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Risk and resilience in the late glacial: A case study from the western Mediterranean

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ABSTRACT

The period spanning the Last Glacial Maximum through early Holocene encompasses dramatic and rapid environmental changes that offered both increased risk and new opportunities to human populations of the Mediterranean zone. The regional effects of global climate change varied spatially with latitude, topography, and distance from a shifting coastline; and human adaptations to these changes played out at these regional scales. To better understand the spatial and temporal dynamics of climate change and human social-ecological-technological systems (or SETS) during the transition from full glacial to interglacial, we carried out a meta-analysis of archaeological and paleoenvironmental datasets across the western Mediterranean region. We compiled information on prehistoric technology, land-use, and hunting strategies from 291 archaeological assemblages, recovered from 122 sites extending from southern Spain, through Mediterranean France, to northern and peninsular Italy, as well as 2,386 radiocarbon dates from across this region. We combine these data on human ecological dynamics with paleoenvironmental information derived from global climate models, proxy data, and estimates of coastlines modeled from sea level estimates and digital terrain. The LGM represents an ecologically predictable period for over much of the western Mediterranean, while the remainder of the Pleistocene was increasingly unpredictable, making it a period of increased ecological risk for hunter-gatherers. In response to increasing spatial and temporal uncertainty, hunter-gatherers reorganized different constituents of their SETS, allowing regional populations to adapt to these conditions up to a point. Beyond this threshold, rapid environmental change resulted in significant demographic change in Mediterranean hunter-gatherer populations.

1. Introduction

When most people think about glacial periods, they imagine a time of environmental hardship; Europe in the Upper Pleistocene is envisioned as a cold and forbidding landscape. Interglacials, conversely, are thought of as representing intervals of better conditions, when conditions were 'milder' and climate 'ameliorated'. From this perspective, the Last Glacial Maximum (LGM) was the interval when Europe and the rest of the world experienced environments most hostile to humanity; after this, conditions gradually improved until we reached the maximally favorable Holocene Interglacial (Richerson and Boyd, 2001). Yet it was while the Earth was in the Upper Pleistocene 'Ice Age' that our species extended its range over all of the world. It is under full glacial conditions that we see evidence for larger group size, more complex technologies, more sophisticated social organization, and more highly developed artistic expression by human hunter-gatherers in Europe than at any time prior to or afterwards—including in the Holocene. Indeed, on the basis of the archaeological record, there is every reason to believe that human populations of Europe were well adapted to living under glacial conditions and highly successful—and may even have been actively managing ecosystems to increase their ability to sustain them (Kaplan et al., 2016). In contrast, human

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groups in the initial millennia of the more 'favorable' Holocene seem to have been smaller, more dispersed, with less 'sophisticated' technologies and less symbolic expression in art. These discrepancies suggest that systematic reassessment of human ecology and environmental contexts would be useful for the transition from the glacial conditions that were 'normal' for most of the history of modern *Homo sapiens* to the interglacial conditions that we take for granted today.

Across the Northern Hemisphere, and for Europe in particular, this transition entailed the retreat of continental ice sheets and warmer temperatures of course. But it also meant increasingly severe ecological disruption. Global warming did not happen gradually as the Pleistocene drew to a close. Very rapid and extreme warming of the Bølling-Allerød Interstadial was followed by sharply colder oscillations returning to fully glacial temperatures in the Younger Dryas; these were followed in turn by even more rapid and severe global warming at the beginning of the Holocene (Clark et al., 2012; Lotter et al., 2012). Average global temperatures rose by as much as 6 °C, and so rapidly that they occurred within the span of human memory (Steffensen et al., 2008)—with equally significant changes in the amount and annual distribution of precipitation.

Plant community composition and species associations changed dramatically across Europe, with the spread of closed canopy deciduous forest at the expense of cool/cold savannah and steppe being the most notable consequence (Ammann et al., 2013; Kaplan et al., 2016). Of course, such significant reorganization in plant communities had a profound impact on the animals that depended on them. Large, herd-dwelling herbivores occupied the open vegetation communities that dominated Europe during the Upper Pleistocene, including elephants, rhinoceros, horse, saiga, and reindeer. In the Holocene Interglacial, they were replaced by forest-adapted game species (e.g., red deer, roe deer, aurochs, wisent) who roamed singly or in small groups.

