Chapter 15
Hydraulic Cities, Colonial Catastrophes, and Nomadic Empires: Human-Environment Interactions in Asia

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Abstract Recent and projected changes in climate highlight the need to understand and predict human-environment interactions. However the diversity of cultures, livelihoods, and political formations today and in the past indicate that relationships between climate, ecosystems, and societies are likely non-linear, complex, and variable over time. A growing network of multi-millennial, absolutely dated annual tree-ring records from Asia provide climatic context for several important historic events which emphasize the diversity of human-environment interactions. Tree rings are an ideal proxy for understanding these relationships due to their extensive spatial coverage, temporal resolution relevant to human systems, and their ability to integrate climate in ways that relate directly to human livelihoods. Herein, we focus on five examples of human-environment interactions in two climatically and culturally distinct regions of Asia: Monsoon and Arid Central Asia. Over the last three millennia, societies have adjusted to climate variability in diverse and (mal)adaptive ways. In Monsoon Asia, drastic swings in moisture availability, notably megadroughts associated with monsoon failure, interacted with socio-political and technical institutions to spur the disintegration of the fourteenth century Khmer kingdom at Angkor and engender continental scale famine in nineteenth

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century colonial Asia. In Arid Central Asia, elevated temperatures and moisture were both a boon and a limitation for historic and modern nomadic pastoralists, depending on the historical context in which climatic events occurred. Future efforts to statistically model and predict human-environment relationships over the arc of human history in Asia will need to account for the diversity of economic, political, and cultural features that filter, dampen, and amplify the effects of climate change on society.

Keywords human-environment interaction • drought • Monsoon Asia • Arid Central Asia • historical climatology

15.1 Introduction

The study of human-environment relationships has been central to tree-ring science for nearly a century (Douglass 1921, 1929; Wissler 1921). During this time, dendrochronological investigations of interactions between society, climate, and ecosystems have primarily centered on three broad topics: (1) tree-ring dating of archeological sites and structures; (2) complex societies and climatic variability; and (3) ecosystem interactions with human activities. In recent decades, concerns about climate change and its diverse effects on societies have renewed interest in how past peoples responded to and interacted with environmental variability. Despite major differences in technology, energy sources, and modes of production, studies of past civilizations and climate change can help us understand resilience and vulnerability of society to future climate (deMenocal 2001). At the same time, current responses and reactions to climate change may help us understand the actions and decisions of human actors in the past (Orlove 2005; Adger et al. 2013). Similar inferences can be made by studying how and to what extent humans modified past ecosystems through fire, agriculture, and other means (Swetnam et al. 1999). These inferences help us contextualize the state of current ecosystems and their potential future trajectories, suggesting management strategies that might be applied today.

Human-environment interactions are multi-directional and often complex relationships between human actors, human institutions, climate, and the environment (Endfield 2012; Adger et al. 2013). Human systems depend on and respond to changing environmental conditions as well as adapt to and modify those conditions. This creates the potential for feedbacks to both the human system and the environment. The diversity of human cultures and actors present today and in the past suggests that human responses, adaptations, and modifications of the environment are not consistent over time. Like the climate system and its forcing mechanisms (Lorenz 1968), the same climatic or environmental driver can have differential effects on societies, particularly as cultures evolve and change over time. These effects and interactions vary across different segments of societies. While powerful elites may benefit from environmental changes, the masses of agricultural peasants may suffer (Davis 2002; Orlove 2005). Societies respond to a variety of forces and stressors, including climate, making it difficult to disentangle climate from other drivers of change. These interactions and complexities make it challenging, though not impossible, to work in a traditional hypothesis testing mode. Individual events or societies cannot be treated as sample units and there are no established metrics of climate response that can be applied or derived for different societies across culture, space, and time. Thus, detailed case studies with local and appropriate paleoenvironmental proxies have been the primary means of understanding relationships between humans and their environment in the pre-instrumental period.

Tree-ring records offer several distinct advantages over many other paleoecological data sources for studying past human-environment interactions. Because they are annually dated, tree rings and their many proxies can be directly related to calendar-dated historical and archeological materials (e.g. inscriptions, journals, births and deaths, tax and trade records). Further, the temporal signals stored in tree-ring records (typically seasonal to centennial), allow us to identify climatic excursions that occur on time frames meaningful for people and ecosystems. Similar arguments can be made for the overlapping spatial scales represented by tree-ring records of past climate, ecosystem processes, and human activities. The abundance of trees with annual rings, particularly in temperate and high latitudes, allows for spatially gridded reconstructions of past temperature or soil moisture capable of resolving climatic features and phenomena at regional to continental spatial scales. Perhaps the most relevant contribution of tree rings to the study of society and climate is that because trees are terrestrial plants, tree growth integrates many of the same environmental conditions important for the production of crops, domesticated animals, and other organisms on which people depend (e.g. Stahle et al. 1988; Pederson et al. 2013, 2014; Bocinsky and Kohler 2014).

