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Research Article

# Isotopic Reconstruction of the Late Longshan Period (ca. 4200–3900 BP) Dietary Complexity before the Onset of State-Level Societies at the Wadian Site in the Ying River Valley, Central Plains, China

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## Abstract

During the late Longshan period (ca. 4200–3900 BP) settlements on the Central Plains of China underwent a diversification in food production technologies, which set the stage for rapid economic and social development. The introduction of novel domesticates such as rice, wheat, cattle, and sheep not only provided more food choices, but also changed ideas concerning land use, farming techniques, and the use and mobilization of large scale labor forces. To better understand the contribution that these new dietary items and practices made to shaping the late Longshan period societies, a stable isotope ratio study of humans (n = 12) and animals (n = 42) was conducted at the late Longshan period site of Wadian. The human $\delta^{13}C$ and $\delta^{15}N$ values are clustered into two distinct groups. One group of nine individuals ($\delta^{13}C$ = −9.9 ± 0.7‰; $\delta^{15}N$ = 7.5 ± 0.5‰) had a predominately $C_4$ diet based on millet grains with little protein input from the domestic animals. The other group of three individuals ($\delta^{13}C$ = −14.3 ± 0.8‰; $\delta^{15}N$ = 10.2 ± 0.3‰) had a mixed $C_3/C_4$ diet of millets and rice and were consuming sheep and cattle. The animals also displayed dietary diversity with the pigs ($\delta^{13}C$ = −11.3 ± 2.5‰; $\delta^{15}N$ = 6.9 ± 1.0‰, n = 10) and dogs ($\delta^{13}C$ = −10.1 ± 1.0‰; $\delta^{15}N$ = 7.2 ± 1.1‰, n = 7) having mostly a $C_4$ plant based diet (millets). In contrast, the cattle ($\delta^{13}C$ = −12.8 ± 2.1‰; $\delta^{15}N$ = 7.6 ± 0.7‰, n = 9), sheep ($\delta^{13}C$ = −16.7 ± 0.9‰; $\delta^{15}N$ = 7.6 ± 0.1‰, n = 2), and cervids ($\delta^{13}C$ = −20.8 ± 0.9‰; $\delta^{15}N$ = 5.0 ± 1.2‰, n = 10) had diets with a greater contribution from $C_3$ sources such as rice and wild plants. The discovery that humans and animals had different subsistence patterns indicates dietary complexity at Wadian and that rice agriculture, and cattle and sheep husbandry practices were already an important part of the local economy by the late Longshan period in the southern region of the Central Plains of China. 

# Introduction

In China, Neolithic landscape use and the development of state societies were shaped by the spread of millets and rice agriculture which was established in the Yellow River and Yangtze River regions at ca. 8000, respectively (Liu *et al*., **2007**; Fuller *et al*., **2009**; Jones & Liu, **2009**; Zhao, **2011**). Further, the introduction of a variety of domesticates: wheat ( *Triticum aestivum* ), sheep ( *Ovis aries* ), and cattle ( *Bos taurus* ) from western Eurasia into China represents one of the earliest known episodes of global food expansion (Jones *et al*., **2011**), and this is observed during the Longshan period (4600–3900 BP) in the northern China (Flad *et al*., **2007**; Zhao, **2009**). This not only provided increased food production and variety to the population, but revolutionized land use patterns and farming technology and allowed the mobilization of large scale labor forces, which set the stage for the formation of state societies in China (Fitzhugh, **2001**; Fuller *et al*., **2007**; Weisskopf, **2010**).

As the geographic and cultural center of China, the Central Plains witnessed a number of major transitions in social complexity from the pre-Yangshao (9000–7000 BP) through Yangshao (7000–4600 BP) to Longshan (4600–3900 BP) periods, and by ca. 3800 BP this region established the earliest state-level organized societies in China (Liu, **2004**; Lee *et al*., **2007**). An important catalyst for these cultural changes and the evolution of these state societies was the rise and intensification of a complex agricultural economy (Zhao, **2007**; Yuan & Campbell, **2009**). Millet farming, characterized by the cultivation of two different types of millets: foxtail millet ( *Setaria italica* ) and broomcorn millet ( *Panicum miliaceum* ), and pig husbandry were the primary food production methods in this region before the new domesticates were integrated into the local subsistence economy. In addition, previous studies have suggest that rice ( *Oryza sativa* ) was already cultivated by ~5000 BP (Qing & Fuller, **2009**), and rice remains become more common at Longshan period sites as such as Huizui (Weisskopf, **2010**), Wangchenggang (Zhao & Fang, **2007**), Xinzhai (Aurora Center for the Study of Ancient Civilizations of Peking University and Zhengzhou Academy of Cultural Relics and Archaeology, **2008**), Wadian (Liu & Fang, **2010**), Youfangtou, and Xiawu (Fuller *et al*., **2007**). In addition, sheep, cattle and, to a lesser extent, wheat are also found at many Longshan period sites in the Central Plains although the routes by which these spread into China remain controversial (Zhao, **2009**; Lü, **2010**; Yuan, **2010**; Dodson *et al*., 2013; Barton & An, 2014; Betts *et al*., 2014).

