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Chapter 9

Why Rice Farmers Don't Sail: Coastal Subsistence Traditions and Maritime Trends in Early China

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9.1 Introduction

The emergence of agriculture had a profound effect on environments and human populations. Its transformative effect has been explored in global syntheses from Diamond (1997) to Ellis (2015), and in terms of human macro-history farming clearly played a role in increasing the potential rates of demographic growth and the expansion of human populations, language families and genetic lineages (Bellwood 2004, 2005). The so-called Language-Farming dispersal model suggests that the demographic transition triggered by the emergence of agriculture led to population growth and outward migration of farming populations and accounts for most of the geographical spread of major modern language families (Bellwood and Renfrew 2003; Diamond and Bellwood 2003). In the context of both mainland and island Southeast Asia, most of the distribution of different language families has been attributed to this process, either directly or indirectly. Thus mainland Southeast Asian languages like Austroasiatic can be traced back to the spread of rice farmers southwards out of China (e.g., Higham

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2003), while Austronesian languages found mainly in island Southeast Asia and the Pacific likewise appear to represent a maritime extension of demographic growth and dispersal derived from the emergence of rice cultivation in China (Bellwood 1997, 2005; Blust 1995). Bellwood (1997, 2004, 2005) has pointed to the origins of rice farming in the Lower Yangtze region, illustrating how cultures like the Neolithic Hemudu were likely precursors to a maritime Neolithic expansion that brought rice and farmers to Taiwan.

Numerous strands of scholarship have contributed to this hypothesis. Since the 1930s, archaeologists have linked material culture in Taiwan to Fujian, Guangdong and the Pacific Islands beyond (Lin 1931, 1955). Artifacts such as shouldered-stone adzes and corded-ware ceramics were among the first links to be recognized, while the work of K. C. Chang (1986) clarified the basic sequence of Taiwan's Neolithic culture history, including its connections with the archaeological traditions found in Fujian and Guangdong (Chang and Goodenough 1996; Tsang 2005). Bellwood (1997, 2005) and Jiao (2007) have been among those promoting the idea that rice agriculture and maritime culture dispersed south along the coast from Hangzhou Bay to Fujian and eventually Taiwan during the Neolithic Period, around 5000 year ago. Parallel work on comparative linguistics has meanwhile established the relationships between the Austronesian language family and some of the most basic branches of the Formosan languages, or the indigenous languages of Taiwan (Blust 1995; Pawley 2003). Reconstructed protolanguage vocabulary has also identified terms related to farming, including words for rice and foxtail millet (Blust 1995; Sagart 2005). More recently, Sagart (2008, 2011) has hypothesized that the origin for these terms stretches even further back, to Sinitic or Proto-Sino-Tibetan languages. As suggested by these linguistic data, not just rice cultivation but also millets, including *Setaria italica* and probably *Panicum miliaceum,* formed part of the original Neolithic cultural traditions brought to Taiwan (Sagart 2008, 2011). Indeed, recent archaeobotanical research at the Taiwanese site of Nankuanli East confirms the presence of all three of these Chinese cereals (rice, *Panicum miliaceum* and *Setaria italica*) in the earliest yet found archaeobotanical assemblage on Taiwan, dating back to at least 4300 BP and perhaps as early as 5000 BP (Tsang et al. 2017).

Since at least the 1970s linguistic data for the Austronesian language family, the most geographically dispersed language family in the world, have been traced back to Taiwan, where all the basal branches in this tree are found among the indigenous Formosan languages. Thus, from these derive the Malayo-Polynesian languages, while other branches have spread through much of island Southeast Asia, throughout the Pacific and even to Madagascar (Blust 1995; Pawley 2003; Spriggs 2011). The structure of this language family tree gave rise to the "express train" model of population expansion and colonization that emanated out of Taiwan, through island Southeast Asia and ultimately out into the Pacific via the Lapita expansion starting ca. 3350 BP (Greenhill and Gray 2005; Spriggs 2011). Although there are criticisms of this linguistic model (e.g., Donohue and Denham 2010), it remains the dominant and most widely accepted explanation for how the far-flung Austronesian languages came to be historically related.

