Week 1

1) Describe three types of paleoproxy data scientists use to reconstruct Earth's climate history.

One of the most important tools for scientists working in paleoclimatology is proxy data, the preserved physical characteristics of an environment that can be examined to piece together a better understanding of the history of climate. These types of proxy data are various and sundry, but key sources of proxy data are corals, ice cores, and tree rings. Corals are useful because, as they grow, their skeletons are constructed from calcium carbonate, which contains oxygen isotopes and trace metals, both valuable pieces of information that can be utilized to glean the temperature of the water at the time of that growth. Mapping these temperature recordings provides the ability to reconstruct the climate of that area over time. Ice cores are typically retrieved from the two poles of the Earth, where ice has built up for millennia, providing scientists with differing layers containing dust, air bubbles, oxygen isotopes, and other historical traces. Much like the information that can be derived from corals, ice cores, with their layers differing year by year, provide vital information on the climate history of a region in terms of temperature, precipitation, atmospheric composition, wind patterns, and volcanic activity. Tree layers, similarly, have rings instead of layers, but provide information through the variance in width, density, and isotopic composition from ring to ring. Tree growth is influenced by climate conditions, and being that tree rings are indicators of that growth, they help to paint a picture of the climate conditions of a region during a tree's lifetime.

2) Describe how climate conditions change between glacial and inter-glacial times.

Glacial periods in Earth history are generally referred to as "ice ages," remarkable time periods during which large ice sheets cover the Northern Hemisphere. When these ice sheets "retreat," so to speak, the Earth enters an interglacial period, which, as the term would indicate, refers to time periods between glacial periods. What we live in now is an interglacial period; specifically, we live in the Holocene. Research into the exact causes of transitions between these two states is ongoing, but it is believed by scientists that times of peak solar radiation are responsible for the transition to interglacial periods, further influenced by processes within the climate system (NOAA, 1). As the Earth shifts between the two states, climate dramatically changes; glacial periods generally see colder temperatures and interglacial periods see comparatively warmer temperatures. The stark shift from glacial to interglacial temperatures can be explained with the positive feedback system linking greenhouse gases and global temperatures. When a large enough increase in solar energy input occurs as a glacial period nears its end, CO2 and other gases trapped in melting ice enters the atmosphere and increases the greenhouse gas concentration, thus increasing temperatures further, which thereby increases the greenhouse gas concentration and on and on. This is a conclusion drawn by scientists after research into the climate records of both Greenland and Antarctica, two locations which gave vital insight into the effects of methane on Northern hemisphere climate variability and CO2 on Southern Hemisphere climate variability (Niels Bohr Institute, 5).

3) Compare the early lifestyles of hunter-gatherers and agricultural groups of people in terms of mobility, obtaining food, obtaining other resources (e.g., water, shelter, etc), and susceptibility to changes in climate.

Prior to the rise of sedentary civilization, humans lived nomadic hunter-gatherer lifestyles. The birth and spread of agriculture significantly altered the lifestyle of humans, transitioning the species to a more settled lifestyle. While the hunter-gatherer forebears moved frequently out of necessity, seeking out vital resources (food, water, and shelter), tracking prey, and moving as the weather required, agricultural groups lived primarily in one location permanently. These agricultural groups, in order to cultivate their food properly, stuck around for the entire year to see through to the end the planting, growth, and harvest of their crops (and later, following domestication of certain species, livestock). Those more nomadic members of the human race retained their mobility, and therefore retained their freedom from the vices of settled society, among which was susceptibility to climactic change, being able to relocate as needed when the climate began to shift. Agricultural groups have proved largely inflexible in early human history, yielding not at all to changing climate until it is much too late, as was the case for the Maya of Central America, who failed to adapt in the face of a drying climate and depleted soil (Sohn, 13). Though

