

BIOARCHAEOLOGY OF ADAPTATION TO CLIMATE CHANGE
IN ANCIENT NORTHWEST CHINA

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ABSTRACT

Elizabeth S. Berger: Bioarchaeology of Adaptation to Climate Change in Ancient Northwest China
(Under the direction of Dale L. Hutchinson)

The 4000 BP climate event was a time of dramatic change, including a cooling and drying climate and the emergence of pastoral practices and a distinct cultural identity across northern Eurasia. However, the link between the climatic changes and the cultural changes has not yet been thoroughly explored. This dissertation therefore assesses human biological measures such as frailty, physiological stress, and nutritional status to ask whether late Holocene climate change precipitated a crisis and collapse of subsistence practices, as has been claimed.

The dissertation employs the theoretical framework of the “adaptive cycle,” an understanding of complex systems that incorporates both change and continuity. The dissertation asks whether the Bronze Age transition, in which humans adapted to the arid climate of the second and first millennia BCE, constituted a “collapse” or “transformational adaptation,” in which the human-environment system changed categorically; or an “incremental adaptation,” in which defining system elements persisted with only peripheral changes. Skeletal samples from six populations (spanning 2600-221 BCE) were examined for bioarchaeological markers of oral health, nonspecific infectious lesions, trauma, stature, and fertility. There was broad continuity and some improvement in population health measures in the Bronze Age study populations, with a decline in health in the Iron Age groups. Bronze Age subsistence systems therefore seem to

have been resilient enough to adapt to the new climate, while the sociopolitical conditions of the Iron Age led to poorer health outcomes.

The Bronze Age transition has often been described in terms of “collapse,” and by critically engaging with this narrative, the current project demonstrates that the transition in fact entailed an incremental adaptation, rather than a collapse. These findings also point to how sociocultural factors can serve as a buffer against environmental stressors in some groups, while themselves serving as stressors in others.

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CHAPTER 1 INTRODUCTION AND BACKGROUND

Bioarchaeologists have often focused on transitional times and places (Ventresca Miller et al., 2014). Consequently, the tools of the field, including paleopathology, paleodemography, and molecular methods of dietary reconstruction, have been used most intensively to investigate the origins of agriculture. This work has found that the impact of the agricultural transition on human health and population structure are not uniform across the globe (e.g., Cohen and Armelagos, 1984; Cohen and Crane-Kramer, 2007; Lambert, 2000; Larsen, 1997; Pinhasi and Stock, 2010; Steckel and Rose, 2002a).

In recent decades, a number of Chinese and international archaeological projects have turned their attention to the “Northern Zone” of China, which in the past was a transitional zone between China and the steppe. This area was once considered peripheral to the development of Chinese civilization, but recently, it has begun to be studied in its own right. As a point of contact between two apparently diametrically opposed ways of life, and the site of millennia of conflict between “the steppe and the sown,” it is a rich area of study for scholars of material culture, language, and bioarchaeology.

Within the Northern Zone, Northwest China (including the Hexi Corridor, the Tibet-Qinghai Plateau, and parts of the Loess Plateau and Inner Mongolia) is a particularly attractive area for research (Figure 1.1). It was an point of contact between eastern and western Eurasia even in prehistoric times: by the end of the 3rd millennium BCE, it was connected to a “old and well-oiled Asian trade network” (Anthony, 2009: 391), and was likely the route by which bronze

metallurgy, domesticated horses, and the cultivation of wheat and barley were introduced to East Asia (Di Cosmo, 2002; Flad et al., 2010; Frachetti et al., 2010; Garvie-Lok and Zhou, 2015; Han, 2008; Jia et al., 2013; Kahn, 2012). In historical times, it became part of the network of trade routes known as the Silk Road.

The Northern Zone, including the Northwest, was also one theater where the effects of late Holocene climate change on human culture played out. In the mid to late Holocene, the shift of the East Asian summer monsoon system led to greater climatic volatility and cooling and drying across the region. This period of dramatic and prolonged climate change is sometimes referred to as the 4000 BP climate change event. This is often cited as the cause of the Bronze Age transition to agropastoralism and later to the iconic highly specialized mobile pastoralism of Inner Asia (Han, 2008; Shelach, 2009), which has been less well-studied than the transition to agriculture (Gresky et al., 2016).

Northwest China in the Bronze Age was therefore transitional in two senses: spatially, it was a meeting place of civilizations and cultural exchange between West and East Asia; and temporally, it was the bridge between Neolithic agriculture and Iron Age pastoralism.

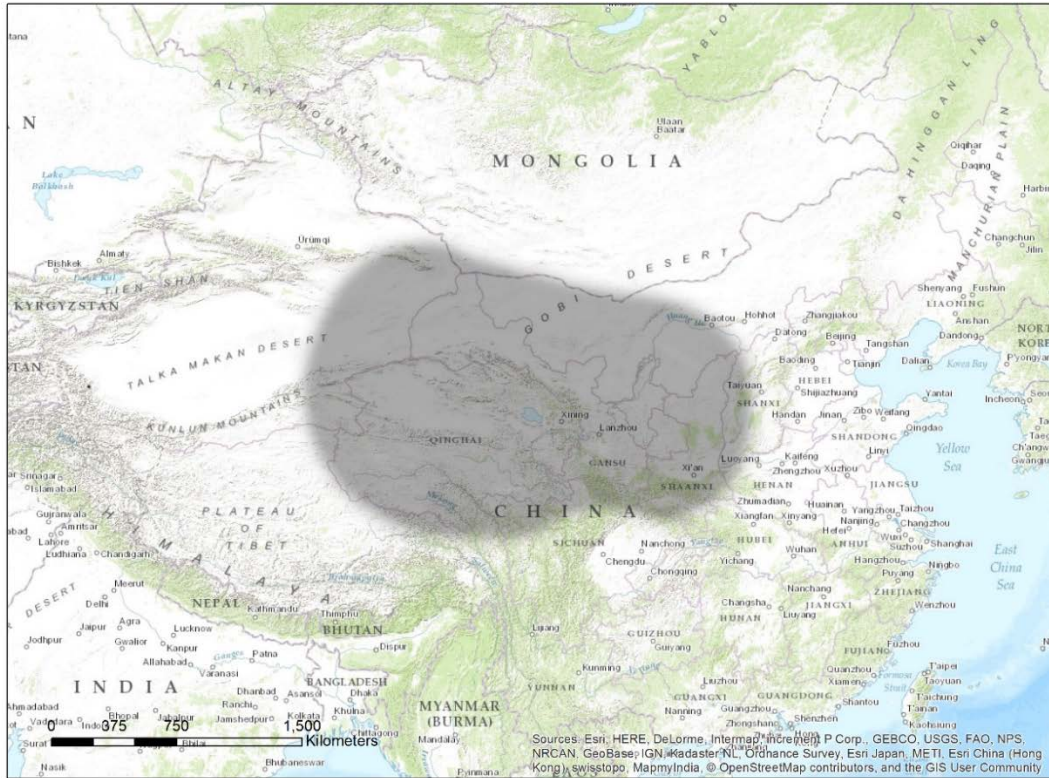


Figure 1.1 Map showing the approximate extent of Northwest China, in Xinjiang, Qinghai, Gansu, Ningxia, and Shaanxi Provinces

1.1 PROJECT RATIONALE

During the Neolithic (c. 6,000 BCE-2,000 BCE), populations across China's Northern Zone (including Manchuria, Inner Mongolia, the Ordos region, and the Gansu Corridor) practiced small-scale agriculture. Then, in the 2nd millennium BCE, populations in these regions developed an agropastoral way of life, relying on mobile or semi-mobile animal husbandry supplemented by agriculture (Han, 2008; Shelach, 2009). Meanwhile, populations in China's Yellow River valley developed a stratified settlement system and political structure reliant on irrigation agriculture (Liu, 1996; Liu and Chen, 2006; Liu, 2004; McNeill, 1976; Shelach, 2009; Underhill, 1994).

For the better part of a century, archaeologists of China have pursued the discovery and classification of prehistoric cultures within the country's borders. Though there are gaps in our understanding of the culture sequence and the forces that drove prehistoric change, the broad outlines of Northern Zone archaeological cultures are relatively well-understood (Di Cosmo, 2002; Gansu and Beijing, 2011; Han, 2008; Shelach, 2009; Xie, 2002). Other than material culture, however, certain elements of the Bronze Age transition are understudied. Quantitative paleobotanical and zooarchaeological data, possibly the most important in reconstructing ancient foodways (Marston, 2011), are almost entirely lacking for prehistoric Northwest China (Dong et al., 2015; Flad et al., 2007), though new and exciting work is ongoing. Human osteological data mostly consist of craniometric studies for the attribution of culture-historical groups to specific racial sub-groups (e.g., Han, 2001; Zhao et al., 2014; Zhu, 2002), though paleopathology and molecular analyses are now becoming more standard.

There have been numerous calls in Chinese and foreign publications to integrate data from multiple disciplines, and to fill in the gaps in our understanding of this period (Flad et al., 2007; Han, 2008; Shelach, 1999; Xie, 2002). Some recent projects, including in other parts of Eurasia, have begun to answer that call (Dong et al., 2013b; Hanks, 2010). In this project, I will present new bioarchaeological data from Northwest China and integrate it with published data on paleoclimate and paleoenvironment, as well as archaeological remains, to clarify the nature of the Bronze Age subsistence transition and what it can tell us about human adaptability to climate change.

To characterize changes in ancient human-environment systems, we have to first define the system that underwent change (Carpenter et al., 2001; Cumming et al., 2005). This is possible for ancient systems using quantitative data about human settlement patterns, population

density, and paleobotanical and zooarchaeological remains—though it is challenging, because archaeological data are mostly of a low resolution. Data from Northwest China are available on paleoclimate and paleoecology (particularly effective moisture and plant cover) (An et al., 2006; Chen et al., 2006; Zhao et al., 2009; Zhou et al., 2012), and much archaeological research has been undertaken there. However, there is not yet enough data on ancient foodways from plant, animal, and human remains to reconstruct the human-environment system in detail.

Therefore, as a preliminary step in assessing the Bronze Age transition in an ecological framework, I have adopted an approach that uses human biological data to characterize the Bronze Age transition. My general hypothesis is that subsistence change in the Bronze Age of Northwest China did not constitute a collapse and reorganization of the human subsistence system, precipitated by the 4000 BP climate change event; but rather represents the persistence of a resilient, complex human-environment system that was able to weather the climate changes of the early Holocene. In other words, this was an incremental, not a transformational, adaptation to climate change. In the case of an incremental adaptation, I would expect to see little detrimental effect on the population, since the subsistence system would remain essentially unchanged, whereas in the case of a transformational adaptation, I would expect the changes in diet or lifeway to lead to categorical changes in population health and demography, including in oral health, physiological stress, frailty, and fertility, as has been found at the origins of agriculture (Cohen and Armelagos, 1984; Lambert, 2000; Larsen, 1997; Pinhasi and Stock, 2010; Steckel and Rose, 2002). (See Chapter 2 for further discussion of these concepts.)

1.2 PROJECT BACKGROUND

1.2.1 Geography and climate

The Northern Zone of China can be divided into several sub-regions, defined by geography and climate. From east to west, these are the semi-arid Inner Mongolian grassland, the semi-arid Loess Plateau, and the northwestern inland arid zone (Han, 2008). The area under study in this dissertation is the western portion of this area, and includes parts of the Loess Plateau and the arid zone, extending over modern-day Gansu Province, Qinghai Province, Ningxia Hui Autonomous Region, and Shaanxi Province. As described above, this area served as a zone of contact between the societies of the Chinese heartland in the Yellow River Valley, the steppe societies to the north, and Central Asian societies to the west.

Geographically, Northwest China is characterized by an arid climate and a varied topography of high mountains and deep basins. There is low precipitation because of the landlocked location and the presence of high mountains; outside the high mountain zones, annual precipitation is around 100-200 mm (Han, 2008), though there are significant differences between lowland and highland zones. The influence of the continental air mass makes the region relatively cold, with extreme seasonal and daily fluctuations. For example, in the semi-arid Loess Plateau, average temperatures in January are 0-10° C, with an average in July of 24° C. The region's basins are characterized by alluvial fans, along which many ancient agricultural settlements have been discovered (Gansu and Beijing, 2011).

The entire Holocene period (11,700 BP to the present) in Northwest China has been characterized by climatic variability, with multi-scalar cycles of warm and wet or cool and dry periods (Han, 2008; Herzschuh et al., 2004; Shi et al., 1993; Shui, 2001; Zhang et al., 2000). The particularly dry and cool climate of Northwest China in the Bronze Age reflects larger-scale

processes taking place across Eurasia (Anthony, 2009; Di Cosmo, 2002; Shelach, 1999; Shelach, 2009; Tarasov et al., 2006; Teng and Shelach, 2011). These processes are attested by paleoclimate data from sediment cores, loess microstrigraphy, lake cores, oxygen isotopes from ice cores (a proxy for temperature), precipitation data, and pollen profiles. Details of the climate change as it progressed in each study area are discussed in Chapters 3 through 5.

The label of “Northwest China,” which I will use throughout this study, privileges the Chinese perspective both in historical texts and in modern scholarly inquiry. However, this label captures a defining characteristic of the area: it was a zone of contact with ancient China, notable for its proximity to but distinctiveness from Chinese civilization. Referring to the Yellow River valley civilization of this time period as “China” is also anachronistic, as the concept of a unified Chinese civilization did not emerge until later. However, using this single term to refer to what is today central China does reflect that a common way of life, eventually encompassing language, material culture, and political organization, was emerging in the Chinese heartland at this time.

1.2.2 Cultural sequence

In this study, I focus on the late third through the mid first millennia BCE. Agriculture was practiced in Northwest China from about 6000 BCE, or the middle Neolithic, though not as intensively as in the Central Plains because of environmental constraints. By the middle Neolithic, there was a large, complex network of trade and cultural contact across what is now China, connecting societies from Gansu in the west to the Shandong Peninsula in the east, and characterized by both local cultural variants and common cultural elements such as ceramic and agricultural technologies (Linduff, 1998). Northwest China entered the Bronze Age around 1900 BCE, and the Iron Age around 1300 BCE, though there was significant local variation (Han, 2008).

There is some debate about the cultural sequence in the region, mainly relating to which archaeological cultures or horizons gave rise to which others. The equation of archaeological cultures to groups attested in the Chinese historical record is still common in the Chinese literature, though this obscures some of the variation in archaeological cultures. In addition, for many sites from this region, subsistence “type” (e.g. sedentary agriculture or mobile pastoralism) has been inferred based on qualitative data such as the presence of certain animal species or tools, or even inferred indirectly based on the resemblance of the site’s material culture to that of other groups thought to be agriculturalists or pastoralists. Nevertheless, it is still helpful to review the published information on the archaeological cultures relevant to this study. The prehistoric cultural sequence of Northwest China in the periods included in this study are presented in Table 1.1.

Table 1.1 Major late Neolithic through late Bronze Age archaeological cultures of Northwest China (after Xie, 2002: 240).

Name	Dates	Location (province[s] and geographic area)	Subsistence practices
Late Majiayao 马家窑	~ 2500-2000	Gansu, Qinghai, Ningxia. Incl. Banshan and Machang types	Small-scale agriculture of foxtail and broomcorn millet. Millet grains found at many sites. Sacrificial remains of domesticated livestock and wild game also found. Sites often located in river valleys, some quite large, up to 200,000 m ² . <i>Important sites:</i> Caiyuan (Ningxia), Liuwan (Qinghai), Zongri (Qinghai), Yangshan (Qinghai) <i>Sites in this study:</i> Mapai and Yangshan (Qinghai)
Qijia 齐家 ¹	~ 2100-1400 BCE	Gansu, Qinghai, Ningxia, Inner Mongolia: upper reaches of the Yellow River and its tributaries (esp. Wei River, Tao River, Huangshui River)	Millet farming with pig husbandry; secondary sheep/goat herding and husbandry of cattle, horse, donkey, and dog; also evidence of hunting <i>Important sites:</i> Qijiaping (Gansu), Mogou (Gansu), Huangniangniangtai (Gansu), Zhangjiazui (Gansu), Liuwan (Qinghai)
Siba 四坝	~ 1950-1430 BCE	Gansu: Hexi Corridor region	Agropastoralism: husbandry mostly of sheep/goat and secondarily of pig, also dog, horse, and cattle; cultivation of cereals (wheat, barley, millet, rye); evidence of hunting. Variable reliance on agriculture vs. animal husbandry across sites (Yang, 1998) <i>Important sites:</i> Donghuishan (Gansu), Ganguya (Gansu) <i>Site in this study:</i> Huoshaogou (Gansu)
Kayue 卡约	~ 1600-600 BCE	Qinghai: upper reaches of the Yellow River and its tributary the Huangshui River	Variable: some sites agropastoralism, some sites primarily pastoralism (mainly sheep/goats, also horses and cattle), some sites primarily agriculture; hunting at all sites <i>Important sites:</i> Sunjiazhai (Qinghai)
Xindian 新店	~ 1400-700 BCE	Gansu, Qinghai, Shaanxi: upper reaches of the Yellow River and its tributaries	Agriculture supplemented by hunting and animal husbandry, primarily of sheep/goats, secondarily of pigs, also of dogs and horses <i>Important sites:</i> Zhangjiazui (Gansu) <i>Sites in this study:</i> Xiaohandi (Qinghai)
Siwa 寺洼	~ 1400-700 BCE	Gansu: Jingshui, Wei, Tao, Xihanshui, and Tao Rivers	Agropastoralism, including settled agricultural activities and husbandry of sheep/goats, horses, and cattle
Nuomuhong 诺木洪	~ 1000-800 BCE	Qinghai: Qaidam Basin	Agropastoralist; husbandry primarily of sheep/goat, also of cattle, horse, and camel; also evidence of agriculture and hunting
Shajing 沙井	~ 900-409 BCE	Gansu: Minqin and Yongchang Counties, and Jinchang City	Primarily animal husbandry of sheep/goats, also of cattle, horses, donkeys, and camels; also evidence of agriculture and hunting <i>Sites in this study:</i> Hamadun and Xigang (Gansu)

¹ The Qijia culture is the earliest bronze-using culture to be discovered within China. See also Di Cosmo (2002), Li et al. (1993), and Linduff (1998).

1.2.3 Evidence for the Bronze Age transition

The rise of pastoralism in China's Northern Zone was a local variant, or multiple local variants, of a process taking place across Eurasia (Di Cosmo, 2002). In the Chinese Northern Zone, pastoralism joined or replaced agriculture, while elsewhere in Eurasia it replaced foraging and hunting (Anthony, 2009). The transition was also complex: it was not a wholesale replacement of agriculture by pastoralism, but was the development of mixed subsistence systems resulting in a diversification of subsistence strategies across the region. Later, in the Iron Age, societies with strong pastoralist identities and specialized economic strategies dominated the political landscape of Inner Asia, though there is evidence that other subsistence strategies, including agropastoralism, persisted into the Iron Age and later (Barfield, 1989; Di Cosmo, 1994; Li et al., 1993). Multiple lines of archaeological evidence attest to this transition, including settlement pattern, artifactual, zooarchaeological, paleobotanical, and bioarchaeological evidence.

1.2.3.1 Settlement evidence

Only one systematic settlement survey has been conducted within the Chinese Northern Zone, in the Chifeng area of eastern Inner Mongolia. However, the results of this survey suggest that settlement structure changed dramatically near the end of the Neolithic. The three-tiered settlement hierarchy of the Neolithic, along with the permanent stone architecture of the largest settlements, disappeared with the advent of a mixed economy and an increasing reliance on pastoralism. The Bronze Age settlement system in the Chifeng area entailed smaller and less permanent settlements, which suggests greater mobility and a different economic system than in the previous periods, though not a less complex society (Chifeng, 2003; Linduff et al., 2002). Less systematic reviews of archaeological data suggest that settlement density across the

Northern Zone also decreased during this time (Dong et al., 2013a; Shelach, 2009; Wagner et al., 2013), and many sites have few and small residential structures and shallow occupational layers (Han, 2008; Xie, 2002). This may have been the result of a shift from agriculture towards pastoralism, or of a diversification of subsistence strategy to include more pastoral production (Deng, 2014). Finally, corrals for domesticated animals have been found at some Bronze and Iron Age sites (Han, 2008).

1.2.3.2 Artifactual evidence

One type of evidence often cited to demonstrate that a group engaged in pastoralism is the presence of “animal style” art, which includes vessel, tool, and ornament types and decorative motifs associated with pastoralist societies across Inner Asia in the Bronze Age and later (Figure 1.2). The style particularly includes bronze items bearing representations of herded and hunted animals (Xie, 2002), which indicates a cultural emphasis on animal resources and also widespread exchange and communication across the steppe (Di Cosmo, 2002; Han, 2008).

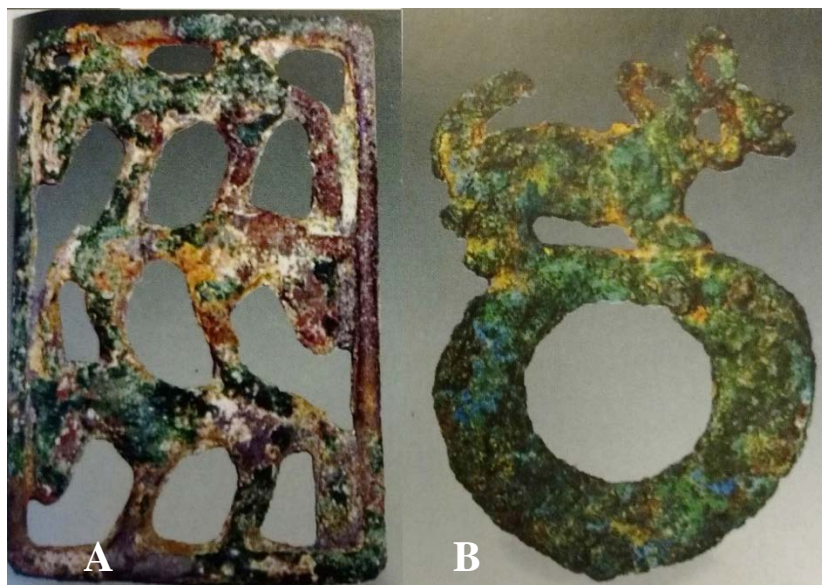


Figure 1.2 A) Bronze horse fitting from Xigang cemetery grave M74; B) dog-shaped bronze plaque from Chaiwan'gang cemetery grave M5 (Gansu, 2001: color plate III)

Also of interest is the presence of tools or implements associated with either agriculture or animal husbandry. In the early Bronze Age of the Northwest (early second millennium BCE), the presence of many arrows and knives, as well as artifacts with animal motifs on them, suggest an economy with a significant herding and/or hunting component. Even later Bronze Age cultures of Northwest China (mid second millennium BCE) still had grindstones, sickles, and other tools for processing grains, in addition to bows and arrows and stone awls, which are associated with hunting and processing animal hides. These artifacts, along with the presence of sacrificial animal remains, furs, and artistic representations of animals, indicate a mixed economy that emphasized both agriculture and pastoralism, to varying degrees in different places. Early Iron Age cultures (late second millennium BCE) still had agricultural implements, including mortars and pestles and grinding stones, though sites from this period also have abundant animal art, and the graves contain meat and dairy offerings, skins, and sacrificial animals (horses, cattle, and sheep). In the Iron Age, knives and weapons associated with hunting and herding, as well as artifacts associated with advanced horseback riding and horse herding, have also been found (Han, 2008; Xie, 2002).

1.2.3.3 Zooarchaeological evidence

The most direct evidence for the rise of pastoralism is the remains of domestic livestock species. Most animal remains so far excavated in the Northern Zone come from mortuary contexts rather than settlements. Though it is difficult to reconstruct foodways from these remains, they still offer information about which animals were present in a given context and which were culturally significant (Barfield, 1989; Di Cosmo, 2002; Han, 2008; Shelach, 2009).

The presence of non-herd animals, for example pigs, may indicate that pastoralism was not practiced (Barfield, 1993). One of the clues that late Neolithic and early Bronze Age cultures

such as Qijia in the Northwest, Zhukaigou in Inner Mongolia, and Upper Xiajiadian in the Northeast practiced settled agropastoralism rather than mobile pastoralism is the presence of pig remains at their sites (Di Cosmo, 2002). The eventual replacement of pig sacrifices with cattle and horse remains in the Kayue culture likely signaled the move away from agropastoralism and towards more mobile and more specialized pastoral forms of subsistence (Di Cosmo, 2002; Shelach, 2009). By the time of the late Bronze Age Shajing culture, the people of Northwest China had domesticated sheep, horse, and cattle, an assemblage that is quite familiar from the later Iron Age, though its adoption may have been a response to complex social factors and not a direct response to climate change (Flad et al., 2007; Shelach, 2009).

The relative number of animal remains at various sites, particularly of sheep/goats, horses, and other herd animals, suggests that the transition to agropastoralism and later pastoralism was most dramatic in the Northwest (especially in the Ordos region, western Qinghai Province, and Gansu Province), and less dramatic or more gradual to the east (in Northeast China and eastern Inner Mongolia) (Di Cosmo, 2002; Owlett, 2016; Shelach, 2009).

Horseback riding was and is a critical element in both agropastoral and mobile pastoral production systems of Inner Asia, and the presence of horses and horse fittings at archaeological sites is often taken as evidence of an economy dominated by animal husbandry. Horse breeding seems to have been introduced to the Qijia Culture of Northwest China from Central Asia along with bronze metallurgy, and both elements appear relatively suddenly in the archaeological record (Di Cosmo, 2002; Flad et al., 2007). Archaeological evidence suggests that horse rearing likely became important to the cultures of the Northern Zone in the second or third millennium BCE, though mounted nomadic pastoralism as practiced in the Iron Age did not arise until the mid-first millennium BCE (Barfield, 1989; Barfield, 1993; Di Cosmo, 2002).

1.2.3.4 Paleobotanical evidence

The most important early agricultural domesticates in Northwest China were broomcorn and foxtail millet, which are found throughout Northwest China beginning in at least the third millennium BCE (An et al., 2004; An et al., 2010; Barton et al., 2009; Garvie-Lok et al., 2004; Jia et al., 2013; Ma et al., 2014; Xie, 2002; Zhao et al., 2014). They seem to have been domesticated in the east, and moved through Northwest China to reach Central Asia (Atahan et al., 2014; Frachetti et al., 2010). The opposite was true of wheat, oats, and barley, which were domesticated in Western Asia and reached Northwest China around 2000 BCE, before they reached the rest of East Asia, diversifying the crop base (Betts et al., 2014; Flad et al., 2010; Garvie-Lok et al., 2004; Li et al., 2010). Even in areas where pastoralism dominated the subsistence system in the Iron Age, such as the Tianshan Mountains, the Pamir Mountains, southern Xinjiang, the Qaidam Basin, and the Hexi Corridor, domesticated wheat, millet, and barley have still been found, indicating that crop cultivation continued into this period (Han, 2008; Zhang et al., 2005).

1.2.3.5 Bioarchaeological evidence

Though bioarchaeology is still a relatively small field in China (Pechenkina, 2015), a number of studies in the last two decades have begun to address the bioarchaeological evidence for subsistence change in the Northern Zone. A few are summarized here; more are discussed in relation to the findings of this study, in Chapters 3 through 5.

At the Late Neolithic Majiayao site of Zongri, Cui et al. (2006) found that the average stable carbon isotope value in human bone collagen ($\delta^{13}\text{C}$ -17.20 — -13.49‰) was consistent with consumption of C_4 plants, likely millet, which was found at the site. Average stable nitrogen

isotope values ($\delta^{15}\text{N}$ 7.59—9.23‰) were in the range of local carnivores, suggesting humans consumed animal products.

Two studies comparing human and animal bone collagen at early Bronze Age sites in Northwest China also found that humans and omnivores appear to have had C_4 -based diets, while domesticated herbivores had mostly C_3 -based diets, probably from grazing on wild plants (Dong et al., 2015; Ma et al., 2014).

Zhang and colleagues (2005) analyzed trace elements from the Chawuhu cemetery in Xinjiang, which dates to the first half of the first millennium BCE. From their analysis of strontium, zinc, and barium, the authors concluded that the meat consumption of the Chawuhu population was high, though they likely consumed more plant foods than some other previously analyzed groups, e.g. the Lop Nur population farther to the west. These data, in addition to the contents of Chawuhu graves (sacrificial horses and sheep, horse fittings, bows and arrows, and felt), paleobotanical remains (barley and wheat found in ceramic vessels), and the common occurrence of dental carious lesions in the Chawuhu population, support the conclusion that the population had a diverse diet comprising both animal foods (such as cattle and sheep meat and dairy) and agricultural foods.

A study of the Gumugou cemetery in Xinjiang (Zhang and Zhu, 2011) attests to the pastoralist subsistence strategy of the population at around 1800 BCE. Nitrogen stable isotope analysis of human bones from the site revealed humans to have a $\delta^{15}\text{N}$ concentration of approximately 13‰—15‰, in the range for local carnivores, indicating a high level of consumption of meat and dairy products. Based on animal remains, bone objects, and felt and leather grave goods, the researchers concluded that the people at Gumugou consumed significant quantities of mutton and beef, supplemented by hunted meat. The average $\delta^{13}\text{C}$ value at the site

was between -18.39‰ and -17.85‰, which is roughly in the expected range for human bone collagen in a population with a diet dominated by C₃ plants (approximately -19‰ to -23‰), and far from the range for C₄ plant consumption (approximately -6‰ to -10‰) (Brown and Brown, 2011). This finding, in combination with paleobotanical remains recovered at the site, led the researchers to conclude that the predominant grain consumed by the population at Gumugou was wheat.

1.3 ARCHAEOLOGY OF THE STUDY SITES

In order to trace the Bronze Age transition in Northwest China, I have selected sites that span the two millennia from the late Neolithic to the Iron Age. They come from the provinces of Shaanxi, Gansu, Qinghai, and Ningxia (Figure 1.3), and are housed at universities and government research institutes in China, where I collected the data for this study.

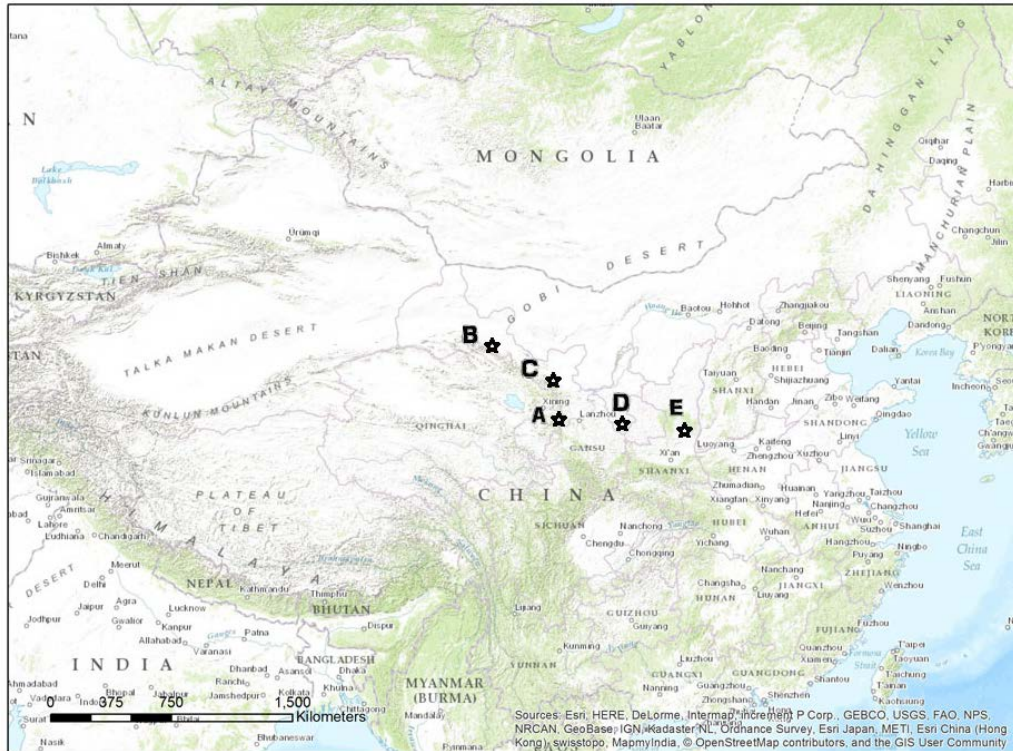


Figure 1.3 Location of sites in the study: A=Mapai/Yangshan and Xiaohandi; B=Huoshagou; C=Hamadun/Xigang; D=Jiulongshan; E=Zhaitouhe and Shijiahe

Site selection was limited by several factors. All the sites under investigation had been previously excavated, some as early as the 1970s and one as recently as 2012. Excavation and curation techniques have changed dramatically in that time, so that earlier excavated skeletal collections consist mostly of crania and pelvises, with a number of individuals missing or damaged due to decades of storage. Next, I was welcomed as a visiting researcher at all four institutions and given access to much material, but I did not have the opportunity to observe collections from certain sites that were under study by other researchers. Finally, I tried to restrict my examination to sites with larger sample sizes, and did not examine sites from the relevant period with very poor preservation or with fewer than 30 individuals. The one exception is the site from Ningxia, which includes only six individuals but which was the only one available for study from the appropriate time period at that institution. This site will be excluded from most statistical

considerations. Additionally, in two cases I pooled skeletal series when they came from cemeteries that were contemporaneous and excavated in the same location (see Table 1.2). These selection parameters have led to some unavoidable temporal gaps between study sites, which I hope to address in future research; but the data in this dissertation still reveal important patterns of change over time, which can address the principal research questions of this study.

I have included in my final sample only those individuals represented by at least two elements (e.g. cranium, pelvis) or by a complete cranium that includes dental remains. I have therefore excluded data from isolated elements or very fragmentary individuals. The number of individuals from each site included in the study therefore does not reflect how many were originally excavated or how many are currently curated in collections, but how many were complete enough for inclusion in this study. My total sample across all sites is 322 individuals. The study sites are presented in Table 1.2.

Table 1.2 Skeletal series included in the study

Province/county/ site name	Archaeological culture (period)	Dates and dating technique	Subsistence strategy (from publications)	Collection *	No. of indi- viduals (322 total)
Sites from the Qinghai Plateau					
Qinghai/Minhe/ Yangshan <i>(pooled with below)</i>	Banshan and Machang (Late Neolithic)	2600-2300 BCE, ceramic typology (Qinghai, 1990)	Agriculture	JLU- RCCFA	32
Qinghai/Minhe/ Mapai <i>(pooled with above)</i>	Machang (Late Neolithic)	2400-2000 BCE, ceramic typology (Qinghai, 1990)	Agriculture	JLU- RCCFA	11
Qinghai/Minhe/ Xiaohandi	Xindian (Middle Bronze Age)	1500-1000 BCE, ceramic typology (Qinghai et al., 2004)	Agriculture	JLU- RCCFA	44
Sites from the Hexi Corridor					
Gansu/Yumen/ Huoshaogou	Siba (Early Bronze Age)	1700-1400 BCE, C-14 (Wu, 2014)	Agro- pastoralism	GPICRA	75
Gansu/Yongchang/Ha madun <i>(pooled with below)</i>	Shajing (Late Bronze Age)	~1000-500 BCE, C-14 (Gansu, 2001)	Pastoralism	GPICRA	17
Gansu/Yongchang/Xi gang <i>(pooled with above)</i>	Shajing (Late Bronze Age)	~1000-500 BCE, C-14 (Gansu, 2001)	Pastoralism	GPICRA	33
Sites from the Loess Plateau					
Ningxia/Guyuan/ Jiulongshan	(Spring and Autumn Period)	771-256 BCE (Zhang et al., In preparation)	Pastoralism	NICRA- GY	6
Shaanxi/Huangling/ Zhaitouhe	Rong (Early to Middle Warring States)	475-221 BCE, ceramic typology (Shanxi et al., 2012)	Pastoralism	NWU	72
Shaanxi/Huangling/Sh ijiahe	Rong, State of Qin (Late Warring States)	475-221 BCE, ceramic typology (Shanxi et al., 2015)	Agriculture	NWU	32

*JLU-RCCFA=Jilin University Research Center for Chinese Frontier Archaeology (Changchun, Jilin);
GPICRA=Gansu Provincial Institute of Cultural Relics and Archaeology (Lanzhou, Gansu);
NWU=Northwest University (Xi'an, Shaanxi); NICRA=Ningxia Insitute of Cultural Relics and
Archaeology (Guyuan, Ningxia)

1.3.1 Qinghai Plateau

1.3.1.1 Yangshan and Mapai, Minhe County, Qinghai Province (青海民和县阳山墓地与马牌墓地)

The cemetery at Yangshan was excavated in 1980-1981, during which time 218 tombs were discovered and excavated (Qinghai, 1990; Qinghai, 2002). The skeletal remains from the cemetery are currently housed at the Jilin University Research Center for Chinese Frontier Archaeology (JLU-RCCFA) in Changchun, Jilin Province. Based on the material culture found in the graves, the site was attributed to the late Neolithic, with artifacts of both the Banshan and the Machang types represented. Ceramic seriation dates the site's occupation to 2600-2300 BCE. The site is located on a terrace in a valley formed by the Songshu River, a tributary of the Huangshui River, at 2200 m above sea level (Qinghai, 1990) (Figure 1.4).



Figure 1.4 Landscape around the Yangshan cemetery (Qinghai, 1990: plate I)

The Mapai cemetery was also discovered in Minhe County, and like Yangshan, is attributed to the late Neolithic (middle Machang period) based on its material culture. It was excavated in 1979-1987, and 62 graves were excavated (Qinghai, 1990; Xie, 2002). It is also stored at the JLU-RCCFA. As only 11 individuals from this site are included in my study, I have pooled them with the remains from Yangshan for analysis (see Chapter 3 for further discussion).

Minhe County is located at the intersection of the Qinghai-Tibetan Plateau and the Loess Plateau, and is divided by the Yellow River drainage system. It is a critical agricultural area of Qinghai Province, with ample water resources and a mild climate despite its relatively high altitude, and has been cultivated since antiquity. In the west of the county there are high mountains with an elevation of about 3500 m above sea level, sloping down to about 2000 m in

the east. The area is characterized by very thick deposits of loess. Despite summer flooding in low-lying areas and high temperatures, there is water all year round, and it is a suitable area for agriculture. The area has rich natural resources, with more sunlight than the North China Plain and a long growing season. It has a temperate climate with mild seasonal differences in temperature, and is well watered by rivers and runoff. Today, Minhe County's river valleys are an important area in Qinghai Province for the cultivation of staple crops, fruits, and vegetables (Qinghai et al., 2004). The remains from both these sites are represented by cranial and fragmentary postcranial remains. Crania are kept separately in archival boxes.

1.3.1.2 Xiaohandi, Hetaozhuang Township, Minhe County, Qinghai Province (青海民和县核桃庄小旱地墓地)

The Xiaohandi cemetery is also located in Minhe County, Qinghai, at the intersection of the Qinghai-Tibetan Plateau and the Loess Plateau, in an area divided by tributaries of the Yellow River. The site is located on the eastern banks of the Milagou River, a tributary of the Huangshui River (Qinghai et al., 2004).

The site of Xiaohandi was excavated three times between 1978 and 1980, during which 367 graves were excavated, attributed by artifact typology primarily to the Zhangjiazui type of the Bronze Age Xindian Culture (Qinghai, 1995; Xie, 2002), which existed between 1500 and 1000 BCE. A smaller cemetery, Shanjiatou, was also excavated in Hetaozhuang in 1980, but is not included in this study.

At other Xindian sites, in addition to evidence for agriculture, archaeologists have found indications of supplementary herding and hunting. Animal remains include cattle, sheep/goat, dog, pig, and horse, with sheep/goat being the most common domesticated animal, followed by pig. Deer remains were also found, indicating that hunting was practiced at Xindian sites. The

remains are stored at JLU-RCCFA, and their condition is similar to that of the Yangshan and Mapai remains. They include crania, stored in archival boxes, and partial postcranial remains.

1.3.2 Hexi Corridor

1.3.2.1 Huoshaogou, Yumen City, Gansu Province (甘肃玉门市火烧沟墓地)

The Huoshaogou site is a key example of the early phase of the Bronze Age Siba Culture. It has been excavated over several seasons, primarily in 1976, when 312 graves were excavated (Xie, 2002; Yang, 1998). The site has been carbon dated with charcoal to 1950-1430 BCE (Xie, 2002), and with human bone to 1700-1400 BCE (Wu, 2014).

The site is located in an arid part of the Hexi Corridor, and both its location and its material culture suggest that the people at the site relied on a mixed economy of herding and farming (Yang, 1998). Grains of foxtail millet were found in one pot from the site. Animal remains found at the site represent both hunted and domesticated animals, and include sheep/goat, pig, dog, cattle, horse, and deer, with sheep/goat and pig being the most abundant (Li, 1993; Xie, 2002; Yang, 1998). The dominance in the faunal assemblage of sheep and pigs suggests that pastoralism was important in this period, though communities were still sedentary. Permanent architecture has also been found at other Siba sites, indicating sedentism. The human remains from Huoshaogou are stored at the Gansu Provincial Institute of Cultural Relics and Archaeology (GPICRA) in Lanzhou. They are represented by crania and selectively curated, fragmentary postcranial remains.

1.3.2.2 Hamadun and Xigang, Yongchang County, Gansu Province (甘肃永昌县蛤蟆敦和西岗墓地)

The fortified late Bronze Age settlement of Sanjiaocheng in Yongchang County is associated with three nearby, contemporaneous cemeteries. The Hamadun cemetery was excavated in 1979, with 20 graves found (Gansu, 1990). That year, a corner of the site containing four houses was also excavated. The Xigang cemetery was excavated the following year, in 1980, with a total of 452 graves excavated (Gansu, 2001). The third cemetery, Chaiwan'gang, was excavated in 1981 and included 113 graves, three houses, and two ash pits (Xie, 2002); the remains from this cemetery were not available for study. Because only 17 individuals from Hamadun were available for study, and Hamadun and Xigang are both closely associated with the same settlement, I pooled the remains from these two cemeteries for my analysis. The Hamadun remains were somewhat better preserved than the Xigang remains (Han, 2001).

Yongchang County is situated in a river basin at the eastern end of the Hexi Corridor. It is an agriculturally productive area with ample sunshine, fed by both meltwater and rainwater, and is also near an area of grassland to the northeast on the Alashan Plateau, so it is suitable for both herding and farming (Gansu, 2001).

These sites are attributed to the Shajing Culture. Remains of wood and charcoal from the Sanjiaocheng site and the Hamadun and Xigang cemeteries have been carbon dated to 900-408 BCE, contemporaneous with the Western Zhou to Spring and Autumn periods in the Central Plains (Gansu, 1990; Xie, 2002). Sanjiaocheng, like other sites discovered from the Shajing Culture, was fortified, and appears to have had some corrals for herd animals (Gansu, 2001); the Shajing Culture seems to have had a three-tiered settlement system (Li, 1994). Remains of one house from the site have been described as the possible remains of a conical yurt or portable dwelling, with a fire pit and storage pits inside (Gansu, 1990; Li, 1994; Xie, 2002). Qualitative

data on food remains and mortuary sacrifices from the sites support the common interpretation of the Shajing lifeway, that it mainly consisted of a pastoral economy supplemented by agriculture. Animal remains found at the site include sheep/goat, dog, horse, cattle, donkey, and camel; sheep/goat specimens were the most abundant, and the donkey and camel may or may not have been domesticated varieties (Gansu Sheng Bowuguan, 1979; Li, 1994). Stone agricultural implements were also found, including hoes, spades, and grinding stones, as well as the remains of cereal crops. Sheep/goat, cattle, and horse skulls and lower legs are common grave offerings. There is significant stratification of graves in terms of the richness of the offerings, with the richest grave at Hamadun (M15) containing 35 animal skulls, among other offerings (Gansu, 1990; Xie, 2002). The remains from Hamadun and Xigang are stored at GPCR, and their condition is similar to that of the remains from Huoshaogou. Other than pelvises, the postcranial remains are very fragmentary, due to selective curation.

The published report includes one chapter by Dr. Han Kangxin of the Institute of Archaeology, Chinese Academy of Social Sciences. The chapter includes estimations of sex and age, a study of paleopathology, and a craniometric study of 13 crania from Hamadun and Xigang. These crania are pictured in the volume, but are no longer stored with the rest of the remains, and so were unavailable for inclusion in this study.

1.3.3 Loess Plateau

1.3.3.1 Jiulongshan, Guyuan City, Ningxia Province (宁夏固原市九龙山墓地)

A salvage excavation was conducted at the Jiulongshan cemetery at Guyuan in 2009, during which time 11 graves were opened. Only six individuals were available for study, though they were well preserved, with most elements present and cortical surfaces and epiphyses intact.

The remains are housed at the Ningxia Institute of Cultural Relics and Archaeology (NICRA) field station in Guyuan City.

Based on artifact typology, the cemetery was attributed to the late Spring and Autumn period (771-476 BCE), and is thought by the original investigators to have been used by a mobile pastoral population. Sheep/goat, horse, and cattle remains were found at the site (Zhang et al., In preparation). Today, this region has a large year-to-year fluctuation in crop yields (Li et al., 1993), which would have encouraged residents to adopt an agropastoral or pastoral subsistence strategy, to mitigate the risks of agricultural production.

