Zooarchaeological and Genetic Evidence for the Origins of Domestic Cattle in Ancient China

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ABSTRACT

This article reviews current evidence for the origins of domestic cattle in China. We describe two possible scenarios: 1) domestic cattle were domesticated indigenously in East Asia from the wild aurochs (*Bos primigenius*), and 2) domestic cattle were domesticated elsewhere and then introduced to China. We conclude that the current zooarchaeological and genetic evidence does not support indigenous domestication within China, although it is possible that people experimented with managing wild aurochs in ways that did not lead to complete domestication. Most evidence indicates that domestic taurine cattle (*Bos taurus*) were introduced to China during the third millennium B.C., and were related to cattle populations first domesticated in the Near East. Zebu cattle (*Bos indicus*) entered China sometime between 2000 and 200 B.C., but much less is known about this species. The role of cattle as ritual and wealth animals seems to have been critical to their initial introduction. KEYWORDS: cattle, domestication, management, zooarchaeology, Neolithic and Bronze Age China.

INTRODUCTION

IN THIS ARTICLE, WE SUMMARIZE THE CURRENT STATE of genetic and zooarchaeological research on cattle domestication in China. Despite the importance of cattle in ancient and modern Chinese societies, there is no English-language synthesis of the zooarchaeological evidence for the origins of Chinese cattle. Our aim is to present the most current list of sites where domestic cattle bones have been securely identified in order to evaluate recent claims for indigenous domestication of Chinese cattle from wild aurochs. We argue that there is no definitive evidence that domestic cattle were present in China prior to about 3600 B.C. Instead, cattle were likely introduced to China during the Late Neolithic period (fourth to third millennium B.C.), possibly through trade routes connecting China and Central Asia. Finally, we discuss some of the ways that ancient people initially exploited cattle for subsistence, labor, raw materials, and rituals. The archaeological evidence for how cattle were used in the Late

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Neolithic offers insight into how they became one of the most important ritual animals in Bronze Age China.

BACKGROUND: ANIMAL DOMESTICATION IN ANCIENT CHINA AND OTHER CHINESE BOVINES

The past few decades of zooarchaeological research have produced important data on the processes of animal domestication in China (Yuan 2008, 2015). Although some animals were domesticated from native Chinese species, many other domesticates were introduced to China from neighboring regions. For example, pigs were domesticated independently in China during the Early Neolithic c. 6600–6000 B.C. (Cucchi et al. 2011; Larson et al. 2005; Larson et al. 2010; Luo 2012; Yuan 2010; Yuan and Flad 2002). Other domesticates do not appear in China until the Late Neolithic and early Bronze Age, when agriculture was already well established. For example, sheep arrived in China by c. 3600–2000 B.C. (Flad et al. 2007; Yuan et al. 2007) and horses by c. 1370 B.C. (Flad et al. 2007; Linduff 2003; Yuan and Flad 2006; Yuan et al. 2007). These animals were introduced to China during periods of increasing long-distance trade and exchange both within China and across Eurasia (Anthony 2007; Chang 1986:234–294; Frachetti 2008; Jaang 2015; Kohl 2007; Sherratt 2006).

There is a good deal of debate about the origins of domestic Chinese bovines. East Asia was once home to several native wild bovines including water buffalo (*Bubalus mephistopheles*), aurochs (*Bos primigenius*), bison (*Bison exiguus*), gaur (*Bos/Bibos gaurus*), and yak (*Bos/Poephagus mutus*) (Zhang 2001; Zhongguo Kexue 1959; Zhongguo Kexue 1979). With the exception of the gaur and wild yak, these species are now extinct. Wild water buffalo bones have been found at many Neolithic and Bronze Age sites, including sites in the Lower Yangzi River Basin dating to c. 5000–3000 B.C. where water buffalo scapulae were used to make agricultural tools (Liu et al. 2004; Liu et al. 2006; Xie 2014). The earliest archaeological evidence for domestic water buffalo in China comes from textual and artistic depictions from Southwest China dating to after the first century A.D. (Liu et al. 2006). Modern DNA research indicates that the origin of domestic swamp water buffalo (*Bubalus bubalis*) may be traced to this region, but it is also possible that water buffalo were first domesticated in parts of Southeast Asia and then introduced to Southwest China (Yue et al. 2013). Ancient DNA analysis of water buffalo remains from Bronze Age sites dating to c. 2000 B.C. in the Yellow River Valley indicates that these animals were all wild water buffalo (*Bubalus mephistopheles*) that did not contribute genetically to modern Chinese domestic water buffalo populations (Yang et al. 2008). It remains unclear when wild water buffalo in China went extinct and when they were replaced by domestic water buffalo populations.

Domestic yaks (*Bos/Poephagus grunniens*) may have been domesticated from wild yaks somewhere on the Qinghai-Tibetan Plateau (Flad et al. 2007). Yak milk, meat, and dung are important to life at high altitudes in this region, but the process of domestication is based solely on modern geographic distributions and there is still no clear zooarchaeological evidence for the process of yak domestication (Flad et al. 2007; Rhode et al. 2007). Modern genetic evidence indicates that yaks were domesticated sometime during the Holocene, perhaps even before 7000 years ago (Guo et al. 2006; Qiu et al. 2015). Ancient DNA and zooarchaeological evidence are still needed to confirm these claims.

To date, there are no zooarchaeological or ancient DNA studies of bovines in the gaur lineage. Modern genetic research indicates that the gayal (*Bos frontalis*) was domesticated from the gaur and subsequently underwent significant hybridization with domestic cattle populations in Southwest China (Gou et al. 2010; Verkaar et al. 2004). It is still unclear whether gayal were first domesticated in Southwest China or elsewhere in Indochina.

EVIDENCE FOR INDIGENOUS CATTLE DOMESTICATION IN CHINA

The origins of domestic Chinese water buffalo, yaks, and gayal remain elusive due to the paucity of zooarchaeological and ancient DNA data. Although we have more information for domestic cattle, the complex relationships between domestic cattle and ancient wild Chinese bovines are also unclear.

Zooarchaeologists and geneticists are currently in general agreement that all cattle worldwide were domesticated from the now extinct wild aurochs (*Bos primigenius*) in two domestication episodes: one in the Near East by c. 8000 B.C. that gave rise to taurine cattle (*Bos taurus*) (Bradley and Magee 2006; Helmer et al. 2005; Hongo et al. 2009) and another in South Asia by roughly 6000 B.C. that gave rise to zebu cattle (*Bos indicus*) (Bradley and Magee 2006; Grigson 1985; Meadow 1996; Meadow and Patel 2003). Although the current genetic evidence indicates that there were two independent centers of cattle domestication, Larson and Burger (2013 : 202) note that the branching patterns seen in mtDNA and Y-chromosomal DNA phylogenetic trees that are used to support the two-center model can also be explained by phenomena such as population structure or genetic drift. Therefore, it is still possible that there was only a single center of cattle domestication in the Near East. Further genetic evidence is needed before we can rule out the possibility that zebu cattle reflect later admixture with South Asian wild auroch populations.

