Exploring the Wetland: Integrating the Fish and Plant Remains into a Case Study from Tianluoshan, a Middle Neolithic Site in China

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1 Introduction

The site of Tianluoshan was discovered and excavated initially in 2004, and several field seasons have taken place ever since. The material culture and chronology indicate that Tianluoshan belongs to the famous Hemudu culture, which is described as a representative of Middle Neolithic culture in the lower Yangtze River region by both Chinese and Western textbooks (Bellwood 2005; Chang 1986; Higham 2005; Liu and Chen 2012; Zhang and Wei 2004). Animal and plant remains are found well preserved due to the waterlogged environment, providing excellent materials for studying subsistence economy, agriculture development, and palaeoenvironment of the Hemudu culture.

Fish, among the wild animals, has been an important and reliable protein resource in the Yangtze River region. In terms of lower Yangtze River valley, water bodies of various kinds can be found: river, brook, lake, pond, wetland, paddy field, etc. There is no doubt fish and other aquatic resources (animals and plants) were playing a very important part in the subsistence, and they still are. Fish remains are commonly present in the archaeological animal assemblages along the Yangtze River, particularly when sieving is systematically applied. At Zhongba Site, for example, a salt production site of the Final Neolithic and Bronze Age in the upper Yangtze River valley, fish remains comprise a considerable majority of the animal assemblage (Flad 2004, 2005; Flad and Yuan 2006). It is proposed that fishing and hunting were the primary modes of meat acquisition in the Yangtze River valley in the Neolithic (Yuan et al. 2008).

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This study attempts to place the food resources back into the ecosystem and to discuss the exploitation of the environment and the interrelationship between humans, environment, and food resources in a broader background.

2 Background Review to the Study Area

The site of Tianluoshan (30°01’N, 121°22′E) is located in a small valley at the southeast edge of the lower Yangtze River region, to the south bank of the Hangzhou Bay (Fig. 1). It is one of the most low-lying areas in the lower Yangtze, only 2–3 m above sea level. Geological investigation indicates that the physiographic settings in this area have remained the same since the Jurassic and Cretaceous periods (Zhejiang Provincial Bureau of Geology and Mine 1989). The main stream on the plain, Yao River, passes through the valley. A group of Neolithic sites have been found along the Yao River, among which Hemudu and Tianluoshan are the most famous and well-preserved ones.

Located in the subtropical zone, the lower Yangtze River experiences a subtropical monsoon-dominating climate, characterized by a mild and humid climate (mean temperature 16.2 °C), high precipitation (about 1300–1400 mm per year), and plenty of sunshine (2061 h annually), making it an ideal place for vegetation growth, animal habitats, and human occupation. The weather shifts significantly between seasons: winter is cold and dry, summer is hot and humid but with little precipitation, and spring and autumn are warm and rainy (Chen 1985, P93–121).

Palaeoenvironmental research reveals that the climate and environment have changed several times throughout the Holocene. The Early and Middle Holocene were warmer and wetter in eastern China. The mean temperature during this climatic optimum could be 2–4 °C warmer than that of today, and southern vegetation zones had shifted northwards (Liu et al. 2007a; Qin et al. 2010; Tao et al. 2006; Yu et al. 1998, 2000; Zhang 2006; Zuo et al. 2016). The climate tended to be temperate and mildly dry from 4000 BC. Palaeoenvironmental studies also detect several

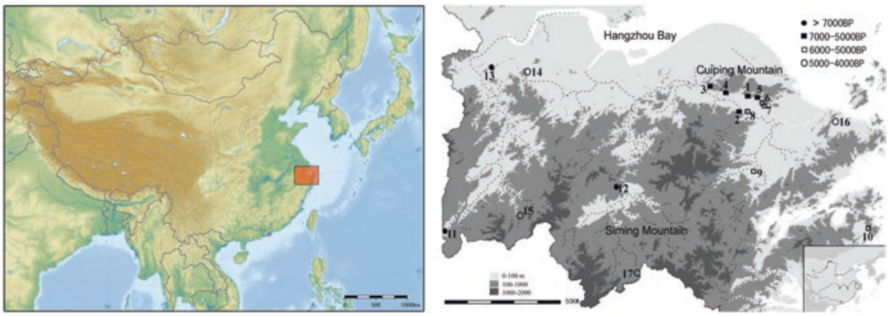

Fig. 1 Location and landforms of the research area and the distribution of Tianluoshan (Qin et al. 2010)

sea-level fluctuations during the Holocene which influenced human diet and caused response (Mo et al. 2011; Zheng et al. 2012).

The Neolithic cultures in the lower Yangtze Region can be divided into three phases by the evolution of society (Liu and Chen 2012). In the early Neolithic phase (7000–5000 BC), sedentism and agriculture arose, and the 'Neolithization' began; in the Middle Neolithic phase (5000–3000 BC), social inequality emerged; the Late Neolithic phase (3000 BC–2000 BC) is symbolized by the rise and fall of early complex societies. In this system, a Pleistocene-Holocene transition era (22000–7000 BC) is named before the early Neolithic phase based on foraging and collecting subsistence economy. As a result, Shangshan, which is usually considered as the earliest Neolithic site in the lower Yangtze (Jiang 2013; Zhejiang Province Institute of Archaeology and Cultural Heritage and Pujiang Museum 2007), is included in this phase.

The Middle Neolithic cultures in the lower Yangtze are represented by the Hemudu culture in the Ningshao Plain and the Majiabang culture and subsequently the Songze culture in the Lake Taihu region (Table 1). It is the key period and key region for rice agriculture, indicated by the large quantities of rice remains which are generally found at sites of this time period, the increasing ratio of rice spikelet bases with morphological features of domestication, and rice fields. The Hemudu culture is named after the type site Hemudu, which was discovered and excavated in the 1970s. Extremely rich materials are preserved due to the waterlogged environment. Wooden pile-structured dwellings, in which mortise-tenon techniques are employed to connect timbers, are found to be approximately 23 m long 7 m wide. Pottery is mainly black and grey, tempered with fibre and/or sand; some of them are decorated with plant and animal motifs. Among all the bone tools from Hemudu, the most eye-catching is the bone spade (or 'Si' in Chinese) which is mainly made from the scapula of water buffalos or sambar. The discovery of abundant animal bones and rice remains, including husks, chaffs, leaves, and rice grains, led to a long-termed discussion on the development of agriculture in the Yangtze River region.

Table 1 The Neolithic chronology of the lower Yangtze River region, summarized from Liu and Chen (2012)

Chronology	Phase	Archaeological culture	Sites
22,000–7,000 BC	Pleistocene-Holocene Transition	Shangshan culture (9,000–7,000 BC)	Shangshan
7,000–5,000 BC	Early Neolithic	Kuahuqiao culture (6,000–5,000 BC)	Xiaohuangshan (7,000–6,000 BC) Kuahuqiao
5,000–3,000 BC	Middle Neolithic	Hemudu culture (5,500–3,300 BC) Majiabang culture (5,000–4,000 BC) Songze culture (4,000–3,300 BC)	Hemudu Tianluoshan Majiabang Xiaodouli
3,000–2,000 BC	Late Neolithic	Liangzhu culture (3,300–2,000 BC)	Fanshan, Yaoshan, etc.

The rice remains were first identified as domesticated rice of *Oryza sativa* subsp. *indica* (You 1976), and the discussions afterwards focus on distinguishing the exact variety of rice (Tang et al. 1999; Zhou 2003). Domesticated dog, pig, and water buffalo are also identified from the faunal assemblage (Wei et al. 1989). With the environmental, archaeobotanical, and zooarchaeological research, Hemudu has been described as a farming society with 'intensive rice agriculture' and written in Chinese and western textbooks (Bellwood 2005; Chang 1986; Higham 2005; Lu 1999). However, a reassessment of the existing comparative data about a decade ago suggests that these claims appeared overstated (Fuller et al. 2007, 2008; Qin et al. 2006). The research on newly excavated materials confirms a heavy reliance on the wild resources, including acorns, aquatic nuts, deer, and fish, even though rice was cultivated (Fuller et al. 2009, 2011; Zhang 2015; Zhang et al. 2011). Molecular biological analysis suggests that the widespread *Bubalus mephistopheles* was an indigenous wild species to prehistoric China (Liu et al. 2006; Yang et al. 2008). The procedure of pig domestication is slightly vague. Although pigs are believed to be domesticated in the Middle Neolithic Yangtze (Yuan and Flad 2002; Yuan et al. 2008), the morphological features, cull patterns, and stable isotope data suggest that they are more like wild boars (Zhang 2015; also see Fuller et al. 2011; Liu and Chen 2012; Yuan et al. 2008).

