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Craft Specialization and Animal Products at the Longshan Period Sites of Taosi and Zhoujiazhuang, Shanxi Province, China

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Craft Specialization and Animal Products at the Longshan Period Sites of Taosi and Zhoujiazhuang, Shanxi Province, China

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by

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ABSTRACT OF THE DISSERTATION

Craft Specialization and Animal Products at the Longshan Period Sites of Taosi and Zhoujiazhuang, Shanxi Province, China

by

Katherine Richards Brunson

Doctor of Philosophy in Anthropology

University of California, Los Angeles, 2015

Professor Paul Jeffrey Brantingham, Chair

The late third millennium BCE was a period of technological and cultural change in China's Yellow River valley. Domestic cattle and sheep were introduced into China from West Asia during this period, marking a shift in the zooarchaeological record and the arrival of new methods of animal exploitation. Using zooarchaeological evidence for the exploitation of secondary products and bone working at the Late Neolithic Longshan period sites of Taosi and Zhoujiazhuang in Shanxi Province, I examine the relationship between animal products, craft specialization, and increasing social complexity. My research suggests that non-subsistence uses of cattle and sheep were important factors that contributed to the adoption of herding in the Central Plains region, and that the nature of cattle and sheep exploitation varied between sites depending on local environmental and cultural conditions. Additionally, I use ancient DNA analysis to identify bovine oracle bones from Taosi and Zhoujiazhuang. Both domestic cattle and wild aurochs scapulas were used in divination rituals, raising the possibility that people experimented with managing native East Asian wild aurochs alongside domestic cattle. The zooarchaeological data presented in this study indicate that greater attention should be paid to the varied non-subsistence uses of animals in ancient China during periods leading up to Bronze Age state formation.

The dissertation of Katherine Richards Brunson is approved.

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TABLE OF CONTENTS

LIST OF FIGURES:

LIST OF TABLES:

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CHAPTER 1

Introduction

Zooarchaeological research on past human-animal relationships reveals that animal exploitation can take multiple forms, and that animals hold diverse social roles (Reitz and Wing 2008; Russell 2012). For complex societies, zooarchaeological studies of animals and their products provide data that can be used to examine broad social and economic processes including the emergence of political economies, the maintenance of status differences, and the changing uses of animals in ritual practice (deFrance 2009). Although zooarchaeologists have examined these issues in-depth for many parts of the world (see reviews in Crabtree 1990 and deFrance 2009), the nature of animal exploitation in ancient Chinese complex societies remains understudied.

The discipline of zooarchaeology in China has developed rapidly over the past few decades, incorporating new scientific methods and techniques (Yuan 2002, 2014). Most research focuses on documenting the domestication processes for key mammalian taxa and describing ancient subsistence patterns (Flad et al. 2007; Yuan 1999, 2008, 2010, 2014; Yuan et al. 2007, 2008). Recent zooarchaeological studies reveal the complex origins and uses of domestic taxa such as pigs (Luo 2012; Yuan and Flad 2002), sheep and goats (Flad et al. 2007; Li 2012; Li et al. 2014a, 2014b), cattle (Lu 2010a, 2010b, 2010c), water buffalo (Liu L. et al. 2006), horses (Liu 2014; Yuan and Flad 2003, 2005a), and camels (You et al. 2014). Additional techniques including stable isotope analysis, morphometrics, and ancient DNA are also contributing to research on domestication and the genetic origins of Chinese taxa (e.g., Barton et al. 2009; Cai et al. 2009, 2011, 2014; Chen et al. 2014; Cucchi et al. 2011; Han et al. 2014; Larson et al. 2005, 2010; Yang et al. 2008). However, the non-subsistence social and economic roles of animals in early Chinese complex societies have not yet received enough attention.

This dissertation contributes to the field of zooarchaeology in China by examining some non-subsistence uses of animals in the complex societies of the middle Yellow River valley during the late third millennium BCE. This is an exciting period for studying social developments leading up to Bronze Age state formation because there is considerable evidence for the emergence of proto-urban centers, increasing violence and warfare, increasing long-distance interactions, and increasing social hierarchy during that time (Chang 1986: 234-294; Chang 1999: 54-65; Liu and Chen 2012: 213-252). Several West Asian domesticates including wheat, barley, cattle, and sheep were also introduced to northern China by the late third millennium BCE, marking a shift toward new agricultural and herding practices (Barton and An 2014; Betts et al. 2014; Flad et al. 2007, 2010; Yuan et al. 2007).

My research focuses on the initial uses of cattle and sheep in the Central Plains region ca. 2,000 BCE. I am particularly interested in how these animals were incorporated into existing systems of animal husbandry. Although sheep and cattle provided new sources of meat for human consumption, I argue that it was their non-subsistence uses as new sources of raw materials, wealth, and ritual power that made their arrival in China so noteworthy. I focus on two case studies: the Longshan period sites of Taosi and Zhoujiazhuang in southern Shanxi Province. I analyze taxonomic diversity, kill-off patterns, and bone working techniques to show how sheep and cattle were incorporated into the craft production and ritual systems of these two centers. I also analyze ancient DNA from bovine oracle bones, finding that both domestic cattle and wild aurochs bones were used in Longshan-era divination rituals. The results raise the possibility that people experimented with managing native wild Chinese bovines alongside domestic cattle and that these animals interbred.

The Longshan period and trans-Eurasian exchange networks:

During the third millennium BCE, multiple proto-urban sites emerged across China. In the middle and lower Yellow River valley, these sites are usually classified as part of the Late Neolithic Longshan culture (ca. 3,000-1,900 BCE). Studies of regional settlement patterns indicate that there was population nucleation at competing regional centers that made up the largest sites within Longshan settlement hierarchies (Drennan and Dai 2010; Liu 2004: 159-91; Underhill et al. 2008). These sites were supported by intensive agricultural practices, show evidence for increasing craft specialization and trade, and were subject to greater inter-polity conflict and warfare (Chang 1986: 234-294; Liu and Chen 2012: 213-252; Underhill 2002).

One of the largest and most important Longshan regional centers is the site of Taosi (ca. 2,300-1,900 BCE) in southern Shanxi Province. Over the past several decades of survey and excavation at Taosi, archaeologists have uncovered a large cemetery, a palace/temple zone, craft production areas, ritual structures, elite and non-elite residences, and rammed earth walls surrounding the site core (He 2013). Taosi eventually lost its position as the primary economic and political center in southern Shanxi Province around 2,000 BCE when several other large sites emerged. One of these regional centers was Zhoujiazhuang, located about forty kilometers south of Taosi. Archaeological investigations at Zhoujiazhuang only began a few years ago, but excavators have already discovered non-elite residences and craft production areas, a large cemetery containing hundreds of burials, and a large moat surrounding the site. Although Taosi and Zhoujiazhuang are contemporaneous, the two sites are quite different in terms of their social and economic organization. No elite structures or burials have yet been found at Zhoujiazhuang that are comparable to those at Taosi. Additionally, as I discuss in my analysis of animal exploitation at the two sites, subsistence patterns and craft production differed significantly at Taosi and Zhoujiazhuang.

K.C. Chang (1986: 234-245) famously argued that social and economic exchanges between competing polities in the Longshan “interaction sphere” promoted increasing social complexity in multiple regions across ancient China and established conditions for the emergence of Chinese states. The rise and decline of Longshan-era regional centers represents a series of experiments with different forms of social organization that set the stage for the emergence of Bronze Age states such as Erlitou (ca. 1,850-1,550 BCE) and the Shang Dynasty capitals at Erligang, Huanbei, and Yinxu (ca. 1,600-1,046) (Schelach and Joffee 2014). Many characteristics of these northern Chinese states were already visible at Taosi and other Longshan sites. Therefore, studying the ways that inter-regional interactions promoted the development of new forms of social and economic organization at Taosi and Zhoujiazhuang contributes to ongoing research on the origins of Chinese civilization.

Broader trans-Eurasian exchange networks also influenced social and economic developments during the Longshan period. During the second and third millennium BCE, mobile pastoralists in the northern Eurasian steppes facilitated the long-distance movement of ideologies, technologies, and domestic plants and animals across Eurasia (Anthony 2007; Frachetti 2008, 2012; Kohl 2007; Sherratt 2006). A great deal of recent scholarship has focused on the introduction of wheat and barley into China and its relationship with trans-Eurasian exchange networks (Barton and An 2014; Bovin et al. 2012; Jones et al. 2011). Wheat and barley likely arrived in China through the Hexi corridor sometime during the third millennium BCE, although the exact routes of introduction are still subject to debate (An et al. 2013; Barton and An 2014; Betts et al. 2014; Dodson et al. 2013; Flad et al. 2010). Wheat and barley spread quickly across northern China and are found at some Longshan sites, but these plants did not make up large proportions of agricultural products until several thousand years later (An et al. 2013; Barton and An 2014; Betts et al. 2014; Boivin et al. 2012; Dodson et al. 2013; Flad et al. 2010; Lee et al. 2007). Millet remained the primary crop at most northern Chinese archaeological sites throughout the third and second millennium BCE (An et al. 2013; Athahan et al. 2011; Crawford et al. 2005; Flad et al. 2010; Jia et al. 2012; Liu et al. 2014; Zhao 2011).

Some scholars argue that environmental factors prevented the rapid adoption of West Asian cultigens as staple crops in China, and that their ultimate adoption was prompted by ecological opportunism (Jones et al. 2011). Other scholars place greater importance on cultural explanations for the slow adoption of wheat and barley in East Asia (Barton and An 2014; Bovin et al. 2012). As Bovin et al. (2012) argue, agricultural innovations in the form of plant and animal translocations are frequently driven by cultural factors, not a need for risk management or food security. If wheat and barley were adopted in China in order to increase the subsistence base, they should have been adopted more rapidly. Instead, cultural resistance—perhaps due to East Asian foodways that focused on boiled grains rather than baked breads—may have delayed the adoption of wheat and barley as agricultural crops. The desire for exotic goods used in prestige and status displays may explain the common presence of small quantities of foreign cultigens at many sites across China and Eurasia during the third millennium BCE (Barton and An 2014; Boivin et al. 2012; Frachetti et al. 2010).

Cattle and sheep were introduced to China at roughly the same time as wheat and barley, but the nature of their introduction through trans-Eurasian trade networks remains understudied.

Like wheat and barley, cattle and sheep remains are initially only found in low frequencies in Chinese contexts. However, sheep and cattle soon became important parts of the subsistence systems at sites such as Taosi and Zhoujiazhuang. Therefore pastoralism was well-established at many sites in northern China before the development of wheat and barley agriculture. If wheat and barley were not significant food crops until the Han (206 BCE-220 AD) or even Tang Dynasties (618-907 AD) (Barton and An 2014; Betts et al. 2014; Boivin et al. 2012), this raises the question of why cattle and sheep herding was adopted two thousand years earlier.

In the following sections, I discuss some of the non-subsistence uses of cattle and sheep that may help to explain their initial adoption in ancient China. I discuss key issues in the zooarchaeological record of the Longshan period in order to contextualize my analyses of animal exploitation at Taosi and Zhoujiazhuang. Although the faunal records at these two large regional centers may not be characteristic of the entire Longshan period, the sites provide important data that has implications for broader questions about animal introduction events, social developments associated with the emergence of trans-Eurasian exchange networks, and the development of Chinese states.

Key issues in the zooarchaeological record of the Longshan period:

This dissertation is composed of three articles that are already published or in preparation for submission to peer-reviewed journals. Together, the articles address several questions that I believe are critical for understanding the zooarchaeological record during the late third millennium BC: 1) how were domestic cattle and sheep introduced into the Yellow River Valley region, and is there evidence for human management of indigenous bovid populations before or after their arrival; 2) how did the arrival of cattle and sheep change the ways that people used animals for non-subsistence utilitarian products; and 3) how did the arrival of cattle and sheep change the ways that people used animals for ritual practice. Here, I briefly discuss these questions within the context of animal domestication in China. I then summarize how I address these issues in the dissertation articles.

1. How were domestic cattle and sheep introduced into the Yellow River valley region and is there evidence for management of native bovid populations?

Animal domestication in China resulted from both indigenous domestication events and introduction events. In this section, I briefly summarize the evidence for animal domestication in China before and after the arrival of cattle and sheep ca. 3,600-2,000 BCE. This is not an exhaustive review since animal domestication in China has been examined in detail elsewhere (Flad et al. 2007; Liu and Chen 2012: 96-118; Yuan et al. 2007; Yuan 2008, 2010, 2014). My goal is to present current genetic, isotopic, and zooarchaeological evidence for the domestication processes of the main domestic taxa in order to contextualize the use of sheep and cattle at Taosi and Zhoujiazhuang.

Animal management exists along a continuum, and there are varying degrees of human intentionality in the domestication process (Zeder 2006a, 2012). For this reason, zooarchaeologists rely on multiple lines of evidence to identify the presence of domesticated animals in archaeological contexts. Potential markers of domestication include: 1) increasing proportions of a given taxa in a faunal assemblage; 2) changes in demographics that suggest intentional culling; 3) the presence of pathologies such as tooth enamel hyperplasias or unusual bone growth caused by draught activities; 4) the appearance of animals in new regions outside of their natural habitat; 5) intentional inclusion of animals in burials or sacrificial offerings; 6) evidence for dietary changes caused by foddering (usually measured through analysis of stable carbon and nitrogen isotopes); and 7) genetic changes (usually assessed through studies of ancient DNA) (Lu 2010a; Luo 2012; Yuan 2008, 2010, 2014; Yuan et al. 2010; Zeder 2006a, 2006b, 2011)[1]. Dietary studies in China rely on isotopic evidence for foddering with millet—a plant with a C4 photosynthetic pathway that will cause increased $\delta^{13}C$ signatures in animal bone apatite and collagen (e.g., Barton et al. 2009; Chen et al. 2014). Genetic studies, both in China and around the world, usually compare mutations in control regions of mtDNA to trace phylogenetic relationships between populations. Through the development of next generation sequencing, geneticists are also increasingly able to examine coding regions of nuclear DNA and specific phenotypic traits associated with domestication (Larson and Burger 2013). Regardless of what methods are used, genetic studies of animal domestication should include DNA from ancient samples because modern DNA can be heavily biased by recent admixture events (Dobney and Larson 2006; Larson and Burger 2013).

Domestic animals in China before ca. 3,600 BCE:

Taxa domesticated indigenously within China during the Neolithic include dogs, pigs, and chickens. As is the case for early animal domestication events in other parts of the world, animal domestication in East Asia appears to be tied to low-intensity plant cultivation at the

[1] Claims about the domestic status of animals found at Chinese sites often depend on comparisons of bone and tooth size measurements. However, domestication does not always cause size reduction. Morphological changes associated with domestication can lag thousands of years behind initial animal management and may also be influenced by environmental factors or sexual dimorphism (Zeder 2011). Commensal taxa such as pigs are especially unlikely to show clear morphological changes because these animals have varied diets, behaviors, and degrees of mutualistic interactions with humans that can alternate between fully domestic and feral (Albarella et al. 2007). Zooarchaeologists working in China still agree that the evidence for size reduction of taxa presented in the following sections is compelling evidence for animal domestication, but earlier animal management may have taken place that did not leave visible changes in the skeleton.

beginning of the Holocene (Yang et al. 2012; Zhao 2011, 2014). The earliest evidence for animal management also suggests that it was performed by seasonally mobile populations or by groups that continued to rely heavily on wild taxa through hunting and gathering (Barton et al. 2009; Bettinger et al. 2010; Yuan 1999). Intensive plant cultivation and animal husbandry did not take place until between ca. 5,000-3,000 BCE, and wild taxa remained important parts of the subsistence systems in many regions, especially in the Yangzi River valley (Barton et al. 2009; Liu et al. 2012; Yuan 1999, 2010; Yuan et al. 2008; Zhao 2011, 2014).

Dogs:

Dogs were likely the earliest domestic animals in China. Modern genetic research indicates that dogs (*Canis familiaris*) were domesticated from gray wolves (*Canis lupus*) sometime before 15,000 years ago, but the exact timing and geographic origins of dog domestication are still under debate (Larson et al. 2012; Lindblad-Toh et al. 2005; Wayne et al. 2006). Some researchers suggest that dogs have a single East Asian origin (Pang et al. 2009; Savolainen et al. 2002), but these studies do not fit with other mtDNA evidence that dog domestication involved multiple geographic centers (Boyko et al. 2009; Larson et al. 2012; Wayne et al. 2006). Researchers have also argued that Middle Eastern wolves made the largest contribution to genetic diversity in modern dog breeds (vonHoldt et al. 2010). A recent ancient DNA study of dog and wolf bones suggests that dogs may have had a European origin (Thalmann et al. 2013); however, this study did not contain ancient samples from East Asia. Therefore, there is currently no consensus on the genetic origins of domestic dogs, especially because recent admixture and bottleneck events have greatly influenced modern populations (Larson et al. 2012; Wayne et al. 2006). Ancient specimens from archaeological sites in China and other parts of East Asia are currently under investigation and may help to improve our understanding of dog domestication and migration events (J. Yuan and K. Dobney, personal communication).

The earliest zooarchaeological evidence for domestic dogs in China comes from the site of Nanzhuangtou in Hebei Province (ca. 8,000 BCE) where a canine mandible was found that falls below the size range of wolves, suggesting that it belongs to a domesticated individual (Yuan 2008, 2010). Other early evidence comes from the site of Jiahu in Henan Province (ca. 7,000 BC), where several dog skeletons have been found in burial pits (Zhang 1999). These animals also have size measurements that fall within the range of *Canis familiaris*, suggesting that they are domesticated dogs (Yuan 2008, 2010).

In addition to body size changes, dietary changes have also been used as evidence for early dog domestication in China. Barton et al. (2009) studied stable isotopes in the bones of humans and animals at the site of Dadiwan in Gansu Province and found that the $\delta^{13}C$ signatures for dogs fall into two groups representing camp-fed dogs and wild dogs or wolves. The authors argue that low-intensity millet cultivation was already taking place during the first occupation phase at Dadiwan (ca. 5,900-5,200 BCE) even though meat procurement still focused on wild animals that may have been hunted with the help of these camp-fed dogs. The identification of millet remains at Nanzhuangtou and rice remains at Jiahu provides further evidence that initial periods of experimentation with plant cultivation took place at the same time that domestic dogs appear in the archaeological record (Yang et al. 2012; Yuan 2008, 2010; Zhao and Zhang 2009; Zhao 2011, 2014).

Pigs:

Pigs are another indigenous Chinese domesticate. Genetic evidence shows that domestic pigs (*Sus domesticus*) were domesticated from wild boars (*Sus scrofa*) in multiple locations across Eurasia, including at least one location in China (Larson et al. 2005, 2010; Wu et al. 2007). Ancient mtDNA evidence from Europe and West Asia reveals that after Near Eastern pigs were introduced to Europe, they interbred or were replaced by pigs domesticated from separate European wild boar populations (Larson et al. 2007; Ottoni et al. 2012). This suggests that the history of pig domestication in Eurasia was very complex and involved multiple introduction, replacement, and turnover events. However, genetic data from China reveals that replacement events may not have been as important in East Asia as they were in Europe or the Near East. Instead, domestic Chinese pigs appear to have descended directly from indigenous Northern Chinese wild boar populations, and there are still several extant Chinese wild boar populations that have not contributed to the maternal lineages of domestic pigs (Larson et al. 2010).

Zooarchaeological evidence indicates that pigs may have had two centers of domestication in China: one in the northern Yellow river valley region and one in the southern Yangzi river valley region, (Flad et al. 2007; Luo 2012; Yuan and Flad 2002). The earliest domestic pig remains have been identified at the site of Jiahu in Henan Province (ca. 7,000 BCE), where multiple lines of evidence including tooth size reduction, a greater proportion of *Sus* remains in the faunal assemblage, age profiles skewed toward younger individuals, and the presence of enamel hyperplasias on *Sus* teeth all point to the management of pigs (Luo 2012; Luo and Zhang 2008; Yuan 2008, 2010). Morphometric analyses also reveal similarities between pig teeth from Jiahu, other northern Chinese Neolithic archaeological sites, and modern domestic pigs (Cucchi et al. 2011). Additional early evidence for pig domestication in the Yellow River valley comes from the site of Cishan in Hebei Province (ca. 6,200 BCE) where *Sus* teeth also have smaller size measurements, where many animals were culled under one year of age, and where several complete pigs skeletons have been found in pit features (Luo 2012; Yuan and Flad 2002).

A second independent domestication event may have taken place in the Yangzi River valley. Some of the earliest evidence for domestic pigs in this region comes from the site of Kuahuqiao in Zhejiang Province (ca. 6000 BC) where pig mandibular teeth show size reduction and tooth crowding (Flad et al. 2007; Luo 2012). In northeast China, another potentially independent domestication event may have taken place at Xinglongwa period sites in Inner Mongolia (ca. 6200-5200 BCE), where pigs have been found in sacrificial contexts and where pig tooth measurements and frequencies of hyperplasias are consistent with domestication (Luo 2012).

Interestingly, the domestication of pigs seems to occur a few thousand years later than the initial domestication of dogs and millet. Perhaps the best example of this phenomenon comes from Dadiwan, where the $\delta^{13}C$ signatures for pigs do not increase until the second phase of occupation (ca. 4500-2900 BCE) when people began to practice full-time millet farming and when all of the dog remains at the site also have signatures consistent with fully domestic diets (Barton et al. 2009). During the Middle Neolithic (ca. 5,000-3,000 BCE), raising domestic pigs became a main part of subsistence practices at many sites in the Central Plains region, supplemented by the hunting of boar, deer, and other wild animals (Luo 2012; Ma 2007, 2008; Wang et al. 2013; Yuan 1999; Yuan et al. 2008). Although pig exploitation decreased in some regions where sheep and cattle herding was adopted, pigs remained one of the most important animals for subsistence throughout the Bronze Age (Luo 2012).

Chickens:

It is possible that chickens (*Gallus domesticus*) are another indigenous Chinese domesticate. The red junglefowl (*Gallus gallus*) is the wild progenitor of domestic chickens, and for many years scholars believed that a single domestication event took place somewhere within the natural range of red junglefowl in Southeast Asia (Fumihito et al. 1996). More recent modern mtDNA research indicates that there may have been multiple centers of domestication in Asia (Liu Y. et al. 2006; Miao et al. 2013). However, much of the genetic diversity seen in modern chickens is due to admixture, and several traits such as yellow colored skin—previously assumed to result from ancient selection events—only emerged in the last 500 years, limiting the applicability of modern DNA to research on chicken domestication (Eriksson et al. 2008; Flink et al. 2014).

Xiang et al. (2014) recently conducted an ancient DNA analysis of chicken bones from several Chinese archaeological sites including Nanzhuangtou (ca. 8,400 BCE), Cishan (ca. 5,900 BCE), Waying in Shandong Province (ca. 2,500-1,500 BCE), and the Jiuliandun Chu Tombs in Hubei Province (ca. 1,000-300 BCE). They identified all of the sampled bones as belonging to the *Gallus* genus, suggesting that there may have been a domestication event in the Yellow River Valley region ca. 8,000 BCE associated with the initial domestication of millet, dogs, and pigs. However, these results are currently under debate because it is possible that the archaeological specimens represent wild *Gallus* and because the natural geographic range of red junglefowl may not have extended as far north as Nanzhuangtou and Cishan (Peng et al. 2015; Peters et al. 2015; Xiang et al. 2015a, 2015b). Additional studies using ancient DNA are still needed clarify the genetic origins of domestic chickens in China.

The zooarchaeological record for chicken domestication in China is even less clear. Deng et al. (2013) conducted morphological analyses of possible chicken remains excavated from Chinese archaeological sites and found that the earliest definitive evidence for domestic chickens only comes from the Late Shang period (ca. 1,200 BC). Nevertheless, Deng et al. argue that chickens were likely domesticated before the Shang Dynasty because bones from what could be either domestic chickens, red junglefowl, or wild pheasants (*Phasianus* sp.) have been found at many Neolithic and Bronze Age sites. Additional zooarchaeological data is still needed to know whether chickens were domesticated during the Early Neolithic at roughly the same time as pigs and dogs or much later during the Middle Neolithic, Late Neolithic, or Bronze Age.

Domestic animals in China After ca. 3,600 BCE:

Cattle:

Zooarchaeological and genetic data indicate that cattle were domesticated from the now extinct wild aurochs (*Bos primigenius*) in two independent events: one in the Near East ca. 8,000 BCE that gave rise to taurine cattle (*Bos taurus*), and one in South Asia as early as ca. 7,000 BCE that gave rise to zebu cattle (*Bos indicus*) (Bradley and Magee 2006; Helmer et al. 2005; Hongo et al. 2009; Loftus et al. 1994, 1999; MacHugh et al. 1997; Meadow 1993, 1996). Genetic studies have identified five main mtDNA haplogroups for ancient *Bos taurus*: T (centered in the Near East), T1 (centered in Africa), T2 (centered in the Near East), T3 (centered in the Near East), and T4 (centered in East Asia) (Achilli et al. 2008; Bradley and Magee 2006; Mannen et al. 2004; Troy et al.2001). Other rare *Bos taurus* haplogroups have also been identified in modern European cattle that may have resulted from interbreeding with European wild aurochs populations (Achilli et al. 2009; Bonfiglio et al. 2010); however, both microsatellite and mtDNA evidence indicate that European domestic cattle are derived from Near Eastern varieties of *Bos taurus* (Loftus et al. 1999; Troy et al. 2001; Bradley and Magee 2006). The origin of African *Bos taurus* is still debated (Bradley and Magee 2006), but the T1 haplogroup is very closely related to the T2 and T3 haplogroups, suggesting that it also originated in the Near East (Achilli et al. 2008).

For modern domestic cattle populations in northern China, the most prevalent haplogroups include T2, T3, and T4 (Lai et al. 2006). Some researchers have argued that there was another independent domestication event in East Asia because the T4 haplogroup is only found in East Asian cattle (Mannen et al. 2004; Lai et al. 2006). However, more recent research demonstrates that the T4 haplogroup is a derived clade within the T3 haplogroup (Achilli et al. 2009). Ancient DNA from northern Chinese archaeological specimens dating to ca. 2,000 BCE also indicates that East Asian *Bos taurus* populations are derived from Near Eastern cattle populations because all ancient individuals belong to the T2, T3, and T4 haplogroups (Cai et al. 2014).

The earliest zooarchaeological evidence for domestic cattle in China comes from the Gansu-Qinghai region of northwest China, where a limited number of possible domestic cattle remains have been found at sites dating to ca. 3,600 BCE (Flad et al. 2007; Lu 2010a, 2010b; Yu et al. 2011). However, definitive evidence for *Bos taurus* exploitation in the Yellow River valley does not occur until ca. 2,500-2,000 BCE (Lu 2010b; Flad et al. 2007; Yuan 2008, 2010; Yuan et al. 2007). At that time, complete cattle skeletons buried as sacrificial offerings have been found at Dahezhuang in Gansu Province (Zhongguo 1974), and at Pingliangtai (Henan Sheng 1983) and Shantaisi (Zhang and Zhang 1997) in Henan Province. However, the proportion of cattle remains in the overall faunal assemblages at most sites remains fairly low, not reaching above about 5% of identified specimens (Lu 2009, 2010b). Only after about 2,000 BCE—at some sites such as Taosi and Zhoujiazhuang—do cattle begin to make up larger proportions of northern Chinese faunal assemblages.

It is still unclear when and how the other type of domestic cattle, *Bos indicus*, entered China. Research on modern zebu cattle mtDNA suggests that both haplogroups of *Bos indicus* (I1 and I2) originated in the Indian subcontinent (Chen et al. 2010). *Bos indicus* haplogroups are common in modern Chinese cattle populations, especially in southern China (Lai et al. 2006; Cai et al. 2014), but to date, no *Bos indicus* remains have been identified in China archaeologically. The earliest evidence for *Bos indicus* in China is an image on a bronze drum dating to the Warring States period (475 BC to 221 BC) from Shizhaishan in Yunnan Province (Zhang 1998: 41-44, 110-112; Chen 1999). More zooarchaeological studies of archaeological sites in southern China are needed to determine the timing and routes of introduction for *Bos indicus*, but it appears that this species was likely introduced to China from the Indian subcontinent or Southeast Asia sometime after 2,000 BC.

There is currently no evidence that cattle were domesticated from native East Asian wild aurochs or that people in China experimented with managing wild bovines prior to the arrival of domestic taurine cattle ca. 2,500 BCE (Lu 2010a, 2010b). Recently, Zhang et al. (2013) argued that that a 10,000 year old *Bos* mandible from northeast China shows evidence for tooth wear that is consistent with animal management. It is highly unlikely that this wild aurochs individual was managed by humans (Lu et al. forthcoming), but Zhang et al.'s work raises some important questions. If East Asian aurochs were present in northern China during the Holocene, did people experiment with managing them? Once domestic cattle were introduced to China, did they interbreed with native aurochs populations? How quickly after the arrival of domestic cattle did aurochs populations go extinct in East Asia? Only through additional ancient DNA and isotopic studies using samples from both domestic cattle and wild aurochs will zooarchaeologists be able to address these issues.

Another interesting question is why cattle herding spread across northern China at such a slow pace. The earliest cattle bones date to 3,600 BCE, but herding did not become common until 2,000 BCE. Pigs were still the most important domestic animals for subsistence at most Late Neolithic sites, with sheep herding predominating at sites in the arid northwest (Yuan 1999). It was not until the Late Shang Dynasty that cattle became one of the most important animals for subsistence and ritual at large urban centers such as Anyang (Campbell 2007, 2015; Campbell et al. 2011; Fiskesjö 2001; Li 2009; Yuan and Flad 2005b). The increasing importance of cattle in the zooarchaeological record began at sites such as Taosi and Zhoujiazhuang, making these important sites for examining the changing social and economic roles of cattle in ancient China.

Sheep and goats:

Genetic and archaeological evidence indicates that sheep (*Ovis aries*) were first domesticated in the Near East by about 8,500 BCE (Bruford and Townsend 2006; Hiendleder et al. 2002; Peters et al. 1999, 2005; Zeder 2011). Genetic research has identified five maternal lineages for domestic sheep (Guo et al. 2005; Hiendleder et al. 2002; Meadows et al. 2007, 2011; Pedrosa et al. 2005; Tapio et al. 2006). Although the Asiatic mouflon (*Ovis orientalis*) is a likely candidate for the wild progenitor of these domestic sheep, the exact relationships between these lineages remains unclear since *Ovis orientalis* mtDNA has not yet been included in phylogenetic reconstructions based on mtDNA (Bruford and Townsend 2006; Meadows et al. 2007, 2011).

However, all domestic lineages are highly divergent from two other wild species of *Ovis*—the Urial (*Ovis vignei*) and the Argali (*Ovis ammon*)—which are unlikely to be the progenitors of domestic sheep (Heindleder et al. 2002; Meadows et al. 2007, 2011; Chen et al. 2006; Tapio et al. 2006).

Modern Chinese sheep represent lineages A, B, and C, with lineage A being the most common (Chen et al. 2006; Guo et al. 2005). Cai et al. (2011) studied ancient mtDNA from sheep at several Chinese Bronze Age sites and found that almost all of the individuals belonged to lineage A. Only one ancient sample from Inner Mongolia belonged to lineage B. None of the samples belonged to Lineage C. Lineage B may have originated in the Near East (Chen et al. 2006), and Cai et al. (2007 and 2011) argue that the presence of this lineage in China is evidence for long distance interactions between East and West Asia. However, the geographic origins of the far more common lineage A remain a mystery. It is important to note that Cai et al. did not find evidence that wild sheep such as argali contributed to sheep DNA in China. More ancient DNA studies from China and across Eurasia are still needed to clarify the nature of sheep domestication and the possibility for multiple independent domestication events.

Like cattle, some of the earliest zooarchaeological evidence for domestic sheep bones in China comes from Qinghai and Gansu Provinces and dates to ca. 3,000 BCE (Flad et al. 2007). By ca. 2,000 BCE, domestic sheep make up significant proportions of faunal assemblages at many sites in northern China including Qijia culture sites in the Hexi corridor, Zhukaigou and Houshiliang in the Ordos region, and Taosi and Zhoujiazhuang in the Central Plains (Flad et al. 2007; Hu et al. 2008; Huang 1996; Yuan 1999, 2008, 2010). Some early sheep remains have also been found in sacrificial contexts at sites such as Baiying in Henan Province and Dongxiafeng in Shanxi Province, but sheep were rarely included in sacrificial offerings until later in the Bronze

Age (Yuan 2008, 2010; Yuan and Flad 2005b; Yuan et al. 2007). Recently, Dodson et al. (2014) directly radiocarbon dated several sheep bones from northern Chinese sites and found that the earliest specimens from Shihushan in northern Shaanxi Province date to between 4,700-4,400 BCE. However, Dodson et al. do not provide convincing evidence that the bone samples with these early dates belong to domestic animals. Therefore, there is still no evidence that domestic sheep were present in ancient China prior to about 3,000 BCE. Although it is unlikely that sheep were domesticated from indigenous Chinese wild bovid populations, the possibility that people may have managed native East Asian wild bovids such as gazelle (*Gazella* sp. or *Procapra* sp.), bharal (*Pseudois nayaur*), or argali (*Ovis ammon*) has not yet been examined.

The introduction of goats (*Capra hircus*) to China is even less well understood. The earliest goat remains in China come from the second phase of occupation at Erlitou (ca. 1,750 BCE) in Henan Province (Yang 2008; Yuan 2010). It is possible that goats arrived in China before 1,750 BCE, but so far no goat remains have been definitively identified in earlier periods. This raises the question of why goats were not introduced to China at the same time as sheep. According to herd management models, increasing the proportion of goats in a mixed herd is a risk management strategy because goats are better-suited to drier climates and reproduce more quickly than sheep or cattle (Dahl and Hjort 1976: 64, 98,103, 238-239; Redding 1981: 72-77, 93-110). The arrival of sheep in China without goats suggests that there was ample pasture land available to herders and that a desire to produce wool or high calorie meat and millk influenced people's herd management decisions more than a desire for herd security (Redding 1981: 159-180).

The sudden adoption of sheep herding followed by the sudden adoption of goats also contrasts with the more gradual adoption of cattle herding. There is variation in where and when these animals first appear, indicating that cattle, sheep, goats, wheat, and barley were likely not introduced together as a single Central Asian package of domesticates. Variation in local animal economies during the adoption of agro-pastoralism has been documented elsewhere in Eurasia, showing that domestic herd animals were not always introduced to new regions at the same times or along the same routes (Arbuckle et al. 2014). Therefore, archaeologists in China must also study the unique introduction processes for each non-native taxon.

Additional animal introduction events during the Bronze Age:

After 2,000 BCE, several additional domestic taxa were introduced to China. As mentioned in the previous sections, goats entered China ca. 1,700 BCE, but the nature of their introduction is not well understood (Yuan 2008, 2010). Zebu cattle also emerged sometime during the Bronze Age, likely entering China from regions to the southwest (Lu et al. forthcoming). Water buffalo (*Bubalus bubalis*) are another non-native domesticate. Ancient DNA analysis of water buffalo remains from Bronze Age sites indicates that these animals did not contribute genetically to modern Chinese domestic water buffalo populations, and that ancient Chinese water buffalo belong to the now extinct wild *Bubalus mephistopheles* species (Yang et al. 2008). It is still unclear when domestic water buffalo first entered China, but we do know that they were not domesticated from *Bubalus mephistopheles* (Liu L. et al. 2006; Yang et al. 2008). Even less is known about yaks (*Bos grunniens*). Yaks may have been domesticated first in northern Tibet, where yak milk, meat, and dung are important to life at high altitudes, but there is still no clear evidence for the process of domestication in this region (Flad et al. 2007; Rhode et al. 2007).

Horses (*Equus caballus*) were domesticated in the Eurasian steppes sometime before ca. 3,700-3,100 BCE, likely in multiple locations and with multiple maternal lineages contributing to modern populations (Anthony 2007:193-224; Levine 2005; Olsen 2006; Vilà et al. 2006). Horses were introduced to central China during the Late Shang period (ca. 1,300 BCE), when horses were frequently included in sacrificial chariot pits in elite mortuary contexts (Linduff 2003; Yuan and Flad 2003, 2005a). Horse remains have also been found at some earlier Qijia culture sites in northwest China, raising the possibility for indigenous domestication from wild Przewalski's horse (*Equus przewalskii*); however, the domestic status of these early horse bones is unclear and they are only found in small numbers, forming a strong contrast to the elaborate and numerous horse burials of the Shang Dynasty (Linduff 2003; Yuan and Flad 2005a). Ancient mtDNA research also reveals that Przewalski's horse was not the wild ancestor of domestic Chinese horses and that both indigenous and introduced maternal lineages contributed to modern Chinese domestic horses (Cai et al. 2009). Therefore, it is likely that horses were rapidly introduced to China along with chariots during the Late Shang period.

Donkeys (*Equus asinus*) were domesticated from the African wild ass (*Equus africanus*) in northeast Africa or the Near East by about 3,000 BCE (Vilà et al. 2006). Domesticated donkey remains have not been found in China prior to the first millennium BCE (Flad et al. 2007). Ancient DNA research confirms that Chinese donkeys are more closely related to the African wild ass than the Asiatic wild ass (*Equus hemionus*), suggesting that donkeys were not domesticated indigenously, but rather introduced as part of trade between East Asia and Central Asia along Silk Road trade routes (Han et al. 2014). Similarly, Bactrian camels (*Camelus bactrianus*) may have been introduced to China as part of long-distance trade networks, with the earliest definitive evidence for domestic camels also dating to the first millennium BCE (Flad et al. 2007; You et al. 2014). Additional ancient DNA research is needed to better understand the origins of Chinese camels and the potential for indigenous domestication from native Bactrian camels found in the Ordos region and Mongolia.

2. How did the arrival of cattle and sheep change the ways that people used animals for non-subsistence utilitarian products?

As discussed in the previous section, cattle and sheep were introduced to China several millennia after the initial domestication of pigs and dogs. The societies of the Central Plains region already had highly productive sources of meat for subsistence, so why did they adopt sheep and cattle herding? Although sheep and cattle provided additional subsistence goods and may have allowed people to take advantage of environmental niches where agriculture was not productive, the use of these animals for non-subsistence products was likely an important additional factor that contributed to their widespread adoption in northern China. The arrival of cattle and sheep not only provided new sources of post-mortem products such as bone, sinew, and hide, but also provided new sources of ante-mortem products such as wool, milk, traction power, and dung for fuel. I argue that these new resources made cattle and sheep herding a profitable enterprise that radically changed the ways people used animals and animal products.

Sherratt (1981, 1982, 1983) notes that the use of animal secondary (ante-mortem) products such as milk, wool, and traction intensified during the third and fourth millennium BC across Eurasia. This shift may have allowed people to grow their herds and build wealth by slaughtering fewer animals while still meeting subsistence needs (Russell 2012: 348-354). Prior to the arrival of herd animals in China, the capacity for using animals for secondary products was limited. Although dogs may have been used for hunting or as guard dogs, and pigs may have helped to keep human settlements clean by serving as privy-pigs that consumed human waste (Nemeth 1994), pigs and dogs generally do not provide many secondary economic products. The arrival of cattle and sheep in China would have allowed for specialization in ante-mortem products that did not require the slaughter of these animals, providing new sources of wealth and status. If the spread of herding in Eurasia was tied to the value of living animals as Sherratt suggests, zooarchaeologists should focus greater attention on the uses of cattle and sheep for wealth, for secondary products, and for ritual value during their initial introduction into China.

The use of cattle for secondary products at Late Neolithic and early Bronze Age sites in China has not been examined in detail, although this issue is currently under investigation (Z. Li and P. Lu, personal communication). At Erlitou (ca. 1,850-1,550 BCE), cart tracks have been found that may provide evidence for the use of draught cattle (Wang 1999; Barbieri-Low 2000). However, there is still no clear zooarchaeological evidence for draught activities during earlier periods. For example, I did not find clear evidence for traction-related pathologies at Taosi and Zhojiazhuang, but I did find that cattle were kept alive to older ages. This suggests that cattle may have been used for secondary products or as wealth animals. Additional research on this issue is still needed in order to understand the potentially varied uses of cattle in Late Neolithic societies.