With the exception of Zhang and colleagues (2013), discussions on the origins of domestic cattle have not examined specifically the possibility that people managed or even domesticated wild cattle in East Asia. Aurochs were naturally distributed across Eurasia and into China during the Holocene (van Vuure 2005), but previous zooarchaeological and ancient DNA research indicates that Chinese aurochs were never domesticated, and that domestic cattle were introduced to China from West Asia (Cai et al. 2014; Flad et al. 2007; Yuan et al. 2007). New evidence, including recent genetic analysis of an early Holocene specimen with stereoscopic tooth wear and unique mtDNA signature, offers an intriguing picture of complex animal management strategies and raises the question of whether there was a third, as yet undiscovered, domestication event in China (Zhang et al. 2013). We discuss this evidence in detail below.

Cattle have been identified at many Chinese archaeological sites (Table 1; Fig. 1). Specimens with earlier dates often come from unsecure contexts or prove to be wild bovines after re-evaluation. For example, for many years scholars believed that domestic cattle were present at the site of Cishan in Hebei Province (c. 6500–5000 B.C.) (Chen 2005 : 57; Wu and Huang 1997; Zhou 1981). However, re-evaluation demonstrated that the Cishan bones are larger than domestic cattle bones and are more similar in size to Pleistocene-era wild *Bison* sp. and *Bos* from North China (Anhui 1992; Lu 2010*b*; Zhongguo Kexue 1959 : 70). Similarly, cattle remains were identified at the site of Jiahu in Henan Province (c. 7000–5500 B.C.) (Henan 1999 : 785–805), but reanalysis indicates that these specimens are morphologically similar to water buffalo (*Bubalus mephistopheles*) (Luo et al. 2015). Bones identified as *Bos* have also been found at the Neolithic sites of Baiyinchanghan in Inner Mongoila (Tang et al. 2004), Xiaojingshan in Shandong Province (Kong 1996), and Peiligang in Henan Province (Kaifeng et al. 1979; Zhongguo Shehui 1984); these also likely represent wild hunted animals. The current evidence indicates that there are no archaeological sites with definitive zooarchaeological evidence for domestic cattle dating to before c. 3600 B.C. Nevertheless, wild cattle were occasionally hunted at earlier Neolithic sites.

Recently, Zhang and colleagues (2013) identified a *Bos* mandible dating to c. 10,600 cal B.P. Found near Harbin in Northeast China, it may provide new evidence for early experimentation with cattle management. Zhang and colleagues found that the lower P4 and M1 teeth on the mandible were heavily worn (Fig. 2a). They argue that such a wear pattern may have been caused by bar-biting or repeated chewing of hard objects, which they interpret as evidence for human management of this animal. Comparisons between mtDNA from the mandible and mitogenome sequences from modern bovine species indicate that the mandible belongs to a new and unique *Bos* haplogroup, haplogroup C. Because millet cultivation was taking place in northern China around roughly the same time (Yang et al. 2012), Zhang and colleagues (2013) propose that people may have experimented with managing animals.

We have argued elsewhere that such claims are premature (Lu et al. 2014). This new find seems to upend the current consensus about cattle domestication, but it is a unique sample and the evidence for intentional human management is weak. Zhang and colleagues (2013) do not include information about the stratigraphic, taphonomic, and depositional factors that influenced the context of the specimen. It is unclear whether there was even human habitation at the site where the mandible was found. Additionally, they present a single line of evidence—symmetrical wear on the lower P4 and M1 teeth—to claim that people were managing this individual bovine. Archaeological studies of bit-wear in horses have shown that wear is usually asymmetrical and manifested on the lower P2 teeth (Anthony 2007 : 194, 207–213; Olsen 2006). We are unaware of similar studies for cattle tooth wear.

During our own observations of modern skeletal comparative collections of ungulates from China, we found that extreme wear on the P4 and M1 can be found in both wild and domestic ungulates of older ages (Fig. 2b–e). Such tooth wear is likely caused by long-term grinding of the mandibular teeth against the maxillary teeth. The mandibular M1 is the first adult tooth to erupt, making it subject to the most extended wear during an animal's life (Grigson 1982; Hillson 2005 : 232). The heavy wear that Zhang and colleagues (2013) observed on the lower P4 and M1 on the mandible from Northeast China could be due to the age of the animal and extended grinding against the maxillary teeth. Without the associated maxilla or associated archaeological materials, we cannot rule out the possibility that the wear pattern on the 10,600 cal B.P. mandible is natural and therefore not yet definitive evidence of cattle management. The mtDNA does not match any known modern *Bos* haplogroups because the mandible is from a now-extinct East Asian form of *Bos primigenius* that did not contribute genetically to later domestic cattle. There is currently insufficient evidence to suggest that there was management of this now extinct species.

Although we do not believe that the cattle mandible in question represents a managed individual, the 2013 study by Zhang and colleagues still raises two significant

Table 1. Sites with the Earliest Evidence for Cattle Exploitation in Ancient China. See Lu 2010*a*, 2010*b*, and 2010*c* for Additional Information on Identification Criteria

Date	Site name	Province	mtDNA haplogroups present?	Dietary signatures consistent with possible millet foddering?	Bone morphology consistent with domestic *Bos*?	Size measurements consistent with domestic *Bos*?	Age structure consistent with domestic *Bos*?	Cattle represent over 5% of identified mammalian faunal specimens?	Archaeological context suggests that domestic cattle were present?	Sources	Notes
C. 3600–2500 B.C.	Fujiamen	Gansu							X	Lu 2010*b*; Zhao 1995	Single scapula with S-shaped incision
	Jiangzhai	Shaanxi				X				Lu 2010*b*; Qi 1988	
	Xishanping	Gansu			X					Flad et al. 2009; Lu 2010*b*; Zhou 1999	
	Shizhaocun	Gansu			X					Flad et al. 2009; Lu 2010*b*; Zhou 1999	
	Xishan	Gansu				X				Yu et al. 2011	
C. 2500–2000 B.C.	Dahezhuang	Gansu							X	Lu 2010*b*; Zhongguo Kexue 1974	Oracle bones; complete female *Bos* skeleton found in structure F1 (skull removed, fetal bones in stomach area)
	Qinweijia	Gansu						X	X	Lu 2010*b*; Zhongguo Kexue 1975	Dozens of cattle mandibles included in funerary offerings
	Pingliangtai	Henan							X	Henan & Zhoukou 1983; Lu 2010*b*	Two complete cattle skeletons buried in pit H53