Previous archaeobotanical (Fuller *et al*., 2007; Zhao, 2007), zooarchaeological (Yuan *et al*., 2007), and isotopic research (Wu *et al*., 2007; Zhang *et al*., 2010) have all identified an important transition in human subsistence activities during the late Longshan period (ca. 4200–3900 BP), and this is especially true for archaeological sites from the south Central Plains. However, there has been no isotopic research focused on sites from the upper Ying River Valley during the late Longshan period where rice, sheep, and cattle are found with increasing frequency during excavations. Thus, it is not known if, and how much of, a contribution that these new domesticates made to the human diet and how the associated technologies might have reshaped socioeconomic organization during this period. To help answer these questions, we present here human (n = 12) and animal (n = 42) isotopic results from Wadian, the largest known Longshan site in Henan Province, China. We then review previous isotopic studies from related Yangshao, Longshan, and Erlitou period sites from the Central Plains along the middle Yellow River region and compare and contrast these data with our results to better understand the dietary diversity and complexity of China during the late Longshan period.

## Archaeological background

The study site, Wadian, is in Yuzhou county of Henan Province. It is located in the upper Ying River Valley, ca. 1000 m west of the Ying River which flows through the southern Central Plains (Figure 1). Previous archeological surveys revealed that it was an important Longshan period regional center, occupying an area of over 100 hectares which made it the largest Longshan settlement site in the south Central Plains (School of Archeaology and Museology of Peking University and Henan Provincial Institute of Cultural Relics and Archaeology, 2007; Fang, 2012). At the moment, an area of ~1800 $m^2$ has been exposed, and large quantity of archaeological remains were unearthed, including some humans but abundant domestic (pigs, dogs, sheep, and cattle) and wild (deer, porcupine, and birds) animal remains (Jia *et al*., 1983; Henan Provincial Institute of Cultural Relics and Archaeology, 2004; Fang, 2012). Like other Longshan sites in the Central Plains, the proportion of pig bones (~70%) ranked first in the faunal assemblage, followed by deer (12%), dogs (5%), sheep (4%), and cattle (4%). Archaeobotanical research found that the most abundant charred grains were from foxtail millet (2253 grains), rice (1144 grains), and broomcorn millet (385 grains), but that only eight charred wheat grains were recovered at Wadian (Liu & Fang, 2010).

Figure 1.

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The location of the Wadian site and contemporary sites in the Central Plains mentioned in the study. (1) = Wadian, (2) = Xinzhai, (3) = Xishan, (4) = Erlitou, (5) = Xipo, (6) = Taosi, and (7) = Dongying Phase 2 (DY-2).

## Materials and methods

Stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope ratios of bone collagen have become a routine method for investigating human and animal diets (for a detailed review see DeNiro, **1987**; Schoeninger & Moore, 1992; Ambrose & Krigbaum, **2003**; Hedges & Reynard, **2007**; Lee-Thorp, **2008**). Because $C_3$ plants have greater discrimination against $^{13}C$ when fixing $CO_2$ than $C_4$ plants, $\delta^{13}C$ values can provide an estimate of the consumption of $C_3$ versus $C_4$ plant based nutrients in terrestrial foodwebs (Farquhar *et al*., **1989**; Tieszen, **1991**; Lee-Thorp, **2008**). Nitrogen isotope ratios are normally used to estimate the trophic levels of humans and mammals in foodwebs, and are based on the assumption that a stepwise trophic shift of 3–5‰ occurs in $\delta^{15}N$ values from plants to herbivores, and from herbivores to carnivores (DeNiro & Epstein, **1981**; Schoeninger *et al*., **1983**; Hedges & Reynard, **2007**; Lee-Thorp, **2008**).

Collagen was isolated from 42 animals and 12 human bones using the protocol outlined in Richards & Hedges (**1999**), modified to include a final stage of ultrafiltration prior to lyophilization as described in Brown *et al*. (**1988**), and the reader is directed to these articles for more information. Details regarding the archaeological context of samples are listed in Table 1. The purified collagen was measured using an Isoprime 100 IRMS coupled with the Vario PYRO cube, with SA methoinine (in-house standard, $\delta^{13}C = -28.15 \pm 0.02‰$; $\delta^{15}N = -4.86 \pm 0.06‰$) and USGS 40 (L-glumatic acid, international standard) as reference materials. After five samples, both standards were inserted into the sample list for calibration and monitoring the stability. When measuring, two runs were made for each sample and the average value of data was used. The stable isotope results were analyzed as the ratio of the heavier isotope to the lighter isotope ($^{13}C/^{12}C$ or $^{15}N/^{14}N$) and reported as 'δ' in parts per 1000 or per mil (‰) relative to internationally defined standards (McKinney *et al*., **1950**) for carbon (Vienna Pee Dee Belemnite, VPDB) and nitrogen (Ambient Inhalable Reservoir, AIR). The measured values of USGS 40 are averaged $-26.31 \pm 0.05‰$ for $\delta^{13}C$ and $-4.55 \pm 0.12‰$ for $\delta^{15}N$, and are comparable with the certified values ($\delta^{13}C = -26.39 \pm 0.04‰$; $\delta^{15}N = -4.52 \pm 0.06‰$), and the measurement errors were less than ±0.1‰ for $\delta^{13}C$ and ±0.2‰ for $\delta^{15}N$.