Like other paleoclimatic and paleoecological approaches, tree-ring studies of human-environment relationships are vulnerable to some important pitfalls, including neo-environmental determinism (Coombes and Barber 2005), the logical fallacy of correlation meaning causation, and other 'reductionist' analyses and interpretations that simplify the complex relationships between people and their environments (Erickson 1999). These critiques are valid as many studies have ignored social and cultural complexity, human agency, historical legacies, and myriad other interesting relationships between people and their environments, all worthy of investigation. These concerns are not just theoretical as they may strongly affect the way we as a society formulate and respond to future climate (Hulme 2011). Provided these limitations are addressed and explored, the strengths of dendrochronology, including precise dating, high fidelity to climate, and environmental integration, allow for detailed case studies capable of responding to these critiques by adding a new source of historical and archeological data, directly tied to human time scales and ecologies. Historical events taking place over months to decades can be situated within the climate—and even the weather—under which they occurred, sometimes revealing unexpected responses and relationships.

With its long human history, diverse ecosystems, and recent economic growth, Asia has been the subject of a growing body of paleoecological research and data development over the last few decades. These efforts have culminated in two large-scale, gridded climate reconstructions as well as several multi-millennial records of past climate. Of particular note is the Monsoon Asia Drought Atlas (MADA) which has been used to explore the hydroclimatic context of several historical events (Cook et al. 2010). Similarly, a network of 422 tree-ring chronologies (Asia 2k) has been used to reconstruct summer temperatures over the past 1200 years, showing persistent periods of cooling (e.g. Little Ice Age; 1350–1880 CE) and warming (e.g. Medieval Climate Anomaly; 850–1050 CE and twentieth century warming) over the continent with important social and economic consequences (Cook et al. 2013). Where site replication is ample, these spatially explicit reconstructions can provide a climatic backdrop for diverse cultures and livelihoods across Asia. Further, Asia hosts several ultra-long chronologies of past moisture extending more than 1000 years (Buckley et al. 2010; Myglan et al. 2012a; Pederson et al. 2014), suitable for addressing questions about climate variability and society over the Common Era.

Here we focus on five case studies of human-environment interactions during the last 3000 years bound by two major geographic regions in Asia: Monsoon Asia and Arid Central Asia (Fig. 15.1). These regions are climatologically distinct

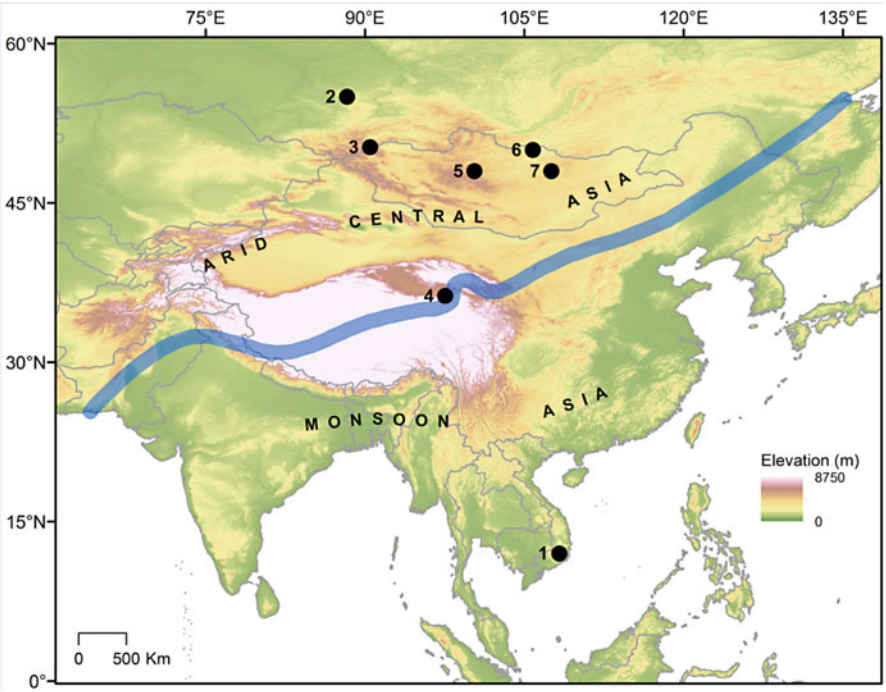

Fig. 15.1 Monsoon and Arid Central Asia regions based on Chen et al. 2008 (*blue* band). Location of tree-ring study sites (numbered circles) including: (*1*) *Fokienia hodginsii* sites (Angkor); (*2 & 3*) *Larix sibirica* (Siberian Scythians); (*4*) *Sabina przewalskii* (Xiatatu Tombs); (*5*) *Pinus sibirica* (Mongol Empire); (*6*) *Pinus sylvestris* and *L. sibirica* (Mongolian Breadbasket); (*7*) *P. sylvestris and L. sibirica* (fire history)

