Climate Change and Cultural Dynamics: A Global Perspective on Mid-Holocene Transitions
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Chapter 1

Climate and culture change: exploring Holocene transitions

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1. Introduction

Understanding climate change and its likely impacts on human culture is one of the great scientific challenges of the 21st century; responding successfully to them will be a major test for global civilization. Given current projections, the remainder of the century is likely to mark a continuing period of global climate change. The papers in this volume explore how past human cultures have responded to changes in climate and consequent changes in vegetation and precipitation patterns. Although the focus of the volume is the Mid-Holocene interval from ca. 9000 to 5000 cal yr BP, climate change and its impact on human culture throughout the Holocene is examined by most of the contributors. We believe that the research documented in this volume offers many lessons of value to scholars, politicians/planners, and the general public.

Interest in climate change has grown in recent years. The scientific literature on the subject has multiplied correspondingly, with research funding directed to the subject soaring in many countries, and major papers documenting the results of this research appearing at a rate undreamed of even a decade ago. Climate change is now explored using a wide array of data types, through multi-proxy records such as ice, lake sediment and pollen cores, tree rings, rodent and other animal nests/middens with their associated plant macrofossil and microfossil/pollen remains, paleosol and goeomorphological/geoarchaeological evidence, and archaeological and paleobiological deposits (Table 1.1). Sediment layers and tree rings, for instance, can document dramatic short-term climatic events such as floods or storms, or the impact of these events on processes such as erosion and fire frequency. Archaeological research has itself grown increasingly sophisticated and multidisciplinary, employing many of the same specializations, and a growing number of archaeologists around the world are working to unravel the relationships between climate and past human culture. Paleobiological evidence such as pollen, phytolith,

Table 1.1. A Summary of data sources used to reconstruct past climates.

Proxy data source	Some of the variables measured	Possible climatic inferences	Typical sampling interval
Ice cores	Ice chemistry, dust, $\delta^{18}O$, δD, CO_2, CH_4, tephra	Atmospheric circulation, temperature, precipitation, atmospheric composition, volcanic activity	Seasonal–annual
Tree rings	Ring width, $\delta^{18}O$, δD, $\delta^{13}C$, $\Delta^{14}C$	Temperature, precipitation (drought), solar variability	Annual
Coral, mollusks	$\delta^{18}O$, Sr/Ca, growth rate	SST, precipitation–evaporation, sea level	Monthly
Pollen	Percent, influx	Temperature, precipitation	10–100 years
Insects	Chironomid, beetle assemblages	Temperature	10–100 years
Soils and sand	Clay content, $\delta^{13}C$, dunes	Humidity, wind, CO_2	Snapshots
Closed-basin	Lake level	Precipitation–evaporation	Snapshots
Lake sediments	$\delta^{18}O$, diatoms	Temperature, salinity	10–100 years
Ice sheets	Former extent, glacial rebound	Area, thickness, bedrock depression	Snapshots
Mountain glaciers	Former extent	Snowline, air temperature	Snapshots
Marine sediments	$\delta^{18}O$, $\delta^{13}C$, foraminiferal assemblages	Global ice mass, ocean circulation, SST	100–1000 years
Raised shorelines	Elevation	Sea level, bedrock depression	Snapshots
Laminated or varved sediments	Reflectance, magnetic properties	Precipitation, wind	Annual

and fire frequency records can be critical for identifying human presence and impact on the landscape; so, too, can geoarchaeological/geophysical analyses, which can tease out anthropogenic signatures as readily as soil formation and sedimentation rates. As the papers in this volume demonstrate, the reconstruction of both past climate change and past human cultural systems is best accomplished by using data from multiple sources, or proxy records, and by specialists from different disciplines working together. Multi-proxy records reveal a more complete picture than can be obtained from individual proxy measures, just as multi-disciplinary research teams with diverse yet complementary perspectives typically attain better insights and understandings than individual scholars working alone.

As scientific knowledge of the causes of climate change has grown, so, too, has public interest in the subject. "An Inconvenient Truth," a film about global warming produced by former United States Vice President Al Gore, won an Oscar for best documentary in February 2007 (see also Gore, 2006). Earlier that same month, the United Nation's Intergovernmental Panel on Climate Change (IPCC) issued its strongest statement to date on changes that are occurring in Earth's climate (IPCC, 2007). The IPCC report noted that Earth's atmosphere now contains more carbon dioxide and methane, greenhouse gases, than at any time over the past 650,000 years, and concluded that a "warming of the climate system is unequivocal" (IPCC, 2007, p. 5). Many people alive today will likely see dramatic increases in global temperature and sea level; decreases in snow cover, sea ice, and land ice sheets and mountain glaciers; increased thawing of permafrost; more and stronger tropical storms; and changes in precipitation regimes in many parts of the planet, including probable increases in rainfall in high latitudes and decreases in lower latitudes (IPCC, 2007, pp. 8, 16). These trends are likely to continue, or perhaps accelerate, and even if greenhouse gas levels are stabilized in the decades to come, changes produced by current levels may continue for centuries.

Present-day global temperature is warmer than any time since the Medieval Warm Period, a time of slightly warmer than average Holocene temperature that occurred from ca. AD 800 to 1200 (ca. 1200–800 cal yr BP) (e.g., Broecker, 2001). Current projections for global climate around ca. AD 2100, based on a doubling of atmospheric carbon dioxide, foresee average global surface warming of between 2 and 4.5°C, with the current best estimate for an increase of about 3° (IPCC, 2007, p. 12). To determine how these changes will impact climate and biota, comparisons are sometimes made with periods in the past when planetary temperatures were higher than they are at present, such as the Eemian, or last interglacial period ca. 125,000 years ago, when polar temperatures were approximately 3–5°C warmer than at present and sea level was as much as 4–6 m above the present stand (IPCC, 2007, p. 9). While the Eemian may be an analogy for current warming, our records from that time are limited, primarily because it lies in the fairly remote past. The Medieval Warm Period is more recent, and potentially instructive, but the changes that occurred had only a few hundred years to play out, and the climate was not too different from that of the present. To understand the consequences of sustained higher than average temperatures, we believe that changes in climate and culture that occurred during the Mid-Holocene warm period (ca. 5000–9000 cal yr BP) are the best case that we can explore in detail.

