

Review

Human-environmental interactions in Mediterranean climate regions from the Pleistocene to the Anthropocene



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ARTICLE INFO

Article history:

Received 4 January 2020

Received in revised form 17 July 2020

Accepted 18 July 2020

Available online 23 July 2020

Keywords:

Climate change

Environmental archaeology

Anthropogenic impacts

Human ecology

ABSTRACT

From mobile hunter-gatherers to a series of state societies, Mediterranean climate regions (MED) around the world have been critical areas for human and biological evolution for millennia. Comprised of five regions on six continents, the MED are important today for human settlement, global food production, transportation, industry, and tourism, but these regions are also extremely vulnerable to projected changes in their typically temperate climate towards more extreme conditions. Researchers and strategists are exploring the implications of these changes for present and future societies, but there has been limited comparative synthesis of past human responses to environmental and climatic change in the global MED and how these data may help prepare and plan for projected changes in the future. This review synthesizes archaeological and paleoenvironmental data, focusing on key demographic, social, economic, and cultural developments that occurred alongside and often in response to past climate and environmental disruption. Past climatic change influenced broader socio-environmental systems, in some cases acting as a driver of population collapse, large-scale abandonment, migration, and socio-political upheaval. These deep time data illustrate the importance of understanding Pleistocene-Holocene human-environmental interactions, land use, and climate change to help evaluate and plan for contemporary and projected environmental change.

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1. Introduction

Climate change is one of the biggest challenges of modern time, with great consequence for biodiversity, food security, infrastructure, and political, social, and economic stability (IPCC, 2014). Researchers are increasingly seeking new approaches for evaluating and anticipating the impacts of global climate change at regional scale, including perspectives from archaeology about past human responses to environmental and climatic challenges (d'Alpoim Guedes et al., 2016; Rick and Sandweiss, 2020; Sandweiss and Kelley, 2012). This review builds on previous work by comparing and synthesizing archaeological evidence for past human-environmental dynamics in Mediterranean climate regions (MED), focusing on major demographic, economic, social, and cultural developments during the terminal Pleistocene (~13.0 ka; all dates are cal yrs BP unless noted), Holocene, and Anthropocene. We use the term Anthropocene throughout this manuscript to refer to the recent past (~50–100 years), present, and future, recognizing that the Epoch has not been formally adopted.

Consisting of five regions (Mediterranean Basin, California, southwestern and southern Australia, the Western Cape Region of South Africa, and central Chile; Fig. 1) located on six continents, the MED are particularly vulnerable to climate change, especially water scarcity and warming scenarios (Alessandri et al., 2014; Christensen et al., 2013; Cramer et al., 2018). These five regions are currently home to dense human populations, encompassing hundreds of millions of people, and are centers of global food and wine production. For instance, California is the biggest producer of crops in the United States with a >\$50 billion industry (>13% of total US cash crops) (California Department of Food and Agriculture, 2018). Similarly, South Australia's 2017–2018 revenue

from cereal crop production, livestock, other foods, and wine was \$20.3 billion (Government of South Australia, 2019). In the Mediterranean Basin, traditional grape, olive, and wheat crops form the backbone of regional/global agricultural economies, and the “Mediterranean diet” is included as part of the United Nations Educational, Scientific, and Cultural Organization (UNESCO) intangible cultural heritage of humanity (Ponti et al., 2018). These regions are also important for global tourism, exemplified by South Africa's Western Cape region receiving 2.6 million visitors in 2018 and central Chile receiving 4.7 million visitors in 2016 (Subsecretaría de Turismo, 2017; Western Cape Government, 2019).

The importance of the five MED for human society has resulted in research focused on anticipating the effects of climate change locally and globally (Alessandri et al., 2014; Cramer et al., 2018; Guiot and Cramer, 2016; Mariotti et al., 2015; Polade et al., 2017). These regions are hotspots of climate change and face significant challenges based on future climate projections (Alessandri et al., 2014). As discussed below, there are shared traits for each of the five regions, as well as regionally dependent characteristics (Esler et al., 2018; Mariotti et al., 2015). Twenty-first century climate change projections suggest significant expansion of arid zones along the equatorial margins of the current regions, poleward expansion in some areas, and contraction in others (Alessandri et al., 2014). Wetter winters and drier summers, and changes in weather extremes could result in amplified floods, droughts, and changes in seasonal cycles, contrasting with typical relatively moderate conditions (Fischer and Schar, 2010; Polade et al., 2017). Projected future precipitation changes, together with increasing temperatures, would have substantial effects on regional drought and fire intensity/frequency (Alessandri et al., 2014; Cramer et al., 2018; Guiot and Cramer, 2016; Polade et al., 2017). For example, changes in regional wind patterns in California, especially the

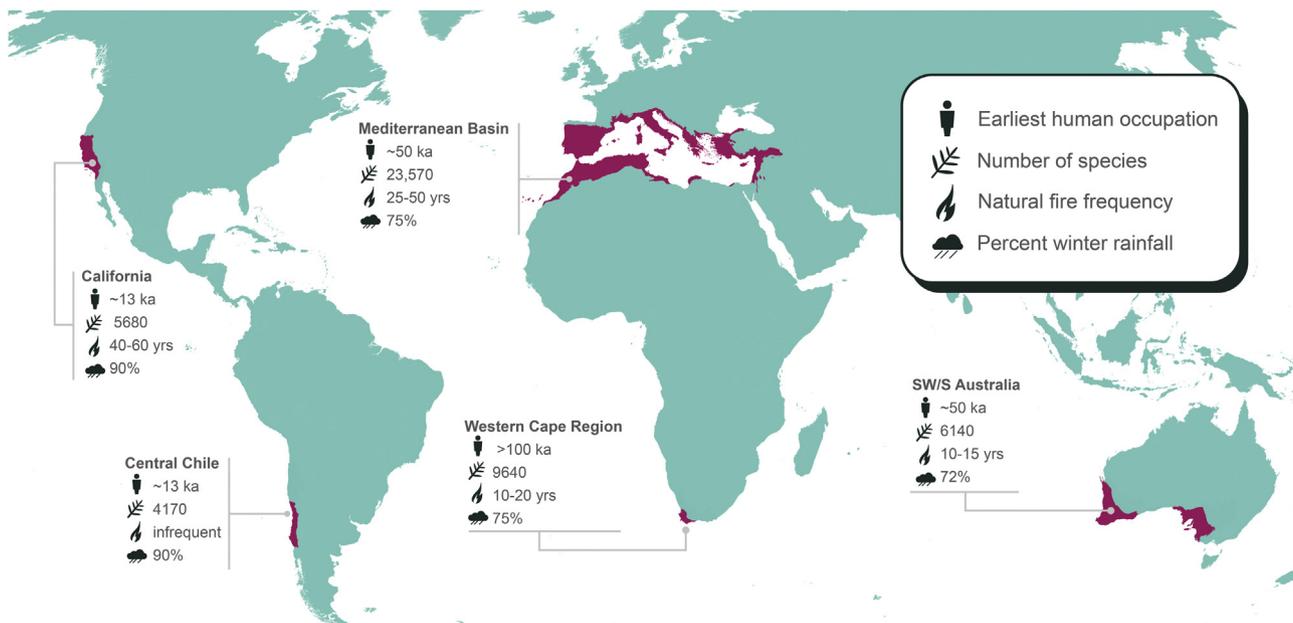


Fig. 1. Location of Mediterranean climate regions, and various environmental and cultural characteristics for each region. These include approximate timing of anatomically modern human occupation, approximate number of vascular plant and vertebrate species per region (rounded to nearest whole number), annual to decadal frequency of natural fire, and the percentage of rainfall in the winter (data follow Rundel and Cowling, 2013; Table 2; Rundel et al., 2018; Table 1). For the Mediterranean and South Africa, other hominids occupied these areas for considerably longer periods of time (>1 million years).

Santa Ana winds which typically drive the extensive autumn fires, could alter the seasonality of fire activity (Guzman-Morales and Gershunov, 2019); and modeling of the recent South African Cape drought and water rationing highlight potential future climatic warming scenarios resulting in an increased frequency and intensity of drought (Otto et al., 2018). Warming climate would also bring significant sea level rise to MED coastal areas, but would vary locally and regionally due to topography, tectonic activity (e.g., uplift and subsidence), current and wind patterns, post-glacial isostatic adjustment, and the rate of polar ice sheet melting (Griggs et al., 2017:11–12). All of these climatic changes would have significant impacts on human welfare and the multi-billion dollar agricultural, commerce, and tourism industries present in the five regions (see Pathak et al., 2018; Ponti et al., 2018; Rogerson, 2016).

The relatively mild climate and mix of different marine and terrestrial environments of the five MED regions has made them a focus of human settlement and social and cultural evolution for millennia, including Greek, Roman, and other empires of the Mediterranean Basin, and hunter-gatherers, agriculturalists, and pastoralists elsewhere (Broodbank, 2013; Méndez et al., 2015; Rick et al., 2005; Williams et al., 2015a). While researchers have investigated long-term paleoclimatic and/or human land use changes in specific regions (Bevan et al., 2019; Brayshaw et al., 2011; Kennett, 2005; MacDonald et al., 2016; Masson-Delmotte et al., 2013; Roberts et al., 2019; Williams et al., 2020), there has been limited comparative analysis at a global scale. This review seeks to fill that gap through comparative synthesis of long-term human-environmental interactions and archaeology in the world's MED.

Scholars continue to debate the timing and onset of the proposed Anthropocene Epoch. For example, the Anthropocene Working Group (Zalasiewicz et al., 2017) is advocating a mid-20th century onset while many archaeologists argue for a much earlier onset, perhaps roughly coeval with the Holocene (Albert, 2015; Bevan et al., 2019; Braje and Erlandson, 2013; Roberts et al., 2018; Smith and Zeder, 2013). Our goals here are not to debate the timing or duration of the proposed Epoch, but instead we undertake a critical review of a wide body of archaeological and paleoecological literature from the global MED to demonstrate the importance of Late Pleistocene and Holocene human-environmental interactions for helping prepare for an Anthropocene future. To that end, we explore the effects of decadal to centennial periods of climate disruption on past human societies in the Mediterranean Basin, California, southwestern and southern Australia, the Western Cape Region of South Africa, and central Chile. We demonstrate that major climatic events can result in changes that manifest several hundred years into the future, underscoring the importance of long-term perspectives on human-climate relationships for effective management and planning during the Anthropocene.

2. Environmental context

Precise definitions have been debated, but most researchers agree that the MED is characterized by warm, dry summers and mild, wet winters, and is situated between ~30–40 degrees N and S Latitude (Blumler, 2005; Esler et al., 2018; Rundel and Cowling, 2013). The MED has been referred to as the Mediterranean Climate Zone, Mediterranean-type ecosystem, and Mediterranean Biome. Here, we subscribe to a definition of the MED, focused on five regions: the Mediterranean Basin, California (portions of Alta and Baja), southwestern and southern Australia, the Western Cape region of South Africa, and central Chile (Fig. 1). Each of these areas has a long record of human occupation and past climate change. Anatomically modern humans have lived in South Africa well in excess of 100 ka, in Australia for 50 ka or more, in the Mediterranean for around 40–50 ka, and in Chile and California

for ~13 ka, with other members of the hominid lineage living in Africa and Europe for considerably longer (see Erlandson et al., 2011; Hoffecker, 2017; Núñez et al., 2001; O'Connell et al., 2018).

Most annual precipitation (in some cases 90% or more) falls during winter (~6 months), with as little as 120–250 mm in lowland coastal areas and as much as 900 mm in upland areas (Rundel and Cowling, 2013). Summer aridity tends to be highest in California and Chile, with South Africa and Australia often having light summer rainfall. Fire is an important driver of change in the MED and fire regimes in these regions and elsewhere around the world have long served important socioecological functions, including managed Indigenous burning that often had important benefits for local ecosystems, resulted in increased biodiversity, and may have helped reduce larger and more destructive natural fires (Bliege Bird et al., 2012; Cuthrel et al., 2012; Power et al., 2018). However, there is increasing evidence that climate change-induced land drying and human activities (e.g., failing to properly extinguish campfires, cigarettes, single species or invasive trees) can exacerbate fire and lead to destructive and uncontrolled burning (Abatzoglou and Park Williams, 2016; Guzman-Morales and Gershunov, 2019; Otto et al., 2018; Rundel et al., 2018; Turco et al., 2018).

Although the MED and its associated biomes and ecosystems cover just 2% of the world's total land area, they have rich biodiversity, including some 50,000 vascular plants, or roughly 20% of the global total (Rundel and Cowling, 2013:212; Rundel et al., 2018). These regions each contain a diverse array of vertebrate species, including 632 mammal, 1682 bird, 919 reptile/amphibian, and 386 fish species (see Fig. 1; Rundel and Cowling, 2013:213). Marine ecosystems and fisheries are also highly productive in the MED, with the rich upwelling of California, Chile, and South Africa accounting for ~20% of global fishery yields (Craig, 2012).