3 Materials and Methods

Tianluoshan is a representative site of the Hemudu culture. It was first excavated in 2004, and several seasons of excavation have been undertaken until now. Estimated through drilling investigation, the whole Tianluoshan site covers about 30,000 m^2 (Sun 2011). Radiocarbon dates indicate that the site was occupied approximately from 5000 to 4000 Cal BC, belonging to the Hemudu culture (Sun 2011; Wu et al. 2011). Both radiocarbon dates and the study of artefacts suggest that the cultural layers (layers 3–8) can be divided into three phases: the earliest phase 1 is from layer 8 to 7, phase 2 is from layer 6 to 5, and phase 3 includes layers 4 and 3 (Fig. 2). The fish remains for this study are from the stratigraphic layers. They are generally well-preserved due to the waterlogged environment; however, those from the upper layers are weathered possibly because of the fluctuation of underground water level. Apart from them, eight 10 metres by 5 metres trenches (K1 to K8,), surrounding the major excavation area, were excavated to build the foundation of a conservation shelter for the site. Several storage pits of acorns and a pit (labelled as 'H1') filled only with fish bones were found in K7. Those fish remains were studied by Nakajima et al. (2010a, b, 2011) and thus shall not be included in this study.

The fish remains were retrieved from wet sieving through two sized meshes: 4.5 and 2.8 mm. However, most of the head bones and girdle bones are very fragmented to be recognized by the collectors who unfortunately are not familiar with the anatomy of fish, leading to a result that the study materials mainly consist of vertebrae,

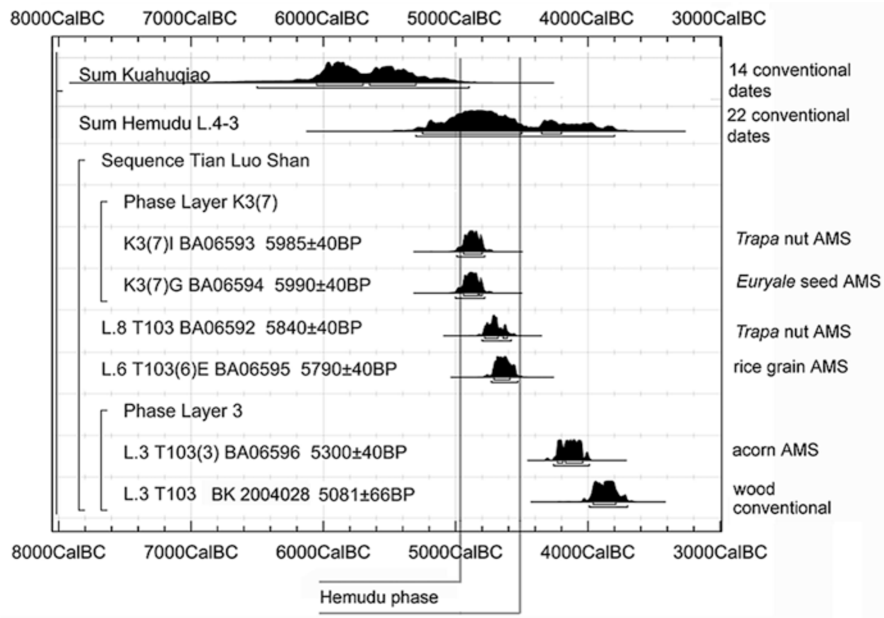

Fig. 2 The radiocarbon dates of Tianluoshan (Wu et al. 2011). The earliest radiocarbon date of Tianluoshan comes from the K3(7) samples (layer 7 in trench DK3), about 4900 Cal BC, followed by layers 8 and 6 in the main excavation area, about 4800–4700 Cal BC. Layer 3 is dated to approximately 4200–4000 Cal BC

basioccipitals, pharyngeal bones, and teeth. Otoliths are not preserved probably due to the acid environment.

Subsamples were taken as the basic units for sorting, recording, identification, and quantification during analysis because of the large quantity of bones from each context. Zooarchaeological procedures were used during this analysis as set forth by Wheeler and Jones (1989) and described by Casteel (1976). The fish remains from each subsample were initially sorted into broad taxonomic categories and identified to genus and species when possible. Any evidence of butchering, weathering, or thermal alteration was recorded. Measurements were taken where appropriate, mainly for the purpose of fish size reconstruction.

3.1 Fish Length Reconstruction

Unlike mammals, fish grow constantly through their lives. As calcium gradually deposits on the outer side of bone structures, older fish tend to have bigger bones and larger size. By reconstructing the original size/length of fish, we may learn about the fishing techniques and strategies. There are several methods to estimate the length of fish. For example, Casteel (1976) summarized and compared five major methods that have been employed in zooarchaeological research. Fishery biologists also study the methods for size reconstruction, to identify and estimate the size of prey fish from fish's stomach content and then to investigate the diet of fishes and the ecosystem (Campbell 1968; Fickling and Lee 1981; Mann and Beaumont 1980; Radke et al. 2000).

After examining the commonly used methods, the single regression method is considered to be simple and accurate enough to meet the research object of this study. Nakajima et al. data (2010b, 2011, 2012) are employed to reconstruct the length of common carp and crucian carp. However, snakehead (*Channa argus*), the most predominant fish from Tianluoshan, has been barely recorded and studied. There is scarce data on the growth rate and seasonal growth of annulus in literature. Therefore, a reference collection of modern wild snakehead is acquired for body length reconstruction and seasonality assessment in this research. Since aquaculture has been well developed in China in order to meet the large demand of fish consumption, and the fish species present at Tianluoshan have become cultured fish now, it is not easy to capture wild fish for reference collection without help.

Reference specimens were collected from Hubei Province with the help of Dr. Zhang E from the Institute of Hydrobiology (IHB), Chinese Academy of Science, following the sampling strategy in Van Neer and colleagues' study (Van Neer et al. 1999, 2004). From December 2012 to July 2013, monthly samples of 22 snakehead specimens were obtained and processed by the IHB. Measurements of the fish and basioccipitals are taken for the reconstruction of regression curve, and the annuli distribution of each individual is recorded for the estimation of fishing seasons.

The single regression method was used to reconstruct the original body length of snakehead from the size of the basioccipital. The correlation between body length and the width of basioccipital was derived from metric data of modern snakeheads, shown in Fig. 3. A single regression equation is derived accordingly:

$$\mathrm{BL} = 42.76W_{\mathrm{basio}} + 39.94$$

3.2 Seasonality Assessment

There are several ways to analyze the seasonality of fishing. The most commonly used method is to read the growth rings on hard tissues. Fish grows following a certain pattern of continuity and periodicity. As fish grows larger, calcium gradually deposits at the margin of hard tissues so that they expand outwards, leaving traces, usually in the form of concentric circles, known as the growth rings or circuli, on them. Among all the hard tissue parts, scales, otoliths, fin spines, opercula, and vertebrae are frequently used for investigating age and growth of fish in fishery and zooarchaeological studies. The growth rate of hard tissues is highly influenced by water temperature and day-length; therefore, in temperate and frigid zones where water temperature and day-length change annually, the growth rings are regularly

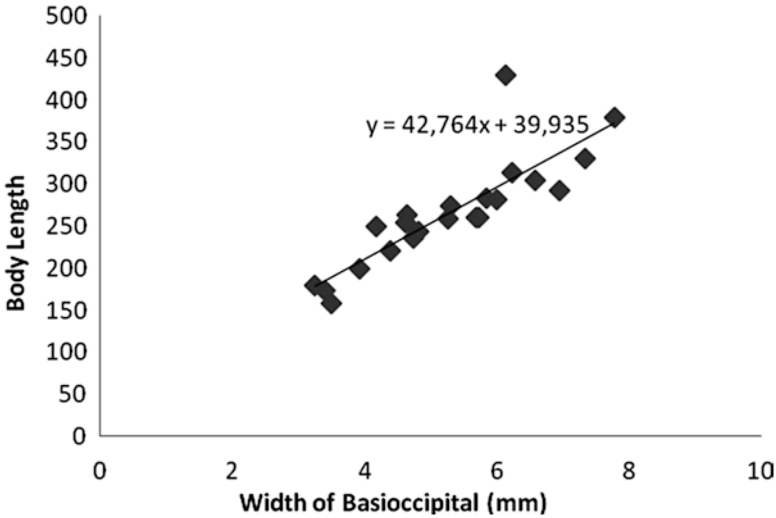

Fig. 3 Regression analysis between body length (standard length) and the width of snakehead basioccipital, based on the measurements of modern specimens

distributed as fast-slow growing circles accordingly (Moyle and Cech 2004; Wurtsbaugh and Cech 1983), providing a good possibility to make a subjective assessment of age and death season.