2. Holocene climate change

The growth and development of modern societies occurred within the Holocene era, from ca. 11,500 cal yr BP to the present, although we are coming to realize that some of the trends toward sedentary life and agricultural intensification date well back into the last glacial era in parts of the world (e.g., Roberts, 1998; Fagan, 2004; Scarre, 2005). The period of extreme cold conditions and maximum ice sheet extent associated with the last glacial occurred about 21,000–18,000 cal yr BP. Global warming and a gradual retreat of the ice sheets began after about 15,000 cal yr BP, and proceeded with cold reversals of varying intensity until about 11,600 cal yr BP, the end of the last extended cold reversal, the Younger Dryas, which began about 12,900 cal yr BP (e.g., Bond et al., 1997, 1999; Gulliksen et al., 1998; Hughen et al., 1998, 2000; Rahmstorf, 2002). The Holocene era, the subject of this book, is assumed by scientific convention to begin at 10,000 ^{14}C yr BP, or about 11,450 cal yr BP, soon after the end of the Younger Dryas, which in climate conditions is the real boundary (Harland et al., 1989; Gibbard, 2003, p. 202).

In this volume, both radiocarbon (^{14}C yr BP) and calendar (cal yr BP) ages are employed, usually the latter, unless specific radiocarbon determinations are being reported, in which case calibrated ages are also commonly presented. Due to fluctuations in radiocarbon production and uptake, radiocarbon ages are considerably different and typically but variably younger than actual calendar ages (Fig. 1.1).

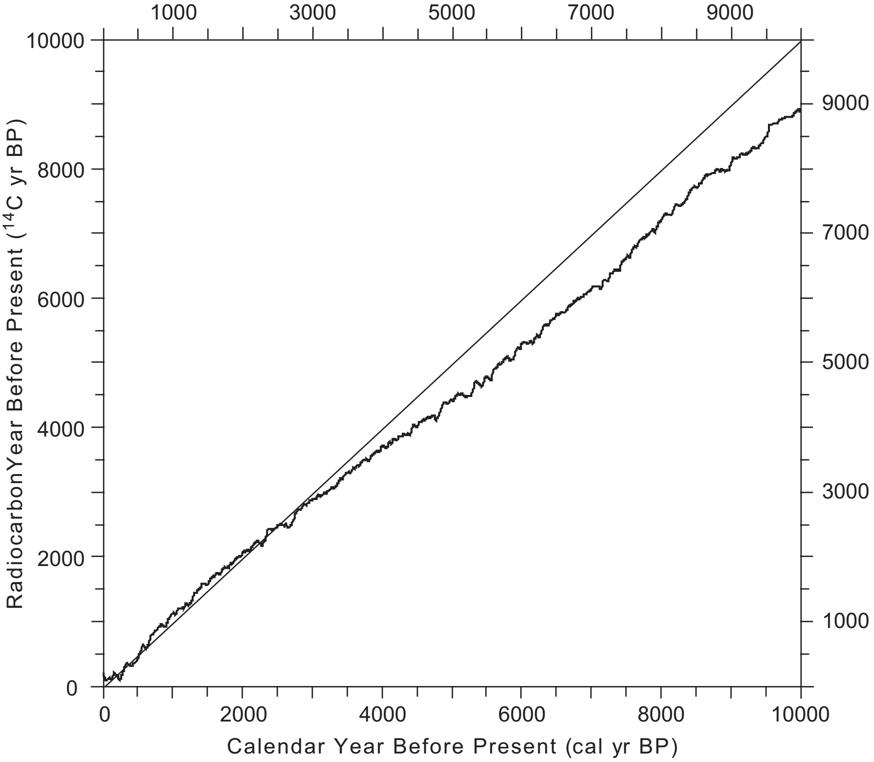

Figure 1.1. Calibration curve from 0 to 10000 cal yr BP for the conversion of radiocarbon ages to calibrated (cal) ages. The curve is based on dendrochronologically-dated tree-ring samples (after Reimer et al., 2004).

The development of the radiocarbon calibration curve has profound implications for archaeological and paleoenvironmental research (e.g., Taylor et al., 1996; Fiedel, 1999; Guilderson et al., 2005). While the offset between radiocarbon and calendar years is comparatively minor in recent millennia, it grows progressively more pronounced deeper in the past, reaching almost 1500 years at the Pleistocene/Holocene boundary 10,000 ^{14}C yr BP (11,450 cal yr BP). Calibrations have now been developed linking the radiocarbon and calendar timescales to the limits of the dating technique ca. 50,000 cal yr BP (Kitigawa and van der Plicht, 1998; Stuiver et al., 1998; Hughen et al., 2000; Reimer et al., 2004; Chiu et al., 2007). In this volume, when calendar ages based on radiocarbon dates are presented, the calibration or calibration program employed is also referenced (e.g., Reimer et al., 2004 or Stuiver et al., 1998; these are the calibrations most typically used).

Although Holocene climate is not characterized by the extreme climate fluctuations of the last glacial, it has been significantly variable. Average annual temperatures have changed by as much as a few degrees C for extended periods, sometimes with very rapid onsets and terminations, occurring on interannual to decadal scales (NRC, 2002). Holocene climate change cycles of approximately 2500 years and 1500 years are well noted in the literature (e.g., Dansgaard et al., 1971, 1993; Denton and Karlén, 1973; Pisias et al., 1973; Stuiver and Braziunas, 1989; O'Brien et al., 1995; Mayewski et al., 1997; Stager et al., 1997; Bond et al., 1997, 1999, 2001; Bianchi and McCave, 1999; Dunbar, 2000; Rahmstorf, 2002, Fleitmann et al., 2003). The pioneering work of Denton and Karlén (1973) demonstrated that globally distributed changes in glacier extent occurred throughout the Holocene about every 2500 years (Fig. 1.2). Alpine glacier extent is directly related to changes in climate, as indicated by the modern example of widespread glacier retreat coincident with climate change over the last century (e.g., IPCC, 2007). Holocene glacier advances occurred at ca. 9000–8000, 6000–5000, 4200–3800, 3500–2500, 1200–1000, and since 600 cal yr BP (Fig. 1.2) and are coincident with rapid climate changes (RCCs) observed in globally distributed proxy records of climate change (Mayewski et al., 2004). These proxy records show that Holocene climate has been dynamic at scales significant to humans and ecosystems. From the perspective of human civilization, many of these changes are fast enough (occurring over a few decades to a few hundred years) to be considered "rapid" and, as the chapters that follow demonstrate, their impacts on past societies have sometimes been quite pronounced.