There were equally severe impacts on coastlines. From the Pleniglacial to the early Holocene, sea level rose by nearly 300 m, inundating tens of thousands of square kilometers of continental shelf in Europe (Siddall et al., 2003; Lambeck et al., 2004; Clark et al., 2009). Simultaneously, rapidly melting ice sheets dumped enormous quantities of fresh water into the north Atlantic, altering thermohaline circulation patterns (Beveridge et al., 1995; Keigwin and Boyle, 2000). The loss of direct access to deep water resources of the continental slope as sea level rose and the shift of cold currents away from the European continent significantly decreased easy access to rich marine resources. From the point of view of these highly successful human populations so well-adapted to a glacial world, the rapid and extreme climate oscillations, sea level rise, and complete reorganization of plant and animal communities that marked the transition to Holocene conditions must have been an eco-catastrophe.

We seek to better understand the long-term consequences of the transition from glacial to interglacial environments for social-ecological-technological systems (SETS) in the western Mediterranean through a scientific assessment of environmental risk and human resilience, and their variable expression in space and time across this region. Prior to the modern, post-industrial era, this is the only time culturally and biologically modern humans have faced such rapid, significant global warming, and its environmental consequences, on a global scale. While hunter-gatherer bands are socially very different than today's urbanized world, this is our only opportunity to assess successful and unsuccessful strategies humans employed in dealing with the multidimensional impacts of such profound global change. Of additional importance is the fact that one set of strategies for adapting to the interglacial conditions of the Holocene was through greatly expanding and intensifying practices for managing 'natural' ecosystems. These practices—which include farming, herding, and forestry—initiated a suite of positive feedbacks that led to the modern urbanized world dominated by tightly coupled socio-natural landscapes whose dynamics are driven as much by human actions as biophysical processes (Ellis et al., 2013).

2. Methods

2.1. Issues for studying long-term change in socio-ecological-technological systems

Archaeology has a unique potential to coordinate interdisciplinary research on long term change in socio-ecological-technological systems (or SETS) (van der Leeuw and Redman, 2002; Redman et al., 2004; Redman, 2007; Ellis, 2015). Realizing this potential is challenging, however. Empirical evidence for prehistoric SETS is in the form of proxies that are static, material residues of dynamic biophysical processes and human decisions and actions. Additionally, it is necessary to synthesize paleoenvironmental and archaeological data that can take very different forms, are produced at very different scales, and are captured in very different formats. Moreover, relevant social and ecological dynamics interacted in complex ways, and were time and space transgressive at multiple scales.

To further complicate matters, the archaeological and paleoecological records are sparse and fragmentary, and relationships between the data that we can study and past socio-ecological-technological processes are far from straightforward. In most cases, proxies are preserved in sedimentary deposits where they have accumulated into time-averaged palimpsests of variable duration. And they are usually altered from their original condition and spatio-temporal organization to varying degrees by human and natural formation processes. Hence, the proxy record is much more coarse grained than the social and ecological dynamics we seek to understand.

To address these issues with the nature of the record of ancient SETS, we take a regional approach, and scale our analyses and interpretations to better match that of available data. To do this, we carry out a multi-disciplinary, multi-scale meta-analysis that builds on data collected in numerous prior research projects. The geographic region of interest for this meta-analysis encompasses the arc of the entirety of western Mediterranean Europe in the broad sense, including all of modern Italy, southern France, and Mediterranean Spain. This region spans diverse landscapes from Alpine zones to the warmest and driest areas of southern Europe, representative of much of the socio-ecological variation of late Glacial Europe beyond the periglacial zones.

We integrate new digital terrain models and results of recent, process-based paleoclimate simulations to complement this large, archaeological dataset. Our analyses employ data science methods anchored in conceptual frameworks of human behavioral ecology and lithic technology theory. We calculate quantitative measures of paleoenvironmental conditions and their spatial/temporal variability across the western Mediterranean, with a focus on measuring change, stability, and uncertainty. We also calculate measures of how SETS responded to environmental change and uncertainty, including metrics for land-use strategies and resource acquisition. Because of the issues discussed above, we emphasize shifts in long term strategies for SETS rather than short term tactics of hunter-gatherer societies.

2.2. Data sources: Terrain

We combine new digital terrain datasets, digital bathymetric

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