**Table 1.** Sample information and isotope data of the human and animal bones from the Wadian site, Henan Province, China

| Lab ID | Species | Context/level | Element | Yield (%) | $\delta^{13}C$ (‰) | $\delta^{15}N$ (‰) | C (%) | N (%) | C:N |
|---|---|---|---|---|---|---|---|---|---|
| 244 | *Homo sapiens* | WD2T4043H2 | Femur | 0.4 | −10.1 | 8.4 | 31.4 | 11.0 | 3.3 |
| 245 | *Homo sapiens* | WD2T4043H24 | Femur | 2.9 | −15.0 | 10.4 | 46.5 | 15.2 | 3.6 |
| 246 | *Homo sapiens* | WD2T4043H43 | Talus | 1.2 | −13.4 | 10.3 | 29.9 | 10.7 | 3.3 |
| 251 | *Homo sapiens* | WD2T4143③ | Talus | 6.3 | −9.6 | 7.3 | 43.8 | 15.0 | 3.4 |
| 252 | *Homo sapiens* | WD2T4143③ | Scapula | 10.1 | −10.1 | 7.3 | 42.9 | 14.1 | 3.5 |
| 253 | *Homo* | WD2T4143③ | Scapula | 6.1 | −9.6 | 6.8 | 43.3 | 15.1 | 3.3 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | *sapiens* | | | | | | | | |
| 254 | *Homo sapiens* | WD2T4143H27 | Calcaneus | 5.4 | −9.6 | 7.3 | 42.7 | 14.9 | 3.3 |
| 255 | *Homo sapiens* | WD2T4143H27 | Calcaneus | 7.1 | −9.9 | 7.7 | 44.3 | 15.3 | 3.4 |
| 256 | *Homo sapiens* | WD2T4143H27 | Maxillary | 2.7 | −14.5 | 9.9 | 42.1 | 15.0 | 3.3 |
| 257 | *Homo sapiens* | WD2T4144H46 | Pelvic | 9.0 | −10.8 | 7.3 | 44.3 | 16.2 | 3.2 |
| 258 | *Homo sapiens* | WD2T4144H46 | Pelvic | 5.3 | −10.8 | 7.4 | 43.1 | 15.1 | 3.3 |
| 259 | *Homo sapiens* | WD2T4144④ | Tibia | 6.0 | −8.7 | 8.4 | 43.8 | 15.5 | 3.3 |
| 199 | *Canis familiaris* | WD2T3944④ | Mandible | 3.4 | −10.9 | 8.1 | 37.4 | 12.7 | 3.4 |
| 200 | *Canis familiaris* | WD2T3944H19 | Ulna | 5.9 | −10.5 | 5.9 | 42.1 | 15.0 | 3.3 |
| 202 | *Canis familiaris* | WD2T4043③ | Mandible | 1.4 | −11.0 | 6.1 | 43.2 | 14.1 | 3.6 |
| 203 | *Canis familiaris* | WD2T4043H2 | Mandible | 7.7 | −10.6 | 7.2 | 42.1 | 15.0 | 3.3 |
| 204 | *Canis familiaris* | WD2T4043H24 | Mandible | 4.5 | −9.1 | 6.5 | 38.3 | 13.0 | 3.4 |
| 205 | *Canis familiaris* | WD2T4044③ | Mandible | 3.1 | −10.3 | 8.5 | 40.1 | 13.8 | 3.4 |
| 242 | *Canis familiaris* | WD2T4144H28 | Tibia | 4.4 | −8.5 | 8.4 | 48.9 | 16.8 | 3.4 |
| 190 | *Sus domestica* | WD2T4144④ | Ulna | 5.7 | −12.3 | 7.7 | 40.8 | 14.7 | 3.2 |
| 191 | *Sus domestica* | WD2T4143H27 | Ulna | 0.1 | −27.7 | −42.8 | 9.0 | 0.8 | 13.1 |
| 192 | *Sus domestica* | WD2T4044H6⑤ | Mandible | 1.5 | −11.8 | 5.5 | 36.7 | 12.4 | 3.5 |
| 193 | *Sus domestica* | WD2T4144③ | Ulna | 6.3 | −12.4 | 7.5 | 42.1 | 15.3 | 3.2 |
| 194 | *Sus domestica* | WD2T4144H28② | Ulna | 0.1 | −24.2 | — | 11.3 | 0.6 | 22.0 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 195 | *Sus domestica* | WD2T4144H28② | Ulna | 7.1 | −11.3 | 5.7 | 42.1 | 14.2 | 3.5 |