agricultural groups were indeed more susceptible to the effects of climate changes, such as decreased precipitation and increased temperatures harming crop production and therefore survivability, nomadic hunter-gatherers could also suffer as once constant sources of food and water grew more scarce; changes in the climate, for example, may have led to one species of prey migrating further away to more favorable conditions, requiring the hunter-gatherer group to shift its own migration patterns accordingly. Later developments, however, would alter how susceptible humans were to climactic changes; the ingenuity of the human mind would lead to the creation of technologies for sedentary peoples to more ably undergo climactic changes, such as the silo pit, which was used by various groups (e.g. usurers in ancient Anatolia and Persia) to store grain in anticipation of seasons of dearth (Beedle, 2). Despite the advances made by early humans, a steady climate remained a prerequisite for this agricultural, sedentary lifestyle. The onset of predictable weather patterns 11,500 years ago is contended to have been an important factor in giving birth to complex civilizations (Sohn, 9). As such, any changes in climate and weather patterns could lead to disaster for agricultural humans. Certainly, however, there were benefits and detriments to each lifestyle for early humans, be they hunter-gatherers or agriculturally subsisting, and these benefits and detriments affected their respective abilities to survive changes in climate.

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Week 2

1) How did the Younger Dryas climate event around 12,000 years ago influence Natufian lifestyle?

The Younger Dryas climate episode represents a relatively brief, but abrupt and impactful, period of general cooling climate conditions back to near glacial conditions, interrupting the shift to warmer interglacial climate conditions ("The Younger Dryas", 1). During the time preceding the Younger Dryas, the Natufian people of the Levant thrived on the newly abundant wild flora and fauna of the arid steppes, hunting and gathering the native animals and vegetation. The Younger Dryas' arrival abruptly forced the Natufian hunter-gatherer society to relocate to more suitable conditions as the colder climate reduced the once plentiful resources to a mere pittance. What was most significant about the shift necessitated by the climatic change was that subsistence by simple hunting and gathering of what roamed and grew wild was no longer feasible; instead, the Natufians both literally shifted their physical location and also shifted their lifestyle towards one of intentional cultivation of what cereals and vegetation they transferred along with them. This began a sedentary, settled, agricultural existence in the areas surrounding their former stomping grounds in the Levant.

2) What factor(s) drove the migration of the Natufian into southern Mesopotamia shortly after 6400 B.C. (~8200 radiocarbon years before present)?

As early agricultural civilization developed and evolved, humans practicing farming became ever more reliant upon agriculture and ever more vulnerable to changes that would affect that agriculture. Eventually, farming was so integral to culture that few were willing to return to a life of pastoral nomadism, so when the climate became drier and cooler around 6400 B.C., much of the Natufian culture elected to move towards more favorable conditions to continue their agricultural lifestyle. Drier, cooler conditions reduced precipitation, which northern Mesopotamian farming relied upon for watering the crops, for the most part (Weiss and Bradley, 5). As rain became scarcer, migration became a necessary option, and so many traveled south to restart. This was, in the end, a fortunate development, as the move to the south precipitated (hah, what a pun) a shift to irrigation agriculture along the Tigris and Euphrates rivers, much more difficult but also much more productive than rain-fed agriculture (Weiss and Bradley, 6).

3) Describe the difference between rain-fed farming and irrigation farming. How did the shift to irrigation farming influence Natufian civilization, in terms of crop production and social construct?

Rain-fed agriculture is not nearly as bountiful in its product as irrigation agriculture, despite being less labor-intensive on the whole. By being forced to shift towards irrigation agriculture, the Natufians achieved something truly great, which was the production of (comparatively) enormous food surpluses, which enabled the true development of civilization to begin (Asayehegn, 28). How? By enabling specialization. Irrigation agriculture led to more food being grown by fewer people, which led to those not employed by the demands of food production in Natufian society to take up specialized roles, such as pottery production, construction, and other jobs (Weiss and Bradley, 4). This would develop and evolve Mesopotamian civilization into the ancient cities we now know it for.

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Week 3

1) How did the early Moche use engineering to overcome the limitations of their naturally arid environment?