1.3.3.2 Zhaitouhe, Huangling County, Shaanxi Province (陕西黄陵县寨头河墓地)

The Zhaitouhe cemetery is located in Huangling County in northern Shaanxi Province, at the northwestern edge of the Loess Plateau and south of the Ordos region. The site is located on the north bank of the lower course of the Hulu River on a sloping tableland, on level open ground.

The cemetery was excavated in 2011 by the Shaanxi Provincial Institute of Archaeology (SPIA), though the human remains are currently housed in the collection of the physical anthropology section of the Northwest University School of Cultural Heritage (NWU-SCH) in Xi'an. The excavation uncovered 90 graves, two pits containing sacrificed horses, and one pit containing a short spear. Because there is no intrusion of graves on each other and the graves are laid out in a relatively orderly fashion, the excavators believe the cemetery was in use for only a short period (Shanxi et al., 2012).

Some artifacts from the cemetery suggest an affiliation with a culture of the early to middle Warring States period (475-221 BCE), specifically in the State of Wei. However, other

artifacts are typical of those associated with the so-called “Rong” people, a term found in the Chinese historical literature that is used to describe western non-Han groups, especially pastoralists. The term is also used by archaeologists to describe this archaeological culture, which has clear differences from the material culture of settled Chinese populations. The excavated Rong vessels bear a resemblance to vessels typical of other Northwest Chinese Bronze Age cultures and suggest cultural contact with the rest of the Northwest, while a few artifacts recovered at the site, including a bronze plaque, even suggest contact with the northern steppe. Cattle, sheep/goat, and horse remains are also found as mortuary sacrifices at Zhaitouhe. No settlement was discovered, though a survey found a large amount of pottery from the Eastern Zhou period (770-476 BCE) on lower ground about 500 m to the south, suggesting occupation may have been concentrated there (Shanxi et al., 2012; Guo et al., 2014; Sun et al., 2012).

A historical text, *The Records of the Grand Historian*, supports the interpretation that a group that would have been known to ancient sedentary Chinese people as the “Rong” existed at the margins of the State of Wei at this time (Shanxi et al., 2012). The excavators characterize Zhaitouhe as the first Rong cemetery discovered in Shaanxi, and state that it is distinct from other Rong cemeteries found in this region, as other Rong groups in this area had close relations with the State of Qin rather than the State of Wei. Therefore, this cemetery provides new information about the migrations and material culture of Northwest Chinese people during the Warring States period.

The human remains were thoroughly excavated and curated and are relatively well-preserved, with most elements present and cortical surfaces intact. Other than complete crania, which are stored in cabinets, remains from single individuals are stored together, and all elements have been curated.

1.3.3.3 Shijiahe, Huangling County, Shaanxi Province (陕西黄陵县史家河墓地)

The cemetery at Shijiahe was discovered in 2012 during the survey associated with the excavation of Zhaitouhe, and was excavated the same year. It is located 4 km from Zhaitouhe, on the same tongue of land, and also on the north bank of the Hulu River (Figure 1.5).



Figure 1.5 View of the location of Shijiahe cemetery (Shanxi, 2013)

A total of 37 graves were excavated at Shijiahe. The burials were quite stratified in terms of their offerings, and include both shaft graves and side chamber graves. Based on the grave types and contents, the excavators attribute the shaft graves to Rong people of the early to middle part of the Warring States period (475-221 BCE), meaning it was likely in use at the same time as, and by the same population as, the Zhaitouhe cemetery (Shanxi et al., 2015; Sun et al., 2015). The grave goods from this period exhibit some influence from the State of Wei, in whose territory it was located, and also from northern bronze-using steppe cultures, as at Zhaitouhe.

Ten graves from the site are side chamber graves. Their grave type and grave goods resemble those of the State of Qin and date to the late Warring States period, and possibly also the later Qin Dynasty (Shanxi et al., 2015; Sun et al., 2015). These graves may represent a second phase of use of the cemetery, after the conquest of this area by the State of Qin around 330 BCE and the area's settlement by Qin colonists.

However, it is also possible that the Rong graves from this cemetery might date to the later part of the Warring States period as well (Shao Jing, personal communication). If this is the case, the Rong and Qin graves of Shijiahe were likely contemporaneous. In fact, my paleopathological analysis supports this interpretation (see Chapter 5). However, my biodistance analysis concurs with the material culture remains, that the Rong of Shijiahe and the Rong of Zhaitouhe were very closely related to each other.

The Shijiahe skeletal remains, like those from Zhaitouhe, were excavated by the SPIA, but are stored at the NWU-SCH. All postcranial elements were excavated and curated, and the remains are in a good state of preservation, with cortical surfaces and epiphyses intact.

CHAPTER 2 THEORY AND METHOD

2.1 EXPLANATIONS FOR THE BRONZE AGE TRANSITION

The cause of the Bronze Age subsistence transition in Northwest China, and across Eurasia, has been the subject of much research in the archaeological and paleoclimatological literature. It seems that the transition was a multi-faceted, long-term development, and that no “prime mover” hypothesis is adequate to entirely explain the transition (Allard and Edenebaatar, 2005). In this study, I have emulated approaches that combine multiple lines of evidence and take into account multiple causal factors, and that make use of recent theoretical advances in human ecology and environmental archaeology.

The most common explanation for the transition in the Northern Zone of China is climatic deterioration, which supposedly forced humans away from the small-scale agriculture of the Neolithic and towards pastoralism as an obligate strategy for exploiting an increasingly marginal environment (Li et al., 1993). However, Shelach (2009) points out that the evidence does not support a robust version of this hypothesis (discussed further below). The next most common explanation is population replacement, that is, a pastoralist population from farther north moved into the area and absorbed the local Neolithic farmers and remnant foragers, converting or forcing them into the pastoralist lifeway. This did happen to a certain degree in later periods, but for the Bronze Age, it is not supported by the evidence. Shelach’s own model privileges the formation of ethnic identity (or “ethnic-like identities” in his terminology) and economic strategy as the main driving force behind the transition (also discussed further below).

Most likely, both internal and external factors contributed to the shift. Shelach (2009) considers both climate and population replacement to be “external factors,” while identity formation is an internal factor. Di Cosmo (2002: 33) classifies “overpopulation, aridization, or simply an increase in the degree of specialization and division of labor between agriculturalists and pastoralists” as internal, while “external” explanations for the appearance of nomadic pastoralism include “invasions or cultural contacts.”

To understand the transition fully, we must be able to detect the signature of pastoral practices and mobility in the archaeological record. Nomadism or mobility is often associated with pastoralism, and though mobility is described in historical sources, these are potentially unreliable sources of information about whether and how it was practiced (Cribb, 1991). Also, historical sources tend to emphasize ethnic affiliations, which are difficult to connect to specific material culture assemblages in the archaeological record.

While archaeology can push the search for the origins of pastoralism and nomadism into the prehistoric past, most models for the origins of pastoralism come from the ethnographic literature, and include economic, political, and social explanations (Barth, 1969; Dyson-Hudson and Dyson-Hudson, 1980; Lees and Bates, 1974; Salzman, 2004). These diverse models, explored more below, reinforce the idea that the origins of pastoralism cannot be explained as a unitary phenomenon or with a single set of explanatory factors.

2.1.1 Climatic explanations

It is not in dispute that climate change took place in the third and second millennia BCE. Though the process varied from place to place, Inner Eurasia overall experienced a cooler and more arid climate beginning in the second or third millennium BCE, with peak aridity occurring around 2000 BCE, along with the expansion of grasslands and the retreat of forests and marshes.

This has been attributed to the weakening of the Asian summer monsoon after 3000 BCE (An et al., 2006; Anthony, 2009; Chen et al., 2006; Li et al., 2014a; Zhang et al., 2000; Zhao et al., 2009; Zhou et al., 2012).

In some models of the origins of pastoralism, climate or ecological change is identified as the driving force behind subsistence change. Studies in human ecology provide us with models of this sort of transition. Abdi (2003) writes about subsistence diversification as a rational strategy in response to ecological risk. Similarly, Moran (2008) writes that East African pastoralists increase their chances of success in their environment through diversification of food production, both within and between households. Spooner (1973) writes that pastoralism's origins may be attributable to the spread of grassland after the intensification of agriculture, or possibly to population pressure leading to exploitation of more marginal environments.

The climate change explanation of the origins of pastoralism, and of other cultural phenomena, appears often in the Chinese archaeological literature (Dong et al., 2012; Eng, 2007; Han, 2008; Li, 1993; Liu and Feng, 2012; Mo et al., 1996; Wu and Liu, 2004). Some attempts have been made to link specific fluctuations in the paleoclimate and paleoenvironmental record to changes in archaeological cultures, but these are often based on large time scales and broad correlations (Contreras, 2017). They often do not adequately account for either the specific impact of the climate changes being called upon as explanatory factors, or the nature of the cultural “collapses” or changes that are being explained. For example, Zhou et al. (2012) propose that the “collapse” of the Qijia culture at 2000 BCE was related distally to a climatic drying event, and proximally to salinization, desertification, and loss of soil fertility from over-exploitation of farmland. This is based on pollen cores from the sites of Donghuishan and Huangniangniangtai, and though climate may have played a role in the culture changes, on its

own climate does not seem to be an adequate explanation for the large-scale cultural changes occurring in the second millennium BCE across Gansu, Qinghai, and Ningxia provinces, where Qijia culture remains are found.

Similarly, Wu and Liu (2001) posit that a single climatic cooling event around 2000 BCE explains the collapse of civilizations in the Nile and Indus River Valleys, the collapse of the major Neolithic cultures of China, and the population pressures that led to the rise of urban Chinese civilization. This explanation is parsimonious, but it lacks a robust definition of “collapse” that can encompass all these scenarios, or any details about climate proxies, dating methods, or specific vegetation changes in various localities associated with this climate event. A more fine-grained analysis of both culture and climate change would be necessary assess to their model, as Holocene climate change was nonlinear, and varied from place to place (Miller, 2013; Zhang et al., 2000). It is also typical for monsoon-related dry intervals in monsoon marginal areas to be asynchronous across different settings (Li et al., 2014a), so it is risky to generalize the effects of a single climate event across large geographic regions. Also, few attempts have been made to link changes in temperature, precipitation, and other climatic variables to the actual carrying capacity and other characteristics of landscapes exploited by humans (Chifeng, 2003; d'Alpoim Guedes et al., 2016; Frachetti, 2008a; Linduff et al., 2002; Shelach, 2009; Tarasov et al., 2006). Chronological resolution of both paleoenvironmental and archaeological data, and characterizing human-environment interaction in ways that can be traced in the ancient past, remains a persistent challenge for scholars around the world (Contreras, 2017).

Finally, some of these climate-based models rely on a categorical understanding of subsistence practices, which masks the complexity and flexibility of real subsistence systems. They posit that arid and semi-arid environments, by virtue of being ecologically “marginal,” are

fragile (Mo et al., 1996) and even culturally marginal places where societies became “stuck” at an earlier “stage” of development of complexity (Han, 2008) or suffer “retrogression” (Zhao et al., 2012; Zhou et al., 2012). However, there is ample archaeological evidence that farming continued in the second millennium BCE, and was later practiced alongside specialized nomadic pastoralism, meaning that categorical frameworks do not accurately represent the transition. As Di Cosmo (2002: 23) writes:

Although herders became gradually more mobile and the aridization of the climate made agriculture more problematic in several areas, this evolutionary trajectory did not necessarily mean the abandonment of agriculture. The more common picture in central Asia during the first half of the second millennium BC, was the development of settled agro-pastoral societies that appear to have wielded considerable political and military power.

Climate change in the second millennium BCE was not unidirectional, but led to greater uncertainty (Hong et al., 2001), so it is reasonable to expect that Bronze Age subsistence change was characterized by diversity and flexibility, not categorical change.

Barth (1969: 25) puts it succinctly: “Ecologic feasibility, and fitness in relation to the natural environment, matter only in so far as they set a limit in terms of sheer physical survival, which is very rarely approached by ethnic groups.” It therefore seems that climate-based explanations for past human behavior cannot represent the whole picture, and obscure the ways in which political and social forces have shaped conflict and inequality throughout history (Correia, 2013). Climate impacts societies in the ways that it does only through the mediation of social and technological factors (Dong et al., 2013a; Holling, 2003; Jia et al., 2013; Rosen,

1995). Climate explanations must therefore be contextualized with analyses of other lines of evidence and sophisticated model-building.

2.1.2 Culture contact explanations

The importance of inter-group interactions to the formation of pastoralist and/or mobile lifeways is well-established in both the ethnographic and the archaeological literature. This interaction may take the form of economic specialization and trade (Cribb, 1991; Linduff et al., 2002), cultural exchange and adoption of technologies (Di Cosmo, 2002; Han, 2008), political strategy (Barfield, 1989; Barfield, 1993), expressing ethnic identity (Bernbeck, 2008; Shelach, 2009), or some combination thereof (Anthony, 1998; Frachetti, 2008a; Frachetti, 2008b; Lees and Bates, 1974).

In the formulation of Barth (1969: 15), interactions and borders are precisely what makes ethnic identity formation possible: “The critical focus of investigation from this point of view becomes the ethnic *boundary* that defines the group, not the cultural stuff that it encloses.” We should therefore expect to see separate territories occupied by, and separate ecological and economic niches being exploited by, groups with distinct ethnic identities. It is highly plausible that the desire of members of a group to distinguish themselves from their neighbors through economic practices was a driving force in the origins of Northern Zone pastoralism or agropastoralism, as in Shelach’s (2009) model. In his reading of the data, pastoralism became dominant in the second half of the first millennium BCE at least partially because this suited the identity the people of this region had adopted.

Later interaction between nomadic pastoralists and sedentary states may be best described by Salzman’s (2004) encapsulation model, whereby nomadic tribes and confederacies

are included within regional polities (see also Chang, 2008). This is helpful in understanding the interaction of the people of Northwest China with early Chinese states (see Chapter 5).

For other parts of Inner Asia, population movement may in fact explain some of the spread of pastoralism, e.g. the possibility that Afanasievo pastoralists moved from the Altai south into the Tianshan Mountains and eventually into the Tarim Basin after 2000 BCE (Anthony, 2009; Mallory and Mair, 2000). However, it seems unlikely that such large-scale population movement can explain what appears to be gradual, in situ development of mixed economies in Northwest China in the Bronze Age.

2.1.3 Hybrid approaches

One challenge in researching the Bronze Age transition is defining the object of study. The prescription of Dyson-Hudson and Dyson-Hudson (1980: 56), that scholars of pastoralism should focus on *variables* rather than *types*, is quite powerful. They write: “The typology ‘nomadic pastoralism’ which locks together livestock herding and mobility into a single arbitrary category will then cease to define a subject suitable for review.” Cribb (1991) also emphasizes that multiple lines of evidence are needed to assign the label of nomadic pastoralism to an archaeological site, and we cannot impose a universal typology on ancient peoples, beyond heuristic devices that can guide our research questions but should not limit our interpretations of data.

Frachetti (2008a: 38) emphasizes the need to allow for complexity: “material and social change—though related processes—may be more accurately modeled vis-a-vis generative mechanisms produced from interactions that balance environmental and institutional structures within the contextual geography of local landscapes.” In other words, material change is not a direct manifestation of social change, and while the two are related, they are actually separate

interacting processes which in turn interact with the geographic and institutional environment in which they are situated, all in an iterative fashion. To this end, Frachetti's (2008b) research program includes data pertaining to spatial relationships of burials and settlements, material culture, faunal and floral remains, and chronology, all at multiple scales. These are obtained through survey, excavation, and paleoecological reconstruction, and spatially modeled using GIS software.

Furthermore, most social-ecological systems comprise multiple stable states (Holling, 2003). Salzman (1980: 6-7) writes that subsistence changes are often "manifestations of shifts among institutionalized alternatives," and are usually not "non-repetitive, directional and cumulative, [but are] often rather in the form of repetitive cycles of alternating phases." He reiterates this in later work (2004: 5):

The assumption that socio-cultural change is discrete and absolute, that change is manifested in a formally (if not temporally) abrupt shift from one particular kind of society to another, is unnecessary and misleading given the understanding that a society is not a single, unalloyed, tightly-integrated system but rather is a complex entity which encompasses a multiplicity of practices and forms and which incorporates sets of behavioral, organizational, and ideological alternatives.

Barton and An (2014) also offer an innovative way to model the adoption of a new technology or subsistence practice. An initial low level of adoption, during which the technology or new domesticate (in their case, wheat) is only rarely found and scarce in the archaeological record is then followed by a triggering event or a critical threshold, after which the innovation spreads rapidly. In their formulation (777):

While it is possible that environmental change leading to dramatic reorganization in the distribution and abundance of moisture, plants and animals might have forced people into mass migration, it is equally (if not more) likely that such changes simply engendered local adjustments to patterns of human subsistence, mobility and social organization. For example, the addition of domestic herd animals and quick-growing cold-tolerant annual grasses to a pre-existing pattern of wild food procurement might have been an adaptation to food insecurity associated with environmental variability and uncertainty.

Thus, subsistence transitions, including the adoption of new domesticates or production strategies, are not necessarily the result of crisis, collapse, and reorganization, but can entail reforms or additions to an existing, stable, and persistent system.

These hybrid approaches point towards a non-typological orientation, and are consistent with the findings of archaeologists, ethnographers, and human ecologists, as well as with the adaptive cycle model of change in complex systems that will be described in the next section. Stripped of typological frameworks, different subsistence systems are not separated by such enormous gaps. Patterns do emerge from archaeological data, but they do not follow a neat dichotomy between “the steppe and the sown.” Rather, they lend themselves to ways of thinking that allow for complexity, recursion, and cyclicity, as embodied by these hybrid approaches to understanding the origins of pastoralism.

2.2 HUMAN ECOLOGY

Theoretical concepts from the field of human ecology are of great use in applying and evaluating these non-typological models of subsistence change. The models described below can accommodate the complexity and non-linearity of the approaches described in the above section.

2.2.1 Adaptive cycle

The field of ecology has produced many bodies of theory that are of use to archaeological research, as sustainability and human adaptability have become topics of interest to archaeologists in recent years (Contreras, 2017; Faulseit, 2016a; Kahn, 2012; McAnany and Yoffee, 2010; Moran, 2008; Redman, 2005). This study is concerned with the developments of the last several decades, when the idea of homeostatic equilibrium in ecosystems, e.g. fixed carrying capacity, has been replaced by more dynamic models. These models incorporate both persistence and change, and take the interaction between elements as the primary driving force (Barker and Gilbertson, 2000; Redman, 2005). For example, a “boom and bust” model is now widely employed in the study of pastoralist and arid human-environment systems (Barker and Gilbertson, 2000). This study’s general hypothesis relies on two such dynamic concepts from the field of ecology: complex adaptive systems, specifically the “adaptive cycle”; and resilience.

The adaptive cycle (Gunderson and Holling, 2002; Holling, 1973) can be used to characterize natural, institutional, or other complex systems. It is more a heuristic device than a testable model, but it can be used to generate testable hypotheses, which I will discuss below. The paradigm of the adaptive cycle posits that stability and transformation are both inevitable in any complex system. The cycle can be used to visualize how systems move between stability and transformation (Figure 2.1).

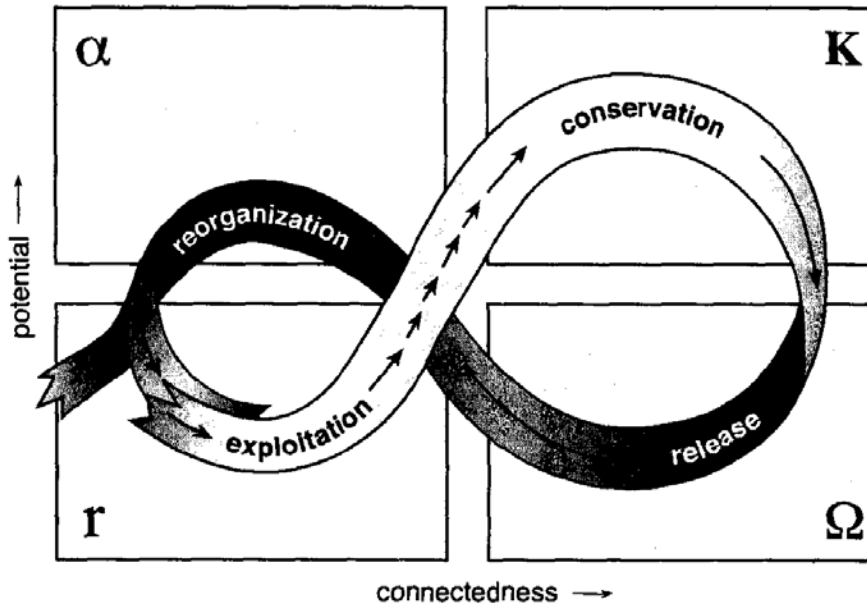


Figure 2.1 The adaptive cycle (Holling and Gunderson, 2002: figure 2-1)

In the K or conservation phase, the system is relatively stable and rigid, with all the elements and their relationships well-established. The system tends to be vulnerable in this phase, and is not very resilient, so in the face of a disturbance, it tends to suffer crisis and collapse. This leads to the omega or release phase, also described as “creative destruction,” when relationships in the system break down and some elements may disappear entirely. The system moves quickly through omega into the alpha, or reorganization, phase, when the system is seeking out a new configuration, and innovations are occurring in the form of new elements colonizing recently opened niches, as well as new relationships forming. In the r, or exploitation, phase, the newly established elements are growing rapidly and competing for resources, establishing their relationships. Finally, the system enters a new conservation phase. In this new cycle, the system could resemble its previous self or a new one entirely. As Holling (2003: xv) puts it, “The ‘front-loop’ of that cycle is the loop of growth. The ‘back-loop’ is the loop of reorganization.”

The cycle has three dimensions (Figure 2.2), all of which are key to understanding the behavior of a system at a given point in the cycle.

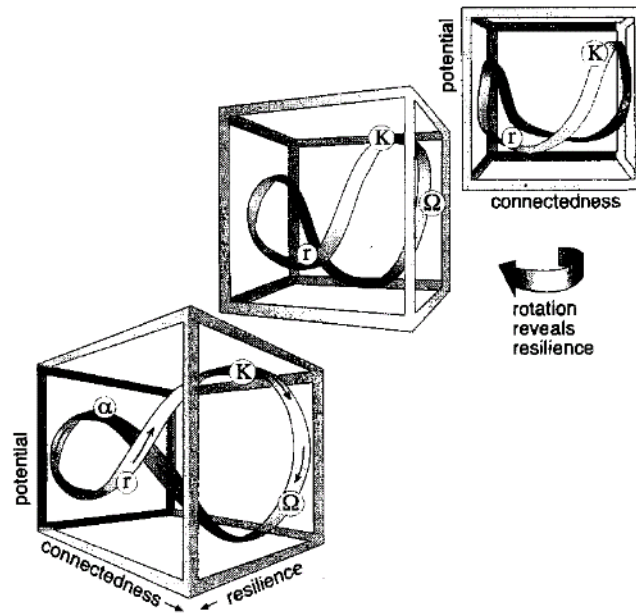


Figure 2.2 The three dimensions of the adaptive cycle (Holling and Gunderson, 2002: figure 2-2)

“Connectedness” refers to how strongly the relationships between system elements are established, and reaches its peak in the K/conservation phase. “Potential” refers to the ability of the system to change and incorporate new elements or relationships, and peaks in alpha/reorganization. The final dimension is “resilience,” or the system’s ability to experience a disturbance and still maintain its identity. Resilience will be discussed in the next section.

The adaptive cycle is useful for characterizing human-natural systems, such as that of agropastoralist societies in a time of environmental change, because it accounts for the dynamic nature of complex systems. Such systems are iterative, reacting to feedback loops and the outcomes of previous cycles. They also function on multiple scales of space and time, each of which influences the others. This inter-scale interaction is what Holling et al. (2002) call the *panarchy*. Energy, matter, and information flow between system elements, between different

scales, and between neighboring systems. This entire configuration is too complex for a single study; in that way, an “ecosystem” is a heuristic device, with artificial boundaries drawn around it to facilitate human understanding of its functions. Systems behave differently at different scales, so studies of ancient climate change and adaptive response must explicitly consider the scale at which the analysis is conducted—the household, the city, or the civilization; a year, a decade, or centuries (Roberts, 2015).

Integration of multi-scalar data is therefore important. Di Cosmo (2002) has likewise stressed the need for more analysis of Eurasian pastoralism at the regional scale, and that researchers should recognize divisions such as watersheds or mountain ranges rather than the less meaningful divisions imposed by modern scholars of the steppe, which are based on historical and current geopolitics (e.g. Manchuria, Mongolia, Xinjiang, etc.). Scholars have conducted such regional-scale analyses in some parts of Eurasia (Anthony et al., 2005; Chifeng, 2003; Frachetti, 2008a; Linduff et al., 2002), as well as publishing some supra-regional syntheses (Anthony, 2009; Di Cosmo, 2002; Mallory, 1989; Shelach, 2009).

Most importantly, paradigms such as the adaptive cycle eschew a simple, linear narrative of human cultural change. There is not a linear relationship between humans and their environment, nor is there a linear relationship between the productivity of an environment for densely settled agricultural production and the development of complex society, an assumption implicit in some literature on this transition (Han, 2008). Embracing this nonlinearity has already led to exciting and fruitful work in Eurasian archaeology (Frachetti, 2008a). This study aims to further expand the use of ecological frameworks to understand the human response to the 4000 BP climate change event.

2.2.2 Resilience

Holling (1986) and Holling and Gunderson (2002) define ecosystem resilience as the ability of a system to experience a disturbance and return to its previous state, without key components or relationships of the system changing (i.e. without losing its system identity). This can also be described as the system remaining in the same “stability domain,” rather than being pushed into a new domain. In terms of the adaptive cycle, a system is most resilient during the alpha/reorganization and r/exploitation phases, before the relationships between system elements are firmly established and when there is more capacity for change within the system. It is least resilient in the K/conservation phase, when the system is stable but also relatively rigid and prone to disruption.

Resilience is a well-studied concept in human ecology, and is reflected in ethnographic accounts of pastoralists as well. For example, it is known that increasing the functional diversity of a system, e.g. by having a complex food web or diverse herd of livestock, increases a system’s resilience (Coughenour et al., 1985; Leslie and McCabe, 2013). Another factor that increases human-environment system resilience is the presence of “multiple stable states” (Robinson and Berkes, 2010: 336), or multiple stability domains in which a system can function and between which it can move as necessary. This is often seen in human-environment systems: Salzman (1980; 2004) thus characterizes cultural changes as usually being reversible due to the presence of “institutionalized alternatives” (2004: 4). A society can best be understood not as conforming to a type, but as “manifesting *multiformity* in activities, structures, and orientations.” This multiformity helps explain how pastoralist systems develop their resilience, and why they are not typically unstable or fragile. Pastoralist systems are often what ecologists call “non-equilibrium but persistent systems” (Barker and Gilbertson, 2000; Goldstein and Beal, 2002; Holling, 1973; Leslie and McCabe, 2013; Leslie et al., 1999)—that is, they do sometimes sustain great

disturbances or even flip between stable states, but they maintain their identity and persist. They are, in fact, highly resilient.

Most large-scale human-environment systems are in fact quite resilient, and disruptions large enough to shift them into a new stability domain are relatively rare (Holling and Gunderson, 2002). Nevertheless, a perspective still dominates much of the research on Eurasian pastoralists that conceives of them as victims of their environment, forced into a “marginal” way of life for lack of access to agricultural lands (Li, 1993). This Sino-centric perspective is still pervasive in the study of ancient Inner Asia (Di Cosmo, 2002), and supports a narrative in which environmental deterioration forced the people of the Northern Zone to abandon agriculture, and thereby to lose the capacity for achieving state-level society.

Resilience theory can help build better models of the human past, that incorporate change and transformation alongside stability and equilibrium. It acknowledges that continuity and change are equally important parts of human-environment systems, and can account for complexity, agency, and contingency in the human past (Contreras, 2017; Faulseit, 2016b; Marston, 2015; McAnany and Yoffee, 2010; Redman, 2005; Schug and Blevins, 2016).

2.3 ETHNOGRAPHY OF PASTORALISM

2.3.1 Pastoralism as an adaptation

The archaeology of pastoralism is a growing field, with a suite of new approaches revealing ancient herd management practices and patterns of mobility and sedentism (Honeychurch and Makarewicz, 2016). Further, because human-environment systems of the past entailed complexity that is difficult to see in archaeological data, the archaeological record is best interpreted in light of ethnographic studies of living peoples. In the ethnographic literature,

mobile pastoralism is often described as an adaptation to marginal environments (usually meaning arid or semi-arid lands). It has been said of mobile pastoralism that its defining characteristic is its variability and flexibility (Frachetti, 2008a; Frachetti, 2008b; Goldstein and Beal, 2002; Gray et al., 2002; Han, 2008; Honeychurch and Makarewicz, 2016; Leslie et al., 1999; Miller, 2013; Robinson and Berkes, 2010; Rosen, 2003; Salzman, 2004; Shelach, 2009). This flexibility allows it to persist in the often unpredictable, marginal ecosystems in which it develops.

Mobile pastoralism can be an adaptation to a local economic system in which there is a demand for pastoral products, or in which economic specialization is encouraged. For example, it has been proposed that pastoralism arose in West Asia when agriculture intensified, and some groups were pushed to the margins of arable land and became pastoralists, where they prospered by trading with the agriculturalists; or, that pastoralism remained a viable alternative to irrigation agriculture when land was rendered unproductive by salinization (Abdi, 2003; Honeychurch and Makarewicz, 2016; Lees and Bates, 1974; Shelach, 2009).

Finally, mobile pastoralism is sometimes cited as an adaptation to life in the sphere of influence of a complex state-level society or empire, in which mobility is a way to avoid the coercion and control of the settled government (Barth, 1961; Frachetti, 2008b; Irons, 1974; Spooner, 1973). In this model, the elite members of the mobile pastoralist society are drawn into the regional system of stratification and take responsibility for maintaining corporate ties with sedentary groups (Barfield, 1989; Dyson-Hudson and Dyson-Hudson, 1980), while maintaining the internal stratification of the mobile pastoralist group and its independence from outside control.

It is also important to distinguish between nomadism and pastoralism: pastoralism refers to subsistence with a specialization in animal husbandry, and nomadism or mobility refers to a wide range of practices usually associated with some form of extensive subsistence (Cribb, 1991; Dyson-Hudson and Dyson-Hudson, 1980). These often co-occur, but are separate phenomena.

It is clear from ethnographic work that there is enormous complexity in the relationships between pastoralists and their environments, as well as in the relationships between groups with different subsistence practices, and even in the relationships between subsistence strategies within a single group. Barth (1961) describes how individual Basseri pastoralist households have relationships with sedentary outsiders, creating an “enmeshing” effect that, in addition to corporate relationships, characterizes interaction between the groups. Economic activities among the Basseri are also fragmented among individual households, which provides short- and long-term stability. Frachetti (2008a), however, points out the difficulty of applying ethnographic findings to archaeological data: on a regional scale, human action has a multi-faceted effect on the environment that cannot be measured archaeologically, and so our picture of the past is “smoothed.”

Though it would be hard to detect, I suspect the sort of fragmented, enmeshed system described by Barth might have existed in Bronze Age Northwest China, which would have increased system memory and redundancy and thereby increased community resilience, within and not just between communities. Variability in local subsistence practices in the Bronze Age might represent village networks of varying specialization and diversification on the household and community level. These networks in turn would have contributed to the processes of iteration and interaction across a pastoralist landscape through time described by Frachetti, which come to us in an artificially smoothed picture.

2.3.2 Limitations of the ethnographic record

Ethnographic studies are of clear significance in the study of archaeological groups and their subsistence practices. There is a particularly rich record of research on pastoralist societies in Southwest Asia from the 20th century (Tavakolian, 2003). However, applying findings from ethnographic studies to archaeological data must be done with caution (Cribb, 1991; Gray et al., 2002; Spooner, 1973). Bernbeck (2008) refers to the “tyranny of the ethnographic record” and criticizes the assumption that ethnographically-derived models can be projected backwards in time (see also Forbes, 1995; Frachetti, 2008a). Some of these models are derived unsystematically, and involve assumptions derived from mobile societies of West Asia (movement of all members of a group, seasonal mobility, and year-round use of a site as evidence of sedentism), which get projected erroneously onto other societies, thus obscuring interesting and important variation.

Categorical thinking derived from ethnographic models can also hinder the identification of nomadic pastoralist societies in the archaeological record (Frachetti, 2008a; Khazanov, 1994). Di Cosmo (2002: 88) echoes this in pointing out that steppe nomads’ development was not straightforward, and that there were regional variants that did not exist along a “linear evolutionary continuum.” Dyson-Hudson and Dyson-Hudson (1980: 18) even go so far as to say that trying to categorize subsistence systems is “intellectually sterile.” As Tavakolian (2003: 299) puts it, “in looking at multiple studies of nomadic pastoralism, how much are we looking at an artificial anthropological category and an ‘ideal’ societal type that forces us to dwell on only spurious cross-cultural similarities?” And in the ethnographic record, are we actually seeing different “types” of nomads, or rather different anthropological approaches? This is nearly impossible to test.

Nevertheless, ethnographic data is critical in the interpretation of archaeological data, since it alerts archaeologists to the existence of such concepts and system components as mosaics or patchiness in resources and subsistence practices, response diversity, flexibility and multiple stable states, institutionalized alternatives, and the nature of ethnic boundaries and identity. Ethnographically-derived models should be used, but with caution—more as heuristic devices or analogies (Abdi, 2003; Wendrich and Barnard, 2008) than as actual models of human behavior to be tested against the archaeological record.

Again, in researching subsistence practices, it is useful to investigate variables rather than types, as advocated by Dyson-Hudson and Dyson-Hudson (1980), and the relevant variables can be gleaned from ethnographic research. Useful parameters for reconstructing subsistence practices in mixed subsistence regimes of the past include: direct and indirect dietary reconstruction from human remains (using oral health and stable isotope analysis); the ratio of far-ranging grazing animals (sheep and goats) to short-range grazing animals (cattle and pig); the ratio of food crops (e.g. wheat) to fodder crops (e.g. barley); the ratio of wild to cereal plant remains from dung burned as fuel, which is evidence for steppe grazing vs. stubble grazing or foddering (Miller, 2013); and variations in $\delta^{15}\text{N}$ values which may indicate manuring of crops (Fraser et al., 2011).

2.4 BIOARCHAEOLOGY OF SUBSISTENCE TRANSITIONS

Bioarchaeology can provide substantial data on ancient subsistence systems. Past bioarchaeological research on subsistence transitions has focused primarily on the health consequences of the origins of agriculture (Lambert, 2000; Larsen, 1997; Steckel and Rose, 2002c; Stock and Pinhasi, 2010), and the methods developed in this work can also be applied to

the study of biological and social consequences of other prehistoric subsistence changes, such as the Bronze Age transition to agropastoralism and pastoralism in Eurasia.

The agricultural transition often entailed increased fertility but an overall decline in health, measured in growth disruptions, oral health, nutritional deficiencies, and infectious disease load. Thus, shorter stature, more dental caries, more nutritional deficiencies, and a higher burden of infectious diseases characterize many early agricultural societies (Cohen, 1997; Cohen and Armelagos, 1984; Lambert, 2000; Lambert, 2009; Larsen, 1995; Steckel and Rose, 2002c; Wood et al., 1992). This epidemiological transition has been documented in most places where agriculture arose in prehistory (Barrett et al., 1998). This includes Egypt (Starling and Stock, 2007), South America (Ubelaker and Newson, 2002), Mesoamerica (Norr, 1984), North China (Pechenkina et al., 2002; Pechenkina et al., 2007), Southwest Asia (Rathbun, 1984), and others.

There is some variation in the agricultural transition between regions. For example, research in Southeast Asia suggests that the negative health consequences observed with early cultivation of maize, wheat, and millet do not appear with the advent of rice agriculture (Clark et al., 2014; Dommett and Tayles, 2007; Douglas and Pietruszewsky, 2007; Halcrow et al., 2013; Krigbaum, 2007). This may be due to several factors, including the high nutritive value and low cariogenicity of rice, the fact that rice cultivation in Southeast Asia was often supplemented by foraging and fishing, and that rice was adopted gradually. Alternatively, these data might indicate that wet rice agriculture led to a different suite of health problems that bioarchaeologists have yet to identify, for example increased parasite loads or burdens of vectored diseases (e.g. schistosomiasis and malaria) from the presence of standing water in rice paddies. Furthermore, the adoption of millet agriculture in China did not lead to a dramatic decline in community health until social complexity and inequality increased in the late Neolithic (Pechenkina, 2015). This

variation also suggests there is significant diversity in human biological and social reactions to subsistence change (Stock and Pinhasi, 2010), and there is a need to contextualize data on subsistence transitions within specific environmental and socio-technological contexts (An et al., 2004).

Decades of skeletal analysis by bioarchaeologists has created a large body of comparative data on health in prehistoric and historic groups around the world. While there is still a need for greater standardization of methods and training (Buikstra and Ubelaker, 1994; Steckel and Rose, 2002b; Ubelaker, 2003), there is some effort to undertake large interregional and diachronic comparative studies of the history of human health (Steckel et al., 2006), to identify large-scale patterns in morbidity and mortality. Some have claimed that only with such relative data can we avoid the most serious limitations of bioarchaeological methods (Cohen, 1997; Cohen and Crane-Kramer, 2003; Ubelaker, 2003; Wood et al., 1992).

For the purposes of this study, it is also important to note that in addition to being difficult to quantify (Meade and Emch, 2010; Wood et al., 1992), health does not have a straightforward relationship to resilience. Good health does not necessarily mean high resilience: very resilient systems are sometimes maladaptive (Holling and Gunderson, 2002; Robinson and Berkes, 2010). I am therefore not interested in health as an absolute measure, but in whether specific measures of stress, diet, demography, etc. changed through time, if they changed categorically, and if those changes were correlated with changes in the human subsistence system or the environment.

2.5 HYPOTHESES

Resilience theory and the adaptive cycle allow us to see ancient societies as adaptable, heterogeneous, and connected, rather than as victims of lost carrying capacity and a slide down

the cultural evolutionary ladder. These concepts therefore provide both a more productive and a more accurate way of modeling the human past than homeostatic or categorical models.

The environmental changes surrounding the 4000 BP climate event in Northwest China are often described as environmental degradation (Han, 2008; Huang et al., 2002; Zhao et al., 2009; Zhou et al., 2012), which increased the marginality of the environment. However, degradation and marginality can only be defined with reference to human values and activities. For example, in a place where reindeer herding is practiced, the opposite environmental change (an increase in temperature and moisture) might be considered degradation, since it would devastate the food system. The environmental change in Northwest China was only a form of environmental degradation insofar as it undermined the existing way of life and made the area more marginal for human occupation.

Rather than an episode of degradation, the Bronze Age transition is perhaps better evaluated as a state change in a complex system. In this scenario, one can hypothesize that some critical feature or relationship within the system was altered in such a way that the system was disturbed beyond its point of equilibrium and shifted into a new form, with a new identity and a new set of components and relationships. In the adaptive cycle framework, the main periods of transformation are between r and K , when competition falls off and the system goes from wide open potential to a fixed order (the loop of growth); and between K and ω , when a disturbance causes a crisis in the system (the loop of reorganization). We can therefore ask, was the Bronze Age transition in Northwest China a case of growth or of reorganization (Holling, 2003)?

The literature on sustainability and development proposes a similar distinction, and provides the terminology I will use throughout this study. According to this framework, when

faced with a climate change event, a human-environment system can react in one of two ways: incremental or transformational adaptation (Clarke et al., 2015; Field et al., 2014; Nelson et al., 2007; O'Brien et al., 2014; Stafford Smith et al., 2011).

In the case of **incremental adaptation**, some changes occur in the system, but all components and relationships that are critical to the identity of that system remain in place. Essentially, the system persists beyond the climate change event, with only marginal changes. The system is therefore resilient enough to withstand disruption and persist in the face of the disturbance (Cumming et al., 2005; Holling and Gunderson, 2002). This is similar to the r/K , or growth, transformation described above.

In the case of **transformational adaptation**, fundamental components of the system or the relationship between components in the system change. This entails the formation of a new system, distinct from the one that existed before the climate change event. In other words, the system moves from one stability domain, or domain of attraction, to another (Holling, 1973; Holling and Gunderson, 2002). Thus, the “collapse” of a subsistence system could be considered a type of transformational adaptation (Clarke et al., 2015). This is similar to the K/ω , or reorganization, transformation described above.

To take a simple example, after Carpenter et al. (2001): we could define a ranching system by its components (humans, sheep, grassland) and the relationships among them (grazing, harvesting). If the grassland is no longer able to support sheep pastoralism—because of a change in climate, unsustainable management practices, the loss of subsidies, etc.—and the humans take up the raising of cash crops instead, this would constitute a transformational adaptation. If, however, the ranchers simply diversify their economic pursuits but continue to raise sheep, or replace their sheep with goats, most of the system’s components and relationships remain in

place. Thus, the system's identity would not be changed, and this would constitute an incremental adaptation.

To distinguish between incremental and transformational adaptation, we have to first define the system identity (Carpenter et al., 2001; Cumming et al., 2005). However, it is not yet possible to do this in a robust way for prehistoric Northwest China, as quantitative data on settlement patterns and plants and animals is largely lacking. Therefore, in this study, I am taking the preliminary step of employing human biological data to distinguish between an incremental and a transformational adaptation. Because biological indicators reflect the influence of both the biophysical and the socioeconomic environment, they are ideal for detecting change in human-environment systems, whatever the suite of environmental and social causes of that change.

In the case of an incremental adaptation, I would expect to see little detrimental effect on the population, since the subsistence system would remain essentially unchanged, whereas in the case of a transformational adaptation, I would expect the changes in diet and lifeway to lead to categorical changes in population health and demography, including in oral health, physiological stress, frailty, and fertility, as has been found at the origins of agriculture.

There is ample archaeological evidence that for all the innovation and change in the Bronze Age of Northwest China, agriculture and sedentism persisted throughout, though some changes to herd composition took place. **Therefore, I favor the latter hypothesis, that environmental change was not drastic enough to precipitate a collapse of existing subsistence practices, and that the Bronze Age transition constituted an incremental, not a transformational, adaptation.**

2.6 BIOARCHAEOLOGICAL METHODS

2.6.1 Sex estimation

Sex was estimated using cranial and pelvic nonmetric traits, in addition to femoral head diameter. I used five standard cranial nonmetric traits, which I scored on a scale of 1 to 5 (1=female, 2=likely female, 3=indeterminate, 4=likely male, 5=male) before making a final estimation (female, probable female, indeterminate, probable male, male, or unable to estimate) .

I used the standard pelvic nonmetric traits from Phenice (1969) to estimate sex: degree of expression of the ventral arc, the degree of concavity of the sub-pubic contour, and the shape of the medial aspect of the ischio-pubic ramus. I scored these on a scale of 1 (female) to 5 (male), and then used a published logistic regression equation to arrive at a probability for male or female (Klales et al., 2012).

A femoral head maximum diameter over 42.9 mm suggests a sex estimation of male, and a diameter under that suggests female. This is based on a study of skeletal remains from a modern Northeastern Chinese population (Liu, 1989), and was used only to confirm pelvic and cranial estimates or if those elements were not usable. My final estimation of each individual's sex was based on a combination of these three measures, or whichever of them were observable for a given individual.

2.6.2 Age estimation

I used a total of five features for age estimation of adult remains, and applied only those that were possible for each individual. The features include the morphology of the pubic symphyseal face (Brooks and Suchey, 1990), the morphology of the auricular surface of the ilium (Lovejoy et al., 1985), the degree of epiphyseal fusion of the medial clavicle for young

adults (Langley-Shirley and Jantz, 2010), the degree of fusion of the lateral-anterior system of cranial sutures (Meindl and Lovejoy, 1985), and the morphology of the sternal ends of ribs (Iscan, 1991). For subadults, I used stage of tooth eruption according to the “London Atlas” (AlQahtani et al., 2010), as well as postcranial measurements and epiphyseal fusion where possible (Schaefer et al., 2009). Finally, I arrived at an estimated range of age-at-death for each individual, based on the overlapping portion of the age ranges of all techniques used for that individual. Age-at-death distributions for each group are presented in Chapters 3 through 5 in tables of age categories; an individual was assigned to a category if all or most of the estimated age-at-death range fell into that category, or was assigned to multiple categories if the age-at-death range overlapped significantly with more than one category.

2.6.3 Paleodemography

Demographic measures such as fertility, life expectancy at birth, and age-specific hazard of death are sensitive to many environmental and social factors. Calculating these measures and drawing causal links with diet, sociopolitical conditions, etc. is especially difficult given the limitations of archaeological samples (Bocquet-Appel and Masset, 1982; Buikstra et al., 1986; Sattenspiel and Harpending, 1983). Furthermore, increased mortality often indicates higher chronic and acute morbidity in a population, but there is variability within and between populations in terms of the frailty of individuals, or their susceptibility to death from a given pathology, also called “hidden heterogeneity” (DeWitte, 2009; Hoppa and Vaupel, 2002; Milner et al., 2008; Wood et al., 1992). Also, reduced average age at death might be due to an increase in fertility rather than in mortality (Sattenspiel and Harpending, 1983), which creates a larger proportion of young individuals in a living population and its derived mortuary sample, and will therefore lower the average age at death in an attritional mortuary sample without a real change

in life expectancy at birth for the living population. (However, Cohen (1997) argues that the effect of birth rate would have to be quite high to distort the average age at death in this way.) Some of these concerns can be addressed with appropriate data collection and statistical methods; for example, life expectancy can be estimated by modeling survivorship with a technique such as hazard analysis. Unfortunately, none of the samples in this study are large enough to allow the use of hazard analysis. Though hazard analysis can be applied to smaller samples than life table analysis, one published “small” sample analyzed with this method is 255 individuals (Gage and Gage, 1988). No one site in my study exceeds 75 individuals, and when a model is fitted to the age and sex distribution at this site, there is no main effect for either sex or the Makeham parameter, which is likely due to the small sample size rather than to the demographic conditions of the mortuary sample. Therefore, I have not employed hazard analysis in this study.