Based on this model, the people of Neolithic Taiwan have been identified as "proto-Austronesian." One of archaeologist Peter Bellwood's major contributions was to synthesize archaeological evidence throughout island Southeast Asia, highlighting cultural similarities in ceramics and other features that link the Indo-Malaysian Neolithic cultures to those of the northern Philippines and Taiwan. Drawing upon linguistic patterns and the cultural inferences of the archaeological record he developed the "language farming" dispersal model, based on the idea that a main demographic motor of expansion was the development of farming and the seeking of new arable lands as agricultural populations expanded (Bellwood 1996, 2005). As these growing agricultural populations spread into the islands they largely replaced, and to some degree incorporated, pre-existing hunter-gatherer populations. Archaeobotanical evidence for movement into the islands and the dispersal of rice outside Taiwan remains limited (Paz 2003; Barton and Paz 2007; Fuller et al. 2010a). However, in the islands in particular a key transformation appears to have taken place, as tuber crops like taro and yams ultimately became more important than rice. This expanding Neolithic world of Austronesian farmers and sailors has provided a narrative that unifies archaeological and linguistic histories of island Southeast Asia and Taiwan for the later Holocene, despite the lack of hard evidence for past agriculture.

This historical narrative can be questioned in three ways. First, we might ask: "Why rice?" Why should rice agriculture have been central to the process of demographic growth and the migration of farmers, and could other forms of food production have been the driving force behind such movements, instead? Second, it begs the question: "What kind of rice?" The range of potential forms of rice cultivation cover a broad spectrum, from upland slash-and-burn systems to much more intensive flood and irrigation systems (Fuller et al. 2011; Weisskopf et al. 2014). Among these various strategies, which forms of rice cultivation might have driven the migrations to Taiwan and beyond? Scant attention has been paid to this particular detail, although the research generally appears to assume it was more intensive and productive forms of wet rice cultivation (e.g., Bellwood 1997: 208, 2005: 125). In fact, our research has shown that current evidence and logical deductions suggest exactly the opposite. Third, we might reasonably ask: "Does the empirical record, when assessed in terms of current hard evidence for agricultural systems and their dispersal, actually support the maritime-based dispersal of rice farming?

In response to these three questions, we propose that early wet rice farmers were neither particularly expansive nor engaged in much maritime activity. Instead they tended to be associated with a focus on freshwater wetland exploitation, with little indication of engagement with the marine. This preference becomes clear in reviewing the empirical record of archaeobotanical, faunal and settlement evidence from the Lower Yangtze River Valley. Indeed, the highly productive systems of wet rice agriculture supported population packing rather than geographical expansion. Looking beyond the Lower Yangtze and the evidence for rice, other forms of food production clearly need to be considered and compared, including millets, low intensity dry rice, and vegeculture. In fact, when potential yields, labor demands, land requirements and sustainability are taken into account it is much more likely that millets and lower intensity forms of rice cultivation lent themselves to geographical expansion in search of new lands. In combination with coastal forager-fisher traditions, this means that Neolithic Lower Yangtze rice farmers are unlikely to have had anything to do with the spread of farming and farmers to Taiwan and the Southeast Asian islands or mainland. Thus, established hypotheses require either rejection or revision.

9.2 Early Wet Rice Cultures of the Lower Yangtze and the Focus on Inland Wetlands

A key region for the early development of rice farming was the Lower Yangtze River Valley, including northern Zhejiang, southern Jiangsu and the areas around Shanghai (Fig. 9.1). Indeed, Neolithic cultures of this region such as Hemudu and Majiabang have long featured in narratives about the emergence of rice agriculture and the origins of the Austronesian Neolithic (e.g., Higham and Lu 1998; Bellwood 1997, 2005). Yet increasing numbers of Neolithic excavations in China have documented additional regions and cultures that cultivated rice early on and that likely contributed independently to one or more trajectories of rice domestication, including Middle Yangtze cultures such as Pengtoushan, the Baligang of the middle Yangtze Han River Valley, and the Jiahu and Shunshanji of the Huai River Valley (e.g., Fuller et al. 2010a, 2010b, 2011b; Qin 2012; Gross and Zhao 2014; Deng et al. 2015; Silva et al. 2015; Stevens and Fuller 2017). Nevertheless, the Lower Yangtze is geographically the closest to Fujian and Taiwan, as well as one of the best documented regions archaeologically and archaeobotanically. It therefore provides a useful focus for considering the roles of freshwater and marine resources relative to the evolution of rice cultivation.