| 196 | *Sus domestica* | WD2T4143H27 | Ulna | 4.3 | −13.2 | 6.1 | 39.4 | 13.8 | 3.3 |
| 197 | *Sus domestica* | WD2T3944H21③ | Ulna | 6.3 | −11.3 | 7.2 | 41.6 | 14.9 | 3.3 |
| 198 | *Sus domestica* | WD2T3944H17 | Mandible | 2.0 | −16.1 | 8.7 | 37.1 | 13.3 | 3.3 |
| 265 | *Sus domestica* | YHW97IVT4H4⑥ | Skull | 6.9 | −8.1 | 6.9 | 44.1 | 15.5 | 3.3 |
| 266 | *Sus domestica* | YHW97IVT4H4④ | Humerus | 3.1 | −8.3 | 6.8 | 42.9 | 14.7 | 3.4 |
| 267 | *Sus domestica* | YHW97IVT4H1③ | Mandible | 2.5 | −9.2 | 7.7 | 43.4 | 15.6 | 3.2 |
| 217 | *Bos* sp. | WD2T3944H17 | Upper M1 | 0.8 | −13.4 | 9.1 | 41.4 | 12.7 | 3.8 |
| 218 | *Bos* sp. | WD2T3944H17 | Mandible | 1.6 | −11.7 | 8.1 | 41.3 | 13.9 | 3.5 |
| 219 | *Bos* sp. | WD2T4043F1 | Tibia | 8.8 | −12.9 | 7.3 | 45.1 | 15.2 | 3.5 |
| 220 | *Bos* sp. | WD2T4043H2 | Lower P4 | 6.1 | −15.1 | 7.7 | 43.6 | 14.3 | 3.6 |
| 221 | *Bos* sp. | WD2T4043H2 | Metacarpal | 5.2 | −13.5 | 7.8 | 42.2 | 15.3 | 3.2 |
| 222 | *Bos* sp. | WD2T4043H2 | Humerus | 7.0 | −13.1 | 7.7 | 37.6 | 13.8 | 3.2 |
| 223 | *Bos* sp. | WD2T4043H2 | Ulna | 6.8 | −13.2 | 7.8 | 42.6 | 15.5 | 3.2 |
| 226 | *Bos* sp. | WD2T4044③ | Phalange II | 1.5 | −10.0 | 6.0 | 41.4 | 14.9 | 3.2 |
| 230 | *Bos* sp. | WD2T4044H28③ | Upper M1 | 2.3 | −9.4 | 7.4 | 39.5 | 14.0 | 3.3 |
| 263 | *Bos* sp. | YHW97IVT6④ | Calcaneus | 3.2 | −16.0 | 8.7 | 44.9 | 14.8 | 3.5 |
| 238 | *Ovis* sp. | WD2T4043H2 | Upper M2 | 6.3 | −17.3 | 7.5 | 48.3 | 16.8 | 3.4 |
| 239 | *Ovis* sp. | WD2T4043H24 | Tibia | 0.1 | −28.5 | — | 19.7 | — | |
| 264 | *Ovis* sp. | YHW97IVT4H27 | Mandible | 6.2 | −16.0 | 7.7 | 42.6 | 15.2 | 3.3 |
| 201 | *Cervidae* | WD2T3944H21 | Ulna | 2.2 | −19.9 | 5.9 | 45.8 | 15.1 | 3.5 |
| 207 | *Cervidae* | WD2T4043H2 | Femur | 4.2 | −21.4 | 5.1 | 42.6 | 15.0 | 3.3 |
| 208 | *Cervidae* | WD2T4043H2 | Tibia | 3.4 | −21.2 | 4.0 | 41.1 | 14.0 | 3.4 |
| 209 | *Cervidae* | WD2T4144H46 | Phalange I | 0.8 | −20.5 | 5.7 | 41.3 | 14.6 | 3.3 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 210 | *Cervidae* | WD2T4043H2 | Metacarpal | 4.3 | −21.5 | 4.7 | 39.4 | 13.7 | 3.4 |
| 211 | *Cervidae* | WD2T4043H2 | Radius | 5.4 | −21.2 | 2.8 | 41.1 | 14.6 | 3.3 |
| 214 | *Cervidae* | WD2T4144H28 | Metatarsal | 4.2 | −18.8 | 6.9 | 42.2 | 15.0 | 3.3 |
| 237 | *Cervidae* | WD2T3944H19 | Talus | 1.9 | −21.6 | 3.5 | 42.3 | 14.4 | 3.4 |
| 240 | *Cervidae* | WD2T4044H28⑤ | Tibia | 6.9 | −21.0 | 5.6 | 48.6 | 16.6 | 3.4 |
| 241 | *Cervidae* | WD2T4144H28 | Pelvic | 5.7 | −20.8 | 5.3 | 48.3 | 16.5 | 3.4 |