and allow the exploration of two cultural counterpoints: the largely sedentary agricultural societies of Monsoon Asia and the predominantly nomadic pastoral societies of Arid Central Asia. Monsoon Asia is influenced by the strength of the Asian Monsoon systems, with strong seasonal rainfall regimes capable of supporting extensive and complex agricultural societies. For Monsoon Asia, we review two case studies that highlight adaptations and vulnerabilities of ancient and historical agricultural societies: (1) hydroclimatic variability and the decline of Angkor and (2) Asian monsoon failure and the late Victorian droughts. In Arid Central Asia, we explore the continental and arid to semi-arid region of northern Asia where several complex and expansive empires arose from nomadic pastoralists during the last 3000 years. We also explore the interactions between recent socio-economic and environmental change. For Arid Central Asia, we review: (1) dendroarcheology and the development of ultra-long chronologies; (2) climate and environment of the Mongol Empire; and (3) socio-economic and environmental synergies in modern Mongolia. All of these case studies provide opportunities to investigate the diverse ways climate and environment have interacted with culture and society during the last 3000 years and point to the diverse and changing relationships between climate, environment, and society.

15.2 Monsoon Asia

Moisture variability in Monsoon Asia is influenced by the relative strength of the dominant monsoon systems, which are linked to land-sea temperature imbalances, resulting in strong, seasonal moisture delivery across much of the continent. Tree-ring data have been used to infer monsoon activity across this region over centuries to millennia. In particular, tree-ring reconstructions identified periods of monsoon failure and their associated megadroughts (Cook et al. 2010). Beyond ring width, other tree-ring parameters, such as stable isotopes and latewood density have been used to infer changes in monsoon intensity over time (e.g. Bräuning and Mantwill 2004; Grießinger et al. 2011), but have yet to be applied directly to human history. It is important to recognize that transitional regions between Monsoon Asia and Arid Central Asia, such as the Tibetan Plateau (TP), can be influenced by multiple climate systems, and these systems can vary in influence over time and space (e.g. Yang et al. 2011; An et al. 2012). As shown in the following case studies, variations in monsoonal moisture have played an important role in the development and disintegration of past civilizations across southern Asia.

15.2.1 Hydroclimatic Variability and the Decline of Angkor

The decline of the "hydraulic city" of Angkor, the capitol of the Khmer kingdom in Cambodia during the ninth to fourteenth centuries, has been the subject of great debate for over a century. In particular, there has been controversy over the causes, rate, and timing of Angkor's disintegration. The Khmer kingdom ruled over a large swath of continental Southeast Asia deriving much of its success by capitalizing on Summer Asian Monsoon rainfall to support complex agriculture, including massive irrigation complexes for which the ancient city of Angkor is renown. Given their elaborate irrigation systems, the Khmer would have been vulnerable to the vicissitudes of the monsoon; however until recently, few (if any) local records of past climate extended to the time of the Khmer, therefore studies of their demise have emphasized political, economic, and technological factors. Addressing this lack of paleoclimatic data, Buckley and others developed two tree-ring width reconstructions of past hydroclimate from the rare Fujian cypress, *Fokienia hodginsii*, that extended 979 years and covered the period of the Khmer kingdom (Buckley et al. 2007, 2010; Sano et al. 2008). Their reconstruction revealed that decades-long periods of weak Asian summer monsoons and related drought have occurred over the past millennium. One of these periods of weakened monsoon and drought in the mid- to late fourteenth century and another more severe drought in the early fifteenth century correspond to the time of Angkor's demise (Fig. 15.2). The fourteenth century droughts were referenced in historical chronicles of the time (Thera 1962) suggesting a direct impact on the Khmer, but the importance