(*Continued*)

	Shantaisi	Henan				X		X	X	Lu 2010*b*; Zhang & Zhang 1997	Nine complete cattle skeletons and one deer skull buried in pit H39
	Guchengzhai	Henan			X	X	X			Lu 2010*b*	
	Huangniangniangtai	Gansu							X	Gansu 1960; Lu 2010*b*	Worked bone artifacts and oracle bones
	Dahancun Nangang	Henan							X	Lu 2010*b*; Zhongguo Shehui 1990	Worked bone artifacts and oracle bones
	Xiaopangou	Henan							X	Lu 2010*b*; Luoyang 1978	Worked bone artifacts and oracle bones
	Baiying	Henan							X	Lu 2010*b*; Zhou 1983	Worked bone artifacts and oracle bones
	Wadian	Henan		X	X			X	X	Lu 2009, 2010*b*	Worked bone artifacts and oracle bones
	Shenzhongji	Shandong							X	Lu 2010*b*; Zhi 1980	Worked bone artifacts and oracle bones
	Shangzhuang	Shandong							X	Lu 2010*b*; Shandong 1985	Worked bone artifacts and oracle bones
	Chengziya	Shandong							X	Fu et al. 1934; Lu 2010*b*	Worked bone artifacts and oracle bones
	Lujiakou	Shandong						X		Lu 2010*b*; Zhongguo Shehui & Shandong 1985	Sudden increase in *Bos* specimens
	Zijing	Shaanxi						X		Lu 2010*b*; Wang 1991	Sudden increase in *Bos* specimens
	Huoshiliang	Shaanxi			X	X				Hu et al. 2008	
	Dongying	Shaanxi		X						Chen et al. 2014	
	Yuchisi	Anhui				X				Lu 2010*b*; Yuan & Chen 2001	
	Zongri	Qinghai						X		An & Chen 2010	Sudden increase in *Bos* specimens
	Wangchenggang	Henan			X			X		Lu 2010*b*; Lu et al. 2007	
C. 2000–1600 B.C.	Taosi	Shanxi	T3, T4	X	X		X	X	X	Brunson et al. 2016; Cai et al. 2014; Chen et al. 2012	Cattle oracle bones and cattle bones in ritual contexts
	Zhoujiazhuang	Shanxi	C, T3, T4		X		X	X	X	Brunson et al. 2016	Cattle and aurochs oracle bones
	Xinzhai	Henan		X	X		X	X	X	Dai et al. 2015	

(*Continued*)

TABLE 1 (*Continued*)

DATE	SITE NAME	PROVINCE	MTDNA HAPLOGROUPS PRESENT?	DIETARY SIGNATURES CONSISTENT WITH POSSIBLE MILLET FODDERING?	BONE MORPHOLOGY CONSISTENT WITH DOMESTIC *BOS*?	SIZE MEASUREMENTS CONSISTENT WITH DOMESTIC *BOS*?	AGE STRUCTURE CONSISTENT WITH DOMESTIC *BOS*?	CATTLE REPRESENT OVER 5% OF IDENTIFIED MAMMALIAN FAUNAL SPECIMENS?	ARCHAEOLOGICAL CONTEXT SUGGESTS THAT DOMESTIC CATTLE WERE PRESENT?	SOURCES	NOTES
	Zhangdeng	Henan		X				X		Hou et al. 2013	
	Xinhua	Shaanxi			X	X			X	Lu 2010*b*; Xue et al. 2005	Worked bone artifacts/oracle bones, sizes within range of domestic cattle
	Huoshiliang	Gansu								Atahan et al. 2011	Dietary signatures inconsistent with millet foddering, suggesting cattle were managed differently than in other parts of North China
	Ganggangwa	Gansu								Atahan et al. 2011	Dietary signatures inconsistent with millet foddering, suggesting cattle were managed differently than in other parts of North China
	Changning	Qinghai	T3							Cai et al. 2014	
	Zhukaigou	Inner Mongolia			X			X		Huang 1996; Lu 2010*b*	Cattle bones make up a large proportion of the faunal assemblage in all occupation phases

(*Continued*)

	Dashanqian	Inner Mongolia	T3, T4							Cai et al. 2014	Identification of Near Eastern *Bos* mtDNA haplogroups in Lower Xiajiadian Culture levels
	Xiaohe	Xinjiang	T2, T3							Cai et al. 2014	
	Erlitou	Henan	T2, T3, T4		X		X	X	X	Cai et al. 2014; Yang 2008	
After c. 1600 B.C.	Yanshi Shangcheng	Henan			X	X	X	X	X	Li, Yuan, et al. 2013; Zhongguo Shehui 1988; Zhongguo Shehui 2002	
	Zhengzhou Shangcheng	Henan			X	X	X	X	X	Henan 1957; Henan 2001; Hu 1993	
	Xiaoshuangqiao	Henan			X	X	X	X	X	Henan 2012	
	Huanbei Shangcheng	Henan			X	X	X	X	X	He & Yue 2011; Lu 2010*d*; Yuan & Tang 2000	
	Yinxu	Henan			X	X	X	X	X	Campbell et al. 2011; Li 2009	
	Dashanqian	Inner Mongolia	T2, T3, T4							Cai et al. 2014	Identification of Near Eastern *Bos* mtDNA haplogroups in Upper Xiajiadian Culture levels