Zooarchaeologists also use the continuous increase of body length (Nakajima 2002, 2006; Nakajima et al. 2010a, b) to estimate the fishing season. Due to the seasonal breeding and the constant growth rate within a species, a fish can only grow to a certain size at a certain age and vice versa.

Plus, fish performs seasonal behaviours, including migration, spawning, and torpor (hibernation), which are triggered by the change of environmental factors (Gabriel et al. 2005; Krause 1956; Matsui 1996; Moss et al. 1990; Stewart 1977). The migrating fish, such as Pacific salmon, were only available to our ancestors in the spawning migration season. Even fish which make local spawning migrations are more vulnerable during their spawning when they school in shallow waters.

In this study, different assessment methods are applied according to fish species and the quality of the study material. The cull season for snakehead is estimated from the distribution of growth rings, by examining the outermost annulus on the articulation surface of the basioccipital. After observing the modern snakehead specimens, we have found that the new annulus normally appears in spring, from February to May, mostly in February. It keeps growing in summer, forming the fast-growing annulus which can be observed slightly lower than the winter annulus. The winter annulus is relatively narrower, dense, and slightly higher than the summer annulus. Each basioccipital with a clear-cut outermost circle is observed under a stereomicroscope, compared with modern specimen, assessed, and recorded. The seasonality of common carp and crucian carp is assessed following Nakajima and colleagues' research, by reconstructing the body length and comparing with the known growth curve. The life history and seasonal behaviours of fish are considered during analysis.

4 Results

4.1 Range and Relative Proportions of Taxa

A total number of 230,000 fish bones from 40 contexts are examined for this study. Seventy-four subsamples, each containing 300–400 specimens, are taken for statistical analysis. Six species of common fish have been identified from the assemblage, including common carp (*Cyprinus* sp. Linnaeus), crucian carp (*Carassius carassius* (Linnaeus)), top-mouth culter (*Culter* sp. Basilewsky), catfish (*Silurus* sp. Linnaeus), snakehead (*Channa argus* (Cantor)), and Japanese sea bass (*Lateolabrax* sp. Cuvier) (Table 2). Fish are mainly identified to the genus level; snakehead and crucian carp can be identified to the species level with the aid of zoogeographical analysis. The common carp is identified as *Cyprinus carpio* by the pharyngeal bone (Nakajima et al. 2011). Statistically, these six species take up nearly 90% of the total number, and snakehead among all the fish shows clear predominance in each phase, from 45% to 70% (Table 2). Crucian carp takes the second place (13–34%), followed by common carp and catfish with a consistent proportion around 5%. The amount of the culter fish and Japanese sea bass is relatively minor, normally less than 1%.

Table 2 Relative taxonomic abundance of fish at Tianluoshan by NISP and NISP %.

Taxon	Family	Phase 1		Phase 2		Phase 3	
		NISP	%	NISP	%	NISP	%
Common carp *Cyprinus* sp. Linnaeus	Cyprinidae	2807	4%	5676	5%	716	6%
Crucian carp *Carassius carassius* (Linnaeus)	Cyprinidae	9070	13%	38,097	34%	1891	15%
Top-mouth culter *Culter* sp. Basilewsky	Cyprinidae	361	0.5%	330	0.3%	37	0.3%
Catfish *Silurus* sp. Linnaeus	Siluridae	2945	4%	5027	4%	747	6%
Northern snakehead *Channa argus* (cantor)	Channidae	48,581	70%	50,338	45%	6477	53%
Sea bass *Lateolabrax* sp.	Serranidae	308	0.4%	643	0.6%	289	2%
Unidentified		1090	7.1%	2303	11.2%	670	18.4%

4.2 Body Length Reconstruction

The body length distribution of common carp from each layer is shown as a single peak spanning a wide range approximately from 180 to 580 mm. According to literatures, fish of this length are from 1 to 5 years old (Hubei Provincial Institute of Hydrobiology 1976). Similar distribution pattern occurs to crucian carp (Fig. 4). The range and peaked point resemble that of H1 (Nakajima et al. 2010a, Fig. 6), but the slope is rather gradual. From the perspective of taphonomy, the content of a pit is usually accumulated in a short time and may receive better preservation. In the case of H1, the fish remains represent a few catches within a short time, probably during the breeding season of crucian carp. Conversely, the fish remains from the stratigraphic layers represent a long-term accumulation and tend to be affected by taphonomic issues such as weathering and trampling.

Shown by the wide span of the distribution, snakeheads of different size, approximately from 140 to 900 mm, used to be captured by the Tianluoshan people. Fish between 200 and 400 mm were captured more often, possibly indicating a selection by fish size (Fig. 5). Snakehead grows fast. Records show that it can reach 19 cm only 1 year after hatching and increase 10 cm per year thereafter (Hubei Provincial Institute of Hydrobiology 1976, P212). The recorded maximum length is 1 m (Novikov et al. 2002). Although snakeheads over 600 mm are rare at Tianluoshan, to catch individuals of such large size may require certain skills.

4.3 Seasonality

The length distributions of common carp and crucian carp from layers are consistent (Fig. 4), indicating all-year-round fishing. By studying the reconstructed body length and growth rate of carp, Nakajima and colleagues (2010a, b, 2011) propose that both common carp and crucian carp from H1 were captured in spring and early summer, possibly during breeding season when fish schooled in shallow water.

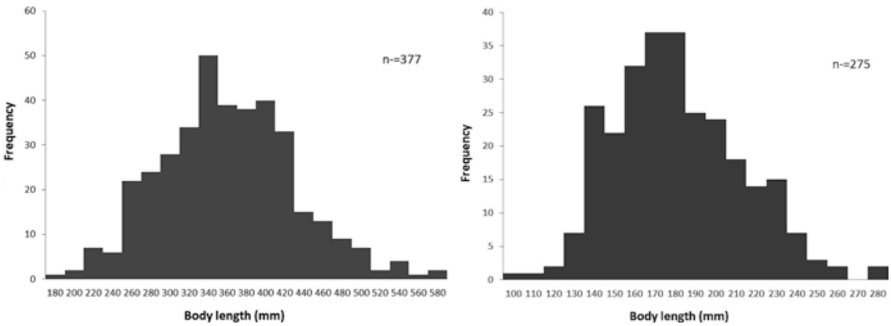

Fig. 4 Body length distribution of common carp (left) and crucian carp (right) from Tianluoshan, without separating phases

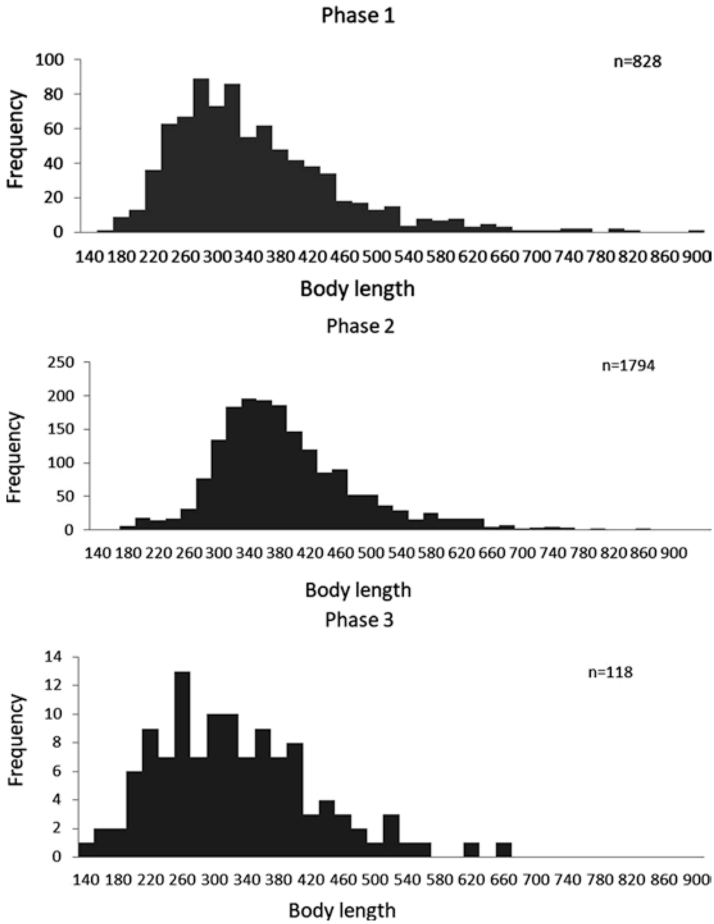

Fig. 5 The body length distribution of snakehead in three phases

The distribution pattern, especially the sudden rise of the distribution curve, shows similarity with that of Nakajima and colleagues' result, possibly indicating that carp fishing became intense in spring and early summer.