Recent research, including work presented in this dissertation, suggests that sheep may have been used for wool or other secondary products at some Late Neolithic and Bronze Age sites in northern China (Li et al. 2014a, 2014b). However, as I discuss in my comparison of sheep exploitation at Taosi and Zhoujiazhuang, there is regional variation in how sheep were used. Only certain sites—perhaps those with the greatest degree of centralized political control—specialized in herding sheep for wool production. Similar patterns have been found in other parts of Eurasia, where there is ample evidence for a link between the development of complex provisioning systems, specialization in animal secondary products, and increasing socio-political complexity. For example, Arbuckle (2012) notes a shift toward raising sheep for wool in Anatolia between 6,000-3,000 BCE that is associated with increasing differentiation between communities and the emergence of competitive elites. In the Iranian highlands, Zeder (1991) argues that urban centers such as Tal-e Malyan were supplied with animals and animal products indirectly, reflecting increasingly complex interactions between urban consumers and rural suppliers. In Middle Saxon period England, Crabtree (1996a; 1996b; 2010) also notes a shift away from non-specialized production to meet local subsistence needs toward specialized production of various animal products including wool. Crabtree argues that the shift toward specialization in certain types of animal products is associated with the emergence of urban centers of craft production and the commercialization of agricultural products. The zooarchaeological data from Taosi and Zhoujiazhuang indicate that similar relationships may have developed in China during the adoption of sheep herding. As additional zooarchaeological data from both rural and urban sites become available, it will be possible to examine the role of sheep in the developing relationships between specialization, commoditization, urbanization, and social differentiation in ancient China.

Finally, there is growing evidence that cattle and sheep were also important sources of new non-subsistence post-mortem products. For example, the introduction of cattle and sheep coincides with significant changes in the bone artifact production industry in China. Although pig bones and teeth were frequently used to make artifacts at Neolithic sites, pre-Longshan period bone working tended to focus on wild artiodactyls (Ma 2010). The arrival of herd animals provided new sources of high-quality domestic animal bone raw materials. Cattle soon became the main taxa used in bone artifact production at Bronze Age centers (Campbell et al. 2011; Ma 2010). I argue that this tradition began at sites like Taosi, where sheep and cattle were the most important taxa for bone working. Although the evidence for perishable materials has not survived archaeologically, it is also likely that hide working industries would have developed at sites like Taosi. Additionally, animal dung may have been used to meet the fuel demands of large population centers where many people were engaged in craft production activities. Dung would have also been an important source of manure for agricultural fields. Herding became a profitable endeavor for Late Neolithic societies because people were able to take advantage of new possibilities for using animals and animal products, with new animal crafts forming an important part of developing economies.

3. How did the arrival of cattle and sheep change the ways that people used animals in ritual practice?

During the Late Shang Dynasty, sacrifice and divination using domestic animals—especially cattle—developed into an elaborate ritual system. These ritual activities, combined with royal hunting of wild animals, helped Shang royalty to maintain order in the world of the living and build connections with the world of the ancestors and spirits (Campbell 2007, 2015; Fiskesjö 2001; Keightley 2000). Chang (1983) has argued that shamanistic activities provided exclusive access to gods and ancestors, and that shamanistic rituals were a means of consolidating political authority in ancient Chinese states. Chang also notes that animals often served as intermediaries that helped people to transcend into the spiritual or ancestral realms, which may help to explain the common representation of animals in Shang Dynasty ritual vessels, the use of animals in sacrifice, and the use of animal bones as a divination medium.

The origins of Shang ritual traditions can be traced to the Middle Neolithic period, when pigs emerged as an important animal for feasting, status displays, and sacrifice, leading to an intensification in pig husbandry at many Chinese sites (Kim 1994; Luo 2014; Ma 2005). Over the course of the Late Neolithic and Bronze Age, cattle replaced pigs as the most important sacrificial animal (Yuan and Flad 2005b). Lu (2010c) has argued that because most of the earliest cattle remains in China are from complete skeletons found in sacrificial contexts, cattle herding may have been adopted in China because these animals were seen as important ritual or wealth animals. Sheep, on the other hand, were not commonly found in sacrificial contexts until the Early Shang Dynasty (ca. 1600-1300 BCE) (Yuan and Flad 2005b). Therefore, various domestic taxa were selected for sacrifice and other rituals in ways that changed through time during the development of complex societies.

Oracle bones are some of the most important artifacts that zooarchaeologists can use to assess the role of animals in ancient Chinese ritual practices. During oracle bone divination, diviners would burn flat animal bones—usually ungulate scapulas or turtle plastrons—and interpreted the cracks that formed (Keightley 1978). Flad (2008) has observed an increasing frequency of oracle bone divination, an increasing proportion of cattle oracle bones, and an increasing standardization in how oracle bones were prepared leading up to the Late Shang Dynasty when oracle bone divination became a central part of Shang royal authority. I identified several oracle bones at Taosi and Zhoujiazhuang. Most of these artifacts were made from cattle scapulas and many were carved prior to burning, suggesting that some of the practices that characterize Shang Dynasty divination were already emerging during the Longshan period. My colleagues and I extracted mtDNA from some of these artifacts and found that wild aurochs bones were also used for divination. These results are surprising because archaeologists working in China tend to assume that bovine oracle bones were only made from domestic cattle scapulas. Therefore, the zooarchaeological record of the Longshan period contains important data that contributes to our understanding of regional and temporal variation in divination practices associated with the emergence of early Chinese states.

Outline of the dissertation:

The three key issues for zooarchaeological research on the Longshan period discussed above are critical for understanding how the arrival of cattle and sheep influenced methods of animal exploitation in ancient China. I address these questions in my dissertation through a series of articles that present zooarchaeological data from the Longshan period sites of Taosi and Zhoujiazhuang.

In the first article, my co-authors and I compare the faunal assemblages at Taosi and Zhoujiazhuang. The data we present include numbers of identified specimens (NISP) and minimum number of individuals (MNI) for each taxon, kill-off patterns based on tooth eruption and wear for pigs, sheep, and cattle, and numbers of worked bone objects in the assemblages. We treat Taosi and Zhoujiazhuang as case studies for understanding how cattle and sheep were initially adopted in northern China. We find that people at Taosi may have specialized in new non-subsistence animal products such as wool, whereas people at Zhoujiazhuang seem to have diversified their animal management systems by taking advantage of a wider variety of both wild and domestic taxa. The article is reprinted from a version published in the *International Journal of Osteoarchaeology*. Since publication, I have conducted additional comparisons of taxonomic diversity between the sites using Simpson's index of diversity. I also calculated rarefaction curves to compare taxonomic richness at the sites. These calculations are included in Appendix 1, and confirm that the differences in taxonomic distributions observed at the two sites are statistically significant. The results suggest that non-subsistence animal products played an important role in the economic systems of emerging political centers.

In the second article, I discuss bone artifact production at Taosi and Zhoujiazhuang. I compare raw material selection, bone working techniques, and artifact types found at the two sites. Cattle and sheep bones were the primary raw material for bone working. However, at Zhoujiazhuang, people continued to make use of many wild animal osseous raw materials, suggesting that bone artisans did not always have access to preferred raw materials and that different sites specialized in the production of certain types of bone artifacts. I also compare bone working at Taosi and Zhoujiazhuang with the more fully developed bone working industries and oracle bone divination practices of later Bronze Age centers, suggesting that some important aspects of these later bone working traditions began during the Longshan period.

In the third article, my co-authors and I present the results of an ancient DNA analysis of the bovine oracle bones from Taosi and Zhoujiazhuang. We found that in addition to using domestic cattle scapulas for divination at both sites, people also used wild aurochs scapulas for divination at Zhoujiazhuang. This is the first evidence for the use of aurochs oracle bones in ancient China and is the first genetic analysis of Chinese aurochs from an archaeological context. The genetic identifications also demonstrate that it is not always possible to distinguish between aurochs and domestic cattle scapulas based on size and morphology alone. It is likely that wild bovines were used in divination at other sites—including later sites such as the Shang capital at Anyang where many bovine oracle bones have been found—but that these cases remain unrecognized. If people in ancient China used wild bovine scapulas to make oracle bones and if these artifacts were prepared with the same care as domestic cattle oracle bones, we will need to re-evaluate the importance given to the domestic status of cattle used in the divination rituals associated with the emergence of royal authority in early Chinese states. The presence of both wild aurochs and domestic cattle at the same site also raises some additional questions about the possibility for interbreeding between domestic cattle and aurochs, management of native aurochs populations, and a potentially slower rate of extinction for East Asian aurochs than previously assumed.

My research shows that sheep and cattle had an important role in the domestic animal economies of proto-state societies in ancient China. However, the work also demonstrates that there are many remaining puzzles and questions that must be addressed. First, zooarchaeologists still need more reliable ways to chronicle the arrival of non-native domestic taxa into China. Isotopic studies and genetic research is of great use in this endeavor. However, we also need to develop better criteria for distinguishing between the bones of domestic taxa and native wild animals in East Asia that have similar morphologies. Accurate identification is necessary for tracing the timings and routes of spread for various taxa such as cattle and sheep. Additionally, zooarchaeological data from more sites of different sizes and types, both rural and urban, is critical for understanding how animals and animal products were involved in processes of economic exchange and specialization. As additional data comes to light, zooarchaeologists will better understand why and how various taxa were adopted at sites across northern China and their impact on animal exploitation systems in complex societies.

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CHAPTER 2

Sheep, Cattle, and Specialization: New Zooarchaeological Perspectives on the Taosi Longshan

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Abstract:

In this paper, we present a zooarchaeological analysis of the Longshan period sites of Taosi and Zhoujiazhuang (ca. 2300-1900 cal. BC) in southern Shanxi Province, China. We compare the faunal record at both sites in terms of the proportions of wild and domestic taxa; the slaughter patterns for the main domesticates; the types of bones used to produce utilitarian and decorative bone artifacts; and the types of bones used for ritual oracle bone divination. Differences in the faunal records at Taosi and Zhoujiazhuang provide insights into the connections between specialization and early urbanism. Our research also provides clues about how sheep and cattle pastoralism was initially adopted in the Yellow River Valley during the late 3rd millennium BC.

Keywords:

Taosi; Zhoujiazhuang; Zooarchaeology; Chinese Archaeology; Shanxi Province; Wool; Wealth Animals; Oracle Bones

Introduction:

Zooarchaeological research in China has produced an exciting narrative about animal domestication that is characterized by both indigenous domestication events and the introduction of non-native domesticates through long-distance interactions (Flad et al. 2007; Yuan et al. 2007; Yuan 2010). In this paper, we focus on the introduction of sheep and cattle to the Middle Yellow River Valley during the terminal Late Neolithic. We examine the faunal record at the Longshan period sites of Taosi and Zhoujiazhuang (ca. 2300-1900 BC; He 2004), Shanxi Province (Figure 2.1). These are two of the earliest sites in China with evidence for extensive sheep and cattle herding. Taosi was also one of the most important population centers in China at that time. At its height between 2100-2000 BC, Taosi was almost equal in size to Erlitou (ca. 1850-1550 BC; Xu 2013), which is considered by many to be the first Chinese state (Liu and Chen 2003). Until now, zooarchaeological research on Late Neolithic and Bronze Age sites has focused on political centers like Taosi, either considering them in isolation or making diachronic comparisons with other well-known sites (e.g., Li et al. 2014a and 2014b; Lu et al. 2007; Yuan et al. 2007). By comparing the faunal records at Taosi and the contemporaneous but less politically complex site of Zhoujiazhuang, we can examine whether patterns in animal exploitation at Taosi were unusual developments associated with this unique site or part of broader regional trends.

Our findings add depth to research on the initial use of sheep and cattle in China. Sheep likely entered China through trade routes along the Hexi corridor ca. 2500 BC (Flad et al. 2007;

Yuan et al. 2007). Previous studies of sheep kill-off patterns at Taosi, Xinzhai, and Erlitou indicate that sheep were used for secondary products, possibly wool (Li et al. 2014a and 2014b). Later in the Bronze Age at the Shang capital at Anyang (ca. 1300-1040 BC), sheep kill-off patterns are more consistent with meat exploitation (Li 2012). However, the apparent shift from initial secondary product exploitation to later meat exploitation is based on only a few sites that are all large political and economic centers. When we include new data from Zhoujiazhuang, we must revise this narrative. Although Zhoujiazhuang was large, no elite burials or elite residential areas have been found yet. This suggests that it did not have the same level of social hierarchy as Taosi and other later political centers such as Erlitou. Sheep were not used for secondary products at Zhoujiazhuang. Therefore specialization in certain animal exploitation systems and animal crafts was not practiced throughout the entire Yellow River region and may have characterized only those large economic centers with greatest social stratification and centralization.

The nature of cattle exploitation during the Late Neolithic/Early Bronze Age is even less well understood. We know very little about how cattle were used between their introduction from West Asia ca. 3000 BC and their development into one of the most important animals for subsistence, bone working, and ritual during the Shang period (Campbell et al. 2011; Lu 2010; Yuan and Flad 2005; Yuan et al. 2007). Our research reveals that cattle were already important sources of bone raw materials for both utilitarian bone tool production and ritual oracle bone divination during the Longshan. We must now examine whether, like sheep, there were differences in how cattle were exploited at sites with different levels of political centralization and how cattle came to hold such an important place in Bronze Age economics and elite ritual practice.

In this paper, we compare the numbers of identified specimens (NISP), kill-off patterns for the main domesticates, raw material selection for bone artifact production, and ritual oracle bone divination at Taosi and Zhoujiazhuang. We argue that people at Taosi specialized in the production of numerous craft goods including secondary animal products like wool. People at Taosi also focused on a limited set of domestic animals for subsistence and as a source of raw materials for making bone tools. At Zhoujiazhuang, people used a more diverse set of animal taxa and did not specialize in non-meat domestic animal products. Our findings add depth to the narrative of animal domestication in China, showing that the initial ways that sheep and cattle were used were closely tied to site-specific social and economic conditions.

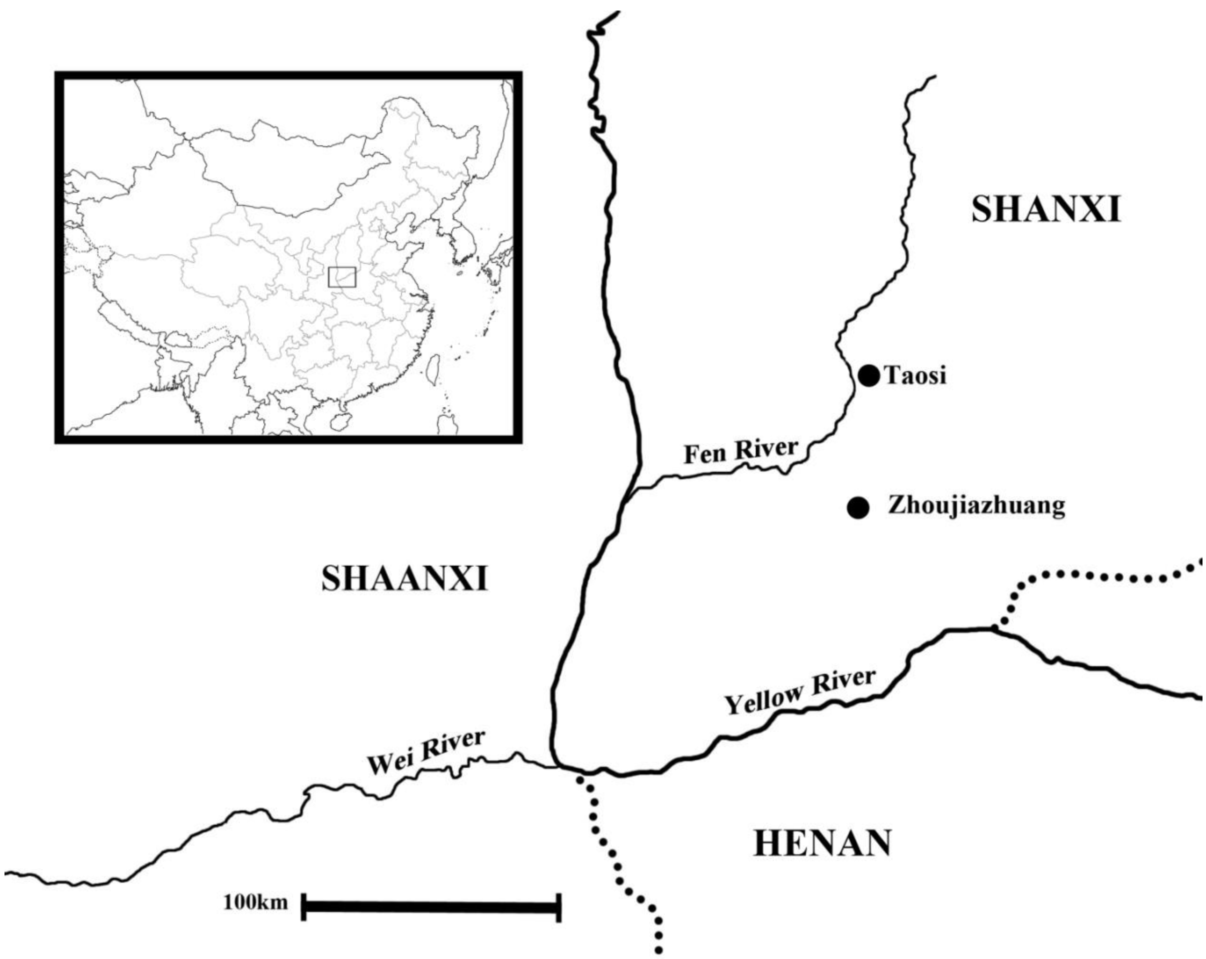


Figure 2.1. Location of Taosi and Zhoujiazhuang

Background:

Taosi was a large urban site located in the Linfen Basin in Xiangfen County (N 35°52′55.90″, E 111°29′54.89″). Pollen and charcoal analysis reveals that the ancient environment around Taosi was a warm and wet temperate zone with mixed coniferous and deciduous forests (Kong and Du 1992; Wang et al. 2011). Analysis of paleobotanical remains from the site reveals that intensive agriculture was taking place focusing on foxtail millet (*Setaria italica*) (Zhao and He 2006).

The early occupation period at Taosi (2300-2100 BC) is under-studied. However, we know that people began building a cemetery in the southeastern quadrant of the city and a large palace in the northeastern quadrant that was surrounded by a rammed earth enclosure (He 2013, 261-264). During the middle occupation phase (2100-2000 BC), Taosi expanded and a rammed earth wall was built around the site's perimeter, enclosing an area of about $3km^2$. The middle period site shows evidence for city planning around a central axis with spatially separated zones for elite residences, elite ritual activities, craft production, and lower class residences. The northeastern quadrant of the city continued to be occupied by elites and an expanded palace was built on top of the early period palace. Large storage pits have also been found in the northeastern quadrant, including one pit with a room at the pit entrance where a guard may have been stationed. This suggests that the city's food supplies were controlled and regulated. The southeastern quadrant of the middle period city contained an enclosure built around a large cemetery and solar observatory structure. The restricted access to the observatory suggests that certain ritual activities were only witnessed by elites or royalty (He 2013, 264-269).

Although nearby sites supplied some craft goods to Taosi, large-scale craft production also took place at Taosi itself. A middle and late period craft production zone for stone tools has been identified in the city's southwestern quadrant (He 2013, 268-269; Zhai 2012). Analysis of lithic production debris from this area reveals that Taosi may have monopolized control over raw materials from the nearby Mount Dagudui quarry and traded these crafts with smaller regional centers where only finished artifacts have been found (Liu et al. 2013; Zhai 2012). Excavations of a rectangular house feature uncovered many stone flakes and showed that the house was connected to an activity area by a pathway, suggesting that lithic production still took place at the household level (Liu et al. 2013: 284-286; Zhai 2012: 54-70; Zhai et al. 2013). However, an unusual structure (middle period FJT2) with a courtyard and rammed earth foundations covering an area of over 1300 m^2 was found nearby and has been interpreted as a managerial building, suggesting that craft production was centrally controlled to some degree at least during the middle Taosi period (Zhongguo and Shanxi 2015).

The late occupation phase at Taosi (2000-1900 BC) was a period of social unrest. Early and middle period elite burials were looted, sections of the city wall were leveled, the palace and observatory were destroyed, and numerous skeletons show evidence of violent death. The site was no longer carefully organized according to activity zones or social status. Instead, commoners' residential areas were spread across the entire site, including areas that were formerly only occupied by elites (He 2013, 269-270).

The upheaval at Taosi corresponds to the growth of several nearby regional centers including Zhoujiazhuang, located 40km away in the Yuncheng Basin in Jiangxian County (N 35°29′10.59″, E 111°28′12.98″). Zhoujiazhuang reached its maximum size of over 2 km^2 during the late Taosi period, and the ceramics and material culture at Zhoujiazhuang are very similar to Taosi (Drennan and Dai 2010). Over the past few years, research at Zhoujiazhuang has focused on lower class residential areas. The most exciting findings at Zhoujiazhuang include a large moat surrounding the site and a cemetery with numerous infant urn burials. We have not yet found royal burials, palaces, or dedicated ritual locations at Zhoujiazhuang like those at Taosi. Craft production also seems to have been organized in kin-group residential units. Although Zhoujiazhuang was the largest site in the Yuncheng basin, it did not reach the same level of complexity as middle period Taosi.

Methods:

The Taosi faunal materials were excavated in 2010 and 2013 and date to all three occupation periods (Table 2.1). A small number of remains from the early and middle periods are associated with upper class residential areas and the palace. However, most of the Taosi materials date to the late occupation phase. These late period materials were found in pits or wall fill that represent midden deposits associated with lower class residential areas. Due to the small sample size for the current study, we have also included NISP data from previous studies by Brunson (2008) and Tao (2007). Our demographic analyses also include data from Brunson (2008). All materials were collected by hand without screening.

The Zhoujiazhuang materials were excavated from 2007 to 2013. Most remains come from midden pits and ditches, although a small number of bones come from house features, burial fill, and other deposits from lower class residential areas. One large pit, H354, contained an unusually large number of faunal remains (discussed below), including many worked bone artifacts. The pit also contained many ceramic and stone artifacts. Two human skeletons were found at the top of H354, suggesting that it was a sacrificial pit.

Preliminary ceramic analysis dates all of the Zhoujiazhuang materials to the late Taosi period. Some dry screening using 1cm x 1cm mesh screens was done during the 2013 field

Table 2.1.
Context Descriptions for Taosi (TS) and Zhoujiazhuang (ZJZ)

	CONTEXT TYPE	DESCRIPTION	NUMBER OF CONTEXTS	NISP
TS: Early Period	Midden pits:	Midden pit within a pond feature that destroyed palace enclosure wall Q10*.	1	6
		Midden deposits associated with the destruction of a palace storage pit*.	1	10
	Wall fill:	Deposits from the foundation of palace enclosure wall Q16 II*.	1	7
	NA	Uncertain.	1	1
TS: Middle Period	Midden pits:	Midden deposits associated with the palace*.	1	1
		Midden deposits associated with the pond feature near the palace*.	3	25
	Wall fill:	Deposits from the foundation of palace enclosure wall Q15 II*.	2	111
		Deposits from the foundation of Taosi outer enclosure wall Q4 II*.	1	81
	Palace kitchen:	Stove pit in palace kitchen area*.	10	24
TS: Late Period	Burial fill:	Mixed fill from low status burials.	2	13
	Destruction layer:	Destruction layers covering Taosi outer enclosure wall Q4 I.	2	39
		Destruction layers covering the former palace kitchen area.	4	55
		Destruction layers covering palace enclosure wall Q15 I.	2	29
	House feature:	Fill from semi-subterranean pit house.	1	5
	Midden:	Garbage-filled ditch.	1	4
	Midden pits:	Garbage-filled pits formed from harvesting clay.	14	321
		Garbage-filled storage pits.	5	52
	Pond feature:	Silt layers in pond feature.	2	8
	Wall fill:	Deposits associated with the foundation of palace enclosure wall Q15 I.	1	23
		Deposits associated with the foundation of outer enclosure wall Q4 II.	1	30
		Deposits associated with the foundation of palace enclosure wall Q16 I	1	108
ZJZ: Late Taosi Period	Burial fill:	Mixed fill from low status burials	3	8
	General fill layers:	Mixed fill deposits.	35	216
	House features:	Fill from semi-subterranean pit houses.	19	134
	Kiln features:	Deposits associated with kiln features.	2	4
	Middens:	Ditches/trenches filled with midden deposits.	21	386
	Midden pits:	Midden pits primarily associated with residential areas.	204	3293
	Sacrificial pit:	Pit (H354) filled with numerous ceramic, stone, and worked bone artifacts. Two human sacrifices found at top of pit.	7	281

The “*” indicates likely elite contexts. Zhoujiazhuang sacrificial pit H354 was found in a low-status residential area, but represents a single event. All other contexts likely represent quotidian deposits from low-status people’s daily activities season, but only 12 out of the 291 contexts from Zhoujiazhuang were screened completely. Screening using smaller screen mesh sizes can greatly increase the numbers of small animal bones recovered from archaeological sites (Casteel 1972; Gordon 1993; James 1997; Lyman 2012; Nagaoka 2005; Peres 2010; Quitmyer 2004; Shaffer 1992; Shaffer and Sanchez 1994; Stahl 1996; Thomas 1969). In the future, it will be important to apply a consistent screening method using smaller mesh sizes in order to recover more small mammal and non-mammal remains.

Species identifications were made using standard guides and comparative collections at the Zooarchaeology Laboratory at IA, CASS in Beijing. Masaki Eda from the Hokkaido University Museum helped identify bird bones. Ribs, vertebrae, and unidentified long bone shaft fragments were only identified to size categories such as small, medium, or large mammal. We do not include these specimens in the present study. Statistical comparisons were performed using the program STATA.

We did not identify any goat bones, but it is possible that goats entered China by the Taosi period since goats are present at Erlitou ca. 1700 BC (Yuan 2010). We classified bones as *Ovis aries*/*Capra hircus* when we could not definitively identify them as sheep. Wild bovids including argali (*Ovis ammon*), blue sheep (*Pseudois nayaur*), and gazelle (*Gazella*) are also found in north China. When we could not definitively identify a specimen as *Ovis*/*Capra*, we identified it as a “medium bovid” even though most of these specimens are likely fragmented sheep bones. We treat all *Ovis*/*Capra* and medium bovid bones as domestic sheep in our analyses.

To date, no water buffalo have been identified at Taosi, although water buffalo bones have been found at other Longshan sites (Liu et al. 2001). We also identified water buffalo bones at Zhoujiazhuang. Ancient DNA research on Chinese water buffalo from the Longshan and post-

Longshan period has identified a now-extinct species, *Bubalus mephistopheles*, that did not contribute genetically to modern domestic water buffalo (Yang et al. 2008). We classify the Zhoujiazhuang water buffalo as this wild species.

We recently completed an ancient DNA study of bovine oracle bones from Taosi and Zhoujiazhuang and found that some of the large bovines at Zhoujiazhuang are in fact wild aurochs (*Bos primigenius*), not domestic cattle (*Bos taurus*). Therefore, it is possible that additional wild aurochs specimens are present in the assemblages. Because the bones of domestic *Bos*, wild *Bos*, and wild *Bubalus* are morphologically similar, most bones were conservatively identified as "large bovines." It is likely that most of these specimens and the specimens identified as *Bos* sp. are domestic cattle and we treat them as cattle in our analyses. Only the specimens identified using ancient DNA are listed as *Bos primigenius* and *Bos taurus*.

Results:

Species present:

Domesticates are the most frequently occurring taxa at both sites (Table 2.2). We discuss pig, sheep, and cattle exploitation in the next sections. Here, we briefly describe the other identified taxa.

Dogs are the fourth most common domestic animals at both sites. In Table 2.2, dogs appear to make up a larger percentage of the Taosi assemblage. However, this is due to quantification methods used by Tao (2007). His NISP counts include elements from complete articulating dog skeletons. Brunson (2008) and our current study counted articulating dog elements only once. Using this method for calculating NISP, dogs make up about 4-6% of both assemblages. During our analysis, we observed that most dog bones belonged to nearly complete or partially articulating skeletons. Butchery marks on dog bones were rare. Dog skeletons also represented both very young and very old individuals, often with severe pathologies. For these reasons, we believe that people generally did not eat dogs at either site. Instead, dogs may have been pets or guard animals that were frequently buried whole in midden pits.

Other possible domestic animals include cats, small rodents, and chickens. We identified an articulating radius and ulna from a single small felid at Taosi; however, the morphologies of post-cranial elements are similar for wild and domestic cats. Hu et al. (2014) recently used isotopic data to argue that domesticated cats were present in China by the Middle Neolithic, but their conclusions are controversial (Bar-Oz et al. 2014). For now we will consider the Taosi cat as wild. We did not identify small rodents to species due to a lack of comparative materials. We have not found evidence that rodents were butchered or eaten, so we group them with the wild taxa. These rodents may be intrusive. Finally, bird bones belonging to the Phasianidae family were identified at both sites. The elements cannot be identified as wild pheasants, red junglefowl, or domestic chickens based on morphology. Currently, the earliest definitive evidence for domestic chickens in China dates to the Shang Dynasty (Deng et al. 2013). To be conservative we assume all Phasianidae bones represent wild birds.

The wild taxa at Taosi suggest that limited hunting took place and that it focused on small game and deer. Non-mammals only make up 1.36% of the assemblage and wild mammals make up 5.26% of the assemblage. Wild animals include deer (cervids), bear (*Ursus*), fox (*Vulpes*), raccoon dog (*Nyctereutes procyonides*), badger (*Meles*), unidentified carnivores, hare (*Lepus*), porcupine (*Hystrix*), bamboo rat (Rhyzomidae), pheasants or jungle fowl (Phasianidae), small and medium sized perching birds (Passeriformes), large birds of prey (Accipitridae) that appear similar to golden eagle (*Aquila chrysaetos*), unidentified birds, unidentified fish, and mollusks.

Most deer are sika deer (*Cervus nippon*), although some roe deer (*Capreolus*) and unidentified large cervids were identified as well.

At Zhoujiazhuang, people took advantage of a larger number and a more heterogeneous set of wild fauna. Whereas cervids make up only 2.14% of the Taosi assemblage, they make up 10.39% of the Zhoujiazhuang assemblage. Moreover, Zhoujiazhuang has a greater variety of deer taxa including roe deer, sika deer, red deer (*Cervus elaphus*), and Père David's deer (*Elaphurus davidianus*). Other wild animals include water buffalo, aurochs, bear, raccoon dog, badger, small carnivores, porcupine, hare, bamboo rat, small rodents, birds in the Accipitridae and Passeriformes families, and fish. Zhoujiazhuang also has a large number of mollusks, especially *Unio douglasiae* (gray), which were often perforated for use as ornaments. Sacrificial pit H354 contained an especially large number of fauna including *Unio douglasiae* (gray) (NISP=1), Unidentified Fish (NISP=3), Phasianidae (NISP=2), Large Birds (NISP=3), Accipitridae (NISP=2), Small Rodents (NISP=6), *Hystrix* (NISP=1), *Lepus* (NISP=2), Small Carnivores (NISP=1), Cervids (NISP=74), Medium or Large Cervids (NISP=4), Medium Cervids (NISP=1), *Cervus nippon* (NISP=9), *Canis* (NISP=9), Large Bovids or Cervids (NISP=2), Large Bovids (NISP=10), *Ovis* (NISP=22), *Ovis*/*Capra* (NISP=24), Medium Bovids (NISP=3), and *Sus* (NISP=102). Out of these specimens, 145 were worked into semi-finished or finished artifacts.

Chi square tests comparing the number of wild and domestic taxa at Taosi and Zhoujiazhuang show that the sites are statistically different ($\chi^2 = 797.75$, $p < 0.001$, df = 1). The natural environment around Zhoujiazhuang may have supported more wild animals, especially because Zhoujiazhuang is located near forested mountains. Additionally, Taosi’s larger size and longer occupation history may have caused more severe over-hunting and resource depression.

However, we also think that the difference in taxonomic diversity reflects varying degrees of specialization in craft production and the domestic animal economy at the two sites.

Pigs:

Pigs account for 52.43% of animals at Taosi and 30.80% of animals at Zhoujiazhuang. The larger pig NISP at Taosi is largely due to sampling bias. The Taosi materials date to all three occupation periods whereas the Zhoujiazhuang materials only date to the late Taosi period when sheep became an increasingly important domesticate. Tao (2007) also included several complete pig skeletons in his NISP counts, which artificially inflates the Taosi pig NISP.

Isotopic studies of Taosi fauna indicate that pigs ate primarily C4 foods and had nitrogen levels consistent with an omnivorous diet, suggesting that they were either foddered with millet agricultural products and/or ate human food refuse and feces (Chen et al. 2012). Lack of variability in $^{87}Sr/^{86}Sr$ ratios in pig teeth indicate that pigs were raised locally (Zhao et al. 2011).

To further examine how people raised pigs at Taosi and Zhoujiazhuang, we constructed age profiles using tooth eruption and wear patterns following Lemoine et al. (2014). We only included left molars or left mandibles containing at least one molar or two premolars. When a specimen fell between two age stages we divided it equally between them, resulting in fractions in the frequency counts.

Kill-off patterns and survivorship curves for pigs at both sites are shown in Figure 2.2. Chi square tests comparing the frequency counts at each age stage (fractions rounded to the nearest whole number) indicate that the age distributions are statistically similar ($\chi^2 = 3.796$, $p = 0.704$, df = 6). We also performed Fisher's exact tests due to the low frequency counts in each

Table 2.2.
NISP and MNI Counts for Taosi and Zhoujiazhuang

	TAOSI									**ZHOUJIAZHUANG**		
	Current Study		Tao (2007)		Brunson (2008)		TOTAL					
TAXON	NISP	MNI	NISP	MNI	NISP	MNI	NISP	MNI	%NISP	NISP	MNI	% NISP
WILD NON-MAMMAL :												
Mollusca	1	1	6	n/a	1	1	8	2	0.14	5	1	0.12
Bivalvia	1	1	0	0	0	0	1	1	0.02	2	2	0.05
Lamprotula	0	0	0	0	0	0	0	0	0.00	2	2	0.05
Lamellibranchia	0	0	0	0	1	1	1	1	0.02	0	0	0.00
Margaritiana sp.	0	0	0	0	0	0	0	0	0.00	2	1	0.05
Unionodae	0	0	0	0	0	0	0	0	0.00	86	1	1.99
Unio douglasiae (gray)	1	1	0	0	0	0	1	1	0.02	215	66	4.97
Unid. Fish	0	0	0	0	3	1	3	1	0.05	5	1	0.12
Cyprinidae	0	0	0	0	0	0	0	0	0.00	1	1	0.02
Large Bird	3	1	0	0	0	0	3	1	0.05	5	1	0.12
Accipitridae	3	2	0	0	0	0	3	2	0.05	2	1	0.05
Medium Bird	2	2	0	0	0	0	2	2	0.04	4	1	0.09
Phasianidae	3	2	0	0	5	1	8	3	0.14	8	3	0.19
Passeriformes	1	1	0	0	0	0	1	1	0.02	2	1	0.05
Unid. Bird	0	0	42	n/a	3	1	45	1	0.81	1	1	0.02
TOTAL WILD NON-MAMMAL:	15	11	48	n/a	13	5	76	16	1.36	340	83	7.87
WILD MAMMAL :												
Small Rodent	8	2	2	2	9	3	19	7	0.34	123	22	2.85
Rhizomyidae	1	1	0	0	0	0	1	1	0.02	1	1	0.02
Hystrix sp.	0	0	0	0	1	1	1	1	0.02	2	1	0.05

Lagomorpha	1	1	0	0	0	0	1	1	0.02	0	0	0.00
Lepus sp.	10	4	21	4	19	4	50	12	0.90	44	4	1.02
Small Carnivore	3	1	4	2	10	6	17	9	0.31	6	1	0.14
Meles sp.	0	0	0	0	0	0	0	0	0.00	1	1	0.02
Felis sp.	2	1	0	0	0	0	2	1	0.04	0	0	0.00
Canidae	2	1	0	0	3	2	5	3	0.09	12	1	0.28
Nyctereutes procyonides	0	0	0	0	0	0	0	0	0.00	2	1	0.05
Vulpes sp.	3	1	0	0	0	0	3	1	0.05	0	0	0.00
Medium Carnivore	0	0	1	1	0	0	1	1	0.02	0	0	0.00
Large Carnivore	2	1	0	0	3	2	5	3	0.09	0	0	0.00
Ursus sp.	3	2	2	2	0	0	5	4	0.09	3	1	0.07
Cervidae	7	2	0	0	0	0	7	2	0.13	169	2	3.91
Large Cervid	0	0	3	2	6	2	9	4	0.16	1	1	0.02
Cervus elaphus	0	0	0	0	0	0	0	0	0.00	1	1	0.02
Elaphurus davidianus	0	0	0	0	0	0	0	0	0.00	3	1	0.07
Medium or Large Cervid	2	2	0	0	4	2	6	4	0.11	55	1	1.27
Medium Cervid	12	4	0	0	19	5	31	9	0.56	144	8	3.33
Cervus nippon	9	2	44	6	0	0	53	8	0.95	62	3	1.43
Small Cervid	0	0	0	0	10	3	10	3	0.18	9	2	0.21
Capreolus sp.	0	0	3	1	0	0	3	1	0.05	5	1	0.12
Medium Bovid or Cervid	13	2	0	0	43	6	56	8	1.00	148	5	3.42
Large Bovine or Cervid	8	2	0	0	0	0	9	2	0.14	49	2	1.13
Bos primigenius	0	0	0	0	0	0	0	0	0.00	3	2	0.07
Bubalus sp.	0	0	0	0	0	0	0	0	0.00	5	1	0.12
TOTAL WILD MAMMAL:	86	29	80	20	127	36	293	85	5.26	848	63	19.62
DOMESTIC MAMMAL:												

Canis familiaris	51	7	752	45	41	10	844	62	15.14	188	13	4.35
Large Bovine	141	6	0	0	88	15	229	18	4.11	317	7	7.33
Bos sp.	7	2	220	9	35	7	262	18	4.70	27	4	0.62
Bos taurus	4	1	0	0	0	0	4	1	0.07	6	1	0.14
Bovidae	1	1	0	0	0	0	1	1	0.02	0	0	0.00
Medium Bovid	34	5	0	0	4	1	38	6	0.68	305	8	7.06
Ovis aries	91	19	542	35	178	28	811	82	14.55	471	71	10.90
Ovis aries/*Capra hircus*	93	6	0	0	0	0	93	6	1.67	489	19	11.31
Sus domesticus	430	28	1843	132	649	61	2922	224	52.43	1331	75	30.80
TOTAL DOMESTIC MAMMAL:	852	75	3357	221	995	122	5204	418	93.38	3134	197	72.51
TOTAL NISP							**5573**			**4322**		

NISP = number of identified specimens
MNI= minimum number of individuals
Taosi: Current Study: Early Period NISP=24; Middle Period NISP=242; Late Period NISP=687; Tao (2007): Early Period NISP=85; Middle Period NISP= 302; Late Period NISP=3098; Brunson (2008): Early Period NISP=24; Middle Period NISP=602; Late Period NISP=509.
Zhoujiazhuang: All materials date to the Late Taosi Period.

age category, confirming that the distributions are similar (Fisher's exact $p = 0.693$). At both sites, there is a large kill-off between Stage B (3-8 months) and Stage C (8-12 months). Pigs reach full size at about one year old. The evidence for heavy culling before 1 year of age suggests that people slaughtered animals to optimize meat yields. This pattern is consistent with pig culling practices throughout the Chinese Neolithic (Luo 2012).