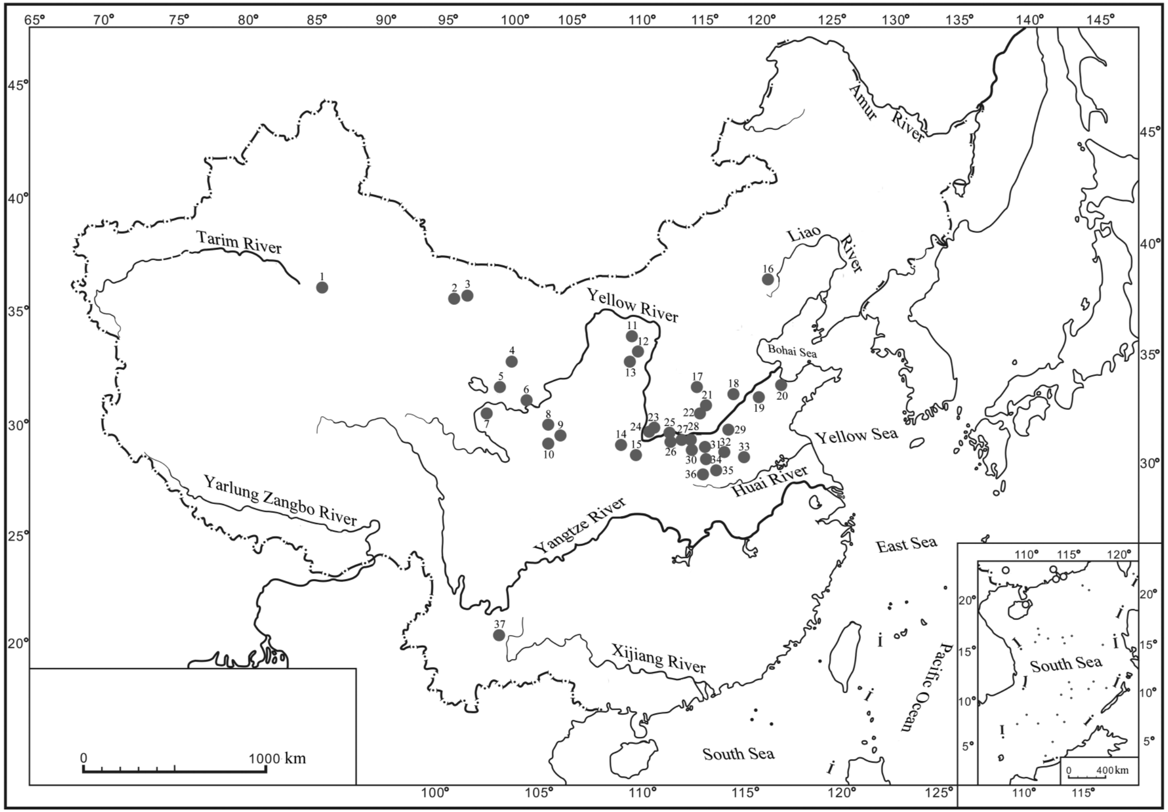

Fig. 1. Map of archaeological sites mentioned in the article: 1. Xiaohe; 2. Ganggangwa; 3. Huoshiliang (Gansu Province); 4. Huangniangniangtai; 5. Changning; 6. Dahezhuang and Qinweijia; 7. Zongri; 8. Fujiamen; 9. Shizhaocun and Xishanping; 10. Xishan; 11. Zhukaigou; 12. Xinhua; 13. Huoshiliang (Shaanxi Province); 14. Dongying and Jiangzhai; 15. Zijing; 16. Dashanqian; 17. Cishan; 18. Shangzhuang; 19. Chengziya; 20. Lujiakou; 21. Dahancunnangang, Huanbei Shangcheng, and Yinxu; 22. Baiying; 23. Taosi; 24. Zhoujiazhuang; 25. Xiaopangou; 26. Yanshi Shangcheng; 27. Erlitou; 28. Xiaoshuangqiao and Zhengzhou Shangcheng; 29. Shengzhongji; 30. Wangchenggang; 31. Guchengzhai and Xinzhai; 32. Shantaisi; 33. Xuchisi; 34. Wadian; 35. Pingliangtai; 36. Jiahu; 37. Shizhaishan.

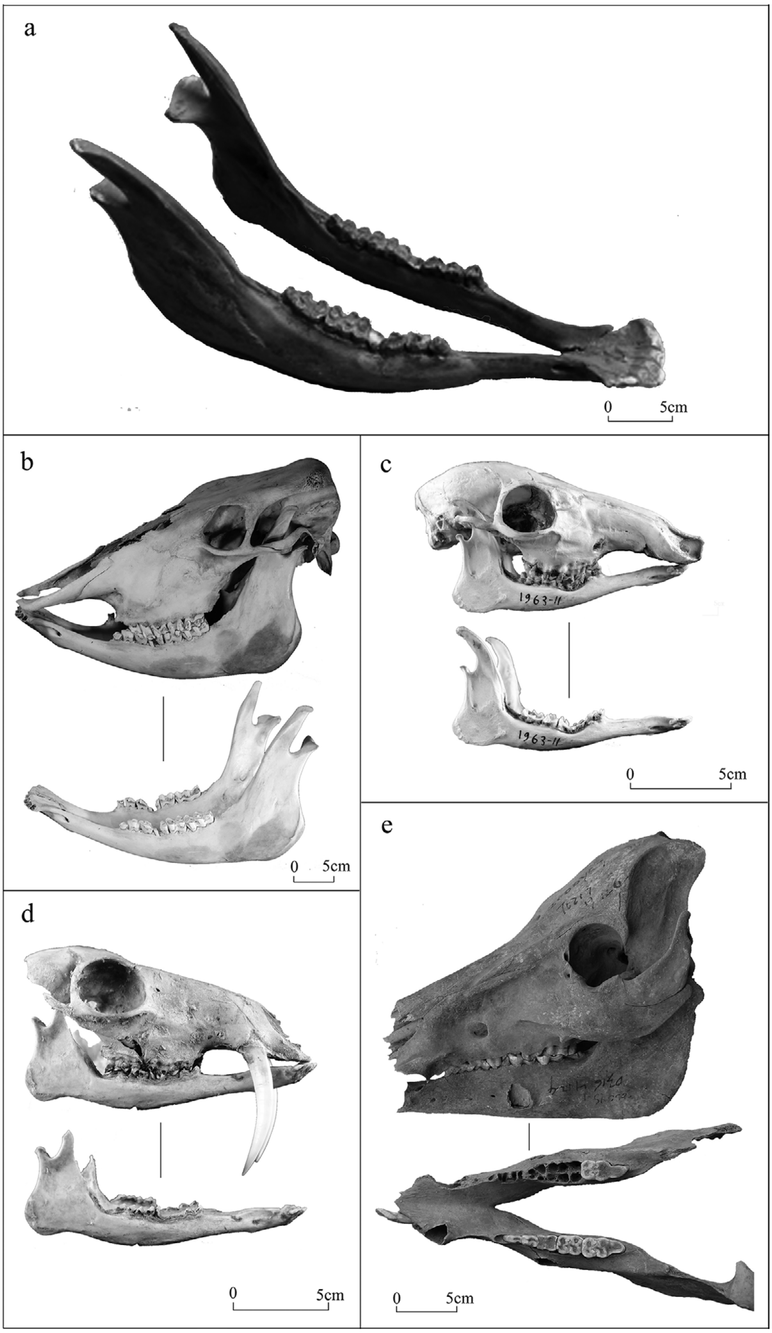

Fig. 2. Severe wear on the mandibular P4 and M1 of old age ungulates: a) *Bos* mandible from Northwest China dating to over 10,500 cal. B.P. (Zhang et al. 2013); b) modern domestic cattle skull and mandible specimen collected from Henan Province from an animal that died of old age and was not bar-bitted (Institute of Archaeology, Chinese Academy of Social Sciences (IA CASS) collections, Beijing); c) modern musk deer skull and mandible (Muséum national d'Histoire naturelle (MNHN) collections, Paris); d) modern water deer skull and mandible (MNHN); e) Shang dynasty domestic pig skull and mandible (IA CASS).

questions: 1) What was the history of East Asian aurochs that belong to haplogroup C?, and 2) What animal exploitation strategies might mobile hunter-gatherers and agriculturalists have used prior to the arrival of domestic cattle in China? Ancient DNA from Chinese cattle and auroch specimens of the T3 and C haplogroups is currently under investigation (Cai Dawei pers. comm., September 2014; Zhao Xin pers. comm., August 2016). This research will greatly increase our understanding of the relationships between wild and domestic cattle in Eurasia.