The RCCs following the 9000–8000 cal yr BP event varied in geographic extent and intensity. They generally involved concomitant high-latitude cooling and low-latitude aridity, a pattern typical of long-term climate trends during the Pleistocene (e.g., Nicholson and Flohn, 1980; Maley, 1982; deMenocal et al., 2000; Gasse, 2000). The most globally extensive of the Holocene RCCs occurred about 6000–5000, 3500–2500, and after 600 cal yr BP. There were less widespread RCCs at around 4200–3800 and 1200–1000 cal yr BP. The age brackets for these RCCs were verified using the well-dated, high-resolution Greenland Ice Sheet Project Two (GISP2) chemistry series (Mayewski et al., 1997), previously correlated with the globally distributed glacier fluctuation record by O'Brien et al. (1995).

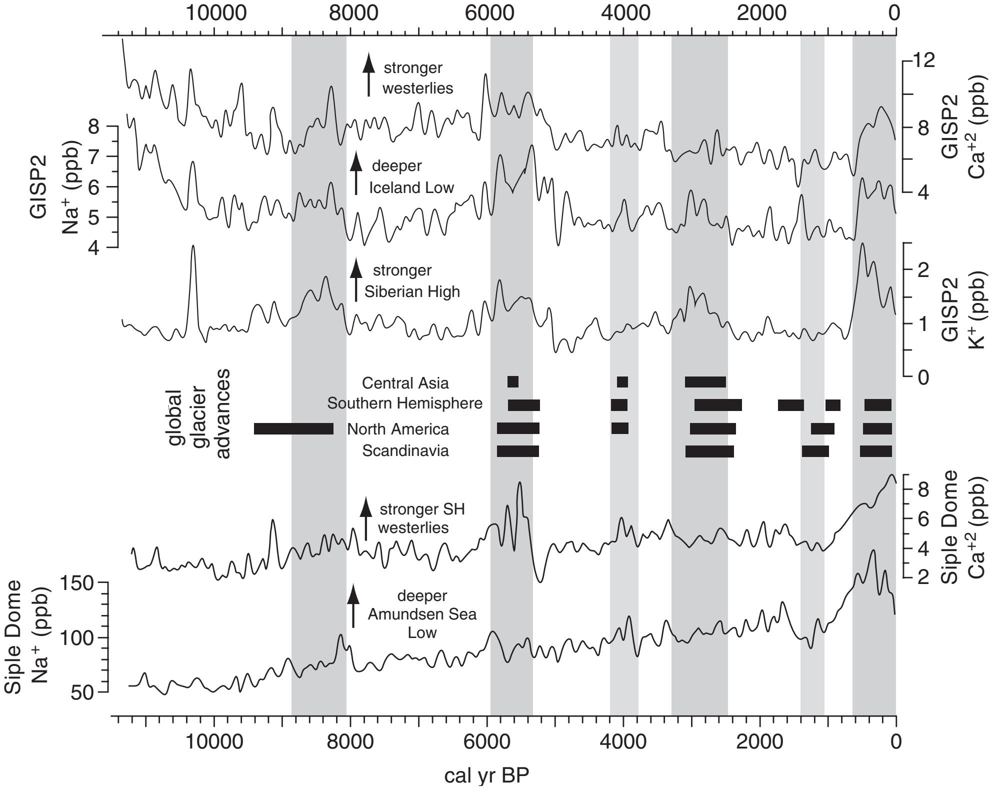

Figure 1.2. Proxy records for middle to high-latitude atmospheric circulation for the last 11,500 years obtained for the Northern Hemisphere from GISP2, Greenland, and the Southern Hemisphere from Siple Dome, Antarctica. Holocene rapid climate change (RCC) events are marked by shaded vertical bars. Changes in GISP2 Na^+ are correlated with December–January–February surface pressure over the area of the Icelandic Low such that increases (decreases) in Na^{++} coincide with decreases (increases) in pressure over this region. Increases (decreases) in GISP2 K^+ are correlated with March–April–May increases (decreases) in pressure over the region of the Siberian High (Meeker and Mayewski, 2002). Changes in GISP2 Ca^{++} are positively associated with September–October–November changes in intensity of the westerlies (Yan et al., 2006). Increases (decreases) in SD Na^+ are correlated with decreases (increases) in September–October–November surface pressure over the region of the Amundsen Sea Low. Changes in SD Ca^{++} are positively correlated with changes in the September–October–November surface mean zonal wind surrounding Antarctica, most notably the region close to 40–50°S in the Indian and Pacific Oceans. Times of distinct glacier advances are shown by horizontal black bars for Europe, North America, and the Southern Hemisphere (Denton and Karlén, 1973), and central Asia (Haug et al., 2001).

In addition to alpine glacier advances at ca. 6000–5000 and 3500–2500 cal yr BP, Northern Hemisphere RCC intervals were characterized by North Atlantic ice-rafting events (Bianchi and McCave, 1999) and strengthened westerlies over the North Atlantic and Siberia (Meeker and Mayewski, 2002; Mayewski and

Maasch, 2006). Cooling occurs over the northeast Mediterranean around 6500 and 3000 cal yr BP (Rohling et al., 2002), most likely related to winter polar air outbreaks. Westerly winds over central North America strengthen ca. 6000–5000 and 4200–3800 cal yr BP (Bradbury et al., 1993).