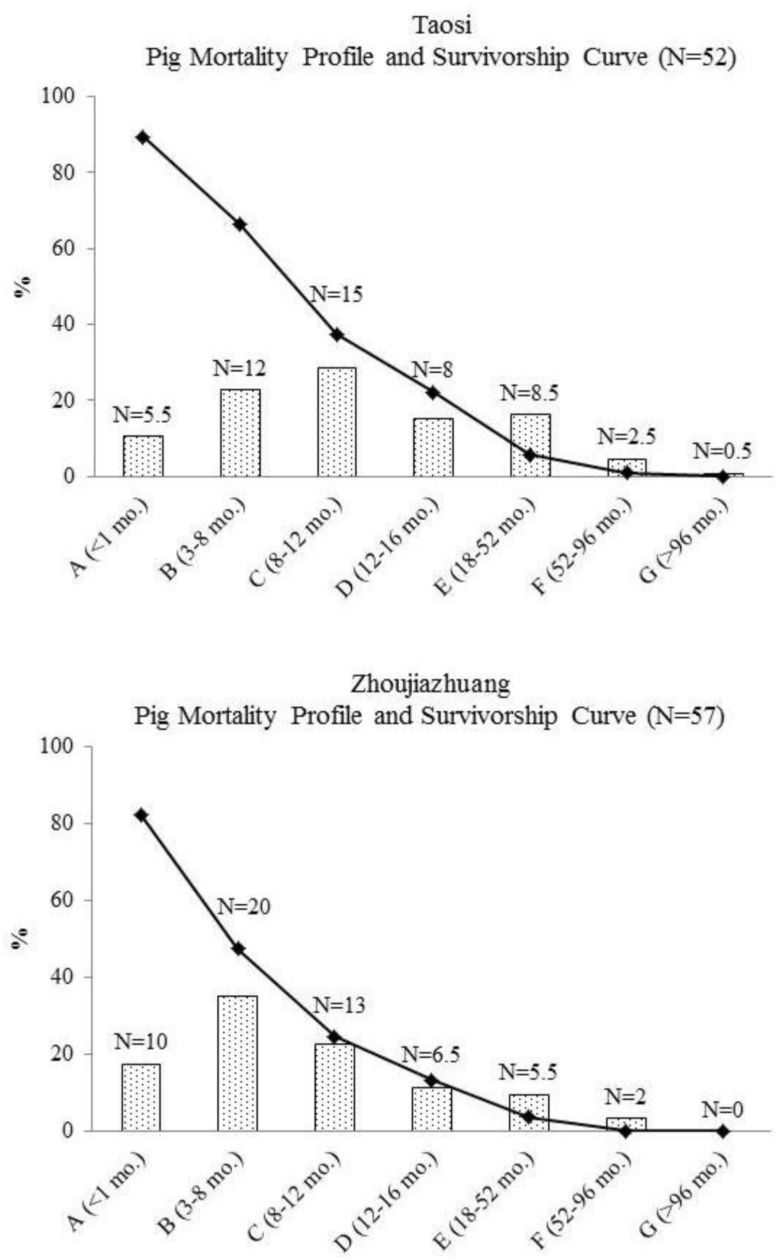


Figure 2.2. Pig age profiles according to the Simplified-A system in Lemoine et al. (2014).

Sheep:

Sheep account for 16.90% of animals at Taosi and 29.27% of animals at Zhoujiazhuang. The smaller number of sheep bones at Taosi is primarily due to contextual biases since the Taosi materials date to all three time periods and the Zhoujiazhuang materials only date to the late period. Tao (2007) and Brunson (2008) identified a sudden increase in the number of sheep bones at Taosi between the middle and late periods, with sheep and pigs being almost equal in frequency during the late period. It seems as though the growing importance of sheep herding during the late Taosi period was not unique to Taosi, but rather part of a regional change that also reached Zhoujiazhuang.

Isotopic studies indicate that sheep at Taosi ate primarily C3 foods, suggesting that they grazed on wild grasses rather than being foddered or grazing on millet stalks in agricultural fields (Chen et al. 2012). Strontium isotopes indicate that some sheep were non-local (Zhao et al. 2011).

To further understand how sheep were used at Taosi and Zhoujiazhuang, we constructed kill-off patterns using tooth age data following Payne (1973 and 1987) and Zeder (2006). Only left mandibles were included. When a specimen fell between age groups it was divided equally between them. Following Vigne and Helmer (2007), we corrected for unequal time scales between age stages by multiplying the raw frequencies by 1/p, where p is the probability that a specimen would fall into an age group given that 1 year = 1.0 (Table 2.3).

The uncorrected survivorship percentages for Taosi are similar to those expected for wool exploitation where many individuals survive to full adulthood (Payne 1973). When corrected for time, the Taosi data suggest that sheep were used for both meat and wool. The scaled histogram (Figure 2.3) is similar to Vigne and Helmer's (2007, Figure 5) example of a wool exploitation pattern with some meat exploitation. There is a large kill-off at Stage C (6 months-1year) followed by a gradual kill-off of older animals. Some young individuals (probably mostly males) were killed once they reached full size to optimize meat yield. Other animals (probably mostly females) were kept alive as breeders and for wool production. Most female ewes stop breeding at around 7 years old. The large kill-off at 6-8 years may represent the slaughter of older females who are no longer reproductively viable.

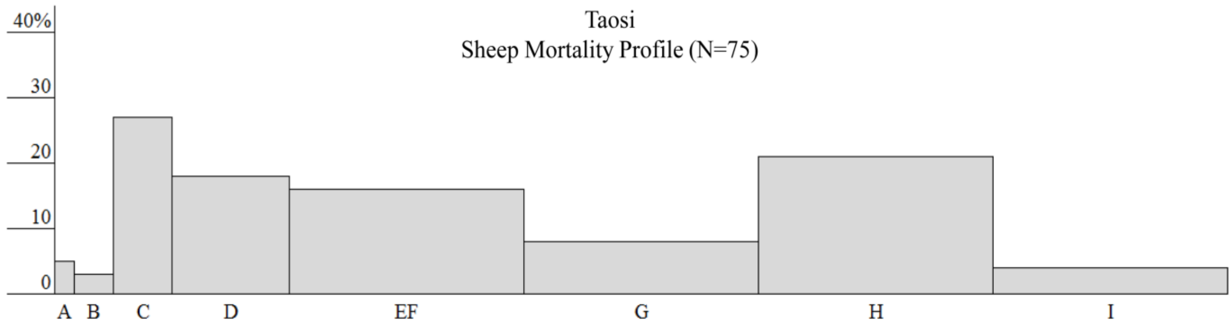
Kill-off patterns for sheep at Zhoujiazhuang are different. The uncorrected survivorship percentages are consistent with Payne's (1973) model for meat exploitation where most individuals are killed at younger ages. When corrected for time, it is clear that a large kill-off took place at Stage C (6 months- 1 year) and Stage D (1-2 years) (Figure 2.3). The histogram falls between Vigne and Helmer's (2007, Figure 5) models for tender and non-tender meat. As was the case at Taosi, very few animals were killed in Stages A or B, suggesting that sheep were not raised for milk at either site.

Chi square tests comparing the corrected age frequency distributions show that the sites are different ($\chi^2 = 15.487$; $p = 0.030$; df = 7; Fisher's exact $p = 0.028$). If we exclude age stages A, B, and I because they contain small NISP counts, we find that the corrected distributions are not statistically different ($\chi^2 = 6.926$, $p = 0.140$, df = 4; Fisher's exact $p = 0.141$). The p value is still low, suggesting that a larger sample size would help clarify the statistics. At this point we believe that the age distributions are different enough to support our argument that sheep were raised in different ways at the two sites.

We also analyzed sheep long bone fusion (Table 2.4). The results are inconsistent with the tooth age data. Epiphyseal fusion may over-estimate the numbers of older age individuals when compared to tooth eruption and wear due to taphonomic biases (Lam et al. 2009). Our observations of skeletal element survivorship suggest that both assemblages were subject to density mediated attrition, so we believe that the tooth age data is more accurate.

Table 2.3.
Sheep Tooth Eruption and Wear Stages Following Payne (1973 and 1987), Zeder (2006), and Vigne and Helmer (2007)

	A (0-2 mo.)	B (2-6 mo.)	C (6 mo. - 1 yr.)	D (1-2 yr.)	EF (2-4 yr.)	G (4-6 yr.)	H (6-8 yr.)	I (8-10+ yr.)	TOTAL
TAOSI									
Frequency	0.5	0.5	8.0	10.2	18.3	9.0	24.0	4.5	75.0
%	0.7	0.7	10.7	13.6	24.4	12.0	32.0	6.0	100.0
% Surviving	99.3	98.7	88.0	74.4	50.0	38.0	6.0	0.0	
Probability (p)	0.2	0.3	0.5	1.0	2.0	2.0	2.0	2.0	
1/p Correction	6.0	3.0	2.0	1.0	0.5	0.5	0.5	0.5	
Corrected Frequency	3.0	1.5	16.0	10.2	9.2	4.5	12.0	2.3	58.6
Corrected %	5.1	2.6	27.3	17.4	15.6	7.7	20.5	3.8	100.0
Corrected % Surviving	94.9	92.3	65.0	47.7	32.0	24.3	3.8	0.0	
ZHOUJIAZHUANG									
Frequency	0.0	2.8	9.7	18.5	17.7	12.0	8.5	0.8	70.0
%	0.0	4.0	13.9	26.4	25.3	17.1	12.1	1.1	100.0
% Surviving	100.0	96.0	82.1	55.7	30.4	13.3	1.1	0.0	
Probability (p)	0.2	0.3	0.5	1.0	2.0	2.0	2.0	2.0	
1/p Correction	6.0	3.0	2.0	1.0	0.5	0.5	0.5	0.5	
Corrected Frequency	0.0	8.4	19.4	18.5	8.9	6.0	4.3	0.4	65.8
Corrected %	0.0	12.8	29.5	28.1	13.4	9.1	6.5	0.6	100.0
Corrected % Surviving	100.0	87.2	57.8	29.6	16.2	7.1	0.6	0.0	



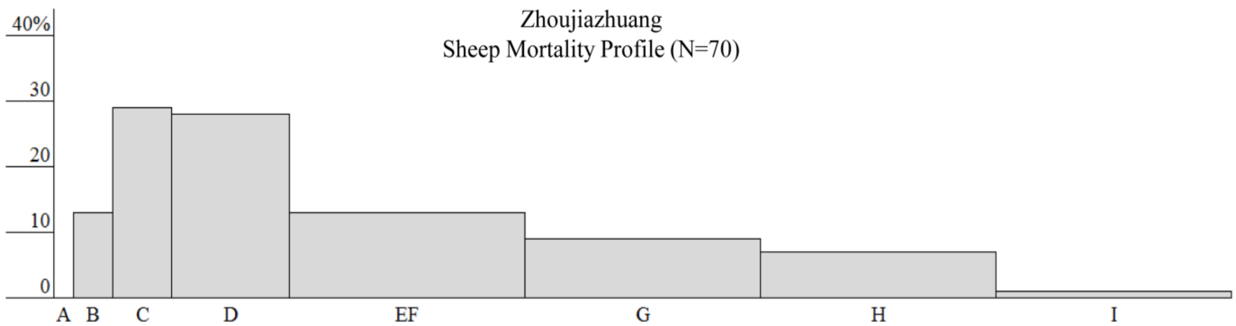


Figure 2.3. Weighted (corrected) histograms showing sheep mortality. A=0-2 months; B=2-6 months; C=6 months-1 year; D=1-2 years; EF=2-4 years; G=4-6 years; H=6-8 years; I=8-10+ years.

Table 2.4.
Sheep Long Bone Epiphyseal Fusion

	Taosi						**Zhoujiazhuang**					
	A	B	C	D	E	F	A	B	C	D	E	F
No. Fused+Fusing	17	43	11	36	21	2	26	75	33	105	31	0
No. Unfused	0	2	0	8	8	0	0	2	7	16	11	0
TOTAL NISP	17	45	11	44	29	2	26	77	40	121	42	0
% Fused+Fusing	100.0	95.6	100.0	81.8	72.4	100.0	100.0	97.4	82.5	86.8	73.8	0.0
% Unfused	0.0	4.4	0.0	18.2	27.6	0.0	0.0	2.6	17.5	13.2	26.2	0.0

Age Stages and Bones Fusing (Zeder 2006):
A (ca. 0-6 mo.): proximal radius
B (ca. 6-12 mo.): distal humerus; pelvis (acetabulum); distal scapula
C (ca. 12-18 mo.): proximal 1st phalanx; proximal 2nd phalanx
D (ca. 18-30 mo.): distal tibia; distal metapodials
E (ca. 30-48 mo.): calcaneus; proximal and distal femur; proximal ulna; distal radius; proximal tibia
F (over 48 mo.): proximal humerus

Cattle:

Cattle make up 8.88% of the Taosi assemblage and 8.09% of the Zhoujiazhuang assemblage. Isotopic studies at Taosi indicate that cattle were eating a mixture of C3 and C4 plants, suggesting that they were either foddered with some agricultural by-products like millet stalks or grazed on millet stalks in agricultural fields (Chen et al. 2012). Strontium isotopes indicate a mix of local and non-local animals (Zhao et al. 2011).

The small sample size makes it difficult to analyze cattle demographics. Age estimates for lower loose teeth and mandibles (Table 2.5) only allow for a few general observations. All of the teeth are from adult individuals over 2 years of age. Several teeth are heavily worn, which suggests that many cattle survived to advanced ages. Epiphyseal fusion data also suggest that most large bovines survived to adulthood (Table 2.6). The fusion data have the same taphonomic biases as those discussed for sheep. However, because both the dental and fusion data confirm the absence of very young individuals, we believe that milk production was not a main goal of cattle exploitation at either site. The apparent preference for adult individuals could mean that cattle were used as draught or transportation animals, although we did not identify pathologies on metapodials or phalanges that would be expected from intensive draught activities. Instead, we believe that cattle were kept primarily as wealth animals at both sites.

Table 2.5.
Large Bovine Tooth Ages

ID#	Element	Teeth Present	Wear (Grant 1982)	Age (Grigson 1982)
TAOSI				
T-106	LT	M2	J	Over 18-24 mo.
08-T-295	LT	M2	J	Over 18-24 mo.
08-T-595	LT	M2	J	Over 18-24 mo.
T-1147	M	alv. for P2 and P3		Over 36 mo.
T-173	M	alv. for P2, P3, and P4		Over 40 mo.
08-T-1381	LT	M3	G	Over 40 mo.
08-T-774	LT	M3	K	Over 40 mo.
T-561	LT	P4	E	ca. 50 mo.
ZHOUJIAZHUANG				
Z-3740	M	dp4	K	Under 36 mo.
Z-3891	M	dp2, dp4, alv. for dp3	dp4: g	Under 36 mo.
Z-5734	M	alv. for dp4 and M1		Over 7-9 mo. and under 36 mo.
Z-713	M	dp4, M1	dp4: g; M1:c-d	Over 8-13 mo. and under 36 mo.
Z-2652	M	dp2, dp3, dp4, M1, M2	dp4: n; M1: g; M2: d	Over 18-24 mo. and under 36 mo.
Z-2199	M	M1	J	Over 8-13 mo. (likely over 24 mo.; heavy wear)
Z-2079	M	M1	K	Over 8-13 mo. (likely over 24 mo.; heavy wear)
Z-1111	M	M1, M2	M1 broken; M2: b-c	Over 18-24 mo.
Z-827	M	P2		Over 32-33 mo.
Z-2840	M	alv. for P2, P3		Over 32-33 mo.
Z-4178	M	alv. for P2, P3		Over 32-33 mo.
Z-3518	M	alv. for P3, P4		Over 36 mo.
Z-3455	M	P2, P3, P4, M1	P4: c; M1 broken	Over 40-50 mo.
Z-2986	M	P2, P3, P4, M1, M2	P4: h; M1: l; M2: k	Over 50 mo.
Z-4869	LT	M1	Broken	Over 5-6 mo.
Z-3887	LT	M1	b-c	Over 8-13 mo.
Z-5080	LT	M1	K	Over 8-13 mo.
Z-1723	LT	M2	C	Over 18-24 mo.
Z-2570	LT	M2	C	Over 18-24 mo.
Z-2080	LT	M2	c-d	Over 18-24 mo.
Z-1135	LT	M2	D	Over 18-24 mo.
Z-1906	LT	M2	G	Over 18-24 mo.
Z-3700	LT	M2	E	Over 18-24 mo.
Z-1045	LT	M3	B	ca. 30-32 mo.
Z-4927	LT	M3	B	ca. 30-32 mo.
Z-2167	LT	M3	J	Over 40 mo.
Z-579	LT	M3	K	Over 40 mo.
Z-1136	LT	M3	K	Over 40 mo.
Z-1180	LT	P4	E	ca. 50 mo.

LT=loose tooth; M=mandible; alv. = alveolus only

Table 2.6.
Large Bovine Long Bone Epiphyseal Fusion

	Taosi					Zhoujiazhuang				
	A	B	C	D	E	A	B	C	D	E
No. Fused+Fusing	19	9	29	9	12	10	16	34	23	13
No. Unfused	0	0	1	4	8	0	0	0	10	8
TOTAL	19	0	30	13	20	10	16	34	33	21
% Fused+Fusing	100.0	100.0	96.7	69.2	60.0	100.0	100.0	100.0	69.7	61.9
% Unfused	0.0	0.0	3.3	30.8	40.0	0.0	0.0	0.0	30.3	38.1

Age Stages and Bones Fusing (Silver 1969):
A (ca. 0-12 mo.): distal scapula; pelvis (acetabulum)
B (ca. 12-18 mo.): distal humerus; proximal radius
C (ca. 18-24 mo.): proximal 1st phalanx; proximal 2nd phalanx
D (ca. 24-42 mo.): distal tibia; distal metapodials; calcaneus
E (ca. 42-48 mo.): proximal humerus; distal radius; proximal ulna; proximal and distal femur; proximal tibia

Bone working:

People at Zhoujiazhuang used more bone and shell raw materials from wild taxa—especially cervid antler and *Unio* shells—for bone artifact production than did people at Taosi (Table 2.7). The frequencies of wild and domestic animal bone artifacts (excluding specimens only identified as small, medium, or large mammals) are statistically different between the sites ($\chi^2 = 47.30$, $p < 0.001$, df = 1; Fisher's exact $p < 0.001$). This difference cannot be explained solely by the fact that there were more wild animals at Zhoujiazhuang. If people did not discriminate between the types of animals used for bone working, we would expect similar proportions of domestic taxa in the bone artifact and overall faunal assemblages, but this is not the case. At Taosi, 84% of artifacts are made from domestic taxa, whereas 93% of the overall assemblage is domestic. At Zhoujiazhuang, only 41% of artifacts are made from domestic taxa, whereas 73% of the overall assemblage is domestic. People at both sites preferentially selected wild animal bones for bone working, but at Zhoujiazhuang the trend is exaggerated. This may be due to environmental differences between the sites. It may also indicate that the bone artisans at Taosi only had restricted access to preferred shell, antler, and wild mammal bone raw materials, perhaps because of the intensive focus on raising domestic animals there.

Table 2.7.
Worked Bone Artifacts by Taxon

	Taosi		Zhoujiazhuang	
TAXON	NISP	%	NISP	%
DOMESTIC TAXA:				
Sus domesticus	9	6.72	32	4.56
Ovis aries	2	1.49	11	1.57
Ovis aries/Capra hircus	13	9.70	43	6.13
M. Bovid	9	6.72	20	2.85
M. Bovid or Cervid	7	5.22	12	1.71
Bos sp.	2	1.49	4	0.57
Bos taurus	3	2.24	2	0.29
L. Bovine	20	14.93	44	6.28
TOTAL DOMESTIC TAXA:	65	48.51	168	23.97
WILD TAXA:				
Bos primigenius	0	0.00	3	0.43
Bubalus mephistopheles	0	0.00	1	0.14
L. Bovid or Cervid	2	1.49	9	1.28
Cervid	4	2.99	73	10.14
S. Cervid	0	0.00	3	0.43
M. Cervid	1	0.75	31	4.42
M. or L. Cervid	1	0.75	25	3.57
Elaphurus davidianus	0	0.00	1	0.14
Cervus nippon	2	1.49	34	4.85
Capreolus sp.	0	0.00	2	0.29
Canid	0	0.00	0	0.00
Unionodae	0	0.00	13	1.85
Unio douglasiae (gray)	1	0.75	38	5.42
Margaritiana sp.	0	0.00	2	0.29
Lamprotula	0	0.00	1	0.14
Mollusca	1	0.75	6	0.86
TOTAL WILD TAXA:	12	8.96	242	34.52
OTHER:				
Homo sapiens	2	1.49	4	0.57
S. Mammal	0	0.00	1	0.14
M. Mammal	27	20.15	78	11.13
L. Mammal	14	10.45	70	9.99
M. or L. Mammal	12	8.96	104	14.84
Mammal	2	1.49	34	4.85
TOTAL OTHER:	57	42.54	291	41.51
TOTAL	134		701	

Note: Oracle Bones from Table 2.8 are also included in Table 2.7.

Oracle bone divination:

Cattle (including domestic *Bos taurus*, wild *Bos primigenius*, and unidentified large bovines) were the most frequently used taxa for oracle bone divination (Table 2.8). Additionally, almost every bovine oracle bone was pre-treated by flattening the scapula and carving hollows to aid cracking during burning. Pig, sheep, and deer oracle bones were not pre-treated. Therefore, the Taosi period may represent the early stages of the shift toward cattle as the most important oracle bone taxa (Flad 2008). Whereas other aspects of ritual practice at Taosi were closely tied to elite control, such as the rituals that took place at the observatory, oracle bone divination was widespread. The oracle bones were found primarily in midden pit contexts at both sites. A few oracle bones were also found in wall fill at Taosi and three oracle bones were found in sacrificial pit H354 at Zhoujiazhuang. It appears that oracle bone use was not associated with royal authority until later in the Bronze Age.

Table 2.8.
Oracle Bones by Taxon

	Taosi		Zhoujiazhuang	
TAXON	NISP	%	NISP	%
Sus domesticus	3	13.64	8	19.51
Ovis aries/*Capra hircus*	3	13.64	5	12.20
Bos sp.	2	9.09	0	0.00
Bos taurus	3	13.64	2	4.88
Bos primigenius	0	0.00	3	7.32
L. Bovine	6	27.27	8	19.51
L. Bovid or Cervid	0	0.00	2	4.88
M. Cervid	0	0.00	2	4.88
Cervus nippon	0	0.00	5	12.20
Capreolus sp.	0	0.00	1	2.44
M. Mammal	0	0.00	2	4.88
L. Mammal	4	18.18	3	7.32
M. or L. Mammal	1	4.55	0	0.00
TOTAL	22	100	41	100

Discussion:

Research on sheep and cattle domestication in China has focused on the geographic and genetic origins of these species (Cai et al. 2011 and 2014; Flad et al. 2007; Yuan 2010), but less is known about how these animals were first used (Lu 2010). We know that by the end of the third millennium BC, agro-pastoralist economies were well established at many sites across northwest China, perhaps due to the shift toward colder and drier climate after the Holocene Climatic Optimum (An et al. 2005). The need to diversify animal exploitation strategies in the face of climate change may have promoted the adoption of sheep and cattle herding. However, we cannot assume that people adopted pastoralism in the same way in all regions. It is important to examine how people used sheep and cattle within specific cultural contexts.

We argue that raising sheep and cattle not only allowed people to take advantage of new environments and manage risk by diversifying their animal exploitation strategies, but also allowed for opportunities to produce new types of animal crafts. People at different sites likely chose to diversify and/or specialize in new animal products depending on their overall degree of economic and political centralization or specialization. Taosi and Zhoujiazhuang provide excellent case studies of these two alternative animal exploitation strategies.

Taosi was an urban site characterized by intensive agriculture and the production of both high quality craft goods such as lacquerware (Gao 1986) and utilitarian objects including ceramics and stone tools (Liu et al. 2013; Zhai 2012). The introduction of sheep and cattle not only allowed for further intensification of the use of domestic animals at Taosi, but also for the development of additional types of crafts and sources of wealth. For example, sheep and cattle provided new raw materials for bone crafting, and most bone artifacts listed in Table 2.7 were made from sheep and cattle bones. Although there is currently no evidence for direct control over craft production by high elites at Taosi, craft specialization did contribute to Taosi's emergence as an urban center (Liu et al. 2013). Bone tool production likely took place at the household level, but raw material availability may have been influenced by food distribution systems that developed in order to supply the growing Taosi population with agricultural products and domestic animal meat. This may help explain why fewer wild taxa were used for bone working at Taosi. The question remains as to how people gained access to animal resources used for subsistence and craft production and how this changed during the Late Period upheaval at the site. In the future, more detailed spatial analysis of the distribution of faunal remains and the skeletal elements present may provide more clues about redistribution and control.

The faunal assemblage at Taosi is overwhelmingly made up of domestic mammals. However, kill-off patterns reveal that the two main domesticates, pigs and sheep, were used in different ways. Taosi residents raised pigs for meat and sheep for both meat and wool, suggesting that wool textiles may have been an important new craft at this economic center. Additional research is still needed to confirm our observations and to provide other lines of evidence for wool production such as increasing numbers of spindle whorls and other weaving tools. Two alternative explanations for the older sheep at Taosi include herd security and animal wealth. If it was necessary to keep sheep alive for herd security (Redding 1981), we would expect larger numbers of adult individuals at Zhoujiazhuang as well, but this is not the case. Exchange of animal wealth also favors animal management systems that increase herd size (Russell 2012: 307-317). If sheep were exchanged for large stock such as cattle, this could explain the focus on older animals at Taosi. However, it is interesting to note that even if sheep were wealth animals, they were likely not perceived as highly valuable animals. Pigs, cattle, and dogs are frequently found in burials or ritual contexts in Neolithic and Bronze Age China (Yuan and Flad 2005; Yuan 2010), including at Taosi (He 2013). We have no similar evidence for sheep. This trend applies to other sites across China as well, where sheep bones are rarely found in sacrificial contexts until the Shang Dynasty (Yuan and Flad 2005).

Cattle, on the other hand, were valuable animals that may have been a new source of wealth for emerging elites at sites such as Taosi. Most cattle at Taosi and Zhoujiazhuang survived into adulthood, although higher resolution age data is still needed. In addition to some potential use for draught or transportation, cattle may have also been used for wealth. Chen et al.'s (2012) isotopic analysis of Taosi cattle indicates that cattle were intentionally foddered. Cattle bones were also preferentially selected for bone working and for oracle bone divination, with most cattle oracle bones being pre-treated. The extra time spent caring for living cattle as well as preparing the bones of dead cattle for divination suggests that these animals were highly valued. People at both Taosi and Zhoujiazhuang seem to have perceived cattle as special animals, suggesting that the importance of cattle in ritual practice was widespread across north China during the adoption of cattle herding and not limited to the largest political centers.

Whereas Taosi provides a case study of a society that specialized in new types of animal resources, Zhoujiazhuang provides a case study of a society that diversified its animal resources. At Zhoujiazhuang, people ate more wild animals and used more wild animal bones for bone working. Environmental differences may explain the larger number of wild animals, but people may have also used more wild animals because craft production and animal exploitation were subject to a lesser degree of centralized control.

Kill-off patterns for pigs and sheep at Zhoujiazhuang do not show evidence for specialized exploitation of non-meat resources. In this way, the Zhoujiazhuang assemblage represents only a slight modification to Chinese animal exploitation systems prior to the introduction of sheep and cattle. Middle Neolithic sites are characterized by both raising domestic pigs and dogs and hunting wild animals (Yuan 1999 and 2010; Luo 2012). Other Longshan-era sites with published zooarchaeological data appear similar to Zhoujiazhuang, with pigs and sheep being killed at young ages for meat and cattle surviving to older ages (Huang 1996; Liu et al. 2001; Lu 2009; Song et al. 2012). At these sites, people may have simply incorporated sheep into an existing Neolithic-style animal exploitation system as a means of diversification for risk management or to exploit additional environmental niches. Sheep herding did not represent a significant change to the primary goal of domestic animal exploitation for meat. Although cattle herding provided new sources of wealth and ritual animals, cattle were still raised in fairly low numbers at most sites until later in the Bronze Age. Bone working at Zhoujiazhuang also continued to favor wild taxa in ways similar to middle Neolithic sites.

Zooarchaeological and bone artifact analyses from more sites are still needed, but at this point it seems that the intensified and specialized use of sheep and cattle resources for wool production and bone working at Taosi may have been quite unusual. In other world regions such as the Near East, zooarchaeological data has proven useful for examining processes of urbanization and centralized control of animal resources, especially secondary animal products such as wool (e.g., Zeder 1988 and 1991; Arbuckle 2012a and 2012b). As more sites in China are analyzed, we will be able to make better assessments about the control of animal products in emerging urban centers and more accurately construct broader narratives about changing patterns in domestic animal management. If the faunal record at Taosi proves to be an exception rather than the rule, it would suggest that control over animal crafts and domestic animal resources was critically important during the emergence of the first Chinese states.

Conclusion:

Although our conclusions are preliminary, the data indicate that sheep and cattle were used for a greater diversity of craft products at Taosi. At sites such as Zhoujiazhuang that lack evidence for a high degree of centralized control over agricultural production and crafting, the adoption of sheep and cattle herding complimented existing Chinese animal exploitation systems that focused on meat production. These findings suggest that there was a great deal of diversity in the ways that people adopted sheep and cattle pastoralism in early urban centers. Our work demonstrates the need for more regional zooarchaeological studies in China. Such comparative studies will be increasingly important as we move beyond the initial research steps of pinpointing the timing and location of animal domestication and introduction events toward understanding the social and economic implications of changes in animal exploitation.

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CHAPTER 3

Bone Artifact Production and Increasing Social Complexity in Late Neolithic China

Abstract:

Craft specialization is frequently linked to increasing social complexity in ancient societies. Worked bone artifacts are largely absent from these discussions, but have great potential to reveal trends in craft specialization. This is especially the case in ancient China where bone artifact manufacturing shifted from small-scale production in households during the Neolithic to mass production in workshops during the Bronze Age. The sites of Taosi and Zhoujiazhuang in southern Shanxi Province provide an opportunity to examine bone working practices during the Late Neolithic Longshan period when many social and economic changes took place leading up to Bronze Age state formation. These sites also provide an opportunity to examine how people initially used domestic sheep and cattle bone raw materials during the adoption of pastoralism in the Middle Yellow River Valley. Patterns in raw material choice, production methods, and the types of artifacts produced reveal that Taosi and Zhoujiazhuang may have specialized in different types of crafts. Additionally, people at Taosi were increasingly engaged in oracle bone divination rituals, suggesting a possible link between economic specialization and ritual intensification.

Keywords:

Chinese archaeology; Longshan; zooarchaeology; craft specialization; bone working; oracle bones

Introduction:

Specialized craft production is a marker of increasing social complexity, but the relationship between specialization and social organization is complex and multi-faceted (Brumfiel and Earle 1987; Costin1991). Archaeologists are keenly aware that the production of utilitarian artifacts and prestige goods do not have to be mutually exclusive and that there is a great deal of variability in the degree and nature of elite involvement in the production activities of ancient societies (Aoyama 2007; Arnold and Munns 1994; Brumfiel and Earle 1987; Clark and Parry 1990; Costin 1991; Costin and Wright 1998; Emery and Aoyama 2007; Flad 2011; Flad and Hruby 2007; Inomata 2001; Sinopoli 1998 and 2003; Wailes 1996; Underhill 1991 and 2002). As Costin (1991) argues, the factors that characterize specialization such as context (independent or attached), spatial concentration (dispersed or nucleated), scale (household or industrial), and intensity (part-time or full-time) occur on a continuum, with specialized production taking multiple forms. Therefore, one goal of anthropologists and archaeologists should be to document the diverse ways that specialization and social complexity are linked in different social contexts (Clark and Parry 1990; Costin 2001:274).

Craft specialization is frequently employed in discussions of increasing social complexity and state formation in ancient China (Bennett 2007; Campbell et al. 2011; Dai 2010; Flad 2007 and 2011; Liu 2003 and 2004; Liu and Chen 2003; Liu et al. 2007; Liu et al. 2013; Underhill 1991, 1996, and 2002; Underhill and Fang 2004). For example, during the Neolithic, a growing demand for feasting and ritual food vessels by emerging elites may have contributed to increasingly specialized ceramic production (Underhill 2002). Specialized lithic production and control over lithic raw material sources may have contributed to the emergence of large regional centers and early states by linking these places to ideologically significant places on the landscape (Bennett 2007), or by producing trade goods that allowed individuals to gain wealth and power (Liu et al. 2007; Liu et al. 2013). During the Bronze Age, control over metal raw materials and the production of ritual bronzes helped those in power to maintain and legitimize their authority (Chang 1980 and 1983; Liu 2003; Liu and Chen 2003). By the Late Shang Dynasty (ca. 1300-1050BCE), craft production—especially ritual bronze production—was increasingly attached to elites in dedicated workshop facilities with a high division of labor (Campbell et al. 2011; Haapanen 2005; Y.T. Li 2003 and 2007; Z. Li 2011; Franklin 1983 and 1990; Underhill and Fang 2004).

Despite the importance placed on craft specialization in explanations for socio-political change in ancient China, the role of worked bone artifacts in these processes remains understudied (for some exceptions see Campbell et al. 2011; Z. Li et al. 2011; Flad 2011; and Ma 2010). There are currently few studies of bone working in Neolithic and Bronze Age China. Recent studies reveal how changes in raw material selection reflect developments in agricultural practices (Xie et al. 2015; Yu 2009), how Neolithic bone tools were manufactured and used (Hou et al. 2009; Y.J. Li 2012), how large-scale bone workshops emerged during the Bronze Age (Ma 2010), and how craft specialization and ritual specialization are related (Flad 2008 and 2011). One particularly useful case is the work of Campbell et al. (2011) and Li et al. (2011) at the Tiesanlu bone workshop in the Shang capital at Anyang. Their analysis indicates that Shang bone workshops produced millions of cattle bone hairpins for both local, non-local, elite, and non-elite consumption. The bone industry played an important role in the economics of early Chinese states (Campbell et al. 2011; Li et al. 2011; Ma 2010), but much less is known about the bone industry in earlier periods and its role in the process of increasing craft specialization that led to Bronze Age state formation.

In this paper, I analyze bone artifacts produced at the Longshan period sites of Taosi and Zhoujiazhuang in Shanxi Province (Figure 3.1). The Longshan period (late third millennium BCE) is characterized by the emergence of multiple chiefdom-level and potentially state-level societies in northern China that developed a shared elite material culture through increasing inter-regional interactions (Chang 1986; Liu 2004; Underhill 1991, 1994, 1996, 2002; Underhill et al. 1998, 2002). Many of the cultural traditions that emerged during the Longshan period were further developed during the Bronze Age dynastic system (Chang 1986), making it an important period for studying the relationships between craft specialization and social complexity.

In terms of the zooarchaeological record, the Longshan period is also significant because domestic sheep and cattle were introduced to north China at that time (Flad et al. 2007; Yuan et al. 2007). Studying Taosi and Zhoujiazhuang—two sites with some of the earliest evidence for extensive exploitation of sheep and cattle—helps us understand how the availability of new domestic animal sources of bone raw materials impacted bone working practices. Cattle bone eventually became the primary raw material used in Bronze Age bone workshops (Campbell et al. 2011; Ma 2010). Therefore Taosi and Zhoujiazhuang provide an opportunity to study the incipient stages in the development of the cattle bone working industry. My results show that although bone artifact production was still a household industry, there are several key developments in bone working practices at Taosi and Zhoujiazhuang that indicate the early stages of development into a more specialized industry. These include: 1) a move toward domestic artiodactyls, especially cattle, as the main raw material source; 2) standardization of production steps used to make certain types of bone artifacts; and 3) variability in the types of artifacts produced at contemporaneous sites. I examine these developments and what they can add to our understanding of craft specialization and increasing social complexity during the

Longshan period. The implications are significant for understanding the role of bone working in ancient societies and how people initially used domestic sheep and cattle bone raw materials as these animals spread into new geographic regions.

Site Background:

Taosi is a walled site located in the Linfen basin. Occupation at the site is divided into three phases: early (ca. 2300-2100 BCE), middle (2100-2000 BCE), and late (ca. 2000-1900 BCE) (He 2004). During its height in the middle occupation phase, the Taosi enclosure covered an area of roughly 2.8km^2 (He 2013:264). Excavators have discovered many impressive early and middle phase features to suggest that Taosi had a well-developed social hierarchy and elite ritual culture, including a cemetery with extravagant elite burials, a palace-temple zone containing a 280m^2 palace structure, and a ritual structure that may have been used as a solar observatory (Gao Wei et al. 1983; Zhongguo and Linfen 1983; Zhongguo et al. 2003, 2004, 2007, and 2008; He 2013: 265-269). Regional settlement patterns indicate that Taosi was the main administrative center for the region, with other large sites controlling areas to the north and south and with some small and medium-sized sites supplying Taosi with ceramics, lithics, and other trade goods (He 2013: 257-261).

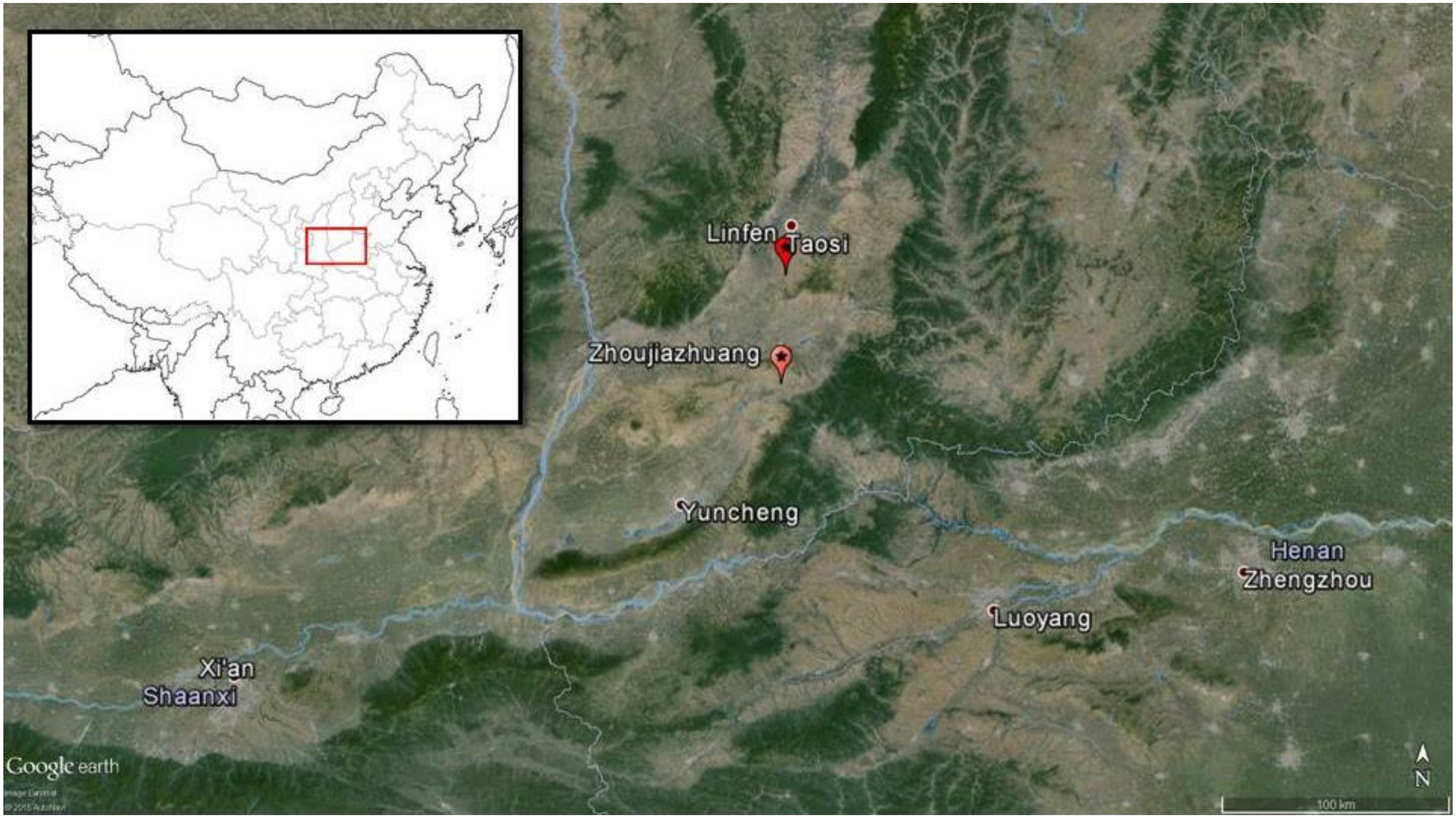

Figure 3.1. Location of Taosi and Zhoujiazhuang in southern Shanxi Province.

