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Review

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

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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

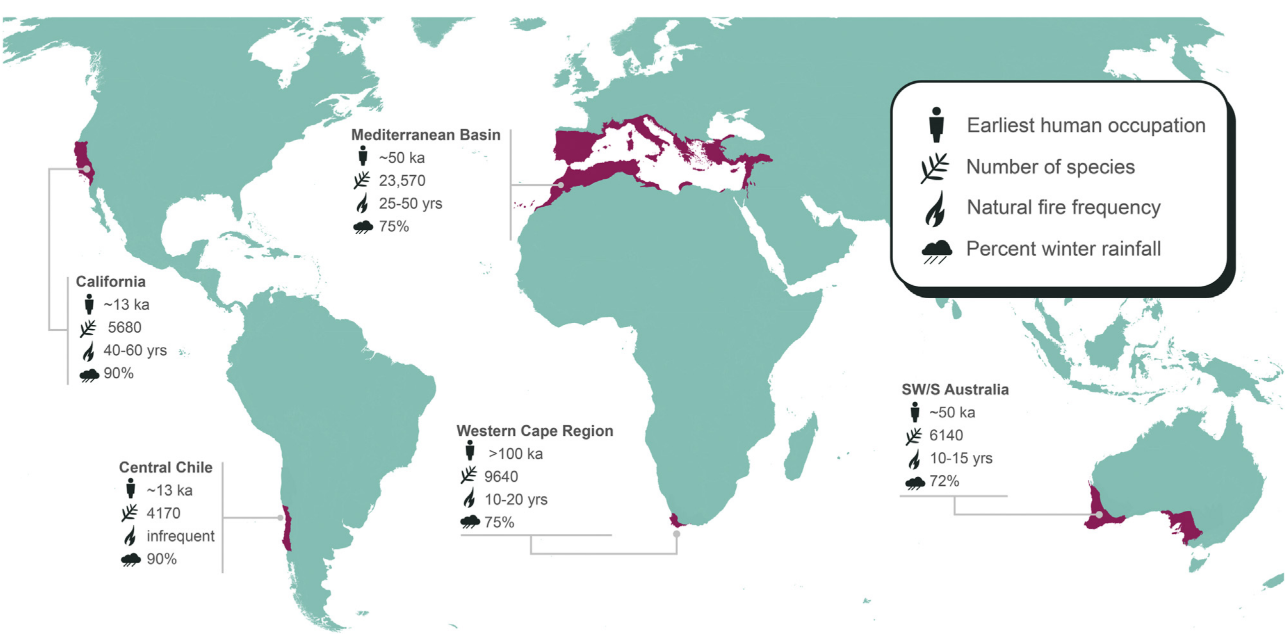

Fig. 1. Location of Mediterranean climate regions, and various environmental and cultural characteristics for each region. These include approximate timing of anatomically modern human occupation, approximate number of vascular plant and vertebrate species per region (rounded to nearest whole number), 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