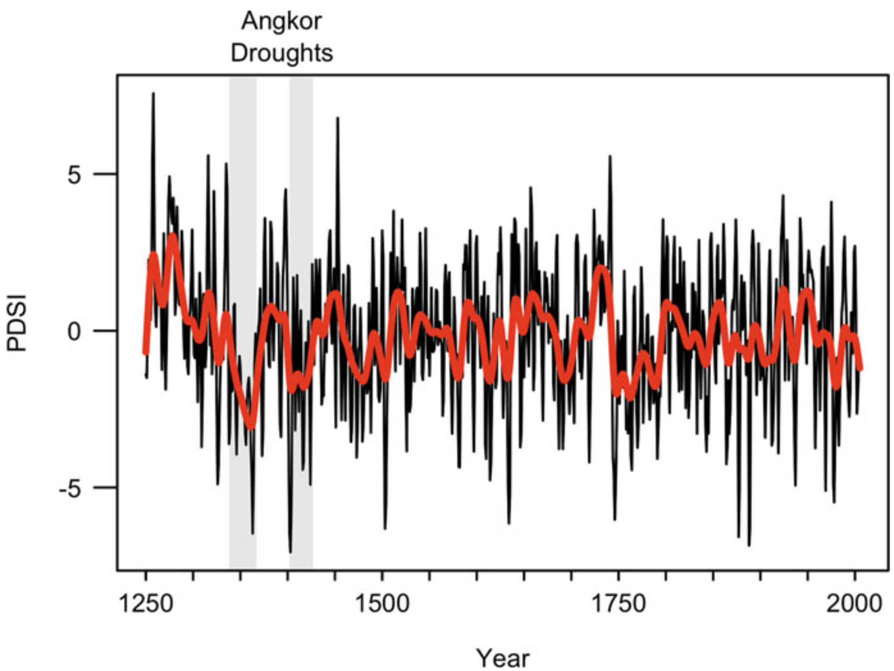

Fig. 15.2 Tree-ring reconstructed PDSI developed from *Fokienia hodginsii* trees in Vietnam (Buckley et al. 2010). The gray bars highlight the severe Angkor droughts of the mid fourteenth and early fifteenth centuries (adapted from Buckley et al. (2010))

of these droughts and intervening floods was not recognized until the *Fokienia* reconstructions were available.

Buckley et al. (2010) inferred that the complex nature of Angkor's canals and reservoirs, though highly adaptive, left the city inflexible and vulnerable to the droughts of the fourteenth and fifteenth centuries. Evidence of occasional extreme floods and depositional events in the canals during these droughts pointed to a suite of climatic conditions that pushed the hydraulic city beyond its adaptive capacity. Though previous archeological research on the canal building at Angkor suggested that the elaborate engineering had led to the decline of the city (Evans et al. 2007), it was the combination of annual tree-ring records, historical documents, and radiocarbon dated depositional material that allowed Buckley et al. (2010) to describe the precise timing of episodic floods and low flow that led to the failure of the irrigation systems. Following fourteenth and fifteenth century droughts and floods, the regional economic focus of the Khmer shifted from intensive agriculture to maritime trade, in part due to the climatic extremes, but also as a result of changing geopolitical forces and economic pressures. Rather than a single, deterministic "collapse" caused by drought, the Khmer appeared to have exhausted their adaptive capacity and realigned the empire in response to a combination of environmental variability and socio-political factors. The hydraulic innovations of the early centuries of the empire became maladaptive under monsoon failure, flood, and socio-economic change. The limits of innovation under multiple environmental and social stressors is a critical inference highly relevant to today's social and environmental challenges.

15.2.2 Spatial and Temporal Context of the Late Victorian Drought

The monsoon failures and associated droughts that were critical for the development and the disintegration of the Khmer, affected Monsoon Asia repeatedly in recorded history with massive consequences for millions of people dependent on seasonal rainfall for agriculture. During the late Victorian drought of 1876–1878, up to 30 million people are thought to have died across Monsoon Asia when the monsoons failed repeatedly. To what extent was this famine caused by climate versus major socio-econmic changes after centuries of colonialism? By the late 1800s, colonial-era imperialism had disrupted local food production throughout the region leaving communities highly vulnerable to local environmental stress and the fluctuations of distant markets (Davis 2002). The late Victorian drought occurred during one of the most severe El Niño events of the last 150 years (Davis 2002) and strong El Niño events have been linked to monsoon failure (Walker and Bliss 1932; Maraun and Kurths 2005) suggesting a possible climatic driver. However, scarce and patchy instrumental records made it difficult to place this historic drought and associated famine in context given the relatively short instrumental record. Longer, spatially explicit records of the monsoon and its drivers were needed to assess the relative contributions and interactions between monsoon failure and colonial-era disruptions in local food production and labor.

Until the development of the MADA (Cook et al. 2010), there was little understanding of the long-term spatiotemporal dynamics of the Asian Monsoon and its mechanistic links to ocean-atmosphere conditons. The MADA is comprised of a network of 327 tree-ring sites covering the last 1000 years arranged in a gridded reconstruction of PDSI (Palmer Drought Severity Index) over the Monsoon Asia Region. The chronologies used in MADA, largely derived from trees in the monsoon and transitional regions, preserve an integrated signal of summer monsoon soil moisture (June–August), critical for agricultural productivity. The MADA yields a seasonal- to centennial-scale view of monsoon failure appropriate for not only understanding Pacific forcing factors, but also the significance of monsoon failure for society and its interactions with colonialism. According to the MADA, the Late Victorian drought ranks as one of the most severe in the last 600+ years and covered nearly all areas of Monsoon Asia (Cook et al. 2010). Though sea surface temperatures (SST) of the eastern equatorial Pacific were elevated, the pattern is not clearly one of a strong eastern Pacific ENSO event, but could have been connected to SST anomalies in the extratropical North Pacific typical of the Pacific Decadal Oscillation.

The late Victorian drought was not simply a climatological event, but an important interaction between climate and society. For example, Davis (2002) argues that in India, more than a century of colonial British rule had led to: dependence of local agriculturalists on distant food sources, loss of local labor, lack of investiment in water management, and low prices for tropical commodities due to global competition. All of these forces undermined local food security. These social and economic changes increased the vulnerability of agricultural communities to climate extremes and amplified the effects of the droughts resulting in famine on a continental scale. In China, a slow bureaucratic response to the drought may have further exacerbated its effects (Davis 2002).