During the late Taosi phase (ca. 2000-1900 BCE), many middle and early phase elite tombs were looted, numerous skeletons show evidence for violent death, and the palace, ritual observatory, and city walls were destroyed (Zhongguo et al. 2005; He 2013: 269-270). Several other large sites emerged in the region during the late Taosi phase, suggesting that Taosi may have lost its position as the primary economic and political center (He 2013; Liu 2004: 111 and 173-175). Although it is possible that the late Taosi period unrest was part of an internal power struggle, there is growing evidence that Taosi may have been attacked by another group or was subject to external cultural influences (Han 2007). Skeletal analysis and ancient DNA indicate that many late phase occupants of Taosi were not genetically related to the middle phase occupants (Zhang et al. 2009). Many late phase human skeletons also have non-local strontium isotope signatures (C. Zhao and He 2014). Additionally, faunal remains indicate a sudden adoption of sheep herding during the late phase, which may indicate the arrival of a new group that practiced sheep pastoralism (Tao 2007; Brunson 2008; Brunson et al. 2015).

Craft production at Taosi focused on a mixture of ceramic wares for elite consumption, utilitarian ceramics and tools for local use, and trade goods. High-quality artifacts such as jades, lacquerware, and polychrome pottery have been found in elite burials, but we do not know to what degree these goods were produced locally (Gao 1986 and 1998; Zhongguo and Linfen 1983). Many kilns have been found at Taosi and ceramic production was highly standardized, indicating that it was a well-developed industry (Li 1996; Shanxi Sheng 1999; Zhongguo and Linfen 1986). Taosi also seems to have monopolized control over lithic raw materials from the nearby Mount Dagudui quarry, producing enough stone tools to surpass local needs and supply finished tools to smaller sites in the region (Liu et al. 2013; Zhai 2012). Spatial patterning in the distribution of stone tool production debris indicates that the southwestern quadrant of the city was a specialized craft production zone (He 2013: 268-269; Zhai 2012). Excavators recently uncovered a middle phase rammed earth building in this zone covering an area of over 1300 m^2 that may have been a managerial building (Zhongguo and Shanxi 2015). Nevertheless, lithic production still took place at the household level and there is currently no evidence that this form of craft production was directly attached to elites (Liu et al. 2013).

Zhoujiazhuang is located in the Yuncheng basin about 40km south of Taosi and has not been excavated or studied as extensively as Taosi. The material culture at Zhoujiazhuang shows many similarities to Taosi, with pottery styles indicating that Zhoujiazhuang dates to the late Taosi period. Settlement patterns indicate that it was the largest site in the Yuncheng basin and was surrounded by a large moat that enclosed an area of about $2km^2$ (Drennan and Dai 2010). No dedicated ritual structures, elite residences, or elite burials have been found at Zhoujiazhuang yet, but excavations have uncovered numerous residential areas with kilns and midden deposits to suggest that craft production took place within residential groups.

The paleobotanical and zooarchaeological records at both Taosi and Zhoujiazhuang indicate that people were engaged in intensive agricultural production focusing on foxtail millet, pigs, sheep, and cattle (Z. Zhao and He 2006; Tao 2007; Brunson et al. 2015). While kill-off patterns for pigs suggest that they were primarily used for meat at both sites, kill-off patterns for sheep are different between the two sites, suggesting that people at Taosi may have raised sheep for secondary products such as wool whereas people at Zhoujiazhuang used sheep primarily for meat. Another key difference between the sites is the greater reliance on wild and non-mammal taxa at Zhoujiazhuang (Brunson et al. 2015).

Methods:

I identified 835 worked bone artifacts while analyzing faunal remains that were excavated from Taosi in 2010 and 2013 and from Zhoujiazhuang between 2007 and 2013 (Brunson et al. 2015; Supplemental Table 3.1). I also identified some artifacts from Zhoujiazhuang in special finds collections separated from the other faunal materials at the time of excavation. Most worked bone artifacts come from midden deposits in non-elite residential areas. The exceptions are 28 artifacts from Taosi that represent refuse from middle phase elite contexts, and 144 artifacts from Zhoujiazhuang that were found in a sacrificial pit (H354). This pit contained an unusually large number of ceramic, lithic, and bone artifacts. Two human skeletons were found placed back to back at the top of the pit. The types of worked bone artifacts in the sacrificial pit are similar to those found in middens, so I combine all contexts together in my analyses.

The worked bone assemblages presented here include finished artifacts, semi-finished artifacts, and production debris. Objects were identified to taxon and skeletal element whenever possible. I assume that specimens identified as *Bos taurus*, *Bos* sp. and Large Bovine are domestic cattle and that specimens identified as *Ovis*, *Ovis*/*Capra*, and Medium Bovid are domestic sheep, although it is possible that some of these bones represent wild individuals. For a more detailed discussion of faunal identification methods and related issues see Brunson et al. (2015). All calculations below use these combined categories.

In other parts of the world, zooarchaeologists have linked low taxonomic diversity in faunal assemblages to the development of increasingly specialized and/or managed agro-pastoralist economic systems in which non-food producing specialists have only limited contact with the specialist pastoralists and hunters that supply population centers with animal products (Zeder 1991; Crabtree 1990:159-161; Wattenmaker 1987: 197). Low taxonomic diversity in worked bone assemblages has also been used as an indicator of bone artifact production specialization (Watson 2012: 314-315). Using Simpson's index—a measurement of the probability that a given species will be drawn at random—I compare taxonomic diversity at the two sites (Magurran 2004: 114-116):

$$D = \sum \left(\frac{n_i[n_i - 1]}{N[N - 1]} \right)$$

D= Simpson's index of diversity

n_i=number of individuals in the *i*th species

N=total number of individuals

Following Watson (2012: 315), I assume that 1/D will decrease as specialization increases. In other words, fewer taxa used to make bone artifacts reflects higher levels of specialization.

I also calculate Simpson's measure of evenness—the distribution of specimens among the various identified taxa—at the two sites (Magurran 2004: 114-116):

$$E_{1/D} = \frac{(\frac{1}{D})}{S}$$

$E_{1/D}$=evenness

D=Simpson's index

S=NTAXA, or the number of taxa in the assemblage

Following Watson (2012: 315), I assume that decreasing $E_{1/D}$ in bone working represents increased specialization because crafting is focused on a more limited number of taxa.

I used the program EstimateS to calculate the Simpson's index for both sites (Colwell 2013). I also used EstimateS to construct rarefaction curves for the number of taxa identified at each site. In this method, the assemblage is randomly resampled to calculate the average number of taxa represented by any sample of N individuals, providing a measure of species richness (Gotelli and Colwell 2001 and 2011; Magurran 2004: 144-148). For the Simpson's and rarefaction calculations, I did not include worked specimens that were only identified to broad size class categories.

Finally, following other studies of specialized bone working (Campbell et al. 2011; Choyke and Bartosiewicz 2001; Emery 2001, 2008, and 2009; Gates St-Pierre and Walker 2007; Legrand-Pineau et al. 2010; Luik et al. 2005; Wake 1997, 2001), I also assume that greater standardization in the methods used to work bones and the production steps involved in artifact production reflect greater specialization. In the next sections, I examine diversity, evenness, and standardization by comparing trends in raw material selection, production methods, and artifact types found at the two sites.

Raw material selection:

I identified 134 worked specimens (5.6% of the total faunal assemblage) at Taosi and 701 worked specimens (4.6% of the total faunal assemblage) at Zhoujiazhuang. Tables 3.1 and 3.2 show the number of worked bone artifacts according to taxon. Diagnostic sections of bones are frequently removed during artifact production. Therefore, many artifacts could only be identified to broad size categories such as "medium mammal" or "large mammal." For those specimens that could be identified with greater certainty, the most common taxa are cattle, sheep, pigs, deer, and mollusks.

Tables 3.3 and 3.4 show the numbers of worked bone artifacts according to skeletal element. Commonly used skeletal elements include ruminant long bones (frequently used to make utilitarian tools such as perforators and spatulas), ungulate scapulas (frequently used in oracle bone divination), cervid antlers (frequently used to make projectile points) and mollusk shells (frequently used to make ornaments).

Calculations of taxonomic diversity indicate that Taosi was less diverse than Zhoujiazhuang (Taosi 1/D=4.58; Zhoujiazhuang 1/D=9.03). Evenness calculations (Taosi S=12; Zhoujiazhuang S=20) also show that taxonomic distributions at Taosi are less even than at Zhoujiazhuang (Taosi $E_{1/D}$ =0.38; Zhoujiazhuang $E_{1/D}$ =0.45). These indices suggest a higher degree of specialization at Taosi. However, taxonomic diversity can increase with sample size (Lyman 2008:196; Grayson 1981). Rarefaction curves constructed for each site overlap in the 95% confidence interval (Supplemental Figure 3.1), indicating that the difference in sample size cannot be excluded as a reason for differences in the number of taxa identified at the sites (Gotelli and Colwell 2001 and 2011). However, when the Simpson's index is plotted for each individual specimen the two curves do not overlap (Supplemental Figure 3.2). This shows that there is a statistically significant difference in taxonomic diversity between the two sites even though there is no difference in taxonomic richness. Therefore, sample size effects alone cannot account for any differences in the distribution of taxa.

Cattle (including *Bos* sp., *Bos taurus*, and large bovines) make up 18.7% of the Taosi worked bone assemblage and 7.0% of the Zhoujiazhuang worked bone assemblage. It is likely that most of the unidentified "large mammal" bone artifacts are also made from cattle bones. The most commonly used skeletal elements for cattle are long bones—especially metapodials—and scapulas. Cattle mandibles are also very common, reflecting the specialized use of cattle mandibles for making knife tools.

Sheep (including *Ovis*, *Ovis*/*Capra*, and medium bovids) make up 17.9% of the Taosi worked bone assemblage and 10.6% of the Zhoujiazhuang worked bone assemblage. The most commonly used sheep skeletal elements are long bones—especially metapodials—and scapulas.

Although pigs (*Sus*) are the most common domestic taxa in the overall faunal assemblages at both sites, making up 45.1% of the overall Taosi faunal assemblage and 30.8% of the overall Zhoujiazhuang faunal assemblage, very few pig bones were worked. Pigs only make up 6.7% of the Taosi worked bone assemblage and 4.7% of the Zhoujiazhuang worked bone assemblage. Moreover, very few artifacts were made from pig long bones. Instead, most pig artifacts were made from canine teeth (primarily used to make plaques and other ornaments) and scapulas (used in oracle bone divination). This suggests that the selection of taxa used for subsistence and for utilitarian and ritual bone artifact production were guided by different criteria.

Cervid bone and antler artifacts are much more common at Zhoujiazhuang than at Taosi. Cervids make up 6.0% of the Taosi worked bone assemblage and 24.1% of the Zhoujiazhuang worked bone assemblage. Most of the cervid artifacts at both sites were made from antler. Several deer species were used, but the most commonly identified cervid taxon is the sika deer (*Cervus nippon*).

In addition to cervids, I also identified worked bones from a few other wild taxa. These include wild aurochs (*Bos primigenius*) and wild water buffalo (*Bubalus mephistopheles*). At Zhoujiazhuang, people also frequently used freshwater mollusk shells, such as the small white shells of *Unio douglasiae* (Gray), to make ornaments. Interestingly, I did not find any other non-mammal bone artifacts at either site. The greater number of wild taxa at Zhoujiazhuang may be due to environmental differences between the sites, since Zhoujiazhuang was located in a more forested area with greater access to freshwater resources.

The mechanical properties of osseous materials are key factors in raw material selection for utilitarian object production (Margaris 2009 and 2014; Scheinsohn and Ferretti 1995). Artiodactyl long bone shafts may have been a preferred material because of their density and strength (Lyman 1984; Lam et al. 1998 and 1999). Antler was also a preferred raw material for making artifacts such as projectile points likely due to its flexibility (MacGregor and Currey 1983; MacGregor 1985:23-29; Margaris 2009 and 2014). The shiny, white or yellow appearance of *Sus* canines and *Unio* shells may explain their use for making decorative ornaments.

Before discussing bone working methods and the types of artifacts produced at Taosi and Zhoujiazhuang, it is important to mention the taphonomic effects that may have influenced the bone artifacts identified at the sites. Skeletal element distributions for the most common mammalian taxa in the overall faunal assemblages are shown in Figure 3.2. Skeletal element distributions for the worked bone artifacts identified are shown in Figure 3.3 for comparison. In the overall assemblage, dense portions of bones such as the distal humerus and distal tibia survived better than less dense portions of bones such as the proximal humerus and proximal tibia. This pattern is consistent with what is expected for density mediated attrition in archaeological faunal assemblages (Lyman 1984 and 1994: 249; Lam and Pearson 2005; Lam et al. 1998 and 1999). The activities of carnivores and rodents may have further contributed to the destruction of less-dense portions of bones. Carnivore chew marks were present on 2.6% of the Taosi assemblage and 2.1% of the Zhoujiazhuang assemblage. Rodent chew marks were present on 1.9% of the Taosi assemblage and 2.1% of the Zhoujiazhuang assemblage. Figure 3.3 also shows a bias against small bones such as carpals and tarsals in the overall faunal assemblage. Most faunal materials were collected during excavation by hand without screening. Screen size influences the numbers of small bones identified in faunal assemblages (Casteel 1972; Gobalet 1989; Gordon 1993; James 1997; Lyman 2012; Nagaoka 2005; Peres 2010; Quitmyer 2004; Shaffer 1992; Shaffer and Sanchez 1994; Stahl 1996; Thomas 1969), and it is likely that smaller worked bone artifacts are also underrepresented due to collection bias.

Although Figure 3.2 reveals several taphonomic biases in the faunal assemblages, when compared to Figure 3.3 it is possible to see a few patterns that are significant to bone working. Some elements may be more common in the overall assemblage because they represent production waste. For example, loose cattle teeth are common in Figure 3.2 likely because they were removed from cattle mandibles during knife production (described in the following sections). Other elements may be more common in the overall assemblage because they were not turned into tools. For example, skulls, pelves, and phalanges of cattle, sheep, and pigs are frequent in the overall assemblages, but are rare in the worked bone assemblages. Finally, for medium cervids and *Cervus nippon* it is possible to tell that some antlers were still attached to the skull (Taosi NISP=1; Zhoujiazhuang NISP=5) and some were naturally shed (Taosi NISP=2; Zhoujiazhuang NISP=7), indicating that people sought out antler for its use as a raw material beyond what was available through hunting alone. Raw material selection was therefore guided not only by the availability of certain taxa or skeletal elements, but also by their desirable natural or symbolic properties (Russell 2001: 273).

Table 3.1.
Taosi Artifacts by Taxon.

Taxon	**Blank**	**Blank (possible)**	**Tube**	**Tube (possible)**	**Blank Production Waste**	**Blank Production Waste (possible)**	**Antler Point Tool**	**Antler Point Tool (possible)**	**Perforator**	**Spatula**	**Chisel**	**Knife**	**Knife (possible)**	**Rasp**	**Needle**	**Projectile Point**	**Ornament**	**Oracle Bone**	**Oracle Bone (possible)**	**Oracle Bone Production Waste (possible)**	**Unid. Worked Object**	**TOTAL**	**%**
Sus			1			1			3								1	3				**9**	**6.7**
Ovis	1					1																**2**	**1.5**
Ovis/Capra	3		3		2								1					3	1			**13**	**9.7**
M. Bovid	1		1			1			1													**9**	**6.7**
M. Bovid or Cervid	2		2		2					1												**7**	**5.2**
Bos sp.																		5				**5**	**3.7**
Bos primigenius																						**0**	**0**
Bubalus																							
Mephistopheles																						**0**	**0**
L. Bovine	3		2		3							1	3					6	1		1	**20**	**14.9**
L. Bovine or Cervid					1									1								**2**	**1.5**
Cervid	1	1						1								1						**4**	**3.0**
S. Cervid																						**0**	**0**
M. Cervid					1																	**1**	**0.8**
M. or L. Cervid					1																	**1**	**0.8**
Elaphurus davidianus																						**0**	**0**
Cervus nippon					1																1	**2**	**1.5**
Capreolus sp.																						**0**	**0**
Homo sapiens									1												1	**2**	**1.5**
S. Mammal																						**0**	**0**
M. Mammal	6	7				1			8	3											2	**27**	**20.2**
L. Mammal		1							1		1					4		4	1		2	**14**	**10.5**
M. or L. Mammal	2								5				1		1	1		1			1	**12**	**9.0**
Mammal	1								1													**2**	**1.5**
Unionodae																						**0**	**0**
Unio douglasiae (gray)																	1					**1**	**0.8**
Margaritiana																						**0**	**0**
Lamprotula																						**0**	**0**
Mollusca	1																					**1**	**0.8**
TOTAL	**21**	**9**	**9**	**0**	**16**	**4**	**0**	**1**	**20**	**4**	**1**	**1**	**5**	**1**	**1**	**6**	**2**	**22**	**3**	**0**	**8**	**134**	
%	**15.7**	**6.7**	**6.7**	**0**	**11.9**	**3.0**	**0**	**0.8**	**14.9**	**3.0**	**0.8**	**0.8**	**3.7**	**0.8**	**0.8**	**4.5**	**1.5**	**16.4**	**2.2**	**0**	**6.0**		**100**

Table 3.2.
Zhoujiazhuang Artifacts by Taxon.

TAXON	**Blank**	**Blank (possible)**	**Tube**	**Tube (possible)**	**Blank Production Waste**	**Blank Production Waste (possible)**	**Antler Point Tool**	**Antler Point Tool (possible)**	**Perforator**	**Spatula**	**Chisel**	**Knife**	**Knife (possible)**	**Rasp**	**Needle**	**Projectile Point**	**Ornament**	**Oracle Bone**	**Oracle Bone (possible)**	**Oracle Bone Production Waste (possible)**	**Unid. Worked Object**	**Total**	**%**
Sus	2	1		1		2			1	2							5	8			10	**32**	**4.6**
Ovis					5	1			1	2			1								1	**11**	**1.6**
Ovis/Capra	2		2	7	9	5			7	2		1	1					5	1		1	**43**	**6.1**
M. Bovid	1	1	4	4	4	2			1	1									1		1	**20**	**2.9**
M. Bovid or Cervid	3			1	3				1	3	1											**12**	**1.7**
Bos sp.					2								1					2		1		**6**	**0.9**
Bos primigenius																		3				**3**	**0.4**
Bubalus mephistopheles					1																	**1**	**0.1**
L. Bovine	6			1	15	4						3	2					8	1	3	1	**44**	**6.3**
L. Bovine or Cervid	2				2	1				1								2		1		**9**	**1.3**
Cervid	11				7	1	1		2	6	1					41					3	**73**	**10.4**
S. Cervid					1					1	1											**3**	**0.4**
M. Cervid	3			1	15	4			2		1			1				2	2			**31**	**4.4**
M. or L. Cervid	3				5	2	9	1			2										3	**25**	**3.6**
Elaphurus davidianus					1																	**1**	**0.1**
Cervus Nippon					25	1			2									5			1	**34**	**4.6**
Capreolus sp.					1													1				**2**	**0.3**
Homo sapiens						2			1												1	**4**	**0.6**
S. Mammal									1													**1**	**0.1**
M. Mammal	26	2	2		3	2			15	14						3		2		1	8	**78**	**11.1**
L. Mammal	23	1			4	1			3	11	2	3				11		3			8	**70**	**10.0**
M. or L. Mammal	5				2				18	11					1	59					8	**104**	**14.8**
Mammal	1				2				12	2					14	2					1	**34**	**4.9**
Unionodae	13																					**13**	**1.9**
Unio douglasiae (gray)																	38					**38**	**5.4**
Margaritiana												2										**2**	**0.3**
Lamprotula																	1					**1**	**0.1**
Mollusca	3															1	2					**6**	**0.9**
TOTAL	**104**	**5**	**8**	**15**	**107**	**28**	**10**	**1**	**67**	**56**	**8**	**9**	**5**	**1**	**15**	**117**	**46**	**41**	**5**	**6**	**47**	**701**	
%	**14.8**	**0.7**	**1.1**	**2.1**	**15.3**	**4.0**	**1.4**	**0.1**	**9.6**	**8.0**	**1.1**	**1.3**	**0.7**	**0.1**	**2.1**	**16.7**	**6.6**	**5.9**	**0.7**	**0.9**	**6.7**		**100**

Table 3.3.
Taosi Worked Skeletal Elements by Taxon.

ELEMENT	Antler Tine Tip	Antler Fragments	Antler with Burr (naturally shed)	Antler + Cranium	Cranium	Mandible	Loose Teeth	Scapula	Humerus	Radius	Ulna	Femur	Tibia	Fibula	Metacarpal	Metatarsal	Unid. Metapodial	Ribs	Unid. Long Bone Shaft	Unid. Fragment	Shell	TOTAL
Sus							3	3		1		2										9
Ovis									1						1							2
Ovis/Capra						1		4	2	1			1		1	1	2					13
M. Bovid										1			1		4		3					9
M. Bovid or Cervid										1			2		1	2	1					7
Bos sp.								5														5
Bos primigenius																						0
Bubalus mephistopheles																						0
L. Bovid						4		7	1	1			1		3	2	1					20
L. Bovid or Cervid																1		1				2
Cervid	1	3																				4
S. Cervid																						0
M. Cervid				1																		1
M. or L. Cervid				1																		1
Elaphurus davidianus																						0
Cervus nippon			2																			2
Capreolus sp.																						0
Homo sapiens					1									1								2
S. Mammal																						0
M. Mammal									1	1			1				1	3	20			27
L. Mammal								5										3	3	3		14
M. or L. Mammal						1		1											4	6		12
Mammal																				2		2
Unionodae																						0
Unio douglasiae (gray)																					1	1
Margaritiana																						0
Lamprotula																						0
Mollusca																					1	1
TOTAL	1	3	2	2	1	6	3	25	5	6	0	2	6	1	10	6	8	7	27	11	2	134
%	0.8	2.2	1.5	1.5	0.8	4.5	2.2	18.7	3.7	4.5	0	1.5	4.5	0.8	7.5	4.5	6.0	5.2	20.2	8.2	1.5	

Table 3.4.
Zhoujiazhuang Worked Skeletal Elements by Taxon.

ELEMENT	Antler Tine Tip	Antler Fragments	Antler with Burr (naturally shed)	Antler + Cranium	Cranium	Mandible	Loose Teeth	Scapula	Humerus	Radius	Ulna	Femur	Tibia	Fibula	Metacarpal	Metatarsal	Unid. Metapodial	Ribs	Unid. Long Bone Shaft	Unid. Fragment	Shell	TOTAL
Sus							17	8	4					3								32
Ovis						1							2		6	1	1					11
Ovis/Capra						2		6	1			2	6		17	9						43
M. Bovid								1		3		1	4		8	2	1					20
M. Bovid or Cervid										1			1		2	5	3					12
Bos sp.						1		3							2							6
Bos primigenius								3														3
Bubalus mephistopheles																1						1
L. Bovid						8		13	1	1		2			8	8	3					44
L. Bovid or Cervid								3		1			1		1		3					9
Cervid	6	66														1						73
S. Cervid				2												1						3
M. Cervid		2						4		1			2		9	10	3					31
M. or L. Cervid	15	9													1							25
Elaphurus davidianus																1						1
Cervus nippon	8	7	3	5				5					1		3	2						34
Capreolus sp.								1								1						2
Homo sapiens												4										4
S. Mammal																				1		1
M. Mammal						1		3	2			6	6					3	50	7		78
L. Mammal						1		3	1			1	2			1		13	34	28		84
M. or L. Mammal																			50	54		104
Mammal																			7	13		20
Unionodae																					13	13
Unio douglasiae (gray)																					38	38
Margaritiana																					2	2
Lamprotula																					1	1
Mollusca																					6	6
TOTAL	29	84	3	7	0	14	17	53	9	7	0	16	25	3	57	43	14	16	141	103	60	701
%	4.1	12.0	0.4	1.0	0.0	2.0	2.4	7.6	1.3	1.0	0.0	2.3	3.6	0.4	8.1	6.1	2.0	2.3	20.1	14.7	8.6	

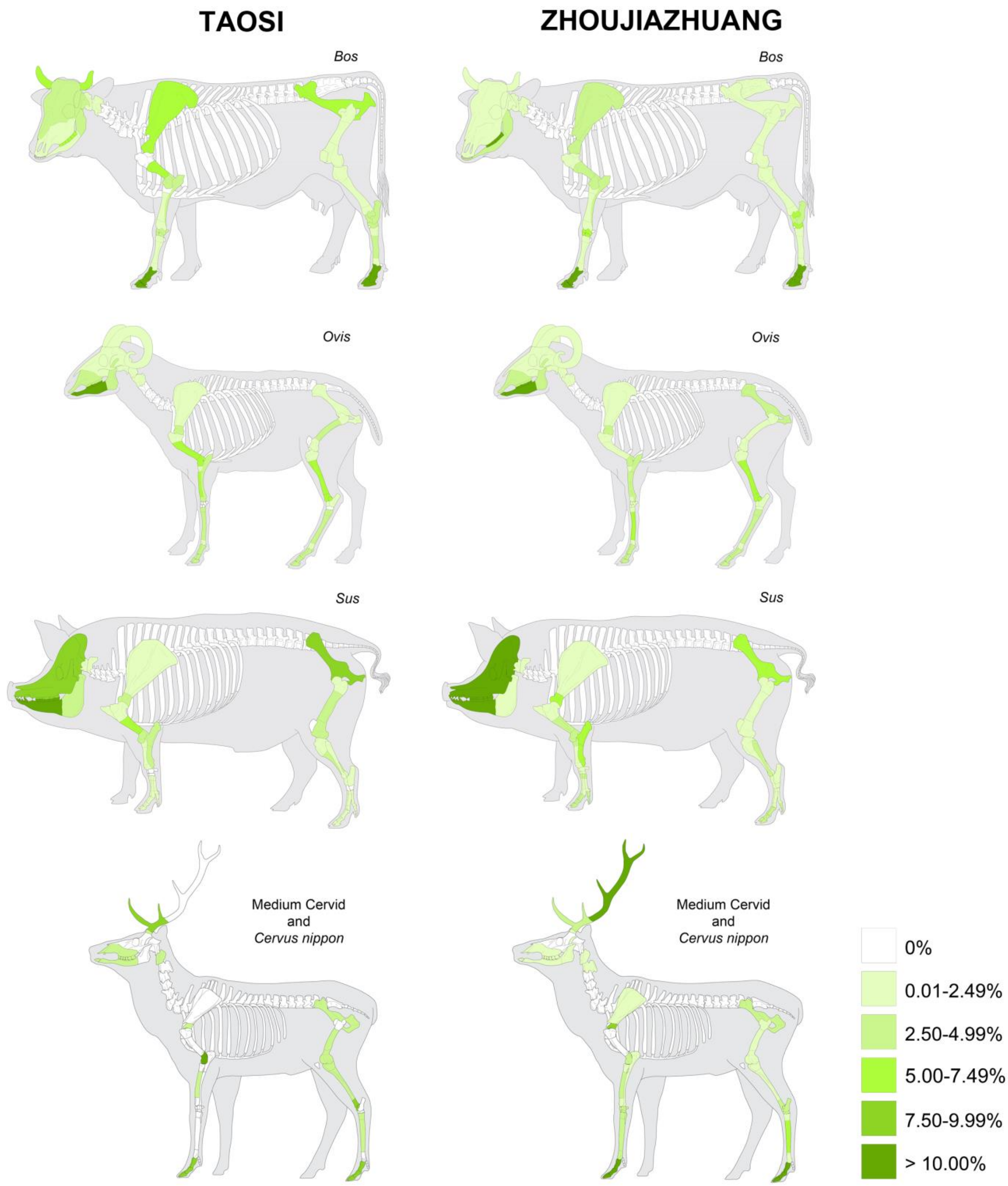

Figure 3.2. Percentage of total NISP (worked and unworked) for each taxon according to element. Ribs and vertebrae were generally not identified to taxon and are not included. *Bos*, *Ovis*, and *Sus* images: Dessin Michel Coutureau (Inrap), en collaboration avec Vianney Forest-© 1996 ArchaeoZoo.org. D'après: Robert Barone, 1976. *Anatomie comparée des mammifères domestiques*, *Tome I Ostéologie – atlas*, Paris: Vigot, pl. 7 (p. 22), pl. 8 (p. 23), and pl. 9 (p. 24). Cervus image: Dessin J.-G. Ferrié – © 2004 ArchaeoZoo.org. Adapté d'après le squelette de renne dessiné par Cédric Beauval et Michel Coutureau pour ArchaeoZoo.org en 2003.

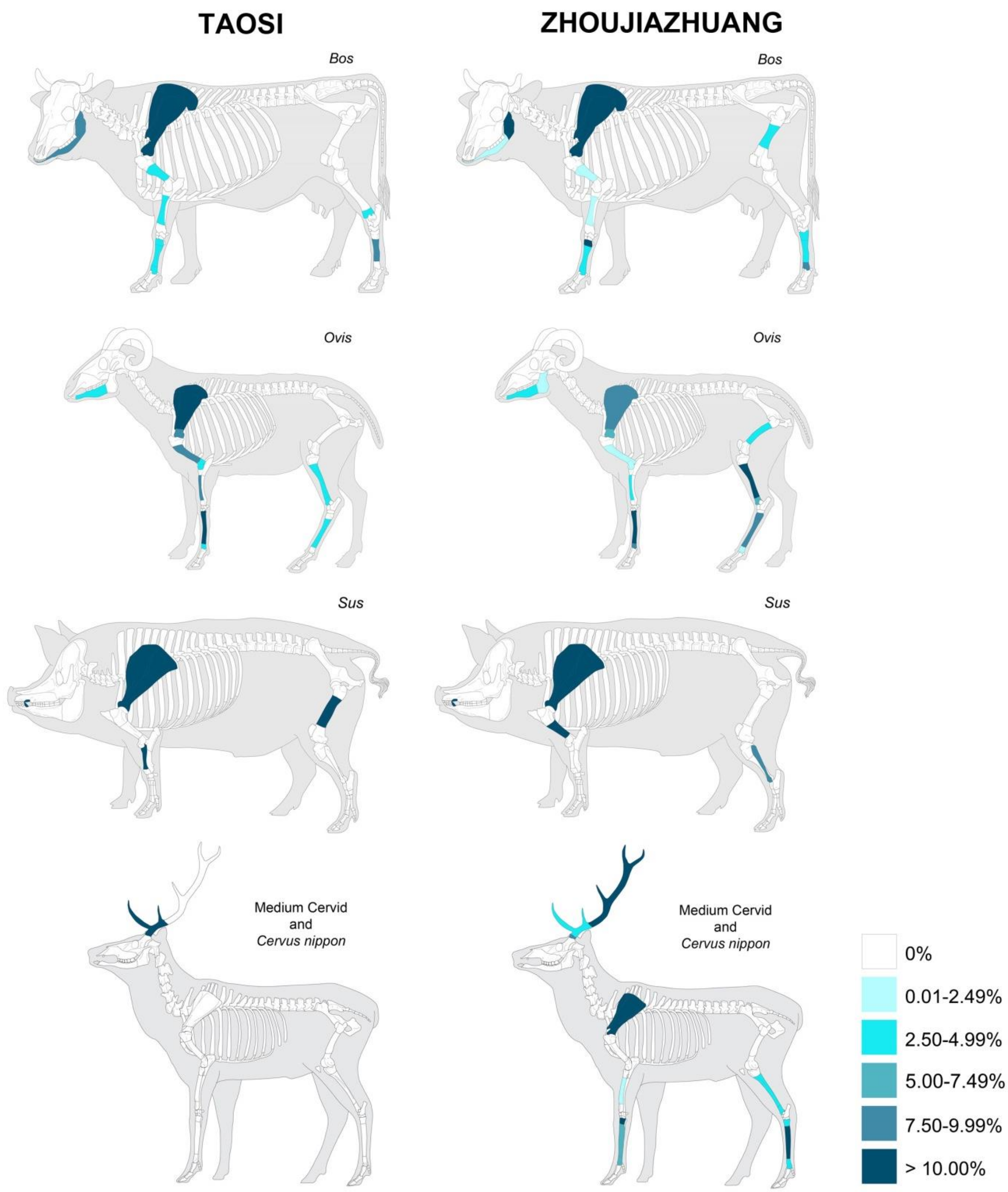

Figure 3.3. Percentage of artifacts identified to skeletal element according to taxon. Ribs and vertebrae were generally not identified to taxon and are not included. *Bos*, *Ovis*, and *Sus* images: Dessin Michel Coutureau (Inrap), en collaboration avec Vianney Forest-© 1996 ArchaeoZoo.org. D'après: Robert Barone, 1976. *Anatomie comparée des mammifères domestiques, Tome I Ostéologie – atlas*, Paris: Vigot, pl. 7 (p. 22), pl. 8 (p. 23), and pl. 9 (p. 24). *Cervus* image: Dessin J.-G. Ferrié – © 2004 ArchaeoZoo.org. Adapté d'après le squelette de renne dessiné par Cédric Beauval et Michel Coutureau pour ArchaeoZoo.org en 2003.

Production methods:

I divided bone artifact production at Taosi and Zhoujiazhuang into three steps: 1) primary reduction through the removal of the articular ends or protruding portions of bones to make tubes or flat segments; 2) formation of rectangular blanks or preforms; and 3) shaping and finishing by grinding or polishing the artifact into the desired final shape. Occasionally objects were further decorated with incisions or additional polishing. Although some scholars include additional reduction steps for core and blank refinement (e.g., Emery 2008), the same basic bone working production steps are generally shared cross-culturally due to the anatomical constraints of bone (Choyke and Bartosiewicz 2001; Gates St. Pierre and Walker 2007; Legrand-Pineau et al. 2010; Luik et al. 2005; Wake 1997, 2001).

People at Taosi and Zhoujiazhuang used four primary techniques for working bone during production steps 1 and 2: 1) direct percussion; 2) wedge splitting; 3) flexion breakage, and; 4) the groove-and-splinter technique. I provide brief descriptions below, but more detailed descriptions of these common bone working techniques with illustrations can be found in David (2007 and 2015) and Provenzano (2001).

Many of the Taosi and Zhoujiazuang artifacts were formed using *direct percussion* hits from a hard object, resulting in flakes that could be used as blanks (Figure 3.9c) or fragments with broken edges that could be ground into perforator or spatula shapes (Figure 3.13a and c). Direct percussion was also used to remove flakes from blanks in order to further shape the artifact (Figure 3.16b). *Wedge splitting*, an indirect percussion technique in which a wedge is forced into a space or crack in the bone, was also used to split bones either using a single hit from an articular end (Figure 3.9a) or by slowly moving the wedge down the length of the bone and striking it multiple times (Figure 3.9d and Figure 3.23b). Some bones and antlers were broken by bending them over an anvil, resulting in jagged *flexion* breaks (Figure 3.4c, right side). Finally, some bones and antlers were broken using a *groove-and-splinter* technique (Clark and Thompson 1953) in which a stone knife or flake was used to make a score mark part way through the bone (Figure 3.5). The application of percussion force or flexion/bending pressure was then used to break the bone along the score mark. Most of the score marks in the Taosi and Zhoujiazhuang assemblages appear to have been made by ground stone knives such as those identified by Zhai (2012: 35-36), resulting in cut marks that are wide, smooth, and V-shaped in cross section (Figure 3.10b). Some score marks were also made by stone flake tools, resulting in abrasions and parallel lighter cuts running parallel to the main score mark (Figure 3.5c, left).

Techniques used for production step 3 include grinding, polishing, perforating, and incising. Shaping of bone artifacts was primarily done by *grinding*, or moving the bone over an abrasive object with a uni-directional motion resulting in parallel striations on the bone (Figure 3.11b and Figure 3.30b). Some artifacts were also *polished* by rubbing the object against a slightly abrasive surface, resulting in a shiny and smooth appearance (Figure 3.12c). Occasionally, a stone flake was used to cut shallow *incision* lines or decorations (Figure 3.30c and d). Finally, some bone objects and shell ornaments were *perforated* using a punch tool or by gouging a hole in the bone, resulting in holes with rough edges (Figure 3.21c and Figure 3.26c and d).

Artifact types:

There is currently no standardized way to classify bone artifacts from Neolithic archaeological sites in China. I classified artifacts using terms that roughly correlate with artifact categories frequently seen in Chinese archaeological reports (e.g., blanks (*guliao* 骨料),

perforators/awls/points (*zhui* 锥), spatulas (*bi* 匕), chisels (*zao* 凿), needles (*zhen* 针), knives (*dao* 刀), projectile points (*zu* 镞), and oracle bones (*bugu* 卜骨)) as well as a few additional terms such as tubes and rasps. These divisions are purely based on form. Artifacts within the same categories may not have had the same function. Some tools were opportunistic, such as the perforators and spatulas made from the bones of numerous taxa and many different skeletal elements (Choyke 1997). Others were carefully planned tools, such as the mandible knives that use a limited set of taxa and skeletal elements and follow standardized production steps, and reflect a shared manufacturing tradition at Taosi and Zhoujiazhuang (Choyke 1997 and 2001).

Artifacts in productions step 1: Primary reduction

Blank production waste (Taosi N=16; Zhoujiazhuang N=107) and possible blank production waste (Taosi N=4; Zhoujiazhuang N=28):

Artifacts classified as blank production waste include discarded rough pieces of antler, long bone articular ends, long bones that were split longitudinally in preparation for blank production, and any other portions of bones discarded during tube and blank preparation. Many of these artifacts have groove-and-snap markings.

Figure 3.4 shows some examples of antler blank production waste including the burr/pedicle area (Figure 3.4a and b) and discarded portions of tines (Figure 3.4c). The flat wide area of the beam, such as the piece shown in Figure 3.4d, would have been further worked into blanks. Figure 3.5 shows examples of artiodactyl long bone articular ends removed using transverse groove-and-snap cuts during tube production. Figure 3.6 shows the ascending ramus of a cattle mandible removed with a transverse groove-and-snap cut. This piece represents debris from the production of a mandible knife.

Figure 3.4. Blank production waste and possible blank production waste made of antler: a) *Cervus nippon* antler (naturally shed) with brow tine and main part of beam removed with score-and-snap technique using a chopping tool (T-257); b) *Cervus nippon* antler (not naturally shed, chopping marks are visible around pedicle to remove the antler from the skull) with brow tine and main part of beam removed with score-and-snap cuts (Z-2016); c) *Cervus nippon* antler tine with transverse score-and-snap cut to remove the tip (left side) and flexion break closer to the beam (right side) (Z-2017); d) *Cervus nippon* antler beam with flexion breaks and score-and-snap breaks (Z-2794).

Figure 3.5. Blank production waste showing the removal of long bone articular ends during tube production using the groove-and-snap technique: a) *Bos* distal metacarpal (Z-3100); b) *Ovis* distal metacarpal (Z-5189); c) *Ovis* distal metacarpal (Z-2003, left) and *Capreolus* distal metatarsal (Z-2004 right); d) *Cervus nippon* proximal metacarpal (Z-1844).

Figure 3.6. Horizontal ramus portion of a large bovine mandible (Z-4203) removed with a groove-and-snap cut during production of a mandible knife like the one shown at the bottom of the image (Z-3619). The knife is broken, but it has a sharpened edge on the left side and a gouged hole still visible on the right side.

Tubes (Taosi N=9; Zhoujiazhuang N=8) and possible tubes (Taosi N=0; Zhoujiazhuang N=15):

Tubes are long bone shafts with the articular ends removed (Figure 3.7). In most cases, tubes would have been split longitudinally into blanks (Figure 3.8 shows tubes with longitudinal score marks). In some cases, tubes may have also been made into tube beads or rings. For example, the tube in Figure 3.7d has multiple scoring marks that suggest the artisan was trying to produce narrow bone rings.

