being able to predict and adapt to the contemporary climatic challenges (Sandweiss and Kelley, 2012, Van de Noort, 2015). The processes, as well as the products, of archaeological investigation may also prove useful in addressing and mediating some of the socio-cultural impacts of climate change on contemporary societies (e.g. Hillerdal and Knecht, in review).

While undeniably of great value, characterising the scale and duration of climatic and environmental changes experienced by past populations, and their impacts on past human societies, is complex. Multiple methodologies and cross-disciplinary approaches are required. Recent developments in the field of biomolecular archaeology, including stable isotope analysis of teeth, micro- and macro-faunal bones, and shell, for example, have advanced our ability to characterise the specific environments within the localities of archaeological sites occupied (e.g. Bernard et al., 2009, Britton et al., 2012, Fabre et al., 2011, Leichliter et al., 2017, Prendergast et al., 2017, Richards et al., 2017, Velivetskaya et al., 2016). Isotope approaches, especially when used in combination with more traditional environmental archaeological techniques such as palynology, the study of microfauna, and geoarchaeology, have the potential to produce detailed palaeoenvironmental constructions on an inter- and intra-site level (e.g. Bernard et al., 2009, Fabre et al., 2011, Jones et al., 2018, Richards and Hedges, 2003, Richards et al., 2017, Stevens and Hedges, 2004, Stevens et al., 2008). By applying these new methods to case studies from across the world it is possible to explore how human and animal populations interacted with their environments, and how they responded to the changes they experienced.

## 2. This Special Section

Based on a session we chaired at the European Archaeology Association meeting in Vilnius, Lithuania in September 2016, this special section seeks to explore new micro- and macro- scale approaches towards reconstructing palaeoclimates and palaeoenvironments, and the impact they had on human activity at key periods. While a number focus on isotope zooarchaeology, the papers presented here use multi-evidential and interdisciplinary approaches applied to a variety of case studies from across the world, ranging from Brazil to Moldova, dating from the middle Palaeolithic to the Holocene, all ultimately seeking to answer questions about how the environment shaped human lives in the past. In this collection of papers, our contributors explore climatic and environmental change, and human-environment and human-animal relationships on a range of scales. The geographical and methodological scope of the papers is vast. International and cross-disciplinary research teams present research from South Africa, Alaska, Brazil, Crimea, Spain, Ukraine, and Moldova, spanning from the earliest periods of the Palaeolithic in the Cradle of Humankind, to the late Holocene of the North American Arctic. The methodological focus of the papers varies from single and dual approaches, to integrated multi-method research designs, and includes palynology, sedimentology, chronology, isotope analysis, zooarchaeology, micro- and meso- wear and big data Bayesian Belief Networks.

Together, we traverse the major themes in environmental archaeology and the human-environmental relationship. Papers by Harper (2019), Val-Peón et al. (2019) and Zubarev et al. (2019) utilise palynology and other methodologies such as sedimentology and scientific dating approaches to reconstruct prehistoric climatic change in Eastern Europe, coastal Brazil and Eastern Crimea respectively. These studies, originating from very different archaeological contexts and research traditions, utilise similar multi-proxy methods and exemplify key approaches towards understanding past human-environment relationships. Harper (2019) constructs a regional climate model for Ukraine, Moldova and Romania for the Late ENeolithic (c. 6,000-3,600 BP). The integration of new climatic data with archaeological data and other multi-proxy evidence underpins the working hypothesis that climate change drove contemporary population movements - a clear example of the impact environmental change can have on human groups. The similar, integrated approach taken by Val-Peón and colleagues (2019) maps environmental change onto prehistoric occupation in the coastal plains of Brazil over the last 8,000 years. Newly-generated palynological data are correlated with dating evidence from sediments, and related to evidence of human occupation from published sites. The study reveals a dynamic and changing environment, characterised by three distinct palaeoenvironmental phases, showing a change from a coastal lagoon environment, which gradually evolved into a coastal marsh, becoming occupied by humans during this transition. This highlights the dynamic connection between environments and human settlement patterns, and fluidity between changing landscapes and the varied ways in which humans interact with them.