The distributions in Fig. 6 show that snakehead fishing is performed throughout the year but more intensively in spring, generally from February to April. Interestingly, the fishing season does not overlap with the spawning season of *Channa argus*, which is usually from late May to July in the Yangtze River region. Fish usually display special behaviours during spawning, including migration, courtship, schooling, and sometimes parenting for a few species. When spawning season comes, snakeheads migrate to shallow and vegetated areas and build a nest by clearing plants in a cylindrical zone. The nest can be recognized from the floating plants. The parents guard their eggs and larvae for about 20 days and are very protective and aggressive during these days. The nesting and parenting behaviours make them exposed and vulnerable to fishermen. Ethnographic records show that

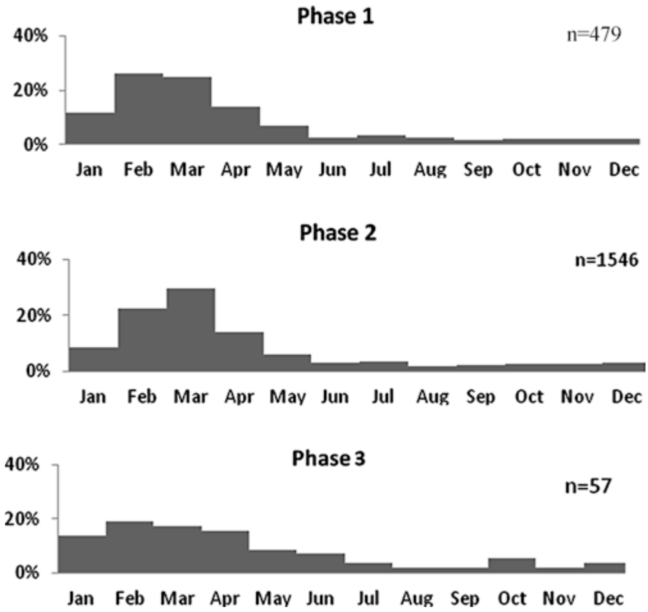

Fig. 6 Seasonality distribution of snakehead, estimated from basioccipitals

villagers in the upper Yangtze River region (Sichuan Province) catch snakeheads by simply irritating them with live bait (e.g. frogs) and then collecting them with scoop baskets (Lan 1958). However, snakeheads also display distinctive behaviour out of the spawning season. When dry season comes, they can either migrate to deep water or bury themselves in mud, reducing metabolism and oxygen demand until the warm monsoon season comes. Plus, snakehead displays a behaviour called 'sunbathing' by the fishermen. In summer and autumn, snakeheads like to float and stay on the water surface on sunny days, possibly because of the low oxygen level when the temperature rises. Catching the 'sunbathing' snakeheads is another common strategy.

Due to the complicated behaviours of snakehead, the fishing season does not have to tally with the spawning season. Fishing season, as well as fishing methods, can be decided according to the environment, change of seasons, and probably other subsistence activities. In this case, fishing is not simply an activity; it is an element in the entire subsistence economy.

5 Archaeobotanical and Environmental Research

Before the discovery of Tianluoshan, the understanding of the Hemudu culture was primarily based on the remains from the Hemudu site. According to the preliminary report (Zhejiang Natural Science Museum 1978) and the final report (Zhejiang

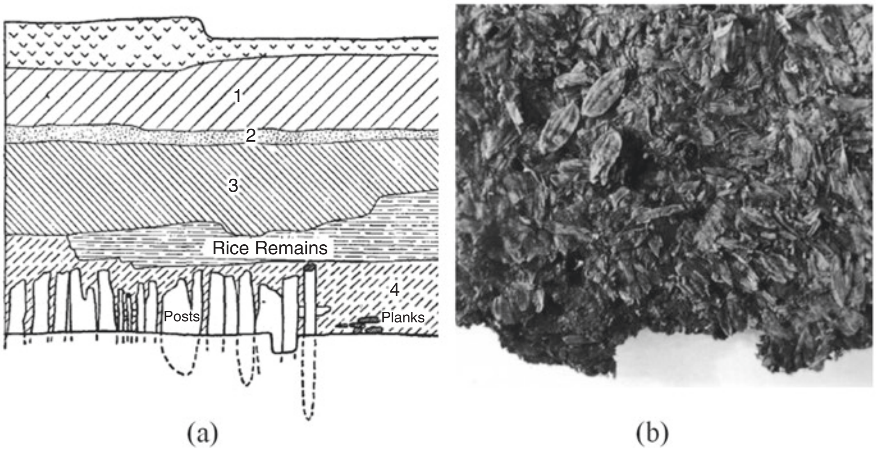

Fig. 7 Stratigraphic profile of Hemudu (**a**) and detailed view on the rice remains. (**b**) 1–4 in graph (**a**) are the four strata of the cultural deposits. The thick layer containing rich rice remains lies between layers 3 and 4. Timber posts are shown planted under layer 4

Provincial Institute of Cultural Relics and Archaeology 2003), animal and plant remains accumulated densely in the Hemudu culture deposits, especially in the early Hemudu culture layer (layer 4). Rice, among all the remains, has been discussed very intensively. Most of the rice remains are straw, leaves, and husks; rice grains are found occasionally (Fig. 7). It was estimated that the thick layers of rice remains might be the debris of 120 tons rice (Yan 1982), although these did not represent a single depositional event judging by the stratigraphic photographs. Dog, pig, and water buffalo among all the species are identified as domesticated animals. Accordingly, Hemudu is presented as an example of early intensive rice agriculture in many texts (e.g. Bellwood 2007; Chang 1986; Higham 1995).

Soon after the excavation, the rice remains were identified as domesticated rice of the *Hsien* variety, i.e. *Oryza sativa* subsp. *indica* (You 1976). Discussions over the following 20 years have focused on identifying the variety of rice and whether they were of the *indica* variety or the *japonica* variety, using different measurements. Hemudu and the lower Yangtze River have been considered as the centre for rice agriculture in the world (Bellwood 2005). The discussions of Hemudu rice have also deeply influenced the research of Neolithic agriculture in China. As Hemudu was considered as a developed agricultural society, archaeologists began to pursue the origins of rice domestication from Early and Middle Neolithic sites. A common opinion is that rice domestication started about ten millennia ago, based on various rice finds such as the rice husks found in pottery debris from Shangshan, represented by Liu and colleagues' studies (Jiang and Liu 2006; Liu et al. 2007b). Meanwhile, Fuller, et al. suggest that the domestication of rice was still in progress during the Middle Neolithic Age (Fuller et al. 2007, 2009).