Cook et al. (2010) demonstrated the extreme nature of the Monsoon failures during the Late Victorian drought. By documenting the severity of the drought in a multi-centennial context, the MADA allows more precise questions to be asked about how the severity and mechanisms of drought may interact with colonialism and other human enterprises. For example, how did the spatial scale of British Colonialism overlap with the scale of monsoon failure to engender such human tragedy? Did droughts of similar extent and severity, but under different socio-economic conditions, produce massive famines in the past? Recent analysis of multi-proxy paleoclimate data suggests that the ninth to thirteenth century Chola kingdom of southeast India could sustain itself under variability in the South Asian and Southeast Indian monsoon by making major investments in water storage, while other local kingdoms weakened under drought (Shanmugasundaram et al. 2017). However, no paleoclimate data sources are available proximal to the Chola kingdom itself, preventing the seasonally and spatially precise inferences that emerged from studies of the Khmer and the late Victorian droughts. As the spatial and temporal extent of the MADA are improved, the variety of human and environmental adjustments and responses to monsoon failure and flooding will be better resolved and may point to paths of resilience for modern societies facing climatic extremes in Monsoon Asia.

15.3 Arid Central Asia

Arid Central Asia comprises the arid regions of the continent that experience continental and extreme climates, including Inner and Outer Mongolia, Tibet, northern and western China, Kazakhstan, Uzbekistan, Kyrgyzstan, and Tajikistan. In this region, the westerlies dominate moisture transport; however, hydroclimatic variability is complex, in part due to significant topographical features. Arid Central Asia was home to several spatially extensive nomadic empires beginning with the Scythians in the eleventh century BCE and continuing through the thirteenth century Mongol Empire. These empires were developed by various ethnic groups that expanded to cover large expanses of the Eurasian steppe. They adopted diverse strategies to address the extreme variability in moisture and productivity typical of the steppe. Some of these strategies included a nomadic lifestyle, widespread trade, and diversified economies. More recently, this region has experienced rapid changes in climate that have affected agriculture, productivity, and fire regimes in concert with rapid social and economic changes.

15.3.1 Dendroarcheology and the Development of Ultra-Long Chronologies from Arid Central Asia

Arid Central Asia has a long and fascinating human history that includes the domestication of the horse, the rapid spread of nomadic pastoralism, and mounted warfare—innovations that have occurred during the last 4000 years. A key challenge for dendrochronology in Asia then is developing ultra-long chronologies capable of characterizing the climatic conditions under which these developments in human societies occurred. There are several ongoing efforts to develop such chronologies by combining long-lived trees, remnant wood, and archeological timbers (Zhang et al. 2003; Panyushkina et al. 2007, Myglan et al. 2008, 2012a, b; Shao et al. 2010). These efforts have resulted in the absolutely dated and floating chronologies of *Larix sibirica* from the Altai and the absolutely dated *Sabina* (*Juniperus*) *przewalskii* chronologies from the Qinghai-Tibetan Plateau. These efforts have faced challenges associated with developing long climate reconstructions from archeological timbers. In particular, the samples used for calibration must be sensitive to the same environmental factors as the archeological timbers. Further, the archeological timbers often produce short segments, limiting inferences about low-frequency climate variation (Cook et al. 1995). Nevertheless, with careful sampling and assessment, climatic inferences can be made. In addition, absolutely dated chronologies can be used to more precisely date archeological sites thus helping to define the timing of important developments in human societies. In combination, data about climatic context and timing of historical/archeological events will likely yield exciting discoveries in coming decades, especially regarding the spread of pastoralism across Arid Central Asia.

The Siberian Scythians were a group of seminomadic tribes that occupied the Altai-Sayan Mountains during the first millennium BCE, part of the much more widespread Scythian culture that extended from the Black Sea to Lake Baykal. Horseback riding and pastoralism were among the economic strategies that allowed the elite Siberian Scythians to establish distant trade networks, slaves, and lavish goods, all preserved in stone burial mounds called “kurgans”. Wooden chambers inside the kurgans have provided the means for developing well-replicated floating chronologies that can be more precisely dated using radiocarbon wiggle-matching where crossdated but floating tree-ring chronologies help constrain C-14 dates (Panyushkina et al. 2007, 2013, 2016). When combined with details of the modern growth of *Larix sibirica*, these chronologies can not only describe the timing of multiple burials relative to one another, but also broadly characterize the climate during periods of population growth, contraction, and out-migration.