The theme of exploring the dynamic interactions between humans and the wider landscape using integrated methodologies is continued in the paper by Zubarev et al. (2019), which draws data generated from historical archives, maps, satellite images, with new evidence from archaeological surveys and excavations to determine human activity patterns in the landscape surrounding the Adzhiel gully in Eastern Crimea. Their findings demonstrated that anthropogenic activity in the landscape commenced in the Upper Palaeolithic, and continued until the Middle Ages. Anthropogenic modifications to the landscape peaked between the 2nd and 5th Centuries AD, where large scale earthworks, such as the Belinskoye hillfort, were created, changing the nature of the landscape. Human occupation and manipulation of their broader environments is an important theme in archaeology, and has implications for our perceptions of what we consider 'natural' landscapes today.

The term environment goes beyond the palaeoclimate, plant communities and topography, and includes the humans and non-human animals that inhabit it. The study of archaeofaunas in particular is key to understanding the living landscapes of the past - to provide proxies for environmental conditions, to better understand their ecology and behaviour, and also to further appreciate the behaviour and decisions of the human groups that depended on them (see overview in Britton, 2018). In addition to traditional zooarchaeological approaches, advanced methodologies, such as ancient DNA analysis, geometric morphometrics and stable isotope analysis, are proving increasingly useful to such endeavours. Isotope zooarchaeology is becoming well established as a sub-field of the discipline, and is useful in disentangling complex aspects of human-environment and human-animal subsistence, economic and socio-cultural relationships (Britton, 2017, Makarewicz, 2016). Animal remains are significant not only in that their isotope values reflect their ecology and the contemporary environmental suite, but also because their presence in the archaeological record is the direct result of human activity. As a result, the isotope signatures of wild animals can provide evidence of animal ecology and of environmental conditions near-synchronous to that human activity (Britton, 2017: 857). In the case of domestic animals, isotopic analysis of their preserved tissues can reveal anthropogenic modifications to their environments, diets, physiologies and life-histories (Makarewicz, 2016, Pilaar Birch, 2013, Zangrando et al., 2014).

Isotope zooarchaeology is highlighted here in four new case studies, including those by Sewell et al. (2019), Jones et al. (2019), Gigleux et al. (2019) and Zavodny et al. (2019). The first three studies focus on wild animals, both as a means of exploring past environments, informing conditions experienced by past human populations (Jones et al., 2019, Sewell et al., 2019), but also as a means of inferring the ecological behaviours of ancestral faunal populations and, through this, to inform contemporary human behaviour (Gigleux et al., 2019). In the more distance past, Sewell et al. (2019), re-evaluate the transition from woodland to grassland in the Cradle of Humankind using Spingbok teeth (2.8-0.8 Ma) as a proxy to reconstruct changes in vegetation through time. The authors integrate carbon and oxygen isotope analysis of tooth enamel with the analysis of dental micro- and meso- wear. As a mixed feeder, Spingbok are able to track changes in not just grassland vegetation but other vegetation types. The new data presented here demonstrate an increase in grassland from 1.7 Ma and complement other means of reconstructing climate and environmental conditions and vegetation such as micromammals, speleothems, and faunal and floral presence. Significantly the new data also suggest more heterogeneous habitats for some areas at this time than previously thought, highlighting the need for multiple methodological approaches and the value of integrated research approaches.

In later Middle and Upper Palaeolithic contexts, the isotope analysis of faunal remains - including both the mineral and proteinaceous components – can also provide invaluable additional proxies to understand what environmental conditions were like for past populations. Here, Jones et al. (2019) use multi - isotopic approaches (bone collagen δ13C, δ15N and δ34S, along with δ18O and δ13C measurements from tooth enamel), alongside other indicators, to reconstruct what the environment was like for Neanderthals and Anatomically Modern Humans occupying the Cantabrian region of Northern Spain in the late Pleistocene. The isotope data reinforce the notion that the region offered a range of micro environments for animals to inhabit, which may have buffered the wider environmental effects of MIS3. The sulphur data also highlight that diverse regions of the landscape were being exploited, both by Neanderthals and modern humans, emphasising that faunal isotopic studies can also prove valuable in illuminating the behaviours of past groups.