At lower latitudes the RCC interval ca. 6000–5000 cal yr BP marks the end of the early to Mid-Holocene humid period in tropical Africa (Gasse, 2000, 2001; deMenocal et al., 2000). Latitudinal shifts of the Atlantic Intertropical Convergence Zone expressed as changes in regional precipitation were inferred from measurements of the concentration of metals (Fe and Ti) in a marine core from the Cariaco Basin (Haug et al., 2001). A transition from wetter to drier conditions in northern South America occurred at the ca. 6000–5000 cal yr BP RCC. A proxy record for El Niño related rainstorms from a lake in Ecuador suggest that El Niño frequency increased following the ca. 6000–5000 cal yr BP RCC, and again after the RCC around 3500–2500 cal yr BP (Rodbell et al., 1999; Moy et al., 2002). This record supports western South American indicators of abrupt changes in El Niño frequency, which dominates interannual–decadal climate variability in the tropical Pacific. Paleoclimate proxy records from archaeological sites and other archives in Peru and the eastern equatorial Pacific show that El Niño activity was weak or nonexistent for at least 3000 years prior to the ca. 6000–5000 cal yr BP RCC (e.g., Rollins et al., 1986; Sandweiss et al., 1996). Between ca. 5800 and 3000 cal yr BP, El Niño was present but less frequent than today. After around 3000 cal yr BP, the frequency and intensity of El Niño activity increased, becoming more similar to that of the present-day (Sandweiss et al., 2001; see Sandweiss et al., Chapter 2).

A multi-proxy climate record derived from lacustrine sediments from subtropical Chile (Jenny et al., 2002) indicates arid conditions between the ca. 9000–8000 and 6000–5000 RCCs after which time effective moisture increased progressively. Using cores from Lake Titicaca, Baker et al. (2001) have shown that maximum aridity and lowest lake level occurred between 8000 and 5500 cal yr BP. The lowest level of Lake Titicaca was reached between 6000 and 5000 cal yr BP after which lake level rose to close to its modern level.

At higher latitudes in the Southern Hemisphere, glaciers advance in the Southern Alps of New Zealand at this time (5000–6000 cal yr BP). Also, a polar ice core record from Siple Dome, Antarctica reveals that atmospheric circulation intensified at ca. 5000–6000 cal yr BP (Mayewski and Maasch, 2006; Yan et al., 2006).

3. Possible causes of Holocene climate change

Millennial scale climate variability during the Holocene may best be explained as a consequence of the dynamic balance between components of the climate system including the hydrologic cycle, heat content of the ocean, atmospheric greenhouse gas variations (including water vapor), and sea-ice extent. The forcing mechanisms likely most important in determining Holocene climate are solar variability (Denton and Karlén, 1973; O'Brien et al., 1995; Mayewski et al., 1997; Bond et al., 2001) superimposed on long-term changes in insolation, which is determined in large measure by Earth's orbital parameters. The natural feedbacks within the climate system may amplify relatively weak forcing related to fluctuations of solar output and relatively small variations in greenhouse gases (Saltzman and Moritz, 1980). The global distribution of changes in moisture balance, temperature, and atmospheric circulation for the 6000–5000 cal yr BP RCC are summarized in Figure 1.3.

Controls on Holocene climate change thus include variations in the hydrologic cycle, sea level, sea-ice extent, and forest cover. In addition, climate change can also be forced by volcanic aerosols, greenhouse gases, insolation changes, and solar variability. The hydrologic cycle that governs the latent heat distribution in the atmosphere through water vapor transport, and also the greenhouse effect, plays a major role in Holocene climate variability. This is clearly indicated by the large fluctuations in lake levels, monsoon activity, and regional precipitation patterns evident in paleoclimate records. Atmospheric methane concentrations decrease after the ca. 9000–8000 cal yr BP RCC, then steadily rise after ca. 6000–5000 cal yr BP RCC (Chappellaz et al., 1993). This, however, is likely the result rather than the cause of roughly synchronous changes in the global hydrological cycle. There are no significant systematic changes in the concentrations of volcanic aerosols (Zielinski et al., 1996; Kurbatov et al., 2006) or atmospheric carbon dioxide (Indermühle et al., 1999) over the Holocene.

Holocene climate variability, particularly during the Mid-Holocene from ca. 5000 to 9000 cal yr BP, has tended to receive relatively little research attention from integrated teams of archaeologists and climatologists. This is rapidly changing,

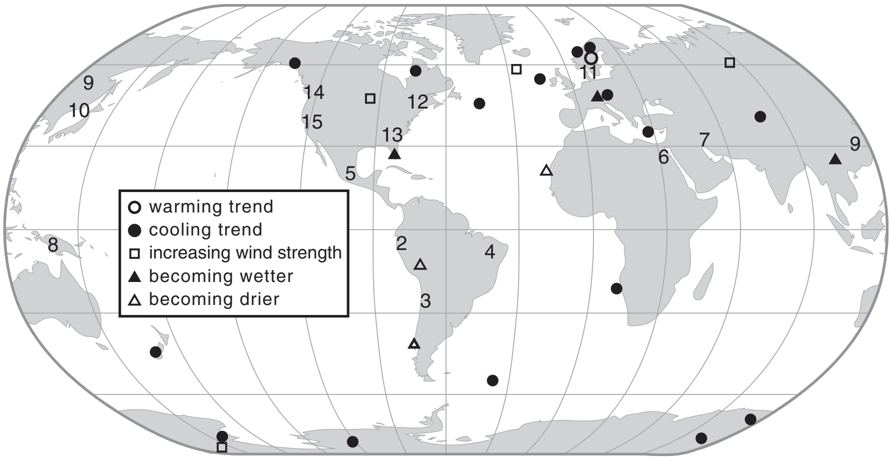

Figure 1.3. The global distribution of changes in temperature, moisture balance, and atmospheric circulation for the ca. 6000–5000 cal yr BP RCC from the Holocene proxy records summarized in Mayewski et al. (2004) are shown. The regions discussed in this book are also marked with the chapter number.

since the warmest part of the Holocene may offer a proxy of the long-term changes that are likely to occur over the next few centuries.