Apart from the rice remains, a variety of fruits and seeds of wild plants are also found at Hemudu, including acorns (*Quercus* sp.), water chestnuts (*Trapa* sp.),

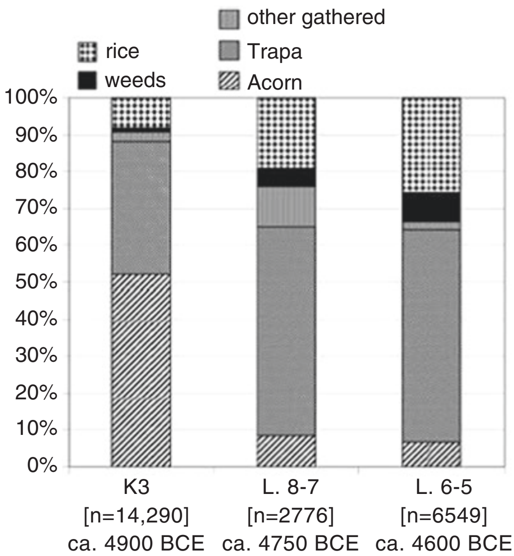

Fig. 8 Proportion of plant remains from sieved samples from the three periods at Tianluoshan (Fuller et al. 2009, Fig. 2)

foxnuts (*Euryale ferox*), peaches (*Amygdalus persica*), and jujube (*Choerospondias axillaris*); many of them are found in storage pits (Qin et al. 2006; Zhejiang Provincial Institute of Cultural Relics and Archaeology 2003, P216–218). Restricted by retrieval methods, smaller seeds and fruits were not collected. The information on plant remains was supplemented by the many more complete samples from Tianluoshan. More than 50 species have been identified from the floral assemblage. There are four predominant plant food resources: acorns (including deciduous *Lithocarpus* and evergreen *Cyclobalanopsis* types), water chestnuts, aquatic foxnuts, and rice. Acorns and wild aquatic plants have been stable food resources for a long time, at Tianluoshan, while rice appeared to be a supplementary resource. However, the proportion of rice increases from 8% to 24% and that of acorns declines remarkably (Fig. 8). The findings of acorn storage pits may indicate that acorns were used as backup food and then gradually abandoned. On the spikelet bases, the proportion of domesticated type increases (Fig. 9), indicating that rice domestication was in progress (Fuller et al. 2009). The finding of ancient field areas where rice grew and farming tools were found (Fig. 10) also supports the conclusion that rice was an important food with targeted production practices.

In palaeoenvironment studies, vegetation and climate are normally reconstructed through micro plant remains such as pollens, phytoliths, and diatoms. Regional pollen diagrams show a large amount of wetland grass (*Typha* and *Cyperaceae*) pollen and declines in oak (*Quercus*, *Lithocarpus/Castanopsis*, *Cyclobalanopsis*) and/or chestnut (*Castanea*) pollen between 6000 and 4500 BC (Kanehara and Zheng 2011; Tao et al. 2006), indicating large areas of wetland and probably a decrease of nut-bearing trees.

Qin et al. (2010) notice that the plant types from archaeological sites usually differ from the functional plants (PFTs) in biome reconstruction. Therefore, they map

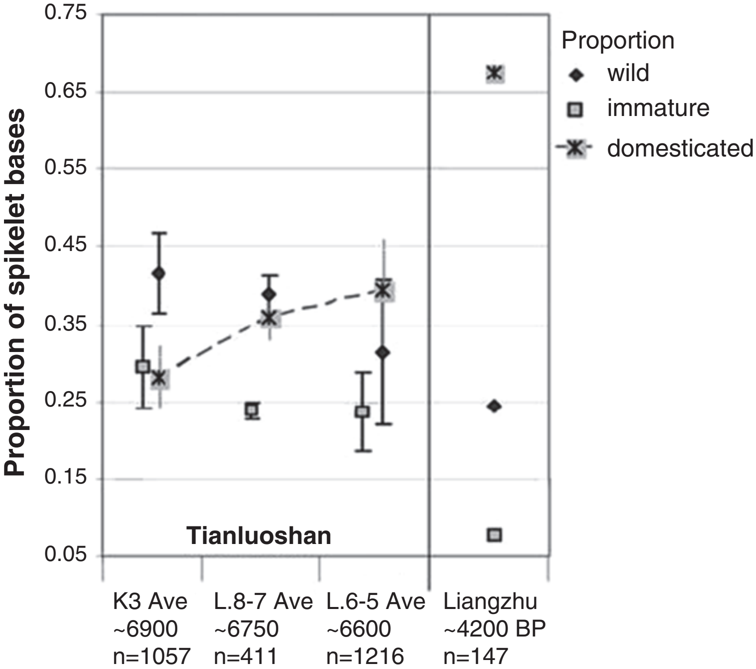

Fig. 9 Proportions of wild, immature, and domesticated rice spikelet bases from three sequential periods at Tianluoshan (Fuller et al. 2009, Fig. 4)

the distribution of Neolithic vegetation using macro plant remains such as seeds and fruits and hence discuss the exploitation of different catchments around the site. The advantage of this mapping is that it can illustrate the distribution in a small-scale area in detail.

In the plains area, there were plants adaptive to humid and aquatic environments, including *Salix*, *Trapa* (water chestnut), *Euryale* (foxnut), *Nymphoides*, *Oryza* (rice), *Typha*, etc. In the subtropical evergreen and broad-leaved forest (Fig. 11, mixed forest A) at the foot of hills, there were *Albizia*, *Broussonetia*, *Ficus*, *Armeniaca*, and *Vitis*; *Camellia* and *Zelkova* could be found in valley foothills. At the elevations between 100 m and 800 m, there was also mixed forest of evergreen and broad-leaved trees (Fig. 11, mixed forest B) but dominated with different trees, including *Lithocarpus*, *Cyclobalanopsis*, *Diospyros*, *Choerospondias*, *Acitinidia*. The highest area of Siming Mountain in the south would have had a distribution of broad-leaved forest mixed with conifers, composed with some trees in mixed forest B (see Fig. 11) and an increasing proportion of *Cinnamomum*. There are also *Amygdalus* (wild peaches), *Morus* (mulberries), and *Liquidambar* (sweet gum), which could have been used for building timbers in the past.

Environmental research on the sea level change indicates that there have been several fluctuations throughout the Holocene. It rose rapidly in the early Holocene

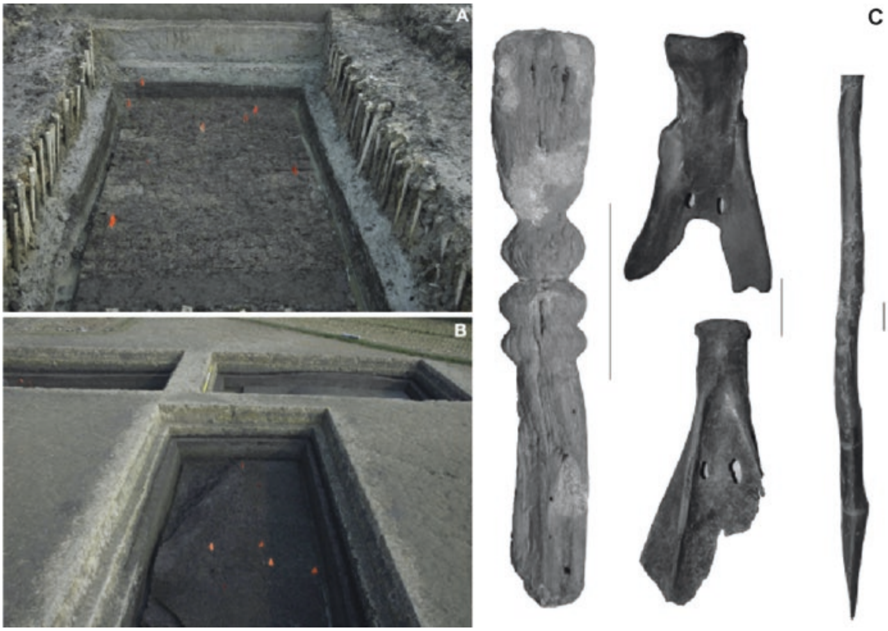

Fig. 10 Two layers of rice-growing fields at Tianluoshan and the relevant farming tools. A is the early rice field dated to 4650–4490 BC, lying 2.8 m deep under the surface. Wooden pegs are used for preventing collapse of the walls during excavations. B is the later field dated to 3340–3090 BC. Red flags mark the locations where pottery sherds are found. C shows the farming tools found at Tianluoshan; from left to right, they are wooden knife, bone spades, and wooden dibble. Spades are found within the settlement and the other two in the paddy field. Scale is 5 cm. Pictures are quoted from Zheng et al. (2009)

and kept at high levels until about 5000 years BC. Part of the coastal plain area was under water during those three millennia. Since around 5000 years BC, the sea level was relatively lower, and a series of low-lying plains was formed (Tao et al. 2006; Zhang et al. 2004). Wang et al. (2006) argue that the sea level started to rise again at about 4000 years BC and stayed at a high level until 1500–1000 BC. Palaeosalinity analysis of diatoms, plant seeds, and sediment samples reveals sea-level transgressions and regressions before, during, and after the occupation of Tianluoshan site (Li et al. 2009, 2010; Mo et al. 2011; Zheng et al. 2012). According to Zheng et al. (2012), there are at least two huge transgressions, which are from 6400 to 6300 BP and from 4600 to 2100 BP, in the Ningshao Plain, since the regression between 7500 and 7000 BP. It is also suggested that the invasion of the sea water could have negative influence to the subsistence and thus the development of the Hemudu culture (Mo et al. 2011). The sea level has been close to the present-day level over the last 3000 years.