In the Lower Yangtze region, cultural developments associated with the emergence of wet rice agriculture can be identified through scrutiny of agricultural and non-agricultural subsistence, technology, landscapes and diet. This region, in particular, has benefited from a large increase in archaeological fieldwork and the practice of systematic archaeological science over the past two decades. With regard to rice domestication, cultural change can be tracked through various traits. The shattering versus non-shattering trait, which makes a crop dependent on humans for successful reproduction, can be seen undergoing a rapid shift between 7000 and 6000 BP, during a period marked by the remains of the Hemudu and Majiabang cultures. As for the bulliform phytoliths, directional linear changes in size actually began around 6000 BP, suggesting the continued evolution of rice plants (in terms of their leaves) under domestication. This shift parallels the evolution of fatter grains, which began alongside non-shattering but continued afterwards in both rice and other cereals (Fuller et al. 2010b; Stevens and Fuller 2017). In addition, under domestication after 6000 BP rice grains split into two types, short and long grain forms, which appear to have quite stable varieties found in different communities and settlements since 6000 BP. For example, these disparate lineages of domesticated rice ultimately stabilized into today's forms of tropical versus temperate *japonica* rice (Garris et al. 2005; Zhao et al. 2011). The origins of such differentiation may date back as far as the Late Neolithic in the Lower Yangtze, although further adaptations that characterize today's temperate *japonica* would have evolved later (Fuller et al. 2016).

The varied pace and timing of the evolution of traits in rice can be understood in relation to the agricultural techniques that facilitated change. Initial domestication was presumably driven by a combination of soil management and the sowing and harvesting of rice through a slow process of co-evolution in which human actions became entangled with plants whose reproductive success was increasingly tied to being harvested and sown by people. Allaby et al. (2017) recently estimated that early engagements between foragers and rice that eventually led to domestication could have begun around 13,000 BP; but there was also a marked increase in the rate of rice evolution between 8000 and 6000 years ago, corresponding to what is normally interpreted as the moment of domestication. The earliest paddy field remains date to the end of this period, discovered at a number of sites associated with the late Majiabang period (6000-5800 BP) as well as at Caoxieshan, Chuodun (Fig. 9.2a), and Jiangli (Cao et al. 2006; Fuller and Qin 2009; Qiu et al. 2014).

In the context of controlled agricultural fields, stronger selection of rice morphological features can be expected (on growth habits and leaf forms, for example), while the distinct populations maintained in such fields would have helped to create the kind of distinct varieties seen in the bimodal distribution of grain shapes across the region. These earliest paddy fields were small shallow pits, usually 1-2 meters in diameter and always measuring less than 10 square meters. One of the advantages to this cultivation method would have been the use of tight control over water and drainage to manipulate the traits of the rice plants' perennial ancestors in order to drive higher annual grain production (Weisskopf et al. 2015). Later, the enlargement of single paddy units can be seen starting with the Songze Culture and into the early Liangzhu (5500-4800 BP) (Fig. 9.2b). Then in the late Liangzhu period a brand new paddy system was established with systematic irrigation, drainage and the use of regular large scale paddy fields separated by well-designed and carefully constructed paths (Zhuang et al. 2014; Weisskopf et al. 2015) (Fig. 9.2c). The discovery of early "shallow-pit" type units buried below this larger, rectilinear field system at Maoshan clearly demonstrates a shift towards more intensified wet rice cultivation in the mid to late Liangzhu period.

In addition to the clear evolution of field systems based on increasingly intensive production of well-watered rice, the archaeological evidence for agricultural tools also presents a clear trajectory of cultural development. Rather than appearing early and in association with the domestication process, tools for harvesting and soil preparation have been found mostly in deposits from the post-domestication era when production was intensifying. There is no evidence of such harvesting tools prior to the domestication of rice. The late Neolithic tool kit in this area included a triangular shaped 'plough', presumably used as a foot plough to turn the heavy clay soils of early fields, a trapezoidal harvesting knife for hand-cutting individual panicles, and a larger stone sickle that could cut plants at the straw. Like the other harvesting tools, the triangular plough had appeared by ca. 5500 BP, during the Songze Period (Shanghai Cultural Heritage Bureau 1985; Zhejiang Provincial Institute of Cultural Relics and Archaeology et al.2006). Developed over the course of the later Neolithic and Bronze Age, these tools were later replaced by Iron tools in the historical period (Fig. 9.2d). Above all, they indicate the substantial labor that went into wet rice fields and food production, an investment that would have tied communities to high value, productive rice lands.