3. Long-term human-environmental dynamics in the MED

The five Mediterranean climate regions each have distinct records of human-environmental interactions synthesized in the sections that follow. Summarizing all of the archaeological evidence for each of these diverse regions is beyond the scope of this review. Consequently, we focus on select major events of the Late Pleistocene and Holocene that illustrate the relationship between major climatic/environmental disturbances and key demographic, cultural, and economic developments. Researchers in each of the regions have previously discussed human responses to climate changes associated with specific major events, including the Little Ice Age, Medieval Climatic Anomaly, El Niño Southern Oscillation, and Holocene Climatic Optimum, that varied in timing and effect in each region. We refer to these events when relevant and consistent with the timing for a specific region.

3.1. Mediterranean Basin

The Mediterranean Basin is a vast and diverse area that was home to 466 million people in 2010 and is projected to be inhabited by 529 million people by 2025 (Grid-Arendal, 2013). From the terminal Pleistocene to the present, this region witnessed migrations, colonization, and the rise and collapse of societies which often evolved differently in the East and West (Abulafia, 2011; Broodbank, 2013; Dawson, 2014; Horden and Purcell, 2000; Knapp and Van Dommelen, 2015; Leppard, 2019). Climate anomalies, along with earthquakes, sea level change, floods, and volcanoes influenced human settlement and adaptation throughout the Holocene (e.g., Benjamin et al., 2017; Brisset et al., 2018; Issar, 1998; Weninger et al., 2009). People also had a significant impact on Mediterranean landscapes, which became increasingly anthropogenic across the Holocene (Abrantes et al., 2012; Braje

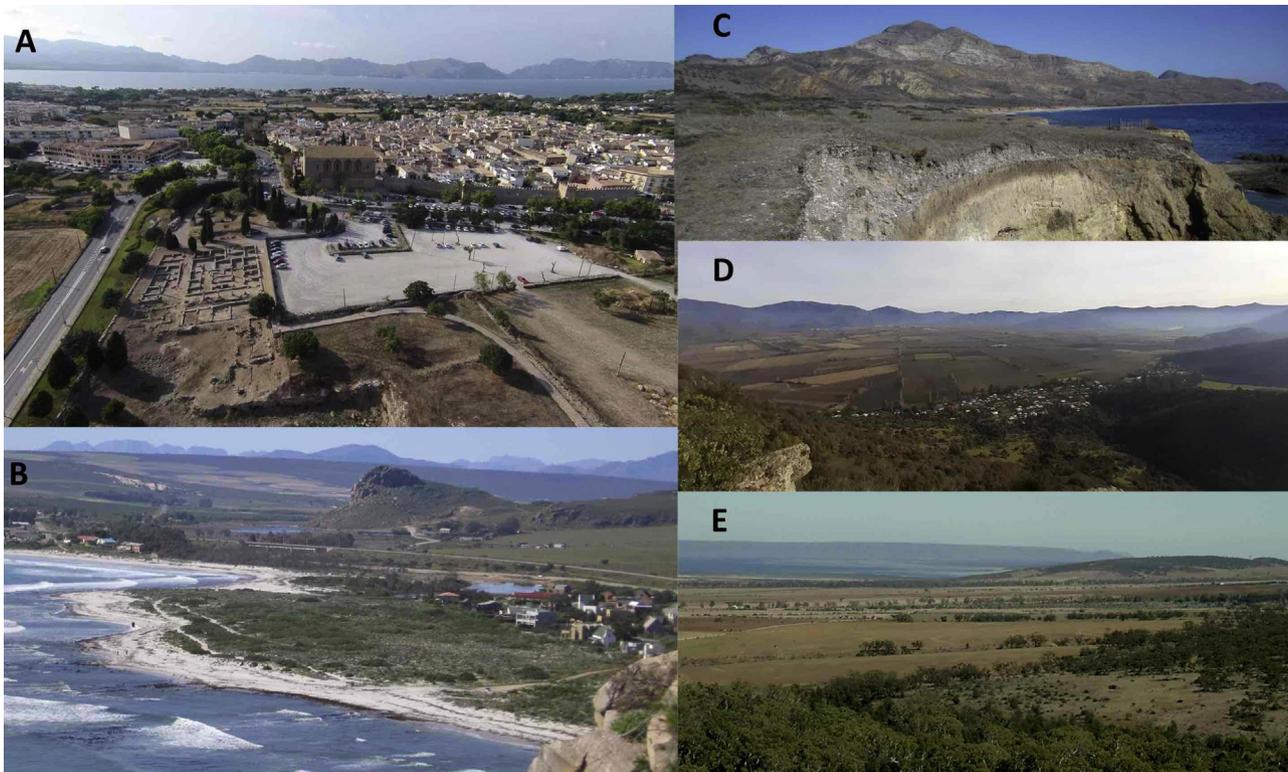


Fig. 2. Cultural landscapes of the ancient MED. A. Excavations at the Roman city of *Pollentia* (Alcúdia, Mallorca, Spain). B. Elands Bay, South Africa, an area with >500 ka of archaeology and modern settlement. C. Late Holocene Chumash village on Santa Cruz Island, California with a dense shell midden. D. Taguatagua Basin, a now drained lake once attracted people since the Terminal Pleistocene. E. Spencer Gulf region, Australia, an area of hunter-gatherer settlement and early marine resource use.

et al., 2017; Hughes, 2014; Masson-Delmotte et al., 2013; Roberts et al., 2019; Zeder, 2008)(Fig. 2).

After the Younger Dryas (11.6 ka), temperatures increased abruptly and significant sea-level rise occurred (Brook, 2014; Roberts, 1998). Forests of perennial trees were abundant between 12.0–6.0 ka, but increasing aridity in the Middle Holocene resulted in vegetation change and an uneven ‘Mediterranization’ of the landscape, including the aridity of the so called 4.2 ka event (e.g., Di Rita and Magri, 2019; Pérez-Obiol et al., 2011; Sadori et al., 2011). The generally optimal, but fluctuating conditions of the Early and Middle Holocene favored rich and varied foraging landscapes that contributed to the spread of Mesolithic hunter-gatherers (e.g., Fernández-López de Pablo et al., 2019). The ‘Neolithic Revolution,’ with the domestication of plants and animals and technological developments in ceramics permanently changed diet and food-processing, resulted in population growth and environmental impacts, and the increasing spread of farming communities from East to West between ~12.0–7.0 ka (Berger et al., 2016; Mercuri et al., 2011; Zilhão, 2001). A particularly abrupt cooling and drying event at ~8.2 ka had an impact on the final Mesolithic and early Neolithic in several places around the Mediterranean basin such as Greece, the Adriatic, Sardinia, Cyprus, the Central Sahara, and the Iberian Peninsula (Berger and Guilaine, 2009; Mercuri et al., 2011). In the Levant, some of the large villages that formed earlier were suddenly depopulated, with sites like Catalhöyük-East completely abandoned (Hassan, 2009; Mercuri et al., 2011:192). This particular cooling event has also been associated with the neolithization of southeastern Europe, the Iberian Peninsula, and Western Mediterranean (e.g., Budja, 2007; Cruz Berrocal, 2012).

Additional climate and environmental change occurred in the Middle Holocene, with dryer conditions and cooling ~6–5.9 ka and increasing aridity ~5.0–4.0 ka (e.g., Mercuri et al., 2011; Roberts et al., 2011). This increasing aridity and temperature after 5.0 ka

may have resulted in declines in arable land, lower agricultural yields, and increased erosion in southern Spain (McClure et al., 2009; see also Barton et al., 2016). These general trends in climate persisted during the Chalcolithic era (Copper Age) and ensuing Bronze Age. These two major periods, especially the Bronze Age, are known for increased agricultural production, the development of hierarchy and progressive urbanization, greater trade and Mediterranean connectivity, and a more pronounced human impact on the landscape, albeit with considerable variability across space and through time (e.g., Broodbank, 2013; Knapp and Van Dommelen, 2015; Kristiansen and Larsson, 2005; Mercuri et al., 2011). During this period, significant climate change ~4.2 ka, including sustained drought, regional aridification, low Nile floods, and occasional heavy rains, may have contributed to the decline of Egypt’s Old Kingdom and other cultures (Bini et al., 2019; Butzer, 2012; Marriner et al., 2012:80; Welc and Marks, 2014; Wiener, 2014). That same climate event has been related to the Chalcolithic to Bronze Age transition in the Iberian Peninsula that fostered a greater emphasis on pastoralism (López Sáez et al., 2014).

Some of the major civilizations of the Bronze Age like the Minoans, Egyptians, and Hittites suffered major disruptions, or even collapse (Late Bronze Age Collapse), around 4.0–3.0 ka when a long drought likely contributed to crop failures, death, and famine in the so-called 3.2 ka event (e.g., Drake, 2012; Kaniewski et al., 2013; for a more nuanced view see Armit et al., 2014; Finné et al., 2017; Knapp and Manning, 2016). The added pressure of the ‘Sea Peoples’—mysterious maritime confederations that raided many areas of the Mediterranean—could have dealt the *coup de grâce* in a steady decline (Kaniewski et al., 2011). With the destruction of the palatial Mycenaean civilization, the Eastern Mediterranean entered into the Greek Dark Ages (Snodgrass, 1971), which persisted until the appearance of the Greek *poleis*, a new organizational system with the well-known city-state model at

~2.9 ka (e.g. Bintliff, 1999; Hansen and Raaflaub, 1995; Hansen, 1993; Snodgrass, 1991). The Iron Age was a period of increasing urbanization, economic developments, and connectivity, interaction, and trade throughout the Mediterranean (e.g. Dietler, 1997; Hodos, 2009; Knapp and Van Dommelen 2015; Manning, 2018). Phoenician and Greek colonization since 3.0 ka was motivated by drier conditions, pursuit of new commodities, and population growth, with a wide East-West diaspora that resulted in unprecedented colonial encounters and hybridization (Dietler, 2010; Hodos, 2009; Van Dommelen, 2012).

The Roman Warm Period, ~2.0 ka, marked the growth of the Hellenistic world and the expansion of Rome across the Mediterranean and beyond (e.g., Post, 2017; Horden and Purcell, 2000). Wheat, wine, and oil were essential for human population growth. The population growth fueled by these commodities resulted in increased urbanization and a higher demand, with the resulting intensification causing greater pressure on resources, deforestation, and pollution (e.g. Hermon, 2009; Hughes, 2014; McCormick et al., 2012). In the Roman Optimum (2.1–0.8 ka), climatic conditions were generally favorable for agriculture and expansion (McCormick et al., 2012). From ~1.7 ka onwards, Barbarian invasions, the decline and fall of Rome, and the rise of the Barbarian kingdoms, coincided with cooler conditions of the Dark Ages (Wickham, 2005). The Late Antique Little Ice Age (1.4–1.3 ka), with cooler conditions, induced by a series of volcanic events, and the spread of the Justinian plague likely had an impact on many parts of the Mediterranean (Büntgen et al., 2016; Harper, 2017; McCormick et al., 2012). Reductions in surpluses and commodities, ruralization, famine, pandemics, and decreases in population occurred (Harper, 2017; McCormick et al., 2012; see also Mordecai and Eisenberg, 2019 for a less catastrophic view of the effects of the Plague), but resilience and adaptation also persisted (Cau Ontiveros and Mas Florit, 2019). Climate change was an important variable in Late Antiquity, but direct causality with the deep social, political, economic, military, and religious transformations in a changing Mediterranean needs to be further scrutinized.

The Islamic expansion, Carolingians, and Byzantium all profoundly changed the Mediterranean milieu. The warm Medieval Climate Anomaly (~1.0–0.65 ka) coincides with these major developments, but also the decline of Byzantium (Lamb, 1965; Xoplaki et al., 2016). Later, the Little Ice Age (0.65–0.15 ka) with cooler conditions, rainy periods, and floods prompted the abandonment of some cultivable lands and the return of forests (Bradley and Jonest, 1993; Mensing et al., 2016). Finally, the Industrial Revolution (0.2–0.1 ka), one of the major revolutions of the Holocene, transformed the region and beyond, resulting in heightened pollution and the onset of major greenhouse gas emissions and ongoing warming that precipitated the modern climate crisis (e.g., Abram et al., 2016).

Today, the Mediterranean is home to dense human populations and is a crucial global food producer, but like in the past, projected increased drought, flooding, and climatic extremes make this area vulnerable to predicted climate change that could also drive human migration (Cramer et al., 2018). The examples from the past described above illustrate that climate is an important variable, alongside social, political, and cultural factors, that influenced several major changes in Holocene demography, economic and subsistence systems, and sociopolitical organization in the Mediterranean Basin. Climate change and warming conditions projected for the Anthropocene in the Mediterranean region would have major effects on food production, water supply, desertification, and human welfare (Cramer et al., 2018). Strategies to address the impacts of drought, food production, and population movements, should focus on multiple levels of society (governmental leaders, citizens, etc.) to build future resilience for the impending challenges that this cradle of civilizations is already facing.