That the Mid-Holocene is a possible analog for future climate trends has, of course, been the subject of appreciable research, speculation, and debate for almost three decades (i.e., Budyko et al., 1978, 1987; Kellogg and Schware, 1981, Kutzbach and Guetter, 1986; Mitchell, 1990), and popular and technical articles and web sites describing global warming often note this possibility. It has long been recognized as well that the Mid-Holocene is not an exact parallel to modern circumstances, since observed Northern Hemisphere warming correlated with changing orbital parameters, specifically an increase in solar insolation, and not by an increase in greenhouse gases. Perhaps fortuitously from the perspective of resolving impacts on climate, biota, and human populations, these different potential causes have led to similar outcomes as far as projections of Northern Hemisphere and particularly high-latitude temperature and precipitation are concerned (Mitchell, 1990, pp. 1180–1183). Precipitation changes in recent years, of critical importance for sustaining agriculture and drinking water, have included "significantly increased precipitation … in eastern parts of North and South America, northern Europe, and northern and central Asia. Drying has been observed in the Sahel, the Mediterranean, southern Africa, and parts of southern Asia" (IPCC, 2007, p. 7). Similar patterns have been noted in models of Mid-Holocene precipitation regimes (e.g., Mitchell, 1990; Ganopolski et al., 1998). The Mid-Holocene thus offers a good example of the nature and magnitude of changes in climate and biota that could occur over the long term in specific regions, and, based on what happened in the past, their possible impact on human societies in these areas.

4. Lessons from the past for the future

How does studying climate and culture change, and particularly events and processes occurring during the Mid-Holocene from ca. 9000 to 5000 years ago, help us in the modern world? In many ways, as the chapters that follow demonstrate. Lessons range from revealing the large-scale changes over time and space that may occur in variables such as vegetation cover and precipitation, and how humans responded to these changes, to developing new or improved analytical techniques and data collection strategies, as well as new ways of thinking about how we can best explore these topics. A primary lesson is that we must constantly strive to obtain the best possible temporal control of both our archaeological and paleoclimatological data, since the more precise absolute dates we have in our paleoenvironmental reconstructions and cultural sequences, the more accurately we can correlate developments over time and space, and perhaps better understand not only what was occurring, but why.

We must continually think about how to improve or develop new and innovative analytical tools to reconstruct past change. Glacial rock flour outflow sedimentation records, typically trapped in lacustrine deposits downstream, for example, are one fairly direct way to measure glacial erosion and retreat (Karlén and Larsson, Chapter 11). Plant micro and macrofossil spatial (including altitudinal) distributions are widely used to delimit the impact of climate change, or to infer that it occurred. During the Mid-Holocene, for example, the subarctic taiga/tundra boundary, or the extent of forest cover, appears to have shifted up to as much as 250 km to the north (Ganopolski, 1998, p. 1918), and pine tree remains have been shown to cluster well above their modern altitudinal range in Scandinavia (e.g., Karlén and Larsson, Chapter 11). Many of the studies herein demonstrate that changes in forest composition and distribution played a major role in Mid-Holocene culture change. A need for greater consistency and a more multivariate approach to exploring paleoclimatic/paleovegetational changes from region to region is, unfortunately, also demonstrated. In most parts of the world more pollen, fire frequency, dendroclimatology, and other proxy measures need to be obtained and examined, many of the existing records need far better temporal controls, and more of these records need to be examined collectively rather than individually. Likewise, we must be careful not to extrapolate past conditions at too great a distance from the sources of the data. For example, locally derived pollen or tree ring reconstructions of past rainfall or fire frequency may not accurately reflect regional conditions, which are moderated by ocean currents and/or other large-scale weather systems. On the other hand, ice core records from remote polar locations can be used to reliably reconstruct past changes in large-scale atmospheric circulation, and related precipitation patterns, on a continental or even hemispheric scale.

Changing climate can also lead to localized or broader scale extirpation of plant and animal species, by forcing them out of their viable ranges. As climate warms, for example, cold tolerant species may be forced to higher and higher elevations, until such refugia no longer exist; such a fate is predicted for many species in the southern Appalachians as global warming intensifies over the next few decades (e.g., Delcourt and Delcourt, 2004). Dramatic declines in eastern North American hemlock (*Tsuga canadensis*) and northern European elm (*Ulmus* spp.) that occurred toward the end of the Mid-Holocene, around 6000–5000 cal yr BP, are attributed in part to pathogen or insect infections, as well as drought, human activity, and other factors, which were in turn facilitated by warming climate (e.g., Digerfeldt, 1997; Dincauze, 2000, pp. 188–191; Bennett and Fuller, 2002; Parker et al., 2002; Foster et al., 2006). These broad changes in vegetation had major impacts on the human societies in these regions, facilitating increased hunting/gathering activities in northeastern North America and the adoption of agriculture in Scandinavia (Sanger et al., Chapter 12; Karlén and Larsson, Chapter 11). Another large-scale change in vegetation that occurred in the Mid-Holocene is the expansion of western red cedar in the Pacific northwest region of North America, a highly effective material in plank house and perhaps boat construction that is thought to have helped facilitate the emergence of complex hunting–gathering societies in this region (Moss et al., Chapter 14). Likewise, the expansion of coniferous longleaf pine in the southeastern United States, a vegetational community sustaining fewer exploitable game animals than the mixed deciduous–coniferous community that was in place previously, apparently led to a marked reduction or relocation of human populations from the Coastal Plain to the deciduous forests of the interior (Anderson et al., Chapter 13).

The Mid-Holocene thus offers several dramatic examples of how comparatively minor (i.e., no more than 2–3°C) changes in temperature can lead to the replacement of formerly dominant plant and animal species over large areas, with a concomitant impact on the human societies dependent upon them. These range changes apply to domesticates as readily as to wild species; as several authors note, small changes in temperature can markedly affect the length of the growing season for certain plant species, and hence their range of occurrence. How climate change might affect agricultural food production is a major focus of current research, since human populations worldwide are critically dependent on these resources. Small temperature changes can also affect animal populations, such as the ranges of anadromous fish and molluscan populations that have been a principal target for human populations around the world for many millennia; some species either cannot survive or actually thrive in warmer waters. As Lutaenko et al. (Chapter 10; see also Sandweiss et al., Chapter 2) demonstrate, molluscan faunal distributions, like pollen data, can help delimit the extent and impacts of warming or cooling episodes, although the authors are also careful to note that many of these species respond in an intricate way to environmental changes, so care must be taken in their interpretation.

It is also clear that the Mid-Holocene was not a period of uniform climate change, of unusual warming or drying across the world, and that it is equally dangerous to assume that climate was broadly similar even within particular regions. In the Amazon basin, the Mayan area, and the Eastern Woodlands of North America, to cite but three examples from the Americas recounted in this volume, rainfall increased in some parts of these regions and decreased in others at various times during the Mid-Holocene (Meggers, Chapter 4; Anderson et al., Chapter 13; Voorhies and Metcalfe, Chapter 5). We must recognize that there is appreciable long- and short-term climatic variability over the course of the Mid-Holocene due to as of yet incompletely understood cycles in solar output or ocean circulation.