# Results

The isotopic results are summarized in Table 1 and plotted in Figures 2a,b. Most samples were well preserved; 50 out of 54 produced good quality collagen with percent yields greater than 1% and atomic C:N between 2.9 and 3.6 (DeNiro, **1985**). Generally, the broad range of animal isotope values indicated variable diets. The cervids had mean $\delta^{13}C$ (−20.8 ± 0.9‰) and $\delta^{15}N$ (5.0 ± 1.2‰) values indicative of a $C_3$ plant-based diet. In contrast, the domestic animals had higher $\delta^{13}C$ values (range = −17.3‰ to −8.1‰) in accordance with their consuming variable amounts of $C_4$ plants. The following mean $\delta^{15}N$ values were observed for the domestic animals: cattle (7.6 ± 0.7‰), sheep (7.6 ± 0.1‰), dogs (7.2 ± 1.1‰), and pigs (6.9 ± 1.0‰), and all were $^{15}N$-enriched compared with the cervids (Figure 2b). The humans at the Wadian site showed a large variation in $\delta^{13}C$ (−15.0‰ to −8.7‰) and $\delta^{15}N$ (6.8‰ to 10.4‰) values, and this indicates that there was dietary diversity and complexity in the community (Figure 2b). Nine individuals plot together with mean $\delta^{13}C$ (−9.9 ± 0.7‰) and $\delta^{15}N$ (7.5 ± 0.5‰) values that were comparable to or slightly elevated over the mean values of the pigs and dogs. In contrast, a group of three individuals have significantly lower mean $\delta^{13}C$ (−14.3 ± 0.8‰) and elevated $\delta^{15}N$ (10.2 ± 0.3‰) values above the cattle and the sheep indicating that they were consuming these animals, but the results are consistent with the consumption of animals with these particular bone collagen isotope values.

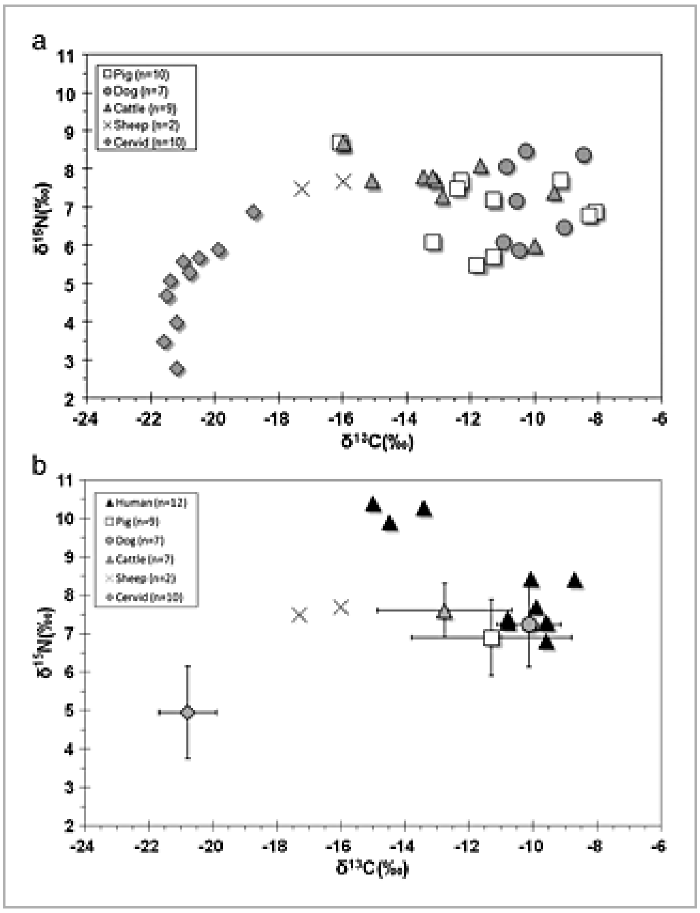


Figure 2.

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(a) $\delta^{13}$C and $\delta^{15}$N values for animals from the Wadian site, Henan Province, China; (b) $\delta^{13}$C and $\delta^{15}$N values for humans and animals (mean ± SD) from the Wadian site, Henan Province, China.