Fertility is easier to measure in a mortuary population than mortality, and is highly sensitive to a number of biological and environment factors. Nutritional status and fecundity, parental decisions and risk-management behavior, and sedentism vs. mobility all influence population fertility in ways that interact and are difficult to predict (Bentley et al., 1993; Leslie and Winterhalder, 2002; Milner et al., 2008; Sattenspiel and Harpending, 1983; Winterhalder and Leslie, 2002). Moreover, a decline in the health status of a group of people does not always lead to lower fertility; for example, population growth at the origins of agriculture is thought by some to have occurred *despite* the decline in dietary quality, representing a trade-off between reproductive fitness and health (Lambert, 2009).

Resource exploitation and fertility are also mutually influential. As Neupert (1999) and Spooner (1973) point out, Ester Boserup’s (1965; 1987) model of agricultural intensification can

be applied in cases of intensifying pastoral production as well. Boserup's model states that population growth in fact precedes food production intensification, and that agricultural intensification is not necessarily a radical revolution or discovery, but rather a logical expansion of technology that is already known to a group farmers or foragers using extensive strategies. If population growth created a need to exploit the environment more intensively, intensifying animal husbandry would be a logical way to provision the population. Evidence of high fertility and population growth prior to the rise of pastoralism in Northwest China would support this idea.

Because fertility has many implications for ancient health and subsistence, in this study I address paleodemographic change in terms of fertility rather than mortality. To accomplish this, I use the juvenility index, a measure of fertility. I use the version of the juvenility index from Buikstra et al. (1986), which is the proportion of people over the age of 30 to people over the age of 5 in the mortuary sample (D_{30+}/D_{5+}). This measure eliminates the problem of poor preservation and under-enumeration of infant remains (because it does not consider individuals under five years old at death), and also avoids many age estimation issues, as individuals only need to be assigned to the "under 30" or "over 30" categories (Bocquet-Appel and Masset, 1982; Chamberlain, 2006; Frankenberg and Konigsberg, 2006).

Whatever the combination of factors at work during the Bronze Age transition, if the marginality of the environment increased appreciably, I would expect to see a detectable change in fertility: either a decline in fertility as women of childbearing age experienced compromised nutritional status and increased physical labor demands, or a rise in fertility as people reacted to an increased infant mortality rate by producing more offspring.

2.6.4 Paleopathology

I observed bony pathological lesions macroscopically and under 3.5x magnification. The categories of recording are based on those in Ragsdale (1993) and Buikstra and Ubelaker (1994). They include abnormal bone formation (e.g. periosteal new bone, active or healing), bone loss (e.g. lytic lesions), trauma (including antemortem, perimortem, or postmortem), porosis (including ectocranial porosity), arthritis (recorded as lipping, porosity, and/or eburnation on the joint surface), vertebral pathologies and anomalies, and oral pathologies. All pathological lesions were described by their location on a specific element and their appearance. In Chapters 3 through 6, I report my findings and interpret their significance. For example, ectocranial porosity indicates an experience of anemia in the first four years of life, possibly megaloblastic anemia from vitamin B₁₂ deficiency or intestinal infections (Walker et al., 2009).

Oral health measures in the study include carious lesions recorded by location on each tooth, antemortem tooth loss (AMTL), alveolar abscesses (buccal/lingual), and pulp exposure from wear or carious lesions. The data on pulp exposure were used to calculate the calibrated carious lesion frequency. The calibration method developed by Lukacs (1995) involves estimating how many teeth were lost antemortem due to pulp exposure from carious lesions, and then adding this to the total observed carious teeth. Duyar and Erdal (2003; Erdal and Duyar, 1999) advocate applying this method separately to the anterior and posterior teeth, as they often develop carious lesions at different rates. I compared the results of these two methods; where the difference was not significant, I report the Lukacs calibrated rate, and where the difference was significant, I report the Duyar and Erdal rate. I also report the uncalibrated rates.

Though oral health measures have very complex etiologies and do not have a linear relationship to diet, it is well-established that diet influences frequencies of carious lesions, calculus, occlusal wear, AMTL, and alveolar abscesses. In a pilot study of 55 individuals from

the Bronze Age cemetery of Tianshanbeilu in Xinjiang, China, which I conducted in the summer of 2013, I found that the population had a very low rate of carious lesions: 4.8% of teeth, or 5.1% calibrated (Lukacs, 1995), as well as only moderate occlusal wear and calculus (Berger et al., 2014). Carious lesions are often linked to the consumption of cariogenic foods such as cereal grains, though the relationship is not linear and is related to oral cavity pH, hygiene, and genetic factors. Low carious lesion frequency might also be related to dairy consumption, as milk is thought not to be cariogenic and even possibly to have a protective effect against carious lesions (Eng, 2007; Katzenburg and Saunders, 2008). Dental wear is associated with the toughness or grittiness of a diet and is often related to food preparation techniques (Smith, 1984).

2.6.5 Growth and development

Interruption of growth in childhood can be due to insufficient nutrition or infection with a parasite or infectious disease organism. Low stature attainment can also be due to poor nutrition or other physiological stress, though delays in growth can be erased with “catch-up growth” that allows an individual to reach a typical height despite growth delays earlier in life (DeWitte and Wood, 2008; Little et al., 1999). Stature is also largely inherited, so genetic factors have to be ruled out when stature differences are observed. To assess stature differences between populations, I measured the maximum length of the humeri, the bicondylar length of the femora, and the maximum length of the tibiae excluding the medial malleolus. I only measured complete long bones whose epiphyses were fused or fusing. As stature estimation formulae developed on modern populations may not be appropriate for the groups in this study, I directly compared long bone lengths between groups, rather than comparing estimated statures.

Linear enamel hypoplasias (LEH) are indicators of interruptions in amelogenesis, which often result from episodes of malnutrition, infectious disease, or parasite infection (Hillson,

1996). A higher rate of LEH generally indicates a higher burden of growth disruptions in a population. However, it is also possible that fewer LEH could indicate a higher burden of physiological insults and higher frailty: if fewer individuals survived childhood insults, fewer would go on to form LEH (Wood et al., 1992). An increase or decline in LEH must therefore be interpreted in light of other evidence for frailty. LEH were identified by visual observation with raking light as horizontal grooves in the enamel, and recorded as present or absent on each tooth.

2.6.6 Biodistance

Population migration and replacement are influenced by environmental change, and can in turn influence a number of the above measures, including adult stature. Many published studies have already found evidence of population movement around North and East Asia in prehistory, including at the sites included in this study (Han, 1990; Han, 2001; Zhang et al., In preparation; Zhao et al., 2014).

To measure the biological distance (biodistance) between the study populations, I recorded nonmetric traits from Hallgrímsson et al. (2004) and Killgrove (2009), narrowed to a list of 20 traits for ease of recording. I recorded each trait as present or absent on only the left side of each skull, unless the left was unobservable, in which case I recorded the right side. If both sides were unobservable, I recorded that trait for that individual as “unobservable.” Recording on only one side reduces the possibility of incorrectly weighting more complete skulls more heavily in the final analysis (Hallgrímsson et al., 2004). Using this binary data, I conducted both a mean measure of divergence (MMD) analysis (Killgrove, 2009) and a Ward’s cluster analysis in SAS 9.4. The results of these analyses are discussed in Chapters 3 through 6.

2.7 STRUCTURE OF THE DISSERTATION

The data I have collected on paleopathology, paleodemography, and biodistance capture the human biological consequences of the Bronze Age transition in three areas of Northwest China. I first discuss the trajectory of population health and demography in each of these three regions, and then discuss them together in the final chapter.

Chapter 1 details the archaeology and geography of the study region and the study sites. Chapter 2 has outlined the theoretical framework on which the dissertation research is based, and the methods that are employed in the research. The next three chapters, Chapters 3 through 5, detail the findings from each of three sub-regions within Northwest China, each of which is located in a different geographic and ecological setting, has a unique trajectory of culture contact and migration, and tells a slightly different story of biocultural adaptation.

Chapter 3 discusses the results from the sites on the Qinghai Plateau in Qinghai Province, comparing the late Neolithic groups from Mapai and Yangshan to the middle Bronze Age group from Xiaohandi. These groups show continuity in health and demography. Chapter 4 discusses the sites from the Hexi Corridor in Gansu Province, comparing the early Bronze Age group from Huoshaogou to the late Bronze Age groups from Hamadun and Xigang. These groups show a marked improvement in population health over time. Chapter 5 discusses the sites from the Loess Plateau in northern Shaanxi Province, and compares the Warring States period groups from Zhaitouhe and Shijiahe, as well as the small sample from Jiulongshan in Ningxia. These show a decline in population health that is more likely related to social factors than to environmental ones.

When all these regional cases are taken together, they reveal the ways in which sociocultural factors can both buffer human groups from environmental stressors, and serve as stressors themselves. The data from these three chapters will be brought together in Chapter 6,

which discusses the findings in relation to the adaptive cycle framework and incremental vs. transformational adaption.

CHAPTER 3 QINGHAI PLATEAU: A MID-ALTITUDE TEMPERATE LOESS ZONE

This chapter presents findings from the late Neolithic sites of Mapai and Yangshan, and the middle Bronze Age site of Xiaohandi, all of which are located in Minhe County, Qinghai. The picture of health and diet that emerges from these sites is complex, but suggests that there was no significant change in diet or lifeway between the two periods, even after the 4000 BP climate change event. This is even more striking given that there seems to have been some population replacement or mixing in this area during the Bronze Age.

3.1 CLIMATE AND ENVIRONMENT

Minhe County, Qinghai is located in a river valley on the eastern edge of the Qinghai Plateau, at the meeting point of the Qinghai Plateau and the northwestern Loess Plateau. It is characterized by a humid continental climate with a dry winter and a mild/cool summer (Köppen climate classification: Dwb) (Kottek et al., 2006). The area has complex geography: the valley's ecology and climate are conducive to agriculture, with a long growing season, but subarctic and cold steppe areas are located not far away.

3.1.1 Paleoclimate and paleoecology

Pollen data from lake sediment cores show that the Northwest Loess Plateau was drier after 2000 BCE (Cui et al., 2006; Liu and Feng, 2012). Some sources date the beginning of this transition to around 1000 BCE (Zhao et al., 2009), and some date it to c. 3000 BCE with a period

of strengthened monsoon activity and increased moisture between 2700-1960 BCE, which was again followed by a dry period (Dong et al., 2012; Dong et al., 2013b). The disparity between these studies results from the fact that the precise sequence of moisture and vegetation change varied between locations and elevations, and change was often cyclical (Dong et al., 2012).

While the transition appears dramatic in some places, it is part of gradual and long-term change in others (Liu and Feng, 2012), and climate changes seem to have differed greatly from place to place, even within a space of several hundred kilometers (Zhao et al., 2007). Archaeological data collected to date suggest that there was a reduction in settlement density in eastern Qinghai during the time of the drought in the third millennium BCE, though it later recovered somewhat (Dong et al., 2013b; Zhao et al., 2012).

Today, eastern Qinghai, encompassing the area around the Huangshui River Valley, is a temperate grassland environment that receives 300-500 mm of precipitation per year. The flora here is dominated by wormwood and sagebrush species (*Artemisia campestris*, *A. salsoloides*, *A. frigida*, *A. gmelini*), feather grasses (*Stipa* spp.), yellow bluestem (*Bothriochloa ischaemum*), Chinese rye grass (*Leymus chinensis*), jiji grass (*Achnatherum splendens*), and sedges (*Carex* spp.). A warm steppe environment pertains in this area below 3000 m above sea level (Dong et al., 2012; Zhao et al., 2009), the zone in which the study sites are located. This area is at the edge of the East Asian summer monsoon zone, and shifts in the monsoon may be responsible for late-Holocene climate change in the region.

Roughly a thousand years passed between the late Neolithic occupation of Yangshan and Mapai (2600-2000 BCE) and the middle Bronze Age occupation of Xiaohandi (1500-1000 BCE). These two occupations therefore straddle the period in which a drying and cooling climate and advancing steppe vegetation changed the landscape of Northwest Chinese. However, this

climatic change does not seem to have had a dramatic impact on the lifeway, diet, or health of people in eastern Qinghai. The transition was likely not extreme or sudden enough to necessitate the abandonment of earlier lifeways in Minhe County, though pastoral practices seem to have developed in the Kayue culture, which was dominant to the west of Minhe County (Liu and Feng, 2012).

3.2 PALEOPATHOLOGY

Because the available samples were relatively small, the samples from Mapai (N=11) and Yangshan (N=32) were combined for this analysis. The two sites are located in Minhe County, Qinghai, in neighboring river valleys. They date from slightly different periods of the late Neolithic, Yangshan being from the late Banshan Culture (2600-2300 BCE) with some elements of the Machang Culture, and Mapai belonging to the Machang Culture (2400-2000 BCE). These are closely related material culture horizons, and there is some debate over whether they should be considered separate cultures at all, or could be considered phases of the late Majiayao culture (Xie, 2002). They also overlap in time, and there was therefore probably extensive contact between the cultures. Because of their cultural relatedness and geographic proximity, it is reasonable to combine them for the analysis.

I also compared paleopathological measures between Yangshan and Mapai to determine if there were significant differences before pooling them. This was made difficult by the fragmentary nature of the remains. No dentition from Yangshan was preserved, so oral health measures could not be compared. Stature also could not be compared, as the Mapai remains were too fragmentary and some bones were represented by only one or two specimens for one or the other sex. No osteoarthritis (OA) was observed at Mapai, probably because of the small sample size. Only one cranium from Yangshan was complete enough to assess for ectocranial porosity

(it did not exhibit any). Therefore, the only measure that can be compared between the groups is the presence of tibial periosteal new bone (Table 3.1).

Table 3.1 Periosteal reaction at Yangshan and Mapai

	Yangshan (N=28)	Mapai (N=6)
Woven	0	1
Rate	0.0%	16.7%
Compact/compact+woven	24	3
Rate	85.7%	50.0%
None	4	2
Rate	14.3%	33.3%

A Chi-square test showed this difference to be significant at the $p < 0.05$ level (Chi-square 6.4762, $p = 0.0392$), and a Fisher's exact test agreed ($p = 0.0326$). However, even if Mapai were removed from the sample, the trend in comparison to Xiaohandi would be the same (see Infectious and metabolic conditions, below). Therefore, given the archaeological justifications for pooling the samples, and the inability to assess their differences with regards to the other paleopathological measures, I conclude that it is still reasonable to combine the groups for the following analysis.

3.2.1 Oral health

Only five individuals from Mapai, and no individuals from Yangshan, could be scored for oral health measures, so the Neolithic sample of dentition is quite small. Fifteen individuals from Xiaohandi had preserved dentition (Table 3.2).

Table 3.2 Oral health measures at Mapai and Xiaohandi

	<i>Calibrated carious lesion rate[†]</i>	<i>Uncalibrated carious lesion rate[†]</i>	<i>Cariou lesion rate: M[†]</i>	<i>Cariou lesion rate: F[†]</i>	<i>Average wear score^{**†}</i>
<i>Mapai*</i>	0.0%	0.0%	0.0%	0.0%	4.8
<i>Xiaohandi*</i>	9.4%	9.5%	0.0%	15.8%	3.9

	<i>AMTL[†]</i>	<i>AMTL: M[†]</i>	<i>AMTL: F[†]</i>	<i>Calculus[‡]</i>	<i>Abscesses[‡]</i>
<i>Mapai*</i>	1.4%	0.0%	1.4%	0.0%	0.0%
<i>Xiaohandi*</i>	20.0%	31.5%	15.2%	0.0%	13.3%

*Lukacs (1995) caries calibration method not significantly different from results using Duyar and Erdal method

**Scored using method developed by Smith (1984)

[†]Number of teeth out of all teeth observed

[‡]Number of individuals out of all individuals with observable teeth

3.2.1.1 Caries

Caries is a common oral pathology in communities that practice agriculture. However, in contrast to agricultural groups in other parts of the world, the frequencies of carious lesions at both Mapai/Yangshan and Xiaohandi is relatively low (Table 3.2).

The small sample size may account for the fact that no carious lesions were observed in the Mapai population, leading to a carious lesion frequency of 0% for the Neolithic sample. The Xiaohandi group had a calibrated carious lesion frequency of 9.4% (uncalibrated rate 9.5%). This is lower than some agricultural populations, but within the range of comparable East Asian prehistoric farming communities (Turner, 1979). The difference between Mapai and Xiaohandi is significant (Chi-square 7.2272, p=0.0072)

Caries is often a progressive condition, so a younger mortuary sample would tend to have a lower carious lesion frequency. However, the difference in carious lesion frequency in the Mapai and Xiaohandi groups cannot be accounted for by age: most of the individuals scored for dental lesions in both populations were in the young adult (20-34 years) and middle adult age categories (35-54 years).

All the carious lesions observed in the Xiaohandi population were in females or probable females. Nine females were scored for oral pathology, and had a calibrated carious lesion frequency of 15.8%. The five males (and one indeterminate individual) scored for oral pathology had no carious lesions. This is not an unexpected finding, as caries prevalence has been found to be higher in females of many populations (Lukacs, 1992; Lukacs and Largaespada, 2006). However, Xiaohandi is the only site in the study with a difference between the sexes in terms of carious lesion frequency that is significant at the $p < 0.05$ level (Chi-square 9.4306, $p = 0.0021$), except for the small group at Jiulongshan (see Chapter 5).

3.2.1.2 Attrition

The Mapai population had an average occlusal wear score (Smith, 1984) across all teeth of 4.8 (on a scale of 0-8), and the Xiaohandi group had an average wear score of 3.9. Pulp exposure due to wear was not frequent within these populations. Though the two scores appear close, and the Mapai population is only represented by 5 individuals, when counts of teeth with each wear score are compared, the two populations' attrition rates are significantly different (Chi-square 22.6527, $p = 0.0009$; Fisher's exact test $p < 0.0001$; Student's t-test $p = 0.0004$). Again, the age distribution between the populations does not seem different enough to account for the heavier wear at Mapai. The difference therefore likely indicates that the population at Mapai had a tougher or more abrasive diet than that of Xiaohandi, perhaps due to food preparation practices such as the use of grinding stones. Grinding stones were still in use in the Bronze Age, though, as two were found at Xiaohandi (Qinghai et al., 2004).

3.2.1.3 Calculus

None of the individuals in the Mapai or Xiaohandi populations exhibited dental calculus. The remains have been stored in conditions that are not ideal for preservation, so it is possible that some calculus has been abraded and lost over time. However, even if this is the case, then there was likely not a large amount of calculus to begin with in these populations. This points to continuity in the diet, or possibly in dental hygiene practices, between the late Neolithic and the middle Bronze Age in Minhe County.

3.2.1.4 Antemortem tooth loss

Antemortem tooth loss (AMTL) is usually the result of a tooth's pulp cavity being exposed, either by a large carious lesion or by heavy occlusal wear (Lukacs, 1995). Given the low frequencies of carious lesions in these populations and the moderate occlusal wear, the rates of AMTL were somewhat surprising: Mapai had a rate of 1.4% of observable alveoli showing AMTL, but Xiaohandi had a rate of 20.0%.

Wear was responsible for most of the pulp exposure in these populations, which suggests most of the AMTL was due to wear. In the Mapai population, no teeth had pulp exposure from a carious lesion, and 25 teeth had pulp exposure from wear. In the Xiaohandi population, one incisor had pulp exposure due to a carious lesion, and 10 teeth (canines, premolars, and molars) had pulp exposure due to wear. Most of the 29 observable teeth lost antemortem were posterior dentition.

The difference between the two sites is difficult to account for, since Mapai has a higher average wear score than Xiaohandi, but had much lower AMTL. Given that most pulp exposure in these populations was due to attrition and not carious lesions, and that attrition decreased, it is difficult to explain the dramatic increase in antemortem tooth loss between the sites (1.4% to

20.0%). This might be accounted for by missing data: 20% of the alveoli at Mapai were unobservable because the alveolar bone was missing. However, 27% of alveoli at Xiaohandi were also unobservable, so the discrepancy is likely a result of Mapai's small overall sample size.

3.2.1.5 Abscesses

Abscesses (infection in the alveolar bone with drainage) were not observed at Mapai, again possibly due to the small sample size of individuals with preserved dentition. At Xiaohandi, 13.3% of individuals with preserved dentition had abscesses (0.069% of observable alveoli). After Mapai, this is the lowest rate of any population in the study. The rate is roughly equivalent to that of the groups in Gansu with mixed agropastoral subsistence systems (see Chapter 4), and much lower than historical agricultural groups in Shaanxi (see Chapter 5).

One individual from Mapai (MHPM10) had sclerotic appositional bone along most of the buccal surface of the alveoli on both the maxilla and the mandible, perhaps from periodontal disease, and a large window on the lingual side of the mandible, though there was no corresponding carious lesion. This individual also had other signs of a systemic infectious disease (see Infectious and metabolic conditions below). Overall, these populations had very low rates of bony infection and inflammation in the oral cavity.

3.2.2 Osteoarthritis

Osteoarthritis (OA) rates were calculated as the rate of spinal osteophytes (out of all adult individuals with any spinal elements present), rate of OA in the upper limb (out of all adult individuals with upper limb elements present), and rate of OA in the lower limb (out of all adult individuals with lower limb elements present). OA was recorded if lipping, eburnation, or

porosity was observed on joint surfaces. Schmorl’s nodes, caused by herniation of the intervertebral disk, were not observed in the Mapai/Yangshan and Xiaohandi populations.

There was no significant difference in the rates of osteoarthritis between Mapai/Yangshan and Xiaohandi (Table 3.3). No individuals from either site had any evidence of arthritis in the spine, perhaps because there were very few spinal elements preserved. In each population, 4.5% of individuals had OA in one or more upper limb elements. In the Mapai/Yangshan population, 8.0% of individuals with lower limb elements preserved had OA, and in the Xiaohandi population, 3.6% of individuals with lower limb elements preserved had OA. This is not a significant difference (Chi-square test=0.4851, p=0.4861; Fisher’s exact test p=0.5966).

Because of curation practices at the time of the excavations, the postcranial remains from these sites are fragmentary, but the lack of clear difference in OA rates between them supports the idea that their labor demands, possibly related to subsistence practices or economic activities such as agriculture, did not change substantially over time.

Table 3.3 Osteoarthritis in Mapai/Yangshan and Xiaohandi

	Mapai/Yangshan	Xiaohandi
Vertebral osteophytes	0/1 individuals	0/5
Rate	0.0%	0.0%
Arthritis upper limb	1/22	1/22
Rate	4.5%	4.5%
Arthritis lower limb	2/25	1/28
Rate	8.0%	3.6%

3.2.3 Trauma

There were three cases of trauma among the remains from Mapai. One was a healing trepanation on a frontal bone (individual MHPM26, an adult probable female aged 17-50 years at death) (Figure 3.1). The second case of trauma was also a healing trepanation, on a parietal bone (individual MHPM29, adult probable female) (Figure 3.2). The third case (MHMM39, adult probable female) had a deformed right humeral head that is slightly distally displaced, which probably indicates that the bone suffered trauma during growth and before the epiphysis fused (Figure 3.3).

There were two cases of trauma in the Yangshan population. One was another healing trepanation on the frontal bone (individual MXYM107, probable male, aged 25-29 at death) (Figure 3.4). The other was an apparent amputation of the right forearm at the midpoint of the radius and ulna (individual MXYM59:2, aged 35-39, probable male). The distal ends of both bones have a well-healed callous and are fused together (Figure 3.5).

These cases are evidence of surgical practices. The amputation might have been a form of punishment or may have been implemented in response to an injury. The trepanations may also have constituted surgical interventions in response to cranial trauma. However, there is no direct evidence for interpersonal violence in any of these sets of remains. (The above cases of trepanation were also previously reported by Zhang et al. (2016).)

At Xiaohandi, there is one case of an antemortem depressed skull fracture (individual MHXM256, female, aged 30-34), overlying the left coronal suture (Figure 3.6). There is also an individual with a healed fracture of the left ulna, near the distal end of the shaft (individual MHXM329, an adult probable female) (Figure 3.7). Given the possibility that this is a “parry” fracture, these two cases of trauma could suggest interpersonal violence.

These cases provide anecdotal evidence for interpersonal violence in the middle Bronze Age in Minhe County. However, there are very few cases of trauma in both the Bronze Age and Neolithic groups in this area, and any conclusions about changes in rates of violence must remain tentative until more paleopathological data are available.



Figure 3.1 Trepanation lesion exhibiting healing on frontal bone of MHPM26 (superior view)



Figure 3.2 Trepanation lesion with healing on parietal of MHPM29 (lateral-anterior view)



Figure 3.3 Deformed right humeral head in individual MHMM39 (anterior view)



Figure 3.4 Trepanation lesion exhibiting healing on frontal bone of MXYM107 (superior view)



Figure 3.5 Amputation of right forearm in individual MXYM59:2 (anterior view)



Figure 3.6 Antemortem depressed skull fracture in individual MHXM256 (lateral-superior view)



Figure 3.7 Healed left ulnar fracture in individual MHXM329 (posterior view)

3.2.4 Growth and development

3.2.4.1 Linear enamel hypoplasias

Linear enamel hypoplasias (LEH) are evidence of growth disruption and subsequent resumption of enamel formation in infancy and early childhood. I observed no LEH in either the Mapai or the Xiaohandi group. This is once again possibly due to the small sample size, but it also suggests that there was not a large load of infectious disease or parasites, nor significant nutritional stress, in these populations during early growth.

3.2.4.2 Stature

Stature is a result of both genetic and environmental factors, and changes in stature can be indicative of changes in levels of nutritional adequacy and other stressors during development. Because no appropriate stature estimation formulae exist for the populations in question, I directly compared the lengths of humeri, femora, and tibiae in each population directly, to look for changes over time in stature attainment.

I compared all three long bones between populations, controlling for sex, as the difference in long bone length between sexes was significant. First, I used notched box plots to look for patterns in the data and compare distributions, and then conducted a two-way ANOVA to check for significant differences (Figure 3.8). In the box plots, the diamonds represent the means, the horizontal bars represent the medians, the upper and lower hinges represent the upper and lower quartiles, the diagonals encompass the 95% confidence interval of the median (sometimes larger than the hinge spread), and the whiskers identify the limits for outliers (± 1.5 times the hinge spread). If the 95% confidence interval of two boxes overlap, the null hypothesis that the means of the two populations are the same cannot be ruled out.

Neither method showed a significant difference between Mapai/Yangshan and Xiaohandi (ANOVA: humeri, female $p=0.5062$, male $p=0.2193$; femora, female $p=0.7900$, male $p=0.3149$; tibiae, female $p=0.8605$, male $p=0.657$). This indicates that there was no change between the populations in terms of nutrition or stressors during development that would impact growth attainment, and that the climate change that took place between the two periods did not lead to lower growth attainment in the later population. Genetic factors also do not appear to have played a role in long bone length, since the two groups were not statistically significantly different in terms of biodistance (see Biodistance below). All metric data are presented in Appendix I.

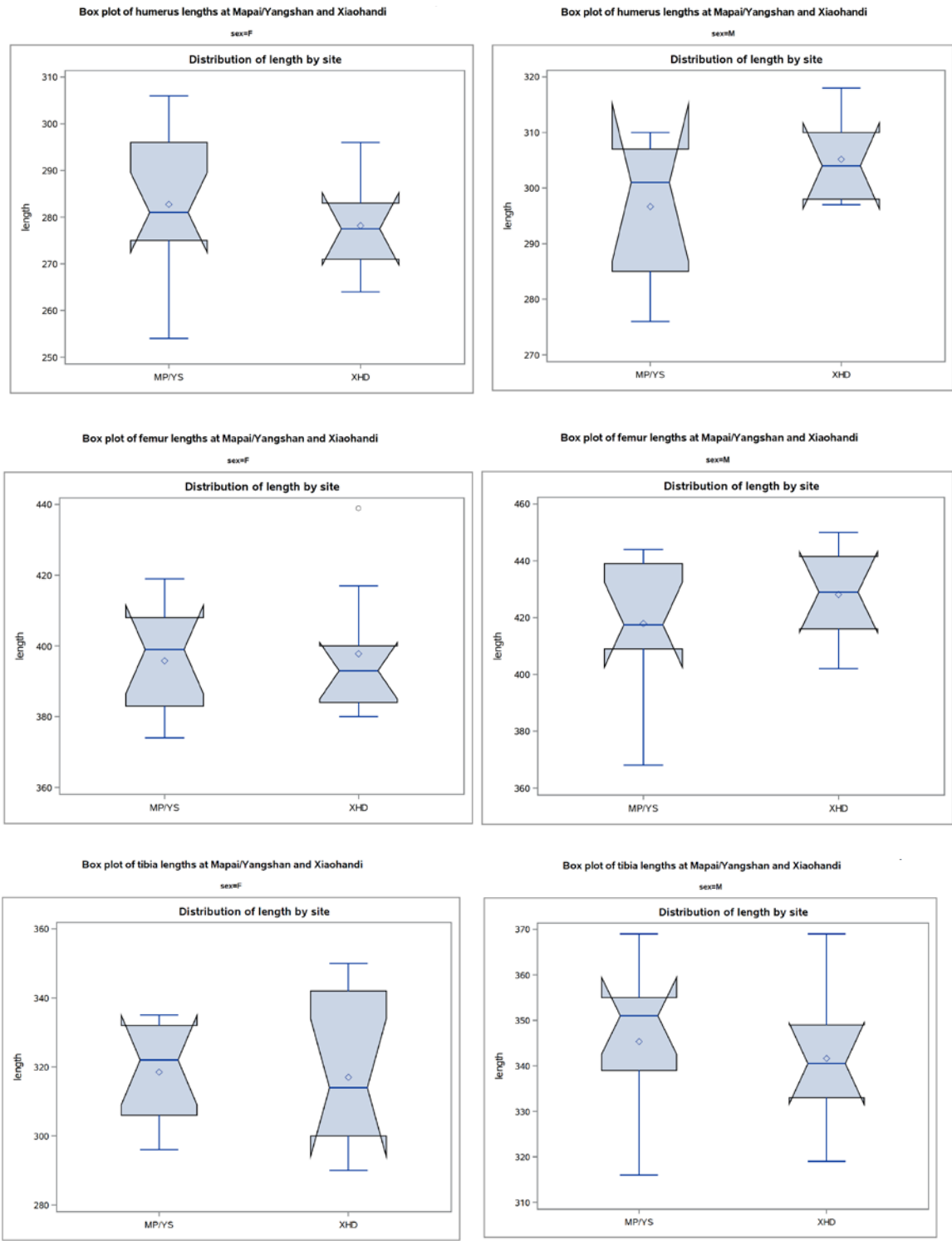


Figure 3.8 Notched box plots of long bones lengths by site and sex

3.2.5 Infectious and metabolic conditions

Most individuals that showed periosteal new bone formation in these groups had lesions on their tibiae, and a large number also had lesions on their femora. This is consistent with previous work that shows the tibia is the most common site of periosteal new bone formation (DeWitte, 2014; Larsen, 1997; Roberts and Manchester, 2007). Because the postcranial remains at these sites are only partially preserved, I calculated rates of periosteal new bone formation based only on tibial lesions, out of the total number of individuals with one or both tibiae present.

Calculated in this way, 76.5% of the individuals with tibiae at Mapai/Yangshan (26 out of 34) had periosteal new bone formation on one or both tibiae. At Xiaohandi, the rate was 38.7% (12 out of 31) (Table 3.4). This is a decline of about 50% from one period to the next, and is statistically significant (Fisher's exact test $p=0.0011$). Even when not accounting for which postcranial elements were preserved, and when taking into account all bones with evidence for periosteal new bone formation, the sites follow the same trend of around a 50% reduction: 70% of the individuals at Mapai/Yangshan had lesions on any bone, compared to only 34% of individuals at Xiaohandi. This may indicate a significant decline from one period to the next in terms of level of infectious diseases, parasite load, or other physiological stressors, though it could also mean an increase in frailty and more individuals dying before subperiosteal bone could form.

Table 3.4 Periosteal reaction at Qinghai sites

	Mapai/Yangshan (N=34)	Xiaohandi (N=31)
Woven	1/34 individuals with tibiae	0/31
Rate	2.9%	0.0%
Compact/compact+woven	26/34	12/31
Rate	76.5%	38.7%
None	7/34	19/31
Rate	20.6%	61.3%

Healing (compact or remodeled) periosteal new bone is an indication of long-term survival after an initial insult, whereas active (woven) periosteal new bone indicates that the source of inflammation was ongoing at the time of death. At Mapai/Yangshan, one individual had only active periosteal new bone on both tibiae, and 26 individuals had healing lesions (three of these had both healing and active). At Xiaohandi, no individuals had only active lesions, while 12 had healing lesions (three individuals had both healing and active). This difference is significant at the $p < 0.05$ level (Fisher's exact test $p = 0.0014$).

The relationship of healing vs. active lesions to differential frailty and death is complex (Wood et al., 1992). Frailty is defined here as an individuals' susceptibility to disease or death that may vary from a population norm (Vaupel et al., 1979; Wood et al., 1992). The Mapai/Yangshan population had a higher overall occurrence of periosteal new bone formation, which means that the Xiaohandi population was either less likely to suffer the insults that cause periosteal new bone formation, or that they were less likely to form skeletal lesions if they did suffer insult. However, given that most or all of the lesions in both populations showed healing, I favor the former explanation, that the difference lies in the burden of stressors faced by the two populations, not in frailty.

Several individuals have other types of bony lesions, though they are too isolated to allow any broader interpretation of population health. One individual from Yangshan (MXYM96:1) has a lytic lesion, a smooth-edged hole that passes through the right posterior superior iliac spine. This could either be a traumatic wound with healing, or possibly a lytic lesion, though it is the only such lesion I observed in this individual's skeleton. One individual from Mapai (MHPM10) had ectocranial porosity on the cranial vault and roofs of the eye orbits, and also a very thin layer of slightly porous new bone on the zygomatics, a rounded inferior nasal border, and sclerotic bone on the alveolar margin and the opening on the mandible described above (under Oral health). This individual had no preserved postcranial remains, so a differential diagnosis of this condition is not possible. Among the individuals from Xiaohandi, two have button osteomas on their crania. Another individual (MHXM343, female, age 23-49) has some porosity in the eye orbits and also porous, active new bone formation on the hard palate and a slightly rounded nasal aperture. This could be a case of lepromatous leprosy, though again, a differential diagnosis is impossible because no postcranial remains were preserved for this individual.

Several individuals in both populations have porosity on the cranial vault (porotic hyperostosis, or PH) or in the eye orbits (cribra orbitalia, or CO) (Table 3.5). At Mapai/Yangshan, of six individuals with preserved crania, three had PH and one had both CO and PH (66.7% of the total total). At Xiaohandi, of eighteen individuals with preserved crania, three had CO, one had PH, and one had both (27.8% of the total). These rates are not significantly different at the $p < 0.05$ level, but they are different enough to indicate a trend of reduction in CO and PH in the later period (Chi-square 2.9037, $p = 0.0884$). Of course, it is also possible that the rates did not decline but that more children died of anemias before they could form CO or PH. However, all the tibial periosteal lesions from Xiaohandi were healing, meaning

frailty was probably low, and it is therefore more likely that the rate of anemias declined rather than that mortality increased.

Table 3.5 Cases of cribra orbitalia (CO) and porotic hyperostosis (PH) at Mapai/Yangshan and Xiaohandi

	Mapai/Yangshan	Xiaohandi
CO	0/6 crania*	3/18
Rate	0%	17%
PH	3/6	1/18
Rate	50%	6%
Both	1/6	1/18
Rate	17%	6%

*Total crania at site (not including fragmentary crania)

3.3 PALEODEMOGRAPHY

3.3.1 Age and sex distribution

The distribution of age-at-death for Mapai/Yangshan may not be representative, as many of the originally excavated remains were not available for study. In a report on the skeletal remains from Yangshan published in 1990, Han (1990) reports the age distribution for 164 individuals, whereas I was only able to examine 32 relatively complete sets of remains from that site, not all of whom could be assessed for age at death. My results show that the highest mortality for females was in the adolescent and young adult age categories, and the highest mortality for males was in the young adult age category. Only females are represented in the old adult age category (Table 3.6, Figure 3.10).

At Xiaohandi, the highest mortality for females was in the young and young/middle adult age categories, and for males was in the young adult age category. Only one individual, a female, is represented in the old adult age category (Table 3.6, Figure 3.11). These data do not suggest major demographic changes between the periods (see Juvenility index below).

Table 3.6 Distribution of sex and age categories at Mapai/Yangshan and Xiaohandi

	Infant 0-5 yrs old	Child 5-10 yrs old	Older child 10-15 yrs old	Adolescent 15-20 yrs old	Young adult 20-34 yrs old	Young/middle adult 20-50 yrs old	Middle adult 35-50 yrs old	Old adult 50+ yrs old	Adult 20+ yrs old	Total
Mapai/ Yangshan										
Female				3	5	1	2	2		13
Male				1	7	1	3			12
Indeterminate/ unknown	1	2	4	1			2			10
Total	1	2	4	5	12	2	7	2	0	35
Xiaohandi										
Female				2	4	6	2	1	1	15
Male				1	6	1	2		2	10
Indeterminate/ unknown	2	1	1	1		1	1			7
Total	2	1	1	4	10	8	5	1	3	32

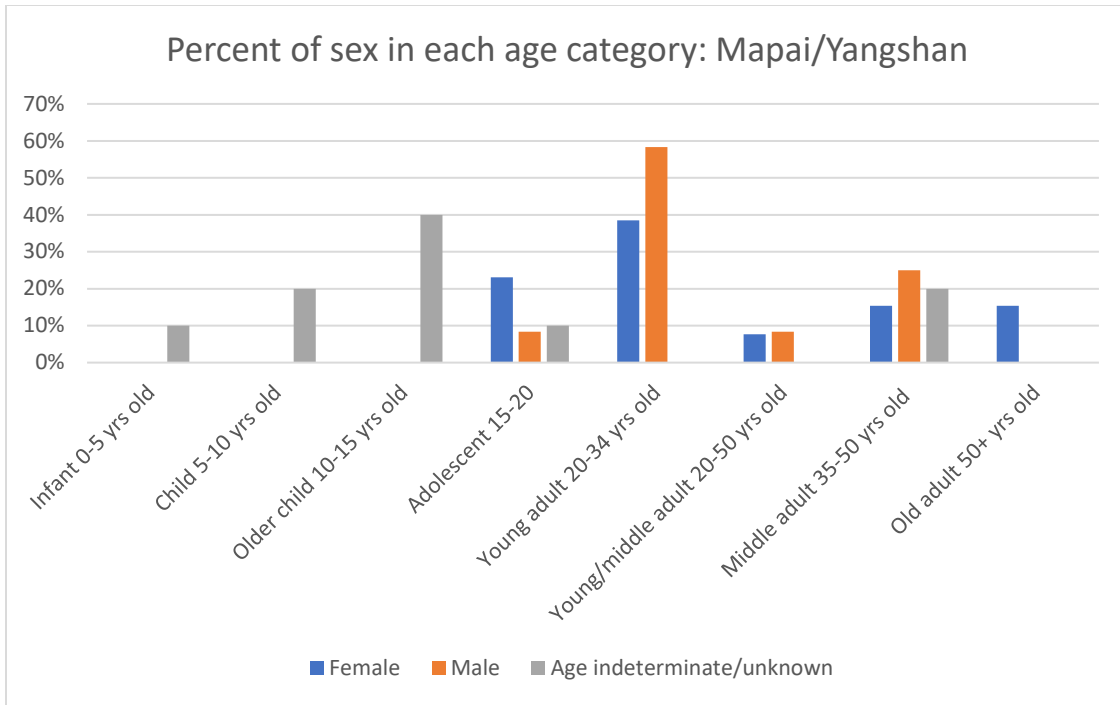


Figure 3.9 Sex and age distribution at Mapai/Yangshan

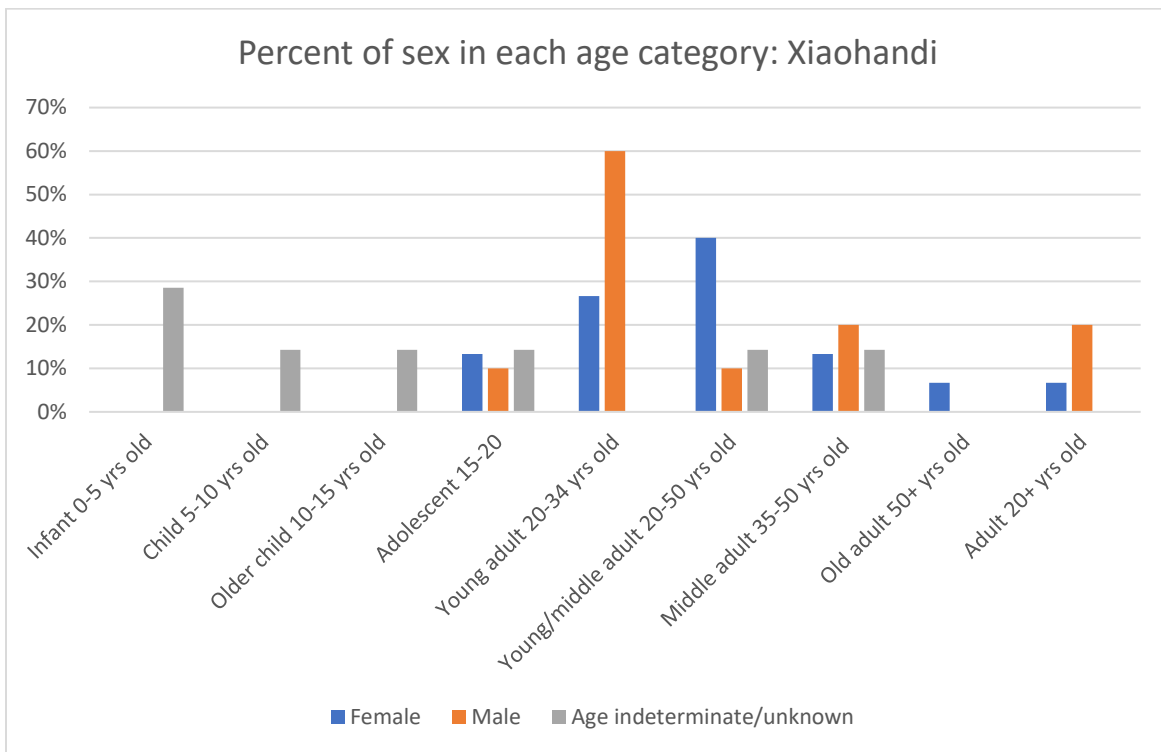


Figure 3.10 Sex and age distribution at Xiaohandi

3.3.2 Juvenility index

The juvenility index (individuals over the age of 30 out of all the individuals over the age of 5) at Mapai/Yangshan, with the 95% comparison interval, is 0.5313 ± 0.1895 . At Xiaohandi the juvenility index with 95% comparison interval is 0.7188 ± 0.1895 . To compare these proportions, I graphed the 95% comparison intervals (Buikstra et al., 1986) (Figure 3.12). The distributions from Mapai/Yangshan and Xiaohandi overlap, meaning that I cannot reject the null hypothesis that these populations have the same juvenility index. Therefore, I have not found evidence for a change in fertility between the populations.

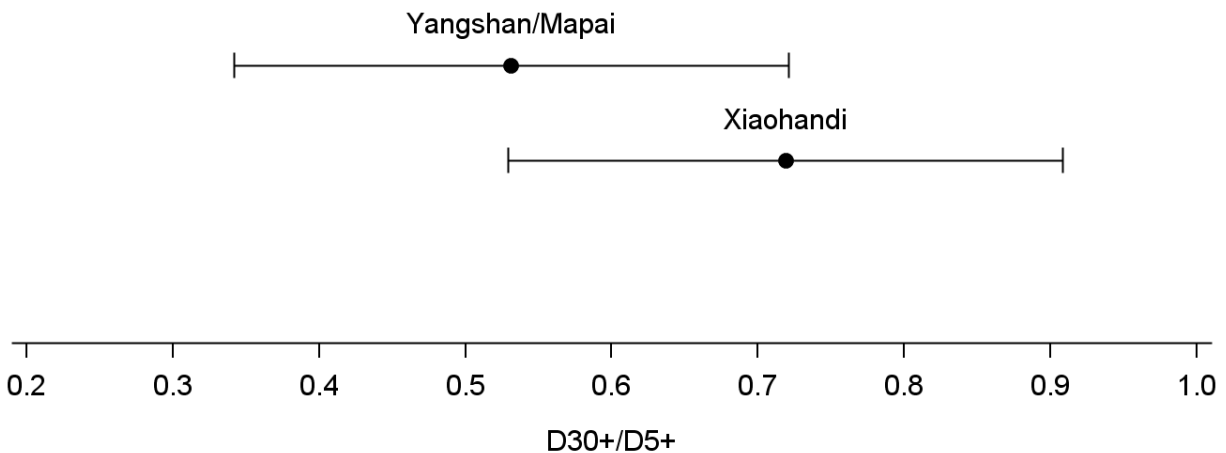


Figure 3.11 Ninety-five percent comparison intervals for the juvenility index of Mapai/Yangshan and Xiaohandi

3.4 BIODISTANCE

No crania from Yangshan were complete enough to score for nonmetric traits. The late Neolithic period is therefore represented by only five crania from Mapai. Xiaohandi is represented by 18 crania that could be scored for nonmetric traits. These traits were evaluated for

biological distance using the mean measure of divergence (MMD) (Killgrove, 2009). All cranial nonmetric traits and MMD results are recorded in Appendix II.