At shorter temporal scales, increases or decreases in interannual to subdecadal climatic variability, as well as increases or decreases in seasonal (i.e., intra-annual) variability, can also have great impacts on cultural systems, perhaps as pronounced as the impacts of longer term climate trends. Thus, exploring the nature of seasonal, annual or decadal scale climatic variability, and how human cultures responded to it, is an important area for research (e.g., Kennett et al., Chapter 15). A classic example of the kind of short-term climate change that must be considered is interannual ENSO frequency, which appears to have increased after ca. 5800 cal yr BP and again after 3000 cal yr BP (Sandweiss et al., 1996, 2001, Chapter 2). Another is fire frequency, which is coming to be widely examined using tree-ring fire scar and sediment/pollen core charcoal particle records (Mohr et al., 2000, Chapter 14; Marlon et al., 2006).

Long-term, global scale climate change is manifest locally in different ways, and while we must not refrain from thinking in terms of global patterns or records of climate change, we also need to explore how these changes and human responses played out locally. As Lu (Chapter 9) also notes, we need to recognize and differentiate macro or global from micro or local scale climate events impacted by geography and human action.

Changes in climate and resource structure were often time transgressive, in some cases with lags between climate change and biotic response indicated; the response of vegetational communities was varied, and could be anywhere from critically dependent to minimally responsive to changes in temperature and precipitation. Local conditions and changes thus may not always proceed in lockstep or close agreement with global patterns. Vegetation changes sometimes lag behind temperature/climate changes by appreciable intervals, up to hundreds of years (Davis and Botkin, 1985); hence, pollen data may not accurately reflect when climate changed, but only responses to it.

Finally, while sudden dramatic episodes of climate change have occurred during the Holocene, such as the so-called "8200 event" (Alley et al., 1997), gradual long-term change (albeit with shorter annual to decadal fluctuations) is more typical. Culture change in many areas, at least during the Mid-Holocene, appears to have been stimulated by gradual, progressive changes in climate and biota, rather than sudden or dramatic changes at any one time.

5. Linkages between climate and culture change

Direct correlations between climate and culture change are sometimes difficult to make; assuming human societies prospered during favorable climatic periods and underwent hardship or collapse during unfavorable periods, for example, is not inevitably or invariably correct, as archaeologists, historians, and geographers have long noted (e.g., Le Roy Ladurie, 1971; DeVries, 1980; Wigley et al., 1981; Crumley, 1994; McIntosh et al., 2000; Tainter, 2000; Crumley et al., 2001; de Menocal, 2001; Redman et al., 2004; Hardesty, 2007; McGovern, 2007; Rosen, 2007). Often there were cultural responses to climate that resulted in greater organizational complexity and larger numbers of people occupying the landscape, even though environmental conditions might have been harsher than during earlier periods for certain types of subsistence activity. As discussed in this book, the Mid-Holocene record demonstrates that environmental change can trigger a range of cultural responses, from collapse, to reorganization, to expansion. In some areas, furthermore, cultural changes are observed, yet a linkage with Mid-Holocene climate is unclear, such as the emergence of agriculture in the New Guinea Highlands (Anderson et al., Chapter 8). The demonstration of spatio-temporal correlation between climate and culture change, of course, does not prove they are related. It does, however, mandate consideration of possible linkages. Among the many critical variables not in themselves directly related to climate, population size and level of socio-political complexity are particularly important. As Fagan (1999) and many others have noted, small mobile groups of foragers often have many more options for dealing successfully with climate stress on local subsistence than do large, settled populations of farmers. Below and in this volume, we tease out some of the implications of this observation in terms of subsistence stress, migration, and technological or organizational change.

We must be careful, therefore, not to assume that all or major changes in past cultural systems had a climatic trigger. Historical trends or traditions at a regional scale can significantly influence adaptations at local scales, just as individual historical events can sometimes have widespread and long lasting ramifications. To understand what is occurring in specific localities we need to recognize the cultural traditions that are in place, as well as the nature of regional political geography. A society's response may be brought about as much by its history and practices, or its location within a given region or in relation to favorable resource patches, as it is to climate change affecting temperature or vegetation. In the Mid-Holocene southeastern United States, for example, some groups occupying resource rich areas appear to have intentionally opted out of the regional trend toward increasing complexity (Anderson et al., Chapter 13). Typically these groups were located in the margins of the region, and hence were not surrounded and circumscribed spatially by other groups. In more central areas, circumscription resulted in populations quickly adapting changes their neighbors made in food production, ceremony, or warfare. Climate change might have thus forced or necessitated culture change in some areas, deliberate efforts to maintain the status quo in others, and no obvious impact in yet others. Whenever possible archaeologists should take advantage of the vast amount that has been learned through paleoenvironmental research. Unfortunately, in many parts of the world this information is underutilized by social scientists, in part because archaeologists and historians do not recognize its significance, and in part because some of them believe human agency trumps or proceeds largely unaffected by climate change (e.g., Kennett and Kennett, 2006, Chapter 7). A major lesson of this book is that climate does have a role in cultural change in most parts of the world when we look at circumstances carefully.

Direct causal links are often hard to delimit, but as the chapters that follow demonstrate, a number of major population shifts and reorganizations occurred during the Mid-Holocene that appear closely linked to concurrent changes in precipitation, sea level, growing season, or vegetation. Evidence for substantial interpersonal conflict or warfare is observed for the first time in many parts of the world during the Mid-Holocene, for instance fortification walls around settlements, burials exhibiting weapons trauma, or sites that have been razed through attack. Whether the widespread conflict is due to the climate change putting stress on people as resources declined in availability, or is a density-dependent phenomenon tied to increasing human populations, is at present unknown; both factors are assumed to have played a role in many areas (e.g., Ferguson, 1984; Haas, 1990; LeBlanc and Register, 2004; Otterbein, 2004; Gronenborn, 2005, 2007).