While rice was the only grain crop grown throughout the Neolithic in the Lower Yangtze, other wetland plants and wild species were also exploited, though there is no evidence for millet cultivation or consumption in this region at that time (Fuller and Qin 2010; Qiu et al. 2016). Other plants of particularly widespread importance include foxnut (*Euryale ferox*) and waterchestnuts (*Trapa natans* sensu lato), while woodland nuts such as acorns decline in use around the time that rice was domesticated, by 6000 BP (Fuller et al. 2007, 2010b; Fuller and Qin 2010). *Trapa* water chestnuts may also have been under cultivation, as suggested by the domesticated morphology found at Tianluoshan and dating to ca. 7000 BP (Guo et al. 2017). While some woodland resources are evident among the fruit and nut assemblages from this period, the predominance of rice, *Trapa* and *Euryale* highlight the importance of freshwater wetlands for subsistence resources.

The key role of wetlands is also reflected in the animal bone record at Tianluoshan and Kuahuqiao. Bird bones among these assemblages are heavily biased towards wetland taxa, such as ducks (*Anatinae*), geese (*Anserina*e), rails (*Rallidae*), herons (*Areidae*) and cranes (*Gruidae*) (Eda et al. 2019). Although fish bone assemblages have been less frequently recovered or studied, one large-scale analysis is available from Tianluoshan (Zhang 2018). In this study of 174,340 fish bones from wet sieved samples, freshwater wetland fish were clearly predominant, such as snakehead (*Channa*), carp (*Cyprinus*), crucian carp (*Carassius*), and catfish (*Silurus*). All of these species could have lived in or around rice stands or nearby deeper water where *Trapa* or *Euryale* would grow. The carp and crucian carp in particular have size ranges that indicate year-round fishing in freshwater wetlands, while the snakeheads were targeted more in spring (Zhang 2018). In this assemblage a small quantity (0.7%) of Japanese sea bass indicates some coastal or estuarine fishing, although this species also swims up into freshwater rivers when not breeding. Despite a few large tuna vertebrae that were hand collected at the site (e.g., Sun 2013) and a single dolphin bone from Kuahuqiao (see Eda et al. 2019: Table 1), marine and coastal resources clearly appear to have been the exception; a form of exotica set apart from the routine worlds of Neolithic inhabitants. Thus these rice cultivators looked inland, especially to wetlands, for their main protein sources.

Table 9.1 Estimated rice consumption, land requirements and carrying capacity for Yangtze River Valley

Site	**Est. Population**	**Lower Est. Rice Needs (kg/yr, 68% of diet)**	**Higher Est. Rice Needs (kg/yr, 80% of diet)**	**Lower Est. Land Needs (900 kg/ha)**	**Higher Est. Land Needs (800 kg/ha)**	**Median Rice Land (ha)**
Tianluoshan, ca. 6700 BP (3 ha)	150	16875	23437.5	18.75	29.29688	*24.02344*
Hemudu, ca. 6700 BP (4 ha)	200	22500	31250	25	39.0625	*32.03125*
Chengtoushan, ca. 6000 BP (8 ha)	400	45000	62500	50	78.125	*64.0625*
Hypothetical 1 ha Site	*50*	*5625*	*7812.5*	*6.25*	*9.765625*	*8.007813*
Maximum Size Based on Wet Rice Farming within 3 km (~280 ha)	**14,000**	**1,575,000**	**2,187,500**	**1050 (based on 1500 kg/ha yield)**	**2242**	**1892**
Hypothetical Dry Rice Site (1 ha)	*50*	*5625*	*7812.5*	*18.75 (based on 600 ka/ha, +1/2 fallow yield)*	*52.08 (based on 300 kg/ha yield)*	*35.42*

The large mammal fauna include a wide range of deer and some pigs and buffalo, likewise indicating an environment of wetlands and inland hill forests (Zhang et al. 2011; Eda et al. 2019: Table 1). Significant numbers of water deer (*Hydropotes inermis*) and water buffalo (*Bubalus* sp.) remains suggest the practice of hunting in and around wetlands, while sika deer and sambar (*Cervus* spp.) point towards woodland habitats. A significant minority of pig and boar bones (*Sus scrofa*) has been interpreted as evidence of the early management of pigs and the hunting of boars beginning sometime after 8000 BP (e.g., Liu and Chen 2012; Zhang et al. 2011).