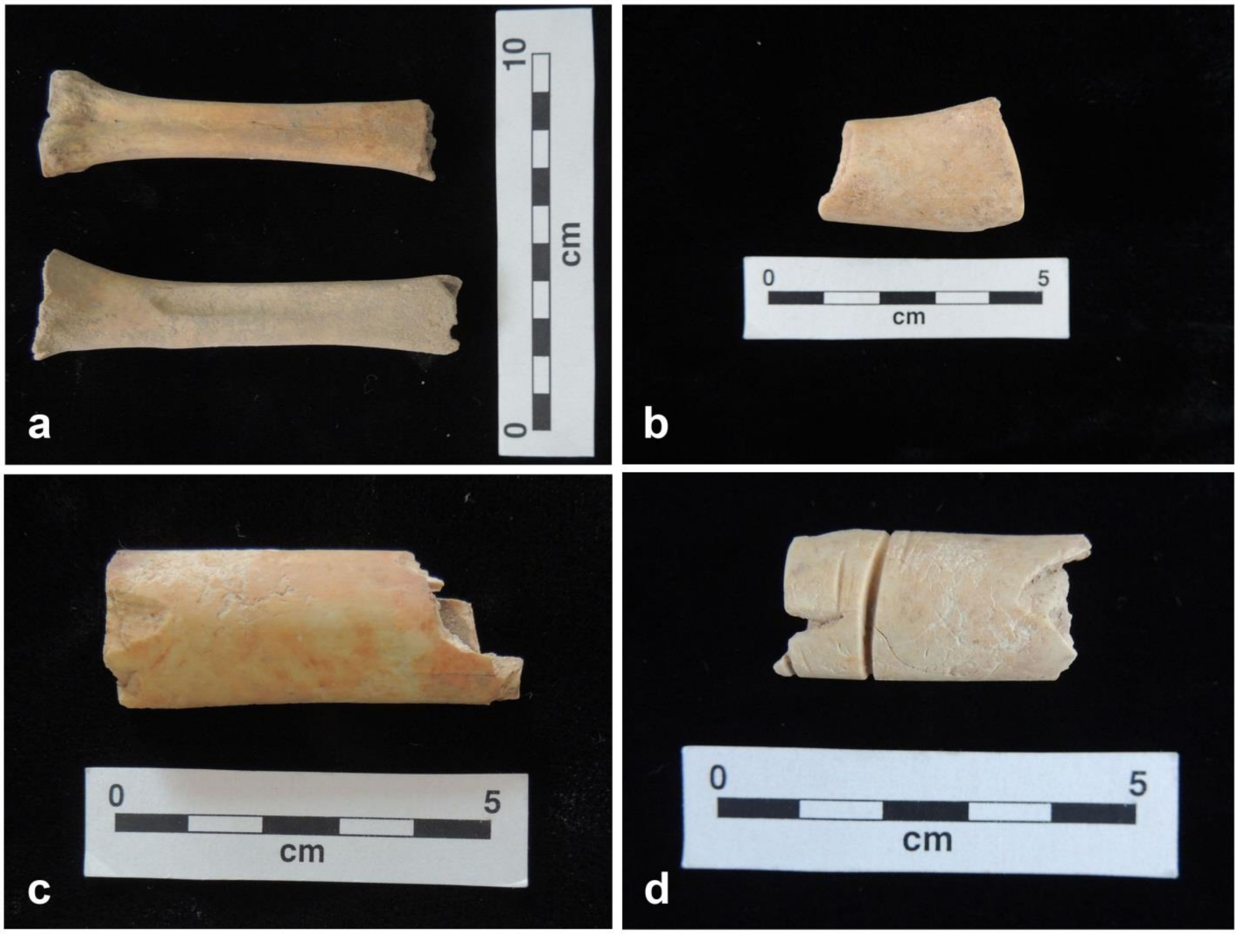

Figure 3.7. Tubes: a) *Ovis*/*Capra* metacarpal with distal end removed with percussion hits (T-442, top) and an *Ovis*/*Capra* radius with a score-and-snap cut to remove the distal end and percussion breaks at the proximal end (T-436, bottom); b) medium mammal femur shaft with polishing over the edges of transverse breaks (Z-4668); c) medium bovid radius from Zhoujiazhuang with distal end removed with percussion breaks (Z-2778); d) medium mammal femur shaft with multiple transverse score-and-snap marks (Z-5191).

Figure 3.8. Tubes with longitudinal score-and-snap marks in preparation for making blanks: a) medium bovid metatarsal shaft (Z-2335); b) large bovid metacarpal shaft (T-706).

Artifacts in production step 2: Blank and preform production

Blanks (Taosi N=21; Zhoujiazhuang N=104) and possible blanks (Taosi N=9; Zhoujiazhuang N=5):

Bone artisans split tubes longitudinally to form long rectangular blanks (Figure 3.9 and 3.10) using direct percussion flaking, wedge splitting, or longitudinal groove-and-snap cuts. Some flaked shell blanks were also made in circular shapes.

Figure 3.9. Blanks: a) medium mammal shaft fragment formed by wedge splitting from the articular end (Z-4580); b) large bovine proximal metacarpal with three longitudinal score and snap marks for making blanks (Z-3295); c) medium mammal shaft fragment formed into a blank with direct percussion hits (Z-4581); d) medium or large cervid metacarpal split longitudinally with wedge splitting hits down the length of the shaft (Z-WB56).

Figure 3.10. Blanks: a) medium mammal shaft fragment showing longitudinal score-and-snap cuts from both the outside and inside surfaces (T-1144); b) medium or large mammal shaft fragment with deep longitudinal score marks on the inside surface of the shaft (T-230); c) *Ovis*/*Capra* metatarsal shaft with proximal end removed with transverse score-and-snap cut and with two longitudinal score-and-snap cuts to split the shaft in half (T-227); d) large bovid metatarsal shaft with transverse cut mark to remove distal end and longitudinal wedge splitting (T-46).

Artifacts in production step 3: Shaping and finishing

Antler point tools (Taosi N=0; Zhoujiazhuang N=10) and possible antler point tools (Taosi N=1; Zhoujiazhuang N=1):

The natural activities of living deer can produce multi-directional scratches, tip fractures, polishing, and other markings on antler surfaces that can be easily mistaken for human-caused modifications (Olsen 1989; Jin and Shipman 2010). I cautiously identified a few antler point tools at Zhoujiazhuang with what appear to be flexion breaks or score-and-snap breaks to remove the tine from the main antler beam. The tines were usually polished, had parallel grinding marks over large areas, or had deep cut marks or chop marks on the surface, suggesting that these modifications were not natural (Figure 3.11). Only one possible antler point tool was found at Taosi.

Figure 3.11. Antler point tools: a) tine with parallel transverse cut marks on right side and smooth scoring mark where the tine was removed from the beam (Z-WB44); b) tine with parallel grinding marks over several large areas and smooth scoring mark where the tine was removed from the beam (Z-2463); c) highly polished tine with small flakes removed from tip and larger flake removed from proximal end (Z-WB46); d) possible antler point tool that is highly polished and burned (Z-WB45).

Perforators (Taosi N=19; Zhoujiazhuang N=69):

I use the generic term "perforator" to refer to any pointed objects including awls and pins because it is not always possible to distinguish between these artifact types when objects are broken and without use-wear analysis. Most perforators were formed by grinding and/or polishing one end of a rectangular blank. Sometimes expedient tools were formed by grinding and polishing a naturally pointed shaft break into an even sharper point. Figures 3.12, 3.13, and 3.14 show a selection of perforators identified at both sites.

Figure 3.12. Perforators from Taosi: a) medium bovid metapodial shaft (T-249); b) medium mammal unidentified shaft fragment (T-229); c) medium or large mammal unidentified fragment ground and polished over entire surface of the artifact (T-1330); d) *Sus* canine split longitudinally and ground/polished into a point at one end (T-1146).

Figure 3.13. Perforators from Zhoujiazhuang: a) *Ovis*/*Capra* metatarsal with break at distal end of shaft ground into a point (Z-WB07) ; b) *Cervus nippon* metatarsal split longitudinally and polished into a point at the distal end of the shaft (Z-3262) ; c) Large mammal unidentified fragment (possibly a rib of a large carnivore) ground and polished into a sharp point (Z-3290); d) *Sus* canine split longitudinally, removed from base of tooth with score and snap break, and ground and polished into a point at one end (Z-4715).

Figure 3.14. More perforators from Zhoujiazhuang: a) burned medium mammal shaft fragment split longitudinally and ground into a point at one end (Z-WB28); b) medium mammal rib ground at an angle to make a point (Z-WB37); c) medium mammal shaft fragment with one end ground into a very fine point (Z-WB52); d) Medium mammal shaft fragment with a naturally pointed break further ground into a point (Z-4911).

Spatulas (Taosi N=4; Zhoujiazhuang N=56):

Spatulas are long narrow objects with one or both ends ground into an acutely angled, rounded working edge that could be used as a burnisher, scraper, or smoother. Some spatulas are very flat and some are more scoop-shaped. Scoop-shaped spatulas frequently make use of the natural curve of long bone shafts. Figures 3.15 and 3.16 show a selection of spatulas identified at both sites.

Figure 3.15. Spatulas: a) medium bovid or cervid metatarsal with one end rounded and thinned into a narrow spatula edge (T1329); b) medium mammal unidentified shaft fragment with groove carved down length of the bone and one end shaped into rounded spatula edge (Z-WB51); c) cervid antler with both ends ground and polished into rounded edges (Z-WB54); d) highly polished large bovine or cervid metapodial with one end flattened into a fairly straight spatula edge (Z-WB55).

Figure 3.16. More spatulas: a) large mammal unidentified fragment that is highly polished and thinned into a spatula edge on one side (Z-3288) ; b) large mammal shaft fragment with one end polished into a rounded edge and with longitudinal flakes removed from other end (Z-WB20); c) medium mammal shaft fragment with one end polished into rounded edge (Z-4146); d) *Ovis*/*Capra* tibia with distal end ground flat and mid-shaft break polished into a rounded edge (Z-WB27).

Chisels (Taosi N=1; Zhoujiazhuang N=7):

Chisels are ground at sharp angles to form a very straight edge. Most chisels are narrow, and maintain a uniform thickness down the length of the tool (Figure 3.17).

Figure 3.17. Chisels: a-b) two views of a chisel made from a large mammal unidentified shaft fragment (T-1334) ; c-d) two views of a chisel made from a medium cervid metatarsal shaft (Z-3821).

Knives (Taosi N=1; Zhoujiazhuang N=9) and possible knives (Taosi N=5; Zhoujiazhuang N=5):

Cattle and sheep mandibles were frequently worked into large knives. It is also possible that these tools were used as spades or shovels. The production steps for making the mandible tools were highly standardized. First, the ascending ramus was removed and discarded. Next, the teeth were removed and the most anterior portion of the mandible was broken or ground flat. The gonion angle was then ground into a sharp cutting edge. In most cases a large hole was gouged a few centimeters back from the knife edge. The horizontal ramus may have been used as a handle for these knife tools, but I did not identify any complete artifacts and it is possible that two separate tools were being made: a knife from the more posterior part of the horizontal ramus and a scraper tool from the more anterior part of the horizontal ramus. Some examples are shown in Figures 3.18 through 3.21.

Two other kinds of knives include small, narrow knives made from split ribs that were ground along one edge and knives made from thick white *Margaritiana* sp. shells (Figure 3.22).

Figure 3.18. Possible knife handles (a-c) and knife (d) from Taosi: a-b) two views of a highly polished large bovine mandible with the most anterior portion and incisors removed (T-590); c) large bovine mandible with anterior portion of mandible and teeth removed (T-173); d) medium or large mammal mandible fragment (found in the same context as T-173 and possibly from the same broken artifact) with gonion angle (left side of image) ground and polished into a sharp knife edge (T-174).

Figure 3.19. More knife handles and possible knives from Taosi: a-b) two views of a highly polished large bovid mandible with anterior portion removed and with score and snap cut on interior/lingual side (T-1147); c) highly polished medium or large mammal mandible, left side is rounded and flattened into a dull edge and right side shows what remains of a circular perforation hole (T-228); d) highly polished *Ovis*/*Capra* mandible with teeth removed suggesting that it was possibly part of a knife handle (T-862).

Figure 3.20. Knives and possible knives from Zhoujiazhuang: a) possible knife handle made from a polished *Ovis*/*Capra* mandible with broken teeth and score-and-snap cuts to remove the anterior part of the horizontal ramus (Z-4142); b) large bovine mandible gonion angle that is ground flat to make a sharp knife edge (Z-3283); c) possible knife handle made from a highly polished *Ovis* mandible with broken teeth and anterior portion of the mandible ground flat (Z-3386); d) *Ovis*/*Capra* mandible with gonion area ground and polished into a sharp knife edge (Z-3387), from the same context as Z-3386 and possibly from the same artifact.

Figure 3.21. Knives and possible knives from Zhoujiazhuang: a) possible knife handle made from a polished large bovid horizontal ramus with teeth removed and anterior portion of the mandible ground flat (Z-2437); b) possible large bovine knife with gonion angle ground and flaked into a blunt edge (Z-4716); c) large bovine mandible flaked into a rectangular shape with a hole gouged in the middle and one end ground into a blunt knife edge (Z-3377); d) a large mammal mandible with the gonion angle ground into a sharp knife edge and a hole gouged a few centimeters from the edge (Z-3252).

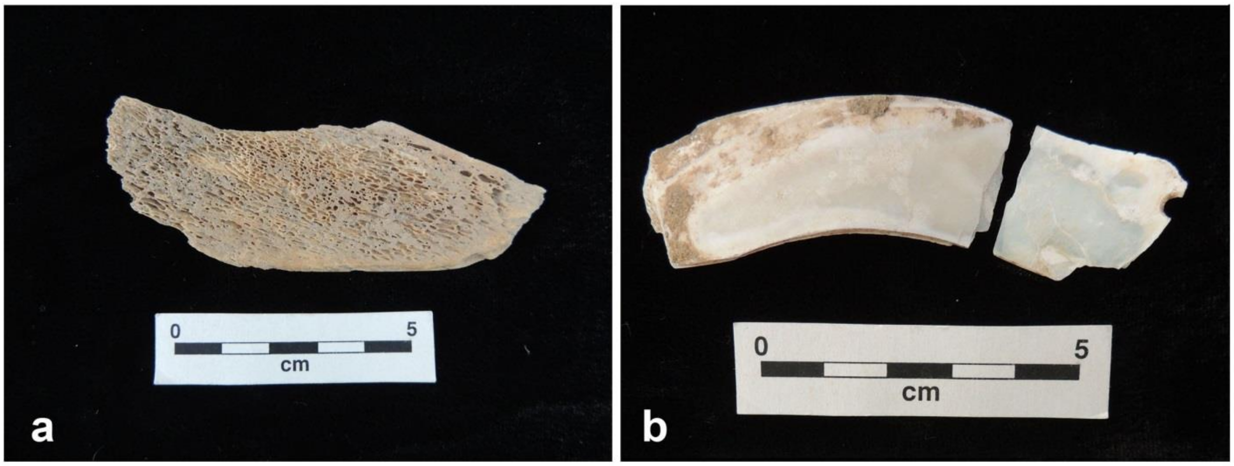

Figure 3.22. Knives from Zhoujiazhuang: a) large mammal rib split longitudinally and ground into a sharp edge (Z-4576); b) *Margaritianna* shell with sharpened edge and circular hole visible on right side (Z-1776).

Rasps (Taosi N=1; Zhoujiazhuang N=1):

I identified two rasps with deep serrated notches on one edge (Figure 3.23). In one case the rasp teeth were formed from pressure flaking and in the other case they were formed by cutting deep parallel grooves into the bone.

Figure 3.23. Rasps: a) large bovid or cervid rib that was split longitudinally, ground flat, and cut with deep grooves to form a serrated edge on the upper left side (T-175); b) interior dorsal shaft of a medium cervid that was split longitudinally with percussion flaking/wedge splitting along the length of the bone, additional pressure flaking was done along the top edge to form rasp teeth (Z-4583).

Needles (Taosi N=1; Zhoujiazhuang N=15):

Needles are usually narrower and more highly polished than perforators. Small holes for threading string or thread are still visible in most cases. Some examples are shown in Figure 3.24.

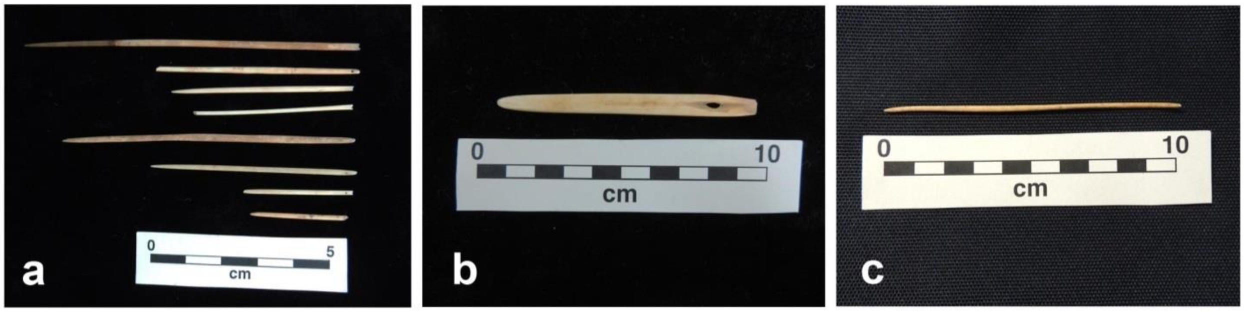

Figure 3.24. Needles: a) Selection of needles from Zhoujiazhuang; b) broad needle made from a medium or large mammal unidentified shaft fragment (Z-WB42); Long thin needle from a medium or large mammal unidentified fragment (T-1324).

Projectile points (Taosi N=6; Zhoujiazhuang N=117):

Projectile points at Taosi and Zhoujiazhuang have a variety of shapes. Type I points are diamond-shaped in cross section (Figure 3.25a and b), Type II points are long, flat, and rectangular in cross section (Figure 3.25c), and Type III points are circular in cross section (Figure 3.25d). Type IV points—the most common type of projectile points—are long, narrow, and triangular in cross section (Figure 3.25e and f).

Projectile points are frequently made from antler. I identified one antler projectile point at Taosi and 41 antler projectile points at Zhoujiazhuang; however, some finished projectile points were so heavily polished that it was not possible to determine if they were made from antler or bone. I also found one projectile point made out of shell at Zhoujiazhuang. Similar types of projectile points were also made out of stone at both sites.

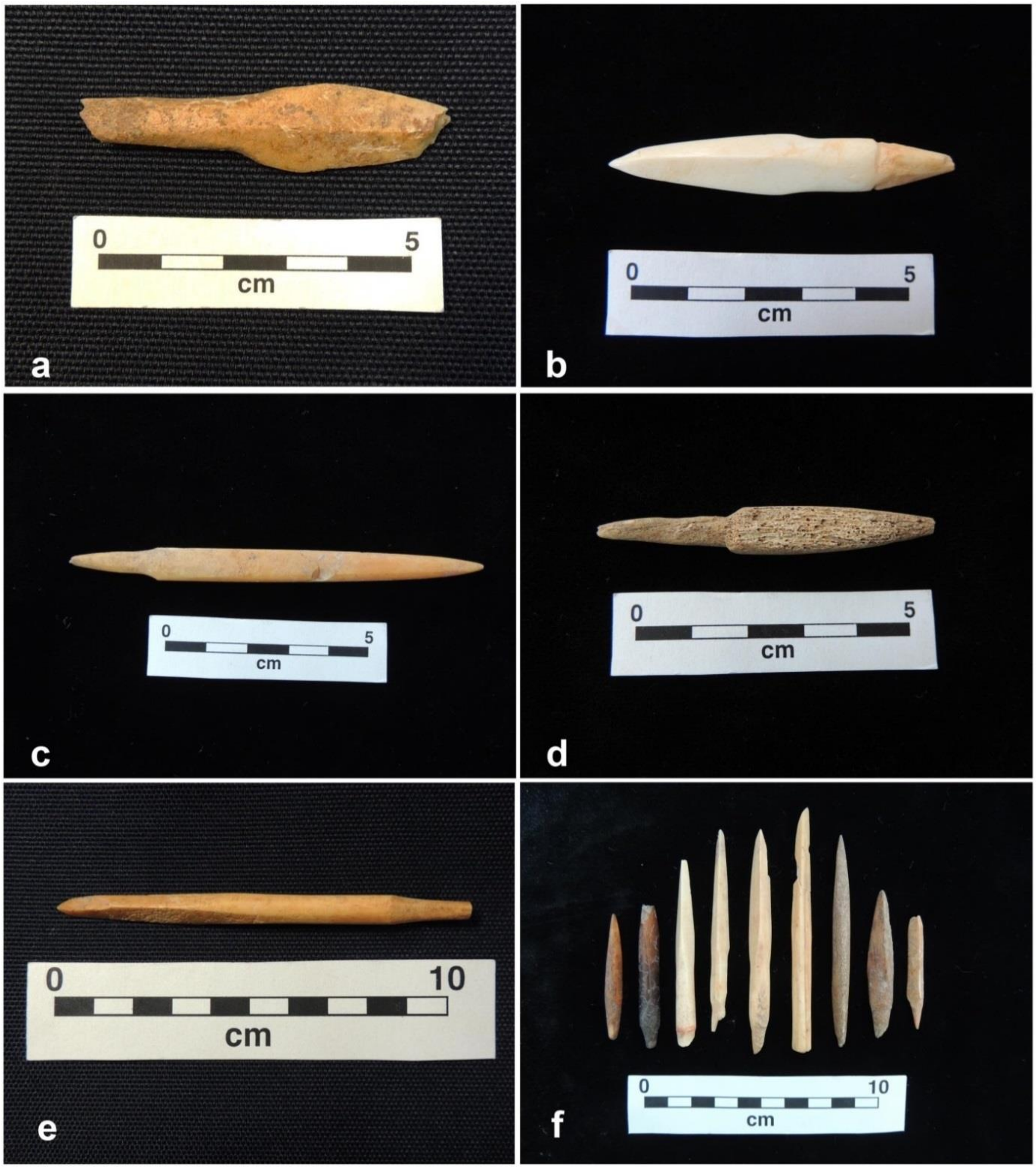

Figure 3.25. Projectile points: a) large mammal long bone Type I point (T-1170); b) large mammal long bone Type I point (Z-P01); c) medium or large mammal shaft fragment Type II point (Z-P12); d) cervid antler Type III point (Z-P38); e) unidentified large mammal bone Type IV point (T-1321); f) selection of Type IV points from left to right: burned cervid antler (Z-P59), burned cervid antler (Z-P60), medium or large mammal unidentified bone fragment with band of red paint around border between the main body and the base (Z-P61), medium or large mammal long bone shaft fragment (Z-P62), medium or large mammal unidentified bone fragment (Z-P63), medium or large mammal long bone shaft fragment (Z-P64), cervid antler (Z-P65), medium or large mammal unidentified fragment (Z-P66), medium or large mammal unidentified fragment (Z-P67).

Ornaments (Taosi N=2; Zhoujiazhuang N=46):

Sus canine teeth were often worked by removing them from the mandible, splitting them longitudinally into curved blanks, and then grinding or polishing them into flat plaques or ornaments (Figure 3.26a and b). Mollusk shells, primarily *Unio douglasiae* (Gray), were also frequently worked into decorative ornaments by perforating the shell so that they could be strung on a string (Figure 3.26c and d). Some shells were also flaked into flat plaques (Figure 3.26c, far left).

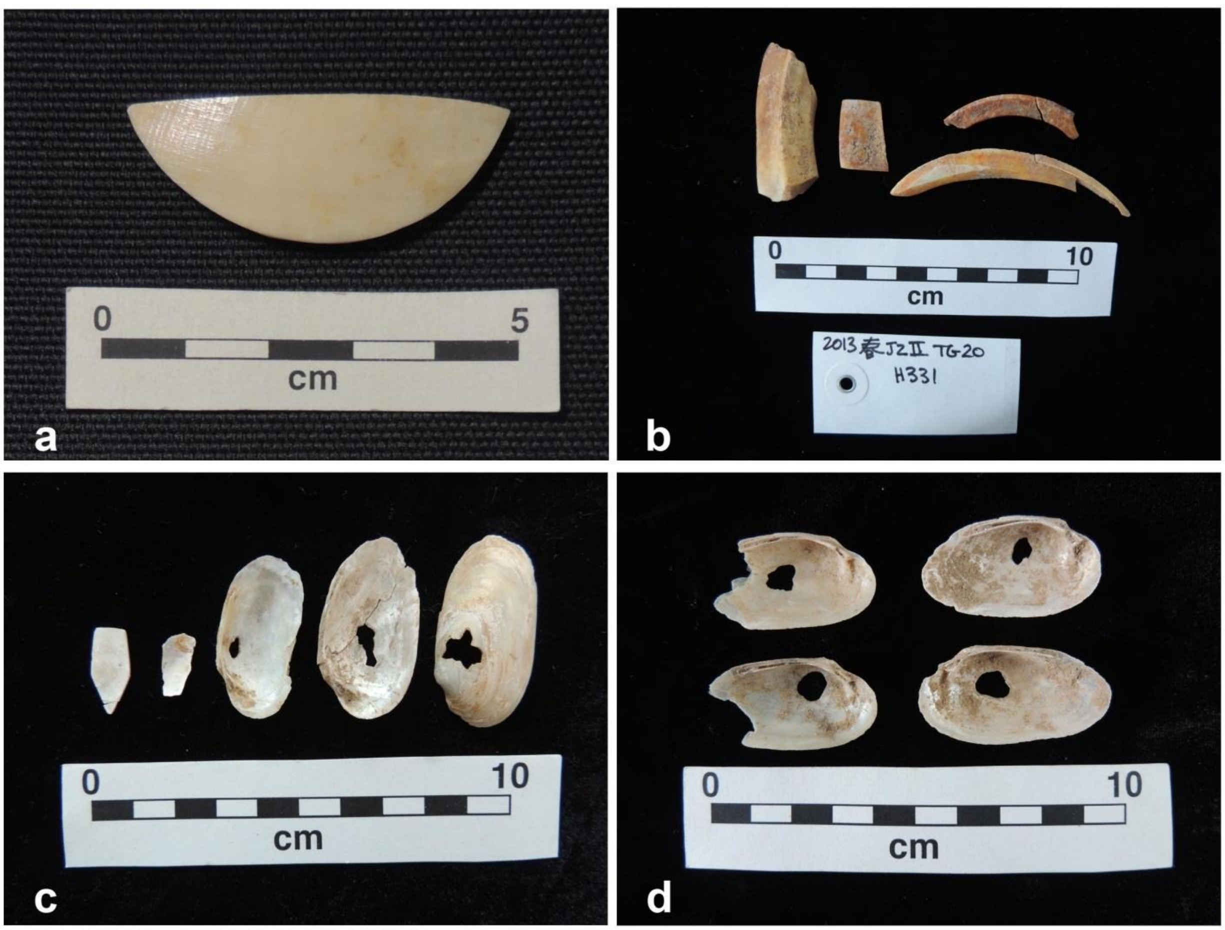

Figure 3.26. Ornaments: a) *Sus* canine plaque ground into semi-circular shape (T-1323); b) *Sus* canine fragments including a tooth that was split longitudinally and cut transversely with a score-and-snap cut (Z-2012), a split tooth ground into a rectangular plaque (Z-2013), a split tooth ground into a semi-circular shape (Z-2014), and an unidentified worked object made from a tooth that was split and ground (Z-2015); c) *Unio douglasiae* ornament in a rhomboid shape (Z-WB60), a flaked shell blank (Z-WB61), and ornaments with perforated holes (Z-WB62 to Z-WB64); d) *Unio douglasiae* shell ornaments with perforated holes (Z-4502 to Z-4505).

Oracle bones (Taosi N=22; Zhoujiazhuang N=41); Possible oracle bones (Taosi N=3; Zhoujiazhuang N=5); Possible oracle bone production waste (Taosi N=0; Zhoujiazhuang N=6):

Oracle bones are a common type of ritual artifact found at Neolithic and Bronze Age sites. They are usually made from thin, flat bones such as ungulate scapulas or turtle plastrons (Keightley 1978 and 1999: 236-247; Flad 2008). During pyro-osteomantic rituals, diviners would use a hot poker to burn the bone and interpret the cracks that formed under the application of heat and pressure (Keightley 1978).

Ungulate scapulas appear to have been used almost exclusively for oracle bone divination rather than for making utilitarian tools. The oracle bones made from pig, sheep, and deer scapulas were all burned directly on the surface of the bone, producing circular burn marks of varied sizes (Figures 3.27 and 3.28). The use of multiple taxa for divination and the process of burning bones without pre-treatment is characteristic of the more *ad hoc* divination practices of Late Neolithic China (Flad 2008). However, most of the cattle scapulas were flattened prior to burning by removing the spine and gouging or grinding away the thickest part of the blade near the neck (Figure 3.29). Sometimes circular hollows were also gouged into the bone to aid the formation of cracks (Figure 3.29a and c). To my knowledge, these are some of the earliest known examples of cattle oracle bones with gouged holes in China. The Taosi and Zhoujiazhuang cases may represent the initial stages in the development of what eventually became highly standardized cattle oracle bone carving and pre-treatment methods that reached their pinnacle during the Late Shang Dynasty at Anyang (Flad 2008; Keightley 1978; Pak 2011). I also identified a few cases of possible oracle bone production waste at Zhoujiazhuang that represent unburned scapulas with their spines removed in a way that suggests possible preparation for use as oracle bones (Table 3.5).

Ancient DNA analysis of some of these large bovine oracle bones reveals that in addition to domestic cattle (*Bos taurus*), people at Zhoujiazhuang also used wild aurochs (*Bos primigenius*) scapulas for making oracle bones (Brunson et al. forthcoming). Moreover, all of the aurochs scapulas were carved and ground to flatten the scapula blade in the same ways that the domestic cattle oracle bones were (Figure 3.29c and d). The extra care and effort put into preparing the bovine oracle bones may have been necessary due to their larger size, but may also suggest that these animals—be they domestic or wild—had a special ideological significance (Fiskesjö 2001).

Table 3.5.
Oracle Bones (OB), Possible Oracle Bones (POB), and Possible Oracle Bone Production Waste (PW).

	Taosi			**Zhoujiazhuang**		
TAXON	OB	POB	PW	OB	POB	PW
Sus domesticus	3			8		
Ovis aries/Capra hircus	3	1		5	1	
Medium Bovid					1	
Bos sp.	2					
Bos taurus	3			2		1
Bos primigenius				3		
L. Bovine	6	1		8	1	3
L. Bovine or Cervid				2		1
M. Cervid				2	2	
Cervus nippon				5		
Capreolus sp.				1		
M. Mammal				2		1
L. Mammal	4	1		3		
M. or L. Mammal	1					
TOTAL	22	3	0	41	5	6

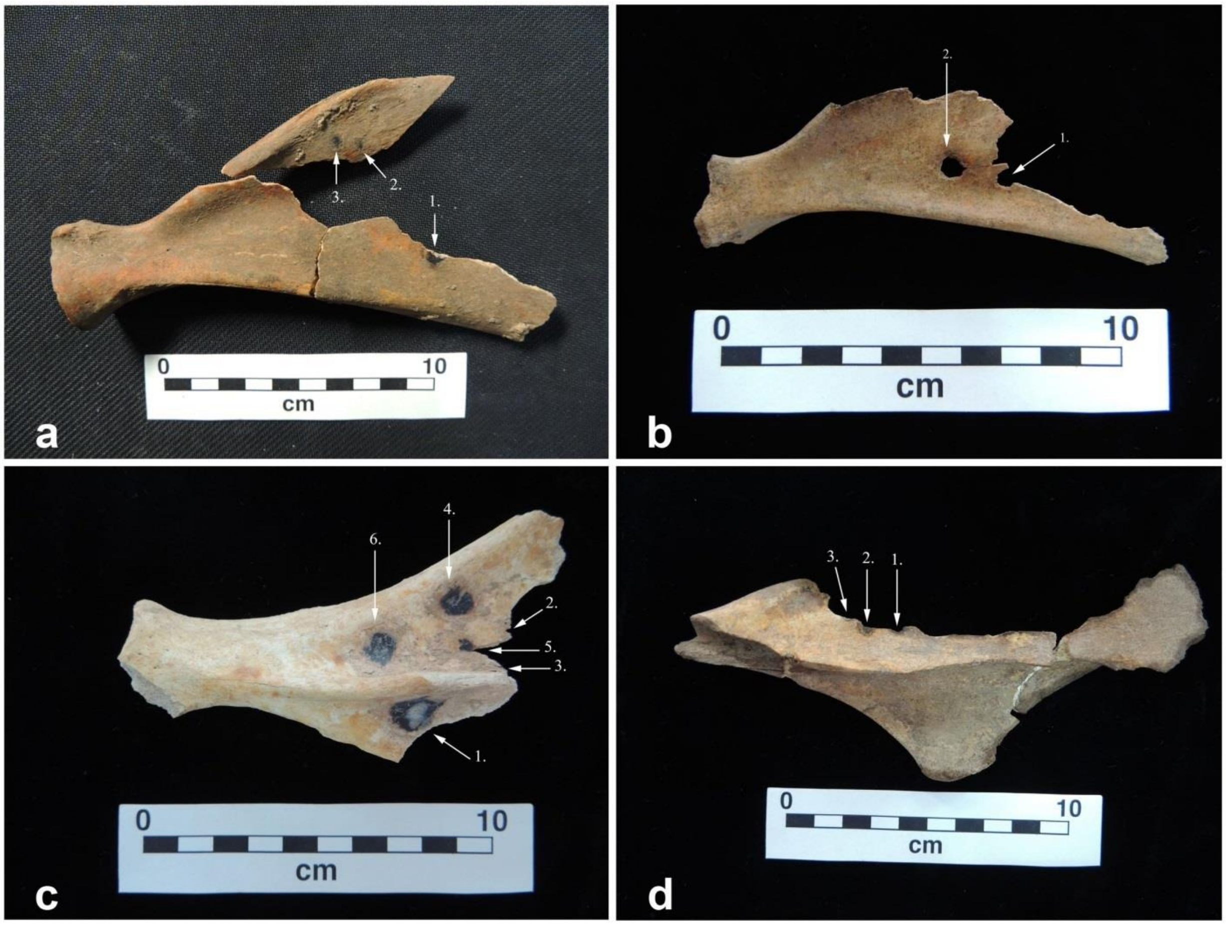

Figure 3.27. Pig scapula oracle bones: a) three small burn marks on medial side (T-1142); b) two small burn marks that broke through the bone on the medial side (T-651); c) large burn marks on the lateral side (Z-3198); d) at least three small burn marks on the medial side (Z-2694).

Figure 3.28. Sheep and deer oracle bones: a) *Ovis*/*Capra* scapula with at least six small burn marks on the medial side (T-1141); b) *Ovis*/*Capra* scapula with at least two small burn marks on the medial side (T-593); c) *Cervus nippon* scapula with at least three large burn marks on the lateral side and spine (Z-1738); d) *Capreolus* sp. scapula with at least six small burn marks on the medial side (Z-2001).

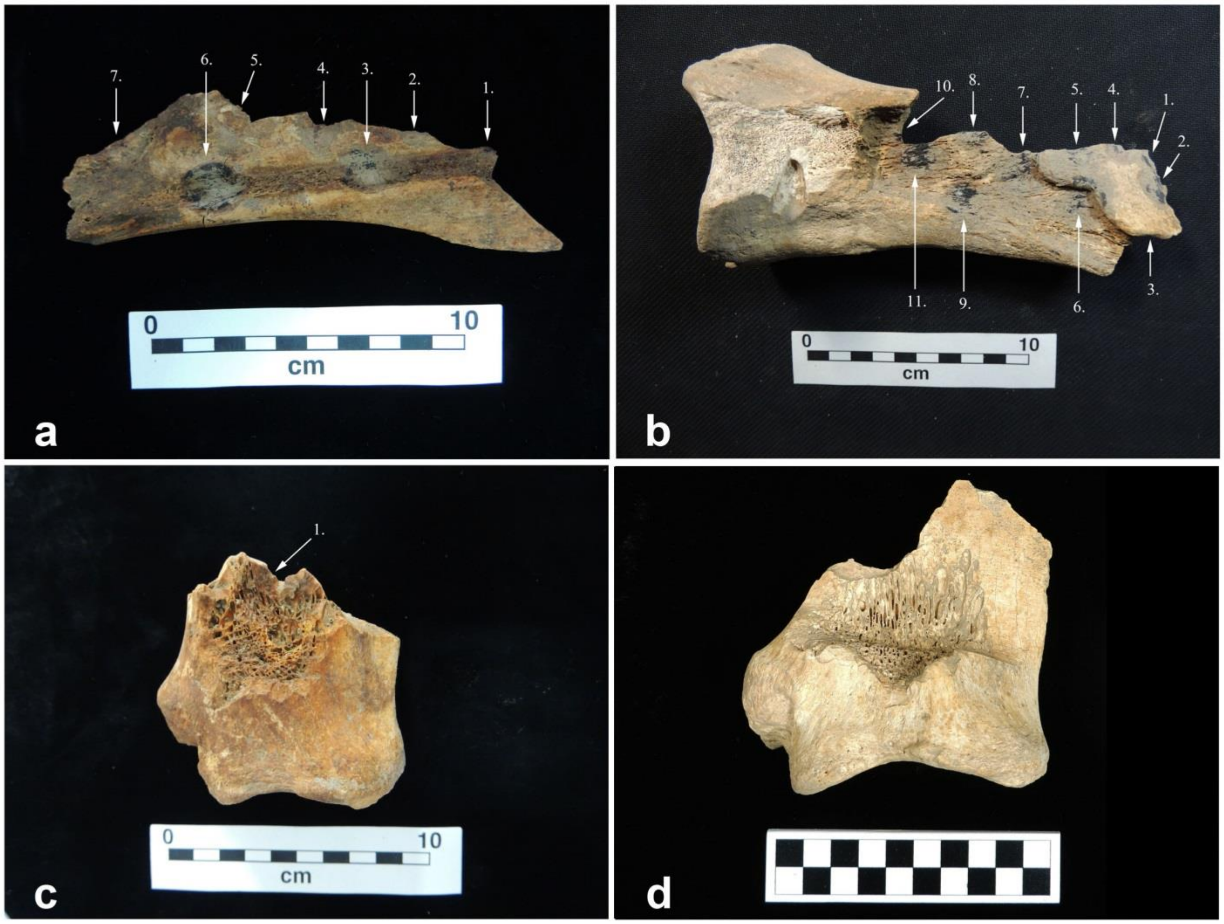

Figure 3.29. Large bovine oracle bones: a) *Bos taurus* scapula with spine removed and holes gouged prior to burning (T-689); b) *Bos* sp. scapula with spine removed and lateral portion of the scapula flattened, at least eleven large burn marks on exposed spongy bone (T-1338) ; c) *Bos primigenius* scapula with at least one burn mark and with the lateral side thinned (Z-2593); d) *Bos primigenius* scapula with no visible burn marks, but with lateral side removed in similar method as other oracle bones (Z-2436).

Unidentified worked objects (Taosi N=8; Zhoujiazhuang N=47):

Some worked objects could not be classified into the artifact types described above. A few are shown in Figure 3.30 including what may have been a scraping tool made from antler (Figure 3.30a) and what may have been a broken comb with decorative incisions (Figure 3.30d).

Figure 3.30. Other unidentified worked bone artifacts: a) *Cervus nippon* antler tool that may have been used as a hide scraper (T-1091); b) *Cervus nippon* tibia ground and polished into a wedge-shaped object (Z-3285); c) broken object made from a medium mammal unidentified shaft fragment with decorative incisions on the surface (Z-3218); d) medium mammal unidentified fragment ground into a very flat object with incised decorations and a drilled hole (Z-3503); e) *Sus* canine tooth objects formed into pyramidal shapes, the object on the top also has a circular hole in the base and may have been used as a decorative top for a hairpin or other ornament (Z-3404 and Z-3405); f) medium or large mammal unidentified fragment formed into an object with a flat tip (Z-WB36).

Human bone artifacts:

I identified a few worked human bone artifacts in both assemblages. Some of these artifacts appear to be expedient tools (Figure 3.31b and c) in which fractures were ground into points, but others were made by more carefully flaking (Figure 3.31a) or cutting the bone (Figure 3.31d). Human bone was commonly used as a raw material in Shang Dynasty workshops (Henan Sheng 2001: 460-483). The use of human bone at Taosi might represent the beginning of this new trend in raw material selection.

Figure 3.31. Human bone artifacts: a) skull fragment that has pressure flaking scars on the right side (T-589); b) fibula with a break on the left side ground into a perforator with a blunt point (T-1110); c) femur with break on the right side ground into a perforator point (Z-1822); d) distal femur from an immature individual (epiphyseal fusion line still visible) with a transverse cut half way through the bone and a longitudinal cut down the length of the shaft (Z-472).