# Discussion

## Animal husbandry practices

Pigs and dogs, the typical indigenous domesticates in China (Yuan *et al*., **2008**; Cucchi *et al*., **2011**), are often grouped together because of their similar diets. Here the isotopic data also indicate that both these species had a millet based diet which could have been because of the direct consumption of millets or millet byproducts (e.g. chaff and straw) as suggested previously at some Neolithic sites in northern China (Pechenkina *et al*., **2005**; Barton *et al*., **2009**; Hu *et al*., **2009**; Chen *et al*., **2012**; Liu *et al*., 2012; Hou *et al*., **2013**). As discussed in the 6th century text, *Qi Min Yao Shu* (齊民要術), millet grains were considered an excellent feed for the rapid fattening of piglets in ancient China, but it is not known how widespread this practice was in the Neolithic of China (Jia & Miu, **1998**). The Wadian pigs have relatively low mean $\delta^{13}$C values compared to pigs from the sites of Kangjia (Pechenkina *et al*., **2005**), Xinzhai (Wu *et al*., **2007**), Taosi (Zhang *et al*., **2007**; Chen *et al*., **2012**), and DY-2 (Chen *et al*., **2014**), although the $\delta^{15}$N values are comparable to the pig populations at these sites (Table 2). This could imply that Wadian pigs ate slightly more $C_3$ fodder, which was likely derived from rice given the relatively high proportion of charred rice recovered at the site (Liu & Fang, **2010**).

**Table 2.** Mean ± SD $\delta^{13}C$ and $\delta^{15}N$ values of human and pig bone collagen from different archaeological sites in the middle Yellow River region of China

| Site | Species | N | $\delta^{13}C$ ± SD (‰) | $\delta^{15}N$ ± SD (‰) | Reference |
|---|---|---|---|---|---|
| Xishan | Human | 39 | −8.2 ± 1.5 | 9.0 ± 0.8 | Zhang *et al*., **2010** |
| Xipo | Human | 31 | −9.7 ± 1.1 | 9.4 ± 1.0 | Zhang *et al*., **2010** |
| Xinzhai | Human | 8 | −9.6 ± 1.4 | 9.0 ± 1.0 | Wu *et al*., **2007** |
| Taosi | Human | 7 | −6.6 ± 1.0 | 8.9 ± 1.3 | Zhang *et al*., **2007** |
| DY-2 | Human | 5 | −8.0 ± 1.3 | 9.4 ± 0.3 | Chen *et al*., **2014** |
| Wadian | Human | 12 | −11.0 ± 2.1 | 8.3 ± 1.3 | This study |
| Erlitou | Human | 5 | −9.4 ± 3.1 | 11.9 ± 4.2 | Zhang *et al*., **2007** |
| Kangjia | Pig | 3 | −10.3 ± 2.4 | 8.7 ± 0.9 | Pechenkina *et al*., **2005** |
| Xinzhai | Pig | 12 | −10.3 ± 3.4 | 6.5 ± 1.6 | Wu *et al*., **2007** |
| Taosi | Pig | 18 | −6.9 ± 1.4 | 7.5 ± 0.6 | Zhang *et al*., **2007** |
| DY-2 | Pig | 7 | −10.5 ± 3.2 | 7.3 ± 1.0 | Chen *et al*., **2014** |
| Wadian | Pig | 10 | −11.4 ± 2.4 | 7.0 ± 1.0 | This study |

Sheep and cattle were first domesticated by the ~11$^{th}$ millennia BP or earlier in West Asia (Zeder, **2009**), and possibly brought to the Yellow River region during the Longshan period (Flad *et al*., **2007**). The widespread distribution of their bones suggests that the Longshan communities throughout the Yellow River Valley were familiar and adapted to the care of these animals. Unfortunately, we only have isotopic results from two sheep, but it is clear that they had a mixed $C_3/C_4$ diet that was likely based on millet byproducts for part of the year. In contrast, the cattle had elevated $\delta^{13}C$ values, despite nearly identical $\delta^{15}N$ values. This indicates that the cattle diet was based more on cultivated $C_4$ crops such as millets (given the low prevalence of wild $C_4$ plants) (Henan Provincial Institute of Cultural Relics and Archaeology, **2004**). In addition, the observed variability in the cattle $\delta^{13}C$ values possibly suggests a more flexible cattle husbandry regime. Cows with elevated $\delta^{13}C$ values obtained substantial amounts of broomcorn or foxtail millet, while those with lower $\delta^{13}C$ values consumed only a small amount of these millets. This could have been the result of grazing on areas beyond the agricultural zone of the community and/or on fallow cropland (Zeng, **1999**). It is also possible the different $\delta^{13}C$ values reflect the cattle could have been imported from other regions, as previous work by Zhao *et al*. (2012) found evidence of animal trade at Wadian.

As a result of the unique digestive physiologies of the sheep and the cattle, both are capable of digesting both millets byproducts and wild plants (Church, 1988). Thus, these animals can be used in conjunction with the pigs and the dogs to fully utilize the barren land at different times of the year during crop rotations, thereby creating a more efficient and productive form of agricultural practice. Thus, we suggest that the importation of sheep and cattle might have modified previous practices of animal husbandry and change land use patterns at Wadian.