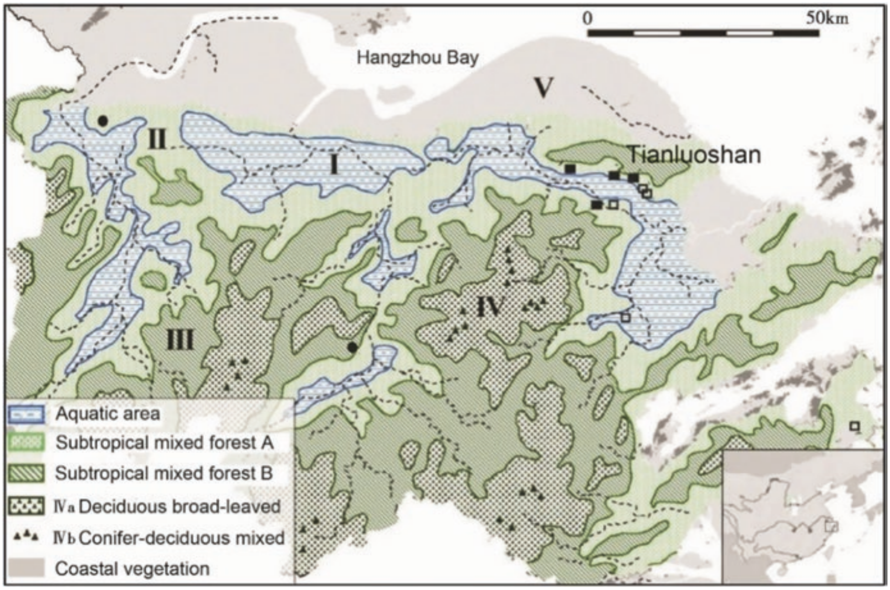

Fig. 11 The vegetation reconstruction of Hemudu culture period in the south of Hangzhou Bay area, including Ningbo-Shaoxing Plain (Qin et al. 2010)

6 Discussion

6.1 Fishing and the Environment

Biological research is fundamental for zooarchaeological topics such as palaeoenvironmental conditions, subsistence, and domestication (Reitz and Wing 2008, P28–29). Knowing fish ecology and behaviours benefits the discussion on fish remains (Wheeler and Jones 1989), especially for integration research, to understand the interrelationship between fish and the environment and to understand why and how people chose to catch these fish.

The most significant characteristic of the Tianluoshan fish assemblage is the absolute predominance of snakehead. As a predatory fish in the ecosystem, the proportion of snakehead in a natural water body is usually quite low. Take the Taihu Lake for example: the total proportion of snakehead and several other fish species take up merely 12.5% of the total population in 2000 (Chen and Wu 2008). In order to solve this puzzle, the life history of snakehead and five other fish are carefully looked through, to find out commons or difference, which may indicate the environment they were caught from.

Channa argus inhabits the tranquil water bodies with muddy bottoms and plenty of aquatic vegetation, such as ponds, reservoirs, and even rice paddies. Snakehead has the ability to breathe directly from air, making them tolerant to brutal conditions like hypoxic waters and dry seasons, which most fish cannot survive. As a top predator in the food chain, snakeheads feed on various organisms, including zooplankton, phytoplankton, insects, small crustaceans, fish, and frogs (Courtenay and Williams 2004; Editorial Committee of Fauna of Zhejiang 1991; Hubei Provincial Institute of Hydrobiology 1976). The habitat environment and behaviours of common carp and crucian carp are very alike. They prefer backwaters with rich vegetation but are tolerant of a wide variety of conditions in natural and artificial reservoirs, even with low oxygen concentrations, high pH levels, high temperature, organic pollutants, etc. (Hubei Provincial Institute of Hydrobiology 1976, P128–129; Kottelat and Freyhof 2007, P145; Yang 1987, P49). The spawning season of carp in this region is generally from April to June; for crucian carp, it is from March or April until early July. Catfish also has a high tolerance for water conditions. They prey on smaller fish, invertebrates, and insects. Culter fish, also known as top-mouth culter fish, is a carnivorous cyprinid in the temperate zone of Europe and Asia. They usually inhabit rivers and floodplain lakes with aquatic macrophytes, living and feeding near the bottom as well as in mid-water and near the surface. Sea bass is an inshore species found in coastal water, estuaries, and fresh waters at the west of the Pacific Ocean. The adults are catadromous, returning to sea to spawn in deeper rocky reefs or inshore areas, and juveniles ascend rivers to brackish or fresh water. Sea basses are commonly found in the estuary of Yangtze River and tributaries, sometimes downstream rivers.

By reviewing the habitat and behaviours of the fish, it is getting clear that most of the fish (except for sea bass) share the same habitat, indicating that they are possibly caught from the same environment. More importantly, they are tolerant to various environment even brutal conditions like low oxygen and high temperature. Plus, the species diversity is quite low, although the number of edible fish species in the lower Yangtze Region is quite large (Editorial Committee of Fauna of Zhejiang 1991; Ni and Zhu 2005). It is summarized that at least 54 species are potential food fish in the study area (Zhang 2015). Here we may ask: which is the cause of low diversity in the fish remains, selective fishing or environmental factors?

Environmental research reveals that Tianluoshan was located near a considerably large area of wetlands, which was an important food resources catchment, and also the probable catchment for fishing (Fuller et al. 2011; Kanehara and Zheng 2011; Zheng et al. 2011). From the perspective of ecology, wetlands can be defined as an ecosystem that arises when inundation by water produces soils dominated by anaerobic processes and forces the biota, particularly rooted plants, to exhibit adaptation to tolerate flooding (Keddy 2000). Wetlands share common features with both aquatic and terrestrial systems. Nevertheless, there are two features that together make wetlands unique: anaerobic soils and water and the distinguishing macrophytes (van der Valk 2006, P3). Anaerobic soils and water is the basic characteristic of wetlands and should be responsible for the corresponding adaption of wetland plants and animals.

The distribution of fish is controlled by factors including oxygen levels, water depth, water chemistry, and water temperatures (Mathews 1998). Generally, fish species are not unique to wetlands and are also found in adjacent lakes and streams. However, due to the anaerobic water and the periodic dry season (with no or very shallow standing water), fish may be absent from some kinds of wetlands. If not, their number and diversity are expected to be much lower compared to fish in other aquatic ecosystems, e.g. riverine and oceanic fish. However for most fish, the anaerobic water is not endurable. Fish which succeed to survive have developed certain ways to overcome the issue. Some have developed special organs to breathe directly from the air, such as catfish, lungfish, and snakehead. They also spawn buoyant eggs which can float on water surface to obtain enough oxygen. Parenting is also very useful to increase the rate of larvae's survivorship. These fish may migrate or hibernate to overcome the dry seasons. A few cyprinids also show great endurance to the wetland environment, especially common carp and crucian carp. They prefer tranquil waters and manage to survive the anoxic conditions in several ways (van der Valk 2006, P78). Wetland is the shelter, feed place, and spawning field for them.

The wetland ecology explains the existence of the fish species at Tianluoshan and the simplicity of the fish assemblage composition: the Tianluoshan people may not have much fish species to choose due to the simple ecosystem of the wetland. Snakehead, among all the fishes from Tianluoshan, is probably the most adaptive to wetland. Although there is no record of the exact proportions of each fish species in the wetland fish populations, it can be inferred that the proportion of snakehead and other air-breathing fish, which are carnivorous, is higher than that in other wide and deep water bodies such as rivers and lakes, where the fish diversity is much higher, just like the Taihu Lake.