3.2. California

The MED of Alta and northern Baja California are well known for their favorable Mediterranean climate and dense urban areas, including San Francisco, Los Angeles, and San Diego/Tijuana. The region has attracted human settlement for over 13 ka, with population densities and social organization varying across space and through time and high cultural diversity in the region often correlating with variable environmental productivity (Coddling and Jones, 2013; Erlandson et al., 2011; Jones and Coddling, 2019; Rick et al., 2005). The transition to interglacial conditions at the end of the Pleistocene resulted in warming and vegetation changes in California's MED, with the earliest sites dated to ~13 ka (Anderson et al., 2010; Erlandson et al., 2011; Moss and Erlandson, 2013; Jones and Coddling, 2019). One of the greatest climate challenges facing early coastal hunter-gatherers in California was sea level rise, which caused dramatic shoreline and habitat changes that presented difficulties (reduced rocky shore kelp forests) and new opportunities (paleo-estuaries) for human settlement and coastal foraging (Graham et al., 2003). Pluvial lakes and marshes were magnets for early settlement and subsistence in California's interior, Great Basin, and larger American West >13.0–8.0 ka that disappeared or were reduced following increased aridity (Moss and Erlandson, 2013).

During the Holocene Climatic Optimum, increased aridity had variable effects on people throughout California's MED. A possible Middle Holocene migration of interior peoples into coastal California marked by the introduction of new stemmed points may have been driven by persistent drought and decreased productivity in the interior ~6.4–4.8 ka (Jones and Coddling, 2019; Kennett et al., 2007). In the San Diego area, climate and environmental change during the Middle to Late Holocene, especially silting in of lagoons beginning ~4.5 ka, may have driven people from the coast into the interior (Warren, 2013). Between ~6.3–4.8 ka increased aridity had little impact on people on the northern Channel Islands, but on the southern islands, where conditions were warmer, drought may have stimulated early village formation and large exchange networks that connected the coast to interior Great Basin deserts (Kennett et al., 2007). Middle Holocene marine climate was generally warmer, but periodic marine cooling, reduced El Niño Southern Oscillation, and other variables (e.g., sea otter abundance) likely enhanced the availability (at least in some areas) of cooler-adapted marine shellfish (*Haliotis rufescens*) that were important on the northern Channel Islands and central California Coast (Glassow, 2015; Jones and Coddling, 2019; Kennett et al., 2007).

Throughout California, the Late Holocene was a period of dynamic environmental and cultural change. Between ~1.5–0.2 ka, Chumash peoples of the Santa Barbara Channel lived in increasingly densely populated and stratified villages, had large exchange networks, and important ritual systems, all while maintaining a hunter-gatherer economy (Arnold, 1992; Johnson, 2000). Drought and unstable marine conditions, particularly during the Medieval Climatic Anomaly, may have been one factor that drove people in the Santa Barbara Channel to coalesce village settlements around productive water sources, engage in greater exchange, and ultimately increase social hierarchy. However, these same patterns did not occur north of Point Conception and some scholars argue for alternatives in the Santa Barbara Channel (Arnold, 1992; Gamble, 2005; Jones et al., 1999; Johnson, 2000; Kennett and Kennett, 2000; Jazwa et al., 2019; Jones and Coddling, 2019). Medieval Climatic Anomaly drought and resource scarcity were also driving factors in increased interpersonal violence, particularly ~1.2–0.7 ka in the Santa Barbara Channel and several parts of central California to varying degrees (Jones and Coddling, 2019; Jones and Schwitalla, 2013). Climate also likely influenced

the dynamics of acorn harvest, an important source of carbohydrates and other nutrients in most of California, especially during the Late Holocene, when drought may have reduced use of interior acorns on the central Coast (Coddington and Jones, 2016). In the Sierra Nevada on the edge of the MED and adjacent Great Basin deserts, heightened variability in temperature and precipitation during the Little Ice Age promoted risk reduction strategies, including lowland aggregation and seasonal dispersal for resources (Morgan, 2009). Finally, Larson et al. (1994) argue that drought and unstable marine conditions may have been a driving factor in pushing the Chumash in the Santa Barbara Channel region to mainland missions in the late 18th and early 19th centuries, though others question the importance of climate change citing instead the major impacts of colonialism on traditional socio-environmental systems (Dart-Newton and Erlandson, 2006).

People also actively shaped California's MED ecosystems during the Holocene and may have had buffering mechanisms (e.g., mobility) for climatic downturns (see Gamble, 2005). Anthropogenic environmental alterations include anthropogenic burning, translocation of plants and animals, and influence on a variety of nearshore marine ecosystems and terrestrial plant communities (Anderson et al., 2010; Braje et al., 2017; Cuthrel et al., 2012; Erlandson and Rick, 2010; Gill et al., 2019; Hofman and Rick, 2018; Lightfoot et al., 2013; Taylor et al., 2016). Fire is a key part of California's MED, with research from the Sierras to coast documenting the interplay between natural and anthropogenic fire cycles (Cuthrel et al., 2012; Lightfoot et al., 2013; Taylor et al., 2016;). Native American burning was likely a greater force than natural fire cycles prior to the 19th century in the Sierra Nevadas, and anthropogenic burning may have increased during the Late Holocene on the northern Channel Islands (Anderson et al., 2010; Taylor et al., 2016). In the central coast Quiroste Valley, anthropogenic burning helped maintain grassland communities compared to shrubs and conifer forests found under natural cycles, with the former producing more resources for human use (Cuthrel et al., 2012; Lightfoot et al., 2013).

Global warming has been exacerbating droughts in California and the broader American West. These droughts, compounded by periods of heavy rain and severe erosion, along with changing fire cycles and intensity, pose great challenges for the MED of California today and are major threats of the Anthropocene (Guzman-Morales and Gershunov, 2019; Polade et al., 2017; Swain et al., 2018; Williams et al., 2020). These issues and their effect on human society have parallels to the past, albeit different in scale and magnitude. Drought and environmental deterioration in parts of Middle Holocene California, declines in acorns and other resources due to drought in Late Holocene central California, and increasing interpersonal violence and social hierarchy related to Medieval Climatic Anomaly drought and climatic instability demonstrate that major climatic events have long-term (century or more) effects on past human societies. Given that human populations are now on an order of tens of millions, a one hundred-fold increase compared with past cultures in California, climatic events of the Anthropocene are likely to have even greater long-term impacts. Exchange and trade with outside regions as well as migration, not unlike past human responses, offer a buffer to some of these challenges, but certainly not all, especially given how important this area is for global food production.

3.3. Southwestern and Southern Australia

Australia's MED formed largely from the incursion of winter (rain-bearing) westerlies from the Southern Ocean into the southern parts of the continent, and indirectly from major river systems, such as the Murray-Darling River (Williams et al., 2015a). These climatic systems are unlikely to have extended in their

current form across the entire ~50.0 ka of Aboriginal presence in Australia, but they were established following the Last Glacial Maximum (~21 ka).

The earliest evidence of Aboriginal people in the southern latitudes of Australia comes from archaeological sites within, or on the fringe of, the MED, including Devil's Lair, Warraty Rockshelter, and Lake Mungo. Devil's Lair demonstrates small rapidly moving human populations visiting the region ~49.0 ka, some 4000 km away from their initial arrival only ~1.0 ka earlier; while sites at Lake Mungo contain some of the earliest human interments in the world (~42.0 ka) and indications of a significant cultural and symbolically complex society (Langley et al., 2011; O'Connell et al., 2018). Archaeological models suggest human populations experienced a major reduction in size (~60%), with settlement contraction and abandonment across much of the continent during the Last Glacial Maximum (Veth, 1993; Williams et al., 2013). Ecological refuges—well-watered ranges and major riverine systems—helped hunter-gatherers transcend increasingly cool and arid conditions (Tobler et al., 2017). Two of these refuges are within the MED. Hunter-gatherers exploited freshwater mussels and fish from the Willandra Lakes System and hunted various terrestrial fauna (macropods, emus, etc.) (Stern, 2015). Similarly, repeated, albeit episodic, occupation of the Last Glacial Maximum Devil's Lair cave system suggests it was a refuge in which people used a range of micro-habitats and heterogeneous resource patches (Dortch, 1979; Tobler et al., 2017). While the main prey was western grey kangaroos, the diverse diet of smaller animal species, which yield fewer calories per human effort, and bone marrow extraction, which requires more intensive processing of animal carcasses, indicates hunter-gatherers were expanding their diet breadth.

Significant environmental change occurred during the Terminal Pleistocene/Early Holocene. Notably sea level rise resulted in the reduction of the continent by ~21% (~2 million km²) (Williams et al., 2018). Concurrent improving climatic conditions in the Holocene Climatic Optimum resulted in population growth, expansion of ranging territories, sedentism (longer patch residence time), and the beginnings of low-level food production (e.g., aquaculture) (Williams et al., 2015a, Williams et al., 2015b). In the MED, this resulted in a much broader range of archaeological sites, like Roonka Flat where ~147 individuals were interred (Pate et al., 1998), and the increasing use of marine resources. Many of the previous refuges were subject to abandonment or a re-structuring of land use (Dortch, 1979; Fitzsimmons et al., 2019). Larger populations utilizing the landscape made undertaking large-scale movements to mitigate environmental distress increasingly difficult and was replaced by diversification of foraging strategies and technological changes (Williams et al., 2015b).

Population increased during the Late Holocene, with hunter-gatherers reaching a peak of ~1.2 million people at ~0.5 ka, a tenfold increase over Pleistocene levels (Williams et al., 2013). The highest populations during this time were in the southeast, including the lower Murray-Darling river system. This increase was likely a result of intensification of earlier technological advancements, including hafting-technology, plant and seed processing, and localized landscape management (fire), helping people better survive climatic downturns, including strong El Niño Southern Oscillation conditions between 4.0–2.0 ka and increasingly turbulent climatic conditions during the Medieval Climatic Anomaly (generally wetter) and Little Ice Age (generally drier) (Williams et al., 2015a). Increased populations led to restricted mobility, greater sedentism, and the formation of strong classificatory kinship systems, complex cultural and symbolic landscapes based on geographic totemism (the 'Dreaming'), distinctive graphic art systems, land rights in the form of ritual property, and formalized exchange networks (Williams et al., 2015b).

Overall, the deep history of the region demonstrates that Aboriginal peoples were heavily influenced by major climatic disruption over the last 13 ka. This primarily stemmed from rapid sea-level inundation in the terminal Pleistocene, which influenced societal and population changes into the Early Holocene, a period of several thousand years. Subsequent ameliorating climate, resulted in these populations thriving later in the Holocene, and developing technological and societal advancement that ensured survival through subsequent climatic downturns. Today, the MED encompass two of Australia's major cities, Perth and Adelaide, with a combined population of ~3.8 million people. More broadly, the regions contain much of the continent's >\$40 billion viticulture industry and significant agricultural lands that feed large parts of Australia. These regions are already affected by climate disruption, including prolonged droughts, fire, water shortages, and heat waves (>40 °C), all projected to increase into the future. Based on the success of past Aboriginal society, increasing technological advancement, especially to buffer against climate extremes, will be one essential strategy in the coming decades.

3.4. Western Cape region of South Africa

Dominated by a MED climate, South Africa's winter rainfall region includes the entire west coast and the south coast's western-most extent, with rainfall decreasing markedly to the north (Chase and Meadows, 2007). The best insights into past human-environmental dynamics in this region are offered by the Lamberts Bay and Elands Bay areas during the Holocene (Chase and Meadows, 2007; Jerardino et al., 2013a). Archaeological sites are common here, with their abundance and distribution related to drinking water availability. Central to human subsistence were rich marine resources supported by the Benguela Current (Kämpf and Chapman, 2016). Hunting and gathering was the focus of human economies throughout the region (Braun et al., 2013), with herding added ~2.0 ka (Sadr, 2013).

Following the Last Glacial Maximum, atmospheric and ocean temperatures increased and sea levels recovered steadily. By 11.0 ka, the shoreline was at the edge of the foraging radius of the oldest site known to be occupied at that time (Parkington, 1990). Hunter-gatherers were few on the landscape, moving between the coast and interior (~60 km), hunting large game and smaller prey (Jerardino et al., 2013b). Increased aridity and 2–3 m higher sea levels followed between 8.0–4.0 ka. The Holocene Climatic Optimum, the warmest part of the Holocene in southern Africa, was thought to have largely driven people out of the area (Jerardino et al., 2013b). However, we know that people adapted to water scarcity and lower terrestrial carrying capacity by forming small groups, seldom visiting the coast, or doing so only for short periods (Jerardino et al., 2013b, 2016). People continued to be highly mobile, but moved mainly to the north and south where lithic raw materials with better-knapping qualities were plentiful. Human diets were largely terrestrial, and diversified with more small terrestrial game and a wider range of marine resources (Jerardino et al., 2013b, 2016).

With cooler and more humid conditions ~4.2 ka (the first Neoglacial), people returned more frequently to the central west coast (Jerardino et al., 2013b). By 3.5 ka, population increased while temperate to cooler and wetter climatic conditions dominated. For the next 1.5 ka, trips to the interior valleys or to the north/south were limited. Around 3.0 ka, hunting of large mobile game was generally replaced by the procurement of small bovids along with the intensified collection of slow-moving prey such as tortoises (Jerardino, 2010, 2012; Jerardino et al., 2013b, 2016). Human populations continued to grow after 3.0 ka, supported by cooler/wetter conditions during the second Neoglacial, 3.0–2.5 ka. Between 3.0–2.0 ka, large game was no longer

hunted, although climatic conditions favored their local distribution. Subsistence focused largely on tortoises and the intense harvest of marine mollusks. At least eight enormous shell middens (megamiddens) made of thousands of cubic meters of material accumulated behind productive rocky reefs. Marine resources contributed significantly to human diet between 3.0–2.0 ka, with local marine taxa and tortoises heavily impacted by human predation (Jerardino, 2010, 2012; Jerardino et al., 2016; Jerardino and Navarro, 2018a, Jerardino and Navarro, 2018b).