The dual benefits of isotope studies on archaeological prey-species is perhaps best highlighted in the paper by Gigleux et al. (2019), which emphasises the usefulness of the zooarchaeological record as an archive for palaeoecology and how, through its study, we can also better inform past human behaviours. Based at the precontact site of Nunalleq in Western Alaska, this study utilises intra-tooth strontium and oxygen isotope analysis to investigate seasonal caribou biogeography during the Little Ice Age - a period of recent global climatic disruption and relative cooling. The data generated evidence the seasonal movements of caribou during this period in a possible north-south migration route along the coast, a route different from herds found in the region today but similar to that described historically. The first study of its type in the Holocene and in North America, this work emphasises the value of isotopic zooarchaeological approaches in illuminating palaeomigrations, and plasticity and conservation of the behaviour of faunal species through time. Significantly, the results also have implications for our understanding of the exploitation of this prey-species at the site, as the new strontium and oxygen data confirm that caribou would have been a locally available winter resource for the inhabitants of Nunalleq.

While studies on wild animals are becoming increasingly routine, the study of domestic species has been at the centre of bioarchaeology and environmental archaeology for decades, and is also the focus of the remaining two papers in this volume (Pitt et al., 2019, Zavodny et al., 2019). Pastoralism and agrarian agriculture marks a shift in the dynamics between human societies and the natural world, and has had immeasurable impacts on past human societies, and their environments (Diamond, 2002, Goudie, 2019). Indeed, for some researchers the dawn of agriculture marks the beginnings of the anthropocene (Li et al., 2009, Ruddiman and Thomson, 2001, Ruddiman, 2003, Smith and Zeder, 2013), during which human activity has been the dominant influence on climate and the environment. Domestication also represents the most fundamental redefining of animal-human relationships in our history as a species. Understanding the processes of domestication, as well as the husbandry and management of domestic fauna in the past, is complex, and requires integrated approaches, and the combining zooarchaeology with new biomolecular techniques has proven fruitful (e.g. Guiry et al., 2014, Jones and Mulville, 2016, McManus-Fry et al., 2018). While both focusing of prehistoric Europe, the final two papers in this special section take very different approaches to reconstructing the conditions and consequences of domestication and domestic animal management in the region.

Animal husbandry strategies can be heavily influenced by the distinctive environments available to past human populations, and the study of these practices in the past can reveal tailored management strategies to the specific conditions encountered. From seaweed-eating and salt-marsh-grazed sheep in prehistoric Britain (Balasse et al., 2006, Britton et al., 2008), to the manipulation of multiple birth seasons in Scandinavian Neolithic cattle (Gron et al., 2015), the isotope analysis of domestic species has proven extremely useful in informing the diverse approaches taken to animal management by past human groups. Here, the paper by Zavodny and colleagues (2019) use this approach to explore animal husbandry in the mountainous regions of Croatia during the Bronze Age and Iron Age. The isotope analysis of bulk bone collagen from cattle and sheep/goats reveals increased variation in carbon and nitrogen isotope values through time, interpreted as evidence of the consumption of graze from an increasing range of areas, and possibly even reflecting seasonal transhumance practices. Pigs, however, demonstrate a different trend, with isotope data consistent through time, suggesting small - scale pig management close to human settlements.