Differences in the artifacts produced at Taosi and Zhoujiazhuang:

Figure 3.32 compares the numbers of artifacts identified at Taosi and Zhoujiazhuang and Table 3.6 lists the contexts of these finds. Most artifacts are from middens associated with lower-class residential areas, making cross-site comparisons useful. Although a systematic study of the spatial distribution of artifacts and production debris is still needed, neither Taosi nor Zhoujiazhuang appear to have had dedicated bone production locations. At Taosi, bone artifacts were made in both elite and non-elite residential areas of the site, suggesting that bone working was not a highly attached industry. In contrast to what is found in Shang period bone workshops, artifacts were also not produced in especially large quantities or in highly standardized sizes and shapes (Campbell et al. 2011; Li et al. 2011; Ma 2010). Therefore bone working was likely done by part-time independent specialists working at the household level (Costin 1991). A large proportion of both assemblages is waste associated with production steps 1 and 2 (blanks, tubes, and blank production waste), indicating that bone artifact production took place at similar degrees at both sites. However, there are some important differences in the proportions of finished artifacts that suggest differences in craft specialization between the two sites.

Projectile points make up a larger proportion of the assemblage at Zhoujiazhuang than at Taosi. This is consistent with greater exploitation of hunted wild animal resources at Zhoujiazhuang (Brunson et al. 2015). It may also indicate greater warfare at Zhoujiazhuang. There is also more antler production waste at Zhoujiazhuang, which suggests that people there may have specialized in making antler projectile points and traded these goods with nearby sites. Similar types of projectile points have been found at Taosi—including forty-five Type IV antler projectile points from middle phase royal burial M22 (Zhongguo et al. 2003) that are not included in the current study—but I found very little antler production waste at Taosi. In fact, there are very few cervid remains in the overall Taosi assemblage (Brunson 2015; Tao 2007). Therefore, people at Taosi may have imported finished antler projectile points from other sites such as Zhoujiazhuang. Different environmental conditions may have allowed people at Zhoujiazhuang to have greater access to hunted wild animals that promoted specialization in artifacts that used desirable wild animal raw materials such as antler.

Zhoujiazhuang also specialized in the production of *Unio* shell ornaments. I often found groups of *Unio* shell ornaments in the same pits as unworked *Unio* shells, suggesting that these artifacts were being produced in batches. Taosi contains very few worked or unworked *Unio* shells. Additional faunal analyses of other sites in the region are needed in order to know if the production and use of *Unio* ornaments was unique to Zhoujiazhuang or if Zhoujiazhuang traded these objects with other sites.

Finally, Taosi has a much larger proportion of oracle bones in the assemblage than Zhoujiazhuang. This may indicate a higher degree of ritual specialization at Taosi focusing on divinatory scapulamancy. Flad (2011: 77, 216-218) has linked larger numbers of oracle bones at the site of Zhongba (ca 1650-200 BCE) in Sichuan Province with the emergence of ritual specialists who were associated with specialized salt production at the site and whose divination activities peaked at times when the success of salt production was uncertain. A similar process of ritual specialization in combination with increasing craft specialization may have been taking place at Taosi and Zhoujiazhuang as well. As people gained wealth, they may have attempted to mitigate the uncertainty of economic endeavors through divination. Taosi's prominence as a political, ritual, and economic center that specialized in the production of multiple craft goods including ceramics, stone tools, and possibly wool textiles may explain why oracle bone divination was more common than at the less politically centralized Zhoujiazhuang. Additionally, the evidence for violence and instability at Taosi during the late occupation phase may have contributed to the greater use of oracle bone divination.

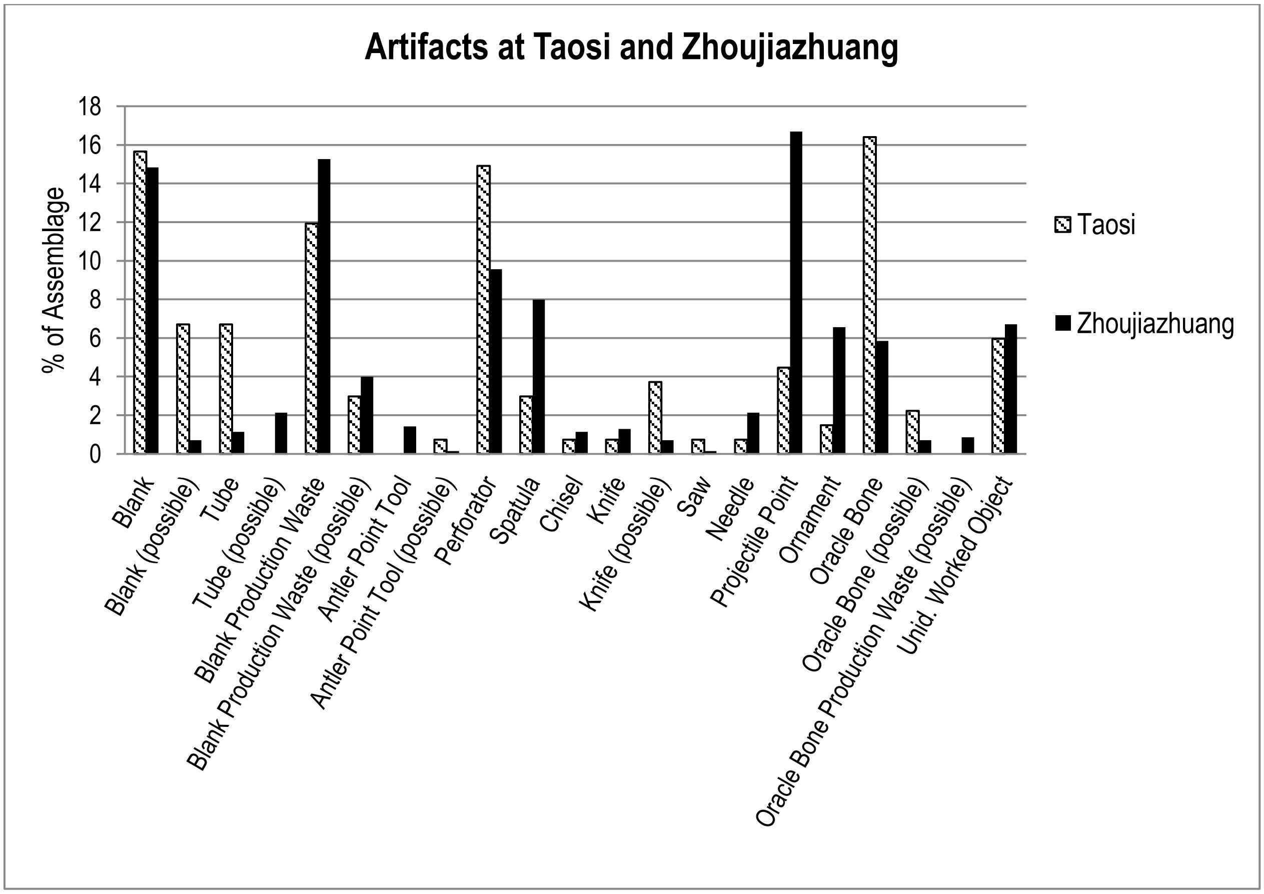

Figure 3.32.

Table 3.6.

Artifact Contexts for Taosi (TS) and Zhoujiazhuang (ZJZ). (M=Middle Taosi Phase; L=Late Taosi Phase; PK=Palace Kitchen; PF=Pond Feature; WF=Wall Fill; DL=Destruction Layer; DLM=Destruction Layer/Midden; GFL=General Fill Layer; MP=Midden Pit; T=Trench; BF=Burial Fill; HF=House Feature; SP=Zhoujiazhuang Sacrificial Pit).

SITE	**DATE**	**CONTEXT TYPE**	**Blank**	**Blank (possible)**	**Tube**	**Tube (possible)**	**Blank Production Waste**	**Blank Production Waste (possible)**	**Antler Point Tool**	**Antler Point Tool (possible)**	**Perforator**	**Spatula**	**Chisel**	**Knife**	**Knife (possible)**	**Rasp**	**Needle**	**Projectile Point**	**Ornament**	**Oracle Bone**	**Oracle Bone (possible)**	**Oracle Bone Production Waste (possible)**	**Unid. Worked Object**	**TOTAL**	**%**
TS	M	PK	1				1				1													3	2.2
	M	PF	1		1			1																3	2.2
	M	WF	4	4	1		1				7				1		1		1				2	22	16.4
	L	DL		1	1							1								1				4	3.0
	L	DLM	3		1		7	1							1					3			2	18	13.4
	L	GFL																1						1	0.7
	L	MP	10	3	3		5	2			9	3	1		2			4	1	14	2		4	63	47.0
	L	PF	1																					1	0.7
	L	WF	1	1	2		2			1	3			1	1	1		1		4	1			19	14.2
TOTAL			21	9	9		16	4		1	20	4	1	1	5	1	1	6	2	22	3		8	134	100
%			15.7	6.7	6.7	0.0	11.9	3.0	0.0	0.7	14.9	3.0	0.7	0.7	3.7	0.7	0.7	4.5	1.5	16.4	2.2	0.0	6.0	100	
ZJZ	L	FL					1	4	2		4	6	2	1				10	1				1	32	4.6
	L	MP	58	2	6	14	82	22	7	1	44	36	4	3	3	1	7	69	40	30	4	6	23	462	65.9
	L	T	5	0	2	1	10				3	1			1			3	3	8	1		2	40	5.7
	L	BF					1				1	1						1	1					5	0.7
	L	HF	3	1			3	1			5	1					1	3						18	2.6
	L	SP	38	2	0	0	10	1	1	0	10	11	2	5	1	0	7	31	1	3	0	0	21	144	20.5
TOTAL			104	5	8	15	107	28	10	1	67	56	8	9	5	1	15	117	46	41	5	6	47	701	100
%			14.8	0.7	1.1	2.1	15.3	4.0	1.4	0.1	9.6	8.0	1.1	1.3	0.7	0.1	2.1	16.7	6.6	5.8	0.7	0.9	6.7	100	

Note: See Supplemental Tables 3.2 and 3.3 for a complete list of excavation provenience designations.

Summary and conclusions:

Bone working was part of a mosaic of craft industries in Late Neolithic China that provided a foundation for Bronze Age state formation. Comparisons between the worked bone assemblages at Taosi and Zhoujiazhuang—two Longshan period sites with different levels of political centralization—reveal differences in production and ritual specialization that may help to explain Taosi's role as one of the most important political and economic centers in northern China during the late Longshan period. The worked bone assemblages at these sites also provide information about the adoption of sheep and cattle pastoralism during the late third millennium BCE and its effects on craft production.

In terms of raw material selection, Taosi is less taxonomically diverse than Zhoujiazhuang, reflecting greater specialization in artifacts made from domestic cattle and sheep bones. Although production was not directly attached to elites, access to raw materials may have been managed to some degree or at least subject to the effects of increasing separation between the people who specialized in raising or hunting animals and those that specialized in non-food production activities. The lower taxonomic diversity at Taosi may also be evidence for resource depression. Taosi was the largest population center in the region for several hundred years (He 2013). It is possible that wild taxa were overhunted at Taosi, but not at sites with short, rapid periods of population nucleation such as Zhoujiazhuang (Drennan and Dai 2010). The Zhoujiazhuang assemblage is more taxonomically diverse and contained some artifact types such as *Unio* shell ornaments, antler production debris, and projectile points that are not as common at Taosi. People at Zhoujiazhuang may have specialized in the production of antler projectile points that could be used in local hunting activities or traded with other sites like Taosi where people did not have frequent access to desirable antler raw materials.

The frequent use of sheep and cattle bone for making bone tools reflects the increasingly important role of these animals in both subsistence and craft production during the Taosi period. Sheep and cattle herding were adopted rapidly and were accompanied by the utilization of sheep and cattle bone for making utilitarian artifacts. The spread of pastoralism likely promoted the development of other related industries such as hide working and horn working as well. However, the different importance of sheep and cattle in bone in the worked bone assemblages at Taosi and Zhoujiazhuang and the different degrees to which people exploited sheep secondary products at these sites (Brunson et al. 2015) indicates that there was variation in how these animals were initially adopted. More zooarchaeological data is still needed, but at this point it seems as though Taosi may have been one of the most powerful centers in the region partially because of the high degree of specialization in raising sheep and cattle and producing associated animal crafts.

Sheep and cattle were also rapidly incorporated into Late Neolithic ritual practice. Sheep and cattle scapulas were frequently used in divination rituals at Taosi and Zhoujiazhuang. Taosi and Zhoujiazhuang also contain some of the earliest evidence for carved cattle oracle bones. This may represent the initial stages of the development of highly standardized cattle oracle bone preparation methods that became associated with Bronze Age state authority (Chang 1980, 1983; Flad 2008). Although sheep bones were frequently used for making both utilitarian and ritual artifacts at Taosi and Zhoujiazhuang, the practice did not continue later in the Bronze Age. Not only do the numbers of sheep (and other non-cattle) oracle bones decrease in frequency through time (Flad 2008), but sheep also appear to have been of little importance in the large-scale bone workshops of the Shang state (Campbell et al. 2011; Li et al. 2011; Ma 2010). Sheep were still important sources of meat at sites such as Anyang (Z. Li 2012), and sheep bone would have been available for use by bone crafters. This raises the question of why people at later Bronze Age centers did not use sheep bone for large-scale bone artifact production given the importance of sheep bone at earlier sites such as Taosi. Additional studies of bone working at other sites will help to determine what caused the shift toward cattle bones as the preferred raw material in Shang bone working.

Specialized craft production, including the production of worked bone artifacts, was a key part of the development of early Chinese states. The Taosi and Zhoujiazhuang cases demonstrate that data on bone working have great potential to clarify Longshan period economic and ritual practices. As more data from worked bone assemblages become available, studies of bone artifacts will make great contributions to ongoing discussions about the relationships between craft specialization and increasing social complexity in ancient China.

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Supplemental Table 3.1.
Number of Identified Specimens (NISP) and Minimum Number of Individual (MNI) Counts for Taosi and Zhoujiazhuang.

	TAOSI			**ZHOUJIAZHUANG**		
TAXON	NISP	MNI	%NISP	NISP	MNI	% NISP
WILD NON-MAMMAL :						
Mollusca	1	1	0.1	5	1	0.1
Bivalvia	1	1	0.1	2	2	<0.1
Lamprotula	0	0	0	2	2	<0.1
Lamellibranchia	0	0	0	0	0	0
Margaritiana sp.	0	0	0	2	1	<0.1
Unionodae	0	0	0	86	1	2.0
Unio douglasiae (Gray)	1	1	0.1	215	66	5.0
Unid. Fish	0	0	0	5	1	0.1
Cyprinidae	0	0	0	1	1	<0.1
Large Bird	3	1	0.3	5	1	0.1
Accipitridae	3	2	0.3	2	1	<0.1
Medium Bird	2	2	0.2	4	1	0.1
Phasianidae	3	2	0.3	8	3	0.2
Passeriformes	1	1	0.1	2	1	<0.1
Unid. Bird	0	0	0	1	1	<0.1
TOTAL WILD NON-MAMMAL:	15	11	1.6	340	83	7.9
WILD MAMMAL :						
Small Rodent	8	2	0.8	123	22	2.9
Rhizomyidae	1	1	0.1	1	1	<0.1
Hystrix sp.	0	0	0	2	1	<0.1
Lagomorpha	1	1	0.1	0	0	0
Lepus sp.	10	4	1.1	44	4	1.0
Small Carnivore	3	1	0.3	6	1	0.1
Meles sp.	0	0	0	1	1	<0.1
Felis sp.	2	1	0.2	0	0	0
Canidae	2	1	0.2	12	1	0.3
Nyctereutes procyonides	0	0	0	2	1	<0.1
Vulpes sp.	3	1	0.3	0	0	0
Medium Carnivore	0	0	0	0	0	0
Large Carnivore	2	1	0.2	0	0	0
Ursus sp.	3	2	0.3	3	1	<0.1
Cervidae	7	2	0.7	169	2	3.9
Large Cervid	0	0	0	1	1	<0.1
Cervus elaphus	0	0	0	1	1	<0.1
Elaphurus davidianus	0	0	0	3	1	<0.1
Medium or Large Cervid	2	2	0.2	55	1	1.3
Medium Cervid	12	4	1.3	144	8	3.3
Cervus Nippon	9	2	0.9	62	3	1.4
Small Cervid	0	0	0	9	2	0.2
Capreolus sp.	0	0	0	5	1	0.1
Medium Bovid or Cervid	13	2	1.4	148	5	3.4
Large Bovine or Cervid	8	2	0.8	49	2	1.1
Bos primigenius	0	0	0	3	2	<0.1
Bubalus sp.	0	0	0	5	1	0.1

TOTAL WILD MAMMAL:	86	29	9.0	848	63	19.6
DOMESTIC MAMMAL:						
Canis familiaris	51	7	5.4	188	13	4.4
Large Bovine	141	6	14.8	317	7	7.3
Bos sp.	7	2	0.7	27	4	0.6
Bos taurus	4	1	0.4	6	1	0.1
Bovidae	1	1	0.1	0	0	0
Medium Bovid	34	5	3.6	305	8	7.1
Ovis aries	91	19	9.6	471	71	10.9
Ovis aries/*Capra hircus*	93	6	9.8	489	19	11.3
Sus domesticus	430	28	45.1	1331	75	30.8
TOTAL DOMESTIC MAMMAL:	852	75	89.4	3134	198	72.5
TOTAL IDENTIFIED:	**953**			**4322**		
UNIDENTIFIED SPECIMENS:						
Small Mammal	18			94		
Medium Mammal	713			4406		
Medium or Large Mammal	22			124		
Large Mammal	89			677		
Mammal	611			5668		
Non-Mammal	1			0		
TOTAL UNIDENTIFIED:	**1454**			**10969**		

Taosi: Early Phase NISP=24; Middle Phase NISP=242; Late Phase NISP=687; Zhoujiazhuang: All materials date to the Late Taosi phase.

Supplemental Table 3.2.
Taosi Excavation Contexts (M=Middle Taosi Phase; L=Late Taosi Phase; PK=Palace Kitchen; PF=Pond Feature; WF=Wall Fill; DL=Destruction Layer; DLM=Destruction Layer/Midden; GFL=General Fill Layer; MP=Midden Pit)

PROVENIENCE	DATE	CONTEXT TYPE	Blank	Blank (possible)	Tube	Tube (possible)	Blank Production Waste	Blank Production Waste (possible)	Antler Point Tool	Antler Point Tool (possible)	Perforator	Spatula	Chisel	Knife	Knife (possible)	Rasp	Needle	Projectile Point	Ornament	Oracle Bone	Oracle Bone (possible)	Oracle Bone Production Waste (possible)	Unid. Worked Object	TOTAL
2010 JXTI T5013 CZK1 (1)	M	PK									1													1
2010 JXTI T5013 CZK1 (11)	M	PK					1																	1
2010 JXTI T5013 CZK1 (4)	M	PK	1																					1
2010 JXTI T5013 H94 (3)	M	PF	1		1			1																3
2013 JXTI TG32 Q15 基槽 2 垫土 2 层	M	WF	2																				1	3
2013 JXTI TG32 Q15 基槽 2 夯土内	M	WF	1	4	1						5				1		1		1					14
2013 JXTI TG33 Q4 基槽 II	M	WF	1				1				1												1	4
Q14 (I) 夯土内	M	WF									1													1
2013 JXTI TG33 (3B)	L	DL		1	1							1								1				4
2010 JXTI T5013 (3)	L	DLM	1				1	1							1					1			2	7
2013 JXTI TG32 (3) 层	L	DLM					1																	1
2013 JXTI TG32 (3B)	L	DLM	2		1		5													2				10
2013 JXTI TG33 (3A)	L	GFL																1						1
2010 JXTI T5013 H59 (1)	L	MP	1		1		2	1												1				6

2010 JXTI T5013 H59 (2)	L	MP	1		1		1	1												2	1			7
2010 JXTI T5013 H93 (2)	L	MP	2																	1				3
2010 JXTI T5013 H93 (3)	L	MP																	1	1				2
2013 JXTI TG32 H100	L	MP	1																	1			1	3
2013 JXTI TG32 H99	L	MP					1																	1
2013 JXTI TG33 H108	L	MP					1					2						1						4
2013 JXTI TG33 H110	L	MP																		2				2
2013 JXTI TG33 H113	L	MP	3	3							1	1			1								2	11
2013 JXTI TG33 H115	L	MP	1								2				1			1		4			1	10
2013 JXTI TG33 H116	L	MP									1										1			2
2013 JXTI TG33 H117	L	MP	1								1									1				3
2013 JXTI TG33 H118	L	MP																		1				1
2013 JXTI TG34 H101	L	MP																2						2
2013 JXTI TG34 H107	L	MP			1						1													2
2013 JXTI TG34 H115	L	MP									2		1											3
2013 JXTI TG34 Q16 解剖沟 H119	L	MP									1													1
2010 JXTI T5013 水塘	L	PF	1																					1
2013 JXTI TG32 Q15 基槽 1	L	WF			1		1																	2
2013 JXTI TG33 Q4 解剖沟 (基槽 I?)	L	WF			1		1													2	1			5
2013 JXTI TG33 Q4 解剖沟表界面	L	WF												1	1	1				1				4
2013 JXTI TG34 Q16	L	WF								1	1							1		1				4
2013 JXTI TG34 Q16 基槽内	L	WF	1	1							2													4
TOTAL			21	9	9	0	16	4	0	1	20	4	1	1	5	1	1	6	2	22	3	0	8	134
%			15.7	6.7	6.7	0.0	11.9	3.0	0.0	0.7	14.9	3.0	0.7	0.7	3.7	0.7	0.7	4.5	1.5	16.4	2.2	0.0	6.0	100

Supplemental Table 3.3.
Zhoujiazhuang Excavation Contexts (GFL=General Fill Layer; MP=Midden Pit; T=Trench; BF=Burial Fill; HF=House Feature; SP=Sacrificial Pit). All artifacts date to the late Taosi phase, but are divided into sequential stratigraphic phases (0-5) or are only identified to the Late Taosi Phase (L).

PROVENIENCE	DATE	CONTEXT TYPE	Blank	Blank (possible)	Tube	Tube (possible)	Blank Production Waste	Blank Production Waste (possible)	Antler Point Tool	Antler Point Tool (possible)	Perforator	Spatula	Chisel	Knife	Knife (possible)	Saw	Needle	Projectile Point	Ornament	Oracle Bone	Oracle Bone (possible)	Oracle Bone Production Waste (possible)	Unid. Worked Object	TOTAL
2011 T0906 (6)	0	GFL							1															1
2011 春 JZI T1106 H203 (4)	0	MP					1		1		1							1						4
2012 JZ 春 TG14 东 H276	0	MP																				1		1
2012 JZITG14 H282	0	MP																				1		1
H292	0	MP																1						1
2011 春 JZI T0806 M67	1	BF									1	1												2
2011 春 JZI T1306 H161	1	MP																1						1
2011 春 JZI T0806 (6)	2	GFL																1						1
2007 秋 JZI T1305 H12 (1)	2	MP									1							1						2
2007 秋 JZI T1305 H17	2	MP																1						1
2007 秋 JZI T1305 H28 (1)	2	MP																1						1
2007 秋 JZI T1305 H28 (4)	2	MP										1												1
2007 秋 JZI T1305 H33 (3)	2	MP									1													1
2007 秋 JZI T1305 H33 (4)	2	MP										1												1

2007 秋 JZI T1305 H33 (5)	2	MP						1	1		1			3
2012 春 JZI T1307 H237 (2)	2	MP		1										1
2007 秋 JZI T1305 (5)	3	GFL									1			1
2011 春 JZI T0906 (5)	3	GFL									1			1
2011 春 JZI T1306 (5)	3	GFL									1			1
2011 春 T0906 (5)	3	GFL					1							1
2009 秋 JZII T6545 (1) F12 (1)	3	HF			1									1
2012 春 JZI F39 (1)	3	HF						1						1
2012 春 JZI F39 (2)	3	HF						1						1
2007 秋 JZI T1305 H18	3	MP									1			1
2007 秋 JZI T1305 H19	3	MP									2			2
2011 JZI T0906 H174 (2)	3	MP			1		1							2
2011 春 JZI T0806 H188 (1)	3	MP									2			2
2011 春 JZI T0806 H201 (1)	3	MP						2			2			4
2011 春 JZI T0806 H201 (3)	3	MP					1				1			2
2011 春 JZI T0906 H174 (2)	3	MP				1		1	1					3
2011 春 JZI T0906 H174 (3)	3	MP						1	1	2				4
2011 春 JZI T0906 H174 (5)	3	MP									2			2
2011 春 JZI T0906 H179 (1)	3	MP						1		1				2
2011 春 JZI T0906 H179 (2)	3	MP			1		1			1	4			7
2011 春 JZI T0906 H179 (3)	3	MP									1		1	2
2012 JZI T1508 H258 (2)	3	MP	1											1
2012 春 JZI H293	3	MP			2									2
2012 春 JZI T1307 H327 (2)	3	MP									1			1
2010 秋 JZI TG9 (3)a	4	GFL						2						2
2011 春 JZI T0906 (4)	4	GFL									1	1		2

2009 秋 JZII T6644 F14	4	HF		1		1									2
2009 秋 JZII T6644 H84 (1)	4	MP		1				1							2
2011 春 JZI T1206 H167 (3)	4	MP							1						1
2012 JZI TG10 H285 (2)	4	MP				1									1
2012 春 JZI H294	4	MP	1	7	1		1				2			2	14
2012 春 JZI H301 (1)	4	MP					1								1
2012 JZI TG14 (3)	5	GFL			1										1
2012 JZI TG14 F40	5	HF			1										1
2009 秋 H89	5	MP							1			1			2
2009 秋 H95	5	MP		1											1
2009 秋 JZII T6644 H82 (1)	5	MP		1		1			1		1		1		5
2009 秋 JZII T6644 H82 (8)	5	MP		1											1
2009 秋 JZII T6644 H98	5	MP			1										1
2009 秋 JZII T6744 H81 (3)	5	MP		1		1									2
2009 秋 JZII T6745 H82 (2)	5	MP	1											1	2
2012 JZI TG14 H299 (2)	5	MP		1					1						2
2012 春 JZI TG13 H284 (1)	5	MP	1				1								2
2012 春 JZI TG14 H288	5	MP		3			1				1				5
2012 春 JZI TG14 H289 (1)	5	MP			1										1
2012 春 JZI TG14 H289 (2)	5	MP	1												1
2012 春 JZI TG14 西 H296	5	MP		2		1									3
2012 春 TG14 H289 (3)	5	MP		3	1										4
2011 春 JZI T0806 M61	L	BF							1						1
2011 春 JZI T0906 M68	L	BF		1											1
2013 春 JZII TG15 M197	L	BF								1					1
2007 秋 JZI T1305 (8)	L	GFL				1			1						2
2007 秋 JZI T1305 (9)	L	GFL					1		1						2

2007 秋 JZI T1405 (6)	L	GFL											1			1
2011 春 JZI T0806 (4)	L	GFL					1									1
2011 春 JZI T0906 (3)	L	GFL								1						1
2012 春 JZI TG11 (3)	L	GFL						1								1
2013 春 JZII TG16 (2)	L	GFL											1			1
2013 春 JZII TG17 (11)	L	GFL				2		3	2							7
2013 春 JZII TG17 (12)	L	GFL						1							1	2
2013 春 JZII TG20 (4)	L	GFL			1	1										2
TG4 (19): 1	L	GFL											1			1
2007 秋 JZI T1404 F4	L	HF											1			1
2013 春 JZII TG17 F49 (3)	L	HF										1	2			3
2013 春 JZII TG19 F47	L	HF	2	1				1								4
2013 春 JZII TG19 F47 (2)	L	HF	1		1		2									4
08 春 JZI IG4 H72	L	MP											1			1
2007 秋 JZI T1305 H22	L	MP						1								1
2007 秋 JZI T1305 H25	L	MP											1			1
2007 秋 JZI T1405 (6) H47	L	MP					1									1
2007 秋 JZI T1405 H54	L	MP											1			1
2009 秋 JZII T6545 (7) 层下 H93 (1)	L	MP			1											1
2011 春 JZI T0806 H142	L	MP				1										1
2011 春 JZI T0906 H205	L	MP											1			1
2011 春 JZI T0906 H209	L	MP											1			1
2011 春 JZI T1206 H212	L	MP			1								1			2
2011 春 JZI T1206 H213	L	MP											1			1
2013 春 JZII TG15 H334 (1)	L	MP	1											1		2
2013 春 JZII TG15 H334 (2)	L	MP									1					1
2013 春 JZII TG15 H334 (3)	L	MP											2			2
2013 春 JZII TG15 H340 (1)	L	MP												1		1

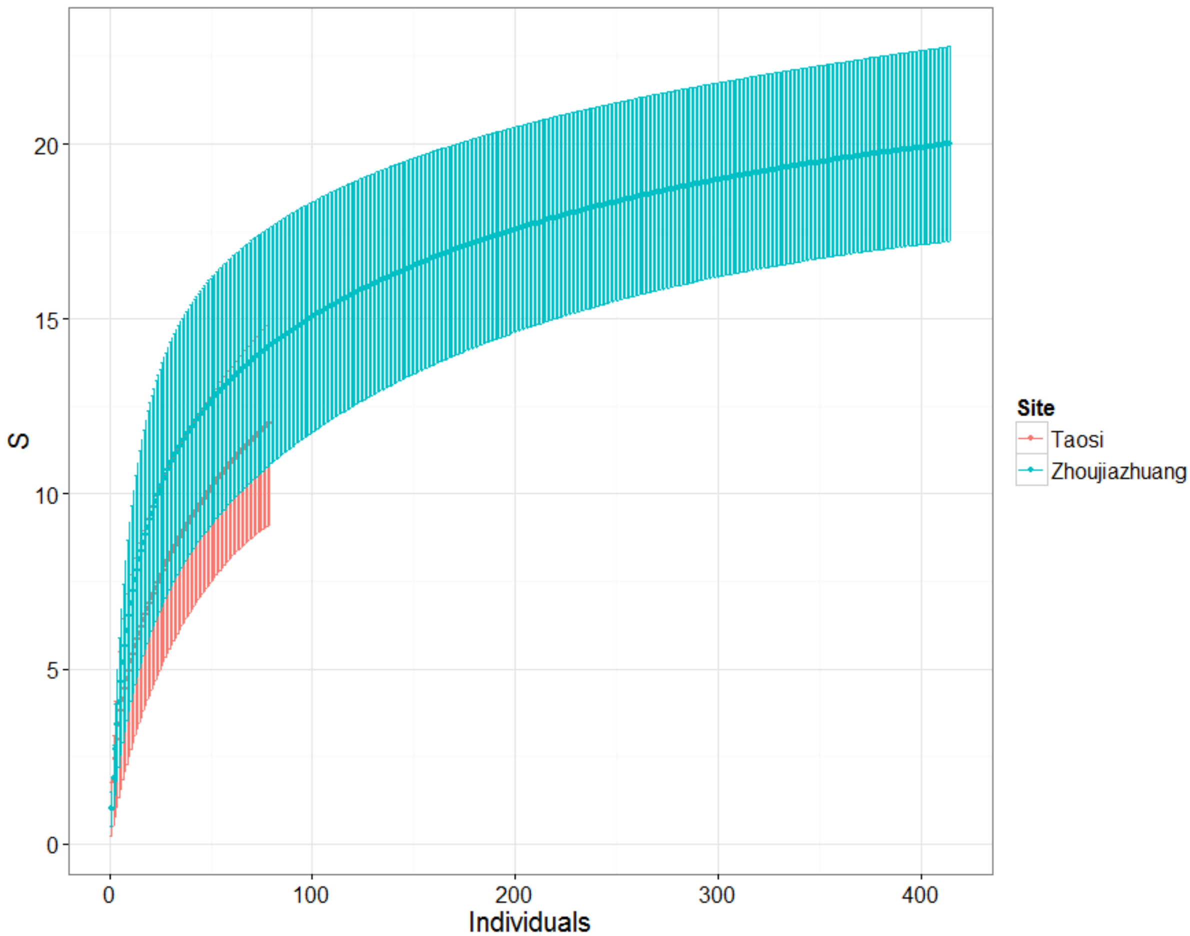
2013 春 JZII TG15 H340 (2)	L	MP									1					1
2013 春 JZII TG15 H346 (1)	L	MP									1					1
2013 春 JZII TG15 H381	L	MP	2		1			1			1	2			1	8
2013 春 JZII TG16 H383 (2)	L	MP									2					2
2013 春 JZII TG16 H383 (5)	L	MP									1				1	2
2013 春 JZII TG16 H403 (1)	L	MP									1	1				2
2013 春 JZII TG16 H403 (2)	L	MP													1	1
2013 春 JZII TG16 H403 (3)	L	MP					1				3		1			5
2013 春 JZII TG16 H408 (1)	L	MP					1			1	2	1				5
2013 春 JZII TG16 H408 (2)	L	MP									1					1
2013 春 JZII TG16 H408 (3)	L	MP						1								1
2013 春 JZII TG16 H409 (1)	L	MP					1									1
2013 春 JZII TG16 H418	L	MP										1				1
2013 春 JZII TG17 H361 (1)	L	MP			1	1										2
2013 春 JZII TG17 H378 (2)	L	MP													1	1
2013 春 JZII TG17 H384 (1)	L	MP						1								1
2013 春 JZII TG17 H384 (1) SCREENED	L	MP												1		1
2013 春 JZII TG17 H384 (2)	L	MP			2									1		3
2013 春 JZII TG17 H385 (1)	L	MP					2									2
2013 春 JZII TG17 H385 (2)	L	MP	3									2				5
2013 春 JZII TG17 H385 (3)	L	MP											3			3
2013 春 JZII TG17 H385 (4)	L	MP	1				1	2	1		2	2	1		2	12
2013 春 JZII TG17 H392 (2)	L	MP		1	1	1										3

2013 春 JZII TG17 H396 (1)	L	MP										1							4					5
2013 春 JZII TG17 H396 (2)	L	MP										1							4				1	6
2013 春 JZII TG17 H396 (3)	L	MP	7				4	1			1	3		1		1		1	4	2			1	26
2013 春 JZII TG17 H396 (4)	L	MP	2		1						1	1	1						3				1	10
2013 春 JZII TG17 H411 (1)	L	MP					1				1				1									3
2013 春 JZII TG17 H411 (2)	L	MP															1	1						2
2013 春 JZII TG17 H411 (3)	L	MP		1			1	1											1					4
2013 春 JZII TG18 H337 (1) (North, H352?) SCREENED	L	MP																	3					3
2013 春 JZII TG18 H337 (1) SCREENED?	L	MP	1									2												3
2013 春 JZII TG18 H337 (2) SCREENED	L	MP	2				3																	5
2013 春 JZII TG18 H337 (3) SCREENED?	L	MP	1			6	2	1											2					12
2013 春 JZII TG18 H337 (4) SCREENED	L	MP	2				1	2			2	1						1	1				1	11
2013 春 JZII TG18 H337 (5) SCREENED?	L	MP	1			1					2													4
2013 春 JZII TG18 H337 (6) SCREENED?	L	MP																		1				1
2013 春 JZII TG18 H352 (1) SCREENED	L	MP	14				1					1						1	2					19
2013 春 JZII TG18 H353	L	MP																1						1
2013 春 JZII TG18 H355 (1)	L	MP											1											1
2013 春 JZII TG18 H355 (2)	L	MP		1				2	1															4
2013 春 JZII TG18 H355 (3)	L	MP	1				2				2	2						2		2			2	13
2013 春 JZII TG18 H373	L	MP																		1				1
2013 春 JZII TG18 H373 (1)	L	MP					2	2				1								1		1		7
2013 春 JZII TG18 H373 (2)	L	MP			1		2																	3

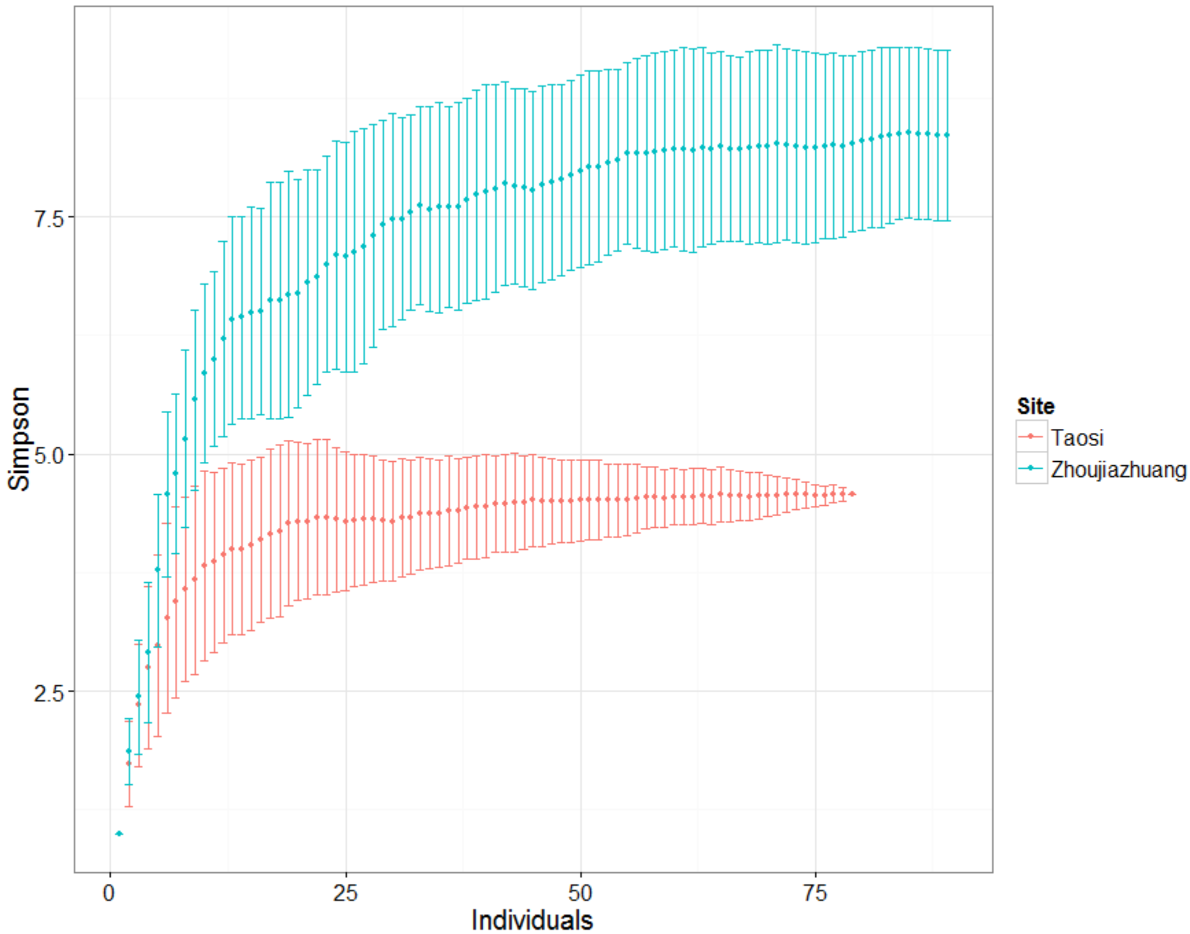
2013 春 JZII TG18 H373 (3)	L	MP														1							1
2013 春 JZII TG18 H373 (4)	L	MP	3			3	2	2		1	1												12
2013 春 JZII TG18 H373 (5)	L	MP																				2	2
2013 春 JZII TG18 H373 (6)	L	MP	1			1	4		2		3	1			1		1	2	1	3			20
2013 春 JZII TG18 H374	L	MP																		1			1
2013 春 JZII TG18 H376 (1)	L	MP	1																				1
2013 春 JZII TG18 H419 (2)	L	MP				1																	1
2013 春 JZII TG19 H354	L	MP																1					1
2013 春 JZII TG19 H354 (1)? Or (6)?	L	MP																1					1
2013 春 JZII TG19 H369 (2)	L	MP																1					1
2013 春 JZII TG19 H370	L	MP																1					1
2013 春 JZII TG19 H371 (1)	L	MP										1											1
2013 春 JZII TG19 H371 (2)	L	MP																1					1
2013 春 JZII TG19 H394	L	MP						1															1
2013 春 JZII TG19 H404 (2)	L	MP									1												1
2013 春 JZII TG20 H331	L	MP	2				6	1			1	2						2	3	1	1		3	22
2013 春 JZII TG20 H331 (2) SCREENED	L	MP	1								2												3
2013 春 JZII TG20 H331 (3)	L	MP																	1				1
2013 春 JZII TG20 H331 (4)	L	MP	2		1		4					1						1					9
2013 春 JZII TG20 H336 (2)	L	MP					1																1
2013 春 JZII TG20 H336 (4)	L	MP					2																2
2013 春 JZII TG20 H341 (2)	L	MP				1																	1
2013 春 JZII TG20 H341 (3)	L	MP																				1	1
2013 春 JZII TG20 H348	L	MP																		1	2		3

2013 春 JZII TG20 H358 (1)	L	MP				1			2										3
2013 春 JZII TG20 H358 (3)	L	MP	1														1		2
2013 春 JZII TG20 H358 (4)	L	MP	1			1												1	3
2013 春 JZII TG20 H358 (5)	L	MP							1										1
2013 春 JZII TG20 H360	L	MP				1													1
2013 春 JZII TG20 H363	L	MP			1	1											2		4
2013 春 JZII TG20 H364	L	MP				1	1												2
2013 春 JZII TG20 H365	L	MP							1										1
2013 春 JZII TG20 H366 (3)	L	MP			1	2											1		4
2013 春 JZII TG20 H386 (2)	L	MP	1																1
2013 春 JZII TG20 H389	L	MP				2						1							3
2013 春 JZII TG20 H390	L	MP	1																1
2013 春 JZII TG20 H399 (2)	L	MP							2										2
2013 春 JZII TG20 H405 (2)	L	MP				1											4		5
2013 春 JZII TG20 H416 (1)	L	MP	1																1
2013 春 JZII TG20 H416 (2)	L	MP				1				1									2
H11 (1)	L	MP								2									2
H63	L	MP							1						1				2
2013 春 JZII TG19 H354 (2)	L	SP	1															1	2
2013 春 JZII TG19 H354 (3)	L	SP	5	1		5			1		1	1			1			1	16
2013 春 JZII TG19 H354 (4)	L	SP	8			1	1		5	3	1	1		3	7			6	36
2013 春 JZII TG19 H354 (5)	L	SP	1							1		1						1	4
2013 春 JZII TG19 H354 (6)	L	SP	17	1		3			3	4		2	1	2	17		2	9	61
2013 春 JZII TG19 H354 (7)	L	SP						1											1
2013 春 JZII TG19 H354	L	SP	6			1			1	2				2	6	1	1	2	22

(8)																								
2013 春 JZII TG19 H354 (9)	L	SP										1											1	2
08 JZ TG3 G5 (7)	L	T																1						1
2013 春 JZII TG16 G18 (2)	L	T													1									1
2013 春 JZII TG18 G15	L	T																	1					1
2013 春 JZII TG18 G17 (1)	L	T	1		1													1	1	4				8
2013 春 JZII TG18 G17 (2)	L	T	1			1	1					1						1	1	2	1			9
2013 春 JZII TG18 G17 (3)	L	T			1		2													1				4
2013 春 JZII TG20 G20 (1)	L	T					6													1			1	8
2013 春 JZII TG20 G20 (4)	L	T	1																					1
2013 春 JZII TG20 G20 (5)	L	T	2				1				3												1	7
TOTAL			104	5	8	15	107	28	10	1	67	56	8	9	5	1	15	117	46	41	5	6	47	701
%			14.8	0.7	1.1	2.1	15.3	4.0	1.4	0.1	9.6	8.0	1.1	1.3	0.7	0.1	2.1	16.7	6.6	5.8	0.7	0.9	6.7	100



Supplemental Figure 3.1. Rarefaction curves showing number of worked artifacts (individuals) plotted against number of species (S) with 95% confidence intervals displayed. Calculations were made on EstimateS statistical program using 100 runs without replacement. Calculations do not include artifacts identified only as S. mammal, M. mammal., M. or L. mammal, L. mammal, or Mammal. Taosi NTAXA=12; Zhoujiazhuang NTAXA=20.