Megamiddens ceased to accumulate around 2.0 ka, roughly when herding spread into southern Africa through mainly cultural diffusion and much less so due to migration of herder groups (Jerardino et al., 2013c). Subsequently, foragers depended on small terrestrial game and marine resources, while other groups took on herding with varying degrees of intensity. With warm and dry conditions during the Medieval Climatic Anomaly, contact among hunter-gatherers and herders became strained and frequent droughts made much of the central and northern west coast unattractive for human settlement (Dewar and Marsh, 2018; Jerardino et al., 2018). During the few visits to the central west coast, people settled atop outcrops (some with stone-built structures) and other high places to view the movement of people, game, and predators. A third, but shorter Neoglacial episode (Little Ice Age) happened immediately after, allowing more frequent visits to high and low places (Chase and Meadows, 2007; Jerardino et al., 2018). However, the high population densities and intense marine food extraction during the second Neoglacial were not repeated during the third.

South African MED foragers and herders of the past relied on higher mobility for facing dry and hot climatic periods, such as during the Holocene Climatic Optimum and Medieval Climatic Anomaly. The largely urban and socially complex context, including uneven access to education and healthcare, low employment rates, and low wages of today, and the projections for future drying and warming of the Anthropocene make this option of mobility and abandonment challenging and likely a last resort in South Africa today. However, the past nomadic strategy of moving away from the areas affected most by climate change can instill much needed urgency in effecting binding strategies that won't require something as drastic as abandonment and mass-migration (Western Cape Government, 2018).

3.5. Central Chile

The MED of Chile is influenced by the interannual variation in the position of the Subtropical Pacific Anticyclone seasonally blocking the westerly wind belt (Garreaud et al., 2009). Bounded by the Pacific Ocean and the Andes, East-West oriented valleys spread within a major depressed central area hosting highly productive agricultural lands and large lake basins, some currently drained. The central depression has produced evidence for small hunter-gatherer occupations as early as 13.0 ka in the Taguatagua basin (Núñez et al., 2001). During the Late Pleistocene the MED, which extended northwards from its current position, was occupied by small mobile groups who preyed upon megafauna that gathered around these lake basins, as also shown by the 12.9 ka record of Quebrada Santa Julia (Méndez and Jackson, 2015). Lake contraction accompanied major changes in temperature and effective moisture that turned the open forests into grasslands and contributed to the demise of large mammals (González-Guarda et al., 2018; Valero-Garcés et al., 2005).

Mountain and coastal habitats were occupied by humans since the Early Holocene, the latter as indicated by the archaeological record in the northernmost limit of the MED where recent coastal urban development has had a more limited reach and a greater number of studies have been conducted (Cornejo et al., 2016;

Méndez et al., 2015). A full-scale coastal adaptation, including marine protein-based diets, have been described since the onset of the Holocene (Jackson et al., 2012a). By ~9.0 ka, combined paleoenvironmental records from the broader region show the onset of dry conditions (Holocene Climatic Optimum), including severe millennial droughts, which prevailed during the Middle Holocene as a response to shifts in the position and strength of the Subtropical Pacific Anticyclone (Jenny et al., 2002; Maldonado and Villagrán, 2006). These coincide with declines in regional human occupation, evidenced by decreases in radiocarbon dates, with sustained droughts exerting pressure on resources (Méndez et al., 2015). For this period, two potential explanations have been proposed; either mobile groups relocated to less affected environments, or there was broad population decline (Barberena et al., 2017). The Taguatagua basin (and other similar areas) may have attracted hunter-gatherers as indicated by the concentration of funerary and residential contexts during this period (Jackson et al., 2012b). By ~5.0 ka, occupations across the landscape multiplied and site types suggest a diversification in activities, which has been interpreted as less residential mobility, favoring logistical moves to specific resources (Cornejo et al., 2016).

The most profound socio-cultural change in central Chile occurred by 2.3 ka when small-scale horticulturalists occupied vast areas of the coast and interior (Sanhueza and Falabella, 2010). Larger settlements, higher discard rates, and more ¹⁴C and TL dates suggest an increase in population density (Falabella et al., 2015; Gayo et al., 2019). Different small-scale groups, identified by a combination of site distribution, formal attributes of pottery, clay source provenance, differences in treatment of the dead, and overall composition of diets, coexisted in this territory (Falabella et al., 2007; Sanhueza, 2016). Though the first domesticates (e.g., *Chenopodium*) predate this period, their incorporation as a staple came during the last 1.0 ka, especially with the introduction of maize (*Zea mays*) (Falabella et al., 2007; Planella et al., 2005). Climatic variability seen in the alternation of flood and drought in lake sediment records for the last 3.0 ka may have affected interannual stability for horticulturalists and agriculturalists (Falabella et al., 2015; Jenny et al., 2002). During the last 1.0 ka of occupation, communities experienced deep changes that led to greater homogeneity in pottery designs, less mobility, larger and more stable settlements, animal husbandry, and formal cemeteries (Falabella et al., 2016). By 0.55 ka, this area became the southernmost frontier of the Inca empire, which introduced pan-Andean architecture, pottery, and varied craftsmanship following the development of renewed socio-political relations with local communities (Uribe and Sánchez, 2016). The cultural heterogeneity and change within the last ~2.0 ka of occupation of the Chilean MED suggests that increased environmental pressures by growing human populations were mitigated by targeting different niches as indicated by the rooted horticultural practices in the valleys and the marginalization of hunter-gatherers into mountain landscapes (Cornejo and Sanhueza, 2003). Human activities resulted in dramatic environmental changes, such as alterations in plant and animal communities from the introduction of domesticates and wildlife into new areas, changes in littoral physiography from shell midden accumulation, and increased landscape burning reflecting a shift from a natural to human-driven fire regime (Gayo et al., 2019).

Today, several major cities occupy the central depression (e.g., Santiago) concentrating ~12.5 million people (65% of the national population), a number that has risen dramatically from pre-Columbian times. This region of important food production now faces a sustained decadal drought, changes in vegetation cover, hill slope erosion, the complete desiccation of lakes in lower altitudes (e.g., Aculeo) and the mountains, massive deaths of cattle, and a 70% increase in the forest fire area (CR2, 2015). Such challenges are

an increasing reality of the Anthropocene and show that currently society is far more exposed to adverse climatic pulses than past human small-scale societies that peopled central Chile. Millennial scale droughts during the Middle Holocene (Holocene Climatic Optimum) resulted in local (or possibly broader) reductions in human population, while smaller scale droughts forced settlement changes for later horticulturalists. Mobility, the main alternative used in the past for dealing with the resource shortcomings of the MED in Chile, is no longer an option given the increasing population pressure and degree of urbanization of this region; yet the redistribution/resettlement of people over an unevenly populated country represents an opportunity to promote the sustainability of landscapes and resources.

4. Synthesis

Living in an age characterized by dramatic climatic and environmental change (IPCC, 2014) requires new perspectives and approaches, including the use of long-term past socio-environmental records to evaluate the interconnections between environmental change and humans to help prepare for the future (Boivin et al., 2016; Cooper and Sheets, 2012; Douglass et al., 2019; Jorgenson et al., 2019). The archaeology of the MED demonstrates a continuum between past human land use and settlement and present-day contexts, providing a window into potential future interactions mitigated by contextual differences. Archaeological research from the MED demonstrates that past climate disruptions (drought, El Niño Southern Oscillation, sea level rise, etc.) were major factors of past social change, and that anthropogenic environmental modification has been an important variable for millennia (Fig. 3). In the Mediterranean Basin and Chile, domestication and agriculture became important components of human subsistence (despite differences in scale), giving rise to increased population densities, socio-political complexity, and the appearance of states/empires. In contrast, the MED of South Africa, Australia, and California were home to largely hunter-gatherers until the arrival of pastoralists or Europeans ~2.0–0.2 ka, but similarly had their own technological adaptations and behaviors to thrive in their environments.

The legacies of past long-term human-environmental interactions helped shape and transform the modern MED through millennia of human-environmental modification. These legacies are most pronounced in the urban civilizations of the Mediterranean Basin, but also in the deep cultural traditions of the other regions. Past climate disruptions had a significant effect on human societies in the five regions, especially climatic downturns (notably droughts) that disrupted human social organization, often resulting in population decline, abandonment, and/or socio-political upheaval (see Barberena et al., 2017; Bini et al., 2019; Jerardino et al., 2013b; Jones et al., 1999 for regional examples). These difficult periods were often followed by a later re-organization and/or reoccupation, often with markedly different strategies, technologies and/or social identities, and with a focus on more marginal areas during favorable environmental conditions (see Cornejo et al., 2016; Jerardino et al., 2013b; McCormick et al., 2012; Williams et al., 2015a, Williams et al., 2015b for regional examples). In the past, like today, people were not moving along blindly in a world predetermined by environmental conditions, they were actively shaping the world around them through the intentional use of fire, domesticated plants and animals, and other ecological changes.

Climate alone cannot explain specific changes in human cultural evolution in the MED, but it was an important catalyst of change (Fig. 3). For example, in several parts of California, Medieval Climatic Anomaly drought likely contributed to variable but increased patterns of inter-personal violence, and may have

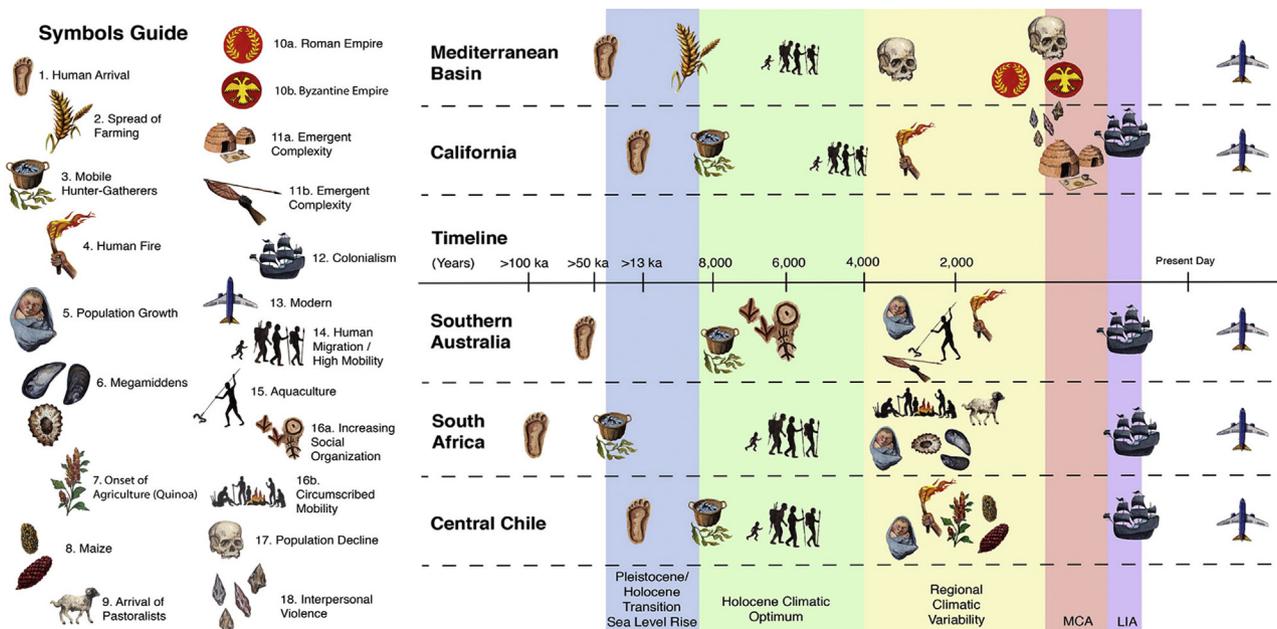


Fig. 3. Generalized timeline of major cultural events and associated climatic changes in MED. Some events are not contiguous across the entire region but have been linked to specific climate events described in more detail in the text. The bottom of the timeline documents key climatic periods or developments during the Late Pleistocene to Holocene. MCA = Medieval Climatic Anomaly and LIA = Little Ice Age. Symbols guide: 1. human arrival 2. spread of farming 3. mobile hunter-gatherers 4. human fire 5. population growth 6. megamiddens 7. onset of agriculture 8. maize agriculture 9. arrival of pastoralists 10a. Roman empire 10b. Byzantine empire 11a./11b. emergent complexity 12. colonialism 13. globalization/modern 14. human migration/high mobility 15. aquaculture 16a. increasing social organization 16b. circumscribed mobility 17. population decline 18. interpersonal violence.

fostered increased socio-political hierarchy and exchange in the Santa Barbara Channel (Jones et al., 1999; Jones and Schwitalla, 2013; Kennett and Kennett, 2000). Drying of the Medieval Climatic Anomaly also influenced the rise and fall of Byzantium in the Mediterranean Basin (Xoplaki et al., 2016;), while Middle Holocene and Medieval Climatic Anomaly droughts in South Africa limited coastal occupation, but increased mobility and particular settlement locations in the latter period allowed people to cope with these challenges (Jerardino et al., 2016, 2018). In Chile, people moved to favorable ecological refuges like the Taguatagua basin, causing a shift in human use of the broader area, with later additions of domesticated crops prompting changes in settlement and land use (Barberena et al., 2017; Falabella et al., 2007; Sanhueza, 2016). In southern Australia, the MED provided safe haven during the Last Glacial Maximum, and drove population increase as well as socio-economic complexity in the Holocene (Williams et al., 2015b).