The MMD is considered significant if it has a value above two standard deviations, that is, a value over 2 for the standardized MMD. Negative MMD values merely indicate a sample size, or that the populations were very closely related (Killgrove, 2009). The mean measure of divergence test shows that the people of Mapai and Xiaohandi did not have significant biological distance between them (MMD: -0.05674, standardized MMD: -0.63025). This agrees with the conclusion of Wang and Zhu (2004), based on metric traits, that the remains from Mapai and Xiaohandi belong to the same biological population. According to my analysis, both sites are also quite closely related to the Rong groups from the Loess Plateau in Shaanxi (see Chapter 5).

The MMD does show that Xiaohandi is significantly different from the early Bronze Age Hexi Corridor group at Huoshaogou (MMD: 0.08854, standardized MMD: 3.47809), and almost significantly different from the late Bronze Age Hexi Corridor group at Hamadun/Xigang (MMD: 0.12483, standardized MMD: 1.92864) (see Chapter 4). This suggests that the Bronze Age people of the Qinghai Plateau and the Hexi Corridor were somewhat biologically distinct, possibly due to the persistence of earlier Neolithic groups in Qinghai or hybridization between Neolithic and later in-migrating groups.

The Ward's cluster analysis paints a slightly different picture than the MMD. According to the cluster analysis of all the sites in this study, Mapai does not cluster with Xiaohandi. It is in a cluster by itself, and separates from all other sites at the first branching point (Figure 3.13). Xiaohandi clusters with the Warring States period Rong groups found in Shaanxi (which are thought to have originated in Gansu; see Chapter 5), the Spring and Autumn period group from Jiulongshan in Ningxia, and the early Bronze Age group from Huoshaogou in Gansu (see

Chapter 4). The cluster analysis may therefore suggest that sometime after the Neolithic, a group from farther north in Gansu or Ningxia migrated south and replaced or interbred with the descendants of the people of Mapai to form the group that lived at Xiaohandi. The position of Mapai in the cluster analysis may also be due to the small sample size.

Wang and Zhu (2004) compared metric traits of the combined Mapai and Xiaohandi populations with other archaeological and modern groups from around China. They concluded that Mapai and Xiaohandi were most closely related to prehistoric groups from Gansu, including those from Huoshaogou (see Chapter 4), Ganguya, Donghuishan, and Lijiashan. This is hard to compare with my results as the authors combined Mapai and Xiaohandi into one group, while my cluster analysis shows them not clustering closely together. However, the authors do point to historic evidence that the Xindian Culture people of Xiaohandi were recorded in early historical texts as belonging to the “Jiang,” a sub-group of the “Rong.” It is very difficult to connect these historical ethnonyms with the complex population history of the region, but it does accord with my finding that the Bronze Age people of Xiaohandi cluster with the later Iron Age Rong people from Zhaitouhe and Shijiahe in Shaanxi.

No skulls from Yangshan were included in this study, but previous research by Han (1990) used craniometrics to compare the site to others in the region. Looking at a larger regional picture, Han found that the remains from Yangshan had the smallest biological distance from Huoshaogou, a larger biological distance from Liuwan and Lijiashan (both Bronze Age groups, from the Qijia and Kayue cultures), and the largest distance from North Asian (Evenki and Mongolian) groups. He concluded that the people from Yangshan were biologically closest to modern North Chinese and ancient groups from Gansu, including Huoshaogou. This could mean they were related to a group that migrated southward onto the Qinghai Plateau, from which the

people of Xiaohandi were possibly derived. This does not accord exactly with my results based on the remains from Mapai, which have the greatest distance with the Gansu groups at Huoshaogou and Hamadun/Xigang (the latter of which shows an affinity with North Asian groups, see Chapter 4 and Appendix II). This might be explained by a different population history for Mapai and Yangshan, or the fact that Han's analysis included both modern and ancient groups.

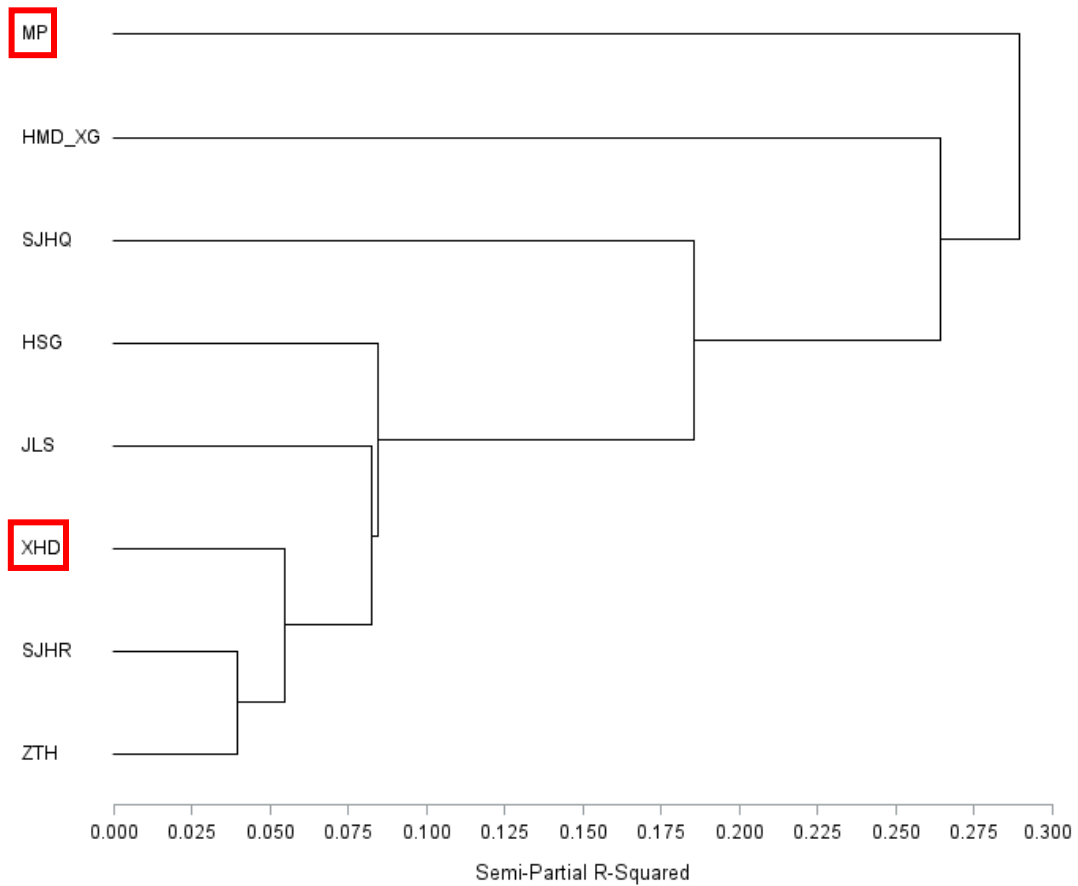


Figure 3.12 Ward's cluster analysis of dissertation study sites, highlighting the position of Mapai (MP) and Xiaohandi (XHD)

3.5 COMPARATIVE DIETARY DATA

Human remains from several sites from Qinghai have been subjected to stable isotope analysis for direct dietary reconstruction, primarily of bone collagen, which reflects mainly the protein component of the diet (Garvie-Lok and Zhou, 2015). These studies suggest an increase in consumption of C₃ plants after 2000 BCE, and provide important comparative data on the diet and potentially on the agricultural practices of the people of Mapai/Yangshan and Xiaohandi. The results of these studies are summarized in Figure 3.14.

The Zongri site is a Neolithic cemetery from eastern Qinghai, whose dates of occupation (3200-2100 BCE from carbon-14 dating) (Cui et al., 2006) overlap with those of Mapai and Yangshan. Though its material culture was given its own name (the Zongri Culture) because of some uniqueness in the ceramics, it bears a close relationship to the late Majiayao Culture found at Mapai and Yangshan. Cui and colleagues (2006) conducted stable isotope analysis of carbon and nitrogen on bone collagen from the cemetery. The results supported the archaeological evidence for millet cultivation in this period: millet grains have been found at Neolithic sites across Northwest China, and the $\delta^{13}\text{C}$ values of the Zongri individuals (mean $-10.64 \pm 0.42\text{‰}$ in the first period of occupation at the site, and $-9.25 \pm 0.38\text{‰}$ in the second) are consistent with consumption of a C₄ plant such as millet (or consumption of animals fed on a C₄ plant). According to their results for $\delta^{15}\text{N}$ (mean $8.93 \pm 0.29\text{‰}$ in the first period, $8.12 \pm 0.30\text{‰}$ in the second), the people of Zongri likely consumed some animal products along with their cultivated food (though no non-human remains were included in the study for comparison). The authors conclude that the people of Zongri were primarily agriculturalists with some contribution of animal protein to their diet. Furthermore, individuals from the later period at the site appear to have had a diet even more dependent on C₄ plant food, with a smaller contribution of animal protein. Remains of fish and deer from the site suggest the people hunted and fished, but it is

possible with future research that evidence may be found for household animal husbandry as well.

Ma et al. (2014) conducted stable isotope analysis on human bone collagen from three sites in southern Gansu, just to the east of Qinghai, that were occupied slightly later than Mapai and Yangshan. Xiahaishi is a site with graves that date to the late Neolithic Machang culture period (the material culture found at Mapai and to a lesser extent at Yangshan) (N=10); Buziping dates to the Majiayao (late Neolithic) and Qijia (early Bronze Age) periods (N=1); and Buzishan also dates to the Qijia period (N=1). The study also included non-human omnivore (dog, pig) and herbivore (sheep/goat, cattle) remains from the three sites (total N=20). The Xiahaishi bones were carbon dated to 2100-1900 cal BCE, and charcoal from Buziping was carbon dated to 2126–1744 cal BCE. The average $\delta^{13}\text{C}$ value for humans across these three sites was $-7.6 \pm 0.4\text{‰}$, similar to that of the omnivores, which indicates a heavy reliance on a C_4 plant food, presumably millet. The $\delta^{15}\text{N}$ value for humans was $8.2 \pm 0.8\text{‰}$, higher than that of the omnivores by 2.4‰ , less than the trophic level difference of $3\text{--}5\text{‰}$.

Herbivores in this study had $\delta^{13}\text{C}$ values of -22.5‰ to -12.1‰ . They fell into two groups: those with $\delta^{13}\text{C}$ values of -19‰ and below, indicative of mostly C_3 plant consumption; and those with $\delta^{13}\text{C}$ values of -15.1‰ to -12.1‰ , indicative of mixed C_3 and C_4 plant consumption. Though domesticated C_3 plant remains have been found in this region from this period, C_3 plants were clearly not a large component of the human or omnivore diet, and so the C_3 component of the herbivores' diet likely came from wild C_3 plants. The C_4 component could be explained by the animals grazing on millet stubble in fields, or by their being provisioned by humans, as they are in modern Mongolian herding practices. The herbivores' $\delta^{15}\text{N}$ values ranged from 2.9‰ to 7.7‰ (mean value $5.8 \pm 2.0\text{‰}$).

The omnivores in the study had a range of $\delta^{13}\text{C}$ values from -22.7‰ to -6.8‰ , which was similar to the human values, suggesting that non-human omnivores had similar access to C_3 and C_4 plant-based foods as the humans. The omnivores also showed a wide range of $\delta^{15}\text{N}$ values (2.4‰ to 8.9‰ , mean value $6.1 \pm 1.8\text{‰}$), which could be explained by differential access to human scraps and waste, or different soil conditions across the area.

In summary, the study found that the individuals of the Machang and Qijia sites of Xiaohaishi, Buziping, and Buzishan consumed mostly C_4 plants, and had domesticated omnivores with similar diets to their own, and domesticated herbivores that ate a combination of wild and domesticated plant foods. The results of this study overall show that millet agriculture was still dominant around 2000 BCE in the part of China where Mapai and Yangshan are located, and that both omnivorous and herbivorous domesticated animals were at least in part provisioned with, or allowed to graze on the stubble of, domesticated millet.

A paleoethnobotanical study (Jia et al., 2013) at Buziping has found both broomcorn and foxtail millet dominating the floral assemblage in both the Majiayao (late Neolithic) and Qijia (early Bronze Age) periods, which accords with the C_4 plant-dominant diet suggested by the stable isotope results of Ma et al. (2014).

Lajia is a site of the Qijia culture (early Bronze Age, between the periods when Mapai/Yangshan and Xiaohandi were occupied). Like the three sites discussed in this chapter, it is located in Minhe County in Qinghai. Zhang (2006)Zhang (2006)Zhang (2006)Zhang (2006)Zhang (2006)Zhang (2006)Zhang (2006)Zhang (2006) reports human bone collagen stable isotope values from 12 individuals from the site as follows: $\delta^{13}\text{C}$ mean value -6.89‰ , $\delta^{15}\text{N}$ mean value 10.3‰ (no standard deviations reported). The author interprets these values as being consistent with a diet of C_4 plants along with consumption of animal protein.

People of the Xindian Culture, the archaeological culture found at Xiaohandi, are believed to have engaged in agriculture supplemented by animal husbandry (primarily of sheep/goats and pigs) and hunting (mainly of deer), a characterization based on qualitative zooarchaeological data (Xie, 2002). During the preceding early Bronze Age Qijia Culture, sheep husbandry came to be more widely practiced than pig husbandry, suggesting that the economy relied at least partially on herding alongside agriculture, a system well-adapted to the local environment (Dong et al., 2012; Dong et al., 2013a).

Shangsunjia is a Bronze Age site from eastern Qinghai that was occupied from 1500-600 BCE, during the Bronze Age Kayue culture period, contemporaneous with the Xindian culture found at Xiaohandi. The site is located in Datong County, Qinghai, approximately 150 km northwest of Xiaohandi. Zhang et al. (2003) report that human bone collagen from 18 individuals at this site have $\delta^{13}\text{C}$ value that ranges from -11.886‰ to -17.486‰, with an average value of -16.117‰. This is consistent with a dietary protein component derived from a mixture of C_3 and C_4 plants. Millet grains have been found at sites in the area dating from the Neolithic through the middle Bronze Age, and wheat has also been found at some other Kayue culture sites. Wheat consumption could therefore account for the C_3 portion of the diet at Shangsunjia. The authors also speculate that the C_3 component of the human diet could be derived from eating pastoral products from animals grazed on wild C_3 plants, but this interpretation would need to be further tested on the remains of domesticated herbivores or with human $\delta^{15}\text{N}$ values to determine their level of consumption of animal products.

Comparative dietary data therefore suggest that in the time of Mapai and Yangshan, in the late Neolithic, human subsistence mainly consisted of millet agriculture with some animal husbandry. Domesticated animals likely consumed both wild and domesticated plant foods. By

the time of Xiaohandi, the middle Bronze Age, millet farming was being supplemented with wheat. The degree to which animal husbandry practices changed, or whether consumption of animal products increased after the climate change, will have to await quantitative zooarchaeological research and further direct dietary reconstruction.

Note that in the summary of results in Figure 3.14, the Neolithic site of Zongri has the lowest $\delta^{13}\text{C}$ values in bone collagen, though they are still in the range for C_4 plant consumption via the protein portion of the diet (Brown and Brown, 2011). The values also have a large range, which may mean the people of Zongri consumed products from animals raised on a variety of plant foods. The $\delta^{15}\text{N}$ values of all the sites cluster relatively closely, except one outlier from Xiahaishi and the mean value from Lajia, which could indicate they consumed more animal protein.

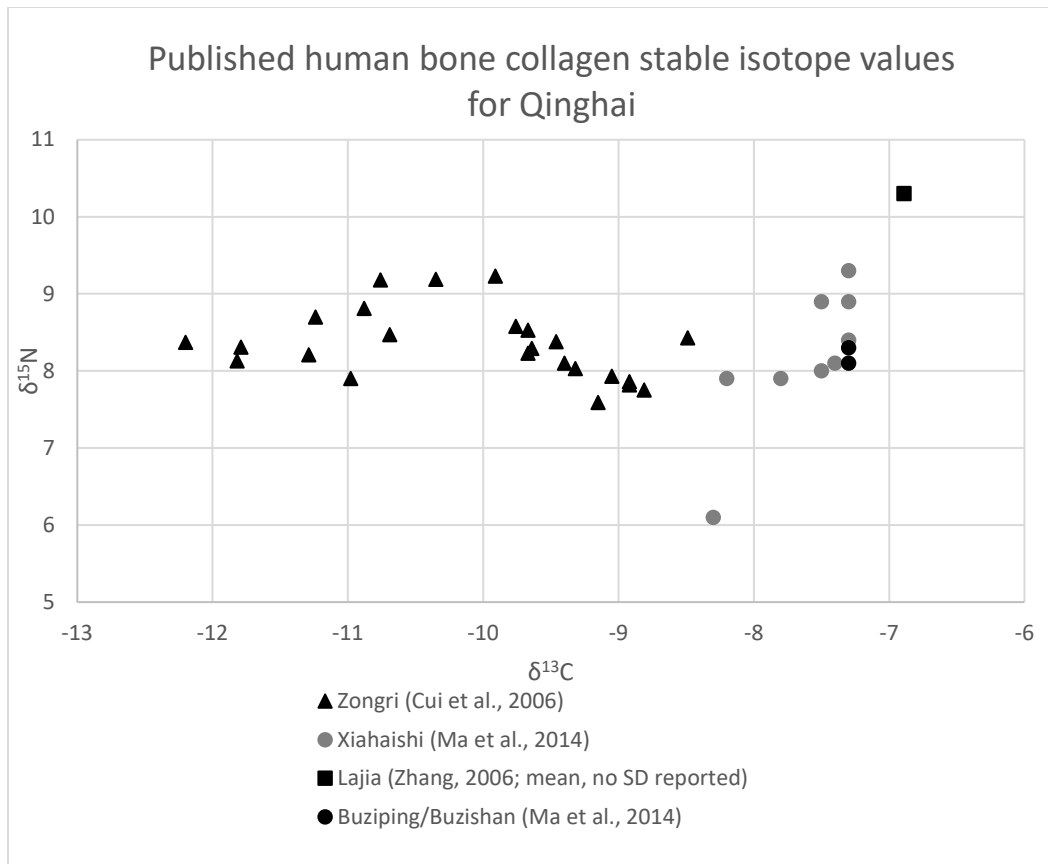


Figure 3.13 Published carbon and nitrogen stable isotope results from human bone collagen in eastern Qinghai. Approximate dates of sites from the above published sources: Zongri: 3200-2100 BCE (late Neolithic); Xiahaishi: 2330-2000 BCE (late Neolithic); Buziping: 2200-1900 BCE (early Bronze Age, Qijia Culture); Buzishan: same; Lajia: same

3.6 SUMMARY: A COMPLEX ADAPTIVE SYSTEM ON THE QINGHAI PLATEAU

The paleopathological data from Mapai/Yangshan and Xiaohandi paint a complex picture of human health over time, but overall do not support the conclusion that the people of eastern Qinghai suffered from the climatic deterioration in the mid to late Holocene:

- diet changed somewhat (cariogenicity and AMTL increased, wear decreased);
- burden of non-specific infections and frailty remained constant (overall tibial periosteal reaction decreased, most lesions in both populations were healing);
- childhood growth disruptions remained steady (no LEH in either population);
- childhood anemias declined (fewer cases of CO/PH);

- nutritional inadequacy or other stressors that impact growth attainment did not change (no change in long bone length);
- fertility remained the same (no change in the juvenility index); and
- activity patterns did not change (no change in OA).

My findings regarding oral health are preliminary, as there was only a small sample of dentition from Mapai, and no dentition from Yangshan, in my study. Still, there were significant differences between Mapai and Xiaohandi in terms of oral health, mainly an increase in carious lesions and AMTL and a decline in dental attrition from the late Neolithic to the middle Bronze Age. Abscesses were absent at Mapai and rare at Xiaohandi, completing the picture of two populations with low rates of infectious and inflammatory processes in the oral cavity. This is somewhat unusual in agricultural populations (with the exception of Southeast Asian rice agriculturalists).

Both populations also had low rates of osteoarthritis in both upper and lower limbs, no observed spinal arthritis, and no significant difference in the rates of OA between the populations. The trepanations and forearm amputation at Mapai/Yangshan, and the fractures of an ulna and a cranium at Xiaohandi, are too anecdotal to draw any population-wide conclusions, but do suggest a possible increase in conflict in the later period. This conclusion would need to be strengthened by more data from contemporaneous middle Bronze Age sites in eastern Qinghai. Periosteal new bone formation on tibiae declined by half from the earlier to the later population, and most of the cases from Mapai/Yangshan and all the cases from Xiaohandi showed healing, indicating low frailty in both populations. CO and PH also declined between populations, suggesting a decrease in childhood anemias.

The lack of LEH at both sites, and the similar stature attainment in both males and females, along with the decrease in CO and PH, suggest that rates of childhood insults was not

high, and that they declined slightly between the populations. Since frailty does not appear to have been high in these groups (most periosteal new bone was healing at the time of death), it is unlikely that these findings are due to high frailty and high mortality, and more likely that they are due to low frequency of childhood stressors.

The lack of indicators for growth disruption, interpersonal violence, infectious disease, and nutritional stress in the populations I have described here suggest that a cautious approach is needed in the interpretation of climatic impacts on human lifeways in the past. As the biodistance data suggest, there was possibly population movement into the area after the 4000 BP climate change event, and people continued to practice agriculture in the middle Bronze Age. It is therefore dubious to interpret highly variable, gradual, and localized cultural change as evidence of widespread cultural “collapse” or drought-induced stress in the Chinese Neolithic and early Bronze Age (Dong et al., 2012; Liu and Feng, 2012), at least until the region has been systematically surveyed to confirm that there were changes in settlement density, and more evidence has been found that social change took place under duress.

After the 4000 BP climate change event, in the second and third millennia BCE, eastern Qinghai did not see a decline in health, or a dramatic increase in conflict, according to my data. According to existing archaeological data, in the Bronze Age cultures of eastern Qinghai, including Qijia, Kayue, and Xindian, agriculture was continuously practiced as a key element of the human subsistence system. Crop diversification and spatial diversification, both forms of risk management in agropastoral production (Marston, 2011), also probably played a role in adapting to the environment of the second millennium BCE: wheat and barley were introduced, and there seems to have been some economic specialization of neighboring groups, with the people of the

Kayue Culture specializing in pastoralism and the people of the Xindian Culture specializing in agriculture (see Chapter 6 for more on evidence of risk management strategies).

Based on the human health data presented here, between the late Neolithic people of Mapai/Yangshan, and the middle Bronze Age people of Xiaohandi, there seems to have been some small changes in health, but continuity in most measures. This accords well with archaeological evidence for gradual change and only slight diversification of subsistence systems in Bronze Age eastern Qinghai. These slight subsistence changes were perhaps required to meet people's needs in a more arid environment, or to deal with new cultural contacts or neighbors with differing economic strategies, but they constituted a reform and not a collapse of the existing subsistence system. They therefore constitute incremental, rather than transformational, adaptation by the people of eastern Qinghai to late Holocene climate change.

CHAPTER 4 HEXI CORRIDOR: A COLD STEPPE AND DESERT ZONE

This chapter presents results from the early Bronze Age Siba Culture cemetery of Huoshaogou and the late Bronze Age Shajing Culture cemeteries of Hamadun and Xigang, all located in the Hexi Corridor. The Hexi Corridor is a semi-arid region of Northwest China that is highly sensitive to regional climate change events, and has experienced marked changes in moisture, vegetation, and human habitation over the past several millennia. This makes it an ideal place to explore the impact of climate change on human populations and to look for evidence of, and to attempt to characterize, human adaptation during the Bronze Age transition.

4.1 CLIMATE AND ENVIRONMENT

The Hexi Corridor is a geographic feature in Northwest China that runs from arid Xinjiang in the northwest to the Loess Plateau in the southeast. The corridor is bounded by the Qilian Mountains in the south and the Beishan Mountains in the north. A number of rivers flow northward out of the Qilian Mountains and form alluvial fans in the Hexi Corridor. Archaeological sites are typically distributed along these river systems, which supported agriculture beginning in prehistoric times (Gansu and Beijing, 2011).

The Hexi Corridor has low precipitation and low effective moisture. Today, Yumen City, the location of the early Bronze Age cemetery of Huoshaogou, is a cold semi-arid or steppe zone (Köppen BSk), bordering on cold desert or arid zones (Köppen BWk). Yongchang County, the location of the late Bronze Age cemeteries of Hamadun and Xigang, is in one of these cold

desert zones (Kottek et al., 2006). Temporal and spatial variations in precipitation across the area depend partly on changes in the East Asian summer monsoon, and on the winter monsoon that originates in the Mongolian plateau and southern Siberia (Liu et al., 2014). The western part of the Hexi Corridor is colder and drier, with lower effective moisture. With regards to the sites discussed in this chapter: in Jinchang, near the sites of Hamadun and Xigang in the middle of the Hexi Corridor, average monthly temperatures range from -9 to 21°C, and annual average precipitation is 163 mm. In Yumen, near the Huoshaogou site in the western Hexi Corridor, average monthly temperatures also range from -9 to 21°C, but annual precipitation is lower, at 60 mm.

This corridor was an important route of contact between East and West Asia in prehistory, and later as part of the Silk Road network. It is likely that bronze and iron casting technology, wheat and barley cultivation, and horseback riding all came from Central Asia to China via the Hexi Corridor (Dodson et al., 2013; Flad et al., 2010; Han, 2008).

4.1.1 Paleoclimate and paleoecology

Climatic fluctuations in the mid Holocene significantly impacted the Hexi corridor. After the mid-Holocene climatic optimum, the area experienced a period of fluctuating temperature and moisture. Changes in the East Asian summer monsoon led to a decrease in effective moisture beginning around 3000 BCE (An et al., 2006; Liu et al., 2014). Effective moisture continued to decline, and the region was consistently arid after 2000 BCE: loess deposition resumed, which indicates a weak summer monsoon, and pollen profiles show a shift from floodplain and forest flora to grasslands (An et al., 2005; Han, 2008; Liu et al., 2014; Zhao et al., 2009). This cooling and drying corresponds to climate changes seen across the region, but local conditions influenced the specific ecological and social consequences across the Hexi Corridor.

A pollen core from Zhuyeze paleolake near the Hamadun and Xigang cemeteries traces this trajectory (Chen et al., 2006). Desert and steppe shrubs and herbs dominated in the mid-Holocene (7100-3800 BP), and the late Holocene saw alternating periods of wet and dry climate. Since around 1800 BCE, the area has been a forest-steppe zone, with the dominant flora being xerophytic and steppe species such as juniper (*Sabina* spp.), pine (*Pinus* spp.), grasses (Poaceae), herbaceous plants (*Artemisia* spp.), and goosefoot (Chenopodiaceae). This corresponds to a prolonged drying event occurred between 1400-400 BCE, a period beginning just after Huoshaogou was in use and encompassing the time of Hamadun and Xigang.

A study of two sections from trench walls at nearby archaeological sites confirms this trajectory (Zhou et al., 2012). The sites of Huangniangniangtai (Qijia Culture, early Bronze Age, 2200-1600 BCE) and Donghuishan (Siba Culture, early/middle Bronze Age, 1900-1400 BCE) are both located in the middle Hexi Corridor near Hamadun and Xigang. Pollen and charcoal from the two sequences show that between c. 1800 BCE and c. 1400 BCE, the proportion of *Artemisia* pollen decreased and the proportion of Chenopodiaceae pollen increased in this area, which suggests a shift from grassland to desert shrubland. The authors suggest that relatively high proportions of Poaceae pollen in the middle of the sequence, decreasing towards the end, might be the result of several centuries of agricultural intensification followed by abandonment of farmland, possibly because the newly adopted cultivation of wheat (in the Poaceae family) required irrigation, which led to soil salinization, and which also corresponded to regional climate change. However, as already described in Chapter 1, there is paleobotanical and artifactual evidence from the Shajing Culture occupation of nearby Sanjiaocheng (900-408 BCE) that farming did continue in the area, though it may have occupied a smaller share of subsistence activities. Also, historical and paleoecological data suggest there were still rich water sources

during the time of the Shajing Culture that formed an oasis in the area around Sanjiaocheng, which would have allowed sedentary, mixed subsistence to continue (Li, 1994).

4.2 PALEOPATHOLOGY

4.2.1 Oral health

A total of 52 individuals from Huoshaogou and 28 individuals from Hamadun/Xigang could be scored for oral health measures (Table 4.1).

Table 4.1 Oral health measures at Huoshaogou and Hamadun/Xigang

	<i>Calibrated carious lesion rate[†]</i>	<i>Uncalibrated carious lesion rate[†]</i>	<i>Carious lesion rate: M[†]</i>	<i>Carious lesion rate: F[†]</i>	<i>Average wear score^{**†}</i>
<i>Huoshaogou*</i>	8.2%	6.0%	5.7%	10.4%	3.3
<i>Hamadun/Xigang*</i>	2.2%	1.5%	8.0%	3.6%	3.9

	<i>AMTL[†]</i>	<i>AMTL: M[†]</i>	<i>AMTL: F[†]</i>	<i>Calculus[‡]</i>	<i>Abscesses[‡]</i>
<i>Huoshaogou*</i>	12.2%	10.4%	9.9%	21.2%	13.5%
<i>Hamadun/Xigang*</i>	14.4%	40.0%	39.8%	17.9%	14.3%

*Lukacs (1995) caries calibration method not significantly different from results using Duyar and Erdal method

**Scored using method developed by Smith (1984)

[†]Number of teeth out of all teeth observed

[‡]Number of individuals out of all individuals with observable teeth

4.2.1.1 Caries

Carious lesion frequency declined from the early to the late Bronze Age (Table 4.1). At Huoshaogou, the calibrated carious lesion frequency (Duyar and Erdal, 2003) was 8.6%, and at Hamadun/Xigang the calibrated frequency was 2.0%, a statistically significant decline (Chi-square test 16.5832, $p < .0001$). This is consistent with a declining reliance on agricultural

products and an increased reliance on pastoral practices in the late Bronze Age, which is suggested by the archaeological evidence (see Chapter 1). Sex differences in carious lesions also declined and reversed, from a higher frequency among females to a higher frequency among males. At Huoshaogou the calibrated frequencies (Lukacs, 1995) were: male 5.74%, female 10.39%; and at Hamadun/Xigang they were: male 8.0%, female 3.6%. Individuals at neither site have a statistically significant difference between the sexes at the $p < 0.05$ level, but the difference at Huoshaogou does suggest a trend (Huoshaogou: Chi-square 3.2088, $p = 0.0732$; Hamadun/Xigang: Chi-square 1.0276, $p = 0.3107$).

4.2.1.2 Attrition

Dental attrition increased slightly, from an average occlusal wear score (Smith, 1984) per tooth of 3.25 at Huoshaogou to an average of 3.92 at Hamadun/Xigang. Statistical tests based on the number of teeth with each wear score (0-8) show that this change is significant (Chi-square 109.9469, $p < .0001$; Student's t-test $p < 0.0001$). This finding may be related to the fact that Huoshaogou has a larger share of its population in the adolescent age category, but it may also demonstrate that diet in the late Bronze Age Hexi Corridor was tougher and more abrasive than that of the early Bronze Age.

4.2.1.3 Calculus

Rates of calculus in the Hexi Corridor remained roughly the same between the early and late Bronze Age. At Huoshaogou, 21.2% of individuals with preserved dentition had calculus; at Hamadun/Xigang, the rate was 17.9%. This difference is not significant (Chi-square 2.1448, $p = 0.1431$; Fisher's exact test $p = 0.1789$). This indicates broad continuity in the diet, or possibly in dental hygiene practices, between the two periods.

4.2.1.4 Antemortem tooth loss

The rate of AMTL increased from 12.2% to 14.4% between the periods. This is not a significant difference (Chi-square 1.1878, $p=0.2758$; Fisher's exact test $p=0.2843$). Most cases of pulp exposure at both sites were due to wear rather than carious lesions (14 cases due to caries vs. 45 cases or 76% due to wear at Huoshaogou, and two due to caries vs. 27 or 93% due to wear at Hamadun/Xigang). It is therefore likely that most of the AMTL at both sites was caused by wear rather than caries. The sex-specific AMTL rates for Hamadun/Xigang are also much higher than the total rate and likely not representative, because sex could only be estimated for nine out of 28 individuals with dentition.

4.2.1.5 Abscesses

At Huoshaogou, 13.5% of individuals with preserved dentition had abscesses (0.022% of observable alveoli), while at Hamadun/Xigang the rate was 14.3% of individuals (0.050% of alveoli). This is not a significant difference (Chi-square based on alveoli with abscesses 0.0104, $p=0.9187$; Chi-square based on individuals with abscesses 0.0665, $p=0.7966$).

4.2.2 Osteoarthritis

Of the individuals with skeletal elements preserved, at Huoshaogou, 88.9% of individuals had spinal arthritis, 12.5% had upper limb arthritis, and none had lower limb arthritis; and at Hamadun/Xigang 50.0% had spinal arthritis, 80.0% had upper limb arthritis, and again none had lower limb arthritis (Table 4.2). Only the difference in upper limb arthritis is significant at the $p<0.05$ level (Chi-square 5.9231 $p=0.0149$; Fisher's exact test $p=0.0319$).

The dramatic increase in upper limb arthritis could indicate a rise in labor demands or a change in the type of labor required. The trend in spinal arthritis runs counter to expectations: the

early Bronze Age people of Huoshaogou would not have ridden horseback, but the late Bronze Age people of Hamadun/Xigang likely did (Barfield, 1989; Barfield, 1993; Di Cosmo, 2002), as horseback riding was common in East Asia by the middle of the first millennium BCE, and horse remains at Shajing sites are abundant (Di Cosmo, 2002; Flad et al., 2007; Gansu and Wuwei, 1984; Gansu, 1990). The changes in spinal and upper limb arthritis are also possibly influenced by the small sample size at Hamadun/Xigang.

Table 4.2 Osteoarthritis at Huoshaogou and Hamadun/Xigang

	Huoshaogou	Hamadun/Xigang
Vertebral osteophytes	8/9 individuals	2/4
Rate	88.9%	50.0%
Arthritis upper limb	1/8	4/5
Rate	12.5%	80.0%
Arthritis lower limb	0/18	0/30
Rate	0.0%	0.0%

4.2.3 Trauma

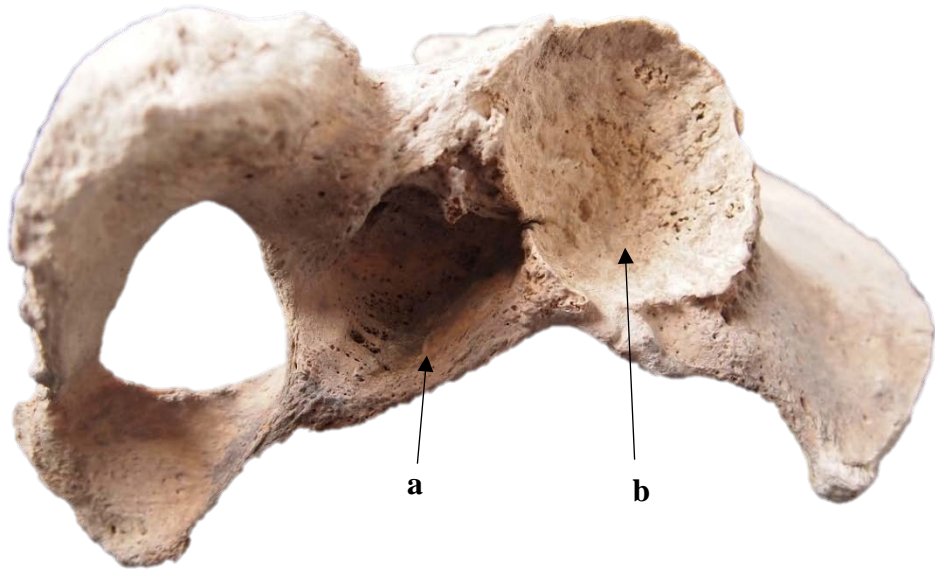
The only observed case of trauma from Huoshaogou is one possibly perimortem depressed skull fracture (YHM214, probable female, aged 13.5-20) (Figure 4.1). No trauma was observed in the Xigang sample, and the only observed trauma cases at Hamadun were one deformed right humeral head with a mushroom shape (YSHM11, male, aged 35-39) (Figure 4.2) and an individual (YSHM6, probable female, aged 40-44) with bilateral hip dysplasia (Figure 4.3). The hip dysplasia was likely congenital, with advanced formation of pseudo-joints on the lateral aspects of the ilia. Both innominate bones were abnormally gracile, and the acetabula were deformed. Unfortunately, the femora were not available for observation.



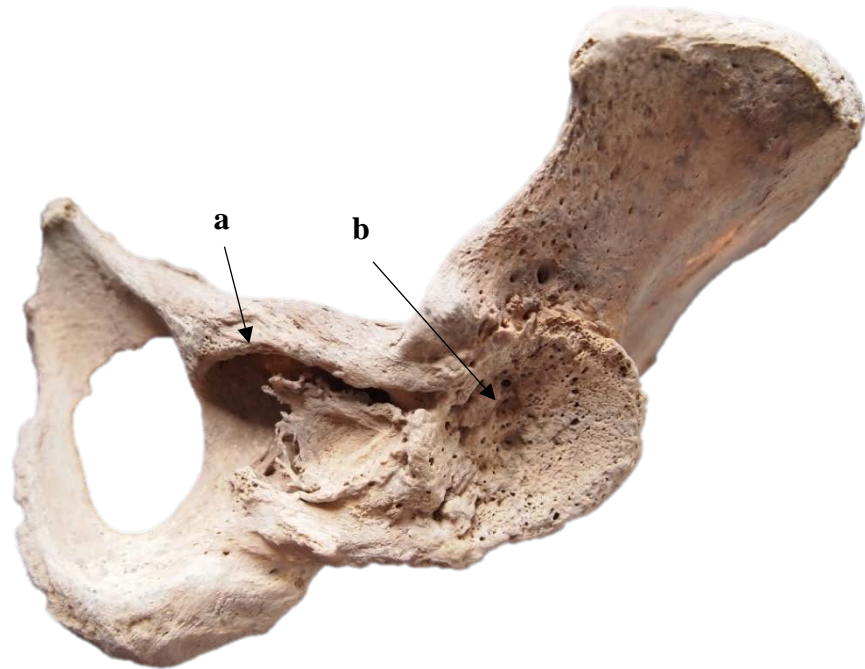
Figure 4.1 Depressed skull fracture in individual YHM214 (superior view)



Figure 4.2 Deformed right humeral head in individual YSHM11 (anterior view)



A



B

Figure 4.3:A-B Innominate bones of individuals YSHM6 with deformed acetabula (a) and pseudo-joints (b) from bilateral congenital hip dysplasia (lateral views)

4.2.4 Growth and development

4.2.4.1 *Linear enamel hypoplasias*

The frequency of LEH declined dramatically from the early to the late Bronze Age. At Huoshaogou, 23.1% of individuals with preserved dentition had LEH (5.4% of observable teeth), and at Hamadun/Xigang, the rate was 3.6% of individuals (0.6% of observable teeth). The difference between the populations was significant, both in terms of individuals with LEH (Chi-square 5.0880, $p=0.0241$, Fisher's exact test $p=0.0273$) and in terms of observed teeth with LEH (Chi-square 14.722, $p=0.0001$).

This may indicate that the frequency of growth disruption in childhood, among those who survived such insults into adulthood, decline dramatically over time. It may also indicate that frailty, or individual susceptibility to disease or death, increased and fewer people were able to survive childhood insults long enough to develop LEH (Wood et al., 1992), but as I will show below, the change in periosteal lesion rates suggests the former interpretation may be correct.

Individual YHM230, a child aged 11.5-12.5 years at death, had ectopic canines that were in the process of erupting anteriorly through the maxillae just lateral to the nasal aperture. This does not appear to have had any pathological sequelae (e.g. maxillary sinusitis).

4.2.4.2 *Stature*

Stature as assessed by long bone length did not differ between the populations of these two sites, as shown in both an exploratory data analysis procedure (notched box plots, Figure 4.4) and a confirmatory procedure. In the box plots, the diamonds represent the means, the horizontal bars represent the medians, the upper and lower hinges represent the upper and lower quartiles, the diagonals encompass the 95% confidence interval of the median (sometimes larger

than the hinge spread), and the whiskers identify the limits for outliers (± 1.5 times the hinge spread). If the 95% confidence interval of two boxes overlap, the null hypothesis that the means of the two populations are the same cannot be ruled out.

An ANOVA comparing lengths of femora between the sites and controlling for sex found no main effect for site ($p=0.8343$). However, the two sites had relatively small numbers of measurable long bones (Huoshaogou had only four individuals with measurable femora, and Hamadun/Xigang had only six). It can be seen in the box plots below that some bones in each sex group are represented by only a single specimen, so more data are needed to confirm these results. See data in Appendix I.

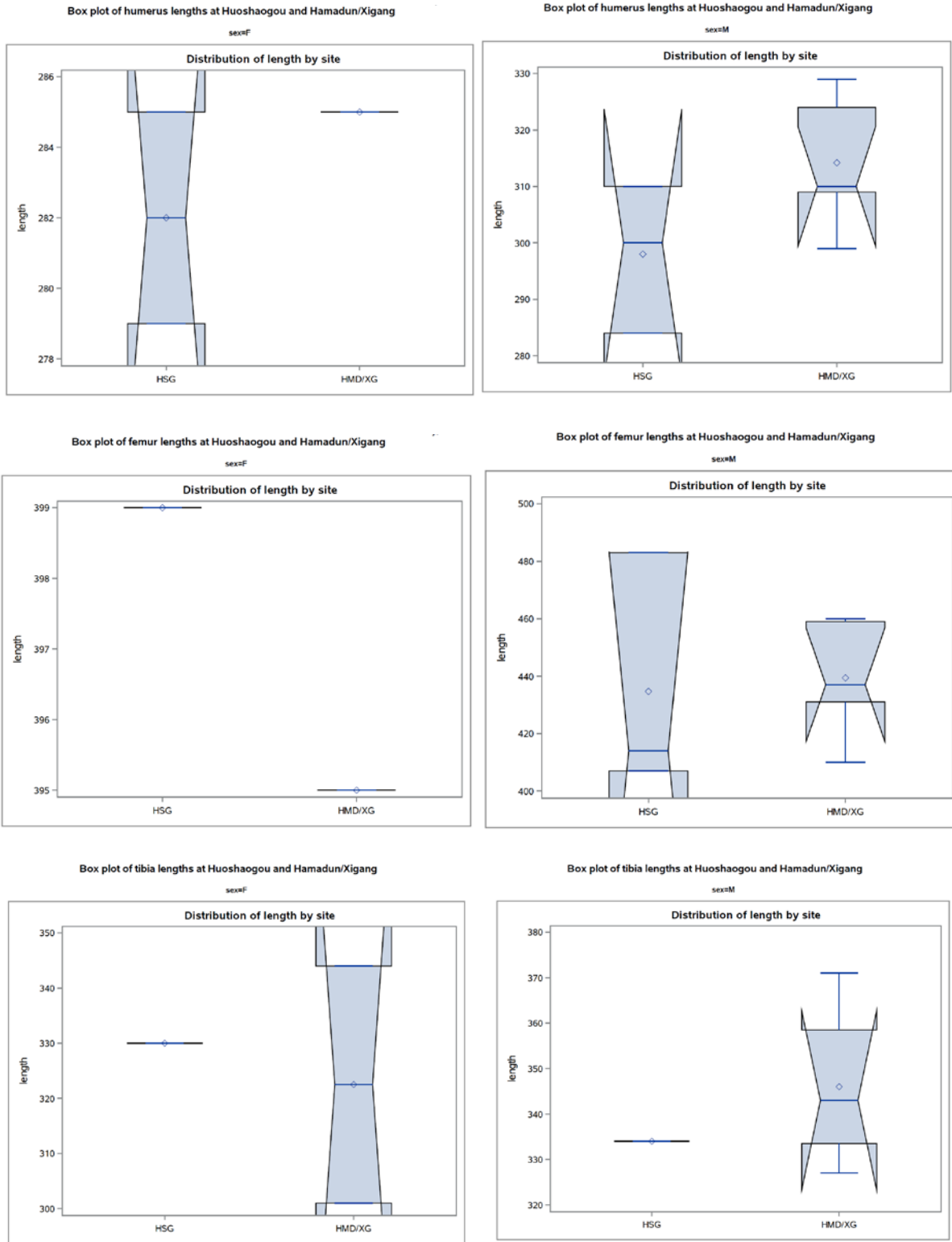


Figure 4.4 Notched box plots of long bones lengths by site and sex

4.2.5 Infectious and metabolic conditions

No pathological lesions were observed in the individuals from Xigang, likely because the bones were in poor condition, and were quite friable with damaged cortical surfaces.