In the Russian Altai region, Panyushkina (2012) suggests that the Siberian Scythian Pazyryk culture of 700–250 BCE responded positively to colder temperatures and increased climatic variability. For example, she observed population growth during cold periods and contractions during warm periods. High variance in tree growth corresponded to increased mobility as documented by the archeological record, possibly resulting in the development of transhumance, a form of pastoralism where people and livestock move to fixed seasonal pastures. Though these inferences may seem counterintuitive when compared to the history of agricultural societies, which arguably benefitted from warmer, more stable conditions (Büntgen et al. 2016), in the context of pastoral nomads, these conclusions are logical. Cold conditions improve mobility on the steppe, particularly for horses. Increased mobility in pastoralists is an economic strategy that increases the net primary productivity pastoralists can extract from the steppe (Honeychurch and Amartuyshin 2007) and may also increase access to trade networks. Though still preliminary, this work on nomads and the contrasting relationships for sedentary agriculturalists strongly argues for place- and culture-specific interpretations of the relationship between climate and society.

While the wiggle-matching approach can be used when chronologies are floating, the ultimate goal for Arid Central Asia is the development of ultra-long absolutely dated chronologies. A major breakthrough in the absolute dating of Siberian Scythian sites occurred in 2012, when an international group of archeologists and dendrochronologists were able to bridge a gap between archeological wood from the Pazyryk (Scythian) culture (600–300 BCE) and remnant wood from the Russian Tuva region (360 BCE–2007 CE) (Myglan et al. 2012a). This effort resulted in a

2367 year long tree-ring record that instantly yielded calendar dates of 35 kurgans from 11 different sites. Further, the results were within a single year deviation from the calendar dates derived from the C-14 wiggle-matching method (Panyushkina et al. 2016). Future work to extend these chronologies using archeological samples has the potential to provide the climate context of the spread of pastoralism across Arid Central Asia—a potentially transformative contribution to the study of human-environment relationships.

Similar efforts have been made to develop ultra-long tree-ring chronologies of *Sabina przewalskii* using living trees, remnant wood, and archeological timbers from the Tibetan Plateau. Wooden beams from several Xiatatu tombs of the Tubo Kingdom in Guolimu County, Delingha City, Qinghai Province, China were used to extend a living and remnant wood chronology to 2332 years, allowing for calendar dates of the tombs themselves (Wang et al. 2008). However, *S. przewalskii* has a mixed climatic signal, responding positively to both precipitation and temperature, making climatic inferences, particularly from the archeological specimens, challenging. At low elevations, *S. przewalskii* is primarily sensitive to spring moisture (Zhang et al. 2003; Sheppard et al. 2004), while at high, treeline locations, modern *S. przewalksii* are more sensitive to summer temperature (Liu et al. 2009). Therefore, one must infer the original growing location of the archeological samples in order to use them as a climate proxy. Despite the challenges of extracting a climate signal from *S. przewalskii*, it has been invaluable in providing a chronology for archeological sites (Wang et al. 2008). *Sabina przewalskii* will continue to provide an important record of environmental variability on the Tibetan Plateau, a region with a complex and dynamic human history that interacted politically and economically with distant empires in China and the nomadic empires of the Mongolian steppe.

15.3.2 Climate and Environment of the Mongol Empire

Despite centuries of study, the success of the thirteenth century Mongol Empire remains enigmatic. In less than a century, the Mongols developed an empire that claimed areas from the Hungarian grasslands to current day Syria, Baghdad, Vietnam, and Japan. Powered by domesticated grazing animals, the empire grew at the expense of sedentary agriculturalists living on the edges of the Eurasian steppe. The Mongol conquests affected the history of civilizations across China to Russia, Persia to India, as well as that of Christianity and Islam, even leaving a genetic fingerprint on the people of Eurasia (Zerjal et al. 2003). Historical sources suggested that the Mongols expanded their realm as a reaction to the extreme droughts typical of the steppe (Toynbee and Somervell 1947), though no paleoecological data from the Mongolian steppe were available to evaluate this hypothesis until Pederson et al. (2014) made a fortuitous discovery of ancient wood on a Holocene lava flow in central Mongolia. Their annually dated record of soil moisture from annual ring widths (900–2011 CE) clearly showed a rapid change from extremely dry conditions

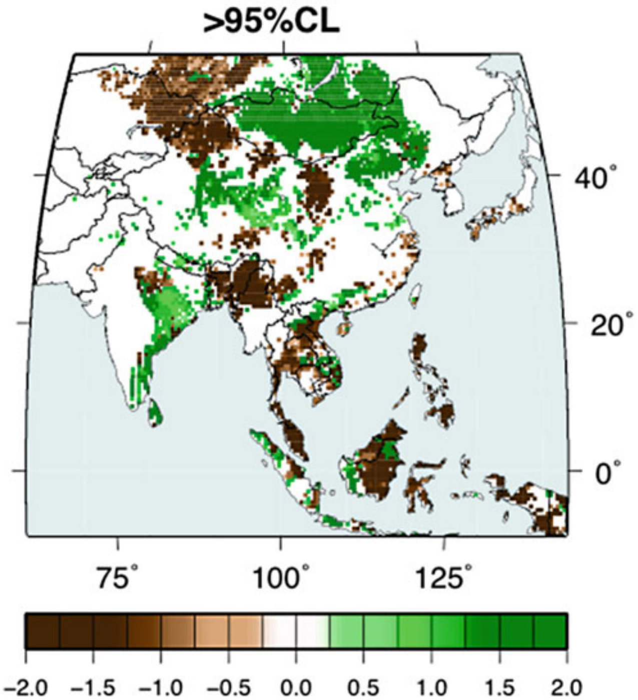

Fig. 15.3 MADAv2 reconstruction of scPDSI using a 0.5° grid and a 1000 km search radius during Mongol pluvial (1211–1226 CE). Areas in color are within the 95% confidence interval. scPDSI values are dry when negative (*brown*) and wet when positive (*green*)