Today, drought, flooding, heat waves, bush-fires, sea level rise, and other risk factors are daunting challenges of the MED, with each of these exacerbated by dense human populations and management decisions on how to use water, agricultural land, and overall intensification of production, and where to allow human settlements (e.g., floodplains, coastal fringes, and fire-prone hillsides). Climate change of the present MED is happening on a more rapid and pronounced scale than in most of the Holocene (IPCC, 2014), but we now have greater technological capacity and the ability to look back at past human responses to climate disruptions and project future change under different environmental and climatic conditions (Alessandri et al., 2014; Guiot and Cramer, 2016). With ~500 million people and key global food resources and economic systems vulnerable to climate change, the MED of the present in many ways is very different from the MED of the deep past. However, much like the way in which climate change is shaping our present world, past changes such as Holocene Climatic Optimum and Medieval Climatic Anomaly droughts left indelible impacts on past societies and caused lasting

alterations to the states and empires of the Mediterranean, many of which form the foundation of Western society. In many instances, such climate events led to, or contributed to, the direct decline of their power and influence.

5. Implications for Anthropocene futures

In the global MED, discernable human-environmental impacts, such as landscape change from agriculture, declines in local resources, and the use of fire, alongside changing climatic conditions, appear in different regions at different times. Perhaps the earliest evidence is in the Mediterranean Basin with domestication and agriculture by at least the Early Holocene, but not widespread in the other regions until later. This in part reflects the dominance of successful hunter-gatherer economies in the Californian, Australian, Chilean (until 2.0 ka), and South African MED, that often leave more subtle, albeit lasting, environmental impacts (Fig. 3; Stephens et al., 2019). Despite differences in timing in each region, widespread anthropogenic technological change and/or environmental alteration, including adaptations to help thrive in more marginal settings, was characteristic of the global MED by the Late Holocene—if not earlier. These data are consistent with recent syntheses of global tropical forests that demonstrate variation in the timing of anthropogenic environmental change, but significant human influence during the Holocene (Roberts et al., 2018).

Our global synthesis of human-environmental interactions in the MED demonstrates the importance of comparing and contrasting seemingly disparate areas. In the case of the global MED, despite the spatial diversity, economies, and population densities of past societies, there appears one constant: climate disruption at various temporal scales served as a catalyst and the resulting changes are often profound and generally played out over the *longue durée*. For example, the 8.2 ka event resulted in the beginning of Neolithization and in part created conditions favorable for subsequent Greek and Roman states; millennial

droughts in the Middle Holocene encouraged changes in mobility and demography in Chile, which may have contributed to the diversity in horticulturalists several thousand years later; and sea level rise in Australia at ~14–8.0 ka resulted in population amalgamation leading to increasing complexity and socio-economic systems some 5000 years later. Our synthesis suggests that climate disruption, working in concert with a variety of social and cultural variables, resulted in decadal to centennial periods of influence over past societies. This suggests that major climatic events can trigger changes several hundred years into the future, and our current planning needs to be thinking at similar timescales. While short-term management and adaptation enable survival of the MED, there are longer term ramifications of climate disruption which need to be more fully explored to avoid catastrophic population collapse and sociopolitical instability like those described above during the Holocene.

This review of past human-environmental interaction in the global MED provides significant information that can help guide future research areas and priorities as we plan for an Anthropocene future, especially patterns of extreme drought that are increasingly affecting the MED. Our review underscores the need for additional global synthesis or comparative analysis of archaeological records of socio-environmental systems and climate from other environmental regions. Review of the diverse and variable global MED has underscored patterns of environmental change and influence that transcend different economic systems, population levels, and regional climatic variability. Our synthesis and similar work (e.g., d'Alpoim Guedes et al., 2016; Sandweiss and Kelley, 2012) can help integrate perspectives from the past at global scale into planning and preparation for the future. While our review illustrates the potential value of such global archaeological comparative synthesis, it also underscores the need to expand and deepen the analysis. For example, more detailed studies of long-term human-environmental dynamics in single MED regions can build on and clarify the larger global issues raised in this review (e.g., Bevan et al., 2019). Although not reviewed in detail here, computational socioecological modeling like the work of Barton et al. (2016) for the Mediterranean Basin is another important area of research that has the potential to help understand natural climatic versus anthropogenic drivers of environmental change in the past. Finally, our work demonstrates the importance of interdisciplinary research that integrates records of the socio-environmental dynamics of the past to help understand how we arrived at the present and how we can work towards a more sustainable future.

Declaration of Competing Interest

The authors declare no competing interests.

Acknowledgments

Funding was provided by our home institutions and FONDECYT#1170408 and Programa Regional CONICYT R17A10002 to Méndez. Katy Marchese illustrated Fig. 1 and Trenton Jung illustrated Fig. 3. We thank Dan Sandweiss for helpful comments on an earlier draft of this paper, as well as the *Anthropocene* editors and two anonymous reviewers. The views expressed in the manuscript are those of the authors, not of any U.S. Federal agencies.

References

Abatzoglou, J.T., Park Williams, A., 2016. Impact of anthropogenic climate change on wildfire across western US forests. *Proc. Natl. Acad. Sci. U.S.A.* 113, 11770–11775.

Abram, N.J., McGregor, H.V., Tierney, J.E., Evans, M.N., McKay, N.P., Kaufman, D.S., Pages 2k Consortium, 2016. Early onset of industrial-era warming across the oceans and continents. *Nature* 536, 411–418.

Abrantes, F., Voelker, A., Sierro, F.J., Naughton, F., Rodrigues, T., Cacho, I., Ariztegui Brayshaw, D., Sicre, M., Batista, L., 2012. Paleoclimate variability in the Mediterranean region. In: Lionello, P. (Ed.), *The Climate of the Mediterranean Region: From the Past to the Future*. Elsevier, London, pp. 1–86.

Abulafia, D., 2011. *The Great Sea: A Human History of the Mediterranean*. Allen Lane, London.

Albert, R.M., 2015. Anthropocene and early human behavior. *Holocene* 25 (10), 1542–1552.

Alessandri, A., De Felice, M., Zeng, N., Mariotti, A., Pan, Y., Cherchi, A., Lee, J., Wang, B., Ha, K., Ruti, P., Artale, V., 2014. Robust assessment of the expansion and retreat of Mediterranean climate in the 21st century. *Sci. Rep.* 4, 7211. doi:http://dx.doi.org/10.1038/srep07211.

Anderson, R.S., Starratt, S., Brunner Jass, R.M., Pinter, N., 2010. Fire and vegetation history on Santa Rosa Island, Channel Islands and long-term environmental change in southern California. *J. Quat. Sci.* 25, 782–797.

Armit, I., Swindles, G.T., Becker, K., Plunkett, G., Blaauw, M., 2014. Rapid climate change did not cause population collapse at the end of the European Bronze Age. *Proc. Natl. Acad. Sci. U.S.A.* 111, 17045–17049.

Arnold, J.E., 1992. Complex hunter-gatherer-fishers of prehistoric California: chiefs, specialists, and maritime adaptations of the Channel Islands. *Am. Antiq.* 57, 60–84.

Barberena, R., Méndez, C., de Porras, M.E., 2017. Zooming out from archaeological discontinuities: the meaning of Mid-Holocene temporal troughs in South American deserts. *J. Anthropol. Archaeol.* 46, 68–81.

Barton, C.M., Ullah, I.I.T., Bergin, S.M., Sarjoughian, H.S., Mayer, G.R., Bernabeu-Auban, J.E., Hemsath, A.M., Acevedo, M.F., Riel-Salvatore, J.G., Arrowsmith, J.R., 2016. Experimental socioecology: integrative science for Anthropocene landscape dynamics. *Anthropocene* 13, 34–45.

Benjamin, J., Rovere, A., Fontana, A., Furlani, S., Vacchi, M., Inglis, R.H., Galili, E., Antonoli, F., Sivan, D., Miko, S., Mourtzas, N., Felja, I., Meredith-Williams, M., Goodman-Tchernov, B., Kolaiti, E., Anzidei, M., Gehrels, R., 2017. Late Quaternary sea-level changes and early human societies in the central and eastern Mediterranean Basin: an interdisciplinary review. *Quat. Int.* 449, 29–57.

Berger, J.F., Guilaine, J., 2009. The 8200 cal BP abrupt environmental change and the Neolithic transition: a Mediterranean perspective. *Quat. Int.* 200 (1–2), 31–49.

Berger, J.F., Lespez, L., Kuzuucuoglu, C., Glais, A., Hourani, F., Barra, A., Guilaine, J., 2016. Interactions between climate change and human activities during the early to Mid-Holocene in the eastern Mediterranean basins. *Clim. Past* 12, 1847–1877.

Bevan, A., Palmisano, A., Woodbridge, J., Fyfe, R., Roberts, C.N., Shennan, S., 2019. The changing face of the Mediterranean—land cover, demography, and environmental change: introduction and overview. *Holocene* 29, 703–707.

Bini, M., Zanchetta, G., Persoiu, A., Cartier, R., Català, A., Cacho, I., Dean, J.R., Di Rita, F., Drysdale, R.N., Finnè, M., Isola, I., Jalali, B., Lirer, F., Magri, D., Masi, A., Marks, L., Mercuri, A.M., Peyron, O., Sadori, L., Sicre, M., Welc, F., Zielhofer, C., Brisset, E., 2019. The 4.2 ka BP Event in the Mediterranean region. *Clim. Past* 15, 555–577.

Bintliff, J.L., 1999. The origins and nature of the Greek city-state and its significance for world settlement history. In: Ruby, P. (Ed.), *Les Princes de la Protohistoire et l'Émergence de l'Étal. Ecole Française de Rome*, Rome, pp. 43–56.

Bliege Bird, R., Coddling, B.F., Kauhaneen, P.G., Bird, D.W., 2012. Aboriginal hunting buffers climate-driven fire-size variability in Australia's spinifex grasslands. *Proc. Natl. Acad. Sci. U.S.A.* 109, 10287–10292.

Blumler, M.A., 2005. Three conflated definitions of Mediterranean climates. *Mid. States Geograph.* 38, 52–60.

Boivin, N., Zeder, M.A., Fuller, D.Q., Crowther, A., Larson, G., Erlandson, J.M., Denham, T., Petraglia, M.D., 2016. Ecological consequences of human niche construction: examining long-term anthropogenic shaping of global species distributions. *Proc. Natl. Acad. Sci. U.S.A.* 113, 6388–6396.

Bradley, R.S., Jonest, P.D., 1993. 'Little Ice Age' summer temperature variations: their nature and relevance to recent global warming trends. *Holocene* 3, 367–376.

Braje, T.J., Erlandson, J.M., 2013. Looking forward, looking back: humans, anthropogenic change, and the Anthropocene. *Anthropocene* 4, 116–121.

Braje, T.J., Leppard, T.P., Fitzpatrick, S.M., Erlandson, J.M., 2017. Archaeology, historical ecology, and anthropogenic island ecosystems. *Environ. Conserv.* 44, 286–297.

Braun, D.R., Levin, N.E., Stynder, D., Herries, A.I.R., Archer, W., Forrest, F., Roberts, D. L., Bishop, L.C., Matthews, T., Lehmann, S.Z.B., Pickering, R., Fitzsimmons, K.E., 2013. Mid-Pleistocene hominin occupation of Elandsfontein, Western Cape, South Africa. *Quat. Sci. Rev.* 82, 145–166.

Brayshaw, D.J., Rambeauc, C.M.C., Smith, S.J., 2011. Changes in Mediterranean climate during the Holocene: insights from global and regional climate modeling. *Holocene* 21, 15–31.

Brisset, E., Burjachs, F., Navarro, B.J.B., de Pablo, J.F.L., 2018. Socio-ecological adaptation to Early-Holocene sea-level rise in the western Mediterranean. *Glob. Planet. Change* 169, 156–167.

Broodbank, C., 2013. *The Making of the Middle Sea: a History of the Mediterranean From the Beginning to the Emergence of the Classical World*. Thames and Hudson, London.

Brook, J.L., 2014. *Climate Change and the Course of Global History: A Rough Journey*. Cambridge University Press, Cambridge.

Budja, M., 2007. The 8200 calBP 'climate event' and the process of neolithisation in south-eastern Europe. *Documenta Praehist.* 34, 191–201.

Büntgen, U., Myglan, V.S., Ljungqvist, F.C., McCormick, M., Di Cosmo, N., Sigl, M., Jungclaus, J., Wagner, S., Krusic, P.J., Esper, J., Kaplan, J.O., de Vaan, M.A.C., Luterbacher, J., Wacker, L., Tegel, W., Kiryanov, A.V., 2016. Cooling and societal change during the Late Antique Little Ice Age from 536 to around 660 AD. *Nat. Geosci.* 9, 231–236.