There is a clear difference between the populations of Huoshaogou and Hamadun in the type of periosteal lesions present (Table 4.3). In the Huoshaogou population, five out of eight individuals with observable tibiae had only active periosteal new bone formation, and one had healing periosteal new bone. However, at Hamadun, seven out of seven individuals with observable tibiae had healing periosteal new bone formation on their tibiae, or a combination of active and healing. This indicates that frailty had declined in the later population, as individuals were better able to survive insults long enough for periosteal new bone to be partly resorbed. This difference in distribution of lesion types is statistically significant at the $p < 0.05$ level (Chi-square 11.4844 $p = 0.0032$, Fisher's exact test $p = 0.0014$).

Table 4.3 Periosteal reaction at Hexi Corridor sites

	Huoshaogou	Hamadun/Xigang
Woven	5/8 individuals with tibiae	0/7
Rate	62.5%	0.0%
Compact/compact+woven	1/8	7/7
Rate	12.5%	100.0%
None	2/8	0/7
Rate	25.0%	0.0%

In the Huoshaogou population, 49 individuals were assessed for ectocranial porosity (Table 4.4). One individual had porotic hyperostosis (PH) (a probable male), five had cribra orbitalia (CO) (one adult female, one whose age could not be estimated, one child aged 11-12, and two adolescent probable females aged 13.5-20 and 14.5-20), two had both PH and CO (one

of these was an adult male, and one an infant aged 4.5-7.5 months), and one had porosity in the orbits and on the sphenoid (a child aged 2.5-4.5 years).

In the Hamadun and Xigang populations, twelve individuals could be assessed for ectocranial porosity. Only one individual from Hamadun (an adult female) had CO. This seems like a marked decline in CO and PH, but does not reach the level of statistical significance at the $p < 0.05$ level (Chi-square 2.5856, $p = 0.1078$).

Table 4.4 CO and PH at Huoshaogou and Hamadun/Xigang

	Huoshaogou	Hamadun/Xigang
CO	5/49 crania*	1/12
Rate	10%	8%
PH	1/49	0/12
Rate	2%	0%
Both	2/49	0/12
Rate	4%	0%

*Total crania at site (not including fragmentary crania)

Two individuals from Huoshaogou had possible rhinomaxillary signs of lepromatous leprosy or another infectious disease. These included slightly rounded nasal margins, especially the inferior margins, and inflammation and resorption of the alveolar margins (Figure 4.5 and Figure 4.6). It is not possible to do a differential diagnosis on these individuals because they did not have preserved postcranial remains (except for the innominate bones of one). Of these, YHM109:2 is a male aged 25-29 at death, and YHM117:1990 is an adult probable female.



Figure 4.5 Individual YHM117:1990, with rounded nasal aperture and periodontal reaction



Figure 4.6 Individual YHM109:2, with rounded nasal aperture and periodontal reaction

4.3 PALEODEMOGRAPHY

4.3.1 Age and sex distribution

The highest mortality for males at Huoshaogou (Table 4.5, Figure 4.7) was in the adolescent age category, followed by the middle adult age category. This is an unusual pattern, as generally females have higher mortality at a younger age than males. For females at Huoshaogou, the highest mortality was in the young and young/middle adult categories (the latter being those whose age could only be estimated as being between 20 and 50). If the young/middle category is split between the young and middle age categories, then the highest mortality for females is in the young adult category, which is typical, largely because these are the primary child-bearing years.

In an earlier study, Han et al. (2005) examined 120 crania from Huoshaogou, which were moved to a different storage location and are no longer available for study. These authors did find typical sex-specific distributions of age-at-death, with female mortality higher in the adolescent, young adult, and old adult categories (15-35 and 55-60 years of age), and male mortality higher in the middle adult category (35-55 years of age).

At Hamadun/Xigang (Table 4.5, Figure 4.8), the pattern is more typical, with the highest mortality among females in the young adult category and the highest among males in the middle adult category. There are equal numbers of old adults of both sexes, which is slightly unusual, since this category is often represented by all or mostly females.

The age-at-death distributions at both sites tend towards a low average age at death, though this could as easily reflect a high birth rate as a high death rate (Sattenspiel and Harpending, 1983). The birth rate does seem to have remained steady between these periods (see Juvenility index, below).

Table 4.5 Distribution of sex and age categories at Huoshaogou and Hamadun/Xigang

	Infant 0-5 yrs old	Child 5-10 yrs old	Older child 10-15 yrs old	Adolescent 15-20 yrs old	Young adult 20-34 yrs old	Young/middle adult 20-50 yrs old	Middle adult 35-50 yrs old	Middle/old adult 35+ yrs old	Old adult 55+	Adult 20+ yrs old	Total
Huoshaogou											
Female				4	9	10	4			4	34
Male				7	2		4	1			14
Indeterminate/ unknown	2	6	7	1	2	2	2				19
Total	2	6	7	12	13	12	10	1		4	67
Hamadun/Xigang											
Female				1	4		1	1	2	1	9
Male				1	2		5		2		11
Indeterminate/ unknown	2	3		2	3		1				11
Total	2	3		4	9		7	1	4	1	31

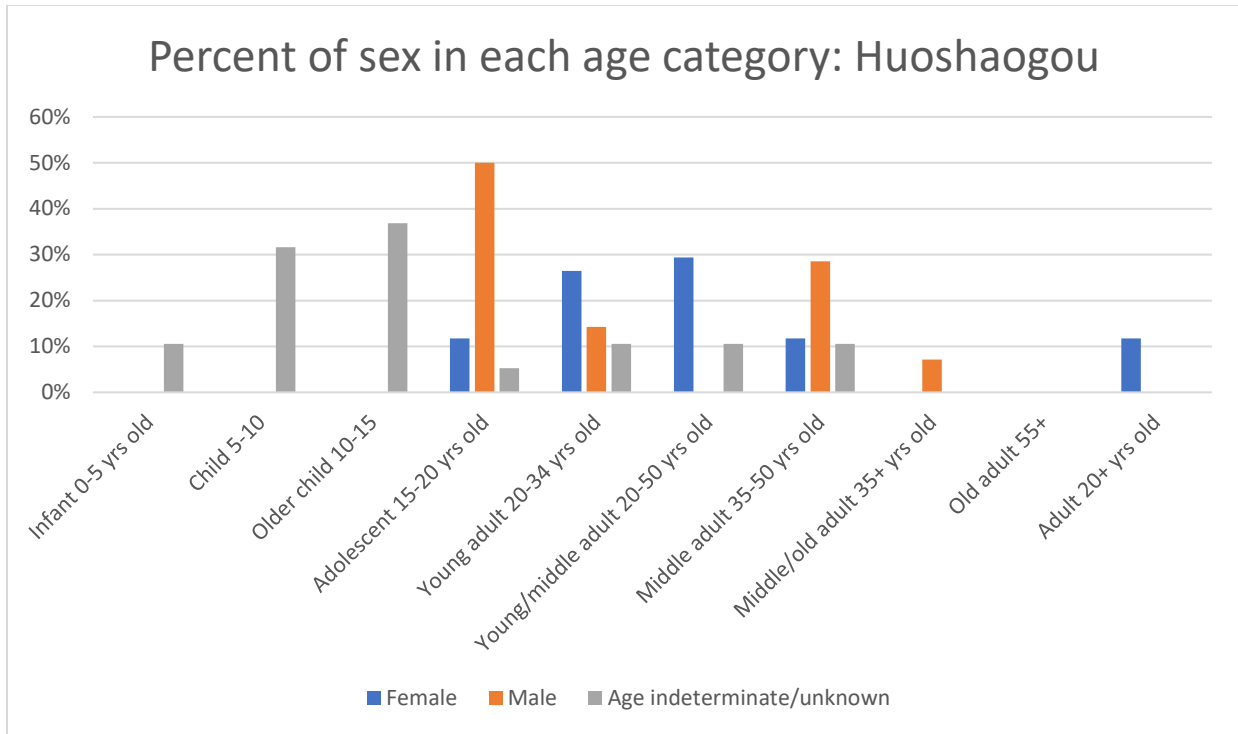


Figure 4.7 Age and sex distribution at Huoshaogou

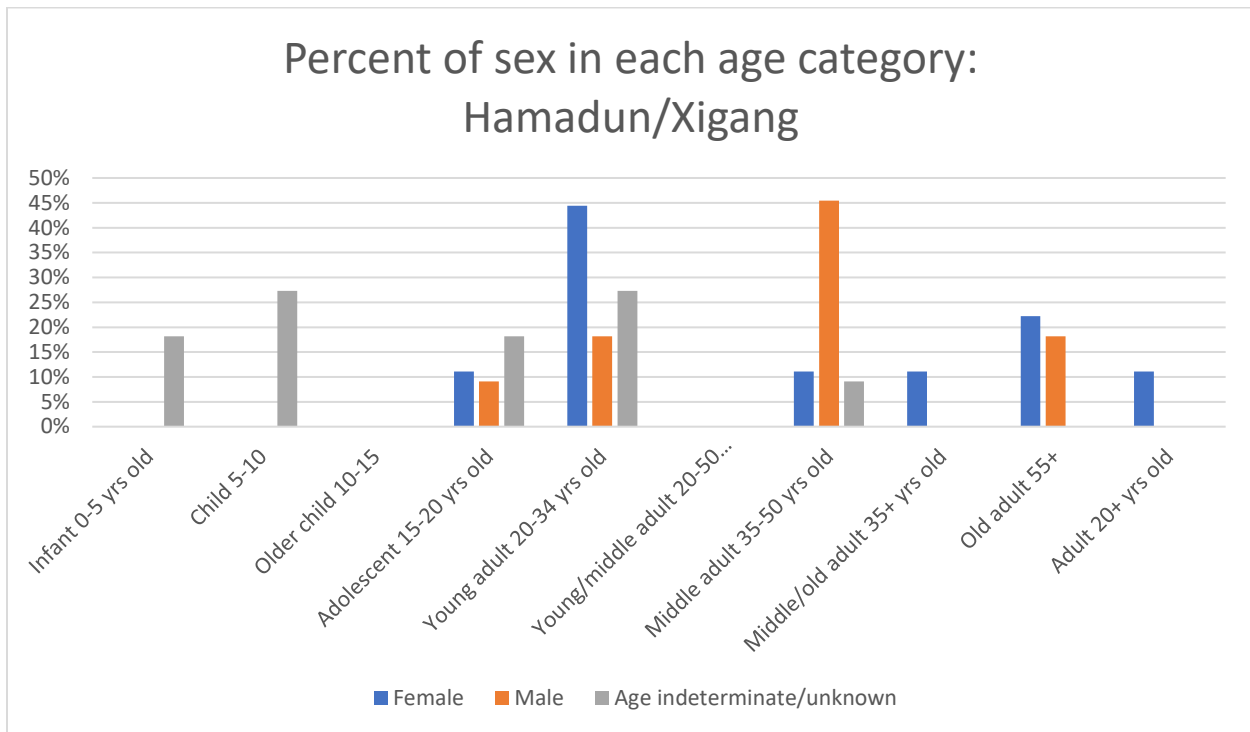


Figure 4.8 Age and sex distribution at Hamadun/Xigang

4.3.2 Juvenility index

The juvenility index (individuals over the age of 30 divided by individuals over the age of 5) and 95% comparison interval of Huoshaogou is 0.4375 ± 0.1339 , and of Hamadun/Xigang is 0.5517 ± 0.1990 (Buikstra et al., 1986) (Figure 4.9). The intervals overlap considerably; thus, I cannot reject the null hypothesis that fertility was the same in both populations.

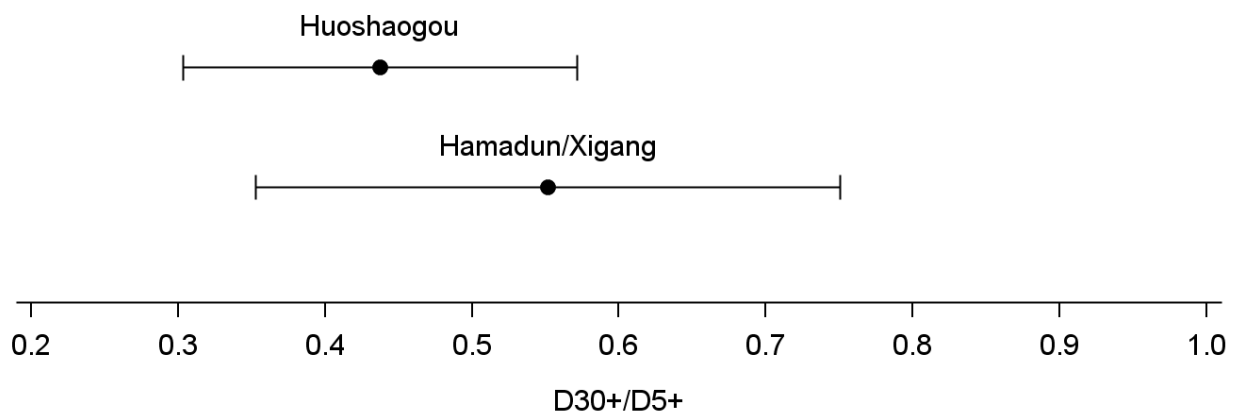


Figure 4.9 Ninety-five percent comparison intervals of the juvenility index of Huoshaogou and Hamadun/Xigang

4.4 BIODISTANCE

A total of 38 individuals from Huoshaogou and seven individuals from Hamadun/Xigang could be scored for cranial nonmetric traits. A biodistance analysis using the mean measure of divergence (MMD) (Killgrove, 2009) showed that the populations from Huoshaogou and Hamadun/Xigang were not biologically distinct groups (MMD: 0.04298, standardized MMD: 0.73896, standardized MMD over 2 indicates statistical significance at $p < 0.05$ level; see Appendix II).

The MMD does show that the Huoshaogou population was biologically distinct from the middle Bronze Age population from Xiaohandi in eastern Qinghai (MMD: 0.08854, standardized

MMD: 3.47809) and from the Warring States period Qin individuals from Shijiahe in the Loess Plateau (MMD: 0.11321, standardized MMD: 2.29837). The Hamadun/Xigang population is also nearly significantly different from Xiaohandi (MMD: 0.12483, standardized MMD: 1.92864). As discussed in Chapter 3, according to the Ward's cluster analysis, the Xiaohandi clusters with groups from farther north, but given this group's biological distance from both Huoshaogou and Hamadun/Xigang, it seems unlikely that they could have originated in the Hexi Corridor. (See Appendix II.)

A Ward's cluster analysis (Figure 4.10) shows that Huoshaogou is in the same cluster as Xiaohandi, the Rong people of Zhaitouhe and Shijiahe in Shaanxi, and the Spring and Autumn period population from Jiulongshan in Ningxia (see Chapter 5). Hamadun/Xigang is in a cluster by itself, and groups with all other sites only very late. This is surprising given that it is not significantly different from the other groups in the MMD analysis, but suggests that there may have been gene flow between Hamadun/Xigang and groups from outside Northwest China.

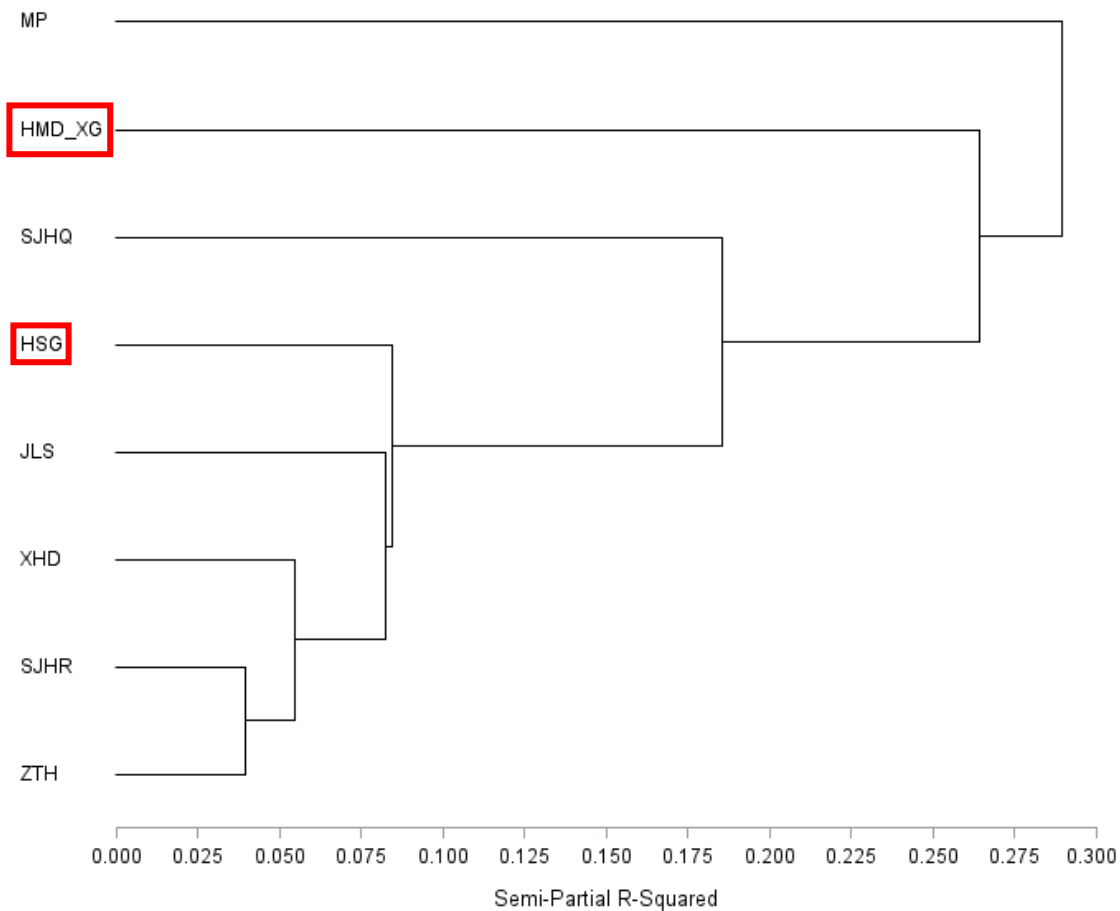


Figure 4.10 Ward's cluster analysis of dissertation study sites, highlighting the position of Huoshaogou (HSG) and Hamadun/Xigang (HMD_XG)

These results support the findings of previously published studies on the same populations by Han Kangxin and colleagues. Han et al. (2005) found that based on metric traits of 120 individuals from the site, Huoshaogou most closely resembled other groups from prehistoric Gansu and modern East Asian groups, including modern Chinese and Korean people, and were clearly less closely related to North Asian and Siberian groups and not at all closely related to West Asian groups.

Han Kangxin (2001) has also published an analysis of a set of 11 crania from Hamadun and two crania from Xigang, which were not available for my study and therefore are not

included in my analysis. Han (2001) found that these crania from Hamadun/Xigang are of a “North Asian type,” and cluster with steppe populations, including Evenki, Buryat, Mongolian, and Spring and Autumn period Ningxia (in the Western Loess Plateau). Therefore, they do not resemble the “East Asian type” skulls from Huoshaogou, which is consistent with my Ward’s cluster analysis.

My results also agree with the biodistance analysis by Zhao et al. (2014). (Following Wang and Zhu (2004), the authors combined the groups from Mapai and Xiaohandi in their cluster analysis.) They found that Huoshaogou clusters first with the other early Bronze Age site of Mogou, affiliated with the Qijia Culture and located in eastern Gansu, and then with the combined Mapai/Xiaohandi group from Qinghai and the other Siba Culture sites of Donghuishan and Ganguya in Gansu. This is similar to my first cluster, which combines Huoshaogou with Xiaohandi and other Northwest Chinese groups. Zhao and colleagues’ Shajing Culture group (the Xigang and Chaiwan’gang cemeteries, both associated with the Sanjiaocheng site) is the second to last to cluster, and groups with the roughly contemporaneous group from Pengpu in Ningxia. In my study, the Shajing Culture groups (Hamadun and Xigang) were also late to cluster with the other Northwestern sites.

Additionally, material culture elements of the late Bronze Age Shajing Culture, with which Hamadun and Xigang were affiliated, have also been identified in Ningxia among the remains of the Xiongnu, an Iron Age group from the steppe (Xie, 2002), and are distinct from the early Bronze Age Siba Culture of Huoshaogou (Gansu, 1990; Li, 1993). It therefore seems that Huoshaogou is closely related to other prehistoric Northwest Chinese groups, while Hamadun/Xigang has some genetic and cultural admixture with steppe groups that migrated south into Northwest China in the Bronze Age.

4.5 COMPARATIVE DIETARY DATA

Few data are available for botanical and faunal remains in Northwest China, and those that are available tend to be qualitative and are mostly drawn from cemeteries rather than settlement sites (Ma et al., 2014). However, some quantitative data are available. For example, Dodson et al. (2013) report that the botanical remains at Huoshaogou comprise more wheat than millet.

The results of direct dietary reconstruction using stable isotope analysis are consistent with this finding: they show an increase in human consumption of C₃ plants in Gansu after 2000 BCE (Garvie-Lok and Zhou, 2015). They also suggest that consumption of C₄ plants continued, and that domesticated herd animals were grazed on wild C₃ plants (Atahan et al., 2011). These studies utilize only bone collagen, which reflects primarily the protein portion of the diet (Ambrose and Deniro, 1986; Bethard, 2013). The results of some key studies are summarized below (Figure 4.11).

Huoshaogou itself has already been the subject of two stable isotope studies of human bone collagen. These studies lack data on non-human animals, and on human bone mineral apatite, but nevertheless offer crucial insights into the Bronze Age human diet in the Hexi Corridor.

Liu et al. (2014: 669) report stable isotope analysis of bone collagen from 27 human individuals from Huoshaogou, which was carried out at Peking University. The study found a trend between 2000 and 1800 BCE of $\delta^{13}\text{C}$ values decreasing by about 5-10‰, indicating the introduction of C₃ plant foods to the human diet. For Huoshaogou, they report a mean $\delta^{13}\text{C}$ value of -12.4‰ ($\sigma = 1.4\text{‰}$) with a range of -14.1‰ to -9.2‰ ; and a mean $\delta^{15}\text{N}$ value of 12.2‰ ($\sigma = 1.0\text{‰}$) with a range of 9.1‰ to 13.8‰ . The $\delta^{13}\text{C}$ value at Huoshaogou suggests predominantly consumption of C₄ plants, likely millets. The depleted $\delta^{13}\text{C}$ value suggests some consumption of

C₃ plants, which might be evidence for early cultivated wheat in the region, or for consumption of animals fed on C₃ plants. This could be tested in the future by examining the difference between $\delta^{13}\text{C}$ values in human collagen and bone apatite. This is also inconsistent with the findings of Dodson et al. (2013), who found more wheat than millet among the botanical remains at Huoshaogou, and therefore it seems more study is needed.

After 1800 BCE, the authors also found a rise of about 1-3‰ in the $\delta^{15}\text{N}$ values. This might indicate increased consumption of animal proteins, or it could mean that cereal crops had more enriched $\delta^{15}\text{N}$, perhaps because of a change in manuring practices, aridity, or soil chemistry. There is paleoenvironmental data (see Paleoclimate and paleoecology above) to support the conclusion that the Hexi Corridor was more arid after 2000 BCE, so this cannot be ruled out as an explanation for the change in $\delta^{15}\text{N}$ values. Sites from the same area appear to share $\delta^{15}\text{N}$ values (sites in the wetter summer monsoon zones have lower $\delta^{15}\text{N}$ values), which further supports the idea that environmental conditions, not changing subsistence practices, are responsible for changes in $\delta^{15}\text{N}$ values.

Interestingly, two individuals from Huoshaogou that were carbon dated to the 4th and 3rd millennia BCE, much earlier than the main occupation, display the higher $\delta^{13}\text{C}$ value of the pre-2000 BCE sites in the study, and therefore have higher values than the Siba-period occupants of Huoshaogou. They are therefore an illustration of the shift from C₄ to mixed C₃ and C₄ plant consumption within a single site (Liu et al., 2014: 671). (These individuals were not available for study during my data collection.)

The authors point out that settlement in Gansu expanded over the course of the third millennium BCE, which was the first time intense human occupation had occurred there. This denser population, along with a drying climate, could have driven the relatively quick adoption

of wheat: wheat requires less land to cultivate than millet, and therefore could have helped avert food shortages. The crop was still new to East Asia at this time, and was not yet being consumed on a large scale on the Loess Plateau to the east. Therefore, environmental and population pressures may have driven the more rapid adoption of this new crop in Western China. If the adoption of wheat in the early Bronze Age was a response to a drier climate, then future dietary stable isotope analysis of the late Bronze Age residents of Hamadun and Xigang should show the continuation and possibly the intensification of C₃ plant consumption.

Zhang (2006) also reports stable isotope values from Huoshaogou, among those of other sites. This report is significantly less detailed as to method, and only reports average values. The average $\delta^{13}\text{C}$ value for human bone collagen at Huoshaogou in this study is -12.48‰, and the average $\delta^{15}\text{N}$ value for bone collagen was 12.75‰ (N=14). These values are within the range reported by Liu et al. (2014). The author concludes that this $\delta^{13}\text{C}$ value indicates mixed consumption of C₃ and C₄ plants. She also discusses the significance of the $\delta^{15}\text{N}$ value, which is higher than that at other sites in the region such as Shangsunjia and Lajia (in Qinghai) and Yanbulake (in Xinjiang), and concludes that this is likely the result of higher consumption of animal protein by occupants of the site. However, as discussed above, this could also be due to changes in soil chemistry or differences in moisture.

Some additional direct dietary reconstructions exist for other sites in the Hexi Corridor, all from the early Bronze Age, roughly the time of Huoshaogou. Atahan et al. (2011) report stable isotope values for faunal bone collagen from the sites of Gan'gangwa and Huoshiliang, carbon dated with charcoal, seeds, and bone collagen to 2292-1758 BCE and 2135-1692 BCE, respectively. Remains of C₃ crops including wheat, barley, and oats have been found at Huoshiliang and other contemporaneous sites in the Hexi Corridor and the Yellow River Valley,

but the stable isotope results from this study suggest they were not yet an important part of the diet at Huoshiliang and Gan'gangwa. The faunal $\delta^{13}\text{C}$ values in this study ranged widely, from -19.4‰ to -7.7‰. They clearly cluster into three groups, indicated different levels of C_3 and C_4 plant consumption: the herbivores showed C_3 or mixed C_3 and C_4 consumption (-4.1‰ to -11.8‰), and only the omnivores and carnivores showed the highest C_4 consumption (most between -11.7‰ and -7.7‰). Wild C_4 plants would not be common at this latitude (Dong et al., 2015), so the herbivores' $\delta^{13}\text{C}$ values suggest that they grazed on wild C_3 plants. The range of herbivore values also suggests grazing in a wide range of ecological contexts with different water regimes, which would be likely in the ecological mosaic of the Hexi Corridor. Omnivores, on the other hand, appear to have been at least partly fed on millets.

Herbivore $\delta^{15}\text{N}$ values ranged from 4.1‰ to 10.0‰, while omnivores had a range of 6.8‰ to 12.2‰. The difference in mean values between these groups is less than the typical trophic level offset, and might have been due to omnivores' consuming some animal protein, or to their consuming millet from manured fields.

An analysis of the human remains and cereal remains at Huoshiliang are presented by Dodson and colleagues (2012). Only two human sets of remains recovered in a salvage excavation were included in this study. The two individuals had $\delta^{13}\text{C}$ values of -8.71‰ and -8.86‰, and $\delta^{15}\text{N}$ values of 6.10‰ and 9.76‰. These values are in the same range as the non-human omnivores for $\delta^{13}\text{C}$, while being quite distinct from the herbivores from the same site, which suggests humans were not consuming large amounts of primary or secondary animal products from their domesticated herbivores.

For $\delta^{15}\text{N}$, the human values are in the same range as both omnivores and carnivores. The human and omnivore values are 1.6‰ removed from the herbivores' values, less than the typical

trophic level effect of 3-5‰, which again suggests that they were not consuming large amounts of animal products. This is surprising, given the evidence for hunting and herding in the Hexi Corridor and their supposedly agropastoral subsistence strategy. This result is similar to the findings of another study in Turkmenistan, which also found high level of plant food consumption in Iron Age agropastoralists (Bocherens et al., 2006).

The authors also report that broomcorn and foxtail millet were most abundant at lower depths at Huoshiliang, and that wheat and oat seeds become more abundant at shallower depths, though the share was still very small compared to that of broomcorn millet (wheat contributed a maximum of 2.41% of seeds in any one arbitrary stratum).

Dong et al. (2015) report the results of a stable isotope analysis of the Qijiaping site, which was affiliated with the Qijia culture (2100-1400 BCE), contemporaneous with Siba but located at the far eastern end of the Hexi Corridor, on the western edge of the Loess Plateau. From a sample of 42 human individuals, the study found an average $\delta^{13}\text{C}$ value for bone collagen of $-8.9 \pm 1.1\text{‰}$ with a range of -13.4‰ to -7.5‰ , and an average $\delta^{15}\text{N}$ value for bone collagen of $9.8 \pm 0.9\text{‰}$ with a range of 8.9‰ to 14.1‰ . The team also analyzed nonhuman herbivore and omnivore remains, and found that the human $\delta^{15}\text{N}$ value was only enriched by 2.4‰ over the herbivore values, less than the typical 3-5‰ trophic level effect. The human bone collagen values for stable carbon isotopes were generally consistent with a C_4 plant-based terrestrial diet, which, based on frequent finds of millet grains at other Qijia sites, was likely the result of consuming millet or millet-fed animals. The herbivores (horse and cattle) appear to have consumed primarily C_3 plants ($\delta^{13}\text{C}$ range: -17.8‰ to -15.8‰), which may mean they were grazed on wild plants. The omnivores (pigs and dogs) showed a range of $\delta^{13}\text{C}$ values: one pig had a value indicative of C_3 plant consumption (-17.5‰), and most of the rest had values

indicating C₄ consumption (-10.7‰ to -7.1‰). One cow and one pig likely had mixed C₃ and C₄ consumption (both -13.1‰). As for δ¹⁵N values, herbivore values fell in the range of 6.7‰ to 8.5‰ with a mean of 7.4 ± 0.7‰, while the omnivores ranged from 6.0‰ to 8.7‰ with a mean of 7.4 ± 0.7‰. These δ¹⁵N values are lower than those of the humans. All this indicates a pastoral system of mixed grazing and provisioning, or grazing on both wild plants and agricultural stubble, for domesticated animals, and consumption of millet and animal products by humans.

The above results are summarized in Figure 4.11. All the published data from this region comes from the early Bronze Age, so chronological comparisons cannot yet be made. Besides a few outliers, it is clear that the diet at Huoshaogou was different from that of Qijiaping and Huoshiliang. This is likely not the result of geographic location or differences in climate alone: Qijiaping is located quite far from Huoshaogou, but Huoshiliang is located close to Huoshaogou, in the arid Hexi Corridor. Also, Huoshaogou is quite different from the other sites in both the δ¹³C and the δ¹⁵N values, suggesting a dietary difference in the protein consumed. The higher δ¹⁵N value may mean more reliance on animal products, and the lower δ¹³C value might suggest the inclusion of some C₃ plants in the diet (Brown and Brown, 2011), possibly introduced through the consumption of products from animals grazed on wild C₃ plants.

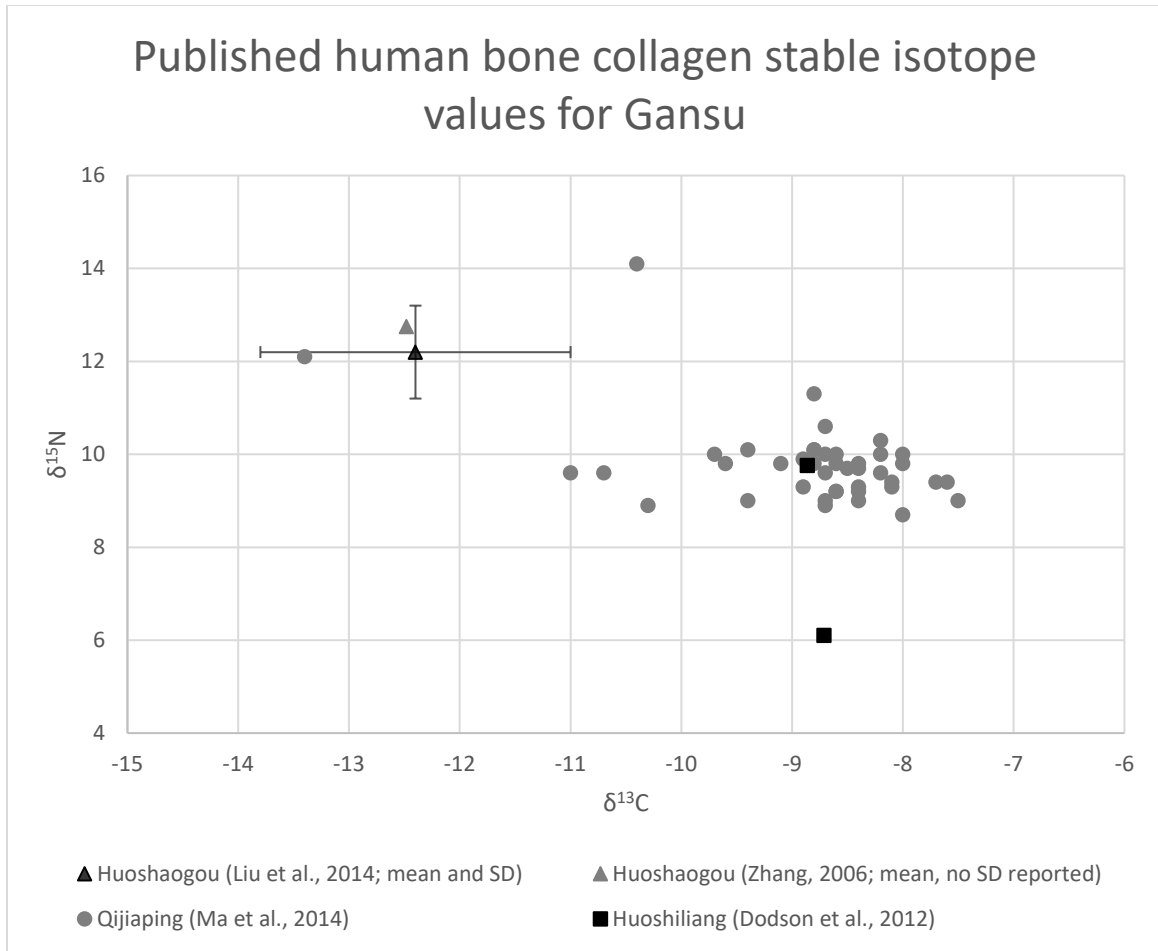


Figure 4.11 Published carbon and nitrogen stable isotope values from human bone collagen for sites in the Hexi Corridor and southern Gansu. Approximate dates of sites from the above published sources: Huoshaogou: 1700-1400 BCE (early Bronze Age, Siba Culture); Huoshiliang: 1600-1500 BCE (early Bronze Age); Qijiaping: 2100-1400 BCE (early Bronze Age, Qijia Culture).

4.6 SUMMARY: A COMPLEX ADAPTIVE SYSTEM IN THE HEXI CORRIDOR

Some literature on the Bronze Age transition in the Hexi Corridor frames the changes in terms of environmental degradation and dramatic changes in human use of the landscape. These claim that limited resources and climate fluctuations constrained when and where civilization developed (Han, 2008: 3), and the string of small but stable oasis cultures of the Hexi Corridor eventually gave way to mobile and conflict-ridden populations living in a harsh, arid climate. Some have referred to “abandonment” and “collapse” across the region (Zhao et al., 2009: 16),

and some have also suggested that human exploitation of the land caused the degradation, though more data is needed to assess this possibility (Han, 2008; Zhao et al., 2009).

There is palynological and other evidence that climate change in the late Holocene did lead to a change in effective moisture, which caused changes in vegetation in the arid and semi-arid regions of China (Zhao et al., 2009). However, there has not been a systematic archaeological survey of Gansu that would allow us to assess the possibility of large dislocations and population movement in response to climate change events. The purported correlations between environmental change and shifts in population or settlement patterns in the archaeological record have therefore been mostly impressionistic. More archaeological data, especially systematic settlement surveys, are needed for a robust exploration of the relationships between archaeological and paleoenvironmental datasets.

I have here presented some data on human health, diet, and demography as a preliminary step towards more robust and fine-grained analysis. Overall, the above findings from Huoshaogou and Hamadun/Xigang suggest that, from the second to the first millennia BCE in the Hexi Corridor:

- diet changed somewhat (cariogenicity decreased, wear increased) but certain elements of the diet remained constant (calculus rates did not change);
- frailty decreased (healing tibial periosteal reaction increased over active tibial periosteal reaction);
- childhood growth disruptions declined (fewer individuals with LEH);
- childhood anemias declined (fewer cases of CO/PH);
- nutritional inadequacy or other stressors that impact growth attainment did not change (no change in long bone length);

- fertility remained the same (no change in the juvenility index); and
- activity patterns changed (upper limb arthritis increased).

These data amount to evidence of some changes in diet, but not a complete and categorical change in subsistence strategy; minor health changes including reduced frailty, but no dramatic shifts in disease burden; and some changes in activity patterns, but no detectable change in trauma. Fertility, a sensitive indicator of population health and demographic change, also did not change between the periods.

Archaeological evidence from the region supports the conclusion that between the second and first millennia BCE, inhabitants of the Hexi Corridor developed more specialized animal husbandry adapted to the arid environment, but continued to practice agriculture, and diversified their crop base by adding West Asian crops such as wheat and barley. The decline in active periosteal new bone formation and enamel hypoplasias suggests declining physiological stress, which may indicate that the more diversified subsistence system of the late Bronze Age was better adapted to the semi-arid environment and to year-to-year unpredictability. The increase in C₃ plant cultivation and specialization of animal husbandry suggests that some changes in subsistence practices may have been precipitated by climate change. However, the archaeological and bioarchaeological evidence suggest that in response to a changing climate, the Bronze Age human-environment systems of the Hexi Corridor underwent incremental adaptation, rather than a transformational adaptation or a collapse.

CHAPTER 5 LOESS PLATEAU: A TEMPERATE LOESS ZONE

This chapter presents data from the Warring States period cemeteries of Zhaitouhe and Shijiahe, located in the western part of the Loess Plateau. Though these sites date to the late first millennium BCE, well after the 4000 BP climate change event, the people of this time had to contend with an arid climate as well as increasing social stratification, life within a state, and conflict between ethnic groups.

5.1 CLIMATE AND ENVIRONMENT

Huangling County, where Zhaitouhe and Shijiahe are located, has a humid continental climate with a dry winter and hot summer (Köppen Dwa) (Kottek et al., 2006). Average daily temperatures range from -5.5 °C in winter to 23.1 °C in summer (China Meteorological Administration). Elevation is around 1 km above sea level (Google Earth).

5.1.1 Paleoclimate and paleoecology

Beginning in the third millennium BCE, the Loess Plateau experienced an oscillating climate and overall cooler conditions (Pechenkina et al., 2002). In the mid-first millennium BCE, when these two sites date from, the northwestern Loess Plateau was experiencing an extended late Holocene dry period, as evidenced by pollen records that show the spread of drought-tolerant plants, with steppe vegetation replacing earlier forest cover (Zhao et al., 2009).

Changes in vegetation were dependent on local conditions, but pollen records from sites near Huangling County agree that the late Holocene was cool and dry. A pollen record from a section of loess in Lantian, in southern Shaanxi Province, shows the presence of forest steppe dominated by pine, as well as herbs and shrubs (*Artemisia* species), which grow well in arid or semi-arid climates (Li, 2005). A study of pollen records from sites across the northwestern Loess Plateau, including the sites of Yaoxian in neighboring Shanxi Province and Shujiawan in Gansu Province, show the rise of Chenopodiaceae (goosefoot plants) and *Ephedra* species (shrubs) (Zhao et al., 2009). This study found that after about 3000 BCE, sites on the northwestern Loess Plateau in river valleys or on terraces had progressed from forest conditions in the mid Holocene to steppe or forest steppe in the late Holocene.

5.2 HISTORICAL AND ARCHAEOLOGICAL RECORD

The Zhaitouhe and Shijiahe cemeteries are located only 4 km apart, each on spit of a land on the north bank the Hulu River, a tributary of the Wei River, which flows into the Yellow River. The Shijiahe cemetery is smaller, and was discovered during a survey associated with the excavation of Zhaitouhe. The two cemeteries have similar material cultural assemblages; no associated settlement has yet been found (Shanxi et al., 2015).

At Zhaitouhe, 90 graves (mostly pit graves) and two horse pits were excavated. Because the graves are laid out in a relatively orderly fashion and there is no intrusion of graves on one another, the excavators believe that the cemetery was in use for a relatively short time. Based on artifact typology, the excavators believe the cemetery was in use during the early and middle phases of the Warring States period (475-221 BCE). The mortuary assemblage consists mostly of ceramics, with some iron ornamental objects, and bronze objects including weapons, vessels, and small objects. Most graves have traces of coffins or other grave furniture, and there are three tiers

of graves based on the grave furniture: no coffins (N=11), single coffins (N=36), or double coffins (N=20); the preservation in the remaining 23 graves was too poor to determine what grave furniture they originally contained. The burial chambers range from 2 to 6 sq m in plan (Sun et al., 2012). Some of the graves had bones of sacrificed animal; there were not many, but they included horse, cattle, and sheep/goat skulls and forelimbs (Sun et al., 2015).

Based on artifact and grave type, the excavators assigned the remains at Zhaitouhe to the “Rong” culture (Shanxi et al., 2012; Sun et al., 2012). “Rong” is an ethnonym taken from the Chinese historical record that refers to a constellation of non-Chinese groups that lived on the Western border of the Chinese states. Though this is an ethnohistorical term, its use by archaeologists to describe a material culture assemblage does denote the affinity between the Zhaitouhe material and that of other Rong sites farther to the northwest, in eastern Gansu Province and the Guyuan area of southern Ningxia. Similar objects have occasionally also been found at other sites in the Central Plains (Sun et al., 2015).

While Rong-type artifacts were most common at Zhaitouhe (around 60% of objects at the site), the excavators also report finding significant quantities of objects that appear to show the influence of Central Plains cultures such as that of the Three Jin States (Wei, Zhao, and Hǎn) (about 35% of objects), and a few objects that appear to show the influence of northern bronze-using cultures of the steppe, such as *fu*-vessels and bronze plaques (less than 5% of objects) (Sun et al., 2012). This mixture of cultural influences has been seen at other Rong sites in Gansu.

The close association of the Rong and Jin-style artifacts at Zhaitouhe means that the people of Zhaitouhe probably had a close cultural relationship with the State of Wei, which controlled the area at this time, and were likely living within the actual borders of the State of Wei (Sun et al., 2012). There were Wei coins found at Zhaitouhe that could not have been cast

later than the middle Warring States period, and some iron objects at Zhaitouhe were cast with the more advanced techniques of the Three Jin states. All these point to the presence of the State of Wei in this area and the dating of Zhaitouhe to the early to middle Warring States period (Sun et al., 2012). In fact, the Rong had a strong presence in the Wei River Valley since around the beginning of the Spring and Autumn Period, and had continuous contact with the Chinese states while remaining culturally distinct (Li, 2006), though two-way cultural exchange also took place throughout this time (Shan, 2016).

There are a number of references to the Rong of this area in Chinese historical texts. The *Zuo Zhuan* states that the “Rong of Guazhou” (near today’s Jiuquan, Gansu Province, at the far western end of the Hexi Corridor) migrated into Jin lands in the late Spring and Autumn period (Guo et al., 2014; Sun et al., 2012). The *Hou Han Shu* (*The Book of the Later Han*) mentions that in the late Spring and Autumn period (771-476 BCE), the Rong had a close relationship with the State of Jin (which later split into Wei, Zhao, and Hán) (Sun et al., 2012). The *Zuo Zhuan* also clearly records the fact that the Rong allied with Jin to defeat the State of Qin in battle (Li, 2006; Sun et al., 2012), but that the Rong were still culturally separate from their Chinese allies and at times came into conflict with them (Lewis, 1990). Finally, the *Shiji* (*Records of the Grand Historian*) mentions that the State of Wei at one point controlled the area where Zhaitouhe is located (known as “Hexi” or “west of the [Yellow] River”, not to be confused with the Hexi Corridor), and fought for control of the area against the State of Qin (Sun et al., 2012).

There is not complete scholarly agreement on where exactly the “Hexi” area was located, but the area of Zhaitouhe would have been under the control of the State of Wei by the middle Warring States period. Therefore, the excavators of the site surmise that the “Rong of Guazhou” migrated to the lands of the State of Jin in the early part of the Spring and Autumn period, and

that the Rong people of Zhaitouhe represent one part of this migrant population that remained under the control of the State of Wei after it split from the old State of Jin. The earlier appearance of Rong type objects farther to the northwest, the resemblance of some objects at Zhaitouhe to those of the Siwa culture from farther west, the apparent influence of northwestern iron smelting technology in the Zhaitouhe artifacts, and the historical record all concur with this interpretation (Guo et al., 2014; Li, 2006; Sun et al., 2012; Zhang, 2014).