The Moche preceded the Inca not only in terms of physical location but also in terms of establishing a legacy of engineering expertise. Unlike the primitive agricultural societies of the Neolithic that we have already discussed, Moche agriculture employed far more sophisticated techniques to expand both food production and raw material production for other purposes. Living in a somewhat favorable topography with access both to the Pacific Ocean and the mountains, the Moche utilized Andean runoff, channeled by long canals, to irrigate vast fields in the Lambayeque floodplain (Alva & Donnan, 2). These fields were also organized with complex irrigation systems and divisions to maximize canal water use and crop production. Huge amounts of grain for food and cotton for textile were produced as a result. Even when conditions grew less favorable and crop production fell in the 6th century as the climate changed, conservation of grain resources and continued fishing production sustained the Moche civilization until El Nino struck (BBC, 16)

2) Describe the extreme climate events that occurred around 560 to 650 AD along the northern coast of Peru. How did these events impact Moche civilization, and what evidence/data are used to support that these climate events occurred.

As the Moche entered the 7th century, what they needed was water for irrigation to replenish their depleted grain supplies, and they certainly got water. The 7th century El Nino events, while they brought plenty of water, brought warm water, crashing the fisheries as conditions became less sustainable for anchovies. The abundant rains that followed flooded the canals, destroyed irrigation networks, polluted water supplies, and decimated fields, harming crop production instead of helping it. Despite this, the Moche soldiered on, it seems, introducing hardier maize varieties, rebuilding irrigation networks, and repairing the cities, things we know about from discovered archaeological evidence; at least, they did so until earthquakes struck. Already in a precarious position, the Moche eventually collapsed in the 8th century, the 30 years of Mega El Nino followed by 30 years of drought having been too much (BBC, 17), weakening the civilization to the point that typical human vices could bring it to a final end (BBC, 23).

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Week 4

1) Describe the three paleoclimate proxies used as evidence of drought around the time of the decline of the Mayan civilization.

In order to corroborate the idea that a period of drought coincided with the Mayan collapse, paleoproxy evidence, including stalagmites, lake sediment cores' oxygen isotopes, and lake sediment sulfur levels. Stalagmites were utilized by researchers led by anthropologist Douglas Kennett in Belize because they were a much more well preserved piece of proxy data for them to use in their studies of the Mayan collapse (Kluger, 5). Because their rate of development is known, they could connect each 0.1 millimeter to roughly 0.5 years, and then they can examine the oxygen isotopes present to form a very fine picture of Mayan climate history. Other evidence has been used by researchers to reconstruct the climate of the Mayan collapse, including lake sediment cores collected from across the Yucatan (NOAA, 3), from which both sulfur levels and oxygen isotopes were used to track changes in climate. Oxygen isotopes prove valuable because periods of strong evaporation leads lake water to become enriched in oxygen-18. Sulfur levels prove valuable because evaporation concentrates sulfur in the lake water, thereby matching variations in oxygen isotopes, enabling data to be corroborated.

Even though the Mayan collapse was likely due to a confluence of unfortunate factors, including overpopulation, deforestation, disease, and El Nino events, the prolonged drought certainly had a disastrous effect on the Mayan civilization as they neared their final years.

2) How did deforestation serve to enhance drought conditions, and what were some of the other impacts of deforestation on the Mayan civilization?

It was already theorized that drought was one of the possible causes for the mysterious Mayan collapse (NOAA, 2), but researchers from Arizona State University and Columbia University decided to set out to prove Jared Diamond's theory that prolonged drought was exacerbated by deforestation. Looking at archaeological data from across the Yucatan, researchers discovered a correlation between rapid deforestation and severe reductions in precipitation (Stromberg, 3). Columbia University researchers developed a computer model to examine this further, running simulations to demonstrate how clearing of Yucatan forests for firewood and agricultural land drastically reduced rainfall across the land, exacerbating the effects of the already detrimental drought. Deforestation reduced precipitation because cleared land absorbs less solar radiation, and consequently, there was less evaporation and therefore less precipitation (Stromberg, 5). Besides reducing rainfall, deforested areas saw greater soil erosion and soil depletion as it was farmed and used with unsustainable practices. The subsequent failure of many farming endeavours in the lowlands diminished trade, driving many to abandon the area, which only diminished trade further until the entire land was abandoned.