- Butzer, K.W., 2012. Collapse, environment, and society. *Proc. Natl. Acad. Sci. U.S.A.* 109 (10), 3632–3639.
- California Department of Food and Agriculture, 2018. California Agricultural Statistics Review 2017–2018. California Department of Food and Agriculture, Sacramento.
- Cau Ontiveros, M.A., Mas Florit, C. (Eds.), 2019. Change and Resilience. The Occupation of Mediterranean Islands in Late Antiquity. Oxbow Books, Oxford.
- Chase, B.M., Meadows, M.E., 2007. Late Quaternary dynamics of southern Africa's winter rainfall zone. *Earth-Sci. Rev.* 84, 103–138.
- Christensen, J.H., Krishna Kumar, K., Aldrian, E., An, S.-I., Cavalanti, I.F.A., de Castro, M., Dong, W., Goswami, P., Hall, A., Kanyanga, J.K., Kitoh, A., Kossin, J., Lau, N.-C., Renwick, J., Stephenson, D.B., Xie, S.-P., Zhou, T., 2013. Climate phenomena and their relevance for future regional climate change. In: Stocker, T.F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P.M. (Eds.), *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, pp. 1217–1308.
- Codding, B.F., Jones, T.L., 2013. Environmental productivity predicts migration, demographic, and linguistic patterns in prehistoric California. *Proc. Natl. Acad. Sci. U.S.A.* 110, 14569–14573.
- Codding, B., Jones, T.L., 2016. External impacts on internal dynamics: effects of paleoclimatic and demographic variability on acorn exploitation along the central California Coast. In: Contreras, D. (Ed.), *The Archaeology of Human-Environment Interactions: Strategies for Investigating Anthropogenic Landscapes, Dynamic Environments, and Climate Change in the Human Past*. Routledge, New York, pp. 195–210.
- Cooper, J., Sheets, P. (Eds.), 2012. *Surviving Sudden Environmental Change: Answers from Archaeology*. University Press of Colorado, Boulder.
- Cornejo, L.E., Sanhueza, L., 2003. Coexistencia de cazadores recolectores y horticultores tempranos en la cordillera andina de Chile Central. *Latin Am. Antiq.* 14 (4), 389–407.
- Cornejo, L.E., Jackson, D., Saavedra, M., 2016. Cazadores-recolectores arcaicos al sur del desierto (ca. 11.000 a 300 años a.C.). In: Falabella, F., Uribe, M., Sanhueza, L., Aldunate, C., Hidalgo, J. (Eds.), *Prehistoria En Chile Desde Sus Primeros Habitantes Hasta Los Incas*. Editorial Universitaria, Santiago, pp. 285–318.
- CR2, 2015. Informe a La Nación. La Megasecuía 2010–2015: Una Lección Para El Futuro. Centro de Ciencia del Clima y la Resiliencia (CR)2, Santiago, Chile.
- Craig, R.K., 2012. Marine biodiversity, climate change, and governance of the oceans. *Diversity* 4 (2), 224–238. doi:<http://dx.doi.org/10.3390/d4020224>.
- Cramer, W., Guiot, J., Fader, M., Garrabou, J., Gattuso, J.-P., Iglesias, A., Lange, M.A., Lionello, P., Llasat, M.C., Paz, S., Peñuelas, J., Snoussi, M., Toreti, A., Tsimplis, M.N., Xoplaki, E., 2018. Climate change and interconnected risks to sustainable development in the Mediterranean. *Nat. Clim. Change* 8, 972–980.
- Cruz Berrocal, M., 2012. The early Neolithic in the Iberian Peninsula and the western Mediterranean: a review of the evidence on migration. *J. World Prehist.* 25, 123–156.
- Cuthrel, R.Q., Striplen, C., Hylkema, M., Lightfoot, K.G., 2012. A land of fire: anthropogenic burning on the central coast of California. In: Jones, T.L., Perry, J.E. (Eds.), *Contemporary Issues in California Archaeology*. Left Coast Press, Walnut Creek, pp. 153–172.
- d'Alpoim Guedes, J., Crabtree, S.A., Bocinsky, R.K., Kohler, T.A., 2016. Twenty-first century approaches to ancient problems: climate and society. *Proc. Natl. Acad. Sci. U.S.A.* 113, 14483–14491.
- Dartt-Newton, D., Erlandson, J.M., 2006. Colonialism, cattle, and coercion in Mission Period California. *Am. Indian Q.* 30, 416–430.
- Dawson, H., 2014. *Mediterranean Voyages: The Archaeology of Island Colonisation and Abandonment*, vol. 62. Left Coast Press, Walnut Creek.
- Dewar, G., Marsh, E.J., 2018. The Comings and goings of sheep and pottery in the coastal desert of Namaqualand, South Africa. *J. Island Coastal Archaeol.* 14, 17–45.
- Di Rita, F., Magri, D., 2019. The 4.2 ka event in the vegetation record of the central Mediterranean. *Clim. Past* 15, 237–251.
- Dietler, M., 1997. The Iron Age in Mediterranean France: colonial encounters, entanglements, and transformations. *J. World Prehist.* 11, 269–358.
- Dietler, M., 2010. Archaeologies of Colonialism. Consumption, Entanglement, and Violence in Ancient Mediterranean France. University of California Press, Berkeley.
- Dortch, C., 1979. Devil's Lair, an example of prolonged cave use in southwestern Australia. *World Archaeol.* 10, 258–279.
- Douglass, K., Walz, J., Quintana-Morales, E., Marcus, R., Myers, G., Pollini, J., 2019. Historical perspectives on contemporary human-environment dynamics in southeast Africa. *Conserv. Biol.* 33, 260–274.
- Drake, B.L., 2012. The influence of climatic change on the late bronze age collapse and the Greek Dark Ages. *J. Archaeol. Sci.* 39, 1862–1870.
- Erlandson, J.M., Rick, T.C., 2010. Archaeology meets marine ecology: the antiquity of maritime cultures and human impacts on marine fisheries and ecosystems. *Annua. Rev. Mar. Sci.* 2, 231–251.
- Erlandson, J.M., Rick, T.C., Braje, T.J., Casperson, M., Culleton, B., Fulfrost, B., Garcia, T., Guthrie, D.A., Jew, N., Kennett, D.J., Moss, M.L., Reeder, L., Skinner, C., Watts, J., Willis, L., 2011. Paleoindian seafaring, maritime technologies, and coastal foraging on California's Channel Islands. *Science* 331, 1181–1185.
- Esler, K.J., Jacobsen, A.L., Pratt, R.B., 2018. *Biology of Mediterranean-type Ecosystems*. Oxford University Press, Oxford.
- Falabella, F., Planella, M.T., Aspíllaga, E., Sanhueza, L., Tykot, R.H., 2007. Dieta en sociedades alfareras de Chile central: aporte de análisis de isótopos estables. *Chungara, Revista de Antropología Chilena* 39 (1), 5–27.
- Falabella, F., Cornejo, L.E., Sanhueza, L., Correa, I., 2015. Trends in thermoluminescence date distributions for the Angostura micro region in Central Chile. *Quat. Int.* 356, 27–38.
- Falabella, F., Pavlovic, D., Planella, M.T., Sanhueza, L., 2016. Diversidad y heterogeneidad cultural y social en Chile Central durante los periodos alfarero temprano e intermedio tardío (300 años A.C. A 1.450 años d.C.). In: Falabella, F., Uribe, M., Sanhueza, L., Aldunate, C., Hidalgo, J. (Eds.), *Prehistoria En Chile Desde Sus Primeros Habitantes Hasta Los Incas*. Editorial Universitaria, pp. 365–399.
- Fernández-López de Pablo, J., Gutiérrez-Roig, M., Gómez-Puche, M., McLaughlin, R., Silva, F., Lozano, S., 2019. Palaeodemographic modelling supports a population bottleneck during the Pleistocene-Holocene transition in Iberia. *Nat. Commun.* 10 (2019), 1872. doi:<http://dx.doi.org/10.1038/s41467-019-09833-3>.
- Finné, M., Holmgren, K., Shen, C.C., Hu, H.M., Boyd, M., Stocker, S., 2017. Late Bronze Age climate change and the destruction of the Mycenaean palace of Nestor at Pylos. *PLoS One* 12 (12), e0189447.
- Fischer, E.M., Schar, C., 2010. Consistent geographical patterns of changes in high-impact European heatwaves. *Nat. Geosci.* 3, 398–403.
- Fitzsimmons, K.E., Spry, C., Stern, N., 2019. Holocene and recent aeolian reactivation of the Willandra Lakes lunettes, semi-arid southeastern Australia. *Holocene* 29, 606–621.
- Gamble, L.H., 2005. Culture and climate: reconsidering the effect of paleoclimatic variability among southern California hunter-gatherer societies. *World Archaeol.* 37, 92–108.
- Garreaud, R.D., Vuille, M., Compagnucci, R., Marengo, J., 2009. Present-day South American climate. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 281 (3), 180–195.
- Gayo, E.M., McRostie, V.B., Campbell, R., Flores, C., Maldonado, A., Uribe-Rodríguez, M., Moreno, P.I., Santoro, C.M., Christie, D.A., Muñoz, A.A., Gallardo, L., 2019. Geohistorical records of the Anthropocene in Chile. *Elementa* 7, 15.
- Gill, K.G., Fauvelle, M., Erlandson, J.M. (Eds.), 2019. *An Archaeology of Abundance: Reevaluating the Marginality of California's Islands*. University Press of Florida, Gainesville.
- Glassow, M.A., 2015. Chronology of red abalone middens on Santa Cruz Island, California, and evidence for subsistence and settlement change. *Am. Antiq.* 80, 745–759.
- González-Guarda, E., Petermann-Pichincura, A., Tornero, C., Domingo, L., Augustí, J., Pino, M., Abarzúa, A.M., Capriles, J.M., Villavicencio, N.A., Labarca, R., Tolorza Sevilla, P., Rivals, F., 2018. Multiproxy evidence for leaf-browsing and closed habitats in extinct proboscideans (Mammalia, Proboscidea) from Central Chile. *Proc. Natl. Acad. Sci. U.S.A.* 115 (37), 9258–9263.
- Government of South Australia, 2019. Primary industries in South Australia fast facts. Government of South Australia, Adelaide.
- Graham, M.H., Dayton, P.K., Erlandson, J.M., 2003. Ice ages and ecological transitions in temperate coasts. *Trends Ecol. Evol. (Amst.)* 18, 33–40.
- Grid-Arendal, 2013. *State of Mediterranean Marine and Coastal Environment. Grid-Arendal/UN Environmental Programme*. <https://grid-arendal.herokuapp.com/resources/5900>.
- Griggs, G., Árvai, J., Cayan, D., DeConto, R., Fox, J., Fricker, H.A., Kopp, R.E., Tebaldi, C., Whiteman, E.A., (California Ocean Protection Council Science Advisory Team Working Group), 2017. *Rising Seas in California: An Update on Sea-Level Rise Science*. California Ocean Science Trust.
- Guiot, J., Cramer, W., 2016. Climate change: the 2015 Paris Agreement and Mediterranean Basin ecosystems. *Science* 354, 465–468.
- Guzman-Morales, J., Gershunov, A., 2019. Climate change suppresses Santa Ana winds of southern California and sharpens their seasonality. *Geophys. Res. Lett.* 5, 2772–2780.
- Hansen, M.H. (Ed.), 1993. *The Ancient Greek City-State: Symposium on the Occasion of the 250th Anniversary of The Royal Danish Academy of Sciences and Letters July, 1–4 1992*. Historisk-Filosofiske Meddelelser 67. Royal Danish Academy of Sciences and Letters, Copenhagen.
- Hansen, M.H., Raaflaub, K. (Eds.), 1995. *Studies in the Ancient Greek Polis, Papers from the Copenhagen Polis Centre 2*. Historia, Einzelschr. 95, Stuttgart.
- Harper, K., 2017. *The Fate of Rome: Climate, Disease, and the End of an Empire*. Princeton University Press, Princeton.
- Hassan, F.A., 2009. Human agency, climate change and culture: an archaeological perspective. In: Crata, S.A., Nuttal, M. (Eds.), *Anthropology and Climate Change. From Encounters to Actions*. Routledge, New York, pp. 39–69.
- Hermon, E. (Ed.), 2009. Société et climats dans l'Empire romain: pour une perspective historique et systémique de la gestion des ressources en eau dans l'Empire romain. *Editoriale Scientifica*, Napoli.
- Hodos, T., 2009. Colonial engagements in the global Mediterranean Iron Age. *Camb. Archaeol. J.* 19 (2), 221–241.
- Hoffecker, J.F., 2017. *Modern Humans: Their African Origin and Global Dispersal*. Columbia University Press, New York.
- Hofman, C.A., Rick, T.C., 2018. Ancient biological invasions and island ecosystems: tracking translocations of wild plants and animals. *J. Archaeol. Res.* 26, 65–115.
- Horde, P., Purcell, N., 2000. *The Corrupting Sea: A Study of Mediterranean History*. Blackwell Publishing, Oxford.
- Hughes, J.D., 2014. *Environmental Problems of the Greeks and Romans: Ecology in the Ancient Mediterranean*. Johns Hopkins University Press, Baltimore.
- IPCC, 2014. In: Core Writing Team, Pachauri, R.K., Meyer, L.A. (Eds.), *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II, and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. IPCC, Geneva, Switzerland, pp. 151.
- Issar, A.S., 1998. Climate change and history during the Holocene in the eastern Mediterranean region. In: Issar, A., Brown, N. (Eds.), *Water, Environment and Society in Times of Climatic Change*. Springer, Dordrecht, pp. 113–128.