in the 1100s to consistently wet conditions in 1211–1226 CE (Fig. 15.3). This short period represents the most persistent pluvial in their 1100-year reconstruction and coincides with the historical record of Ghengis Khan's rise to power and period of most rapid expansion of the empire.

During this remarkable period of environmental stability and high grassland productivity, the steppe would have supported large numbers of domesticated grazing animals and horses, which may have given the mounted Mongols an advantage over their neighbors. This productivity would have also allowed for the well-documented concentrations of animals and warriors that convened on the central Mongolian steppe prior to invasions. However, as the Mongol empire expanded its reach and its trade networks, the influence of climate would likely have become less important, eclipsed instead by political and economic factors.

Similar arguments about climate and environment have more recently been proposed to explain the rapid withdrawal of the Mongols from Hungary, though in this case, short-term climatic and environmental conditions may have constrained the Mongols and their horses (Büntgen and Di Cosmo 2016). Warm, wet conditions during spring of 1242 CE reduced the mobility of the Mongols in the swampy terrain of the Hungarian steppe and limited access to pasture and food in a landscape already decimated by war. In both cases, the rise of the Mongols and their withdrawal from Hungary, accurate dating of tree-ring records located proximal to the center of human action and the well-demonstrated relationship between tree growth and grassland productivity allowed historians to make new inferences about the role of grassland productivity and environmental conditions in enabling and constraining the development and spread of the Mongols. These new inferences are dependent on the precise timing of climatic phenomena and their direct connection to environmental constraints under which human actors made decisions. However, the differential effects of similar climate conditions (both were affected by wet conditions) on historical events highlight the importance of place- and time-specific context of human-environment interactions.

15.3.3 Environmental and Economic Synergies in Modern Mongolia

Tree-ring records of past climate and environment can not only help us understand human-environment relationships of past societies, but also contextualize modern events, policies, and institutions. Evaluating past hydroclimate relative to recent climatic conditions is essential for understanding the natural range of moisture variability in a region, and can be useful for water resource managers when preparing for water usage in the future (Woodhouse et al. 2006). Tree rings have been particularly successful in placing recent changes in hydroclimate in context both because of their ability to integrate water availability at the scale of a watershed and because they allow water managers and water users to view past hydroclimate at a time increment relevant to current management. Agriculture and mining, both growing sectors of the Mongolian economy, accounted for 35% of Mongolia's GDP in 2014 (NSO 2014). The sustainability of these water-demanding practices has recently been called into question, especially in light of well-documented climate change in Mongolia (Priess et al. 2011; Karthe et al. 2014).

Agriculture has increased rapidly in Mongolia over the past several decades, particularly in the northcentral region of the country due to elevated moisture as well as opening of markets in 1992. Both Selenge and Yeruu River streamflow reconstructions in the "Mongolian Breadbasket" indicate that the twentieth century was the wettest over the past three centuries (Pederson et al. 2013; Davi et al. 2013), possibly enabling agricultural expansion. However twenty-first century conditions may be drier and warmer than in the past 2000 years, suggesting that the last few decades of moisture were extremely unusual (Pederson et al. 2014) and future warming could pose serious constraints on Mongolia's growing agricultural sector.

The recent extreme variability in hydroclimate in Mongolia would also suggest rapid increases in fire occurrence, given the strong relationships between drought and fire in other semi-arid forest regions (Swetnam and Betancourt 1998; Westerling et al. 2006; van Mantgem et al. 2013). Instead, fire activity in Mongolia has closely followed changing sociopolitical and economic transitions (Saladyga et al. 2013;

Hessl et al. 2016). Where grazers and fire compete for grass, drought may reduce fuel continuity and volume, preventing the spread of fire and reducing fire activity (Bond and Keeley 2005; Hessl 2011). This effect was particularly strong following the opening of Mongolian markets to capitalism in 1992. Since that time, total livestock numbers have more than doubled, from 25 million animals to more than 50 million in 2014 (Hessl et al. 2016). In the decades following Mongolia's democratic revolution and adoption of capitalism, herding animals became concentrated around the capital city of Ulaanbaatar reducing and sometimes eliminating fire activity from locations with centuries-long histories of fire (Saladyga et al. 2013). Though warming temperatures have significantly altered Mongolia's climate since at least the 1940s, human-environment interactions due to sociopolitical and economic factors appear to have overriden climatic factors to shape the Mongolian landscape (Fernandez-Gimenez 2000). These results have implications for fire and climate change in other grasslands with high-intensity grazing and, conversely, where grazers have been removed from the landscape.