Both human and animal populations have tended to concentrate in well-watered areas with high exploitable biomass throughout history and prehistory. As climate and resource structure changed during the Mid-Holocene, so, too, did the size and presence of human populations in many areas; aridity commonly resulted in reduced biomass, including that of plants utilized by human populations, just as increased precipitation sometimes led to greater available biomass, and hence larger populations. As Wendorf et al. (Chapter 6) and other authors herein demonstrate, minor changes in rainfall frequency may have a much greater impact in marginal areas such as desert and grassland regions than in tropical areas/areas with much greater vegetation cover. With aridity can come heavy erosion, as vegetation cover is removed, compounding the impact on cultural systems; what rain that does occur may be more likely to run off, rather than be absorbed. In some areas such as the Atacama Desert of Peru and the Sahara of North Africa (e.g., Grosjean et al., Chapter 3; Wendorf et al., Chapter 6), exploitable subsistence resources were highly sensitive to minor changes in rainfall or temperature; when conditions changed from arid to hyperarid, human populations could no longer be maintained in some areas, resulting in depopulation or abandonment.

Human societies sometimes develop highly effective ways of dealing with climate change, especially if change leads to resource uncertainty. Technological and organizational changes are the most common strategies observed in the archaeological record from the Mid-Holocene; in the Sahara, the ability to dig deep wells, for example, allowed for use of more arid areas and for people to stay in some areas when climate became even drier (Wendorf et al., Chapter 6). Development of storage technology and organizational networks to produce and redistribute food surpluses also allowed people to buffer periods of climate-induced shortfall, at short-term scales. Long-distance trade networks appear in many areas during the Mid-Holocene, reflecting greater interaction between populations. Increased interaction between peoples in different environmental settings was likely an effective strategy to alleviate unevenly distributed subsistence stress brought on by climate change or other factors.

What kinds of sites or areas are occupied or abandoned also bears consideration. As Meggers (Chapter 4) has noted, a pronounced hiatus in rockshelter occupations occurs in the Amazonian area during the Mid-Holocene, for reasons that are not entirely clear. Locally, the period was warmer and wetter with greater biomass; use of rockshelters may have been more common when climate was colder or biomass more restricted, requiring different collection and storage strategies that may have been facilitated by the occupation of rockshelters. We need to recognize ecological and probably cultural refuges during periods of climate change/stress. Likewise, effectively delimiting anthropogenic landscape and vegetation change from climatic induced change is a continuing challenge. Changes in human settlement over time and in specific settings need to be carefully documented and tightly correlated with regional climate histories, to understand the impacts of climate change on these societies. These impacts are measured in the number of sites, the size of sites, and the density of artifacts or features such as structures or burials. We must evaluate whether hiatuses at individual sites correspond to regional changes in population numbers, or instead to population relocation, movement, or re-organization.

Another way human populations respond to climate change/stress is through migration, relocating from one area to another. The Mid-Holocene is a time of large-scale population movement, with some areas abandoned and others more densely settled. What are specific causes of migrations, and how does environmental change play a role? Unless organization and technology are capable of mitigating climate-induced reduction in subsistence resources, groups are at its mercy and must relocate from less to more favored areas, or die out. How, where, and why people moved in the past has become a major area for archaeological research (e.g., Anthony, 1990; Kelly, 2003). As Kennett et al. (Chapter 15) show, a wide range of data can be used to explore Mid-Holocene human migrations/movements, including archaeological, skeletal biological, and linguistic data. Changing biotic regimes, increases or decreases in desertification, or rising sea levels can each, in their own way, result in dramatic reductions in exploitable landmass in some areas, forcing population relocations. The locations of land masses exposed or covered by fluctuating sea level also influenced human migration patterns, by cutting off or favoring movement in certain directions. Mid-Holocene changes in winds and currents likewise impacted maritime voyaging in some areas.

Another pattern evident in many parts of the world during the Mid-Holocene, especially after ca. 6000 cal yr BP, is a dramatic increase in human use of shellfish, although it must be acknowledged up front that our knowledge of pre-Mid-Holocene use of marine resources is sparse in most coastal areas, where the ancient shorelines are submerged to varying depths. The reason we have so many surviving coastal sites from the Mid-Holocene on is tied to a global decrease in sea-level rise, as ice sheet melting slowed, shorelines reached modern levels, and estuaries formed and became stable. Voorhies and Metcalfe (Chapter 5) note, however, that sea-level stabilization since the Mid-Holocene has biased our perspective on earlier human use of coastal areas, and maritime technology in general, a point Perlman (1980) and Richardson (1981) made some decades ago. Use of coastal resources dates back almost 100,000 years in southern Africa, for example, and people reached Australia across ca. 80 km of open ocean some 45,000 years ago (Erlandson, 2002; O'Connell and Allen, 2004; Anderson et al., Chapter 8). Rising sea levels have, however, effaced much of the earlier coastal archaeological record, a problem that we will likely be facing again in the near future given global warming. Sea-level rise associated with global warming and ice sheet melting, in fact, is likely to create a vast new underwater archaeological record as well as destroy incalculable numbers of existing sites in the centuries to come, since much of the world's population, including in some of the world's largest and longest occupied cities, resides on or near the coast, and has done so for much of the Holocene. The destruction of the present and past record of human occupation and civilization along the coasts, while a major calamity for archaeology and history, is likely to be viewed as a minor concern when compared with the challenges and changes that relocating these populations will bring about.

Sea level is affected by many factors, however, so local changes may not exactly mirror global increases or decreases in ice volume. In areas of low relief, like ancient southern Mesopotamia (Kennett and Kennett, 2006, Chapter 7), comparatively minor rises in sea level resulted in major transgression as well as site burial or erosion. Arguments positing minimal human occupation in some areas may be simply an absence of evidence, because the archaeological record has been partially or totally lost to sea-level rise and associated shoreline erosion (e.g., Richardson, 1981). When examining past or possible future sea-level fluctuations, accordingly, we must recognize that this process has not been completely consistent from area to area, due to localized factors such as rebound or subsidence.