What's interesting about the Mayan collapse is that they appeared to continue deforestation despite knowing its potential detriments on their livelihoods, raising questions about our own civilization's current trajectory.

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Week 5

1) Describe the impacts of the cool and wet climatic conditions in the Four Corners region at ~1300 years ago and ~700 A.D on Anasazi civilization.

The periods of cool and wet climate conditions were evidenced to researchers through examination of cave stalagmites, paleoproxy data which possessed thicker calcite bands in wet years. This evidence of cooler climate coincided with the emergence of maize cultivation in the Southwest until 300 AD, as well as with the rise of cliff-dwelling civilization and population growth in the 8th century (Labrador, 3). Thus, it is indicated that these conditions helped to promote the establishment of the Anasazi culture.

2) Approximately when did the Anasazi experience drought, and how did this drought impact their civilization.

Tree ring paleoproxy data has been used to establish that a terrible drought occurred in the modern day American Southwest in the latter portion of the 13th century. It is around this time that the Anasazi are believed to have collapsed. For approximately 23 years, there was very little to no rain in many Anasazi-inhabited areas. A drought had been experienced in the 12th century as well, but conditions this time appeared to worsen (Roberts, 10). The shifting climate, with so many unpredictable events in such a relatively short span of time, combined with a harsh governing structure, ultimately resulted in the development of paranoia and violence amongst the Anasazi culture that gradually tore the civilization apart (Roberts, 12). Perhaps after so many years of deforestation and depletion of the land's resources, the time had come (National Park Service, 13). Faced with drier conditions, dwindling food supplies, and a violent government, villages began to turn on one another in a bid to hold on to what resources they had left.

3) Describe two or three possible factors that could have influenced the Anasazi to flee their native lands.

Researchers presently agree that the environmental changes witnessed in the region was a major push factor that induced the Anasazi exodus (Roberts, 27). Drought, a drying climate, heat, and the ensuing chaos and violence that came with these poor conditions encouraged the Anasazi to leave, but other factors help to explain why abandoning their homeland would have been considered wise. Some theorize that the Kachina Cult's religious beliefs may have enticed the Anasazi to migrate to new lands based on evidence of Kachina imagery across the Southwest, but this has not yet been verified (Roberts, 28). This theory may hold some weight when considering other findings that suggest much of the migration was family- or clan-based, but it still requires further evidence to be considered seriously. Some also ponder whether Anasazi communities simply grew too large to be sustained, leading to internal strife that promoted migration. The mystery of the Anasazi exodus, while partially explained, still continues to be studied.

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Week 6

1) How did the purpose of irrigation systems in Angkor differ slightly from those of other civilizations we have examined in class? For example, did they serve only one function?

Other civilizations that we have examined throughout this course have primarily constructed irrigation systems as a means of stabilizing and maximizing agricultural production in settled areas. Angkor, similarly, constructed extensive and elaborate water management structure, partly for agriculture. It, however, differed, in that irrigation systems not only provided a vital agricultural service, but they were also critical to managing flooding and served to be emblematic of royal power (Lovgren, 10). Certainly, irrigation systems built by other civilizations could be multipurpose as well, but they were traditionally made with only agricultural needs in mind. Angkor's complex water management system was more important as a tool to control flooding and for the king to control the people. Angkor is wondrous now, and it was wondrous then.

2) Describe the sequence of drought and monsoons that impacted Angkor between ~1330 and ~1420.