15.4 Future Steps

Many of the aforementioned studies describe linkages between humans and their environment over relatively short periods of time or small spatial scales. Some recent efforts, however, have focused on the relationship between climate variations and cultural changes over continental or hemispheric scales. In particular, changes in temperature over much of the northern hemisphere have been cited as an important impetus for societal catastrophes in the past. For example, Büntgen et al. (2016) investigated the impacts of the "Late Antique Little Ice Age" (536–660 CE), a distinct period of cooling across Europe and Asia initiated by extensive volcanism and supported by land-ocean feedbacks and a solar minimum. This cool period coincided with notable societal hardships, including reduced agricultural activity, empire collapse, invasions, and mass migrations suggesting a linkage between cold conditions and social instability. Similarly, Liu et al. (2009) used long tree-ring records from the Tibetan Plateau to suggest that historically cold periods were associated with dynastic collapses in China over more than two millennia. They argue that these collapses are indirectly linked to low temperatures, which are associated with reduced crop output, famine, and subsequent societal unrest. These broad-scale assessments may be the direction that human-environment studies will take in the future, but they will need to address concerns about the discrepancy between the scale and proximity of the proxies relative to the cultures those variables are said to affect, the differential responses of societies to environmental changes, and the role of human agency in mitigating, adapting, and amplifying environmental change.

Whereas many human-paleoenvironment studies qualitatively compare historical events with extreme climatic conditions, efforts have been made to explicitly quantify these relationships. Zhang et al. (2007) used correlation analyses to identify relationships between temperature, and socioeconomic measures, such as agricultural production, population size, and the number of wars across Europe and Asia. For example, they found that cycles of war and peace were related to variability in northern hemisphere temperatures, where the number of wars and temperature were inversely correlated. Similarly, Zhang et al. (2011) investigated the causal relationship between climate and crisis in Europe from 1500–1800 using 16 socioeconomic and demographic variables. They used correlation and causality analyses among these factors, in conjunction with social theories, to elucidate the effects of climate change on ecological and human systems. Effectively marrying ecological, climatological, and historical inferences remains an important challenge, and one that will likely be explored further in the future. Quantifying the relationship between humans and their environment is challenging given the inherent differences of these systems and their complex interactions. Further, identifying the appropriate metric of human response is also a challenge since human demographics and historical events are not necessarily consistently recorded over time and may contain significant bias. Nevertheless, identifying models of human interaction with the environment that have predictive power is a tantalizing proposition that could help us understand current responses to climate change.

Although annually resolved tree-ring data provide climate information relevant to discrete historical events, an understanding of lower frequency climate variability, and its drivers, could provide useful information on longer time-scale processes, for example the spread of pastoralism across Central Asia. Additionally, other proxies from tree rings, including anatomical wood properties, and newly developed methods (e.g. image analysis), have yielded new insights in other regions (e.g. Fonti et al. 2010; Drew et al. 2012; Björklund et al. 2015; O'Donnell et al. 2016) and should be further explored in Asian tree-ring records. Multiple proxies, including ice cores, speleothems, tree rings, and sediment records, may be used to gather information on multiple time scales of paleoclimatic variability, while still taking advantage of the calendar dates provided by tree-ring records. For example, paleoclimatic records capturing hydroclimate over longer periods than tree rings show that moisture variability in Arid Central Asia and Monsoon Asia are out of phase over multi-centennial and millennial time scales (Chen et al. 2008; An et al. 2012), a climatic inference that may have had interesting effects on the interactions between societies across Asia in the past. An assessment of these processes and how they might persist or change could have important implications for future climate and economies across Asia.

15.5 Conclusions

Paleoenvironmental data, and dendrochronology in particular, can illuminate the complex and variable environmental histories that constrain and enable human actors. The case studies reviewed here support the variable and diverse nature of human-environment relationships, suggesting that similar climatic conditions can affect societies and cultures differently and can even have opposing effects at different times on the same society. Recent efforts to expand the study of human-environment relationships to broader spatial scales or across time using quantitative methods are still in their infancy, but will need to respond to critiques about the applicability of distant proxies to local conditions, differential effects and responses of cultures over time, and the ways in which climate interacts with other stressors. Future efforts in assessing human-environment interactions might take advantage of the existing paleoenvironmental data from a variety of sources to more fully characterize past climatic variability and its influence on environmental and human systems. Many critical questions about the past and future of Asia remain—in particular, the role of human institutions like colonialism in amplifying or dampening monsoon dynamics, the role of climatic variability/stability in the spread of pastoral nomadism, the effect of the dipole in moisture across Arid Central Asia and Monsoon Asia on interactions between societies, and the complexities of modern climate and environmental change in the context of rapid socio-economic development across Asia. With precision calendar dates, high fidelity to climate, and multiple millennium-long proxies relevant to the human enterprise, tree rings will undoubtedly play a critical part in answering these questions.

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