Additional zooarchaeological studies of aurochs in China would be necessary in order to clarify whether people managed these animals. People may have experimented with managing aurochs—perhaps by keeping animals as lures to bring other wild animals closer to their camps to facilitate hunting—but such experiments would have been short-lived and did not lead to full domestication. However, in other parts of the world, at sites with similar dates as the Harbin mandible specimen, people were already managing cattle in complex ways. For example, people brought cattle and other animals to the island of Cyprus before 8,000 B.C. There is zooarchaeological evidence for directed breeding of these animals and additional introductions of new domestic lineages from the mainland (Vigne et al. 2011). Therefore, it is possible that people in East Asia were also managing cattle at sites with similar dates during the early Holocene.

Resource management and domestication occur along a fluid and dynamic continuum. Multiple pathways can result in animal domestication (Zeder 2012, 2015). In the future it will be important to consider the nature of auroch exploitation in China and ask why these animals were never domesticated while other animals such as pigs were.

EVIDENCE FOR THE INTRODUCTION OF DOMESTIC CATTLE INTO CHINA DURING THE LATE NEOLITHIC

Most genetic and zooarchaeological data support the hypothesis that cattle were introduced to China from West Asia between 3600 and 2000 B.C. (Cai et al. 2014; Flad et al. 2007). We discuss both lines of evidence below.

Genetic Evidence

Two modern mtDNA haplogroups of *Bos indicus* (I1 and I2) originated in the Indian subcontinent (Chen et al. 2010). *Bos taurus* has five main mtDNA haplogroups: T (centered in the Near East), T1 (centered in Africa), T2 (centered in the Near East), T3 (centered in the Near East and Europe), and T4 (centered in East Asia) (Achilli et al. 2008; Bradley and Magee 2006; Mannen et al. 2004; Troy et al. 2001). These haplogroups are defined by polymorphisms in a 240 bp region of the mtDNA D-loop (Mannen et al. 2004; Troy et al. 2001). Another *Bos taurus* haplogroup, T5, is defined based on variants in other areas on the mtDNA genome (Achilli et al. 2008).

Current mtDNA evidence indicates that European domestic cattle are derived from Near Eastern varieties of *Bos taurus* (Bradley and Magee 2006; Loftus et al. 1994; Loftus et al. 1999; Troy et al. 2001). 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). Because the T4 haplogroup is only found in East Asian cattle, some have argued that there was another independent domestication event in East Asia (Lai et al. 2006; Mannen et al. 2004); however, more recent research shows that the T4 haplogroup is a derived clade within the T3 haplogroup (Achilli et al. 2009).

Other rare divergent *Bos* mtDNA haplogroups—P, Q, R, and E—have been identified in modern and ancient cattle populations in Europe, reflecting interbreeding between female wild aurochs and male domestic cattle (Achilli et al. 2009; Achilli et al. 2008; Bailey et al. 1996; Bonfiglio et al. 2010; Edwards et al. 2007; Edwards et al. 2010; Lari et al. 2011; Mona et al. 2010; Schibler et al. 2014; Stock et al. 2009; Zeyland et al. 2013). Analyses of Y-chromosome DNA have also been used to argue for past introgression from male aurochs in Europe (Götherström 2005), but this evidence has since been questioned (Bollongino et al. 2008). Nevertheless, the mtDNA evidence indicates that auroch-domestic cattle hybrids did exist. Moreover, recent whole genome sequencing data from a British auroch specimen provide strong evidence for admixture between European aurochs and domestic cattle of Near Eastern origin (Park et al. 2015). It is still unclear whether such hybrids represent single gene flow events or repeated intentional breeding of aurochs into domestic cattle populations in Europe (Schibler et al. 2014). The possibility for interbreeding between domestic and wild cattle in other regions, including China, has not yet been examined in detail.

In China, studies of mtDNA population structure in living cattle populations reveal that *Bos taurus* haplogroups are more common in northern China whereas *Bos indicus* haplogroups are more common in southern China, with evidence for hybridization in-between (Cai et al. 2007; Cai et al. 2014; Lai et al. 2006). Studies of Y-chromosome DNA in modern Chinese cattle show a similar geographic pattern, with *Bos taurus* haplogroup Y2 predominating in northern China and *Bos indicus* haplogroup Y3 predominating in southern China (Li, Xie, et al. 2013). This suggests a strong historical north–south divide between taurine cattle and zebu cattle exploitation.

For *Bos taurus*, both modern and palaeogenetic research support a Near Eastern origin for Chinese cattle. The T2, T3, and T4 haplogroups are the most common haplogroups in modern Chinese populations (Lai et al. 2006). All of these haplogroups are derived from Near East cattle populations (Achilli et al. 2009). Ancient DNA from 46 cattle specimens from northern Chinese archaeological sites dating to c. 2000 B.C. shows that all of the sampled animals also belonged to the T2, T3, and T4 haplogroups of *Bos taurus* (Cai et al. 2014). The genetic origins of *Bos indicus* in China are less well understood. Currently, there are no ancient DNA studies of zebu cattle. All of the ancient Chinese cattle specimens studied so far have been identified as *Bos taurus* (Cai et al. 2014), which suggests that *Bos indicus* did not enter northern China and the Central Plains until some time after 2000 B.C., but the situation in southern China remains unclear.

Other than the *Bos* mandible analyzed by Zhang and colleagues (2013), no ancient DNA analyses of cattle specimens dating to before c. 2000 B.C. have been published. Until more studies are published, we cannot say with certainty whether early potential cases of domestic cattle in China all represent domestic populations introduced from outside of China or animals in the process of domestication from native Chinese aurochs.