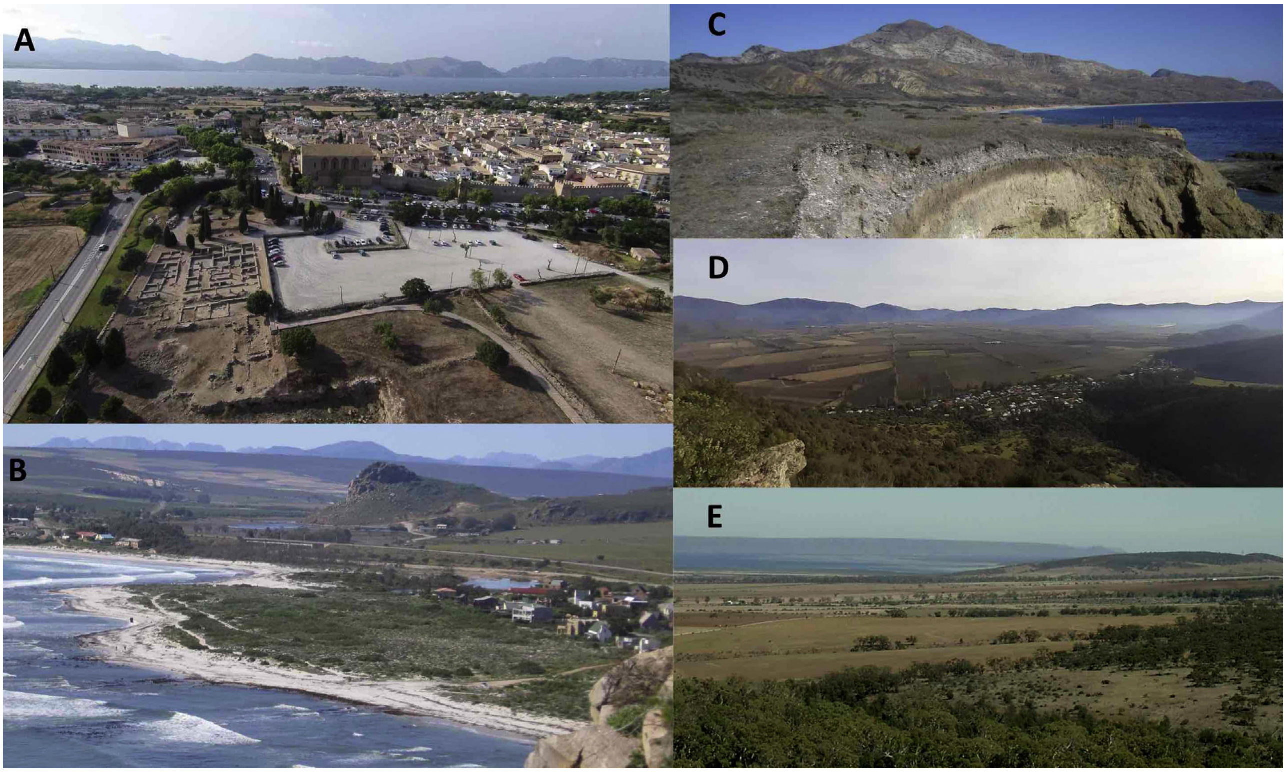

Fig. 2. Cultural landscapes of the ancient MED. A. Excavations at the Roman city of *Pollentia* (Alcúdia, Mallorca, Spain). B. Elands Bay, South Africa, an area with >500 ka of archaeology and modern settlement. C. Late Holocene Chumash village on Santa Cruz Island, California with a dense shell midden. 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 Mordecay 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 (Codding and Jones, 2013; Erlandson et al., 2011; Jones and Codding, 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 Codding, 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 Codding, 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 Codding, 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 Codding, 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 Codding, 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 (Codding 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 (Dartt-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; Lightfooot 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; Lightfooot 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; Lightfooot 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 hierachy 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, Warratyi 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 km^2) (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 Anthopocene 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 ^{14}C 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 adaptions 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

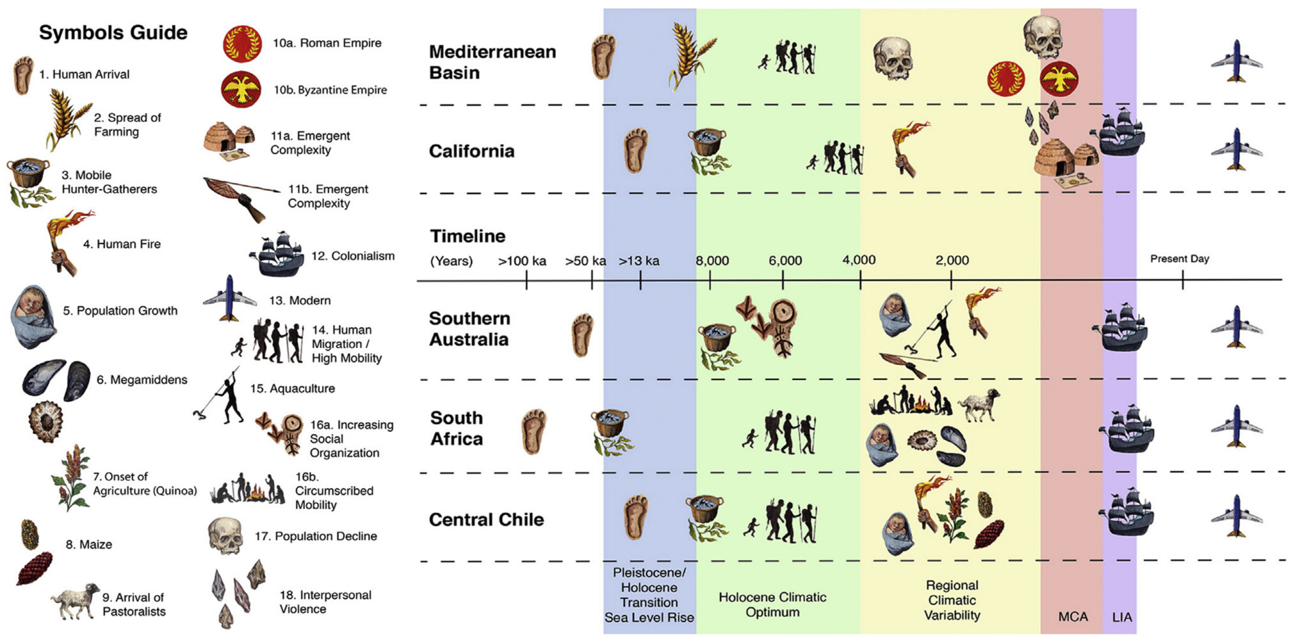

Fig. 3. Generalized timeline of major cultural events and associated climatic changes in MED. Some events are not contiguous across the entire region but have been linked to specific climate events described in more detail in the text. The bottom of the timeline documents key climatic periods or developments 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.

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