Studies led by Brendan Buckley of Columbia University have attempted to explain the mysterious collapse of the Angkor Kingdom. Utilizing tree-ring data from the *Fokienia hodginsii*, the scientists reconstructed nearly eight centuries of the past climate of Angkor and the surrounding region. What this evidence revealed was that for three decades, beginning in 1330 AD, a mega-drought occurred, an event that would have been absolutely devastating for the local populace. That same evidence indicated that another severe, two-decade long drought occurred beginning in 1400 (Krajick, 4). Angkor, being a civilization reliant on complex irrigation and farming, would likely have been drastically harmed by both of these occurrences, experiencing crop failure and a possible rise in infectious disease as the dense population starved and grew weak (Krajick, 5). Furthermore, between these droughts, intense monsoon seasons likely inflicted much damage upon the Angkor irrigation network, which would have fallen into disrepair from disuse during the first drought. With extensive drought followed by destructive, intense monsoons, and with a final severe drought, it is no surprise that the Angkor Kingdom would have been sufficiently weakened as to collapse.

3) Two of the driest years in the last 760 years occurred in what years in Angkor? What climatic event originating in the Pacific Basin is correlated with these events?

1402 and 1403 were two of the driest years on record in the past eight centuries, occurring back to back as the final severe drought of the Angkor civilization got underway. Only a scant few decades after these dry aberrations, Angkor would collapse. When considering the unusually dry year of 1888 and how it was caused by that year's El Nino event, researchers theorize that it is likely for an El Nino event in the early 15th century to have similarly caused unusually dry conditions in Angkor's region between 1402 and 1403 (Krajick, 6).

4) In what way did the periods of mega-drought decrease the efficacy of Angkor's irrigation system during later times of monsoonal rains?

Years upon years of drought led to disuse of Angkor's hydraulic network, allowing buildup of coarse debris and sediment. When the monsoonal rains finally did arrive, this siltation would have led to terrible clogging and breakdown of the entire system. Given the intensity of the showers as well, dried-up areas and unmaintained sections of the irrigation system were also vulnerable to damage by the monsoonal rains as sudden erosion occurred. These instances of damage would have radiated out in their effects, exacerbating issues with entire sections of the irrigation system as failure was experienced at key points. Though it appears that Angkor attempted to reconstruct and reroute vital sections of their hydraulic systems, they ultimately failed (Krajick, 7).

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Week 7

1) What is an archipelago, and why are these regions particularly sensitive to climate change?

An archipelago is another term used to refer to a collection or chain of islands in a general geographic area. The Philippines, for instance, is an archipelago. Archipelagos prove uniquely sensitive to the vicissitudes of climate change, existing at times on the precipice of survivability, where even the most minute climatic change could prove immensely consequential. What arable land there is on these rocky masses could easily be turned useless by a shifting climate, the harsh conditions growing unfavorable for human habitation. There are only so many resources to use and so much land to retreat to as areas become inhospitable (Krajick, 4).

2) What are the general geographic regions of Viking culture and civilization?

The Vikings were certainly a multifarious people, in addition to being one of the most successful of their kind. Many of them raiders by trade, settlements were established all across Europe in places far from their homeland. Ranging far and wide from Northern Asia to the southern Mediterranean briefly to even the far northern coast of North America (Vinland), the Vikings

traversed a multitude of lands (Krajick 3). The Vikings first arose in Scandinavia, of course, centered around modern-day Norway. Over the centuries, they spread across Northern Europe and established many settlements, the most successful of which included those in modern-day Russia as well as in Britannia. Greenland and Iceland were colonized by Viking seafarers, as well.

3) Did the Vikings succumb quickly to changes in climate or were they more adaptable? Be sure to include specific examples from the reading this week.

Vikings, being such a varied group, had varied responses to a changing climate. Some were rather successful in how they dealt with changing conditions, adapting and surviving for many centuries. The Greenland Vikings, for instance, surprisingly endured for quite some time, in spite of how inhospitable Greenland is by its very nature. They apparently settled during a warm period, (Strickland, 23) but eventually fell victim to climate instability. Even during the Little Ice Age, however, the Greenland Norsemen managed to subsist for some time (Persson, 3). While many had previously believed these Vikings to have died out in short order, new studies have revealed that industrious, thoughtful use of the surrounding landscape and adaptation to the worsening conditions enabled survival for many decades. Andrew Dugmore of the University of Edinburgh asserts that the archaeological evidence demonstrates a gradual centralisation of power and resources and a shift towards trapping (Persson, 10). Eventually, however, they succumbed to a dwindling population resulting from the worsening climate conditions. It is telling, however, of Viking adaptability and resilience.