Zooarchaeological Evidence

A comprehensive picture of the zooarchaeogical data for the management of cattle in ancient China requires close analysis of cattle bones from Chinese archaeological sites. We have surveyed published cases with detailed morphological descriptions of bones and complete contextual and zooarchaeological information. This survey relies on identifications that are based on morphological comparisons, size measurements, identification of skeletal pathologies, analysis of herd demographics and age structure, archaeological context, or a combination of these, because only through an assessment of such data can we even begin to consider whether identified cattle bones relate to animal management and domestication (Lu 2010*a*). Table 1 lists the sites with early evidence for domestic cattle based on our analysis of published faunal materials (for detailed descriptions see Lu 2010*a*, 2010*b*, 2010*c*; Lu et al. 2014), as well as through studies of ancient DNA (Cai et al. 2014) and stable isotopes (Chen, Hu, et al. 2016).

The earliest domestic cattle remains come from the Gansu-Qinghai region of Northwest China. Several possible domestic cattle remains have been found at sites in Gansu Province dating to 3600–2500 B.C. Examples include bones morphologically similar to domestic *Bos taurus* excavated from Majiayao Culture (c. 3400–2700 B.C.) levels at the sites of Shizhaocun and Xishanping (Flad et al. 2009; Zhou 1999). A cattle scapula used for oracle bone divination has been found from Majiayao Culture layers at the site of Fujiamen (Zhao 1995) (Fig. 3c). This sort of ritual use of animal bones *may* reflect animal management, although it is important to note that many early oracle bones were not obtained from domesticated taxa (Flad 2008). Bones with size measurements consistent with those for domestic cattle have also been found from Yangshao Culture levels dated to 5600–4900 B.P. at the site of Xishan (Yu et al. 2011). These data suggest that the Gansu-Qinghai region and the Yangshao or Majiayao periods contain evidence for early Chinese exploitation of domestic cattle on a small scale. Even so, the number of cases is limited. With additional data from other regions of China, this picture might change. *Bos* remains that have size measurements consistent with domestic cattle have also been found at Jiangzhai in Henan Province (Lu 2010*b*; Qi 1988), but the early date of these remains requires further study.

The earliest definitive evidence for *Bos taurus* exploitation is found at sites centered along the Yellow River Valley that date to c. 2500–2000 B.C. during the terminal Late Neolithic period. Cattle skeletons buried as sacrificial offerings have been found at Dahezhuang (Fig. 3b) and Qinweijia (Zhongguo Kexue 1974, 1975) in Gansu Province, and at Pingliangtai (Henan and Zhoukou 1983) and Shantaisi (Zhang and Zhang 1997) (Fig. 3a) in Henan Province, again reflecting the use of these animals in important ritual practices. The Shantaisi case is particularly interesting because nine cattle skeletons were found in a sacrificial pit along with a small deer skull, suggesting that wild and domestic animals were sometimes included together in ritual contexts. The Shantaisi bones also have been measured, and their size is consistent with domestic cattle. Numerous sites in Gansu, Qinghai, Shaanxi, Henan, Anhui, and Shandong Provinces contain fragmentary cattle bones in the faunal assemblages, including some that were worked into artifacts such as oracle bones (Table 1; Fig. 3c).

Based on age estimates derived from tooth eruption and wear patterns and horn core morphology, we infer that cattle were domesticated at some sites such as Gu-

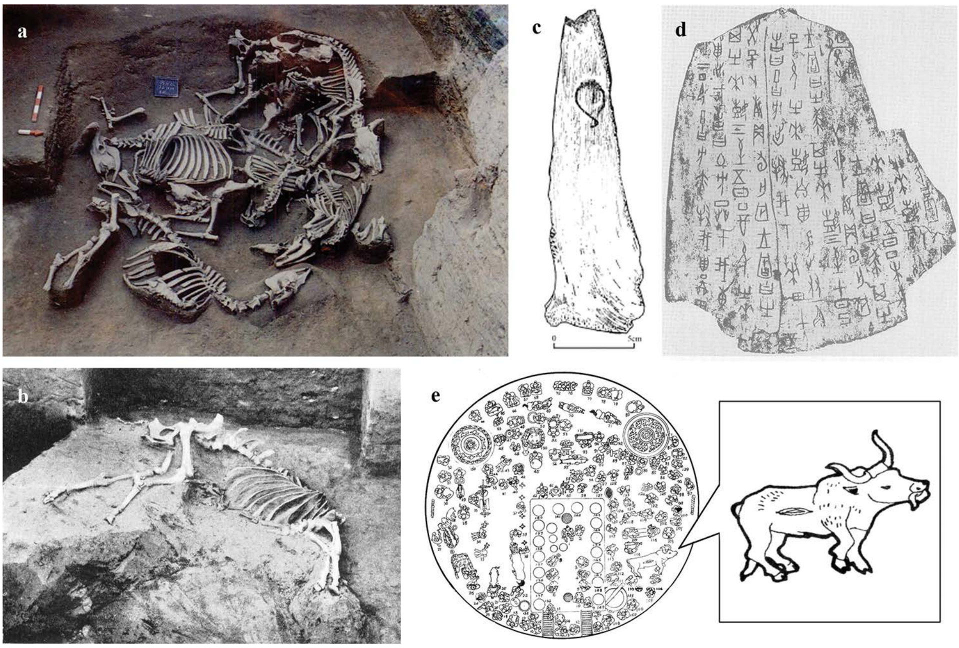

Fig. 3. a) Cattle skeletons found in a sacrificial pit at Shantaisi (Zhang and Zhang 1997); b) female cow skeleton with skull removed and fetal calf remains present inside the stomach, found inside of a building at Dahezhuang (Zhongguo Kexue 1974); c) incised cattle scapula oracle bone from Fujiamen (Zhao 1995); d) Shang dynasty oracle bone with written inscription (Keightley 1999:242, fig. 4.4); e) image of *Bos indicus* on a bronze drum from Shizhaishan (Zhang 1998).

chengzhai in Henan Province (Lu 2010*b*). Specifically, the presence of juvenile animals suggests that ancient people were managing the cattle population at Guchengzhai to some degree. Stable isotope analyses of cattle bones from Wadian in Henan Province and Dongying in Shaanxi Province may also reflect cattle management. During the terminal Late Neolithic period, cattle at these sites had elevated δ^{13}C signatures, suggesting that people in Central China may have foddered cattle with C4 plants such as domesticated millet (Chen, Fang, et al. 2016; Chen, Hu, et al. 2016). This alone is not proof of domestication since wild cattle could have grazed in millet fields and there are also wild C4 plants in China. Nevertheless, the isotope data provides another supplemental line of evidence pointing to the presence of fully domesticated cattle at these sites.