## Human subsistence

Farming made a very important contribution to human diets at Wadian, and flotation results reveal that the majority of the plants were millets (mainly foxtail millet) and rice as well as edible weeds such as *Setaria sp*. and *Digitaria sp*., with only a few charred wheat grains recovered (Liu & Fang, 2010). Thus, it is unlikely that wheat played a major role in human diet at Wadian. In order to estimate the contribution of millets vs. rice in the human diet, the simple two-end mixing model developed by Cai & Qiu (1984) is used here.

Previous studies have shown that Neolithic foxtail millet and rice have $\delta^{13}C$ values of approximately −11.3‰ and −24.9‰, respectively (Cai & Qiu, 1984; McGovern *et al*., 2004; Pechenkina *et al*., 2005; Yang *et al*., 2011). Thus, humans consuming an exclusive millet diet would have $\delta^{13}C$ values near −6.3‰, and those with an exclusive rice diet would have a $\delta^{13}C$ value of −19.9‰, assuming the standard fractionation factor of +5‰ from plants to bone collagen (van der Merwe & Vogel, 1978; Lee-Thorp *et al*., 1989). Using this model the estimated contribution of rice-related foods to the human diet roughly ranged from ~25% to 62% assuming that the $C_3$ isotopic signature was entirely derived from rice, which seems likely given the abundant charred rice remains unearthed with the foxtail millet (Liu & Fang, 2010). In addition, the proportion of rice into the diet of Wadian farmers is far more abundant than that of the Yangshao farmers at Xishan, Xipo, and other late Longshan sites nearby in the Central Plains (Pechenkina *et al*., 2005; Zhang *et al*., 2010). Wadian is surrounded by wetlands and rivers, and the climate is characterized by high temperatures and humidity compared to the north Central Plains, and all of these factors made the region an ideal environment for rice cultivation. Given the increased site density of Wadian, the co-existence of several competing communities in the area and the large numbers of weapons and traumatic deaths found compared to the preceding periods in the upper Ying River Valley (Liu, 2004; Henan Provincial Institute of Cultural Relics and Archaeology *et al*., 2008), rice might have been cultivated here to meet the increased food demands of a growing population. Thus, the archaeobotanical and isotopic results come together in this study to confirm that rice began playing an indispensable role in human diet at Wadian and thus the Central Plains region since at least the late Longshan period.

Nine individuals have a cluster of $^{13}C$-enriched values indicative of having a substantial amount of $C_4$ dietary sources. Appling the above mixing model, these individuals consumed a mean diet that was composed of approximately 74% millets or millet related foods. In addition, because the human $\delta^{15}N$ values were nearly identical to those of the omnivorous pigs and dogs as well as herbivorous sheep and cattle, it is clear that these individuals were primarily consuming millet grains and not so much millet-fed domestic animals. This finding is in agreement with the results from other Longshan agriculture communities from the Central Plains (Pechenkina *et al*., 2005; Wu *et al*., 2007; Zhang *et al*., 2007; Atahan *et al*., 2014; Chen *et al*., 2014).

In contrast to these nine individuals, is a cluster of three individuals with lower δ$^{13}$C and higher δ$^{15}$N values (#245, #246, #256 in Table 1; Figure 2b). The $^{13}$C-depleted values indicate that these three people consumed a substantial amount of $C_3$ foods (likely rice) which is consistent with the high level of rice recovered from the cereal remains (Liu & Fang, **2010**). The δ$^{15}$N values are elevated by approximately +2.7‰ above the sheep and cattle, indicating that individuals were more likely consuming these animals to some extent rather than directly eating the millet grains. However, it is also possible that these three individuals were migrants to the Wadian site from the south where rice cultivation was the primary subsistence practice in the Millet-Rice Blended Zone (Fu *et al*., **2010**; Guo *et al*., **2011**). Past archaeological research in this area determined that cultural diffusion and exchange was common between the Central Plains and Yangtze River catchment during the late Longshan period (Zhao *et al*., **2012**). In particular, the discovery of wide flat-foot tripods, grooved pottery basins, bird sculptures as well as additional objects attributed to the Shijiahe culture (ca. 4500–4000 BP) from the middle Yangtze River drainage area among the excavated material at Wadian indicates that there was long-distance movement of people and goods from the south (Henan Provincial Institute of Cultural Relics and Archaeology, **2004**).

## A survey of dietary complexity in the southern Central Plains of China

As stated above, the introduction and rise of the use of novel domesticates during the Longshan period changed previous agricultural practices that were based on millets, and these new foods introduced $^{13}$C-depleted items into the diet of the society. This dietary transition is also observed by the comparison of the Wadian humans to other previously published archaeological sites related from the Central Plains of China (Table 2 and Figure 3). The mean δ$^{13}$C values at Wadian are the lowest, indicating that these humans were consuming more $C_3$ food such as rice and domestic ruminant products. However, there is little difference in the Wadian mean δ$^{15}$N values compared to the other sites (Figure 3). In addition, this human diet being slightly more $^{13}$C-depleted than the other sites parallel the pig isotopic results in Table 2. Thus, both these findings suggest that rice planting and ruminant animal husbandry were present as subsistence strategies during the late Longshan period in the southern Central Plains. However, it must be stressed that the $^{13}$C-depleted mean result of the humans is influenced by the three individuals that group together. Future work using sulfur stable isotope ratios (δ$^{34}$S) and the direct radiocarbon dating of the remains are needed to determine if these individuals were geographically different or from another time period in relation to the larger cluster of nine individuals so that we will have a better understanding of these dietary difference at Wadian.