Pitt et al. (2019) take a very different approach to reconstructing the management of animals in the past, and use big data and statistical approaches to explore the factors influencing the distribution of chickens across Europe, from the Bronze Age to the Roman period. This study utilises numerous previously published datasets and applies Bayesian Belief Networks to explore the biotic and abiotic factors affecting the dispersal of chickens in prehistoric Europe, and the different species associations that occur as chickens are introduced to new environments by humans. The close affinity between chickens and foxes, an association that troubles farmers and smallholders to this day, demonstrates the predator-prey relationships that can develop with the introduction of new species into an ecosystem. The importance of sieving remains to recover small and large species consistently is integral to this approach, and serves as a reminder to environmental archaeologists to employ this methodology. This study also highlights the power and potential of 'big data' approaches in zooarchaeology, integrating zooarchaeological results from more than 11,000 different sites, allowing recurrent trends in animal management by humans, and its consequences for archaeological ecosystems, to emerge.

## 3. Concluding Thoughts

The diverse case studies presented here are unified through both their study of environmental and ecosystem change in archaeological contexts, but also through their multi-method, multi-levelled approaches to human-environmental relationships. In many of the studies, we are pleased to see that animals, whether wild or domestic, are considered central to this relationship. The range of methodologies used here - from palynology to dental microwear to stable isotope analysis - highlight the range of analytical approaches that should employed to investigate complex dynamics of past human-environment interactions. The studies utilise materials from a range of sites, and site types, from the single site of Nunalleq (Gigleux et al., 2019) to the tens of thousands of sites incorporated into the study by Pitt et al. (2019). These very different datasets emphasise the value of different scales of enquiry in modern archaeology, and the complementarity and necessity of both site-specific and more regional work, along with broader synthesise and multivariate statistical analyses of large datasets.

Many of the studies presented here also highlight the dual potentials of the archaeological record, as both a means of better understanding the lives of past peoples, but also as an archive for illuminating the dynamics of ecological and environmental change processes in periods far beyond the reach of modern earth and biological science. Archaeological and historical data are increasingly being seen as valuable to ecology and particularly to conservation biology (Lyman, 1996, Lyman and Cannon, 2004, Rosania, 2012, Szpak et al., 2012, Wolverton and Lyman, 2012), and the stage is set to see new cross-disciplinary studies in coming years, integrating not only novel materials but methodologies and discourse from all three fields (Britton and Guiry, in press, Izdebski et al., 2016, Torben and Lockwood, 2013). The fuller integration of specialists from the natural sciences, specifically climate science, into archaeology could greatly enrich both fields and the exploration of human-environmental relationships in deeper time.

As with ecology, the integration of archaeology with other ‘harder’ sciences remains a challenge, not least due to the material limitations of the archaeological record in terms of sample size and its punctuated, interrupted and biased (i.e. anthropogenic) nature. At least some of these perceived failings are strengths: For example, the oxygen isotope analysis of archaeological faunal remains - the product of human activity - can generate terrestrial palaeoclimate proxy data near synchronous to that activity (e.g. Bernard et al. 2009).

New means of analysing data, such as computational modelling, are likely to increase the usefulness and applicability of archaeological datasets to the study of how climate can influence human societies past, present and future (e.g. d'Alpoim Guedes et al., 2016). When our ambitions lie not only in reconstructing climatic and environmental change, but also in understanding its impacts on human societies in the broadest sense, increased cross-disciplinary initiatives with human geographers, anthropologists and other social scientists – as well as community stakeholders – should also be central, permitting the better understanding the diverse, culture-specific impacts and perceptions of climate change (e.g. Adger et al., 2009, Adger et al., 2013, Hillerdal and Knecht, in press, Turner and Clifton, 2009). For our own part, archaeologists should not only aspire to contribute to the climate change debate but also continue to integrate broad datasets from a range of specialisms into our own research designs when exploring past climatic and environmental change, and its impacts. It is only through embracing the complementarity of diverse lines of enquiry that we can more fully understand these impacts - ecological, economic, social and cultural - and do justice to our incomplete, interrupted and imperfect record.

## Acknowledgements

We would like to thank all our contributors for submitting their work to be part of this special collection of papers. Many thanks to Andy Howard and Chris Hunt for their patience and guidance during preparation and publication, and to the wider production team for their assistance. Thanks also to Charlotta Hillerdal and Joshua Wright (Aberdeen) for taking the time to provide comments on an earlier draft
of this introduction.

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