Supplemental Figure 3.2. Number of worked artifacts plotted against calculated Simpson's index values with 95% confidence intervals displayed. Calculations were made on EstimateS statistical program using 100 runs without replacement. Calculations do not include artifacts identified only as S. mammal, M. mammal., M. or L. mammal, L. mammal, or Mammal. Taosi NTAXA=12; Zhoujiazhuang NTAXA=20.

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CHAPTER 4

Ancient DNA Reveals Presence of Wild Aurochs Oracle Bones in China and Possibility for Interbreeding between Wild Aurochs and Domestic Cattle

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Abstract:

Domestic cattle were introduced to China from Central Asia between 3600-2000 BCE. Most of the earliest archaeological cases of domestic cattle bones in China come from sacrificial or ritual contexts, especially in the form of oracle bones used in divination rituals. These oracle bones eventually became closely tied to royal authority and are the source of the earliest written inscriptions in ancient China. Here, we present an ancient DNA analysis of uninscribed bovine oracle bones from the Longshan period (late third millennium BCE) archaeological sites of Taosi and Zhoujiazhuang. In addition to making oracle bones out of domestic cattle scapulas, people also used wild aurochs scapulas for oracle bone divination. These represent the first known cases of aurochs oracle bones in ancient China. We propose some morphological criteria that may be useful for distinguishing between the scapulas of domestic cattle, wild aurochs, and wild water buffalo found in Chinese archaeological sites, but conclude that it may not always be possible to identify bovine scapulas based on morphology alone. Because both wild aurochs and domestic cattle were sometimes present at the same sites and their bones were used in similar ways to make oracle bones, this raises the possibility that these species interbred and that people in ancient China experimented with managing indigenous Chinese wild bovines.

Key words:

Oracle bones; Longshan; *Bos taurus*; *Bos primigenius*; *Bubalus mephistopheles*; ancient DNA

Significance statement:

We have identified the first wild aurochs oracle bones in ancient China. The use of aurochs scapulas for oracle bone divination adds complexity to our understanding of the role of domestic cattle in ancient Chinese divination rituals. Our results indicate that wild aurochs bones may be present in other Chinese zooarchaeological assemblages and collections of oracle bones, but that these cases remain unrecognized. Additional zooarchaeological, genetic, and isotopic research may help clarify whether domestic cattle interbred with East Asian wild aurochs and whether indigenous Chinese bovines were managed alongside domestic cattle.

Introduction:

Domestic taurine cattle (*Bos taurus*) were introduced to China from West Asia between 3,600-2,000 BCE (Flad et al. 2007 and 2009; Lu 2010; Yuan et al. 2007). Not only did the adoption of cattle herding provide new opportunities for animal management, which had previously focused on raising domestic pigs (Luo 2012; Yuan 2010), but it also provided a new animal for use in ritual activities. Most of the earliest cases of domestic cattle in China come from sacrificial or ritual contexts (Lu 2010; Lu et al. forthcoming). By the Shang Dynasty (ca. 1600-1046 BCE), cattle had replaced pigs as the most important sacrificial animals at Chinese archaeological sites (Yuan and Flad 2005).

One of the main ritual uses for cattle in ancient China was in oracle bone divination. Animal bones burned during pyro-osteomantic rituals—also known as oracle bones—are a common type of bone artifact found in both domestic and royal ritual contexts at Chinese Neolithic and Bronze Age archaeological sites. Diviners would use a hot poker to burn thin bones such as ungulate scapulas or turtle plastrons and then interpret the cracks that formed during the application of heat (Keightley 1978 and 1999: 236-247). Although people used bones from many different types of animals for divination, cattle oracle bones increased in frequency through time (Flad 2008). During the Late Shang Dynasty at Anyang (ca. 1250-1046 BCE), most oracle bones were made from cattle scapulas, including many oracle bones used in royal divination rituals and inscribed with the earliest surviving writing in ancient China (Chang 1980; Flad 2008; Keightley 1978 and 1999; Li 1977).

The domestic nature of cattle oracle bones has been central to arguments about Shang Dynasty religion and the Shang world view. Some scholars believe that the Shang divided the chaotic world of the wild from the ordered world of the domestic, emphasizing the ability of the Shang kings to "domesticate" and bring order to the spiritual and material worlds through rituals such as divination (Campbell 2007 and 2015; Chang 1983; Fiskesjö 2001; Keightley 2000: 107-113). Both during the Shang and in preceding periods, cattle and turtle oracle bones were often pre-treated by thinning the bone and drilling or carving hollows to direct the formation of cracks during burning (Flad 2008; Keightley 1978; Pak 2011). Oracle bones made from other taxa generally were not pre-treated. This suggests that special care and attention was given to the preparation of cattle oracle bones because domestic cattle were an important animal in ancient Chinese religion and ideology.

Cattle were the main animal used in Shang Dynasty oracle bone divination, and archaeologists have assumed that all earlier bovine oracle bones were also made from domestic cattle bones. However, native wild aurochs (*Bos primigenius*) and wild water buffalo (*Bubalus mephistopheles*) were also present in North China during this time period (Liu et al. 2001 and 2006; Yang et al. 2008; Lu Peng, personal communication). The bones of cattle, aurochs, and water buffalo are morphologically similar and it is possible that wild bovines were used in divination, but that these cases remain unrecognized and unclassified. If people in ancient China used wild bovine scapulas to make oracle bones and if these artifacts were prepared with the same care as domestic cattle oracle bones, our understanding of the role of cattle in the development of divination rituals would need to be re-evaluated.

It is also possible that wild bovine bones remain unrecognized in archaeological faunal collections in China more generally. This is especially likely for aurochs bones, which are rarely identified after domestic cattle were introduced to China. Although there is currently no evidence that East Asian aurochs populations interbred with domestic cattle or that people in ancient China managed wild bovines, very few sites or specimens have been analyzed. If aurochs and water buffalo were present at the same sites alongside domestic cattle and if they were used in similar ways, we would need to question the assumption that wild aurochs disappeared as soon as domestic cattle arrived in northern China and that water buffalo bones found archaeologically always represent wild, unmanaged animals.

In this article, we examine bovine oracle bones from the Longshan period sites of Taosi and Zhoujiazhuang (ca. 2000 BCE). These sites contain some of the earliest evidence for extensive cattle exploitation in China, including some of the earliest pre-treated bovine oracle bones. We use ancient DNA to identify the species that provided the raw material used to make the oracle bones. We also discuss morphological criteria for distinguishing between the scapulas of *Bos taurus*, *Bos primigenius*, and *Bubalus mephistopheles*. Our results reveal that both wild aurochs and domestic cattle were used to make oracle bones, but that it may not always be possible to identify aurochs scapulas based on morphology alone. Previously identified oracle bones and zooarchaeological collections need to be carefully re-examined to determine if aurochs were also present at other Chinese sites. Because both wild aurochs and domestic cattle were sometimes present at the same sites and their bones were used in similar ways, this raises the possibility that these species interbred and that people also experimented with managing indigenous wild bovines in ancient China.

Archaeological context:

The Longshan period (late third millennium BCE) is a well-known cultural horizon in central China that is characterized by early urbanism and increasing long-distance interactions between regional cultural variants (Chang 1986: 234-294; Chang 1999: 54-65). Although a few possible domestic cattle remains have been identified at pre-Longshan era sites (Flad et al. 2007 and 2009; Yu et al. 2011; Zhao 1995; Zhou 1999), it is not until about 2,000 BCE that cattle bones are found in large numbers outside of ritual contexts (Lu et al. forthcoming).

The Longshan sites of Taosi (ca. 2300-1900 BCE) and Zhoujiazhuang (ca. 2000-1900 BCE) in the Yellow River Valley provide some of the earliest evidence for extensive cattle herding in China, with cattle making up about 8-9% of the faunal assemblages (Brunson et al. 2015; Tao 2007). Taosi is located in the Linfen basin (N 35°52′55.90″, E 111°29′54.89″) in southern Shanxi Province (Figure 4.1). It was a large, urban political and economic center with rammed earth city walls, elite palace structures, socially stratified burials, specialized craft production zones, and ritual buildings including what may have been a solar observatory (He 2013). Zhoujiazhuang, located about 40km south of Taosi in the Yuncheng basin (N 35°29′10.59″, E 111°28′12.98″) was another large site with a similar material culture as Taosi. However, no palaces, elite burials, dedicated craft production zones, or dedicated ritual structures have yet been found at Zhoujiazhuang.

Zooarchaeological evidence indicates that cattle at both sites survived to older ages than expected for meat production, perhaps because cattle were being raised as wealth animals (Brunson et al. forthcoming). Additionally, cattle bones were a main raw material for making utilitarian bone artifacts and oracle bones at both sites. All of the oracle bones we analyzed were broken pieces found in refuse pits along with other fragmentary animal bones, ceramics, and stone tools. As was the case at most Late Neolithic sites, oracle bone use at Taosi and

Zhoujiazhuang was widespread and still fairly ad hoc compared to later periods when it became more closely associated with elite ritual practice (Flad 2008).

In this study, we focus on a few of the most complete bovine oracle bones for which we could also examine morphological traits and take size measurements. Almost all of these oracle bones were modified or pre-treated prior to burning by thinning the lateral side of the scapula and removing the spine. In some cases, circular hollows were also carved and the bone was burned inside of the hollows, showing that this method of preparing and burning oracle bones was already beginning during the Longshan period.

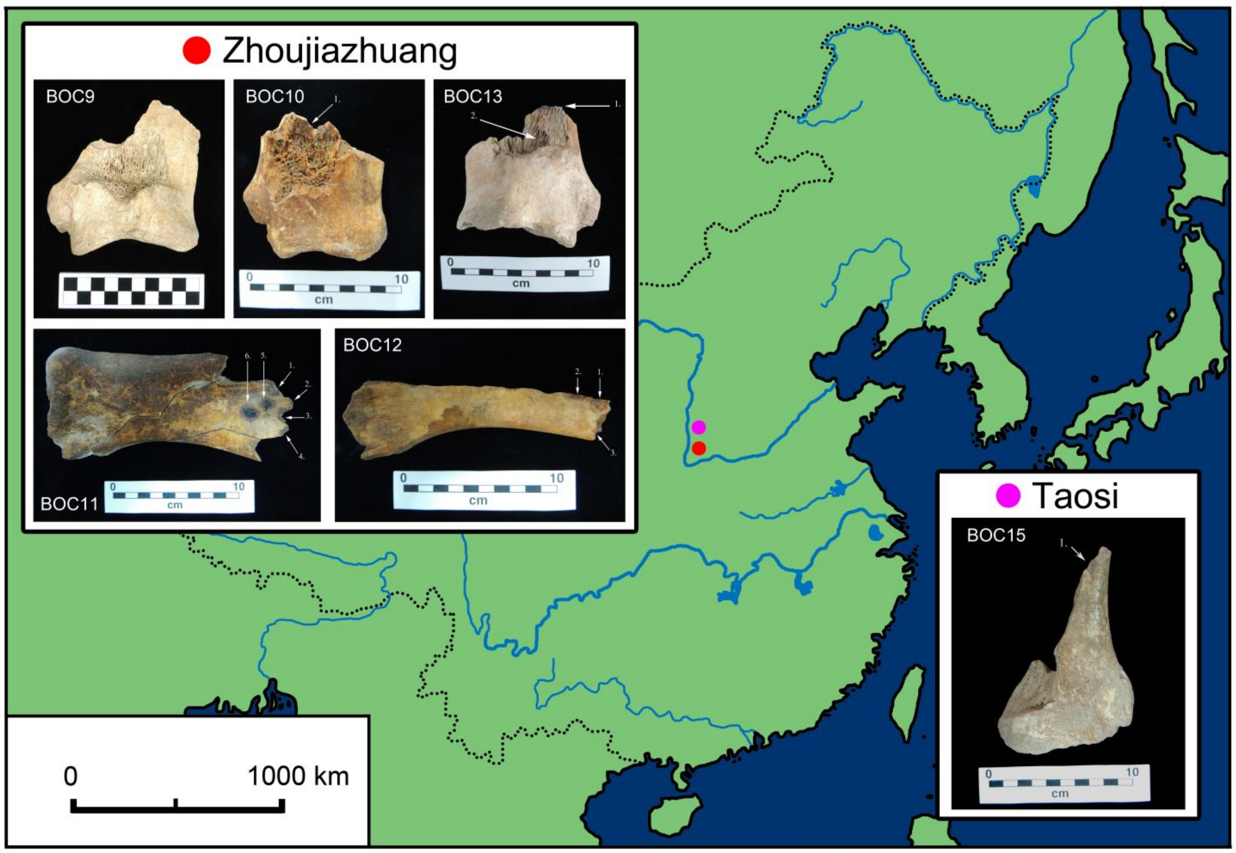

Figure 4.1. Map of Taosi and Zhoujiazhuang.

Materials and methods:

We analyzed eight bovine oracle bone scapulas, as well as several non-oracle bones as controls (Supplemental Table 4.1). These controls include two unmodified scapulas, three calcaneae, and one astragalus that we were able to identify to species with confidence based on morphology. Each bone was measured following von den Driesch (1976) and observations were made prior to removing 1-2g of bone sample for DNA analysis. DNA extraction and amplification were performed in the dedicated Ancient DNA Laboratory at the Institute of Archaeology, Chinese Academy of Social Sciences (IA CASS) in Beijing following a modified silica-spin column method (Yang et al. 1998).

Samples were decontaminated by submerging in 100% commercial bleach for 7 minutes, rinsing with distilled water, and irradiating under UV light for 30-45 minutes on each side. The decontaminated samples were then ground into powder using a liquid nitrogen grinding mill and incubated overnight at 50 °C in lysis buffer (0.5 M EDTA pH 8.0, 0.5% SDS, and 0.5 mg/mL proteinase K). The solutions were centrifuged and 3mL of supernatant was transferred to Amicon Ultra-4 10K centrifugal filters (Millipore, Billerica, MA). The extracts were centrifuged until less than 100 μL of liquid remained and then purified using a Qiagen QIAquick nucleotide removal kit following the manufacturer's protocols (QIAGEN, Hilden, Germany).

We selected previously published PCR primers that target mitochondrial D-loop control regions for cattle (L16022/H16178 and L16137/H16315 (Cai et al. 2014; Troy et al. 2001)) and water buffalo (F213/R381 (Yang et al. 2008)). We used a 30μL PCR reaction volume containing 50mM KCl, 10mM Tris-HCl, 2.5mM $MgCl_2$, 0.2mM dNTP, 1.0 mg/mL pig gelatin, 0.3 μM of each primer, 3.0 μL DNA, and 1.5-3.0 U AmpliTaq Gold (Applied Biosystems). We ran the PCR for 60 cycles (95 °C for 30 seconds (denaturing), 52 °C for 30 seconds (annealing), and 70 °C for

40 seconds (extension)) with an initial 12 minute denaturing period at 95 °C and a final 7 minute extension period at 72 °C. We visualized 5 μL of PCR product on a 2% agarose gel using SYBR Green staining.

Sequencing results were aligned using Clustal X 2.1 (Larkin et al. 2007). Phylogenetic trees were constructed in MEGA6 (Tamara et al. 2013). We used comparative sequences available on GenBank for *Bos taurus* (V00654) (Anderson et al. 1982), *Bos indicus* (EU177870 and EU177868) (Achilli et al. 2008), and European *Bos primigenius* (GU985279) (Edwards et al. 2010). Cattle haplogroups were assigned following previous studies of mutations in the mitochondrial D-loop sequence from V00654 (Anderson et al. 1982; Cai et al. 2014; Mannen et al. 1998 and 2004; Troy et al. 2001). Water buffalo haplogroups were assigned following previous studies of mutations in the D-loop sequence from swamp (NC_006295) and river (AY195595) varieties of *Bubalus bubalis* (Kierstein et al. 2004; Lei et al. 2007; Yang et al. 2008).

Results:

We successfully extracted DNA from all of the samples. BLAST results and comparisons with previously studied ancient bovine mtDNA sequences indicate that ten specimens (five oracle bones, two unworked scapulas, two calcanei, and one astragalus) are domestic *Bos taurus*. Three specimens (all oracle bones) are wild *Bos primigenius*. One specimen (a calcaneus) is wild *Bubalus mephistopheles* (Figure 4.2). Thus, both domestic *Bos taurus* and wild *Bos primigenius* were used to make oracle bones. Because two of the *Bos primigenius* oracle bones were made from left scapulas, at least two aurochs individuals were present at Zhoujiazhuang.

We identified two haplogroups of *Bos taurus* (T3 and T4) at both sites (Table 4.1). These haplogroups have also been identified at Taosi in previous studies of ancient cattle DNA (Cai et al. 2014). The *Bos primigenius* samples closely align with an aurochs specimen (KF525852) from northeastern China recently identified as belonging to a new *Bos* haplogroup, haplogroup C (Zhang et al. 2013). We have also assigned the aurochs oracle bones to this East Asian aurochs haplogroup. The one water buffalo specimen (BOC6) belongs to water buffalo haplogroup KJ1 (Table 4.2), which has been linked to the extinct Chinese species *Bubalus mephistopheles* (Yang et al. 2008). We believe that BOC6 should also be identified as wild *Bubalus mephistopheles*. A phylogenetic tree with all of the samples and comparative sequences from GenBank are shown in Figure 4.3.

To examine morphological and metric traits that may be useful for identifying the various bovine taxa, we focused on the distal scapula, which is denser than other parts of the scapula and more likely to survive archaeologically. Although the largest aurochs scapula (BOC9) falls within the size range of European *Bos primigenius* (Degerbøl and Fredskild 1970), the two other aurochs scapulas (BOC10 and BOC13) overlap in size with *Bos taurus* (Figure 4.4). Additionally, the *Bos taurus* and *Bos primigenius* scapulas are morphologically similar. We observed that the aurochs scapulas all have a more pronounced notch on the lateral side of the glenoid cavity. The supraglenoid tubercle also tends to be more bulbous in the aurochs specimens, but this observation needs to be tested on additional comparative materials. It may simply be related to the animal's size since the large cattle scapula BOC15 also has a bulbous coracoid process.

Our initial observations of modern water buffalo scapulas from collections at IA CASS and the Henan Provincial Institute of Archaeology suggest that the cranial lip of the glenoid cavity tends to project distally in *Bubalus* more than in *Bos*. This observation has also been made by other zooarchaeologists working in China (Li Zhipeng, personal communication). However, we have not yet been able to examine any archaeological *Bubalus mephistopheles* scapulas to test if these observations hold for ancient water buffalo as well.

Our research followed several criteria for assessing the authenticity of ancient DNA results (Poinar 2003): extractions and amplifications were conducted in dedicated facilities with separate pre and post PCR workspaces, multiple extractions were taken from each sample, negative controls were used during both DNA extraction and PCR amplification, and our results were found to be reproducible at a second laboratory using separate samples from the same specimens.

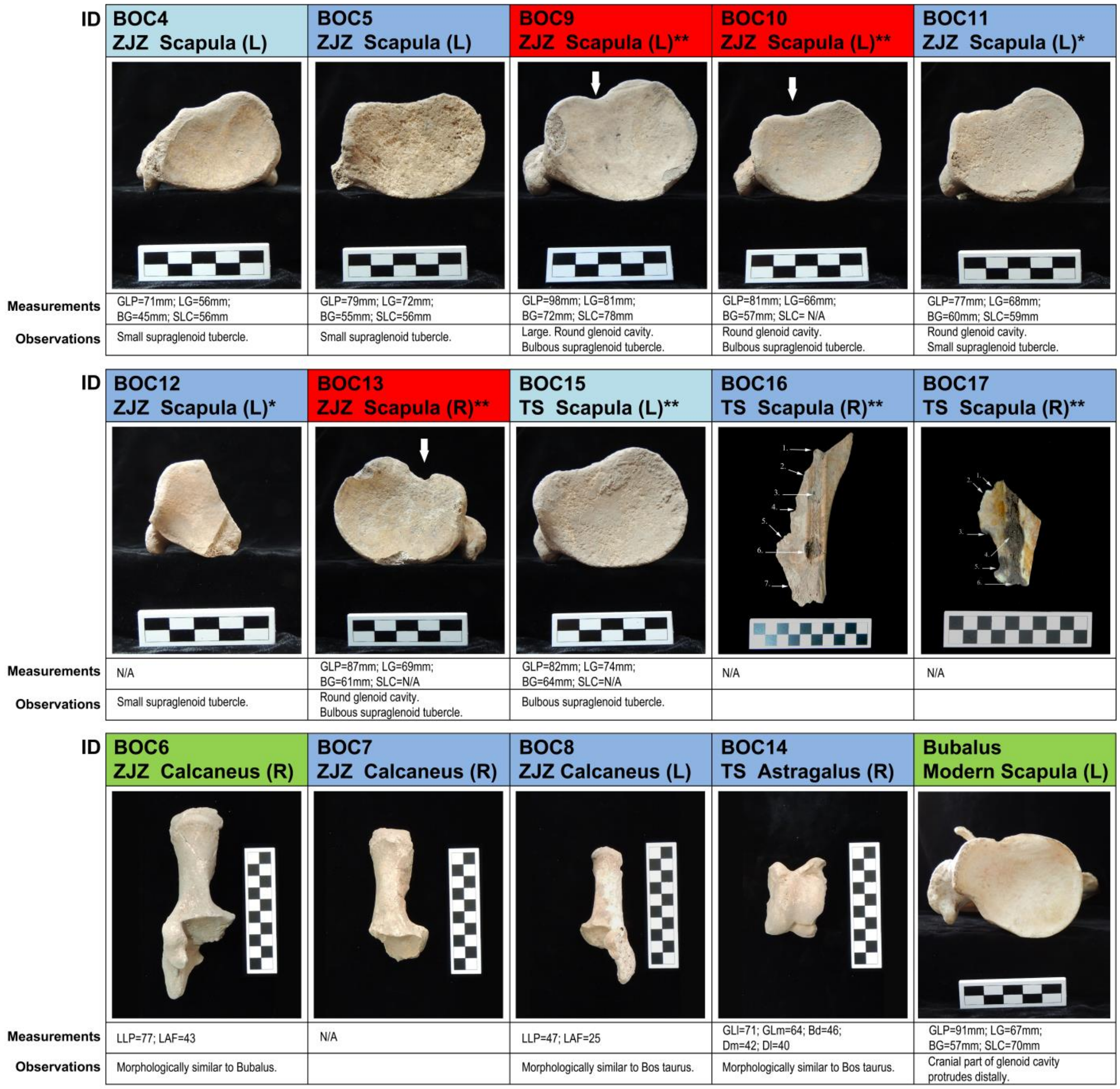

Figure 4.2. Specimens from Zhoujiazhuang (ZJZ) and Taosi (TS) included in the analysis. Oracle bones are indicated with a * and pre-treated oracle bones are indicated with a **. Calcaneus measurements include the length of the lateral process (LLP) and length of the articular facet for the *os maleolar* on the lateral process (LAF). Other measurements follow Dreisch (1976). Blue indicates *Bos taurus* specimens, red indicates *Bos primigenius* specimens, and green indicates *Bubalus* specimens.

Table 4.1.
Variable Positions in Archaeological Sequences using Primers L16022, H16178, L16137, and H16315.

ID	16042	16055	16057	16068	16083	16084	16085	16093	16095	16110	16113	16119	16125	16127	16139	16178	16201-16202	16224	16225	16231	16234	16243-16244	16250	16260	16264	Haplogroup
V00654	T	T	G	T	A	C	T	G	A	C	T	T	A	C	C	G	-	C	C	C	T	-	A	C	G	**T3**; *Bos taurus* reference sequence
KF525852	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	.	A	.	.	T	.	.	G	T	A	**C**; East Asian *Bos primigenius*
BOC4	C	.	.	.	.	.	.	A	.	.	.	.	.	.	.	.	-	T	T	.	.	A	.	.	.	**T4**
BOC5	.	C	.	.	.	.	.	.	.	.	.	.	.	.	.	.	-	.	.	.	A	.	.	.	.	**T3**
BOC7	.	C	.	.	.	.	.	.	.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	**T3**
BOC8	.	C	.	.	.	.	.	.	.	.	.	.	.	.	.	N	N	N	N	N	N	N	N	N	N	**T3**; PCR fail for L16137 and H16315
BOC9	.	.	A	C	G	T	C	.	.	T	.	C	T	T	.	.	A	.	.	T	.	.	G	T	A	**C**
BOC10	.	.	.	C	G	T	C	.	G	.	C	C	T	.	T	.	A	.	.	T	.	.	G	T	A	**C**
BOC11	.	C	.	.	.	.	.	.	.	.	.	.	.	.	.	A	-	.	.	.	.	.	.	.	.	**T3**
BOC12	.	.	.	.	.	.	.	.	.	.	.	C	.	.	.	.	-	.	.	.	.	.	.	.	.	**T3**
BOC13	.	.	.	C	G	T	C	.	G	.	C	C	T	.	T	.	A	.	.	T	.	.	G	T	A	**C**
BOC14	.	.	.	.	.	.	.	.	.	.	.	C	.	.	.	.	-	.	.	.	.	.	.	.	.	**T3**
BOC15	C	.	.	.	.	.	.	A	.	.	.	C	.	.	.	N	N	N	N	N	N	N	N	N	N	**T4**; PCR fail for L16137 and H16315
BOC16	.	.	.	.	.	.	.	.	.	.	.	C	.	.	.	.	-	.	.	.	.	.	.	.	.	**T3**
BOC17	.	C	.	.	.	.	.	.	.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	**T3**

Dots indicate identical sequences and dashes indicate a deletion/insertion.

Table 4.2.
Variable Positions for Water Buffalo Sample BOC6 using Primers F213 and R381.

ID	16058	16066	16067	16073	16074	16081	16084	16088	16095	16101	16102	16120	16122	16123	16127	16140	16142	16146	16147	16159	16159	16163	16168	Haplogroup
NC_006295	A	G	G	C	A	C	G	G	G	T	C	A	T	G	C	G	C	G	C	A	T	C	C	Swamp type
AY195595	G	A	A	T	A	C	G	G	G	A	T	A	C	A	T	A	T	A	T	G	T	T	T	River type
BOC6	A	A	A	T	G	T	A	A	A	A	C	G	C	A	T	A	T	G	C	A	C	T	T	KJ1

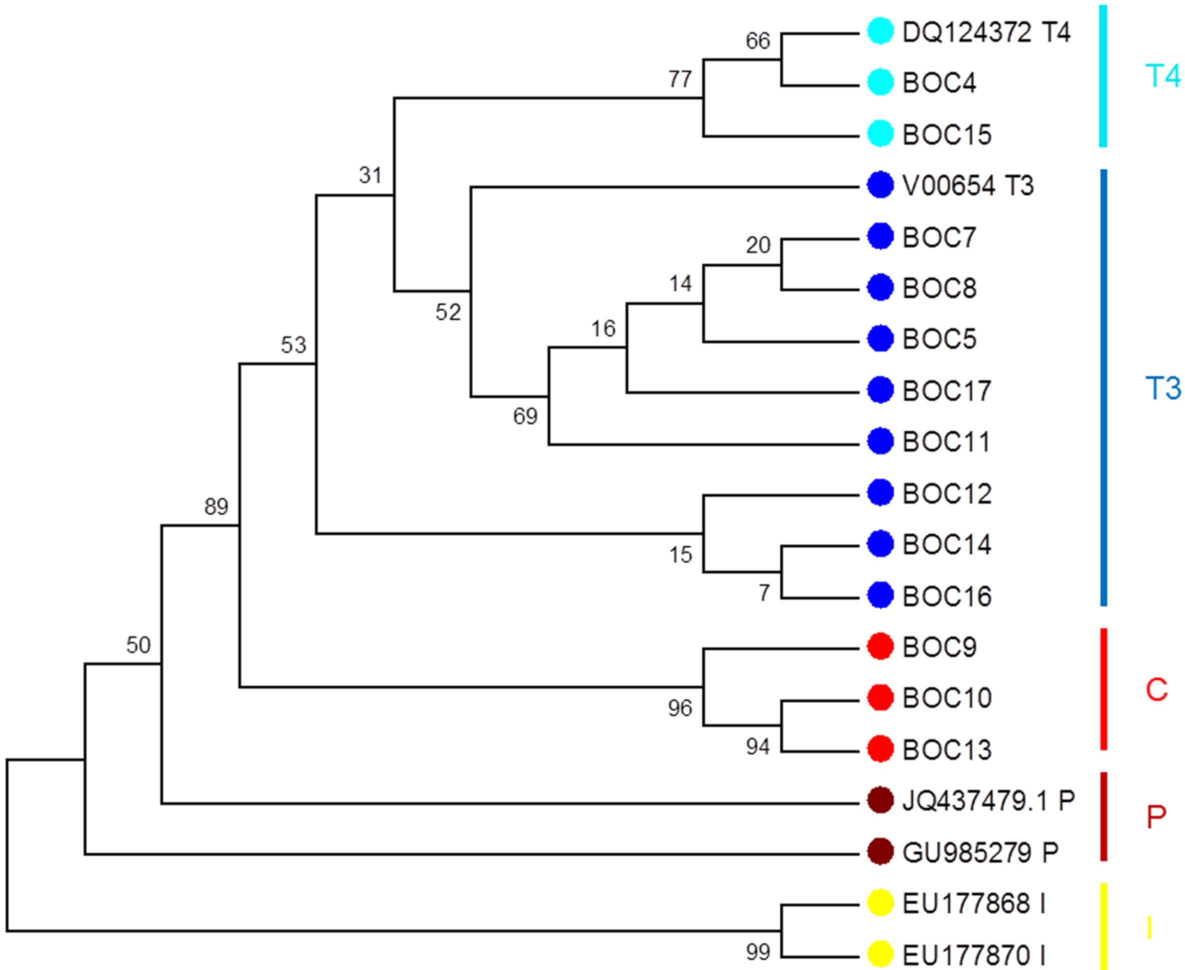

Figure 4.3. Neighbor-joining phylogenetic tree for *Bos* samples.

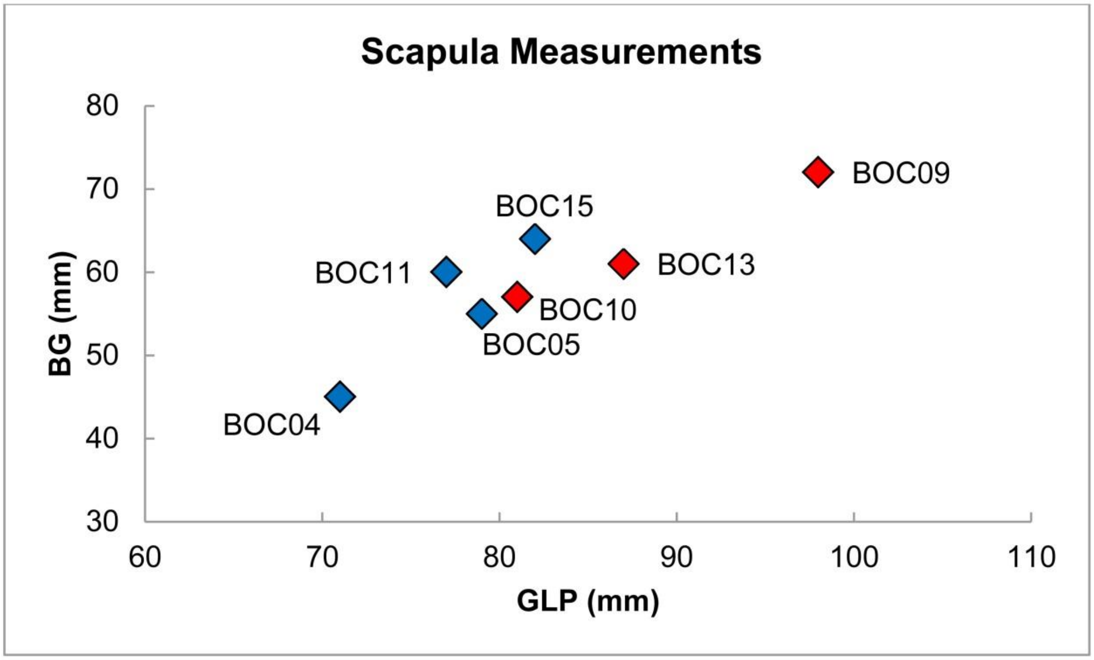

Figure 4.4. Scapula measurements. *Bos primigenius* scapulas are shown in red and *Bos taurus* scapulas are shown in blue. Standard aurochs measurements listed in Degerbøl and Fredskild (1970) range from 81-100mm for GLP and 58-77mm for BG. There is considerable overlap between the largest *Bos taurus* scapulas and the smallest *Bos primigenius* scapulas.

Discussion:

The *Bos taurus* haplogroups we identified at Taosi and Zhoujiazhuang are consistent with the hypothesis that Chinese domestic cattle originated in the Near East. Archaeological and genetic evidence indicates that cattle were domesticated from wild aurochs around 10,000 years ago in two independent events that took place in the Near East (giving rise to *Bos taurus*) and in South Asia (giving rise to *Bos indicus*) (Bradley and Magee 2006; Loftus et al. 1994 and 1999; MacHugh et al. 1997; Meadow 1993 and 1996; Troy et al. 2001; Zeder 2011). All cattle from Chinese archaeological sites dating to the Shang Dynasty and earlier have been identified as *Bos taurus*, and it is unclear when *Bos indicus* was introduced to China (Lu et al. forthcoming). Out of the five main mtDNA haplogroups for *Bos taurus*, the T2, T3, and T4 haplogroups are the most common in modern Chinese cattle populations (Lai et al. 2006). All of these haplogroups originated in the Near East (Achilli et al. 2009; Bradley and Magee 2006; Loftus et al. 1994 and 1998; MacHugh et al. 1997; Troy et al. 2001). Ancient DNA analysis of Chinese Bronze Age cattle remains has only identified the T2, T3, and T4 haplogroups, confirming the Near Eastern origin for some of the earliest Chinese domestic cattle (Cai et al. 2014).

There is currently no archaeological or genetic evidence indicating that cattle were domesticated indigenously from Chinese wild aurochs (Lu et al. forthcoming). However, all previous research on ancient cattle genetics, including our current study, has only focused on a small section of mtDNA. We still cannot draw final conclusions about whether cattle and aurochs interbred in China. In addition to the three aurochs oracle bones presented here, only one other ancient DNA study of East Asian wild aurochs has been published. Using next generation sequencing of a single aurochs specimen from northeastern China, that study identified the new *Bos* haplogroup C that is distinct from all known modern *Bos taurus* haplogroups, suggesting that East Asian aurochs did not contribute genetically to domestic cattle (Zhang et al. 2013). However, studies of modern European cattle reveal that when domestic *Bos taurus* was introduced to Europe from the Near East, some populations interbred with local European wild aurochs, resulting in the rare *Bos taurus* haplogroups P, Q, and R (Achilli et al. 2008 and 2009; Bonfiglio et al. 2010; Götherström et al. 2005). If both domestic cattle and wild aurochs were present at Chinese sites like Zhoujiazhuang, it is also possible that these species interbred. With more ancient DNA data from additional samples, it may be possible to determine with more certainty whether or not East Asian wild aurochs and domestic cattle populations did interbreed.

Although we did not identify any water buffalo oracle bones, we did identify one bone specimen from Zhoujiazhuang as water buffalo. Ancient DNA research on Chinese water buffalo has shown that these animals did not contribute genetically to modern Chinese water buffalo and instead belong to the now extinct species *Bubalus mephistopheles* (Yang et al. 2008). To date, no water buffalo bones have been found at Taosi. The presence of wild water buffalo and wild aurochs only at Zhoujiazhuang is consistent with other zooarchaeological evidence that people at Zhoujiazhuang exploited more wild animal resources than did people at Taosi (Brunson et al. forthcoming).

Since both wild and domestic bovines were present in north China at sites like Zhoujiazhuang, it is possible that people experimented with managing wild bovines after the introduction of domestic cattle even if these species did not interbreed. This seems especially possible for aurochs at Zhoujiazhuang because aurochs and cattle oracle bones were used in similar ways to make oracle bones. Stable isotope analysis of animal bones from Taosi has found that domestic cattle were foddered with millet stalks (Chen et al. 2012). In the future, comparisons of the diets of aurochs, water buffalo, and domestic cattle identified at Zhoujiazhuang and other sites may help to determine if people were also foddering wild bovines.