The proportion of cattle remains in the overall faunal assemblages at terminal Late Neolithic sites is generally low (Lu 2010*b*), so we believe that cattle were not a significant source of subsistence resources. Instead, they may have been more closely tied to infrequent yet important religious and ritual activities. After about 2000 B.C., cattle herding became widespread across northern China and an increasingly important part of the domestic animal economy. It is safe to accept the domestic status of cattle at these sites due to the large proportion of cattle bones in the faunal assemblages. Domestic cattle played an important role in subsistence, craft production, and ritual practice in northern China after about 2000 B.C. During the late occupation phase of Longshan-period Taosi and Zhoujiazhuang (c. 2000–1900 B.C.) in Shanxi Province, for example, cattle make up about 8% of the mammalian faunal assemblages and cattle bones are one of the main raw materials for bone working and oracle bone production (Brunson et al. 2016). Stable carbon isotope analysis also indicates that cattle at Taosi had elevated $\delta^{13}C$ signatures, suggesting that they may have been foddered with millet by-products (Chen et al. 2012); however, there is still not sufficient evidence to rule out the possibility that the elevated $\delta^{13}C$ signatures were caused by feeding on wild C4 plants. Strontium isotope analysis indicates that while some cattle were raised locally, others were brought to the site from surrounding regions (Zhao et al. 2011*a*). Moreover, all cattle at Taosi and Zhoujiazhuang survived beyond two years of age (Brunson et al. 2016), further suggesting that people at these sites may have paid special attention to raising and caring for adult cattle.

Other sites dating to after 2000 B.C. show similar trends in cattle management. At Xinzhai (c. 2050–1750 B.C.) in Henan Province, cattle make up about 5–10% of the mammalian faunal assemblage and have elevated $\delta^{13}C$ signatures that suggest people may have foddered these animals with millet products (Dai et al. 2015). At Zhukaigou (c. 2200–1500 B.C.) in Inner Mongolia, cattle make up between 15 and 40% of the identified mammal specimens in each occupation phase (Huang 1996). At Erlitou (c. 1900–1500 B.C.) in Henan Province, cattle make up about 10–25% of identified mammal specimens (Yang 2008), and strontium signatures indicate a mix of local and non-local animals (Zhao et al. 2011*b*). Zhangdeng (c. 2000–1600 B.C.) in Henan Province has stable carbon and nitrogen isotope signatures for cattle that are consistent with possible millet foddering (Hou et al. 2013). These sites also frequently contain cattle oracle bones and cattle remains in other ritual contexts, indicating that the ritual value of cattle remained high as cattle herding became more common.

It is important to note that there may have been considerable regional variation in herding practices at this time. Atahan and colleagues (2011) found that cattle at Huoshiliang and Gangangwa (c. 2300–1700 B.C.) in Gansu Province had relatively low $\delta^{13}C$ signatures and highly variable $\delta^{15}N$ signatures. They argue that people at these sites may have employed mobile pastoralist strategies in which cattle grazed beyond the agricultural zone. People probably traded and transported animals over great distances to graze in distinct ecological contexts. This would lead to variation in nitrogen signatures due to differences in aridity or salinity. In another example, Qiu and colleagues (2014) conducted palaeobotanical and isotopic analyses of cow dung samples from Xiaohe in Xinjiang (c. 1700–1400 B.C.). They found that cattle were eating primarily C3 plants such as reeds (*Phragmites australis*) and varying amounts of C4 plants such as grasses (*Eragrostis* sp.) and sedges (*Carex* sp.). This shows that elevated carbon isotope signatures may not always be caused by millet foddering. Further research is needed to understand variation in cattle exploitation and dietary composition in different regions.

At sites dating to after c. 2000 B.C., cattle were frequently involved in ritual practices. Examples include the dozens of cattle oracle bones that have been found at sites such as Taosi, Zhoujiazhuang, Zhukaigou, and Erlitou (Brunson et al. 2016; Chen and Li 2013; Huang 1996). At the Xiaohe cemetery in Xinjiang, offerings of cattle skulls, milk, and dung were included in funerary offerings (Qiu et al. 2014). By the Shang dynasty (1600–1046 B.C.), domestic cattle exploitation had become a central part of northern Chinese subsistence and ritual practices (Lu 2015). Millions of cattle were supplied to the largest capital cities such as Anyang in Henan Province; their bones were used to make hairpins and other artifacts in huge bone workshops (Campbell et al. 2011; Ma 2010). Thousands of cattle were also included in sacrificial offerings at Anyang (Okamura 2005; Yuan and Flad 2005), demonstrating the diverse roles that these animals had at large political centers.

To date, no prehistoric zebu cattle remains have been identified in Chinese archaeological sites. The earliest evidence for *Bos indicus* in China is an image on a bronze drum dating to the Warring States period (475–221 B.C.) from Shizhaishan in Yunnan Province (Chen 1999; Zhang 1998 : 41–44, 110–112; Fig. 3e). 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 introduced to China from the Indian subcontinent or Southeast Asia several thousand years later than *Bos taurus* was from the northwest.

THE USE OF CATTLE IN NEOLITHIC AND BRONZE AGE CHINA

The introduction of *Bos taurus* into China occurred just prior to the development of the first Chinese states (Chang 1986; Liu and Chen 2003). It also coincided roughly with the appearance of sheep, wheat, and early metal technologies at Chinese archaeological sites c. 3000–2000 B.C. (Barton and An 2014; Cai et al. 2011; Dodson et al. 2013; Flad et al. 2007; Flad et al. 2010; Jaang 2015; Liu et al. 2014). Proto–Silk Road trade routes in Northwest China, especially in the Gansu-Qinghai region, were key pathways through which new Central Asian domesticates and technologies were introduced and adopted according to local environmental and social conditions (Jaang 2015; Liu et al. 2014). Archaeological evidence suggests that when cattle were first introduced into China, they were used at least in four characteristic ways that had an influence on how herding developed during the Late Neolithic and early Bronze Age.