6.2 Investigating the Fishing Methods: Ethnographic and Zooarchaeological Analysis

Fishing hooks, net sinkers, harpoons, and stone walls are probably the commonest fishing tools that have been discovered from archaeological sites, yet they may only represent a small proportion of all fish-capturing methods that were used at the site, for that many of them do not leave archaeological evidences. Ethnographic records are important resources for archaeological research when direct evidence of fishing techniques is absent, and also the reference data to reveal how the uncovered fishing artefacts worked. Archaeologists have been receiving help from ethnographic records for decades. Louis Binford benefited from Nicholas Gubser's (1965) and John Campbell's (1968) ethnographic work among the Nunamiut, and his work (Binford 1978, 2014) further contributes to the interpretation of archaeological faunal record.

Interestingly, no fishing tools like harpoons or net sinkers have been reported from Tianluoshan (Sun 2011). At the site of Hemudu, which has larger amount of fish remains, direct evidence of the fishing gear is also very rare: two stone net sinkers and two harpoons made of bone (Fig. 12) (Zhejiang Province Institute of Archaeology and Cultural Heritage 2003), indicate that the fishing gear must have been far more abundant than those that have been preserved. There could be two

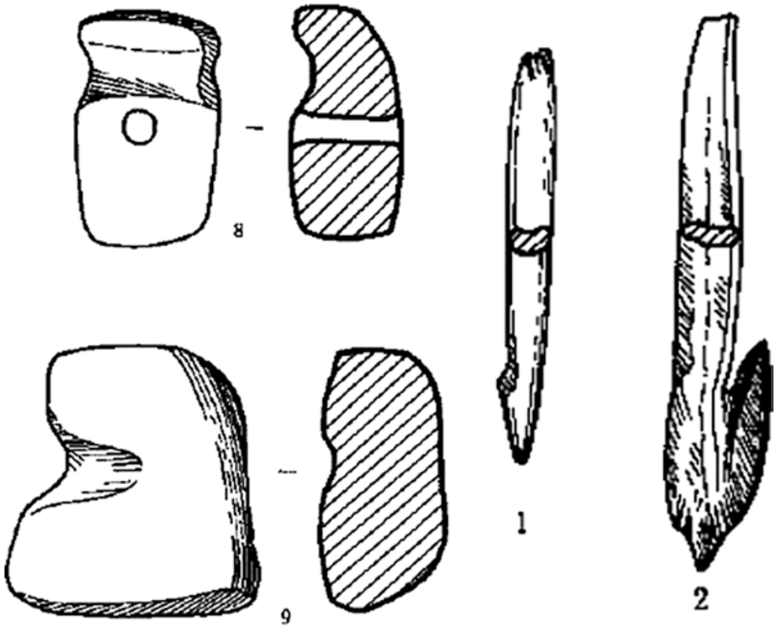

Fig. 12 The excavated fishing tools from Hemudu: net sinkers (left) and harpoons (right) (Zhejiang Provincial Institute of Cultural Relics and Archaeology 2003).

explanations for this scarcity of fishing tools: on one hand, most of the fishing gear was made of organic substance such as wood, bamboo, rope, etc., which could be hardly preserved; on the other hand, people might use nonconventional fishing gears which had not been correctly identified by archaeologists.

Fishing in wetlands is severely restricted by the environment. In deep and vast water bodies, netting and hooking can be the most applicable methods, but not in shallow waters. The low water level makes it difficult to cast or set nets, and the rich vegetation causes obstacles for both netting and hooking. Instead, ethnographic evidence show that some fishing equipment is especially applicable for wetland fishing, such as scoop baskets, traps, and a variety of 'falling gear' (Fig. 13), which are nets or pots particularly designed to clamp down on top of the fish and close in on them (Gabriel et al. 2005). The environmental limitations of wetlands have eliminated many common fishing methods and narrowed the possible choices to a few methods. Nevertheless, the wetland fishing gears share a common feature: they rarely leave any archaeological evidence. It is difficult to investigate the fishing techniques and skills at Tianluoshan directly from artefacts.

Each fishing gear and method usually applies to certain targets which are classified by various criteria, such as behaviour (e.g. nocturnal and migrating fish), habitat (e.g. deep/shallow water fish), or simply size, causing selectivity (Colley 1987; Lagler 1978; Millar 1995; Rollefsen 1953). Therefore, it is possible to discuss the fishing strategies by analyzing the species composition of fish remains, mortality

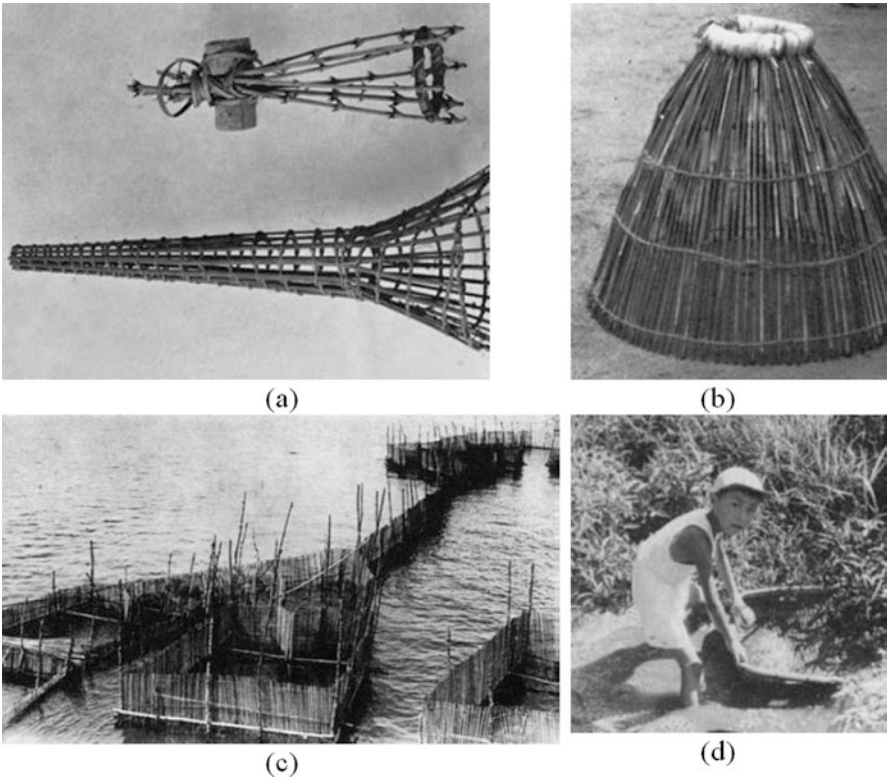

Fig. 13 Fishing gears which are applicable for wetland: (**a**) thorn-lined traps of Oceania; (**b**) cover pots used in Kerala, Southern India; (**c**) fences arranged as traps off the Ivory Coast (Photographed by Gabriel et al. 2005); (**d**) winnowing basket used as scooping basket in Japan, indicating that a tool can be multifunctional (Gabriel et al. 2005)

profiles, and the size of fish. A simple example is that catastrophic mortality profile possibly implies fish poisoning. In Balme's (1983) study on the fish remains from four sites along the Darling River in western New South Wales, she was able to distinguish gill net and drum trap fishing by their distributional patterns of fish length (Fig. 14b).

Figures 4 and 5 show a selection of fish by body size. Interestingly, although the sizes of the three predominant fish vary greatly from each other, the size reconstruction indicates that the selection by size is quite similar, concentrating on the individuals between 140 mm and approximately 450 mm. Hence, for crucian carp, which is much smaller than the other two species, the size of fish selected tends to be 140 mm and above. This result indicates that fish selection could possibly be caused by fishing methods. It also infers that those three species were possibly captured using the same fishing methods, rather than being targeted by individual species.