All of the aurochs oracle bones and most of the domestic cattle oracle bones we analyzed were pre-treated by flattening the lateral side of the scapula and carving hollows to direct the formation of cracks. Similar pre-treatment methods for bovine scapulas eventually became highly standardized later in the Bronze Age, which some scholars argue is a sign of increasing state control over oracle bone divination (Flad 2008; Keightley 1978 and 2000). The Taosi and Zhoujiazhuang cases show that the practice of pre-treating oracle bones was already taking place to some degree in the Yellow River Valley by 2,000 BCE and that it was not unique to domestic cattle scapulas. The use of aurochs bones for divination at Zhoujiazhuang may indicate that both wild and domestic bovines were seen as equally important ritual animals or that aurochs could be used as a substitute for domestic cattle. It may also indicate that people could not tell the difference between the de-fleshed scapulas of aurochs and cattle because they look so similar. People may have simply flattened the thicker parts of the scapulas of both species to increase the surface area available for making burn marks. The use of pre-treated wild aurochs oracle bones at Zhoujiazhuang suggests that the specialized treatment of oracle bones at later Bronze Age sites may not have been reserved for domestic cattle either.

We still need to examine additional comparative collections of East Asian water buffalo and aurochs post-cranial skeletons to identify morphological traits that can be used to differentiate the bones of *Bubalus mephistopheles*, *Bos primigenius*, and *Bos taurus*. However, we propose a few preliminary criteria that may be of use for identifying bovine scapulas at other Chinese sites: 1) the aurochs scapulas we analyzed all have a deep notch in the lateral side of the glenoid cavity that is generally not as pronounced in domestic cattle; 2) the aurochs scapulas tend to have a larger and more bulbous supraglenoid tubercle compared to domestic cattle; 3) the cranial portion of the glenoid cavity in water buffalo scapulas protrudes distally more than in either species of *Bos*. These traits may not always be visible on fragmentary or broken archaeological scapulas. Pre-treated oracle bones may be even harder to identify because diagnostic sections of the scapula may be removed. For example, most Shang Dynasty oracle bones from Anyang have the entire lateral side of the glenoid cavity removed and a notch cut from the supraglenoid tubercle (Keightley 1978: 13-23). Additionally, because there can be considerable size overlap between wild and domestic bovines, size alone cannot be used to identify or exclude the presence of wild bovines. These considerations pose challenges to research on oracle bones and to zooarchaeological research on East Asian cattle in general.

It is unclear when aurochs went extinct in China. Aurochs are listed in many Chinese faunal reports for Paleolithic sites and Neolithic sites, but as soon as domestic cattle start to appear in China, faunal reports rarely include identifications of aurochs. It is possible that wild aurochs persisted in China long after the introduction of domestic cattle, but that their bones have been mis-identified. Our research indicates that archaeologists working in China need to be aware of the possibility that people may have managed native wild bovine populations and that aurochs bones could be present, but unrecognized, in many zooarchaeological and bone artifact assemblages. Developing additional morphological, genetic, and isotopic methods for distinguishing between wild and domestic East Asian bovines and for determining if these species interbred will be critical for future research on the spread of cattle herding into China and its effects on how people used native wild bovines.

Conclusion:

We have identified the first known cases of aurochs oracle bones in ancient China. Our results suggest that it may not always be possible to identify aurochs oracle bones based on morphology alone. Previously identified oracle bones and zooarchaeological collections should be carefully re-examined to determine if aurochs were also present at other Chinese sites. Although there is currently no genetic evidence that domestic cattle and wild aurochs populations interbred, ancient DNA research on Chinese cattle is only just beginning. The application of additional zooarchaeological, genetic, and isotopic research will be critical for understanding the conditions under which cattle herding was adopted in China, the relationship between domestic cattle and East Asian wild aurochs, and the role of cattle, aurochs, and water buffalo in ancient Chinese ritual practice.

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Supplemental Table 4.1.
Archaeological Contexts of Sampled Oracle Bones from Taosi (T) and Zhoujiazhuang (Z)

Lab Code	ID#	Oracle Bone?	Site	Archaeological Context	Skeletal Element	Side	Taxon
BOC04	Z-130	No	Z	2012 JZI T1508 H258 (1)	Scapula	L	*Bos taurus*
BOC05	Z-2893	No	Z	2013 JXTII TG17 H384 (1)	Scapula	L	*Bos taurus*
BOC06	Z-4844	No	Z	2013 JZII TG18 H355 (1)	Calcaneus	R	*Bubalus mephistopheles*
BOC07	Z-2664	No	Z	2013 JZII TG18 G17 (2)	Calcaneus	R	*Bos taurus*
BOC08	Z-4930	No	Z	2013 JZII TG18 H355 (3)	Calcaneus	L	*Bos taurus*
BOC09	Z-2436	Yes (pre-treated)	Z	2013 JZII TG18 H373	Scapula	L	*Bos primigenius*
BOC10	Z-2593	Yes (pre-treated)	Z	2013 JZII TG18 G17 (2)	Scapula	L	*Bos primigenius*
BOC11	Z-2592	Yes	Z	2013 JZII TG18 G17 (2)	Scapula	L	*Bos taurus*
BOC12	Z-1741	Yes	Z	2013 JZII TG20 H405 (2)	Scapula	L	*Bos taurus*
BOC13	Z-4926	Yes (pre-treated)	Z	2013 JZII TG18 H355 (3)	Scapula	R	*Bos primigenius*
BOC14	T-39	No	T	2013 JXTI TG32 (3B)	Astragalus	R	*Bos taurus*
BOC15	T-566	Yes (pre-treated)	T	2010 JXTI T5013 H59 (1)	Scapula	L	*Bos taurus*
BOC16	T-689	Yes (pre-treated)	T	2010 JXTI T5023 H93 (2)	Scapula	R	*Bos taurus*
BOC17	T-171	Yes (pre-treated)	T	2013 JXTI TG33 Q4	Scapula	R	*Bos taurus*

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CHAPTER 5

Conclusion

The roles of cattle and sheep in late third millennium BCE and early second millennium BCE social developments remain understudied. This dissertation provides new data to suggest that the exploitation of these animals and their associated economic and ritual products was a critical part of the emergence of proto-state and state societies. Taosi and Zhoujiazhuang were two of the earliest sites in the Central Plains region to adopt sheep and cattle herding on a large scale. Many aspects of animal management associated with northern Chinese Bronze Age societies, such as the increasing importance of sheep herding and the use of cattle bones as raw materials for bone working and for oracle bone divination, were in incipient stages of development at Taosi and Zhoujiazhuang. Therefore, studying the zooarchaeological record at these sites provides a unique glimpse at a transitional period in the Chinese archaeological record.

In chapter 1, I presented key issues in the zooarchaeology of the Longshan period and summarized the genetic, isotopic, and zooarchaeological evidence for animal domestication in China before and after the arrival of cattle and sheep ca. 3,600 BCE. I noted that the adoption of cattle and sheep herding represented a radical change in animal management. Prior to 3,600 BCE, domestic animal exploitation in the Central Plains focused on pigs, dogs, and possibly chickens. These animals provided subsistence and ritual resources for Early and Middle Neolithic societies. After 3,600 BCE, the remains of herd animals are increasingly frequent in the zooarchaeological record. In addition to providing new subsistence resources, these animals provided new sources of non-subsistence ante-mortem animal products such as milk, wool, dung, and traction power as well as post-mortem products such as hides and bone raw materials. The availability of new animal products provided opportunities for specialization in animal crafts. For example, cattle bone working soon transformed into a massive industry at large urban centers. Cattle also replaced pigs as the most important ritual animals, and oracle bone divination using cattle scapulas was closely tied to emerging state power.

In chapter 2, I presented faunal data from the sites of Taosi and Zhoujiazhuang. I noted that pigs were the most common taxa at both sites, but that sheep bones increase in frequency during the late Taosi occupation phase. At Taosi, NISP counts and comparisons of taxonomic diversity indicate an intensive focus on domestic animals. At Zhoujiazhuang, both the overall faunal assemblage and worked bone assemblage reflect a greater reliance on wild taxa than at Taosi. Kill-off patterns based on tooth eruption and wear reveal that most pigs were slaughtered before one year of age at both sites, indicating that they were primarily used for meat. However, sheep kill-off patterns are different at the two sites. At Taosi, sheep survive to older ages, suggesting that people may have specialized in production of sheep secondary products such as wool. At Zhoujiazhuang, sheep kill-off patterns fit a meat exploitation model, suggesting that people may have adopted herding as a means of diversifying subsistence production. Cattle survive to older ages at both sites, indicating that they may have been used for secondary products or were kept as wealth animals. Although variation in animal exploitation at Taosi and Zhoujiazhuang may reflect environmental differences, it may also reflect differences in the degree of centralized control over access to domestic animal resources.

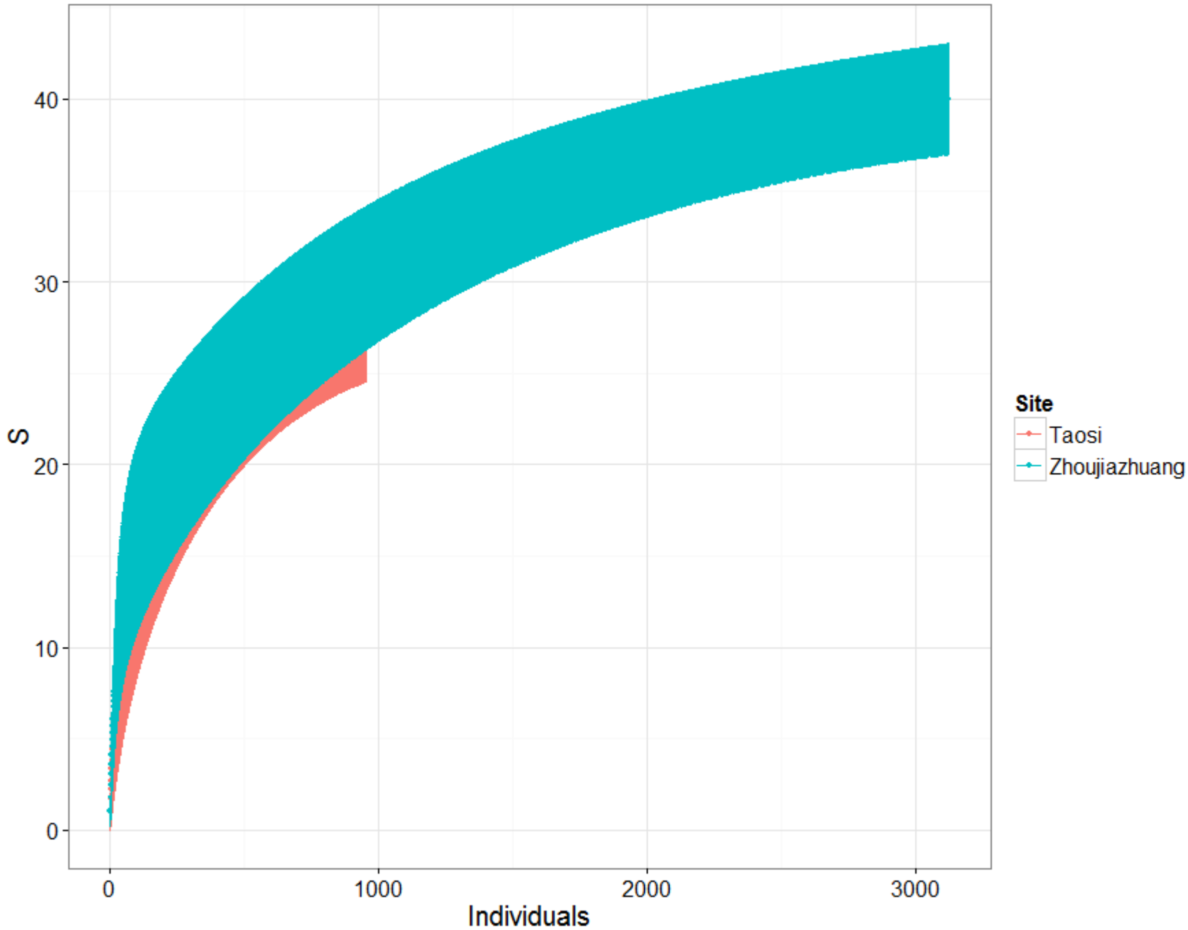
In chapter 3, I described bone working at Taosi and Zhoujiazhuang in more detail. I discussed differences and similarities in raw material selection, artifact production techniques, and the types of artifact made at the two sites. The Zhoujiazhuang worked bone assemblage contains more artifacts made from the bones and shells of wild taxa, especially projectile points made from cervid antlers and ornaments made from *Unio* shells. The Taosi worked bone assemblage is heavily focused on domestic taxa, with cattle long bones serving as a preferred raw material. The Taosi collection also contains many oracle bones, which may reflect the site's importance as a ritual center in the region. My analysis indicates that bone artifact production, although still occurring at a household scale, was performed in increasingly specialized ways that reflect the emergence of a bone artifact production industry in northern China.

In chapter 4, I presented the results of a pilot ancient DNA study of cattle oracle bones from both sites. I identified bone samples to taxon based on their mtDNA sequences, revealing that both wild aurochs and domestic cattle were used to make oracle bones at Zhoujiazhuang. Size measurements and morphological observations of scapulas indicate that it may not always be possible to distinguish between aurochs and domestic cattle oracle bones without the use of biomolecular data. I also included several non-oracle bone samples in the study as controls. One of these specimens was a wild water buffalo calcaneus from Zhoujiazhuang that I also identified as water buffalo based on morphology. Therefore multiple bovine taxa were present at Zhoujiazhuang, raising the possibility for interbreeding between East Asian aurochs and domestic cattle, and for experimentation with management of native wild aurochs or wild water buffalo. The results also demonstrate that zooarchaeologists still need to test the reliability of morphological criteria used to identify cattle, aurochs, and water buffalo in China.

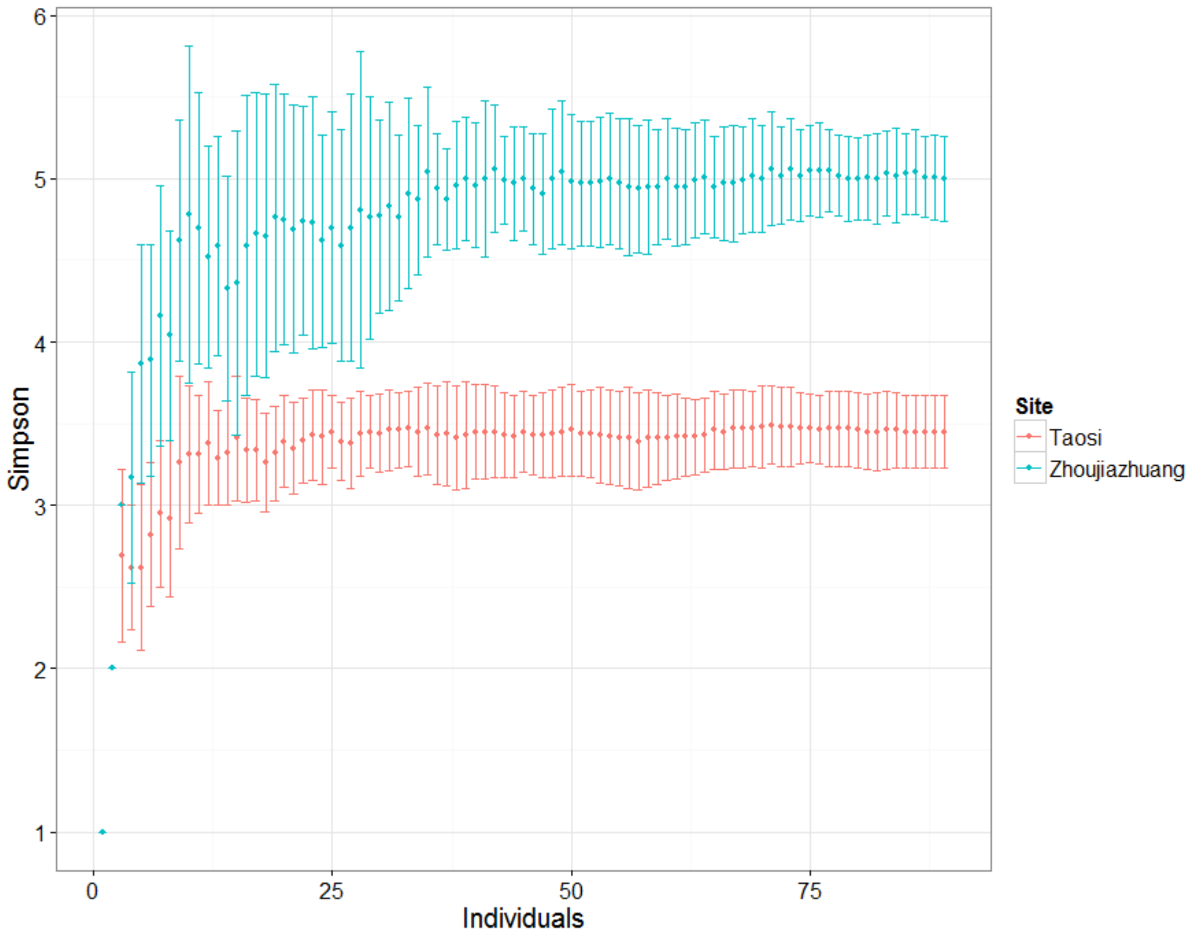
This dissertation is a small attempt to draw attention to social aspects of animal exploitation and the nuances of animal introduction events in China. There are still many remaining questions about the variability in how cattle and sheep were initially used in Chinese contexts, how herding allowed people to take advantage of new environmental niches, and how these animals interacted with native East Asian wild bovids. Zooarchaeologists working in China are increasingly concerned with these issues. As additional data from more sites becomes available, zooarchaeologists will be uniquely positioned to comment on the ways that animals and animal products contributed to the development of early Chinese civilizations.

APPENDIX 1

Rarefaction Curves and Simpson's Index of Diversity Calculations for the Overall Taosi and Zhoujiazhuang Faunal Assemblages



Rarefaction curves showing number of individuals plotted against number of species (S) with 95% confidence intervals displayed. Calculations were made on EstimateS statistical program using 100 runs without replacement. Calculations do not include artifacts identified only as S. mammal, M. mammal., M. or L. mammal, L. mammal, or Mammal. Taosi NTAXA=28; Zhoujiazhuang NTAXA=40.



Number of identified specimens (individuals) plotted against Simpson's index values with 95% confidence intervals displayed. Calculations were made on EstimateS statistical program using 100 runs without replacement. Calculations do not include artifacts identified only as S. mammal, M. mammal., M. or L. mammal, L. mammal, or Mammal. Taosi NTAXA=28; Zhoujiazhuang NTAXA=40. Taosi 1/D=3.5; Zhoujiazhuang 1/D=5.06.

APPENDIX 2

Taosi Skeletal Element Survivorship for Select Taxa

OBS=observed NISP; EXP=expected NISP based on MNI counts; %SURV=percent survivorship, calculated as OBS/EXP*100; %NISP=OBS/TOTAL NISP*100.

	Sus				**M. Bovid (including *Ovis* and *Ovis*/*Capra*)**				**L. Bovine (including *Bos* and L. Bovine)**			
ELEMENT	OBS	EXP	%SUR	%NISP	OBS	EXP	%SUR	%NISP	OBS	EXP	%SUR	%NISP
Antler Fragments	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Antler with Burr (naturally shed)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Antler + Cranium	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Horn Core	NA	NA	NA	NA	2	36	5.6	0.9	8	8	100.0	5.3
Cranium	41	NA	NA	9.5	3	NA	NA	1.4	6	NA	NA	4.0
Maxila/Premaxila with Teeth	35	54	64.8	8.1	9	36	25.0	4.1	2	8	25.0	1.3
Mandible	19	NA	NA	4.4	8	NA	NA	3.7	5	NA	NA	3.3
Mandible with Teeth	64	54	118.5	14.9	35	36	97.2	16.1	3	8	37.5	2.0
Loose Teeth	36	NA	NA	8.4	14	NA	NA	6.4	8	NA	NA	5.3
Scapula	29	NA	NA	6.7	12	NA	NA	5.5	16	NA	NA	10.5
Scapula (Dist)	20	54	37.0	4.7	8	36	22.2	3.7	8	8	100.0	5.7
Scapula (Blade)	9	NA	NA	2.1	4	NA	NA	1.8	8	NA	NA	5.3
Humerus	36	54	66.7	8.4	22	36	61.1	10.1	11	8	137.5	7.2
Humerus (Prox)	3	54	5.6	0.7	1	36	2.8	0.5	0	8	0.0	0.0
Humerus (Shaft)	24	54	44.4	5.6	16	36	44.4	7.3	8	8	100.0	5.3
Humerus (Dist)	18	54	33.3	4.2	14	36	38.9	6.4	5	8	62.5	3.3
Radius	14	54	25.9	3.3	19	36	52.8	8.7	5	8	62.5	3.3
Radius (Prox)	8	54	14.8	1.9	5	36	13.9	2.3	0	8	0.0	0.0
Radius (Shaft)	8	54	14.8	1.9	15	36	41.7	6.9	2	8	25.0	1.3
Radius (Dist)	1	54	1.9	0.2	7	36	19.4	3.2	3	8	37.5	2.0
Ulna	21	54	38.9	4.9	8	36	22.2	3.7	4	8	50.0	2.6
Femur	25	54	46.3	5.8	8	36	22.2	3.7	5	8	62.5	3.3
Femur (Prox)	2	54	3.7	0.5	2	36	5.6	0.9	2	8	25.0	1.3
Femur (Shaft)	15	54	27.8	3.5	6	36	16.7	2.8	2	8	25.0	1.3
Femur (Dist)	11	54	20.4	2.6	2	36	5.6	0.9	2	8	25.0	1.3
Patella	0	54	0.0	0.0	0	36	0.0	0.0	3	8	37.5	2.0
Tibia	14	54	25.9	3.3	22	36	61.1	10.1	5	8	62.5	3.3
Tibia (Prox)	2	54	3.7	0.5	1	36	2.8	0.5	2	8	25.0	1.3
Tibia (Shaft)	12	54	22.2	2.8	16	36	44.4	7.3	2	8	25.0	1.3
Tibia (Dist)	3	54	5.6	0.7	12	36	33.3	5.5	2	8	25.0	1.3
Fibula	8	54	14.8	1.9	NA	NA	NA	NA	NA	NA	NA	NA
Calcaneus	5	54	9.3	1.2	4	36	11.1	1.8	4	8	50.0	2.6
Astragalus	10	54	18.5	2.3	3	36	8.3	1.4	6	8	75.0	4.0
Other Carpals + Tarsals	0	702	0.00	0.0	0	324	0.00	0.0	6	72	8.33	4.0
Metacarpal	9	216	4.2	2.1	13	36	36.1	6.0	3	8	37.5	2.0
Metacarpal (Prox)	9	216	4.2	2.1	6	36	16.7	2.8	1	8	12.5	0.7

Metacarpal (Shaft)	9	216	4.2	2.1	10	36	27.8	4.6	1	8	12.5	0.7
Metacarpal (Dist)	3	216	1.4	0.7	3	36	8.3	1.4	1	8	12.5	0.7
Metatarsal	1	216	0.5	0.2	11	36	30.6	5.1	5	8	62.5	3.3
Metatarsal (Prox)	1	216	0.5	0.2	6	36	16.7	2.8	1	8	12.5	0.7
Metatarsal (Shaft)	1	216	0.5	0.2	8	36	22.2	3.7	4	8	50.0	2.6
Metatarsal (Dist)	1	216	0.5	0.2	1	36	2.8	0.5	2	8	25.0	1.3
Unid. Metapodial	5	NA	NA	1.2	9	NA	NA	4.1	1	NA	NA	0.7
Unid. Metapodial (Prox)	0	NA	NA	0.0	0	NA	NA	0.0	0	NA	NA	0.0
Unid. Metapodial (Shaft)	5	NA	NA	1.2	8	NA	NA	3.7	1	NA	NA	0.7
Unid. Metapodial (Dist)	2	NA	NA	0.5	1	NA	NA	0.5	0	NA	NA	0.0
Phalanges	9	1296	0.7	2.1	7	432	1.6	3.2	23	96	24.0	15.1
Pelvis	33	54	61.1	7.7	5	36	13.9	2.3	8	8	100.0	5.3
Sacrum	0	27	0.0	0.0	0	18	0.0	0.0	0	4	0.0	0.0
Hyoid	0	27	0.0	0.0	0	18	0.0	0.0	0	4	0.0	0.0
Atlas	7	27	25.9	1.6	3	18	16.7	1.4	3	4	75.0	2.0
Axis	2	27	7.4	0.5	1	18	5.6	0.5	1	4	25.0	0.7
Vert.	7	NA	NA	1.6	NA	NA	NA	NA	11	NA	NA	7.2
Ribs	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
TOTAL NISP	430				218				152			
MNI	27 (unique left mandibles with teeth)				18 (unique left mandibles with teeth)				4 (right scapulas)			

	Canis f.				**M. Cervid or *C. nippon***			
ELEMENT	OBS	EXP	%SUR	%NISP	OBS	EXP	%SUR	%NISP
Antler Fragments	NA	NA	NA	NA	0	NA	NA	0.0
Antler with Burr (naturally shed)	NA	NA	NA	NA	2	NA	NA	9.5
Antler + Cranium	NA	NA	NA	NA	1	NA	NA	4.8
Horn Core	NA	NA	NA	NA	NA	NA	NA	NA
Cranium	7	NA	NA	14.6	0	NA	NA	0.0
Maxila/Premaxila with Teeth	4	16	25.0	8.3	1	4	25.0	4.8
Mandible	0	NA	NA	0.0	0	NA	NA	0.0
Mandible with Teeth	10	16	62.5	20.8	1	4	25.0	4.8
Loose Teeth	1	NA	NA	2.1	0	NA	NA	0.0
Scapula	4	NA	NA	8.3	1	NA	NA	4.8
Scapula (Dist)	4	16	25.0	8.3	1	4	25.0	4.8
Scapula (Blade)	0	NA	NA	0.0	0	NA	NA	0.0
Humerus	5	16	31.3	10.4	3	4	75.0	14.3
Humerus (Prox)	4	16	25.0	8.3	0	4	0.0	0.0
Humerus (Shaft)	3	16	18.8	6.3	0	4	0.0	0.0
Humerus (Dist)	1	16	6.3	2.1	3	4	75.0	14.3
Radius	2	16	12.5	4.2	1	4	25.0	4.8

Radius (Prox)	2	16	12.5	4.2	0	4	0.0	0.0
Radius (Shaft)	2	16	12.5	4.2	1	4	25.0	4.8
Radius (Dist)	0	16	0.0	0.0	0	4	0.0	0.0
Ulna	1	16	6.3	2.1	0	4	0.0	0.0
Femur	3	16	18.8	6.3	1	4	25.0	4.8
Femur (Prox)	3	16	18.8	6.3	0	4	0.0	0.0
Femur (Shaft)	3	16	18.8	6.3	1	4	25.0	4.8
Femur (Dist)	1	16	6.3	2.1	1	4	25.0	4.8
Patella	0	16	0.0	0.0	0	4	0.0	0.0
Tibia	2	16	12.5	4.2	3	4	75.0	14.3
Tibia (Prox)	2	16	12.5	4.2	1	4	25.0	4.8
Tibia (Shaft)	1	16	6.3	2.1	1	4	25.0	4.8
Tibia (Dist)	0	16	0.0	0.0	2	4	50.0	9.5
Fibula	0	16	0.0	0.0	NA	NA	NA	NA
Calcaneus	0	16	0.0	0.0	0	4	0.0	0.0
Astragalus	0	16	0.0	0.0	2	4	50.0	9.5
Other Carpals + Tarsals	0	208	0.0	0.0	0	36	0.0	0.0
Metacarpal	5	80	6.3	10.4	0	4	0.0	0.0
Metacarpal (Prox)	5	80	6.3	10.4	0	4	0.0	0.0
Metacarpal (Shaft)	5	80	6.3	10.4	0	4	0.0	0.0
Metacarpal (Dist)	5	80	6.3	10.4	0	4	0.0	0.0
Metatarsal	1	64	1.6	2.1	1	4	25.0	4.8
Metatarsal (Prox)	1	64	1.6	2.1	1	4	25.0	4.8
Metatarsal (Shaft)	1	64	1.6	2.1	1	4	25.0	4.8
Metatarsal (Dist)	1	64	1.6	2.1	0	4	0.0	0.0
Unid. Metapodial	0	NA	NA	0.0	0	NA	NA	0.0
Unid. Metapodial (Prox)	0	NA	NA	0.0	0	NA	NA	0.0
Unid. Metapodial (Shaft)	0	NA	NA	0.0	0	NA	NA	0.0
Unid. Metapodial (Dist)	0	NA	NA	0.0	0	NA	NA	0.0
Phalanges	0	480	0.0	0.0	2	48	4.2	9.5
Pelvis	2	16	12.5	4.2	1	4	25.0	4.8
Sacrum	0	8	0.0	0.0	0	2	0.0	0.0
Hyoid	0	8	0.0	0.0	0	2	0.0	0.0
Atlas	0	8	0.0	0.0	1	2	50.0	4.8
Axis	1	8	12.5	2.1	0	2	0.0	0.0
Vert.	NA	NA	NA	NA	NA	NA	NA	NA
Ribs	NA	NA	NA	NA	NA	NA	NA	NA
TOTAL NISP	48				21			
MNI	8 (unique left mandibles with teeth)				2 (right distal humerus)			

Note: Specimens from complete or partial dog skeletons are not listed in the table above. These include: 1) a complete skeleton missing the cranium, left scapula, and several metapodials and phalanges; 2) two fairly complete puppy skeletons with all bones unfused; and 3) the upper body of a single individual missing the cranium and extremities.

APPENDIX 3

Zhoujiazhuang Skeletal Element Survivorship for Select Taxa

OBS=observed NISP; EXP=expected NISP based on MNI counts; %SURV=percent survivorship, calculated as OBS/EXP*100; %NISP=OBS/TOTAL NISP*100.

	Sus				**M. Bovid (including *Ovis* and *Ovis/Capra*)**				**L. Bovine (including *Bos* and L. Bovine)**			
ELEMENT	OBS	EXP	%SUR	%NISP	OBS	EXP	%SUR	%NISP	OBS	EXP	%SUR	%NISP
Antler Fragments	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Antler with Burr (naturally shed)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Antler + Cranium	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Horn Core	NA	NA	NA	NA	8	176	4.6	0.6	8	30	26.7	2.3
Cranium	147	NA	NA	11.0	11	NA	NA	0.9	5	NA	NA	1.4
Maxila/Premaxila with Teeth	137	150	91.3	10.3	37	176	21.0	2.9	5	30	16.7	1.4
Mandible	20	NA	NA	1.5	36	NA	NA	2.9	16	NA	NA	4.6
Mandible with Teeth	137	150	91.3	10.3	169	176	96.0	13.4	13	30	43.3	3.7
Loose Teeth	162	NA	NA	12.2	284	NA	NA	22.5	55	NA	NA	15.6
Scapula	95	NA	NA	7.1	46	NA	NA	3.6	29	NA	NA	8.2
Scapula (Dist)	74	150	49.3	5.6	36	176	20.5	2.9	17	30	56.7	4.8
Scapula (Blade)	21	NA	NA	1.6	10	NA	NA	0.8	12	NA	NA	3.4
Humerus	92	150	61.3	6.9	47	176	26.7	3.7	23	30	76.7	6.5
Humerus (Prox)	3	150	2.0	0.2	1	176	0.6	0.1	3	30	10.0	0.9
Humerus (Shaft)	53	150	35.3	4.0	23	176	13.1	1.8	13	30	43.3	3.7
Humerus (Dist)	50	150	33.3	3.8	32	176	18.2	2.5	9	30	30.0	2.6
Radius	49	150	32.7	3.7	87	176	49.4	6.9	15	30	50.0	4.3
Radius (Prox)	42	150	28.0	3.2	31	176	17.6	2.5	7	30	23.3	2.0
Radius (Shaft)	19	150	12.7	1.4	57	176	32.4	4.5	6	30	20.0	1.7
Radius (Dist)	2	150	1.3	0.2	17	176	9.7	1.3	3	30	10.0	0.9
Ulna	82	150	54.7	6.2	38	176	21.6	3.0	10	30	33.3	2.8
Femur	33	150	22.0	2.5	16	176	9.1	1.3	13	30	43.3	3.7
Femur (Prox)	4	150	2.7	0.3	5	176	2.8	0.4	5	30	16.7	1.4
Femur (Shaft)	25	150	16.7	1.9	11	176	63	0.9	7	30	23.3	2.0
Femur (Dist)	6	150	4.0	0.5	3	176	1.7	0.2	2	30	6.7	0.6
Patella	1	150	0.7	0.1	0	176	0.0	0.0	0	30	0.0	0.0
Tibia	50	150	33.3	3.8	136	176	77.3	10.8	7	30	23.3	2.0
Tibia (Prox)	5	150	3.3	0.4	1	176	0.6	0.1	2	30	6.7	0.6
Tibia (Shaft)	23	150	15.3	1.7	67	176	38.1	5.3	1	30	3.3	0.3
Tibia (Dist)	28	150	18.7	2.1	93	176	52.8	7.4	5	30	16.7	1.4
Fibula	44	150	29.3	3.3	NA	NA	NA	NA	NA	NA	NA	NA
Calcaneus	33	150	22.0	2.5	20	176	11.4	1.6	10	30	33.3	2.8
Astragalus	13	150	8.7	1.0	20	176	11.4	1.6	11	30	36.7	3.1
Other Carpals + Tarsals	2	1950	0.1	0.2	17	1584	1.1	1.3	23	270	8.5	6.5
Metacarpal	38	600	6.3	2.9	101	176	57.4	8.0	18	30	60.0	5.1
Metacarpal (Prox)	38	600	6.3	2.9	30	176	17.1	2.4	8	30	26.7	2.3
Metacarpal (Shaft)	26	600	4.3	2.0	73	176	41.5	5.8	8	30	26.7	2.3

Metacarpal (Dist)	8	600	1.3	0.6	20	176	11.4	1.6	4	30	13.3	1.1
Metatarsal	30	600	5.0	2.3	72	176	40.9	5.7	15	30	50.0	4.3
Metatarsal (Prox)	29	600	4.8	2.2	38	176	21.6	3.0	6	30	20.0	1.7
Metatarsal (Shaft)	19	600	3.2	1.4	50	176	28.4	4.0	4	30	13.3	1.1
Metatarsal (Dist)	8	600	1.3	0.6	2	176	1.1	0.2	7	30	23.3	2.0
Unid. Metapodial	16	NA	NA	1.2	16	NA	NA	1.3	7	NA	NA	2.0
Unid. Metapodial (Prox)	4	NA	NA	0.3	3	NA	NA	0.2	1	NA	NA	0.3
Unid. Metapodial (Shaft)	7	NA	NA	0.5	6	NA	NA	0.5	3	NA	NA	0.9
Unid. Metapodial (Dist)	10	NA	NA	0.8	7	NA	NA	0.6	3	NA	NA	0.9
Phalanges	49	3600	1.3	3.7	53	2112	2.5	4.2	43	360	11.9	12.2
Pelvis	68	150	45.3	5.1	45	176	25.6	3.6	6	30	20.0	1.7
Sacrum	0	75	0.0	0.0	0	88	0.0	0.0	2	15	13.3	0.6
Hyoid	0	75	0.0	0.0	1	88	1.1	0.1	1	15	6.7	0.3
Atlas	28	75	37.3	2.1	2	88	2.3	0.2	5	15	33.3	1.4
Axis	5	75	6.7	0.4	3	88	3.4	0.2	1	15	6.7	0.3
Vert.	NA	NA	NA	NA	NA	NA	NA	NA	11	NA	NA	3.1
Ribs	NA	NA	NA	NA	NA	NA	NA	NA	1	NA	NA	0.3
TOTAL NISP	1331				1265				353			
MNI	75 (unique left mandibles with teeth)				88 (unique left mandibles w/ teeth)				15 (unique left scapulas)			

	Canis f.				**M. Cervid or *C. nippon***			
ELEMENT	OBS	EXP	%SUR	%NISP	OBS	EXP	%SUR	%NISP
Antler Fragments	NA	NA	NA	NA	27	NA	NA	13.1
Antler with Burr (naturally shed)	NA	NA	NA	NA	7	NA	NA	3.4
Antler + Cranium	NA	NA	NA	NA	5	NA	NA	2.4
Horn Core	NA	NA	NA	NA	NA	NA	NA	NA
Cranium	4	NA	NA	2.1	0	NA	NA	0.0
Maxila/Premaxila with Teeth	4	26	15.4	2.1	1	20	5.0	0.5
Mandible	0	NA	NA	0.0	1	NA	NA	0.5
Mandible with Teeth	22	26	84.6	11.7	5	20	25.0	2.4
Loose Teeth	9	NA	NA	4.8	1	NA	NA	0.5
Scapula	4	NA	NA	2.1	18	NA	NA	8.7
Scapula (Dist)	4	26	15.4	2.1	17	20	85.0	8.3
Scapula (Blade)	0	NA	NA	0.0	1	NA	NA	0.5
Humerus	10	26	38.5	5.3	7	20	35.0	3.4
Humerus (Prox)	1	26	3.9	0.5	0	20	0.0	0.0
Humerus (Shaft)	2	26	7.7	1.1	0	20	0.0	0.0
Humerus (Dist)	8	26	30.8	4.3	7	20	35.0	3.4
Radius	13	26	50.0	6.9	11	20	55.0	5.3
Radius (Prox)	6	26	23.1	3.2	3	20	15.0	1.5
Radius (Shaft)	7	26	26.9	3.7	7	20	35.0	3.4
Radius (Dist)	9	26	34.6	4.8	3	20	15.0	1.5

Ulna	14	26	53.9	7.5	4	20	20.0	1.9
Femur	9	26	34.6	4.8	6	20	30.0	2.9
Femur (Prox)	5	26	19.2	2.7	1	20	5.0	0.5
Femur (Shaft)	6	26	23.1	3.2	3	20	15.0	1.5
Femur (Dist)	2	26	7.7	1.1	2	20	10.0	1.0
Patella	0	26	0.0	0.0	0	20	0.0	0.0
Tibia	13	26	50.0	6.9	11	20	55.0	5.3
Tibia (Prox)	1	26	3.9	0.5	2	20	10.0	1.0
Tibia (Shaft)	10	26	38.5	5.3	3	20	15.0	1.5
Tibia (Dist)	9	26	34.6	4.8	7	20	35.0	3.4
Fibula	3	26	11.5	1.6	NA	NA	NA	NA
Calcaneus	5	26	19.2	2.7	8	20	40.0	3.9
Astragalus	4	26	15.4	2.1	9	20	45.0	4.4
Other Carpals + Tarsals	10	338	3.0	5.3	10	180	5.6	4.9
Metacarpal	5	130	3.9	2.7	19	20	95.0	9.2
Metacarpal (Prox)	5	130	3.9	2.7	9	20	45.0	4.4
Metacarpal (Shaft)	5	130	3.9	2.7	7	20	35.0	3.4
Metacarpal (Dist)	4	130	3.1	2.1	9	20	45.0	4.4
Metatarsal	29	104	27.9	15.4	17	20	85.0	8.3
Metatarsal (Prox)	34	104	32.7	18.1	5	20	25.0	2.4
Metatarsal (Shaft)	28	104	26.9	14.9	11	20	55.0	5.3
Metatarsal (Dist)	24	104	23.1	12.8	4	20	20.0	1.9
Unid. Metapodial	3	NA	NA	1.6	5	NA	NA	2.4
Unid. Metapodial (Prox)	2	NA	NA	1.1	1	NA	NA	0.5
Unid. Metapodial (Shaft)	1	NA	NA	0.5	3	NA	NA	1.5
Unid. Metapodial (Dist)	2	NA	NA	1.1	2	NA	NA	1.0
Phalanges	7	780	0.9	3.7	23	240	9.6	11.2
Pelvis	9	26	34.6	4.8	6	20	30.0	2.9
Sacrum	1	13	7.7	0.5	0	10	0.0	0.0
Hyoid	0	13	0.0	0.0	0	10	0.0	0.0
Atlas	1	13	7.7	0.5	2	10	20.0	1.0
Axis	5	13	38.5	2.7	1	10	10.0	0.5
Vert.	4	NA	NA	2.1	2	NA	NA	1.0
Ribs	NA	NA	NA	NA	NA	NA	NA	NA
TOTAL NISP	188				206			
MNI	13 (unique right mandibles w/ teeth)				10 (unique right scapulas)			

Note: Specimens from three nearly complete dog skeletons are not listed in the table above.