1) Subsistence — Isotopic studies of past human diets indicate that at least some people living at terminal Late Neolithic sites may have been eating beef. For example, Chen and colleagues (2015) found that some human bones at Wadian had elevated δ^{15}N signatures, but low δ^{13}C signatures consistent with a primarily C3 diet. They argue that these individuals may have eaten more sheep and cattle meat than other people at Wadian who had low δ^{15}N and high δ^{13}C signatures consistent with low-meat diets of primarily C4-based plants such as millet. However, this alone is not proof that people were eating beef since eating cervids or other wild animals that consume primarily C3 diets would produce a similar pattern. Isotopic evidence for the frequent trade and transport of animals at terminal Late Neolithic and Bronze Age sites further suggests that cattle were supplied to population centers as part of a complex food production process that involved herders who took advantage of new pastoralist landscapes (Atahan et al. 2011; Zhao, Li, et al. 2011; Zhao, Yuan, et al. 2011). Nevertheless, cattle herding remained small-scale during the initial introduction of cattle into China, and cattle bones are only found sporadically or in low frequencies at early sites. Comparisons of the relative proportions of various domestic taxa in Chinese faunal assemblages indicate that pigs remained the most important domestic animals for subsistence throughout the Neolithic and early Bronze Age, with sheep herding predominating at sites in the arid northwest (Luo 2012; Yuan 1999). At sites where cattle bones have been found in sufficient numbers to permit investigation of demographic (kill-off) patterns, there is currently no evidence that herds were managed to produce milk for human consumption (Brunson et al. 2016; Lu 2010*b*). Therefore, the early use of domestic cattle in China was likely not closely associated with a need to raise animals to meet subsistence requirements. Only after c. 2000 B.C., when cattle start to make up significant proportions of Chinese faunal assemblages, did cattle herding become a main source of subsistence products.

2) Cattle as Labor Animals — The introduction of cattle into China was not definitively related to the use of cattle for draft power. The presence of primarily adult and aged cattle at sites such as Taosi could be interpreted as evidence that people kept cattle alive to be used as beasts of burden in old age. However, there is minimal evidence for skeletal pathologies associated with intensive draft activities at Taosi (Brunson et al. 2016). Cart tracks have been found at Erlitou and other Bronze Age sites, but humans may have pulled these carts instead of cattle (Barbieri-Low 2000; Wang 1999). Cattle could also have been used as pack animals rather than for draft. More research is needed before claims can be made about the use of cattle as labor animals. There is currently no evidence that cattle were used consistently for labor at the time of their introduction to northern China (Yuan 2015 : 263–264).

3) Bone Raw Materials — Cattle provided ancient Chinese artisans with a readily available source of high-quality bone raw materials (Ma 2010). For example, cattle bones were frequently used to make a wide variety of bone tools at sites such as Taosi and Zhoujiazhuang (Brunson et al. 2016). Bovine bones turned into digging tools have also been found at the Qijia Culture period sites of Qinweijia and Dahezhuang in Gansu Province (Zhongguo Kexue 1974 : 45, 1975 : 73). At Erlitou, a bone workshop has been discovered in which the predominant raw material was bones from domestic cattle (Chen and Li 2016). By the Erligang and late Shang dynasty periods, cattle were the main species used to make mass-produced bone hairpins and other bone artifacts at huge workshops in Shang capital cities (Campbell et al. 2011; Ma 2010). Raising cattle had become a significant element in the Shang economy, with cattle meat and bones moving around these cities in complex supply and redistribution systems (Campbell et al. 2011). However, it is likely that the availability of cattle bone was a supplementary benefit to raising cattle rather than the initial impetus for adopting cattle herding during the Late Neolithic.

4) Religious Ritual and Sacrifice — The archaeological contexts where Late Neolithic and Bronze Age cattle remains have been found indicate that cattle were valued as ritually symbolic animals at the time of their introduction to China (Lu 2010*c*). Some of the earliest evidence for domestic cattle in China comes from sacrificial contexts and oracle bones. This suggests that cattle were associated with rituals tied to elite ancestor worship and methods for legitimizing claims to power and authority. The isotopic evidence that cattle were foddered at sites such as Wadian, Taosi, and Xinzhai indicates that people paid special attention to raising cattle (Brunson et al. 2016; Chen et al. 2012; Chen, Fang, et al. 2016; Dai et al. 2015), possibly because they were considered sacred animals or wealth animals. Between the Late Neolithic and late Shang dynasty, cattle replaced pigs as the most common sacrificial animals (Yuan and Flad 2005). The number of cattle oracle bones also increased through time. By the late Shang dynasty, cattle bones were the most common material used for oracle bone divination, holding a primary role in the rituals tied to royal religious power (Flad

2008; Keightley 1999) (Fig. 3d). Interestingly, water buffalo also feature prominently in Shang art, such as in the numerous bronzes containing water buffalo imagery or the stone water buffalo figurines from Fuhao's tomb (Zhongguo Shehui 1980: 157, 162, 200, 201). The sheer volume of ritual bovine remains indicates that ritual use could have been a major driver in Late Neolithic management systems, at least in the north. Many interesting research questions remain about who controlled these animals, how meat and bone materials were redistributed, and the strategies people used to raise cattle on a large scale in different regions.

SUMMARY AND FUTURE DIRECTIONS

No definitive evidence for indigenous cattle domestication in China currently exists. Additional research is needed to determine whether people experimented with managing native wild aurochs prior to the introduction of domestic cattle. Genetic and zooarchaeological data both suggest that domestic *Bos taurus* was introduced to China from West Asia between 3600 and 2000 B.C. Cattle management may have occurred at lower intensities before 2500 B.C., but large-scale cattle exploitation did not take place until after about 2000 B.C. *Bos taurus* likely entered China through the Gansu-Qinghai region, but the exact timing and routes of introduction are still unknown and it is unclear whether *Bos taurus* reached China as a single introduction event or in multiple waves. *Bos indicus* likely entered southern China sometime after 2000 B.C., but the timing and routes of introduction remain a mystery.

Since our current interpretations are based on a small number of sites and samples, more zooarchaeological studies of Late Neolithic faunal assemblages are needed. A key part of this research would be to develop better ways to distinguish between aurochs and domestic cattle through morphometrics, especially since there can be significant size overlap between wild and domestic individuals (Degerbøl and Fredskild 1970; Helmer et al. 2005). Additional techniques may also be useful for identifying wild and domestic bovines, such as the analysis of bone stable isotopes to identify dietary changes indicative of intentional foddering (Chen, Hu, et al. 2016). More ancient DNA studies are also needed to clarify the phylogenetic history of East Asian bovines and identify the origins of early domestic cattle remains.

The initial adoption of cattle herding in China provided people with opportunities to use newly available animal resources in innovative ways. Cattle could be used for subsistence, as draft animals, as sources of raw materials such as bone and hide, and as wealth or ritual animals. People undoubtedly used domestic cattle in multiple ways, but it is likely that ritual demands drove their increasing importance in ancient China. This had an effect on the availability of meat and bone materials that would have provided new economic opportunities in emerging state societies. Future archaeological research is needed to better understand who controlled these animals, the relationships between elites and those who raised the cattle, how cattle were supplied to major urban centers, and whether cattle were raised differently than other domestic animals. Through the development and application of additional genetic and zooarchaeological research, we will better understand the domestication process for Chinese cattle and how the adoption of herding influenced the development of Late Neolithic and Bronze Age societies in China.

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