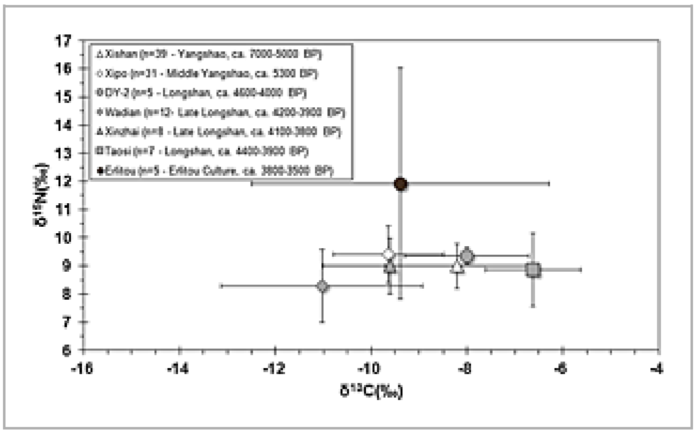


Figure 3.

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$\delta^{13}C$ and $\delta^{15}N$ values from this study compared with previously published results from archaeological sites in the Central Plains of China. Data are from Zhang *et al*. (**2010**) for Xinshan and Xipo, from Zhang *et al*. (**2007**) for Taosi and Erlitou, from Chen *et al*. (**2014**) for DY-2, from Wu *et al*. (**2007**) for Xinzhai, and from this study for Wadian.

Given the high degree of standard deviation in the $\delta^{13}C$ values, the elevated $\delta^{15}N$ values, and the higher proportions of rice, cattle, and sheep recovered from the archaeological assemblages, this subsistence strategy appears to continue from the late Longshan period into the Erlitou Culture (ca. 3800–3500 BP) (Yuan *et al*., **2007**; Zhang *et al*., **2007**; Zhao, **2007**), when the first so-called dynasty was established in China (Liu, **2004**). Thus, the increased agricultural complexity and animal husbandry practices during the late Longshan period are established prior to and correlate with the formation and expansion of state-level societies. These novel and advanced subsistence strategies played an important role in shaping human psychology about land use patterns and labor organization (Weisskopf, **2010**; Barton & An, **2014**) and human interaction (Talhelm *et al*., **2014**). For example, if prime fields for traditional millet cultivation became scarce, locals might organize labor to create paddyfields for rice cultivation and reserve enough space for grazing sheep and sometimes cattle. Thus, the establishment and expansion of agricultural complexity were a key force that drove social organization, culture, and even the formation of state-level societies, and this is an area of research that deserves much more attention in Chinese archaeology in the future.

# Conclusions

The late Longshan period is a time of rapid economic change characterized by diversified food production technologies in both agriculture and animal husbandry. The diversity and complexity of the dietary patterns at the site of Wadian in the Ying River region were revealed by stable isotope ratio analysis of human and faunal remains. As expected $^{13}C$-enriched values for pigs and dogs indicate that millet fodder was used in the diet, while the $\delta^{15}N$ values show that these animals mainly consumed plant foods and scavenged on household refuse. Cattle and sheep were the new domestic species in the late Longshan communities, and the isotopic results indicate highly diversified cattle husbandry practices. Although the use of millets as fodder was common for cattle, some individuals with $^{13}C$-depleted values likely spent time grazing outside of the main agricultural zones, like the sheep. Thus, the introduction of cattle and sheep not only provided additional dietary resources to the community, but also influenced the livestock husbandry strategies, use of agricultural byproducts, and modified land use and the organization of labor.

While the number of humans studied was limited, two isotopic clusters were identified at Wadian. One group of nine individuals had $\delta^{13}C$ and $\delta^{15}N$ values nearly identical to the pigs and the dogs indicating that their diet was similar to these animals and largely based on millets. The other group of three individuals showed evidence of a mixed millets/rice diet and the consumption of sheep and cattle. The discovery of these two groups with different dietary patterns also suggests that Wadian possessed economic and agricultural complexity related to the cultivation of both rice and millets, a possible increased organized labor force, and a more efficient land use pattern during the late Longshan period. Finally, additional isotopic research is needed at Wadian and other sites in the

Ying River region, and this combined with zooarchaeological, archaeobotanical, radiocarbon dating, and landscape archaeology will provided an improved picture of this dietary transition and how it likely influenced the formation of state-level societies in China.

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### References

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