- Jackson, D., Méndez, C., Aspíllaga, E., 2012a. Human remains directly dated to the Pleistocene-Holocene transition support a marine diet for early settlers of the Pacific coast of Chile. *J. Island Coastal Archaeol.* 7 (3), 363–377.
- Jackson, D., Aspíllaga, E., Rodríguez, X.-P., Jackson, D., Santana, F., Méndez, C., 2012b. Las ocupaciones humanas del sitio arqueológico de Santa Inés, laguna de Tagua Tagua, Chile Central. *Rev. Chil. Antropol.* 26, 151–168.
- Jazwa, C.S., Kennett, D.J., Winterhalder, B., Joslin, T.L., 2019. Territoriality and the rise of despotic social organization on western Santa Rosa Island, California. *Quat. Int.* 518, 41–56.
- Jenny, B., Valero-Garcés, B.L., Villa-Martínez Urrutia, R., Geyh, M., Veit, H., 2002. Early to mid-Holocene aridity in central Chile and the southern westerlies: the Laguna aculeo record (34°S). *Quat. Res.* 58, 160–170.
- Jerardino, A., 2010. Large shell middens in Lamberts Bay, South Africa: a case of hunter-gatherer resource intensification. *J. Archaeol. Sci.* 37, 2291–2302.
- Jerardino, A., 2012. Large shell middens and hunter-gatherer resource intensification along the West Coast of South Africa: the Elands Bay case study. *J. Island Coastal Archaeol.* 7, 76–101.
- Jerardino, A., Malan, A., Braun, D. (Eds.), 2013a. The Archaeology of the West Coast of South Africa. Cambridge Monographs in African Archaeology 84, British Archaeological Reports International Series 2526. Archaeopress, Oxford.
- Jerardino, A., Klein, R.G., Navarro, R., Orton, J., Horwitz, L.K., 2013b. Settlement and subsistence patterns since the terminal Pleistocene in the Elands Bay and Lamberts Bay areas. In: Jerardino, A., Malan, A., Braun, D. (Eds.), *The Archaeology of the West Coast of South Africa*. Archaeopress, Oxford, pp. 85–108.
- Jerardino, A., Fort, J., Isern, N., Rondelli, B., 2013c. Cultural diffusion was the main driving mechanism of the Neolithic transition in southern Africa. *PLoS One* 2014 (9), e113672.
- Jerardino, A., Kaplan, J., Navarro, R., Nilssen, P., 2016. Filling-in the gaps and testing past scenarios on the central West Coast: hunter-gatherer subsistence and mobility at 'Deurspring 16' shell midden, Lamberts Bay, South Africa. *S. Afr. Archaeol. Bull.* 71, 71–86.
- Jerardino, A., Navarro, R., 2018a. Large-scale hunter-gatherer exploitation of marine resources in South Africa, part I: Kreefbaai megamiddens, Lamberts Bay area. *S. Afr. Archaeol. Bull.* 73 (208), 93–107.
- Jerardino, A., Navarro, R., 2018b. Large-scale hunter-gatherer exploitation of marine resources in South Africa, part II: Grootrif and Malkoppan megamiddens, Lamberts Bay area. *S. Afr. Archaeol. Bull.* 73 (208), 108–125.
- Jerardino, A., Navarro, R., Orton, J., Button, R., Halkett, D., Webley, L., Madelon, T., Hoffman, T., February, T., 2018. Late Holocene climatic and cultural variability at a focal point of settlement near Lamberts Bay, South Africa: test excavations at Soutpansklipheuwel. *S. Afr. Archaeol. Bull.* 73 (207), 13–34.
- Johnson, J.R., 2000. Social responses to climate change among the Chumash Indians of south-central California. In: McIntosh, R., Tainter, J., McIntosh, S. (Eds.), *The Way the Wind Blows: Climate, History, and Human Action*. Columbia University Press, New York, pp. 301–327.
- Jones, T.L., Codding, B., 2019. Foragers on America's Western Edge: The Archaeology of California's Pecho Coast. University of Utah Press, Salt Lake City.
- Jones, T.L., Schwitalla, A., 2013. Archaeological perspectives on the effects of medieval drought in prehistoric California. *Quat. Int.* 188, 41–58.
- Jones, T.L., Brown, G.M., Raab, L.M., McVickar, J., Spaulding, W.G., Kennett, D.J., York, A., Walker, P.L., 1999. Environmental imperatives reconsidered: demographic crises in western North America during the Medieval Climatic Anomaly. *Curr. Anthropol.* 40, 137–170.
- Jorgenson, A., Fiske, S., Hubacek, K., Li, J., McGovern, T., Rick, T., Schor, J., Solecki, W., York, R., Zycherman, A., 2019. Social science perspectives on drivers of and response to global climate change. *WIREs Clim. Chan.* 10, e54.
- Kämpf, J., Chapman, P., 2016. The Benguela Current upwelling system. In: Kämpf, J., Chapman, P. (Eds.), *Upwelling Systems of the World: A Scientific Journey to the Most Productive Marine Ecosystems*. Springer International Publishing, Switzerland, pp. 251–314.
- Kaniewski, D., Van Campo, E., Van Leberghe, K., Boly, T., Vansteenhuyse, K., Jans, G., Nys, K., Weiss, H., Morhange, C., Otto, T., Bretschneider, J., 2011. The Sea Peoples, from Cuneiform tablets to carbon dating. *PLoS One* 6 (6), e20232. doi:http://dx.doi.org/10.1371/journal.pone.0020232.
- Kaniewski, D., Van Campo, E., Guiot, J., Le Burel, S., Otto, T., Baetman, C., 2013. Environmental roots of the late Bronze age crisis. *PLoS One* 8 (8), e71004.
- Kennett, D.J., 2005. The Island Chumash: Behavioral Ecology of a Maritime Society. University of California Press, Berkeley.
- Kennett, D.J., Kennett, J.P., 2000. Competitive and cooperative responses to climatic instability in coastal Southern California. *Am. Antiq.* 65, 379–396.
- Kennett, D.J., Kennett, J.P., Erlandson, J.M., Canariato, K.G., 2007. Human response to Middle Holocene climate change on California's Channel Islands. *Quat. Sci. Rev.* 26, 351–367.
- Knapp, A.B., Manning, S.W., 2016. Crisis in context: the end of the Late Bronze Age in the eastern Mediterranean. *Am. J. Archaeol.* 120, 99–149.
- Knapp, A.B., Van Dommelen, P. (Eds.), 2015. *The Cambridge Prehistory of the Bronze and Iron Age Mediterranean*. Cambridge University Press, Cambridge.
- Kristiansen, K., Larsson, T.B., 2005. *The Rise of Bronze Age Society: Travels, Transmissions and Transformations*. Cambridge University Press, Cambridge.
- Lamb, H., 1965. The early medieval warm epoch and its sequel. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 1, 13–37.
- Langley, M., Clarkson, C., Ulm, S., 2011. From small holes to grand narratives: the impact of taphonomy and sample size on the modernity debate in Australia and New Guinea. *J. Hum. Evol.* 61, 197–208.
- Larson, D.O., Johnson, J.R., Michaelsen, J.C., 1994. Missionization among the coastal Chumash of central California: a study of risk minimization strategies. *Am. Anthropol.* 96, 263–299.
- Leppard, T., 2019. Social complexity and social inequality in the prehistoric Mediterranean. *Curr. Anthropol.* 60, 283–308.
- Lightfoot, K.G., Cuthrell, R.Q., Boone, C.M., Byrne, R., Chaez, A.S., Collins, L., Cowart, A., Evett, R.R., Fine, P.V.A., 2013. Anthropogenic burning on the central California coast in late Holocene and early historic times: findings, implications, and future directions. *Calif. Archaeol.* 5, 371–390.
- López Sáez, J.A., Abel-Schaad, D., Pérez-Díaz, S., Blanco-González, A., Alba-Sánchez, F., Dorado, M., Ruiz-Zapata, B., Gil-García, M.J., Gómez-González, C., Franco-Múgica, F., 2014. Vegetation history, climate and human impact in the Spanish Central System over the last 9000 years. *Quat. Int.* 353, 98–122.
- MacDonald, G.M., Moser, K.A., Bloom, A.M., Potito, A.P., Porinchi, D.F., Holmquist, J. R., Hughes, J., Kremenetski, K.V., 2016. Prolonged California aridity linked to climate warming and Pacific sea surface temperature. *Sci. Rep.* 6, 33325. doi:http://dx.doi.org/10.1038/srep33325.
- Maldonado, A., Villagrán, C., 2006. Climate variability over the last 9900 cal yr BP from a swamp forest pollen record along the semiarid coast of Chile. *Quat. Res.* 66, 246–258.
- Manning, J.G., 2018. *The Open Sea: the Economic Life of the Ancient Mediterranean World From the Iron Age to the Rise of Rome*. Princeton University Press, Princeton.
- Mariotti, A., Pan, Y., Zeng, N., Alessandri, A., 2015. Long-term climate change in the Mediterranean region in the midst of decadal variability. *Clim. Dyn.* 44 14376–1456.
- Marriner, N., Flaux, C., Kaniewski, D., Morhange, C., Leduc, G., Moron, V., Zhongyuan, C., Gasse, F., Empereur, J.-Y., Stanley, J.-D., 2012. ITCZ and ENSO-like pacing of Nile delta hydro-geomorphology during the Holocene. *Quat. Sci. Rev.* 45, 73–84.
- Masson-Delmotte, V., Schulz, M., Abe-Ouchi, A., Beer, J., Ganopolski, A., González Rouco, J.F., Lambeck, J.K., Luterbacher, J., Naish, T., Osborn, T., Otto-Bliessen, B., Quinn, T., Ramesh, R., Rojas, M., Shao, X., Timmermann, A., 2013. Information from paleoclimate archives. In: Stocker, T.F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P.M. (Eds.), *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, pp. 383–464.
- McClure, S.B., Barton, C.M., Jochim, M.A., 2009. Human behavioral ecology during the transition to agriculture in Valencia Spain. *J. Anthropol. Res.* 65, 253–269.
- McCormick, M., Büntgen, U., Cane, M.A., Cook, E.R., Harper, K., Huybers, P., Litt, T., Manning, S.W., Mayewski, P.A., More, A.F.M., Nicolussi, K., Tegel, W., 2012. Climate change during and after the Roman Empire: reconstructing the past from scientific and historical evidence. *J. Interdiscip. History* 43, 169–220.
- Méndez, C., Jackson, D., 2015. Terminal Pleistocene lithic technology and use of space in central Chile. *Chungara, Revista de Antropología Chilena* 47 (1), 53–65.
- Méndez, C., Gil, A., Neme, G., Nuevo Delaunay, A., Cortegoso, V., Huidobro, C., Durán, V., Maldonado, A., 2015. Mid Holocene radiocarbon ages in the subtropical Andes (~29°–35° S), climatic change and implications for human space organization. *Quat. Internat.* 356, 15–26.
- Mensing, S., Tunno, I., Cifani, G., Passigli, S., Noble, P., Archer, C., Piovesan, G., 2016. Human and climatically induced environmental change in the Mediterranean during the Medieval Climate Anomaly and Little Ice Age: a case from central Italy. *Anthropocene* 15, 49–59.
- Mercuri, A.M., Sadori, L., Uzquiano Ollero, P., 2011. Mediterranean and north-African climate adaptations to Mid-Holocene environmental and climatic changes. *Holocene* 21, 189–206.
- Mordecay, L., Eisenberg, M., 2019. Rejecting catastrophe: the case of the Justinianic plague. *Past Present* 244 (1), 3–50.
- Morgan, C., 2009. Climate change, uncertainty and prehistoric hunter-gatherer mobility. *J. Anthropol. Archaeol.* 28, 382–396.
- Moss, M.L., Erlandson, J.M., 2013. Waterfowl and lunate crescents in western North America: the archaeology of the Pacific Flyway. *J. World Prehist.* 26, 173–211.
- Núñez, L., Grosjean, M., Cartagena, I., 2001. Human dimensions of Late Pleistocene/Holocene arid events in Southern South America. In: Markgraf, V. (Ed.), *Interhemispheric Climate Linkages*. Academic Press, New York, pp. 105–117.
- O'Connell, J.F., Allen, J., Williams, M.A.J., Williams, A.N., Turney, C.S.M., Spooner, N.A., Kamminga, J., Brown, G., Cooper, A., 2018. When did *Homo sapiens* first reach Southeast Asia and Sahul? *Proc. Natl. Acad. Sci. U.S.A.* 115, 8482–8490.
- Otto, F.E.L., Wolski, P., Lehner, F., Tebaldi, C., van Oldenborgh, G.J., Hogesteeger, S., Singh, R., Holden, P., Fuckar, N.S., Odoulami, R.C., 2018. Anthropogenic influence on the drivers of the Western Cape drought. *Environ. Res. Lett.* 13, 124010.
- Parkington, J.E., 1990. A view from the south: southern Africa before, during and after the last glacial maximum. In: Gamble, C.S., Soffer, O. (Eds.), *The World at 18,000 BP, vol. 2*. Unwin Hyman, London, pp. 214–228.
- Pate, F.D., Pretty, G.L., Hunter, R., Tuniz, C., Lawson, E.M., 1998. New radiocarbon dates for the Roonka Flat aboriginal burial ground, South Australia. *Austral. Archaeol.* 46, 36–37.
- Pathak, T.B., Maskey, M.L., Dahlberg, J.A., Kearns, F., Bali, K.M., Zaccaria, D., 2018. Climate change trends and impacts on California agriculture: a detailed review. *Agronomy* 8 (3), 25. doi:http://dx.doi.org/10.3390/agronomy8030025.
- Pérez-Obiol, R., Jalut, G., Julià, R., Pèlachs, A., Iriarte, M.J., Otto, T., Hernández-Beloqui, B., 2011. Mid-Holocene vegetation and climatic history of the Iberian Peninsula. *Holocene* 21, 75–93.
- Planella, M.T., Cornejo, L.E., Tagle, B., 2005. Alero Las Morrenas 1: evidencias de cultígenos entre cazadores recolectores de finales del período Arcaico en Chile central. *Chungara, Revista de Antropología Chilena* 37 (1), 59–74.