Shijiahe has a more complicated history of use. Thirty-seven graves were found, 27 of which were pit graves and 10 of which were side chamber graves. The material culture assemblage found in the pit graves was nearly identical to that of Zhaitouhe: mostly Rong-style artifacts virtually indistinguishable from those of Rong sites in eastern Gansu and southern Ningxia province; some objects from the Central Plains culture of the Three Jin States; and a few objects with clear influence from northern steppe cultures (Shanxi et al., 2015; Sun et al., 2015). According to the excavators, based on artifact typology, these graves date to the early to middle part of the Warring States period. Since these graves and their contents are so similar to those of Zhaitouhe, and since the two cemeteries are located only 4 km apart, they may have been used by the same group of people (Shanxi et al., 2015; Sun et al., 2015). The burial chambers of the shaft graves range from 3 to 7 sq m in plan, and have either single, double, or triple coffins (single coffin graves are the most abundant), making these graves marginally richer than those of Zhaitouhe in construction, though many Zhaitouhe graves contained crania and forelimb elements of horse, cattle, and sheep/goats as offerings, while Shijiahe contained no such offerings (Sun et al., 2012; Sun et al., 2015).

The interesting difference between Shijiahe and Zhaitouhe emerges when one examines Shijiahe's side chamber graves. The grave type, as well as the mortuary objects, are typical of

the material culture of the State of Qin in the late Warring States period, and are mostly represented by daily use ware ceramics. In these graves, material remains from the Rong or northern steppe assemblages are rarely found (Sun et al., 2015). These graves also tend to be smaller and have less rich mortuary assemblages and grave furniture than the pit graves, suggesting that the individuals buried in these graves were the commoners or civilians of the State of Qin. Finally, these ten chamber graves are distributed mainly around the edges of the cemetery, somewhat separate from the pit graves.

The presence of two distinct styles of graves and mortuary assemblages may point to two phases of use for the Shijiahe cemetery: an earlier phase of use by Rong people living within the State of Wei during the early and middle Warring States period; and a later phase of use by a Qin population in the late Warring States and possibly into the Qin Dynasty, beginning after the conquest of this area by the State of Qin (Shanxi et al., 2015; Sun et al., 2015). This interpretation is borne out by the historical record: the *Shiji* states that the Qin conquered this area, likely no later than 330 BCE (Sun et al., 2015). This would have put the area under the direct control of the State of Qin in the late Warring States period. Therefore, in the late Warring States period, Rong and northern steppe influences disappear from the Shijiahe graves, and Qin-style side chamber graves with Qin mortuary assemblages appear, with only rare examples of the previous occupants' material culture. This change in material culture suggests that after the conquest, the Qin forced out the previous occupants and began using Shijiahe as a burial place for their own commoners. It is recorded in many places in the textual record that after the Qin conquered new territory, it was common practice to force out the previous inhabitants and move in a new population of Qin settlers, forced migrants who were mostly criminals or peasants.

There is another interpretive possibility, however. Artifacts from the Shijiahe shaft graves may not be numerous enough to determine the graves' affinity with the early Warring States period, and they may in fact date to the late Warring States (Shao Jing, personal communication). For instance, in SHSM33, a shaft grave, at least one ceramic vessel had morphological traits associated with the late Warring States or even the Qin Dynasty (Sun et al., 2015). This would mean that after the Qin conquest in 330 BCE, the Rong people who remained behind lived alongside the new Qin settlers and were buried in the same cemetery at Shijiahe, still with distinct mortuary traditions and somewhat distinct material culture assemblages. This is consistent with other parts of the historical and archaeological records that document a gradual Sinification of the people living on the borders of Chinese states throughout the Spring and Autumn, Warring States, and Qin Dynasty periods (Shan, 2016).

As will be shown below, the paleopathological record supports this latter interpretation. The health profiles of the Rong from Zhaitouhe and the Rong from Shijiahe are quite distinct, whereas the health profile of the Rong from Shijiahe and the Qin from Shijiahe are virtually indistinguishable. This similarity in health profiles suggests that the two groups buried at Shijiahe lived under similar conditions of diet, disease, and labor.

5.3 PALEOPATHOLOGY

5.3.1 Oral health

A total of 44 out of 72 individuals at Zhaitouhe had preserved dentition. All 23 Rong individuals from Shijiahe had preserved dentition, and eight out of nine Qin individuals from Shijiahe had dentition (Table 5.1).

Table 5.1 Oral health measures at Zhaitouhe and Shijiahe

	<i>Calibrated carious lesion rate[†]</i>	<i>Uncalibrated carious lesion rate[†]</i>	<i>Carious lesion rate: M[†]</i>	<i>Carious lesion rate: F[†]</i>	<i>Average wear score^{***†}</i>
<i>Zhaitouhe*</i>	12.9%	11.0%	10.7%	15.0%	4.6
<i>Shijiahe (Rong)**</i>	16.8%	16.1%	14.8%	24.9%	4.2
<i>Shijiahe (Qin)**</i>	21.4%	20.8%	27.0%	10.7%	4.4
	<i>AMTL[†]</i>	<i>AMTL: M[†]</i>	<i>AMTL: F[†]</i>	<i>Calculus[‡]</i>	<i>Abscesses[‡]</i>
<i>Zhaitouhe*</i>	15.1%	14.3%	17.2%	13.6%	27.3%
<i>Shijiahe (Rong)**</i>	9.7%	8.0%	15.3%	60.9%	56.5%
<i>Shijiahe (Qin)**</i>	10.4%	13.2%	0%	62.5%	62.5%

*Duyar and Erdal caries calibration method (Duyar and Erdal, 2003; Erdal and Duyar, 1999)

**Lukacs caries calibration method (not significantly different from results using Duyar and Erdal method) (Lukacs, 1995)

***Scored using method developed by Smith (1984)

[†]Number of teeth out of all teeth observed

[‡]Number of individuals out of all individuals with observable teeth

5.3.1.1 Caries

Zhaitouhe and Shijiahe had by far the highest frequencies of carious lesions of any sites in the entire study (see Chapter 6). Caries is in part a consequence of diet, specifically the consumption of cariogenic, starchy foods (Larsen, 1997). Despite the fact that the Rong are traditionally considered to have been agropastoralists from Northwest China and the Qin were settled agriculturalists, all three groups had notably high carious lesion rates, approaching that of the roughly contemporaneous group at the Xinghong site in Henan, an urban Chinese population (17.6%) (Okazaki et al., 2016).

There is a significant difference at the $p < 0.05$ level between the carious lesion frequencies of the Rong of Zhaitouhe and the Rong of Shijiahe, even though the excavators concluded that the two cemeteries were in use during the same time period, likely by the same population (Chi-square 3.9736 $p = 0.0462$). This difference could be interpreted to mean that the two cemeteries were actually not used at the same time by the same population, or it may mean that the people buried at the two sites were contemporaries but had different diets. In contrast, there is no significant difference in carious lesion frequency between the Rong from Shijiahe and the Qin from Shijiahe (Chi-square 1.9484 $p = 0.1628$), which suggests that they shared a similar diet.

Both sites have notable sex differences, with females having higher rates of carious lesions. In the case of Zhaitouhe the difference is not quite statistically significant at the $p < 0.05$ level but still suggests a trend (Zhaitouhe: Chi-square 3.1414 $p = 0.0763$; Shijiahe Rong graves: Chi-square 7.4576 $p = 0.0063$; Shijiahe Qin difference not significant because this group includes only one female). This is possibly due to biological differences in oral chemistry between males and females (Hillson, 2001), though it has sometimes been cited as evidence of a division of labor in food procurement or preparation (Lukacs, 1992; Lukacs and Largaespada, 2006).

The high carious lesion frequency at both these cemeteries suggests a more cariogenic diet than that of areas farther to the northwest, in Gansu and Qinghai. The high rate might indicate that millet, the dominant staple crop of the Loess Plateau at this time, constituted a significant portion of the diet. Human diet can be further clarified when the settlements associated with these cemeteries are found, and tools and paleobotanical remains can be analyzed, and when the human remains can be studied with stable isotope analysis for direct dietary reconstruction. The higher frequency of carious lesions at Shijiahe also cannot be

explained by age, since the average age at death was lower at Shijiahe than at Zhaitouhe (see Age and sex distribution, below).

5.3.1.2 Attrition

The average attrition scores (Smith, 1984) at the two sites were higher than at any other site in this study, except for the late Neolithic population at Mapai. Again, there is a significant difference between the level of dental attrition in the Rong of Zhaitouhe and the Rong of Shijiahe (Chi-square 170.1496 $p < 0.0001$; Student's t-test $p < 0.0001$). The difference between the Rong and Qin populations from Shijiahe was not significantly different in a Chi-square test or a t-test (Chi-square 10.4228 $p = 0.1659$; Student's t-test $p = 0.1056$). These differences may be due to different contents of the diet, or differences in food preparation, such as how grain was milled. Alternatively, the lower occlusal wear at Shijiahe could be due to the fact that the population had a younger average age-at-death.

5.3.1.3 Calculus

In individuals with dental calculus, very few teeth had calculus and there was usually very little calculus on each tooth. Therefore, the rates of calculus were calculated as a percent of individuals in each population with any calculus on the dentition. Again, there is a significant difference between the Rong of Zhaitouhe and the Rong of Shijiahe (Chi-square 18.0925 $p < 0.0001$), while there is no significant difference between the Qin and the Rong of Shijiahe. There is still no general agreement on the interpretation of differing calculus rates. However, increased protein consumption increases the alkalinity of the oral environment, which encourages the mineralization of plaque into calculus (Pechenkina et al., 2002). So, there may be a connection between meat consumption and calculus accretion, and the higher calculus rate at

Shijiahe might indicate more meat consumption. Shijiahe also had lower dental attrition, which might have allowed more calculus to form.

5.3.1.4 Antemortem tooth loss

The rate of antemortem tooth loss (AMTL) was higher at Zhaitouhe than at Shijiahe. Once again, the difference between the Rong of Zhaitouhe and the Rong of Shijiahe was significant (Chi-square 8.0939 $p=0.0044$), while the difference between the Qin of Shijiahe and the Rong of Shijiahe was not (Chi-square 0.3739 $p=0.54091$).

There was no significant difference between AMTL in males and females at Zhaitouhe (Chi-square 1.0589 $p=0.3035$). There was a significant sex difference among the Rong of Shijiahe (Chi-square 6.2449 $p=0.0125$), and among the Qin at Shijiahe, though there was only one Qin female (Chi-square 4.1853 $p=0.0408$; Fisher's exact test $p=0.0457$). Most of the pulp exposure at both sites was due to occlusal wear rather than caries. The average wear score was higher at Zhaitouhe, which explains the higher AMTL rate.

5.3.1.5 Abscesses

Many individuals with abscesses had more than one abscess, so I calculated the rate of abscesses as the number of individuals with abscesses. Again, the differences between the Rong of Zhaitouhe and the Rong of Shijiahe was significant (Chi-square 4.0739 $p=0.0435$), while the difference between the Qin of Shijiahe and the Rong of Shijiahe was not significant (Chi-square 0.2555 $p=0.6132$).

5.3.2 Osteoarthritis

In all three populations (Rong at Zhaitouhe, Rong at Shijiahe, and Qin at Shijiahe), the highest rate of osteoarthritis (OA) was in the spine (48.4%, 73.7%, 55.6%), followed by the upper limb (28.1%, 47.6%, 33.3%) and then the lower limb (19.7%, 38.1%, 22.2%) (Table 5.2). The lowest rates of OA were found in the Zhaitouhe population, followed by the Qin of Shijiahe and then the Rong of Shijiahe. This supports the interpretation that the Rong of Zhaitouhe were of a higher status than those of Shijiahe, and had lower labor requirements.

Table 5.2 Osteoarthritis at Zhaitouhe and Shijiahe

	Zhaitouhe	Shijiahe (Rong)	Shijiahe (Qin)
Vertebral osteophytes	30/62 individuals	14/17	5/9
Rate	48.4%	73.7%	55.6%
Arthritis, upper limb	18/64	10/21	3/9
Rate	28.1%	47.6%	33.3%
Arthritis, lower limb	13/66	8/21	2/9
Rate	19.7%	38.1%	22.2%

Schmorl's nodes were also present in the spinal columns of five individuals at Zhaitouhe. Schmorl's nodes, which are caused by herniations in the intervertebral discs, were not found in any of the other study populations, except Jiulongshan (see below). These lesions, and the high rates of spinal OA, might be the result of horseback riding, a practice which had reached North China by about the 7th century BCE and the Chinese states by the 4th century BCE (Graff, 2002). The individuals from the Hexi Corridor (see Chapter 4) exhibited equivalent rates of spinal OA, though those samples were small (13 individuals total). Spinal OA could also be explained by heavy labor demands, or by the rough terrain of Huangling County.

5.3.3 Trauma

More cases of trauma were observed in the Loess Plateau populations than in the Qinghai or Hexi Corridor populations (see Chapters 3 and 4): of the 21 individuals in the entire study that exhibited trauma, 11 came from these two sites on the Loess Plateau. Though the evidence is anecdotal, it suggests elevated trauma rates from falls and from interpersonal conflict. The higher rate of trauma might also be partly due to the fact that the Loess Plateau sites had mostly complete postcranial remains, while the other sites in the study had fragmentary postcranial remains.

At Zhaitouhe, two adult probable male individuals had sharp trauma to the frontal bone, one of which was perimortem (on the left side) (Figure 5.1) and one of which was possibly perimortem (on the right side). These are most likely cases of interpersonal violence.



Figure 5.1 Perimortem sharp edge trauma to the frontal bone on individual SHZM37 from Zhaitouhe (lateral-superior view)

There were also several individuals with healing fractures, including one healing fibula fracture (with no corresponding tibia fracture); one healing metacarpal fracture; one healing rib fracture; one case of healing bilateral complete femoral fractures with nonunion (Figure 5.2); and one case of a healing poorly aligned complete right femur fracture and ipsilateral healing rib fractures (Figure 5.3). The two cases of femoral fractures are consistent with falls from height, possibly sustained while horseback riding (one was estimated male, one estimated probable female from cranial nonmetric traits). The femoral fractures could also be explained by the terrain of the area: steep bluffs and rocky tablelands surround the Hulu River, and falls may have been common. These individuals, especially the one with complete fracture and nonunion of both femora, would have had significantly impaired mobility. Despite the severity of these fractures, neither appears to have suffered infection, which suggests these were not compound fractures.

Among the Rong of Shijiahe, there were two individuals with healing rib fractures, and one with a healing clavicle fracture. There was also one young adult male individual with probable Legg-Calvé-Perthes disease, evidenced by a malformed femoral head and abnormally pronounced deepened acetabulum, who also had some hypertrophy of the contralateral tibia and talus (Berger et al., 2017) (Figure 5.4).



Figure 5.2 Proximal left femoral shaft with nonunion of complete fracture, individual SHZM73 from Zhaitouhe (proximal is to the right, anterior view)



Figure 5.3 Healed, misaligned complete fracture of the right femoral diaphysis in individual SHZM78 from Zhaitouhe (proximal is to the right; anterior view)



Figure 5.4 Probable Legg-Calvé-Perthes disease in individual SHSM22 from Shijiahe (the hole in the diaphysis is postmortem damage; posterior view)

Among the Qin of Shijiahe, there was one individuals with a healing depressed fracture on the right side of the frontal bone. This is a possible indication of interpersonal violence. These two cemeteries were in use during the Warring States period, a time when military conflict was common. Historical documents also record that the Rong fought for the State of Jin against the State of Qin (Li, 2006; Sun et al., 2012; Zhang, 2014). Given that males far outnumber females in both these cemeteries, it would be reasonable to expect to find evidence of violent conflict in their skeletons. The lack of violent trauma in these men could mean that this particular group of Rong did not fight for the Chinese state, that individuals injured in conflicts were buried elsewhere, or that by the time of the interments at Zhaitouhe and Shijiahe, the Rong were no longer fighting in military conflicts.

In addition to vertebral osteophytes and Schmorl's nodes, spinal trauma was common at Zhaitouhe and Shijiahe, probably from either horseback riding, navigating rough terrain, or

heavy labor. Among the Zhaitouhe population, two individuals had spondylolysis without reattachment, and four had compression fractures of vertebral bodies. Among the Rong of Shijiahe, two individuals had compression fractures of vertebral bodies. Among the Qin of Shijiahe, two individuals had spondylolysis without reattachment, and one had a compression fracture of a vertebral body.

5.3.4 Growth and development

5.3.4.1 Linear enamel hypoplasias

Rates of individuals with LEH were significantly different ($p < 0.05$) between the Rong of Zhaitouhe (4.5%) and the Rong of Shijiahe (30.3%) (Chi-square 8.7062 $p = 0.0032$, Fisher's exact test $p = 0.0059$). Rates of observed teeth with LEH were also significant (Zhaitouhe: 0.7%, Shijiahe Rong: 6.1%; Chi-square 28.5886, $p < 0.0001$). This suggests the Rong individuals from Shijiahe faced more growth disruptions as children, which further supports the interpretation that the two cemeteries may have been distinguished by status (whether or not they were in use at different times). No LEH was observed in the Qin of Shijiahe, which is possibly due to the small sample size. The difference in individuals with LEH between the Rong of Shijiahe and the Qin of Shijiahe did not reach the level of statistical significance at the $p < 0.05$ level, though the Chi-square test does suggest a trend (Chi-square 3.1449 $p = 0.0762$, Fisher's exact test $p = 0.1460$), while the rate of teeth with LEH was significantly different (Chi-square 11.1053, $p = 0.0009$).

5.3.4.2 Stature

There were no statistically significant differences in long bone lengths for humeri, tibiae, or femora for either sex between these populations. In the notched box plots (Figure 5.5), the

diamonds represent the means, the horizontal bars represent the medians, the upper and lower hinges represent the upper and lower quartiles, the diagonals encompass the 95% confidence interval of the median (sometimes larger than the hinge spread), and the whiskers identify the limits for outliers (± 1.5 times the hinge spread). If the 95% confidence interval of two boxes overlap, the null hypothesis that the means of the two populations are the same cannot be ruled out.

The only comparison that approached statistical significance at the $p < 0.05$ level was in the comparison of tibiae lengths of females of the Rong of Zhaitouhe and the Rong of Shijiahe (ANOVA $F=4.74$, $p=0.0545$). This finding does not support the idea that the Rong individuals from Shijiahe were of a lower status than those from Zhaitouhe, as in both sexes the Shijiahe individuals had longer tibiae. However, it should be noted that there were few female specimens among the Qin from Shijiahe (this is apparent in the box plots below). See Appendix I.

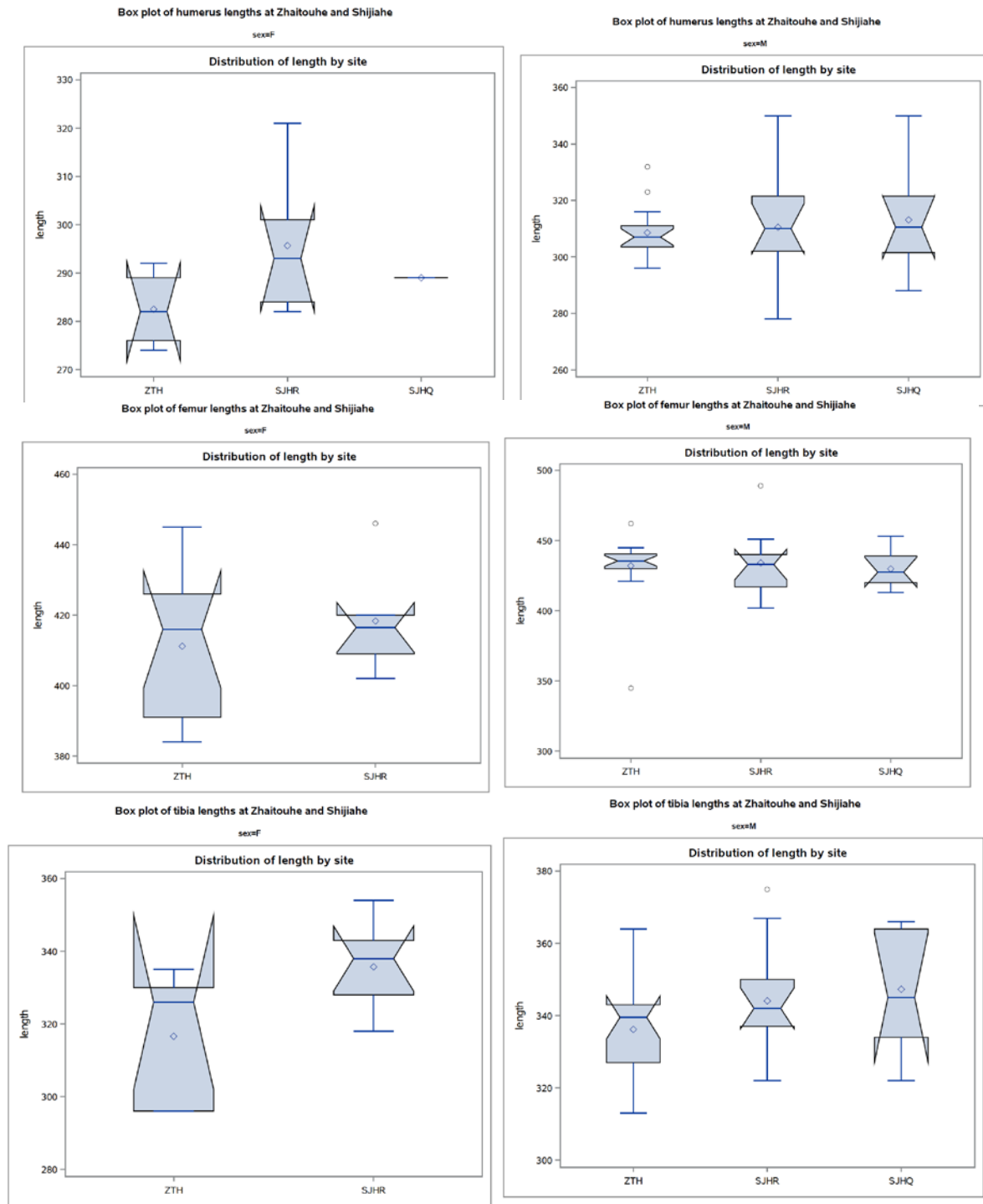


Figure 5.5 Notched box plots of long bones lengths by site and sex

5.3.5 Infectious and metabolic conditions

The population of Zhaitouhe had more healing than active tibial periosteal lesions, and the two groups at Shijiahe both had only healing lesions (Table 5.3). However, fewer individuals overall at Zhaitouhe had periosteal lesions on the tibiae: 62.3% of individuals from Zhaitouhe with observable tibiae had no periosteal lesions, while only 33.3% of Rong individuals at Shijiahe with observable tibiae had no lesions. This may support the interpretation that the Zhaitouhe individuals were of a higher status, and suffered fewer infectious conditions that would lead to periosteal lesions. Alternatively, it could indicate greater frailty, or susceptibility to disease and death (Vaupel et al., 1979; Wood et al., 1992), if they did not survive the insults long enough to develop lesions. However, the predominance of healing lesions over active ones supports the former interpretation.

The difference in rates and types of periosteal lesions between the Rong of Zhaitouhe and the Rong of Shijiahe was significant at the $p < 0.05$ level (Chi-square 10.673 $p = 0.0048$, Fisher's exact test $p = 0.0068$). The difference between the Rong of Shijiahe and the Qin of Shijiahe was not significant (Chi-square 0.045 $p = 0.9778$, Fisher's exact test $p = 1.0000$).

Table 5.3 Tibial periosteal lesions at Zhaitouhe and Shijiahe

	Zhaitouhe	Shijiahe (Rong)	Shijiahe (Qin)
Woven	6/61 individuals with tibiae	0/21	0/8
Rate	9.8%	0.0%	0.0%
Compact/ compact+woven	17/61	14/21	5/8
Rate	27.9%	66.7%	62.5%
None	38/61	7/21	3/8
Rate	62.3%	33.3%	37.5%

In the Zhaitouhe population, 22% of individuals had cribra orbitalia (CO) or porotic hyperostosis (PH) (Table 5.4). Among the Rong of Shijiahe, 38% of people had one or both, and among the Qin of Shijiahe, 12.5% had one or both. None of these differences is significant at the $p < 0.05$ level (Rong of Zhaitouhe vs. Rong of Shijiahe: Chi-square 1.9738 $p = 0.1600$; Rong of Shijiahe vs. Qin of Shijiahe: Chi-square 1.7732 $p = 0.1830$).

Cranial porosity indicates that an individual experienced anemia in early childhood (Walker et al., 2009). The rates of CO and PH in these populations is comparable to the rates in other study populations, and only reach a significant difference with the other study populations that had high rates of CO/PH (Zhaitouhe vs. Yangshan/Mapai: Chi-square 5.4405 $p = 0.0197$; Zhaitouhe vs. Jiulongshan, Chi-square 5.4405 $p = 0.0197$; see Chapter 6 for more discussion).

Table 5.4 CO and PH at Zhaitouhe and Shijiahe

	ZTH	SJHR	SJHQ
CO	2/42 crania*	0/21	0/8
Rate	5%	0%	0%
PH	5/42	7/21	0/8
Rate	12%	33%	0%
Both	2/42	1/21	1/8
Rate	5%	5%	12.5%

*Total crania at site (not including fragmentary crania)

Finally, one Rong individual from Shijiahe and one from Zhaitouhe had ossification of the anterior longitudinal ligament on their thoracic vertebrae, suggesting distal idiopathic hyperostosis (DISH), and one individual from Zhaitouhe had fusion of syndesmytes around the margins of several thoracic vertebrae, suggesting ankylosing spondylitis.

5.4 PALEODEMOGRAPHY

5.4.1 Age and sex distribution

At Zhaitouhe, the highest mortality among females was in the young and young/middle age categories, and the highest among males was in the middle age category, which is typical (Table 5.5, Figure 5.6). However, the large representation of males in the old age category is unusual. Furthermore, there are nearly twice as many males as females in the Zhaitouhe mortuary sample and no subadults other than two adolescents, so the demographics of the mortuary population are clearly not representative of the living population at Zhaitouhe. Among the Rong of Shijiahe, the highest mortality among females was in the young adult category, and mortality among males was equally high in the young and middle age categories (Table 5.5, Figure 5.7). Again, there are nearly twice as many males as females and virtually no subadults in this mortuary population. The Qin of Shijiahe are represented almost entirely by males, whose highest mortality was in the young and middle adult categories (Table 5.5, Figure 5.8).

If Zhaitouhe and Shijiahe were in use at different times—Zhaitouhe during the early to middle Warring States period, and Shijiahe during the late Warring States period—it is surprising that both cemeteries have a similar imbalance of sexes represented in the mortuary population, and an absence of subadult remains. It is possible that mortuary practices that dictated the burial of children separately from adults persisted from one period to the next. As far as the sex imbalance, this is hard to explain. One possible explanation is that females may have had a very high infant mortality rate, and therefore are underrepresented in the adult mortuary sample. For all three groups, mortality tends towards the young adult age category, and average age at death was lower at Shijiahe than at Zhaitouhe. This could reflect higher mortality or higher fertility, though fertility does not differ between the sites (see Juvenility index, below).

Table 5.5 Distribution of sex and age categories at Zhaitouhe and Shijiahe

	Adolescent 15-20 yrs old	Young adult 20-34 yrs old	Young/middle adult 20-50 yrs old	Middle adult 35-50 yrs old	Middle/old adult 35+ yrs old	Old adult 50+ yrs old	Adult 20+ yrs old	Total
Zhaitouhe								
Female	2	6	5	2	4	3	3	25
Male		7	3	20	1	7	6	44
Indeterminate/ unknown		1						1
Total	2	14	8	22	5	10	9	70
Shijiahe (Rong)								
Female		4			2	2		8
Male	1	5	3	4			1	14
Indeterminate/ unknown		1						1
Total	1	9	3	4	2	2	1	23
Shijiahe (Qin)								
Female		1						1
Male		3	1	2	1			7
Indeterminate/ unknown							1	1
Total		5	1	2	1		1	9

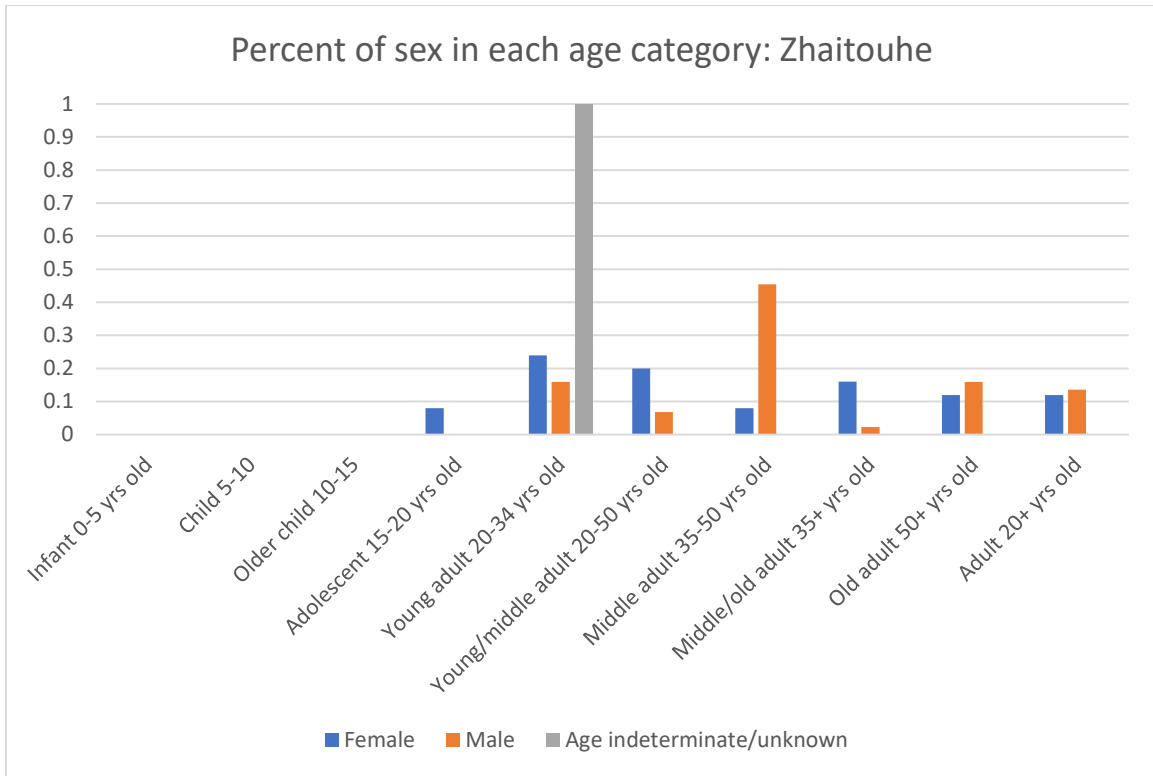


Figure 5.6 Sex and age distribution at Zhaitouhe

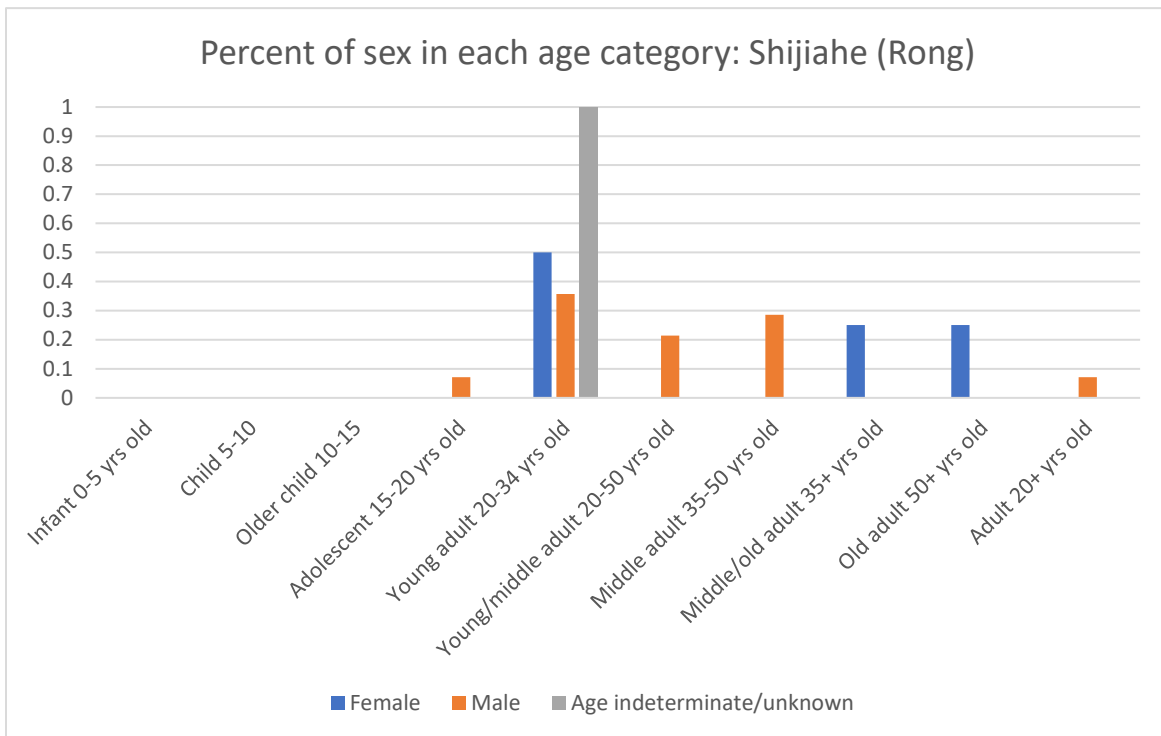


Figure 5.7 Sex and age distribution at Shijiahe (Rong)

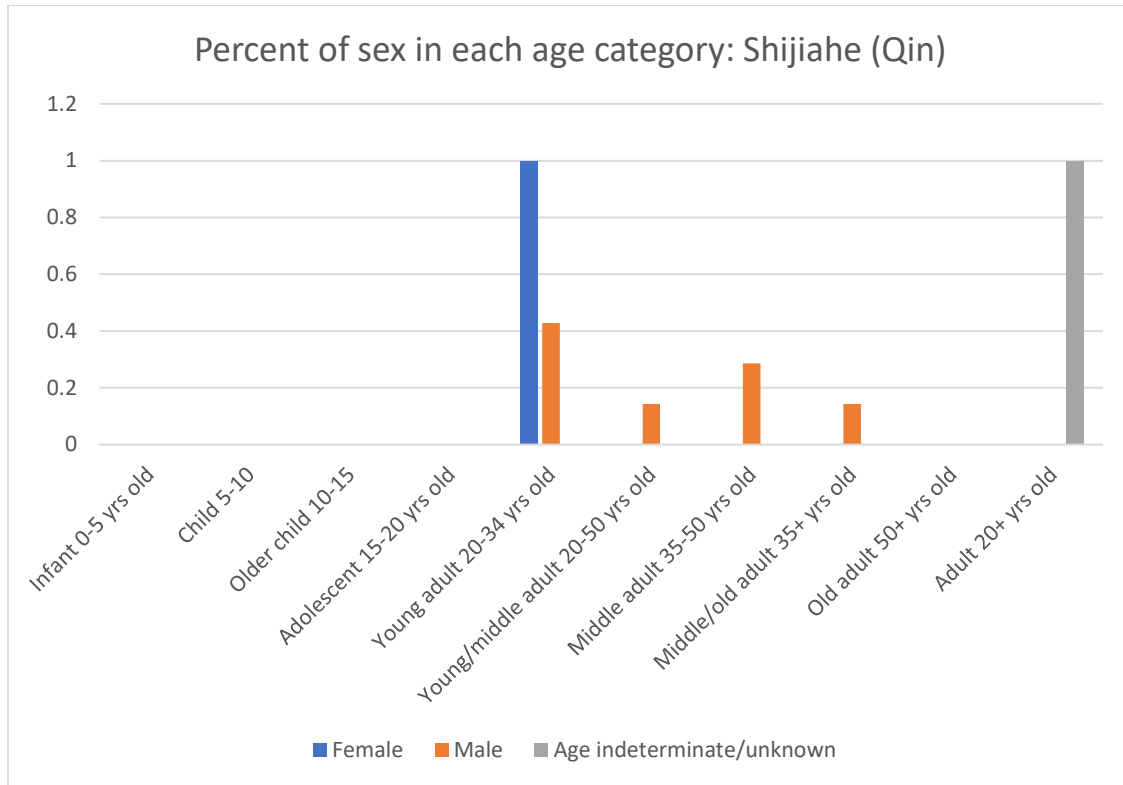


Figure 5.8 Sex and age distribution at Shijiahe (Qin)

5.4.2 Juvenility index

I calculated a 95% comparison interval (Buikstra et al., 1986) for the juvenility index (individuals over 30 divided by total individuals over 5) of Zhaitouhe (0.7541 ± 0.1372) and Shijiahe (Rong: 0.6087 ± 0.2234 ; Qin: 0.7778 ± 0.2897) (Figure 5.9). The comparison intervals for all three groups overlap. This suggests that there was no difference in fertility between these populations. However, subadults were clearly underrepresented: other than a few adolescents, there are no subadult individuals from either of these sites. Therefore, these are likely not representative mortuary populations and the juvenility index is not a reliable indicator of the fertility of the living populations. At most, I can say that I have failed to find evidence for different fertility between these three groups.

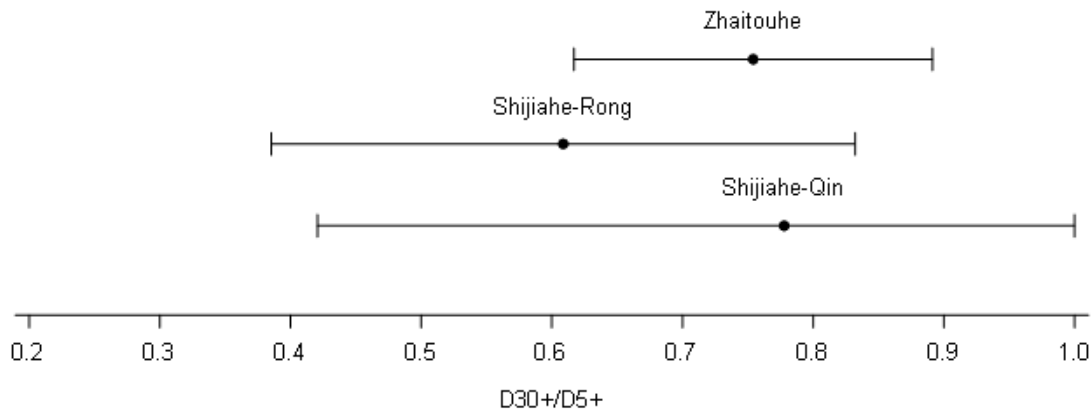


Figure 5.9 Ninety-five percent comparison intervals of the juvenility index of Zhaitouhe and the two groups from Shijiahe

5.5 BIODISTANCE

The Rong of Zhaitouhe and the Rong of Shijiahe were not biologically distinct populations, according to a mean measure of divergence (MMD) (Killgrove, 2009) analysis based on cranial nonmetric traits (MMD: -0.02824, standardized MMD: -0.94783; threshold for significance of standardized MMD is 2.0). Moreover, they had the closest biological relationship of any two populations in the study, according to a Ward's cluster. This supports the excavators' conclusion, based on material culture, that there was a close affinity between these two groups (Figure 5.10). In my analysis, these two Rong populations clustered most closely with the middle Bronze Age Xindian group at Xiaohandi in Qinghai (see Chapter 3), next with the Spring and Autumn period group at Jiulongshan in Ningxia (see Comparative case: the Jiulongshan site, below), and then with the early Bronze Age Siba Culture group from Huoshaogou in the Hexi Corridor (see Chapter 4). These are all groups from Northwest China that lived in the late second and mid-first millennium BCE.

The Qin of Shijiahe were also not significantly different from either Rong group, but they do not cluster with the Northwest Chinese groups in the Ward's cluster analysis. This is striking,

as the Qin and Rong had been in contact for centuries at this point, both in Gansu where they both originated, and in the Wei River Valley where they both migrated after the fall of the Western Zhou (Li, 2006). According to the MMD, the Qin are significantly different from the early Bronze Age Huoshaogou population, which was quite temporally and geographically distant at the far end of the Hexi Corridor (standardized mean measure of divergence: 2.29837, significance set at 2.0).

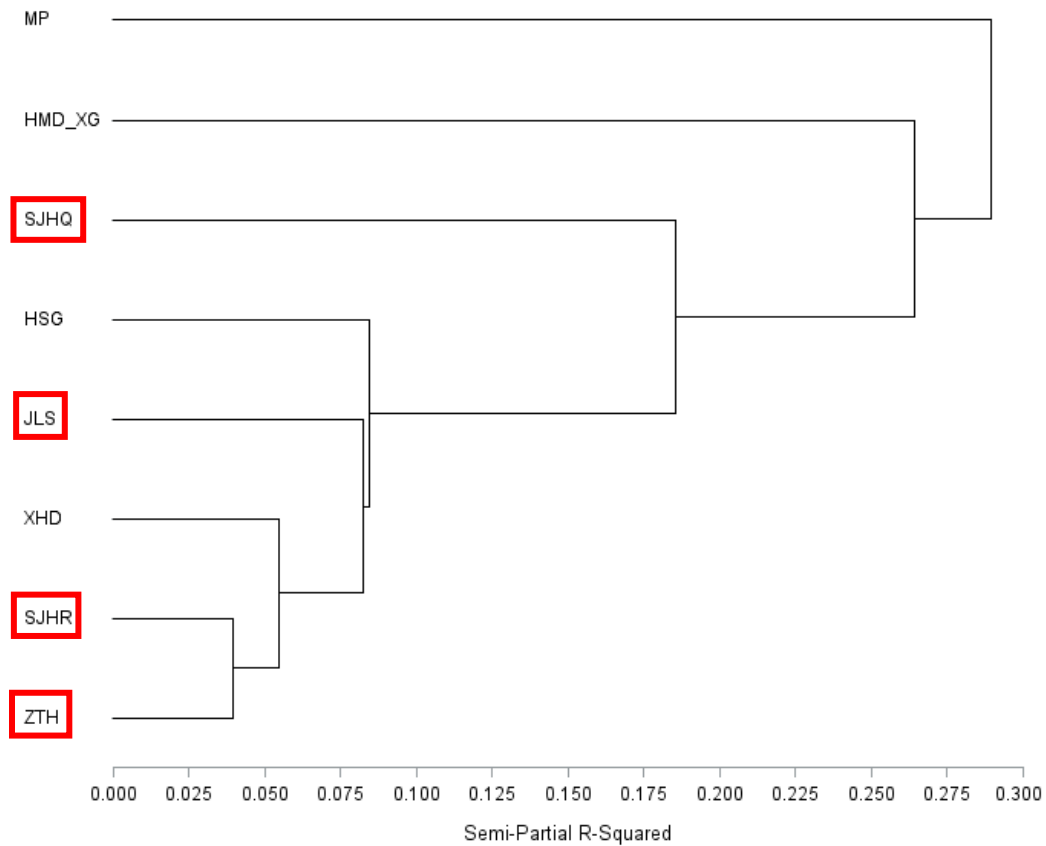


Figure 5.10 Ward's cluster analysis of dissertation study sites, highlighting the position of Zhaitouhe (ZTH), the Rong and Qin groups from Shijiahe (SJHR and SJHQ), and Jiulongshan (JLS)

5.6 COMPARATIVE DIETARY DATA

Some dietary reconstruction has been conducted on populations from the Loess Plateau, which provides comparative data, especially for the Qin. Most of the research concerns isotopic

signatures of early agriculture during the Neolithic (e.g. Barton et al., 2009; Lee et al., 2007), but still provides some background for a study of the Iron Age Warring States period populations in this dissertation. The results of these studies are summarized in Figure 5.11.

Ling and colleagues (2010) analyzed the carbon and nitrogen stable isotopes of bone collagen from 25 individuals from the Qin culture site of Sunjia'nantou, in Fengxian County in western Shaanxi Province. The individuals in this study span the middle of the Spring and Autumn period (771-476 BCE) to the late Warring States period (475-221 BCE). The investigators found that the $\delta^{13}\text{C}$ values for the population (excluding one outlier) fell between -8.92‰ and 12.81‰, with an average value of 10.78‰. The $\delta^{15}\text{N}$ values clustered relatively closely: aside from one outlier, the values ranged from 6.75‰ to 9.37‰, with an average value of 8.45‰. As the $\delta^{13}\text{C}$ values fall well within the range for C_4 plants, the authors conclude that the staple food of the Qin people of Sunjianantou was millet. Also, they conclude that the $\delta^{15}\text{N}$ indicates some supplementation with animal protein, though no analysis was conducted on non-human animals as a baseline.

Pechenkina and colleagues have also studied the effects on human health and diet of the Neolithic period Yangshao-Longshan transition—the aggregation of settlements and increasing social complexity that accompanied a cooler climate in the third millennium BCE (Pechenkina et al., 2005; Pechenkina et al., 2002; Pechenkina et al., 2007). The results of these studies of Neolithic groups are useful as a baseline for studies of later occupations in the region. These studies found that among populations on the Loess Plateau (specifically in Shaanxi and Henan Provinces), millet formed the foundation of human diets and those of their domesticated omnivorous animals by the middle Neolithic Yangshao period (5000-3000 BCE). In the late Neolithic Longshan period, community health declined. For example, the researchers found

lower stature and more porotic hyperostosis in the late Neolithic populations. These individuals also had less dental attrition, possibly due to more intensive processing and cooking of millet, and more calculus, possibly due to increased meat consumption. The authors found that in the early Dynastic period (first millennium BCE), poorer community health persisted.