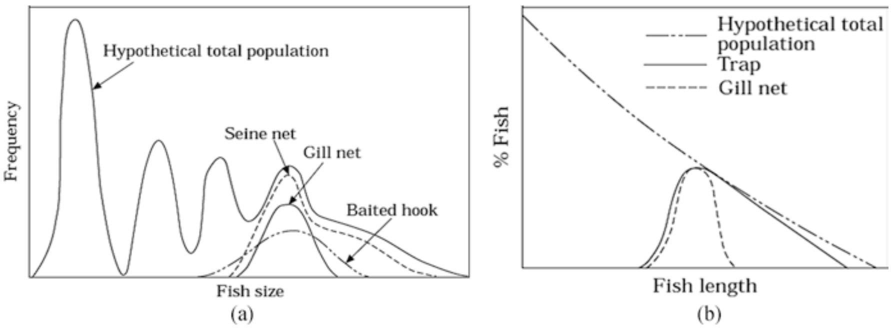

Fig. 14 Fishing gear selectivity model (**a**) for gill net, hook, line, and seine net (Hamley 1975) and (**b**) for drum trap and gill net (Balme 1983)

Yet, it is quite difficult to decide the exact fishing methods merely from fish size reconstruction. They can be narrowed down to a group of methods which have a selection of fish size, such as trapping, scooping, and covering with falling gear. One or several of them could have been practised at Tianluoshan.

In conclusion, interpreting fishing strategy at archaeological sites requires a sophisticated knowledge of fish behaviour and habitat, according to which the specific fishing gears were chosen and the fishing strategy was applied. When there is not enough direct evidence of fishing gears, the deduction of fishing methods can be made according to the analysis of fish remains, sometimes with the assistance of ethnographic records.

6.3 Scheduling the Exploitation of Aquatic Resources

Scheduling the exploitation of various resources is an important part of the subsistence economy. Some resources are only available at fixed time in a year, like fruits, nuts, and migratory fish, while the others are available throughout the year, but their distribution, the costs and risks of acquiring them, and the quality of their nutrients and by-products may vary between seasons. By scheduling the resource exploitation, we can find out how people cope with fluctuating abundances of edible resources and solve conflicts when several resources are available at the same time.

In addition, the seasonal cycles in resources have significant impacts on the sites and societies. On one hand, they influence where sites are located, when they are occupied, how many people live there, and the activities that occur at them (Reitz and Wing 2008, P261). On the other hand, they influence the coordination of labour among men and women of different age groups within the society (Gragson 1993; McGovern 1994).

The edible resources from Tianluoshan can be roughly categorized into two groups: seasonal and nonseasonal. Fruits and nuts are highly seasonal resources which can be only collected in fixed seasons of the year. Plus, the fruiting season is usually rather short, so it requires great labour to collect the fruits and nuts before they get rotten or eaten by animals. For instance, the harvest season of acorns from Tianluoshan is suggested to be from August to November due to lack of species-level identification; this is also the period when the majority of Lithocarpus and Cyclobalanopsis in South/Southeast China fruit (Fuller et al. 2011). In reality, the peak season for acorn collecting is perhaps 1–3 weeks only, as acorns just begin to fall off trees once they come into maturity (Hillman 2000). There was possibly conflict in the time and labour that were spent on acorn gathering and rice cultivation, and the conflict would eventually become more serious as rice agriculture developed. In the meantime, hunting and fishing only occasionally occurred in autumn. This was probably arranged on purpose to avoid the extremely busy season.

In general, it shows a well-planned scheduling for exploiting different resources in a year. The events are dispersed throughout the year, barely overlapping. Fishing was practised throughout the year according to the seasonality reconstruction but was more intense in certain months. For snakeheads, the intensified fishing mostly occurred in spring; but as time goes by, the fishing season extended. The concentrated fishing seasons for the cyprinids occurred slightly later, normally from late spring to summer. By integrating with the seasonality of aquatic plants, the exploitation of the aqua resources is regularly scheduled at different seasons of the year (Fig. 15).

The schedule of exploiting the common aquatic resources indicates that the wetlands were constantly used for subsistence. As the harvest of aquatic plants is highly restricted by seasonality, fish may well have been the routinely procured resource for consumption. The seasonality analysis of sika deer and wild boar remains shows that hunting is relatively intense during winter, avoiding conflict with fishing and collecting.

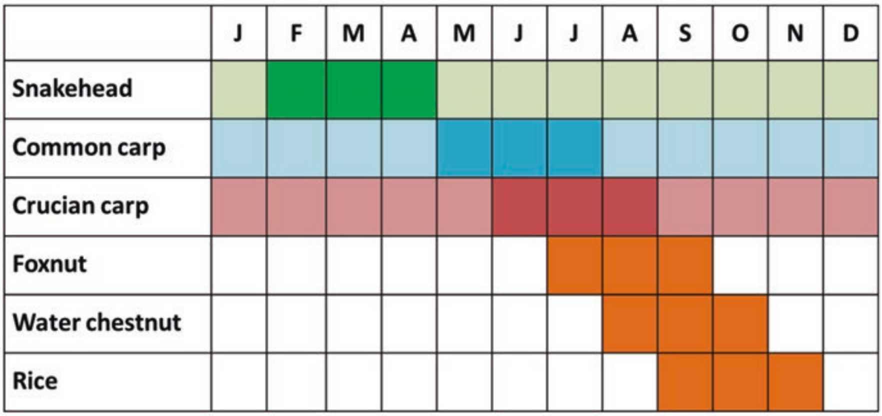

Fig. 15 Seasonality of fishing at Tianluoshan, comparing with fruiting period of selected aqua plant taxa based on *Flora of China* and *Flora Hubeiensis* (Fuller et al. 2011). Coloured blocks represent the months when the resource is exploited, and dark-coloured blocks show the time when exploitation is intensified

7 Conclusion

The presence of substantial quantities of fish remains confirms that fishing was an important component in the subsistence economy at Tianluoshan. The analysis indicates snakehead, crucian carp, and common carp can be regarded as co-staples. The limited range of fish species suggests that the inhabitants of Tianluoshan were specialized fishers rather than broad-spectrum foragers. The presence of wetland, riverine, estuarine, and marine fish indicates varied environment for fish exploitation; however, detailed analysis of the three predominant fish suggests that fishing mostly occurred in a rather concentrated area, i.e. the wetlands.

Integrated with the archaeobotanical results, the importance of wetlands in the Tianluoshan subsistence is highlighted. Archaeobotanical research indicates that aquatic plants from the wetlands, including wild water chestnuts, foxnuts, and cultivated rice, were the major plant food resources at Tianluoshan throughout the Hemudu period. In addition, although not included in this research, a large number of soft-shelled tortoise and waterfowl which inhabit the wetland has been uncovered from Tianluoshan. These findings indicate that wetland might be the core region for subsistence at Tianluoshan.

Ecology is about the natural environment and the interrelationships between organisms and their surroundings. It includes information about an animal's living, such as where it lives; what it eats; what, where, and how it pursues food; the breeding season; living style (group or isolated); etc. Such knowledge is fundamental for any hunting and fishing activities; hence it is accumulated and passed down by the hunters and fishermen from generation to generation. It is also fundamental for zooarchaeological studies investigating past subsistence economies. A stable subsistence system is founded on firmer ground, based on biological and ecological knowledge, allowing for repeated and reliable success in securing targeted species (Reitz and Wing 2008, P88).

Fishing is a complicated subsistence activity which involves various tools, techniques, and strategies. Strategically, there is no clear boundary between fishing and hunting. Many methods are known in both fishing and hunting, such as spearing, harpooning, shooting, and trapping (Gabriel et al. 2005, P2). The comprehensive analysis of the fish remains, artefacts, and environment suggests that a variety of size-selective fishing methods adaptive to the wetland environment were probably applied at Tianluoshan. The specific techniques might include trapping, scooping, and using falling gear. Most of the fishing tools involved were possibly made of plant materials.

This analysis may push us to reconsider the function of some structures in the settlement. At the low-lying area of the site, a feature made of a group of stakes is interpreted as a fence and log-bridge structure separating the settlement and the outside (Sun 2011). However, it is proposed here that the structure of this feature might have been a fishing barrier, like the one used by Native Americans and in Fig. 13c. Hopefully more evidence will be uncovered in the future to understand the function of this kind of features.

It requires a broad knowledge about animal habitats, behaviours, life history, the environment, and the ecosystem to establish an efficient and sustainable schedule for hunting, fishing, and gathering events. The intensified exploitation of varied resources was arranged at different times of the year to avoid conflicts in labour and time. However, the exploitation season of certain resources seemed to be related judging from the ecological and cultural background. Rice cultivation might have influenced the scheduling of other resources. As rice farming became more and more important in the cultures thereafter, the scheduling strategy might have changed accordingly.

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