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Week 8

1) Choose an ancient civilization that interests you and discuss how climate either helped or hindered their success (or possibly both).

The Cahokia story has always been one of the more interesting to me. Such an impressive civilization with so much potential arising in North America, potentially capable of rivaling the Mesoamerican civilizations one day, so quickly coming to be then fading away. So what happened? Despite continued debate, some research indicates that the Medieval Climate Anomaly, an unusually warm period, precipitated the rise of a Cahokian civilization reliant on the production of corn; when the climate shifted back towards an abrupt cool during the Little Ice Age, they promptly collapsed. The dates coincide, and there is compelling evidence to support this theory. This is telling of how fleeting a civilization's success can be, and Cahokia is definitely a story I will continue to look in to.

2) Given the six civilizations we have explored in this class, what common threads intertwine most civilizations, in terms of climate? For example, what climate factors are humans, in general, most susceptible to, and how has our ability to overcome these challenges changed through time?

Humans, living in sedentary societies, are predisposed to a reliance on the natural weather patterns as they pertain to precipitation and heat, factors that must exist within certain limitations for extensive agricultural production to be viable. For a civilization to survive, a steady supply of food and water is key. As can be observed throughout recorded human history, many of the civilizations that have fallen as a consequence of climatic change have fallen due to the shocks to the food supply and all those effects that radiate outwards from that shock. The Maya, for instance, met with collapse throughout the entire lowlands as precipitation grew scarcer and scarcer, soil became depleted, and arable land ran out, leading to poor harvests, and, by extension, difficult conditions in the major trading centers of the region. Thus did trade proceed to break down as steady anxiety grew and spread, ultimately contributing to a break down of economic relations and the reemergence of violent competition over the scant remaining resources of the Mayan lowlands. In this way, the Maya were not unique. Similarly, the Moche culture, in light of poor weather conditions resulting from particularly nasty El Nino events, witnessed disastrous breakdown of agricultural production, leading to violent competition and tribalism over remaining resources. Developing more resilient food production technologies and systems has enabled our society to become more resistive to such shocks, but supply stocks are still ever so finite; should irreversible catastrophe occur, and food production dwindle, a Malthusian crisis may still certainly play out. It is true, we have more long-term supplies; we have better infrastructure, more productive crops, but there are limits on how far human ingenuity can go to make use of what we have.

3) How do you think modern humans are prepared to deal with a changing climate in terms of adaptability, mobility, population size and dynamics, resources, etc.

In many ways, the civilization of the present is far removed from all the civilizations of the past. But in many other ways, the ways that count, the civilization of the present is the exact same as our forebears. The exact same natural events that brought ruin to those who came before could easily bring ruin to our civilization should we fail to anticipate and provide for disaster. In fact, given the enormous scale of our civilization and the reliance of such a high percentage of sedentary people on such a low percentage of agricultural producers, even relatively minor events can have far reaching effects. Even the United States, for instance, was ill-prepared and able to deal with Hurricane Katrina's utter destruction of the lower Louisiana area. New Orleans' recovery was slow and tenuous, and it still will never be the same as it was in the time before. We have many fine systems and organizations in place that are designed to deal with the consequences of a changing climate, and all the crises that arise. Much as the old adage about the slowly boiling frog goes, however, will our systems be able to mitigate a large crisis when it's too late to reverse the situation? We can move hundreds, maybe thousands of people at a time, but what about millions? Our civilization is impressive, the most impressive to ever exist on this Earth, but civilization is and always has been a thin veneer, easily stripped away by nature inducing our basest reactions. How large populations react to the consequences of a changing climate will play a significant role in how well modern society handles the results of a changed climate. Our population centers are huge, and a small number of people are responsible for delivering many of these centers' resources; if these arteries are severed, it will be difficult to manage, to say the least.

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