Stable isotope analysis of human bone collagen and apatite, and that of domesticated animals, from the Neolithic supports the conclusion that people of the Loess Plateau in the Neolithic consumed primarily C₄ plants, most likely millet, as well as products from animals who scavenged or were foddered with millet (Pechenkina et al., 2005). Animals with high C₄ plant consumption included pigs and dogs, who were probably consuming millet either directly, or in the form of human food scraps or human waste. Humans may also have been eating meat or eggs from millet-fed chickens. Herbivorous domesticates such as sheep/goat and water buffalo, however, had predominantly C₃-based diets, indicating that they were grazing on wild plants and not being foddered with millet. Humans were probably also consuming these C₃-fed herbivores or their milk, as evidenced by the difference between the $\delta^{13}\text{C}$ values in human bone apatite and collagen: the $\delta^{13}\text{C}_{\text{ap-col}}$ values at the two middle Neolithic sites of Jiangzhai and Shijia ($5.8 \pm 0.7\text{‰}$ and $6.2 \pm 0.7\text{‰}$, respectively) are consistent with a diet in which the $\delta^{13}\text{C}$ value of the dietary protein is lower than that of the diet overall.

Guo and colleagues (2011) reexamined the middle Neolithic Jiangzhai site and found a $\delta^{13}\text{C}$ value in human bone collagen of -11.5‰ to -8.5‰ , with a mean of $-9.7\text{‰} \pm 1.0\text{‰}$, similar to the -10.0‰ found by Pechenkina and colleagues (2005). Remains of millet were also found at Jiangzhai, indicating that the C₄ signature in the human diet came from consuming millet or products from millet-fed animals. The average $\delta^{15}\text{N}$ value in human bone collagen at the site was $8.5 \pm 0.5\text{‰}$, and ranged from 7.8‰ to 9.7‰ , which the investigators interpret as evidence that

consumption of animal products was not an important part of the human diet at Jiangzhai and varied considerably within the group, though no non-human animals were analyzed.

Zhang et al. (2010) conducted bone collagen stable isotope analysis of nitrogen and carbon for the three Neolithic sites of Xishan, Xipo, and Yuhuazhai. The human values mostly fell into the range of C₄ plant consumption, though a group of nine individuals from Yuhuazhai seem to show a significant C₃ component in the protein portion of their diets. The authors attribute this to their consuming products from grazing animals: they also tested animal bone from Xipo and several other sites, and found that pigs and dogs fell strongly into the C₄ dietary range, while deer had low $\delta^{13}\text{C}$ values and were probably consuming wild C₃ foods. A small number of sheep were also tested, which gave mixed results, though they probably were not being consumed at this time, and were instead being used for wool (Dong et al., 2017; Li et al., 2014b).

Finally, $\delta^{13}\text{C}$ values from human bone collagen from six sites in the Wei River Valley suggest that human diet was heavily reliant on C₄ plants until around 2000 BCE (Atahan et al., 2014). By the middle of the first millennium BCE, some sites in the Wei River valley still had relatively high $\delta^{13}\text{C}$ values, but others had lower $\delta^{13}\text{C}$ values (below -14), indicating that millet had been superseded as a staple food and that the diet had been diversified to include a significant portion of C₃ plants, possibly wheat, barley, and/or rice.

Some of the increase in C₃ plant consumption could be due to an increase in human consumption of animals grazed on wild plants, as the wild fauna of the Loess Plateau is dominated by C₃ plants, with C₄ plants at no more than 30% abundance (Ma et al., 2014). However, direct consumption of clearly C₃ plants did increase in the Zhou period, along with increasing sex differences in diet (Dong et al., 2017).

Figure 5.11 presents a summary of the above published studies. Note that the stable carbon and nitrogen isotope values of human bone collagen from sites of the Neolithic (black) and Iron Age (gray) mostly overlap, indicating broad continuity in the diet from the seventh to the first millennia BCE. A few sites with small sample sizes, a few outliers from larger sites, and the lower values from Yuhuazhai (Zhang et al., 2010) show lower $\delta^{13}\text{C}$ values, but for the most part, the individuals in these studies are still within the expected range for consumption of C_4 plants in the protein portion of the diet (Brown and Brown, 2011).

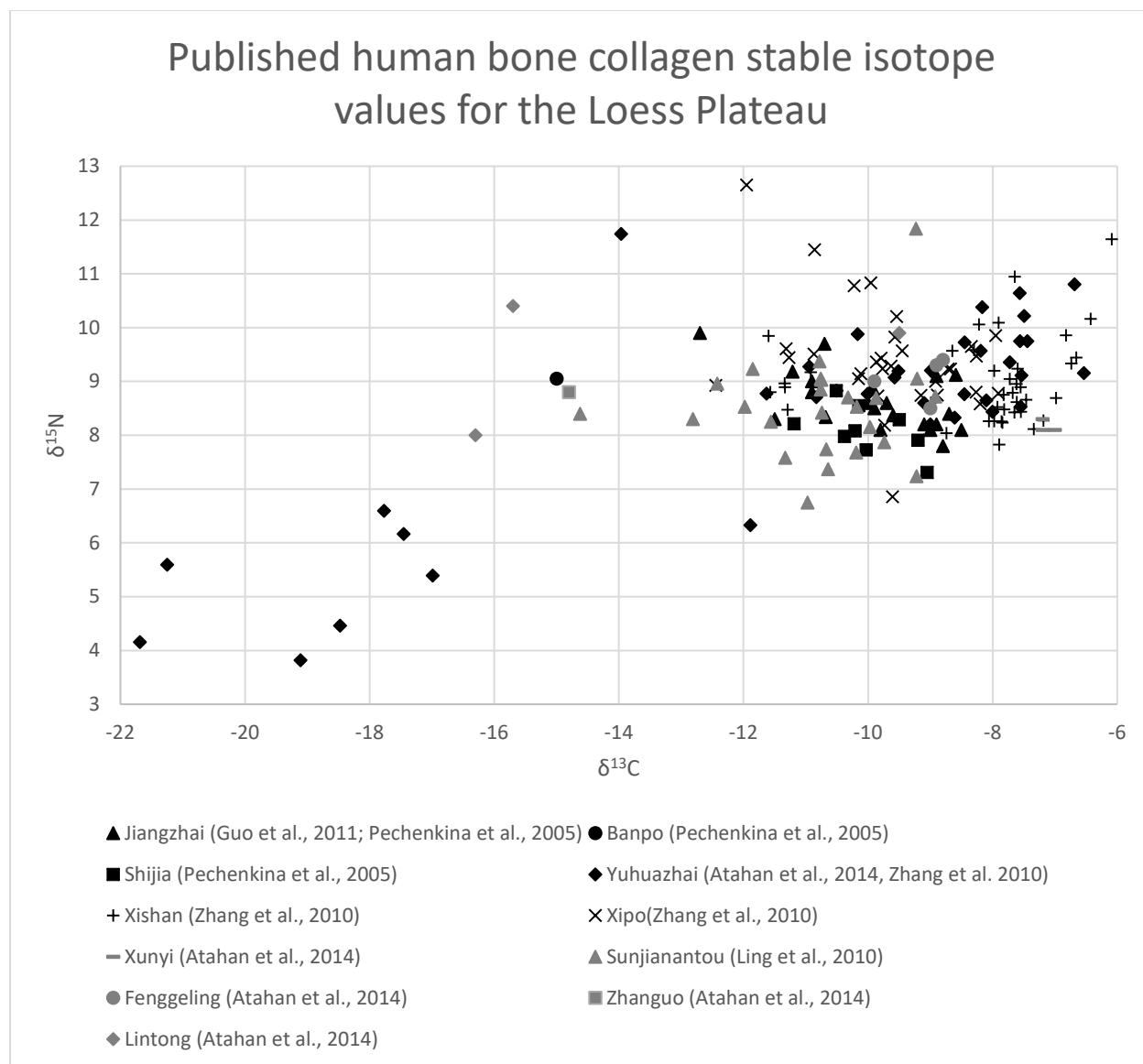


Figure 5.11 Published carbon and nitrogen stable isotope values from human bone collagen from the Loess Plateau in Shaanxi. Sites in black are Neolithic, sites in gray are Iron Age. Approximate dates of sites from the above published sources: Jiangzhai: 4900-4000 BCE; Banpo: 4700-3600 BCE; Shijia: 4400-4000 BCE; Yuhuazhai: 3700-3400 BCE; Xishan: 4500-3800 BCE; Xipo: 3300-2900 BCE; Xunyi: 3400-2000 BCE; Sunjianantou: 600-300 BCE (middle Spring and Autumn period to middle Warring States period, Qin culture); Fenggeling: 400-300 BCE; Zhanguo (Warring States): 460-300 BCE; Lintong: 300 BCE-100 CE

5.7 COMPARATIVE CASE: THE JIULONGSHAN SITE

The Jiulongshan site was the only site from the relevant time period, with complete sets of human remains, that was available for study in the collections of the Ningxia Hui Autonomous Region Institute of Cultural Relics and Archaeology. The mortuary population consisted of only

six individuals, so I did not include this site in statistical comparisons with other study populations. I include it here as an anecdotal comparative sample.

Jiulongshan is located in the south of Ningxia near Guyuan City, which is on the northwestern border of the Loess Plateau (Wang and Zhu, 2004). The site was excavated in 2009, and a report on the craniometrics of this small population is in preparation (Zhang et al., In preparation). The individuals in this population consist of one child aged 3-4.5 years at death, one male and one female adolescent, one male young adult, and one male and one female middle adult.

Guyuan has a humid continental climate with dry winters and mild/cool summers (Köppen Dwb). It has a cooler summer than the area of northern Shaanxi where Zhaitouhe and Shijiahe are located, and resembles Minhe County in Qinghai in terms of climate (see Chapter 3). Like other parts of northwest China, the climate of this area is influenced by the East Asian monsoon system. It is located near cold semi-arid steppe areas (BSk). According to Zhang et al. (In preparation), the cemetery's material culture suggests that it dates to the Spring and Autumn period (771-476 BCE), and the presence of domesticated herd animals in the graves suggest it may have belonged to a mobile pastoralist society.

Oral health measures from Jiulongshan are consistent with the interpretation of this group as a specialized pastoralist society. Five individuals were examined for oral health (the sixth individual was the young child) (Table 5.6). The people from Jiulongshan had a carious lesion frequency of 4.5% (not calibrated, as there was no pulp exposure from carious lesions at this site), which is one of the lowest in the study. All carious lesions were in male individuals, which is atypical of agricultural societies and might be attributable to the small sample size, or to differential access to agricultural products within the society. The average wear score per tooth

was 2.94, the lowest in the study. One individual was entirely edentulous (in the maxilla; the mandible was not present), which accounts for almost all antemortem tooth loss in the group. Three out of five individuals with dentition had dental calculus (60% of the sample), and only one individual had an abscess (20% of the sample).

Table 5.6 Oral health measures at Jiulongshan

	<i>Calibrated carious lesion rate</i> [†]	<i>Uncalibrated carious lesion rate</i>	<i>Carious lesion rate: M</i> [†]	<i>Carious lesion rate: F</i> [†]	<i>Average wear score</i> ^{**†}
<i>Jiulongshan</i> *	4.5%	5.6%	10.5%	0.0%	2.9

	<i>AMTL</i> [†]	<i>AMTL: M</i> [†]	<i>AMTL: F</i> [†]	<i>Calculus</i> [‡]	<i>Abscesses</i> [‡]
<i>Jiulongshan</i> *	19.1%	0.0%	33.3%	60.0%	20.0%

*No calibration (no pulp exposure from carious lesions)

**Scored using method developed by Smith (1984)

[†]Number of teeth out of all teeth observed

[‡]Number of individuals out of all individuals with observable teeth

Though the sample was small, the distribution of arthritis appears to resemble that of the Shaanxi sites discussed earlier in this chapter. Three of three individuals with spinal elements had spinal osteophytes; two of four individuals with upper limb elements had upper limb arthritis; and only one of five individuals with lower limb elements had lower limb arthritis. In addition, two individuals had Schmorl's nodes. These do not appear in any other population in the study except Zhaitouhe, and like the spinal osteophytes, might be a result of horseback riding (the terrain is not as rough around Jiulongshan as it is around Zhaitouhe).

One individual (male, aged 16-17 at death) had paracondylar processes on the occipital bone with corresponding abnormal processes on the atlas, which can sometimes result from a fracture, for example, a fall from horseback (Weiss, 2013) (Figure 5.12).

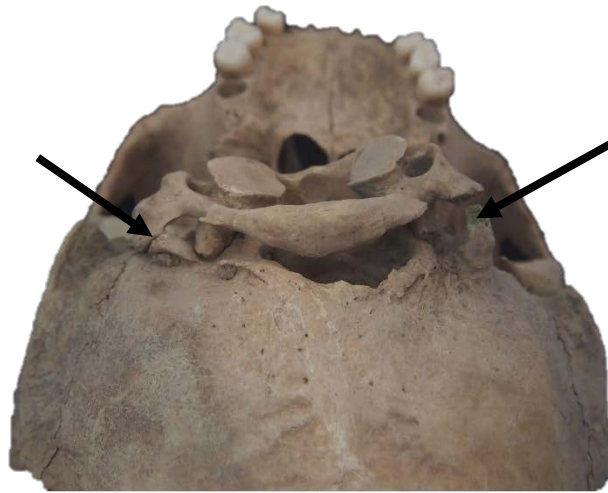


Figure 5.12 Paracondylar processes and abnormal atlas on the occipital bone of individual YKJM1 from Jiulongshan (posterior view, caudal direction is up)

Two individuals from this group exhibit other pathological lesions. The edentulous individual (YKJM9), estimated female aged 45-55, has a second cervical vertebra that is missing the dens. This does not appear to be traumatic, and appears to be a congenital absence, which is rare (Bajaj et al., 2010). Clinical literature also suggests it often causes pain or weakness in limbs, especially following trauma. This is interesting in light of the fact that this individual has a number of fractures. There are compression fractures in four lower vertebrae (and two with Schmorl's nodes). She has a well-healed but slightly displaced fracture on the left second rib. Finally, the right ulna is also fractured at the midshaft, and the fractured end is completely covered with compact bone, indicating healing, but the distal end of the ulna is not present, indicating nonunion of the fracture. The entire right radius is present and no evidence of a fracture is present, ruling out amputation. In addition, she has a number of fused vertebrae: one group of three thoracic vertebrae is fused at the laminae and articular facets, though the bodies

are completely unfused. Another pair of thoracic vertebrae are fused at the articular facets, one of which is wedged from a compression fracture of the vertebral body.

In terms of growth disruptions, no cases of linear enamel hypoplasias were discovered in this small group. Stature at Jiulongshan, as measured by long bone length and controlling for sex, was not significantly different from any other site in the study (ANOVA p-values all greater than 0.05, no main effect for site).

All individuals in the Jiulongshan sample had periosteal new bone formation on their tibiae, and all individuals had either compact or both compact and woven new bone (Table 5.7). This means that while all the individuals in this sample had endured systemic infection or other physiological insults, all had survived the insults long enough to begin remodeling of the periosteal lesions. This indicates relatively low frailty in the population.

Table 5.7 Tibial periosteal lesions at Jiulongshan

	JLS
Woven	0/6 individuals with tibiae
Rate	0.0%
Compact/compact+woven	6/6
Rate	100.0%
None	0/6
Rate	0.0%

Two adults from Jiulongshan displayed pinpoint porosity on the cranial vault (porotic hyperostosis), and one exhibited both porotic hyperostosis and coalescing porosity on the roofs of the eye orbits (cribra orbitalia). This is evidence that these individuals survived anemia in childhood, possibly megaloblastic anemia from vitamin B₁₂ deficiency or intestinal infections (Walker et al., 2009) (Table 5.8).

Table 5.8 CO and PH at Jiulongshan

	JLS
CO	1/6 crania*
Rate	17%
PH	2/6
Rate	33%
Both	1/6
Rate	17%

*Total crania at site (not including fragmentary crania)

As for biodistance, the mean measure of divergence analysis shows that the Jiulongshan population is not statistically significantly different from any other population in the study, although it is perhaps too small for the differences to reach statistical significance. In the Ward's cluster analysis, it is in the same cluster as other Northwest Chinese groups, including the Rong groups from Zhaitouhe and Shijiahe, the middle Bronze Age group from Xiaohandi in Qinghai, and the early Bronze Age group from Huoshaogou in Gansu. The juvenility index at Jiulongshan was 0.4, though the 95% comparison interval (Buikstra et al., 1986) was extremely broad, which suggests this sample is too small to provide data on fertility.

5.8 SUMMARY: A COMPLEX ADAPTIVE SYSTEM ON THE LOESS PLATEAU

The Rong of Zhaitouhe and the Rong of Shijiahe clearly had a close affiliation, as evidenced by their similar material culture, biological relatedness, and proximity to each other. However, the Rong of Shijiahe more closely resemble the Qin of Shijiahe in terms of their health. Therefore, in contrast to the interpretation of the excavators that the two Rong groups were contemporaneous, bioarchaeological data suggest the Rong of Shijiahe lived later, alongside the Qin.

The health differences between Zhaitouhe and both groups from Shijiahe are also mostly consistent with the people of Zhaitouhe being of a higher status or enjoying better population health:

- diet changed somewhat (cariou lesion rate increased, wear decreased, calculus increased);
- frailty remained constant (overall tibial periosteal reaction increased, but lesions in both periods were healing);
- childhood growth disruptions increased (LEH increased);
- childhood anemias remained constant (no significant change in CO/PH);
- nutritional inadequacy or other stressors that impact growth attainment may have changed (tibia length increased among the Rong);
- fertility remained the same (no change in the juvenility index); and
- activity patterns changed (increase in OA).

The lower carious lesion rate at Zhaitouhe suggests a more diverse, less millet-dependent diet, and the higher rates of attrition could be due to a higher average age at death. Also, despite their higher average age at death, the people of Zhaitouhe had fewer cases of OA (suggesting lower labor demands), far lower rates of linear enamel hypoplasias (suggesting fewer growth disruptions in childhood), and fewer cases of periosteal new bone overall (suggesting fewer physiological insults, though this may also suggest higher frailty). The higher average age at death may indicate lower mortality or lower fertility, though the juvenility index does not indicate any change in fertility. Stature and CO/PH also did not differ significantly between Zhaitouhe and Shijiahe, except for somewhat longer tibiae at Shijiahe. Furthermore, there were fewer animal sacrifices found in graves at Shijiahe (Sun et al., 2015).

The dry conditions that have characterized the late Holocene across Northwest China had already prevailed for some time in the western Loess Plateau when these cemeteries were in use. The Rong people buried at Zhaitouhe and Shijiahe were likely descendants of agropastoralist peoples from farther northwest in Gansu, Qinghai, or Ningxia that were closely related biologically and culturally to those discussed in the previous chapters. That they allied themselves with one Chinese state (Wei), and continued to live among and co-exist with another conquering state (Qin), could be seen as a form of adaptation.

The health profiles of Zhaitouhe and Shijiahe differ from each other and from that of the sites on the Qinghai Plateau and in the Hexi Corridor (Chapters 3 and 4). However, all the paleopathological measures fall within the range of the other sites (see Chapter 6 for discussion). They do not appear to have had a quantitatively different diet, set of labor demands, or disease burden. It seems that their adaptation to life on the Loess Plateau, within the borders of Chinese states, constitutes an incremental adaptation. However, it was an adaptation to changing social conditions implemented through social mechanisms, rather than an adaptation to environmental change.

The Loess Plateau sites represent a case in which sociopolitical conditions—in particular, living under the control of states, in proximity to other ethnic groups—was a stronger determinant of health than changes in the climate or natural environment. The Rong people of Zhaitouhe presumably experienced stressors associated with being a non-Chinese group living under a Chinese state, but the Rong people of Shijiahe may have experienced additional stressors from being lower-status individuals within their own community. The Qin individuals of Shijiahe, although not outsiders to the Chinese state, were likely low status individuals as well, who were forcibly relocated to the newly conquered area. Therefore, in the Warring States period

of Huangling County, sociopolitical conditions and status differences had a larger influence on health, and extracted a larger price for adaptation, than did ecological conditions.

CHAPTER 6 DISCUSSION AND CONCLUSIONS

As the preceding three chapters have shown, I have not found bioarchaeological evidence for a collapse of subsistence systems in Northwest China between the mid third and mid first millennia BCE. The data paint a complex picture, but overall, they lend support to the hypothesis of incremental adaptation, rather than transformational adaptation, to the 4000 BP climate change event

In the eastern Qinghai Plateau, physiological frailty remained more or less constant from the late Neolithic to the early Bronze Age, while rates of nonspecific infection declined (see Chapter 3). Carious lesion rate increased, possibly indicating increased consumption of agricultural products (though the sample of Neolithic dentition was small). Oral health overall was good in both populations. Rates of osteoarthritis (OA) in the spine, upper limbs, and lower limbs did not change significantly between the populations, indicating a constant level of labor demands. Stature and fertility did not change significantly, no linear enamel hypoplasias (LEH) were found in either population, and cribra orbitalia (CO) and porotic hyperostosis (PH) declined, indicating fewer cases of anemia in childhood. All this suggests that though the climate had become cooler and drier, the later population continued to rely primarily on agriculture for subsistence. Population health did not change dramatically, and in some respects (tibial periosteal reaction, CO/PH) improved. Diversification of the subsistence base may explain this successful adaptation: by the middle Bronze Age, wheat and barley were being raised alongside

millet as a staple crop (Zhang et al., 2003), and the neighboring Kayue Culture was more specialized in pastoral production.

In the Hexi Corridor, there was an even more dramatic improvement in health from the early to the late Bronze Age, even though this region is more arid and marginal for agriculture (see Chapter 4). Frailty and rates of nonspecific infectious lesions declined, LEH declined, and CO and PH declined. Stature and fertility did not change significantly. Diet may have changed somewhat, as carious lesion rates declined and occlusal wear increased. Upper limb OA increased, which might mean a slight change in labor requirements. Once again, diversification of the existing agropastoral system likely accounts for this change: archaeological and chemical studies suggest that by the late Bronze Age, animal husbandry had begun to play a larger role in subsistence practices, which would likely have increased the resilience of the human-environment system.

The groups from the Loess Plateau date to the Warring States period, after the drier and cooler climate conditions were well established. Therefore, the main adaptive challenge to the Northwest Chinese populations at this time seems to have been to ethnic and political conflict and social inequality, not to environmental stressors. The Rong people who lived in the Loess Plateau in the early Warring States period seem to have adapted to life within a Chinese state: they had high rates of carious lesions, possibly from relying heavily on agricultural products for their diet. The Rong of the late Warring States, however, suffered worse population health, likely because they were lower-status individuals who were forced to remain behind after the area was conquered by the State of Qin. Stature, CO/PH, and fertility did not change significantly. However, this later group had a higher carious lesion rate (indicating a less diverse, more grain-dependent diet), more OA (indicating higher labor demands), more LEH (indicating more growth

disruptions in early childhood), and more periosteal lesions (indicating a higher burden of infection). Furthermore, the Qin people buried alongside the Rong were not statistically significantly different from them in almost any bioarchaeological measure. This suggests that the low-status people of the Qin and Rong had similar lifeways.

Below, I will discuss some of the measures that are meaningful when compared across all sites in this study, and the theoretical implications of these findings.

6.1 DIET

The groups from the Loess Plateau have the highest rates of carious lesions in the study (Table 6.1). This probably indicates that they were more reliant on agricultural products. Females had higher carious lesion rates than males in all groups except Hamadun/Xigang and Jiulongshan. These two exceptions are both agropastoralist groups who were partly reliant on animal husbandry (Figure 6.1), and males and females in these groups may have had different access to food resources than in other groups.

Occlusal wear is highest in the late Neolithic group at Mapai, and in the Warring States groups at Zhaitouhe and Shijiahe (Figure 6.2). These populations practiced agriculture (Atahan et al., 2014; Barton et al., 2009), but they are also temporally and geographically distant from each other. AMTL is highest in Xiaohandi, an agricultural population, and Jiulongshan, an agropastoralist population (Figure 6.3), meaning AMTL likely had different causes in different groups and is not correlated with diet in a simple way. The rate of calculus is highest in the Warring States groups from the Loess Plateau, though this might be due to the fact that these remains were the best preserved. Abscesses are also most abundant in the Loess Plateau groups, which is likely related to their high rates of carious lesions.

These oral health measures are progressive conditions, and thus their rate in a population can be affected by average age-at-death in that population, but many of these groups have quite small sample sizes, which makes it difficult to control for age-at-death. However, it is clear that dietary change over the course of the Bronze Age transition was complex, and does not support the idea of a categorical or linear change in subsistence.

Table 6.1 Oral health measures for all sites in the study

	<i>Calibrated carious lesion rate</i> [†]	<i>Uncalibrated carious lesion rate</i> [†]	<i>Carious lesion rate: M</i> [†]	<i>Carious lesion rate: F</i> [†]	<i>Average wear score</i> ^{**}
<i>Mapai</i>	0.0%	0.0%	0.0%	0.0%	4.8
<i>Xiaohandi</i> **	9.4%	9.5%	0.0%	15.82%	3.9
<i>Huoshagou</i> **	8.2%	6.0%	5.7%	10.4%	3.3
<i>Hamadun/Xigang</i> **	2.2%	1.5%	8.0%	3.6%	3.9
<i>Jiulongshan</i> ***	4.5%	5.6%	10.5%	0.0%	2.9
<i>Zhaitouhe</i> *	12.9%	11.0%	10.7%	15.0%	4.6
<i>Shijiahe (Rong)</i> **	16.8%	16.1%	14.8%	24.9%	4.2
<i>Shijiahe (Qin)</i> **	21.4%	20.8%	27.0%	10.7%	4.4

	<i>AMTL</i> [†]	<i>AMTL: M</i> [†]	<i>AMTL: F</i> [†]	<i>Calculus</i> [‡]	<i>Abscesses</i> [‡]
<i>Mapai</i>	1.4%	0.0%	1.4%	0.0%	0.0%
<i>Xiaohandi</i> **	20.0%	31.5%	15.2%	0.0%	13.3%
<i>Huoshagou</i> **	12.2%	10.4%	9.9%	21.2%	13.5%
<i>Hamadun/Xigang</i> **	14.4%	40.0%	39.8%	17.9%	14.3%
<i>Jiulongshan</i> ***	19.1%	0.0%	33.3%	60.0%	20.0%
<i>Zhaitouhe</i> *	15.1%	14.3%	17.2%	13.6%	27.3%
<i>Shijiahe (Rong)</i> **	9.7%	8.0%	15.3%	60.9%	56.5%
<i>Shijiahe (Qin)</i> **	10.4%	13.2%	0%	62.5%	62.5%

*Duyar and Erdal caries calibration method (Duyar and Erdal, 2003; Erdal and Duyar, 1999)

**Lukacs caries calibration method (not significantly different from results using Duyar and Erdal method) (Lukacs, 1995)

***No calibration (no pulp exposure from carious lesions)

**Scored using method developed by Smith (1984)

[†]Number of teeth out of all teeth observed

[‡]Number of individuals out of all individuals with observable teeth

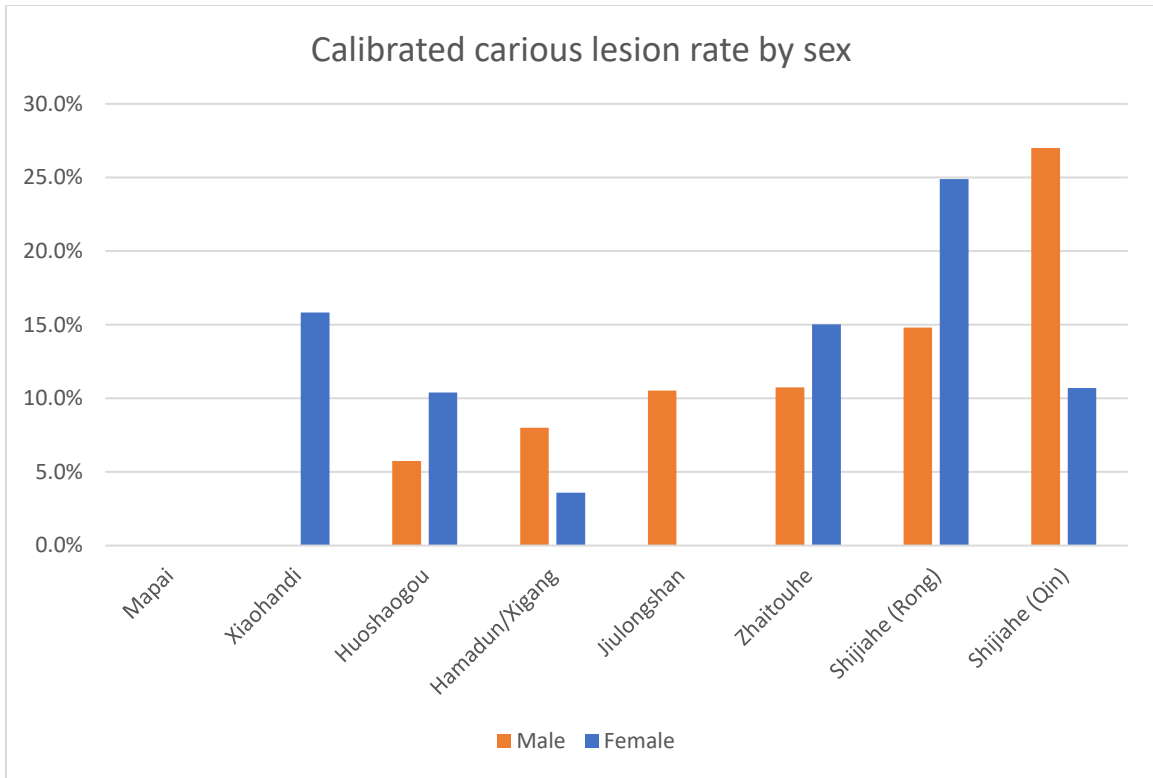


Figure 6.1 Percent of observable teeth with carious lesions, by sex, across all sites in the study

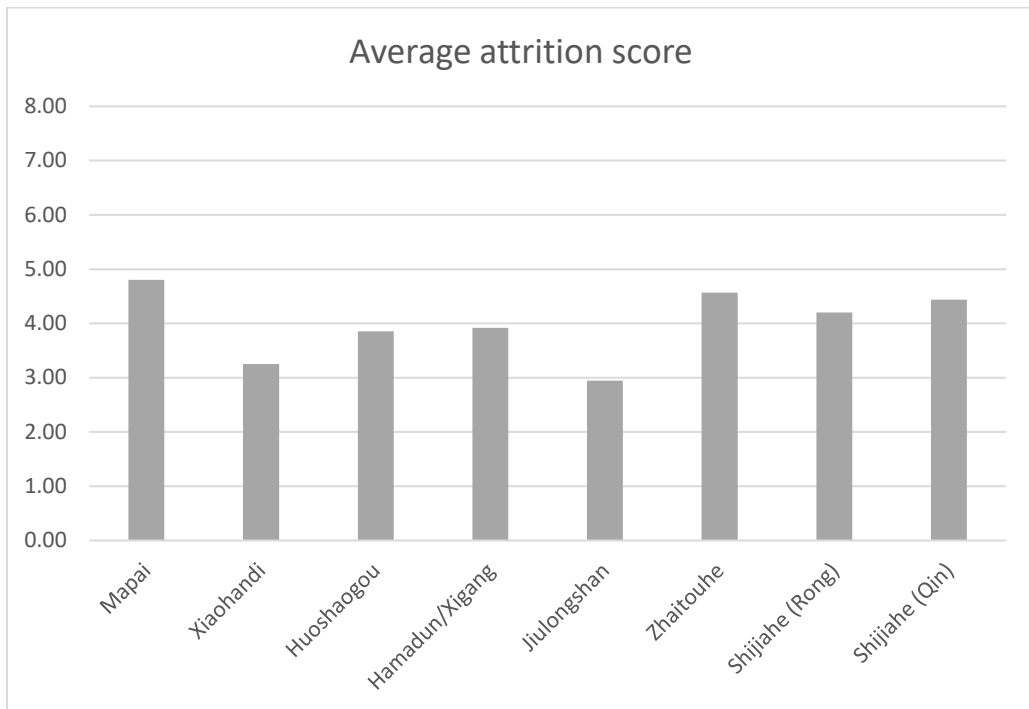


Figure 6.2 Average attrition score of all observable teeth at each site in the study

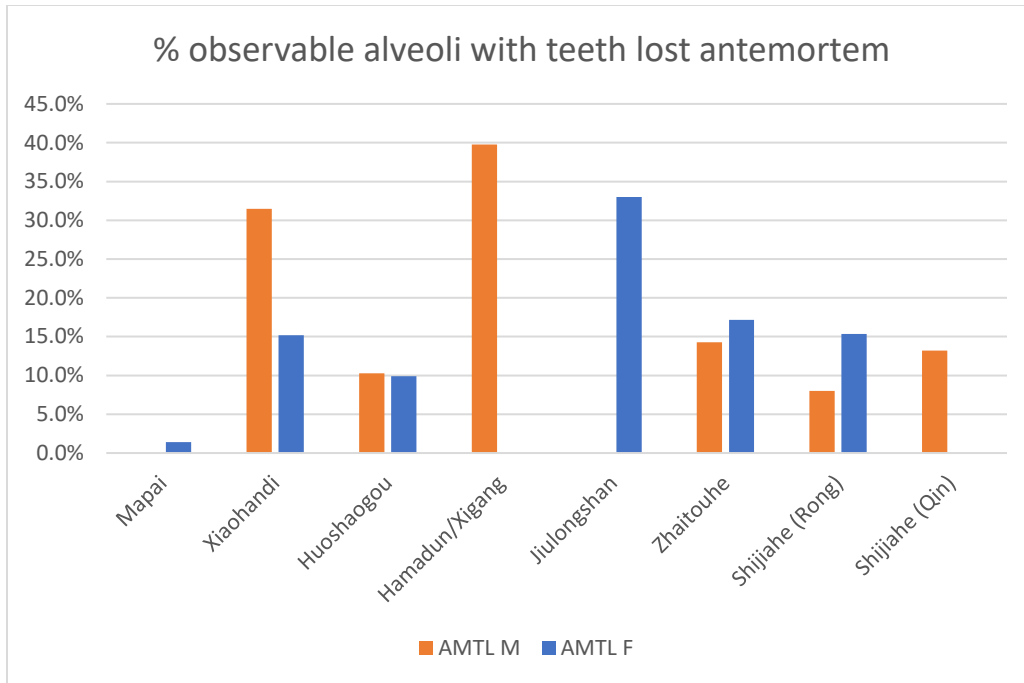


Figure 6.3 Percent teeth lost antemortem, by sex, across all sites in the study

6.2 PALEOPATHOLOGY

A total of 172 individuals of the 322 in this study exhibited visible pathological lesions, most of which were instances of osteoarthritis (OA) or periosteal new bone formation. Some of the measures show meaningful differences across the study populations, especially in the areas of OA, trauma, growth disruptions, and infectious and metabolic conditions.

6.2.1 Osteoarthritis

Differences in OA may be obscured by the poor preservation of postcranial remains in some of the groups. Therefore, the percent of individuals with OA at each site shown in Figure 6.4 was calculated as a percentage of individuals with those elements preserved, rather than a percentage of all individuals at each site.

The absence of spinal OA in the Qinghai sites (Mapai/Yangshan and Xiaohandi) is likely due to the near complete lack of preserved spinal elements, but even upper and lower limb OA in these groups is low. The Hexi Corridor sites (Huoshaogou and Hamadun/Xigang) saw an enormous rise in upper limb arthritis from the middle to the late Bronze Age, which may be due to changes in labor requirements with the intensification of animal husbandry at the later site. Spinal OA was high in both these groups.

The difference between the Qinghai Plateau and Hexi Corridor sites might reflect a difference in labor demands between the two regions. Archaeological evidence suggests that the Qinghai groups predominantly practiced agriculture and that the Hexi Corridor groups practiced agropastoralism, with increasing specialization in animal husbandry over time. However, to truly understand these subsistence systems, quantitative zooarchaeology and paleoethnobotany, and more data from recently excavated human skeletal remains, will be necessary.

The pattern of OA was the same at all four Loess Plateau site (Jiulongshan, Zhaitouhe, Shijiahe-Rong, and Shijiahe-Qin), with the highest rates in the spine, the next highest in the upper limbs, and the lowest rates in the lower limbs. The high rate of spinal arthritis at Jiulongshan (all adult individuals exhibited spinal OA) may be the result of horseback riding. Zhaitouhe had lower rates of OA than either the Rong or the Qin at Shijiahe, possibly because of lower labor demands (see Chapter 5).

The higher rates of upper limb and spinal OA in the groups located in the most arid areas of the Northwest (Huoshaogou, Jiulongshan, and Hamadun/Xigang) could indicate that they were more reliant on pastoral production, as both Gresky et al. (2016) and Eng (2016) found mechanical stress increased with reliance on pastoralism. The lower rates at Zhaitouhe and Shijiahe could suggest they had a more mixed subsistence system or relied more on agriculture.

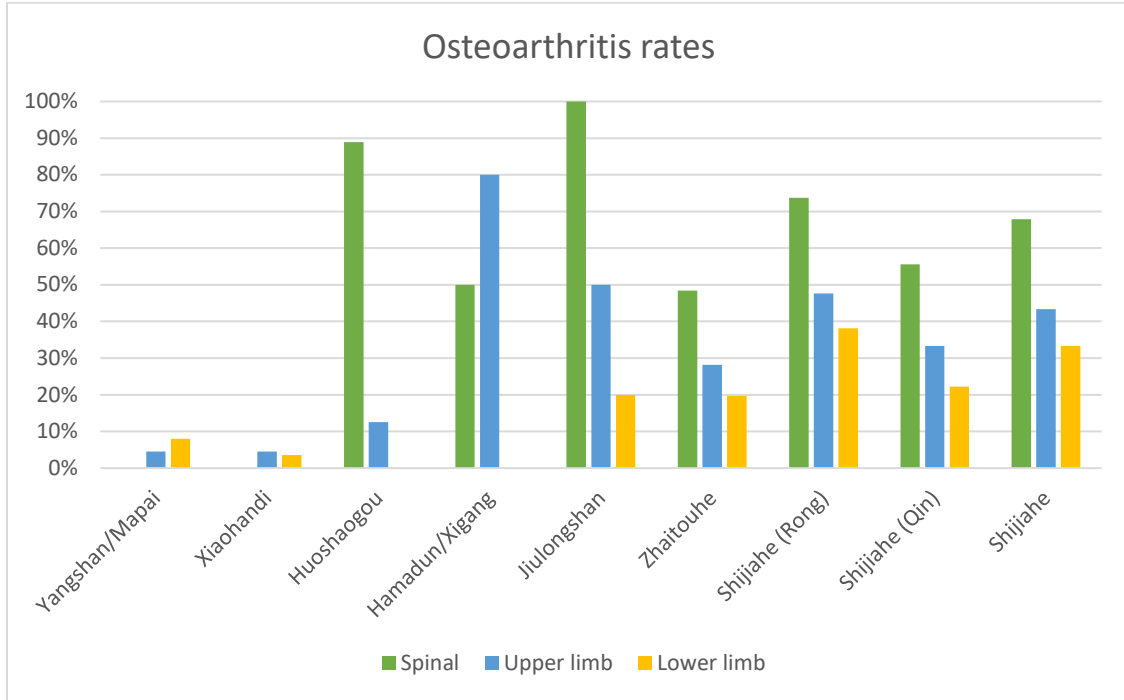


Figure 6.4 Percent individuals exhibiting OA in different areas of the body, across study sites

6.2.2 Trauma

Only 20 individuals in the entire sample of 322 showed trauma (6.2% of the total). A few individuals had cranial trauma indicative of interpersonal violence (blunt and sharp trauma), though most of the trauma cases involved fractures of the limbs, ribs, or clavicles that were likely accidental. In several cases, the trauma would have caused significantly impaired limb function, including a case of bilateral congenital hip dysplasia, femoral fractures, and several cases of necrosis of the femoral and humeral heads.

Only three individuals, 0.9% of the total, had perimortem trauma, all of which affected the cranium. Given that the groups in this study lived during a time of climate change, population movement, and the rise and expansion of state power, this lack of evidence for interpersonal violence is surprising. Take for instance the cemeteries of Hamadun and Xigang: they are

associated with the settlement of Sanjiaocheng, which was walled and therefore presumably experienced some level of conflict or competition, but the people from these cemeteries exhibit no perimortem trauma or evidence for interpersonal violence. The lack of evidence for violent conflict is also surprising for the Zhaitouhe and Shijiahe groups, who lived during the Warring States period in the Wei River Valley, a time and place where the historical record attests to frequent warfare and conflict. During the later Warring States, China averaged more than one war per year; small farmers were required to serve in the military and support state war machines; and the primary goal of battle was slaughtering as many enemy soldiers as possible to reduce the power of other states, making it an exceptionally bloody time (Li, 2013). It can only be concluded that either the cemeteries of Shijiahe or Zhaitouhe were not used to bury individuals who had participated in battles, or these particular groups (most of whom were Rong and not “Chinese”) did not provide much military service. It has previously been found that level of violence in ancient China varied by time period and by level of involvement with the Chinese state, with some frontier populations of later historic periods perhaps protected from violence by living within the state’s infrastructure (Eng and Zhang, 2013).

6.2.3 Growth and development: LEH, stature

There are only four groups in the study that exhibit LEH: Huoshaogou and Hamadun/Xigang (Hexi Corridor sites), and Zhaitouhe and the Rong of Shijiahe (Loess Plateau sites) (Figure 6.5). The decrease in LEH from Huoshaogou to Hamadun/Xigang implies a successful adaptation to new environmental conditions and a decline in childhood growth disruptions (see Chapter 4), and the lower rate in the Rong of Zhaitouhe than the Rong of Shijiahe supports the interpretation that the Rong of Shijiahe were lower status individuals and suffered more growth disruptions in childhood (see Chapter 5).

The lack of LEH in all the other groups in the study may be explained by the small sample size: the four groups with no LEH each had between five and 15 individuals with dentition preserved, while the groups in which LEH was observed had between 23 and 52 individuals with dentition preserved. LEH may be rare enough in these groups that a larger sample size is required to observe it.

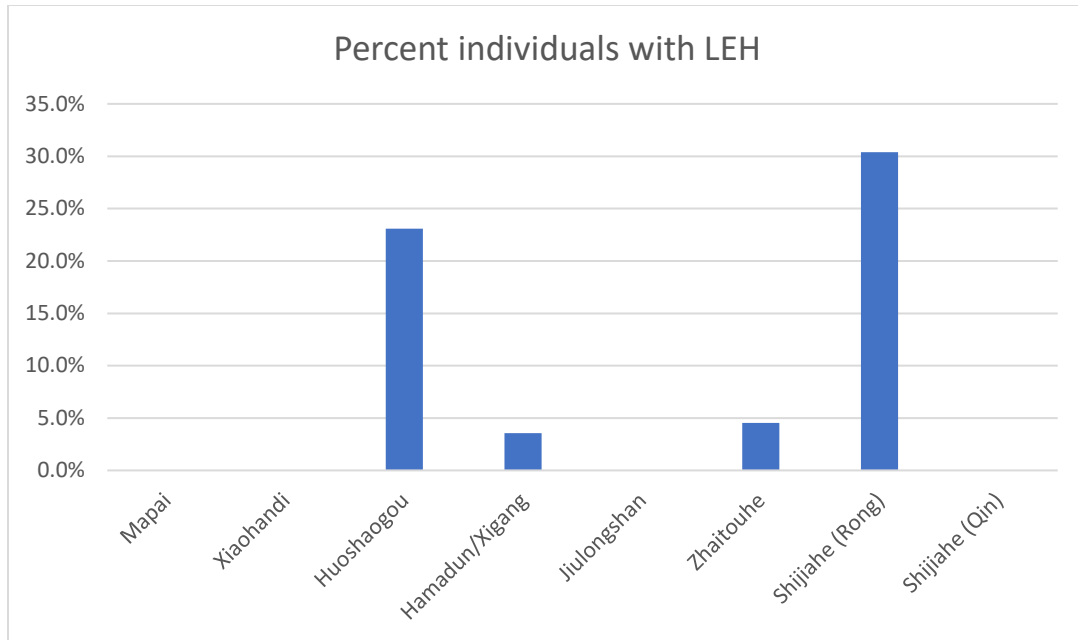


Figure 6.5 Percent individuals affected by LEH across all sites

Though LEH revealed different levels of childhood growth disruptions, adult stature attainment did not differ between any of the sites. An ANOVA of lengths of adult humeri, femora, and tibiae shows a significant main effect for sex, but no significant main effect for site, and there was no significant interaction between sex and site (see Appendix I). In other words, stature differed between males and females, but did not differ between sites, and the sex difference holds for all sites. (The type I sum of squares returned a value of $p < 0.0001$ for the main effect for sex for each of the three bones, and returned a $p > 0.05$ for the main effect for site

for each of the three bones. The partial eta-square is over 0.26 for all three bones, which indicates a large effect size for the main effect for sex (Cohen, 1988.)

Notched box plots also demonstrate that there is no significant difference in long bone length for either sex across the sites (Figure 6.6). The relationship between stature and health is complicated, as stature is strongly controlled by genetic factors, and even stressed or malnourished individuals are capable of “catching up” in their growth and attaining an adult stature that is comparable to others in the same population (DeWitte and Wood, 2008; Little et al., 1999). There is some evidence that this incurs a cost, and can lead to higher morbidity and earlier mortality (Watts, 2013). See the next section for further discussion.