As Moss et al. (Chapter 14) note, archaeologists worldwide have argued that the rapid decrease in sea-level rise and hence coastal stabilization in the Mid-Holocene is thought to have encouraged the development and human exploitation of coastal estuarine resources. Marine resource use, and not just the development of agriculture, appears to have facilitated the development of elaborate cultures in many parts of the world during the Mid-Holocene. The Jomon culture in Japan (Lutaenko et al., Chapter 10), the Shell Mound and coastal Archaic cultures in the southeastern United States (Anderson et al., Chapter 13), and various societies along the western coast of North America (Moss et al., Chapter 14) are all examples of complex, hunting–gathering cultures that emerged at this time. Evidence for coastal resource exploitation has great antiquity, vastly predating the Mid-Holocene (Erlandson, 2002); how prevalent or effective it was during periods of comparatively greater change in sea level, as during the early part of the Holocene, is less well explored. We have to be careful not to let the expectations from such models blind us to what might actually be occurring. In both the southeastern United States and the Northwest Coast, for example, recent careful examinations have documented older and more complex sites, particularly shell middens, than we once thought existed (Anderson et al., Chapter 13; Moss et al., Chapter 14). Continuity with earlier Holocene adaptations rather than dramatic changes may be indicated, contra existing models that see an increase in the use of shellfish and anadromous fish as a response to sea-level stabilization. For instance, Terminal Pleistocene coastal groups in southern Peru targeted particular marine fish and mollusk species for intensive exploitation (Sandweiss et al., 1998), a practice that continued throughout the Holocene.

As a number of the papers in this volume also demonstrate, climate change during the Mid-Holocene helped shape the development of complex societies in several parts of the world, both through the occurrence of conditions favorable to the aggregation of larger numbers of people as well as the emergence of less favorable conditions that required new social strategies to maintain existing populations. We need to carefully consider the roles environmental variables, including changes in these variables, played in early state formation; many of the chapters herein explore these issues (e.g., Sandweiss et al., Chapter 2; Grosjean et al., Chapter 3; Voorhies and Metcalfe, Chapter 5, Wendorf et al., Chapter 6; Kennett and Kennett, 2006, Chapter 7; Lu, Chapter 9; Lutaenko et al., Chapter 10). Sea-level and climate change led to increased competition for resources, and this, coupled with "the expansion and ultimate stabilization of aquatic habitats ... favored increased population densities" (Kennett and Kennett, 2006, p. 69, Chapter 7). This process happened in several parts of the world, but primary or initial state formation occurred in only a small number of areas, including southern Mesopotamia, western South America, central China, and Mesoamerica (as opposed to in the Sea of Japan, the Pacific Northwest Coast of North America, northern Europe, the Amazon basin, or in the southeastern US), at least in part because diverse and productive suites of domestic plants and animals were also present. Sea-level stabilization in the Mid-Holocene did make the resources of coastal areas more predictable, and perhaps more bountiful, which is why complex (if not state level) societies are observed in coastal areas in many parts of the planet at this time.

Variation in rates of sea-level rise and fall can have major consequences for human societies, specifically in how such groups respond to the changes in exploitable land surface as well as in coastal/estuarine resources. The northern end of the Persian Gulf, for example, was approximately 400 km inland of its present location in the Mid-Holocene, around 6000 cal yr BP. Sites currently well removed from the ocean were quite close at the time they began their rise to prominence, such as Ubaid, Eridu, and Ur (Kennett and Kennett, 2006, pp. 74, 78, Chapter 7). Moister conditions also occurred, which likely facilitated greater crop productivity. But while the early part of the Mid-Holocene was a time of increased moisture in Mesopotamia, with higher lake levels (Kennett and Kennett, 2006, p. 76, Chapter 7), and in the Sahara (Wendorf et al., Chapter 6), just the opposite occurred in the midsouth of the United States (Anderson et al., Chapter 13). Regional trends toward greater aridity occur, but do not become pronounced in southern Mesopotamia until after ca. 6000–5500 cal yr BP, and particularly after 5000 cal yr BP, after states had emerged.

Since climate and cultural change can both occur over a wide range of timeframes, we must explore and evaluate the relationships between the two using multiscalar and multi-temporal perspectives. That is, some aspects of culture change cannot be recognized unless archaeological data are examined at a number of different spatial scales, from the site to the locality to the larger region, or over varying periods of time, from the annual or decadal to the generational and centennial scales. As Moss et al. (Chapter 14) observe, we must be careful to look to the primary data, the artifact assemblages and paleobiological remains in actual sites, rather than assume we know what is happening from later summaries or our own preconceptions of what should be present; primary reports often contain data not presented in later generalizations about these sites. Likewise, we must be ready to go back to sites and collections and re-examine them using new analytical technologies and new theoretical perspectives.

Finally, Mid-Holocene research has helped us to refine our archaeological research methods and approaches, such as procedures for site discovery, and to identify factors favoring preservation or erosion. Decreases in lake/river/spring levels during the Mid-Holocene, followed by their rise, for example, can mask archaeological sites/settlements located near their margins. Permanently submerged deposits may have better preservation than deposits characterized by fluctuating water levels. As Sanger et al. (Chapter 12) note, vegetation changes can influence erosion rates; as ground cover composition changes, so, too, will site visibility. Changes in sea level and precipitation can impact sedimentation and erosion rates, resulting in greater burial or loss of the archaeological record from certain times; Kennett and Kennett (2006, p. 81), for example, note that in Mid-Holocene Mesopotamia there may be many unrecognized Ubaid period sites ''deeply buried under alluvium.'' We need to look in places previously ignored, and work to recover what we can from areas currently being lost or that are likely to be lost in the years to come.

6. Conclusion

The regional overviews in this volume make it abundantly clear that:

1. The Holocene was not a time of global climatic stability; change occurred at multiple spatial and temporal scales.
2. The Mid-Holocene was an era of significant social and cultural transformation in many but by no means all parts of the world.
3. Neither climatic nor cultural changes were universal or unidirectional.
4. In many parts of the globe, there were notable spatial–temporal correlations between cultural and climatic change during the Mid-Holocene. It is tempting to see correlation as causation, but that is usually an oversimplification of complex, multi-scalar, multi-modal, dynamic processes.

We have much left to learn about a critical period in human and earth history, a period that has important lessons for all of us as contemporary global change becomes our reality. It is our intent and hope that this volume will provide a global baseline for those future studies of the Mid-Holocene world.

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