- Polade, S.D., Gershunov, A., Cayan, D.R., Dettinger, M.D., Pierce, D.W., 2017. Precipitation in a warming world: assessing projected hydro-climate changes in California and other Mediterranean climate regions. *Sci. Rep.* 7, 10783. doi: <http://dx.doi.org/10.1038/s41598-017-11285-y>.
- Ponti, L., Guitierrez, A.P., Boggia, A., Nettle, M., 2018. Analysis of grape production in the face of climate change. *Climate* 6, 20. doi:<http://dx.doi.org/10.3390/cli6020020>.
- Post, R., 2017. The environmental history of Classical and Hellenistic Greece: the contribution of environmental archaeology. *Hist. Compass* 15 (10), e12392.
- Power, M.J., Coding, B.F., Taylor, A.H., Swetnam, T.W., Magargal, K.E., Bird, D.W., O'Connell, J.F., 2018. Human fire legacies on ecological landscapes. *Front. Earth Sci.* 6, 151. doi:<http://dx.doi.org/10.3389/feart.2018.00151>.
- Rick, T.C., Sandweiss, D.H., 2020. Archaeology, climate, and global change in the Age of Humans. *Proc. Natl. Acad. Sci. U.S.A.* in press.
- Rick, T.C., Erlanson, J.M., Vellanoweth, R.L., Braje, T.J., 2005. From Pleistocene mariners to complex hunter-gatherers: the archaeology of the California Channel Islands. *J. World Prehis.* 19, 169–228.
- Roberts, N., 1998. *The Holocene. An Environmental History*. Blackwell Publishing, Oxford.
- Roberts, N., Eastwood, W.J., Kuzucuoglu, C., Fiorentino, G., Caracuta, V., 2011. Climatic, vegetation and cultural change in the eastern Mediterranean during the Mid-Holocene environmental transition. *Holocene* 21, 147–162.
- Roberts, P., Boivin, N., Kaplan, J.O., 2018. Finding the Anthropocene in tropical forests. *Anthropocene* 23, 5–16.
- Roberts, N., Woodbridge, J., Palmisano, A., Bevan, A., Fyfe, R., Shennan, S., 2019. Mediterranean landscape change during the Holocene: synthesis, comparison, and regional trends in population, land cover, and climate. *Holocene* 29, 923–937.
- Rogerson, C.M., 2016. Climate change, tourism, and local economic development in South Africa. *Local Econ.* 31, 322–331.
- Rundel, P.W., Cowling, R.M., 2013. Mediterranean-climate ecosystems. In: Levin, S.A. (Ed.), *Encyclopedia of Biodiversity*. second edition Academic Press, New York, pp. 212–222.
- Rundel, P.W., Arroyo, M.T.K., Cowling, R.M., Keeley, J.E., Lamont, B.B., Pausas, J.G., Vargas, P., 2018. Fire and plant diversification in Mediterranean-climate regions. *Front. Plant Sci.* 9, 851.
- Sadori, L., Jahns, S., Peyron, O., 2011. Mid-Holocene vegetation history of the central Mediterranean. *Holocene* 21, 117–129.
- Sadr, K., 2013. A short history of early herding in southern Africa. In: Bollig, M., Schnegg, M., Wotzka, H.-P. (Eds.), *Pastoralism in Africa: Past, Present and Future*. Berghahn Books, New York, pp. 171–197.
- Sandweiss, D.H., Kelley, A.R., 2012. Archaeological contributions to climate change research: the archaeological record as a paleoclimatic and paleoenvironmental archive. *Annu. Rev. Anthropol.* 41, 371–391.
- Sanhueza, L., 2016. *Comunidades Prehispanas De Chile Central Organización Social E Ideología (0-1200 d.C.)*. Editorial Universitaria.
- Sanhueza, L., Falabella, F., 2010. Analysis of stable isotopes: from the Archaic to the horticultural communities in central Chile. *Curr. Anthropol.* 51, 127–136.
- Smith, B.D., Zeder, M., 2013. The onset of the Anthropocene. *Anthropocene* 4, 8–13.
- Snodgrass, A.M., 1971. *The Dark Age of Greece. An Archaeological Survey of the Eleventh to the Eighth Centuries BC*. Edinburgh University Press, Edinburgh.
- Snodgrass, A.M., 1991. Archaeology and the study of the Greek city. In: Rich, J., Wallace-Hadrill, A. (Eds.), *City and Country in the Ancient World*. Routledge, London and New York, pp. 1–23.
- Stephens, L., ArchaeoGLOBE Project Team, 2019. Archaeological assessment reveals Earth's early transformation through land use. *Science* 365, 897–902.
- Stern, N., 2015. The archaeology of the Willandra: its empirical structure and narrative potential. In: McGrath, A., Jebb, M. (Eds.), *Long History, Deep Time*. ANU Press, Canberra, pp. 221–240.
- Subsecretaría de Turismo, 2017. *2016 Anuario De Turismo*. Servicio Nacional de Turismo (SERNATUR), Santiago. <https://www.sernatur.cl>.
- Swain, D.L., Langenbrunner, B., Neelin, J.D., Hall, A., 2018. Increasing precipitation volatility in twenty-first-century California. *Nat. Clim. Change* 8, 427–433.
- Taylor, A.H., Trouet, V., Skinner, C.N., Stephens, S., 2016. Socioecological transitions trigger fire regime shifts and modulate fire-climate interactions in the Sierra Nevada, USA, 1600–2015 CE. *Proc. Natl. Acad. Sci. U.S.A.* 113, 13684–13689.
- Tobler, R., Rohrlach, A., Soubrier, J., Bover, P., Llamas, B., Tuke, J., Bean, N., Abdullah-Highfold, A., Agius, S., O'Donoghue, A., O'Loughlin, I., Sutton, P., Zilio, F., Walshe, K., Williams, A.N., Turney, C.S.M., Williams, M., Richards, S.M., Mitchell, R.J., Kowal, E., Stephen, J.R., Williams, L., Haak, W., Cooper, A., 2017. Aboriginal mitogenomes reveal 50,000 years of regionalism in Australia. *Nature* 544, 180–184.
- Turco, M., Rosa-Cánovas, J.J., Bedia, J., Jerez, S., Montávez, M.C.L., Provenzale, A., 2018. Exacerbated fires in Mediterranean Europe due to anthropogenic warming projected with non-stationary climate-fire models. *Nat. Commun.* 9, 3821.
- Uribe, M., Sánchez, R., 2016. Los incas en Chile. Aportes de la arqueología chilena a la historia del Tawantinsuyo (ca. 1400 a 1536 años d.C.). In: Falabella, F., Uribe, M., Sanhueza, L., Aldunate, C., Hidalgo, J. (Eds.), *Prehistoria En Chile Desde Sus Primeros Habitantes Hasta Los Incas*. Editorial Universitaria, pp. 529–572.
- Valero-Garcés, B.L., Jenny, B., Rondanelli, M., Delgado-Huertas, A., Burns, S.J., Veit, H., Moreno, A., 2005. Palaeohydrology of Laguna de Tagua Tagua (34° 30' S) and moisture fluctuations in Central Chile for the last 46 000 yr. *J. Quat. Sci.* 20 (7–8), 625–641.
- Van Dommelen, P., 2012. Colonialism and migration in the ancient Mediterranean. *Annu. Rev. Anthropol.* 41, 393–409.
- Veth, P.M., 1993. *Islands in the Interior: The Dynamics of Prehistoric Adaptations Within the Arid Zone of Australia*. International Monographs in Prehistory, Ann Arbor.
- Warren, C., 2013. Environmental stress and subsistence intensification. *Calif. Archaeol.* 4, 39–54.
- Welc, F., Marks, L., 2014. Climate change at the end of the Old Kingdom in Egypt around 4200 BP: new geoarchaeological evidence. *Quat. Int.* 324, 124–133.
- Weninger, B., Clare, L., Rohling, E., Bar-Yosef, O., Böhner, U., Budja, M., Bundschuh, M., Feurdean, A., Gebe, H.G., Jöris, O., Linstädter, J., Mayewski, P., Mühlenbruch, T., Reingruber, A., Rollefson, G., Schyle, D., Thissen, L., Todorova, H., Zielhofer, C., 2009. The impact of rapid climate change on prehistoric societies during the Holocene in the eastern Mediterranean. *Documenta Praehist.* 36, 7–59.
- Western Cape Government, 2018. *Western Cape Climate Change Response Strategy 2nd Biennial Monitoring & Evaluation Report 2017/18, Progress in Preparing for Climate Change*. .
- Western Cape Government, Department of Environmental Affairs and Planning, 2019. *Western Cape Tourism*. . <https://www.westerncape.gov.za/general-publication/western-cape-tourism>.
- Wickham, C., 2005. *Framing the Early Middle Ages: Europe and the Mediterranean, 400–800*. Oxford University Press, Oxford.
- Wiener, M.H., 2014. The interaction of climate change and agency in the collapse of civilizations ca. 2300–2000 BC. *Radiocarbon* 56, S1–S16.
- Williams, A.N., Ulm, S., Cook, A.R., Langley, M., Collard, M., 2013. Human refugia in Australia during the Last Glacial Maximum and Terminal Pleistocene: a geo-spatial analysis of the 25–12ka Australian archaeological record. *J. Archaeol. Sci.* 40, 4612–4625.
- Williams, A.N., Ulm, S., Sapienza, T., Lewis, S., Turney, C.S.M., 2018. Sea-level change and demography during the Last Glacial termination and Early Holocene across the Australian Continent. *Quat. Sci. Rev.* 182, 144–154.
- Williams, A.P., Cook, E.R., Smerdon, J.E., Cook, B.I., Abatzoglou, J.T., Bolles, K., Baek, S. H., Badger, A.M., Livneh, B., 2020. Large contribution from anthropogenic warming to an emerging North American megadrought. *Science* 368, 314–318.
- Williams, A.N., Ulm, S., Turney, C.S.M., Rodhe, D., White, G., 2015b. The establishment of complex society in prehistoric Australia: demographic and mobility changes in the Late Holocene. *PLoS One* 10 (6), e0128661.
- Williams, A.N., Veth, P., Steffen, W., Ulm, S., Reeves, J.M., Phipps, S.J., Smith, M., 2015a. A continental narrative: human settlement patterns and Australian climate change over the last 35,000 Years. *Quat. Sci. Rev.* 123, 91–112.
- Xoplaki, E., Fleitmann, D., Luterbacher, J., Wagner, S., Haldon, J.F., Zorita, E., Teleis, I., Toreti, A., Izdebski, A., 2016. The Medieval Climate Anomaly and Byzantium: a review of the evidence on climatic fluctuations, economic performance and societal change. *Quat. Sci. Rev.* 136, 229–252.
- Zalasiewicz, J., Waters, C.N., Summerhayes, C.P., Wolfe, A.P., Barnosky, A.D., Cearreta, A., Crutzen, P., Ellis, E., Fairchild, I.J., Galuszka, A., Haff, P., Hajdas, I., Head, M.J., Ivar do Sul, J.A., Jeandel, C., Leinfelder, R., McNeill, J.R., Neal, C., Odada, E., Oreskes, N., Steffen, W., Syvitski, J., Vidas, D., Wagemann, M., Williams, M., 2017. The Working Group on the Anthropocene: summary of evidence and interim recommendations. *Anthropocene* 19, 55–60.
- Zeder, M.A., 2008. Domestication and early agriculture in the Mediterranean Basin: origins, diffusion, and impact. *Proc. Natl. Acad. Sci. U.S.A.* 105, 11597–11604.
- Zilhão, J., 2001. Radiocarbon evidence for maritime pioneer colonization at the origins of farming in west Mediterranean Europe. *Proc. Natl. Acad. Sci. U.S.A.* 98, 14180–14185.