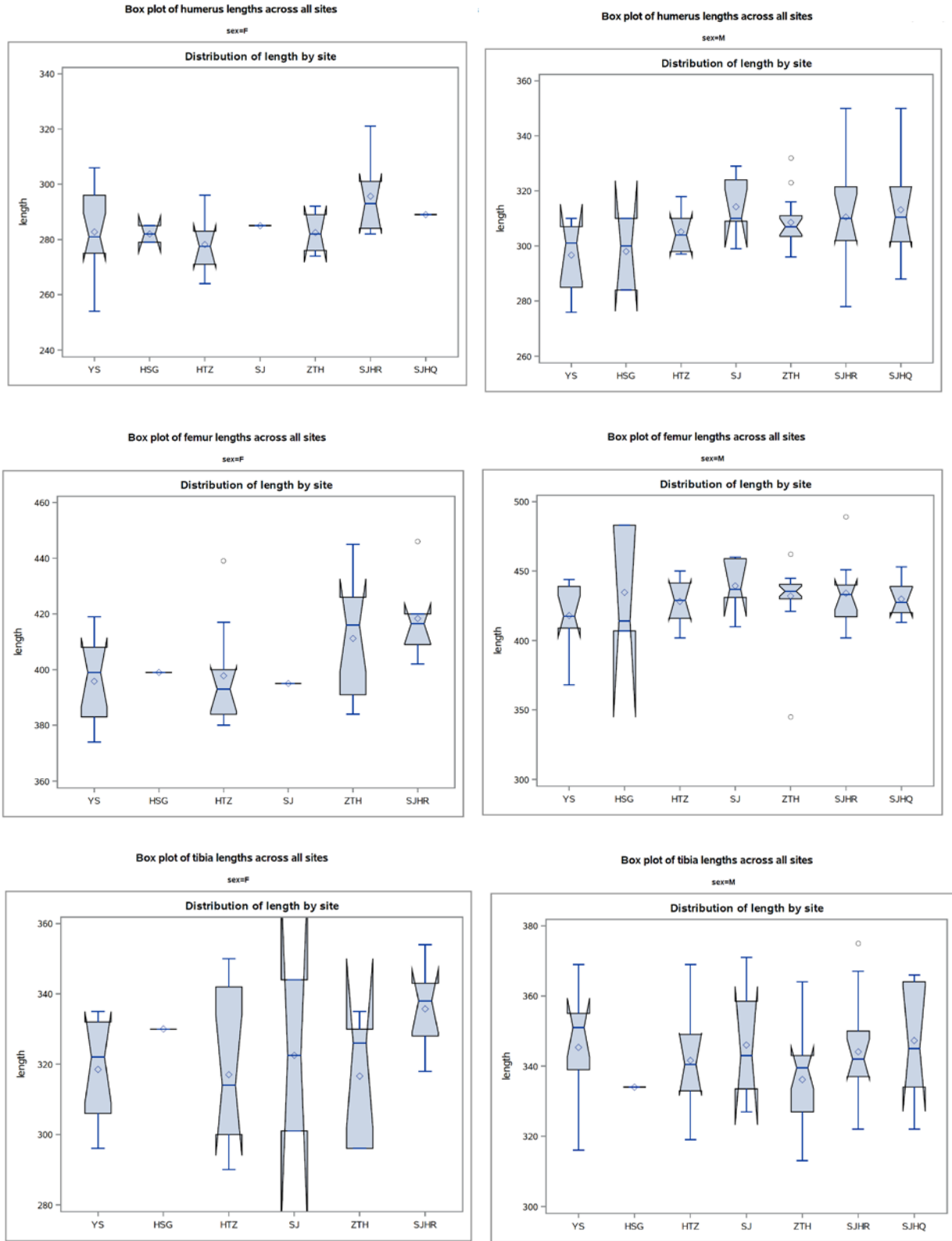


Figure 6.6 Notched box plots of long bones lengths by site and sex

6.2.4 Infectious and metabolic conditions: periosteal reaction, CO/PH

Figure 6.7 and Table 6.2 show the change in rates of tibial periosteal lesions, and of healing versus active lesions, across all sites in the study. At the Qinghai sites (Mapai/Yangshan and Xiaohandi), the number of lesions decreased over time, and most lesions were healing at the time of death. At the Hexi Corridor sites (Huoshaogou and Hamadun/Xigang), the number of lesions stayed constant, but went from mostly active to mostly healing at the time of death. Among the Loess Plateau sites, Zhaitouhe has the lowest rate of periosteal lesions in the entire study, while both the Rong and the Qin of Shijiahe have a significantly higher rate, which again suggests a lower status or greater amount of hardship faced by the people of Shijiahe.

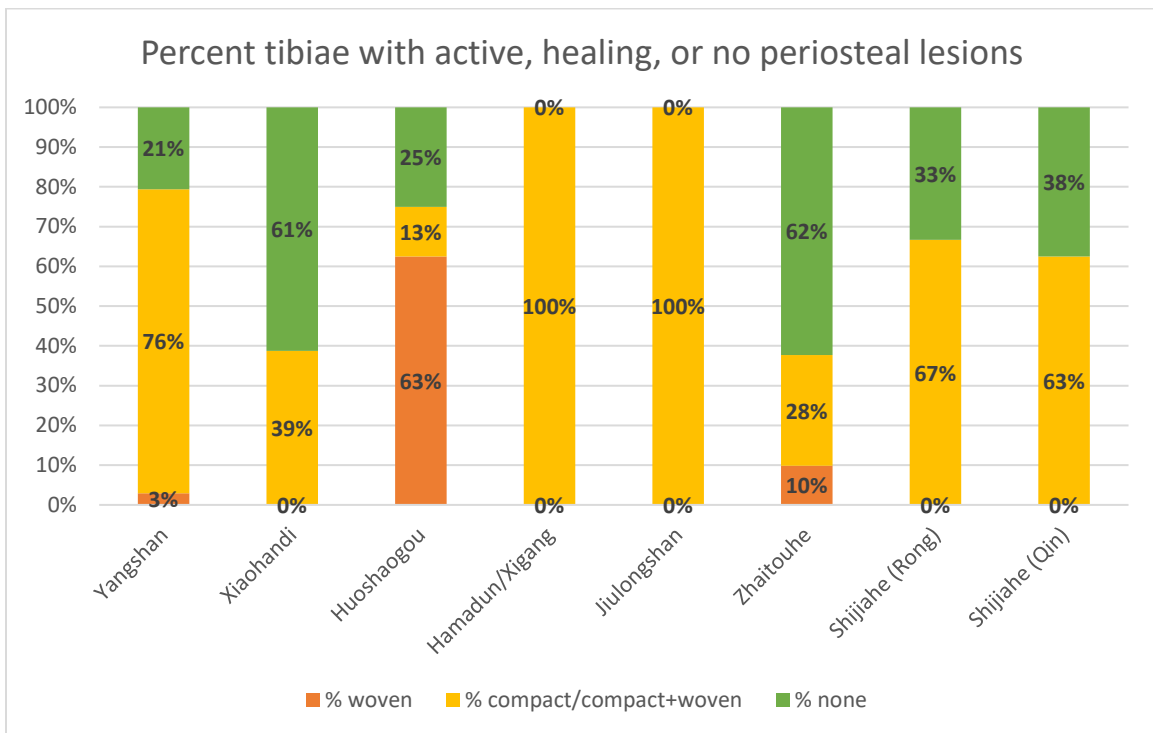


Figure 6.7 Tibial periosteal lesions that are active (woven) vs. healing (compact) across all sites

Table 6.2 Numbers and percentages of individuals with active tibial periosteal lesions, healing lesions, and no lesions across all sites in the study

	Yangshan	Xiaohandi	Huoshagou	Hamadun/ Xigang	Jiulongshan	Zhaitouhe	Shijiahe (Rong)	Shijiahe (Qin)
Woven bone (active)	1/34 individuals with tibiae	0/31	5/8	0/7	0/6	6/61	0/21	0/8
Rate	3%	0%	63%	0%	0%	10%	0%	0%
Compact bone/ compact+woven bone (healing)	26/34	12/31	1/8	7/7	6/6	17/61	14/21	5/8
Rate	76%	39%	13%	100%	100%	28%	66.7%	67.5%
No reaction	7/34	19/31	2/8	0/7	0/6	38/61	7/21	3/8
Rate	21%	61%	25%	0%	0%	62%	33.3%	32.5%

Table 6.3 and Figure 6.8 reveal interesting parallels between the rates of periosteal lesions and ectocranial porosity (CO and PH). CO and PH are evidence of anemia in childhood, and in this study the lesions seem to correlate with periosteal lesions in adulthood. The overall rate of periosteal lesions and the rate of CO/PH both decline in the Qinghai sites (Mapai/Yangshan and Xiaohandi), and the rate of active periosteal lesions and the rate of CO/PH decline in the Hexi Corridor sites (Huoshagou and Hamadun/Xigang). The relative frequencies of periosteal lesions and CO/PH are mostly consistent across the four Loess Plateau groups (Jiulongshan, Zhaitouhe, Shijiahe-Rong, Shijiahe-Qin), except for a significant difference in CO/PH between Zhaitouhe and Jiulongshan (Chi-square 5.4405 p=0.0197).

This correlation between CO/PH and periosteal lesions holds for individuals as well, not only for populations. Of the individuals in this study with CO/PH, 22 also had periosteal lesions, and only four had no periosteal lesions (an additional 13 individuals with CO/PH had no

postcranial remains and therefore could not be assessed for periosteal lesions). This suggests that individuals who experienced anemia in childhood were somehow more susceptible to periosteal lesions later in life. This finding is difficult to interpret, as the relationship between childhood stressors and adult morbidity and mortality, as well as the pathophysiology of both CO/PH and periosteal lesions, are still debated (Klaus, 2014). Also, the majority of periosteal lesions observed in this study were healing at the time of death. I have up to this point interpreted this as evidence of lower frailty. However, it is possible that anemia early in life may have increased morbidity later in life, that is, it predisposed people to contract infections or to develop a skeletal stress response such as periosteal lesion formation after contracting an infection.

To disentangle the factors at work, other measures of childhood stress such as LEH, long bone length, and vertebral neural canal size would need to be included in the analysis, along with age-at-death, to assess whether childhood morbidity led to increased mortality, as has been found in other archaeological populations (Watts, 2013). There does not appear to be a relationship in this study between LEH and either CO/PH or periosteal lesions, but a more rigorous statistical model would be needed to fully assess this.

Table 6.3 Numbers and percentages of individuals with CO and PH at each site in the study

	Mapai/ Yangshan	Xiaohandi	Huoshagou	Hamadun/ Xigang	Jiulongshan	Zhaitouhe	Shijiahe (Rong)	Shijiahe (Qin)
CO	0/6 crania at site*	3/18	5/49	1/12	0/6	2/42	0/21	0/8
Rate	0%	17%	10%	8%	0%	5%	0%	0%
PH	3/6	1/18	1/49	0/12	2/6	5/42	6/21	0/8
Rate	50%	6%	2%	0%	33%	12%	33%	0%
Both	1/6	1/18	2/49	0/12	1/6	2/42	1/21	1/8
Rate	17%	6%	4%	0%	17%	5%	5%	13%
Total %	67%	28%	16%	8%	50%	21%	38%	13%

*Not including fragmentary crania

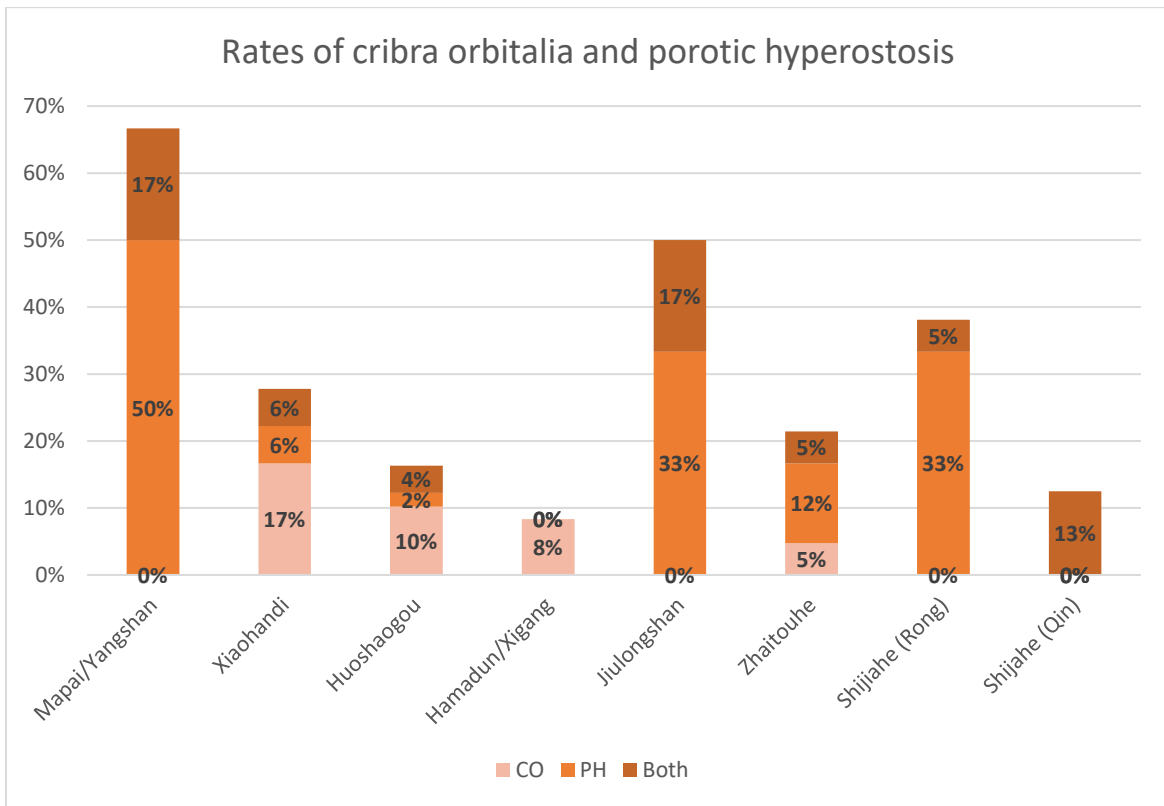


Figure 6.8 Percent of all individuals with observable crania affected by CO and PH across all sites

These measures of morbidity and mortality are indirect measures of health, which can be defined either as lack of illness or as the ability to rally from physiological insults (Meade and Emch, 2010). Health is a widely-accepted measure of population adaptability and sustainability. However, health does not have a straightforward relationship to resilience. A resilient system that can adapt with only incremental changes is not necessarily “healthy,” and in fact highly resilient systems are sometimes maladaptive for the humans within them (Holling and Gunderson, 2002; Robinson and Berkes, 2010). I am therefore not claiming that lower frailty, fewer growth disruptions, etc. indicate that a population was more resilient, i.e. better able to adapt.

The question being asked in this study is rather whether the adaptive events surrounding the 4000 BP climate event were incremental or transformational. The health changes described above are complex and represent a mosaic of continuity, decline, and improvement; also, many fundamental indicators of population health, such as fertility, did not change. This suggests that the adaptation was incremental rather than transformational, and did not lead to categorical changes in diet, health, and lifeway.

6.3 PALEODEMOGRAPHY

The sites in this study were too small to conduct a hazard analysis, and therefore I did not address mortality. Instead, I have calculated the juvenility index, a simple but powerful measure of fertility. The juvenility indexes and 95% comparison intervals for all populations in the study (other than the small site of Jiulongshan) are presented below in Table 6.4 and Figure 6.9.

The comparison intervals show that we cannot reject the null hypothesis that these sites all have the same juvenility index, and therefore they likely had the same fertility rate. The only exception to this is Zhaitouhe and Huoshaogou, whose comparison intervals do not overlap.

However, as discussed in Chapter 5, the Zhaitouhe cemetery did not include any children or infants, and only included two adolescents, so the distribution of age-at-death for this group is probably not representative of living population structure. The paleodemographic changes in Bronze Age Northwest China, especially age-specific mortality, should be analyzed with more data and larger sample sizes in the future.

Table 6.4 The juvenility index and 95% comparison intervals for all sites in the study (other than Jiulongshan)

Site	N (D5+)	D30+/D5+	95% Comparison Intervals
Yangshan/Mapai	32	.5313	.3418-.7207
Xiaohandi	32	.7188	.5293-.9082
Huoshagou	64	.4375	.3036-.5714
Hamadun/Xigang	29	.5517	.3527-.7507
Zhaitouhe	61	.7541	.6169-.8913
Shijiahe-Rong	23	.6087	.3853-.8321
Shijiahe-Qin	9	.7778	.4206-1.000

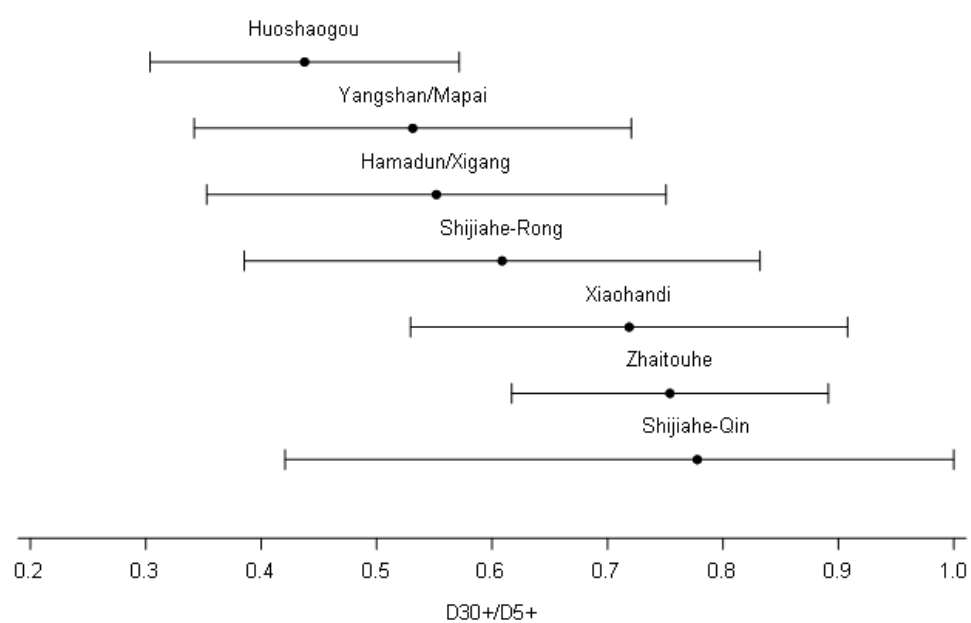


Figure 6.9 Ninety-five percent comparison intervals for the juvenility index for all sites in the study (other than Jiulongshan)

6.4 BIODISTANCE

The results of the biodistance analysis indicate that there was population movement and gene flow throughout Northwest China during the period of this study. A Ward's cluster analysis based on cranial nonmetric traits is presented in Figure 6.10; see Appendix II for the complete cranial nonmetric trait counts and mean measure of divergence results.

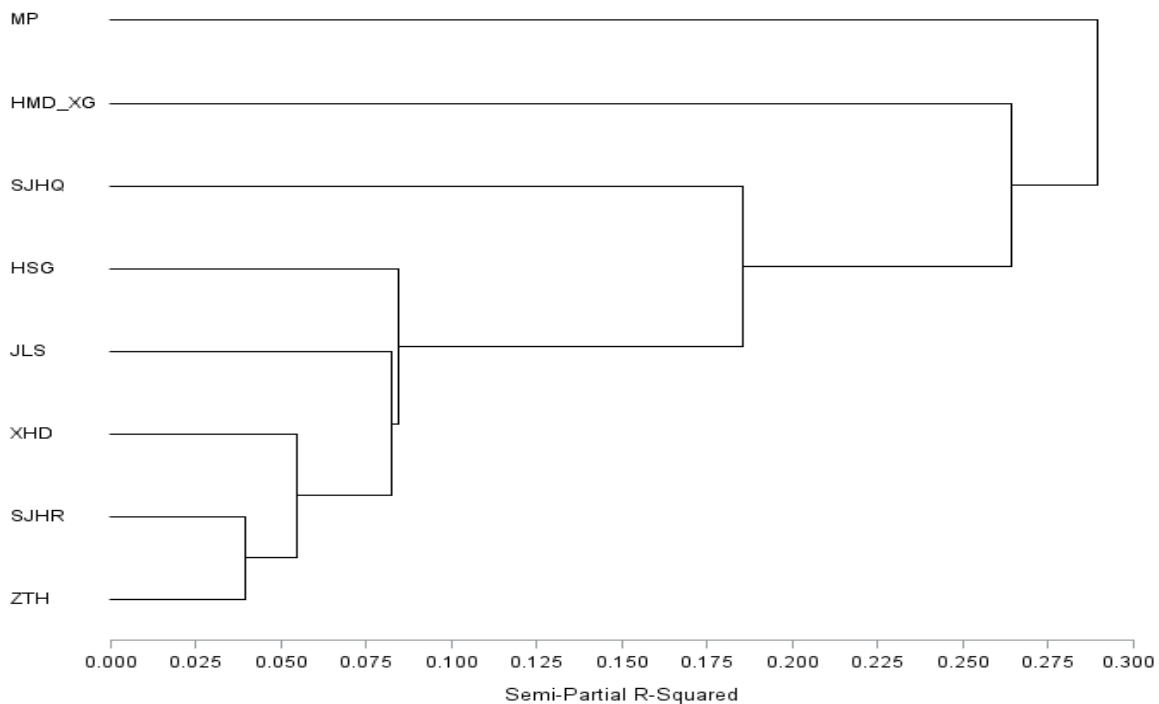


Figure 6.10 Ward's cluster analysis of the biodistance of all sites in the study, based on cranial nonmetric traits. MP=Mapai; HMD_XG=Hamadun/Xigang; SJHQ=Shijiahe (Qin); HSG=Huoshaogou; JLS=Jiulongshan; XHD=Xiaohandi; SJHR=Shijiahe (Rong); ZTH=Zhaitouhe

The relationship between populations within the sub-regions of the study (Qinghai Plateau, Hexi Corridor, and Loess Plateau) are discussed in more detail in Chapters 3 through 5. Here I will discuss the overall picture of migration in Northwest China that emerges from this biodistance analysis.

There is one clear cluster in the analysis, which includes Jiulongshan, Zhaitouhe, the Rong of Shijiahe, Xiaohandi, and Huoshaogou. I will refer to this as the Northwest Chinese

cluster. These groups were not all contemporaneous, but they all lived in neighboring areas of Northwest China in the second and first millennia BCE.

The Mapai group, who lived in eastern Qinghai in the late Neolithic, is isolated in this cluster analysis. It does not cluster closely with the Xiaohandi group, which lived in the same area in the middle Bronze Age. Therefore, the people of Mapai possibly were replaced by or merged with the group represented by the Xiaohandi remains. Given that Xiaohandi is part of the Northwest Chinese group, it appears that these people migrated onto the Qinghai Plateau from farther north, though probably not from the Hexi Corridor, as the mean measure of divergence analysis shows that Xiaohandi was biologically distinct from the groups at both Huoshaogou and Hamadun/Xigang (see Chapter 4).

It seems that a group from even farther north migrated into the Hexi Corridor during the Bronze Age. The group that lived at Huoshaogou in the early Bronze Age is part of the Northwest Chinese group in the Ward's cluster analysis. The other population from the Hexi Corridor, the late Bronze Age group at Hamadun/Xigang, is the closest to Huoshaogou in geographic proximity but does not cluster closely with it. It is likely that the people of Hamadun/Xigang originated farther north, or had mixed with a population from farther north, since another study has found they are most closely related to steppe populations such as Mongolians (Han, 2001).

Yet another southward migration appears to have taken place in Ningxia. The group from Jiulongshan is part of the Northwest Chinese cluster. However, the site of Pengpu in Ningxia, which is from the same area as Jiulongshan but dates to slightly later, in the late Spring and Autumn or early Warring States period, has been found to relate more closely to the Hamadun/Xigang population and to northern steppe groups (Zhao et al., 2014). It is therefore

possibly that Pengpu represents yet another group from farther north that came into the area, in this case during the Iron Age, and replaced or lived alongside people of the Northwest Chinese cluster.

Finally, the Rong of Zhaitouhe and Shijiahe are part of the Northwest Chinese cluster. The historical and archaeological records agree that the Rong originated in Gansu. The Qin population of Shijiahe, on the other hand, does not cluster closely with the Rong in the Ward's cluster analysis (though they were not significantly different from either Rong group in the mean measure of divergence analysis). The Qin, like the Rong, migrated from west of Shijiahe, and by the Warring States period had lived alongside the Rong for centuries and had some shared material culture (Li et al., 1993). However, this cluster analysis suggests there was little gene flow between the groups, which attests to the separation of cultural groups living in the area at this time.

This cluster analysis tells a story of continual southward and eastward movement of populations in Northwest China in the second and first millennia BCE, which is consistent with other previous studies that show close ties between the Neolithic and Bronze Age inhabitants of Gansu, Qinghai, and the Loess Plateau (Han and Pan, 1984; Lee, 2013). In Qinghai, the Neolithic population was succeeded by members of the Northwest Chinese group. In Gansu and Ningxia, populations that were part of the Northwest Chinese group were succeeded by groups from even farther to the north, from the steppe. In Shaanxi, the Rong and the Qin both came from farther west in the first millennium BCE—the Rong as subjects or allies of Chinese states, and the Qin as conquerors (Figure 6.11).

This agrees broadly with the analyses of Dodson et al. (2012), Han (2001), and Zhao et al. (2014), who essentially have found a Gansu/Qinghai/Ningxia grouping similar to my

Northwest Chinese group. This group is distinct from eastern and southern Chinese groups, and also from north Asian groups.

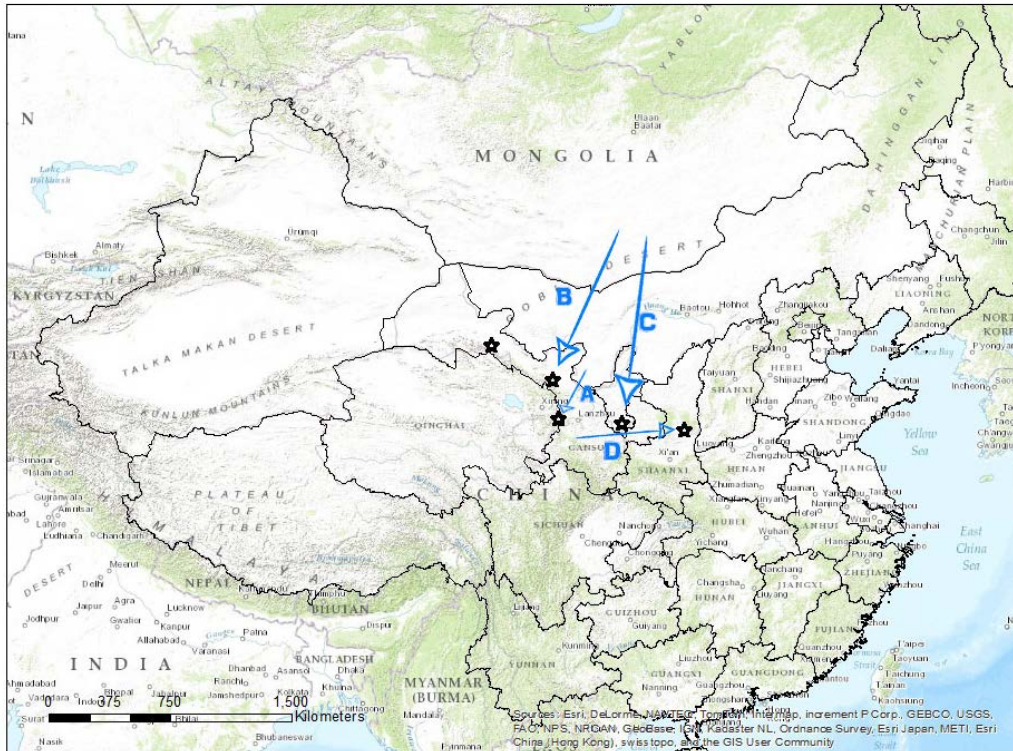


Figure 6.11 Migrations described in the text, based on a biodistance analysis of cranial nonmetric traits and published biodistance studies: A=migration of Northwest Chinese group into eastern Qinghai; B=migration of North Asian group into the Hexi Corridor; C=migration of North Asian group into Ningxia; D=migration of Rong people into the Loess Plateau

6.5 EVIDENCE FOR RISK MANAGEMENT

I have described the evidence for an incremental adaptation during the Bronze Age transition, and the lack of evidence for a transformational adaptation or “collapse.” This incremental adaptive response to the 4000 BP climate change event might be explained by the flexibility and resilience inherent in agropastoral societies, discussed in Chapter 2.

In addition, the archaeological record points to an increase in risk management strategies during the Bronze Age transition. These strategies may have been what allowed the people of Bronze Age Northwest China to maintain their way of life with only incremental changes and

still thrive, as the bioarchaeological record suggests they did. The two primary risk management strategies practiced by agropastoral societies are *diversification* (including spatial, temporal, and crop diversification) and *intensification* (Marston, 2011).

Spatial diversification is evident in the archaeological remains from Northwest China. In the middle Bronze Age Qinghai Plateau, the highlands were occupied by pastoralists of the Kayue Culture, while river valleys at lower elevations were occupied by agriculturalists of the Xindian Culture, such as the people of Xiaohandi (Dong et al., 2012; Dong et al., 2013a). The Kayue sites are located far from rivers, in what may have been summer grazing areas, and the Xindian and Kayue groups may well have traded with each other for agricultural and pastoral products, as has been observed ethnographically elsewhere (Dong et al., 2013a). This period also saw the introduction of barley and wheat, which grows well at higher elevations.

In the early Bronze Age Hexi Corridor, there is qualitative evidence that sites specialized in either agriculture or pastoralism (Li, 1993). In the late Bronze Age Hexi Corridor, the dominance of herd animals such as sheep/goat, horse, cattle, camel, and donkey also indicates spatial diversification, as these animals were likely grazed on uncultivated land, which would entail an extensive production strategy that took advantage of multiple ecological zones. Archaeologists have even found the remains of what appears to be a conical yurt-like tent at the late Bronze Age site of Sanjiaocheng, suggesting at least partial residential mobility (Gansu, 2001; Xie, 2002). Stable isotope analysis of animal remains from the Hexi Corridor supports the conclusion that domesticated herbivores were grazed on wild plants beyond the agricultural zone, rather than being foddered with millet or allowed to graze on agricultural stubble, which would have made the survival of the herds independent of the success of the agricultural crop, and therefore would have reduced risk (Atahan et al., 2011).

Temporal diversification can include culling animals at different times of the year and raising crops that can be harvested at different times of the year, or spending different amounts of time in agricultural and pastoral activities (Marston, 2011). In the future, systematic collection and analysis of zooarchaeological and paleobotanical remains could be used both to demonstrate culling patterns of animals and seasonality of culling, and to reconstruct the agronomic traits of ancient domesticated plants.

Crop diversification is also evident in the archaeological record from Northwest China. The importance of both plant and animal husbandry by the late Bronze Age strongly suggests an economy with a diversified subsistence base. Furthermore, the Bronze Age transition corresponds to the adoption of wheat and other West Asian C₃ crops into the East Asian agricultural assemblage: in addition to the paleobotanical evidence (Flad et al., 2010; Frachetti et al., 2010), multiple studies of stable carbon isotopes in human bone collagen show that C₃ plants such as wheat were introduced to the human diet after about 2000 BCE in both Gansu and Qinghai (Garvie-Lok et al., 2004; Garvie-Lok and Zhou, 2015; Liu et al., 2014; Ma et al., 2016; Zhang et al., 2003). Even the increase in the ratio of foxtail to broomcorn millet around 2000 BCE in eastern Gansu Province may indicate an adaptation to a drier climate, as foxtail millet requires less water (Jia et al., 2013). Liu et al. (2014) raise the possibility that denser human settlement combined with a drying climate in the second millennium BCE may have necessitated the relatively swift adoption of wheat in Gansu. Adopting multiple staple crops is a clear form of diversification.

The other form of risk management—intensification—is also evident in Northwest China in the Bronze Age. Specifically, the presence of storage pits at various sites in the Northwest (Gansu, 1990; Xie, 2002) indicates the production of an agricultural surplus. Furthermore,

around the time of the 4000 BP climate change event, settlement data suggest there was a dramatic increase in site density in the western Loess Plateau (An et al., 2004), which may have either resulted from or led to an intensification of food production.

Multiple lines of evidence thus support the conclusion that the people of Northwest China were engaging in risk management practices during the Bronze Age transition. The adoption of these practices—crop, spatial, and possibly temporal diversification, as well as intensification—represent adaptation to new and less predictable ecological conditions, and may explain the success of Northwest Chinese populations at adapting to late Holocene climate change.

6.6 CONCLUSION: BIOARCHAEOLOGICAL EVIDENCE FOR INCREMENTAL ADAPTATION

Both social and biological mechanisms play an adaptive role in events such as the Bronze Age transition, and such transitions may also be initiated by both ecological and sociocultural conditions. It is therefore nearly impossible to disentangle environmental and historical or sociocultural causes of change in human-environment systems (Li et al., 2017), or separate culture's role as both adaptation and stressor (Gray et al., 2003: 4). An anthropological outlook reminds us that human adaptive responses are the outcome of the interplay of many factors, among them natural resources, ecology, and social relations (McMichael, 2001: 6; Redman, 2005). Further, because these factors can all become embodied, the study of human remains is an ideal place to begin a multidisciplinary investigation of adaptation in the past.

The Bronze Age transition in Northwest China is a complex case of climate change, environmental deterioration, and human adaptation. Paleoenvironmental reconstructions indicate that the human subsistence system should have been disrupted, but detailed archaeological data and the human biological data presented here demonstrate that the agropastoral production

system of the time proved resilient, and that the transition did not result in the collapse, resource shortages, or physiological stress that might be expected.

In the case of the Qinghai Plateau and the Hexi Corridor, changes to the human-environment system may have been motivated by both ecological and social factors. However, ecological conditions were the main potential stressor of the time, and culture appears to have served as a buffer against potential hardship and collapse of the human-environment system, as has been observed in other archaeological cases (Rosen, 1995), leading to better population health. In the case of the Warring States period in the Loess Plateau, social and political factors led the Rong to adapt to life within Chinese states, and the social stratification and conflict of the time led to worsening population health. For these groups, culture was the greatest stressor, illustrating the “pathogenic role of social inequalities” (Farmer, 1996). Other bioarchaeological studies within China have likewise found negative health outcomes of contact with states (Eng, 2007; Hernandez, 2014; Pechenkina et al., 2007).

The groups described in this study also lived in a place that has been described as ecologically marginal. The apparent resilience shown by these groups is therefore striking. Social and ecological system resilience are linked (Adger, 2000: 350), and this study suggests that both the social and the ecological systems of the time were more resilient than might be expected if only the large-scale ecological conditions are taken into account.

Furthermore, these data support the conclusion that the Bronze Age transition in Northwest China constituted an incremental, rather than a transformational, adaptation to climate change. If the transition had been transformational, involving a collapse of the previous subsistence system, one would expect to see evidence of a categorical change in the human-environment system, most clearly demonstrated in human health, diet, and population structure.

This would be reflected in clear changes in oral health, physiological stress, burden of growth disruptions, infectious and metabolic pathological conditions, and fertility, which I have not observed.

These findings are also consistent with the archaeological evidence, which shows that agriculture and sedentism continued into the late Bronze Age and beyond, though with implementation of risk management strategies, including spatial and crop diversification and intensification. Grazing of domesticated animals seems to have played a greater role in the economy of certain groups after the Bronze Age transition, but as a form of diversification, not as a replacement of the existing agricultural production system. As Barton and An (2014: 778) put it, “Exotic attributes, like wheat, barley, sheep, goats and metal, were merely incorporated into preexisting systems.” The human-environment system in fact seems to have become more efficient at extracting resources during the course of the Bronze Age transition, despite the deterioration in environmental conditions, as my data show decreased frailty and decreased burden of childhood anemias and growth disruptions in some groups. It is even possible that a more arid climate was beneficial to late Neolithic and Bronze Age agriculture, as the dominant crops at the time were well adapted to arid environments (An et al., 2004).

Further bioarchaeological research on the Bronze Age transition would benefit from stable isotope data from both bone collagen and bone apatite, for direct dietary reconstruction, and larger skeletal samples for hazard analysis to assess changes in age- and sex-specific mortality. These data will allow more high-resolution diachronic comparisons of diet and lifeway. Also, the archaeological signatures of risk management strategies such as diversification (Marston, 2011) will hopefully someday be more clearly identifiable through appropriate quantitative datasets of plant and animal remains and settlement patterns. Herd management

practices, farming techniques, and population size and impact on the environment can also be reconstructed with careful, quantitative paleoethnobotanical, zooarchaeological, and geoarchaeological analyses modeled on innovative research already being carried out in China and elsewhere in the world (Contreras, 2017; d'Alpoim Guedes et al., 2016; Makarewicz, 2014; Miller, 2013; Wang et al., 2016). These data should be collected through collaboratively designed and implemented multidisciplinary research projects that make full use of the richness and vast quantity of archaeological data being recovered in China. Such work will provide greater context to the bioarchaeological data presented here.

In light of this study's findings, it is time for the conversation about the Bronze Age transition in North China to move away from a narrative of collapse and towards a more dynamic model of human adaptation and resilience in prehistory. The archaeological record necessarily comes to us as a "smoothed" picture, representing only average conditions in the past (Frachetti, 2008b). Only by making use of as many datasets as possible can we avoid obscuring fine-grained changes in human-environment systems of the past. Human-environment systems are complex systems, which means they are constantly changing, and the system characteristics—in terms of efficiency, risk, adaptedness, and what constitutes a desirable state—are constantly changing as well (Nelson et al., 2007). Archaeology also undoubtedly has a role to play in the ongoing study of climate change, adaptation, and sustainability that is of such critical importance in the 21st century (d'Alpoim Guedes et al., 2016; Dann, 2015; Dawdy, 2009; Marston, 2015). Future studies of human adaptation to ancient climate change will also benefit from attention to human biological evidence, within a rich context of archaeological and ecological data.

APPENDIX I: ADULT POSTCRANIAL MEASUREMENTS

These lengths include the maximum length of the humeri, the bicondylar length of the femora, and the maximum length of the tibiae without the intercondylar eminence.

Qinghai Plateau sites	Bone	Sex	N	Mean	St dev	Min	Max
Mapai/Yangshan	Humeri	M	6	296.67	13.68	276.00	310.00
		F	15	282.73	14.86	254.00	306.00
	Femora	M	10	417.90	23.53	368.00	444.00
		F	10	395.80	23.13	402.00	446.00
	Tibiae	M	9	345.33	17.83	316.00	369.00
F		10	318.50	14.49	296.00	335.00	
Xiaohandi	Humeri	M	6	305.17	8.08	297.00	318.00
		F	6	278.17	11.02	264.00	296.00
	Femora	M	8	428.13	16.57	402.00	450.00
		F	10	397.80	18.02	380.00	439.00
	Tibiae	M	8	341.63	14.99	319.00	369.00
F		11	317.00	22.74	290.00	350.00	
Hexi Corridor sites							
Hexi Corridor sites	Bone	Sex	N	Mean	St dev	Min	Max
Huoshaogou	Humeri	M	3	298.00	13.11	284.00	310.00
		F	2	282.00	4.24	279.00	285.00
	Femora	M	3	434.67	42.00	407.00	483.00
		F	1	399.00	-	-	-
	Tibiae	M	1	334.00	-	-	-
F		1	330.00	-	-	-	
Hamadun/Xigang	Humeri	M	5	314.00	12.15	299.00	329.00
		F	1	285.00	-	-	-
	Femora	M	5	439.40	20.91	410.00	460.00
		F	1	395.00	-	-	-
	Tibiae	M	4	346.00	18.46	327.00	371.00
F		2	322.50	30.41	301.00	344.00	
Loess Plateau sites							
Loess Plateau sites	Bone	Sex	N	Mean	St dev	Min	Max
Zhaitouhe	Humeri	M	16	308.56	9.07	296.00	332.00
		F	4	282.50	8.06	274.00	292.00
	Femora	M	20	432.05	22.32	345.00	462.00
		F	11	411.18	20.41	384.00	445.00
	Tibiae	M	18	336.17	12.89	313.00	364.00
F		5	316.60	19.07	296.00	335.00	
Shijiahe-Rong	Humeri	M	11	311.36	19.54	278.00	306.00
		F	6	295.67	14.32	282.00	321.00
	Femora	M	10	435.80	23.13	402.00	489.00
		F	6	418.33	15.12	402.00	446.00
	Tibiae	M	12	345.58	14.59	322.00	375.00
F		7	335.71	11.50	318.00	354.00	
Shijiahe-Qin	Humeri	M	9	311.78	18.12	288.00	350.00
		F	1	289.00	-	-	-
	Femora	M	9	428.44	13.31	413.00	453.00
		F	-	-	-	-	-
	Tibiae	M	8	344.63	16.53	322.00	366.00
F		-	-	-	-	-	

**APPENDIX II: CRANIAL NONMETRIC TRAITS AND BIODISTANCE ANALYSIS
RESULTS**

In the following table, the rows represent the twenty cranial nonmetric traits used in the biodistance analysis. The columns represent each site's number of individuals with the trait present ("p") and the number of individuals scored for that traits ("n"). The sites are: JLS=Jiulongshan, SJHR=Shijiahe (Rong), SJHQ=Shijiahe (Qin), ZTH=Zhaitouhe, HMD/XG=Hamadun/Xigang, XHD=Xiaohandi, HSG=Huoshaogou, and MP=Mapai.

	JLS p	JLS n	SJHR p	SJHR n	SJHQ p	SJHQ n	ZTH p	ZTH n	HMD/X p	HMD/X n	XHD p	XHD n	HSG p	HSG n	MP p	MP n
Asterionic ossicle	2	5	3	20	2	7	3	24	0	6	5	20	4	34	2	3
Bregmatic bone	0	5	1	20	0	8	0	23	0	7	0	19	10	35	0	4
Condylar facet double	1	5	1	22	0	8	0	21	0	7	0	22	2	34	0	4
Coronal ossicle	0	5	0	17	0	8	0	22	1	6	2	20	1	34	2	5
Epiteric bone	1	5	4	17	0	7	5	23	0	7	6	20	5	34	2	4
Extra infraorbital foramen	0	5	1	16	1	6	1	20	0	4	3	21	3	36	0	5
Gonial eversion	1	4	11	21	4	8	6	20	0	5	4	12	8	29	0	3
Lambdoidal suture ossicle	1	5	8	21	4	7	11	24	1	6	12	22	6	30	4	5
Mastoid foramenextrasutural	2	5	6	22	1	8	9	24	1	7	7	22	9	36	2	4
Mental foramen multiple	0	4	0	20	0	8	1	22	0	5	0	12	1	29	0	3
Metopism	0	5	1	21	3	8	0	24	0	7	3	23	1	37	2	5
Occipitomastoid ossicle	1	5	2	16	0	8	4	23	0	6	4	20	3	34	0	3
Os Inca	0	5	1	21	1	7	2	22	0	6	0	20	3	30	0	3
Ossical at lambda	1	5	3	21	1	7	3	22	0	6	1	20	4	29	1	3
Ossified apical ligament	1	5	1	19	1	7	0	21	0	6	1	22	2	32	0	4
Parietal foramen	4	5	15	21	8	8	16	23	3	7	17	22	21	34	3	5
Parietal notch ossicle	2	5	6	18	1	7	3	23	0	6	6	19	2	35	1	3
Sagittal bone	0	5	0	20	2	8	1	20	0	7	1	21	0	33	1	4
Supraorbital foramen	5	5	16	19	7	8	22	23	2	6	22	23	37	38	5	5
Zygomatico facial foramen	5	5	20	20	7	7	23	24	6	6	19	23	34	35	5	5

The following table contains the results of the mean measure of divergence analysis. Each row contains the designations of the two sites being compared (“Site1” and “Site2”), the mean measure of divergence statistic (“mmdi”), and the standardized mean measure of divergence (“smmd”), which is the MMD divided by the standard deviation.

Site1	Site2	mmdi	smmd
HMD_XG	HSG	0.04298	0.73896
HMD_XG	JLS	0.05361	0.49862
HMD_XG	MP	0.17740	1.45106
HMD_XG	SJHQ	0.14933	1.68640
HMD_XG	SJHR	0.06871	1.06256
HMD_XG	XHD	0.12483	1.92864
HMD_XG	ZTH	0.05835	0.93186
HSG	JLS	-0.07286	-1.06678
HSG	MP	0.14566	1.74547
HSG	SJHQ	0.11321	2.29837
HSG	SJHR	0.00966	0.38168
HSG	XHD	0.08854	3.47809
HSG	ZTH	0.02075	0.89131
JLS	MP	-0.13429	-1.01313
JLS	SJHQ	-0.04997	-0.50671
JLS	SJHR	-0.14605	-1.95383
JLS	XHD	-0.10906	-1.45623
JLS	ZTH	-0.09533	-1.31031
MP	SJHQ	0.00259	0.02278
MP	SJHR	0.06839	0.76174
MP	XHD	-0.05674	-0.63025
MP	ZTH	0.05216	0.59396
SJHQ	SJHR	0.01096	0.19653
SJHQ	XHD	0.01584	0.28442
SJHQ	ZTH	0.05925	1.10294
SJHR	XHD	-0.01350	-0.42373
SJHR	ZTH	-0.02824	-0.94783
XHD	ZTH	-0.01230	-0.41183

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