Taken together, the food resources discovered from Neolithic sites in the Lower Yangtze allow us to reconstruct early land use and resource catchment in this area (e.g., Qin et al. 2010; Fuller and Qin 2010; Zhang 2018). Material culture from the Liangzhu Period also reflects the same catchment and resource management systems, in which birds, freshwater fish and turtles remain a recurrent theme (Fig. 9.3). Neolithic inhabitants' engagement with this landscape is further reflected in their diet, which can be reconstructed through isotopic data (Fig. 9.4). In dietary terms, the Lower Yangtze is characterized by a C_3 terrestrial and wetland type, a signature markedly distinct from either maritime hunter-gatherers, maritime millet farmers, or terrestrial millet farmers (see Fig. 9.4). Two archaeological discoveries of canoes in this region, at the Kuahuqiao Site (8000 BP) (Jiang 2013) and Maoshan (4500 BP) (Zhao et al. 2013; Zhuang et al. 2014; see Fig. 9.3), also indicate the existence of simple riverine and wetland boat technologies.

We therefore conclude that neither subsistence interests nor transportation technologies link Lower Yangtze Neolithic populations to the sea. Instead, freshwater wetlands and nearby woodlands were the main landscape features exploited by Lower Yangtze rice farmers. These communities appear to have looked inland, and not towards the sea.

9.3 Wet Rice and Alternative Neolithic Production Systems: The Mathematics of Demography and Land Use

The idea that rice farmers migrated southwards from the Lower Yangtze, dispersing out of this region by boat, was based on the underlying demographic logic of demic diffusion. This theory supposes that a growing population splinters, with daughter populations moving outwards in search of new land to settle and farm (Ammerman and Cavalli-Sfroza 1971; Bellwood 2014). Rindos (1980, 1984) explained that such migration events will occur when local populations grow to or beyond their natural carrying capacity. Carrying capacity itself will fluctuate between years due to factors like variations in yield, and the extent of this instability may speed up or slow down overall migration rates. Shennan's (2018) recent synthesis of Neolithic datasets from Europe took an explicitly demographic perspective, however, and identified a tendency for dispersal to occur when regional populations were growing rapidly, but before growth slowed; in other words, well before reaching carrying capacity. The European data therefore imply that populations can disperse in search of new agricultural territory not only when they reach their maximum size (as implied by the Rindos model), but during an intermediate period of rapid growth.

This theory also makes sense in light of comparative ethnographic studies indicating that many traditional small-scale societies operate well below carrying capacity, in what Sahlins (1972) called "underproduction" or the "underuse of resources" (42). Using data from a range of traditional production systems, their populations and computed potential productive capacity, Sahlins found that all of them appear to have under-produced. Only a couple of the groups produced at 65% or 75% of their capacity, while the average rate of production was only about 45% of their estimated capacity (Sahlin 1972: 42-48; cf. Carlstein 1980: 239). Thus, it may not be carrying capacity *per se* that drives fission, but rather population growth to a threshold at which increasing effort is needed to keep feeding more people. In either case, the total potential carrying capacity will effect how quickly a population grows and at what point migration is likely to begin (Fig. 9.5).

These observations raise two questions about the nature of early subsistence in East and Southeast Asia. First, what specific and inherent differences in carrying capacity (CC) and its associated underproduction (~60% CC) between different regions or crops would have raised or lowered the ceiling at which populations grew? And second, what similar differences determined the point at which daughter populations dispersed? Based on the existing evidence, wet rice agriculture appears less likely to propel population migration than alternative rainfed forms of agriculture, including both rainfed and upland rice and millets.

It is well known that rice productivity varies significantly based on water availability during the growing season, as well as varying demands for labor input and potentially different outputs of greenhouse gases (e.g., Fuller et al. 2011a, 2016). Previously we suggested that the higher labor demands of wet rice might have restricted the appeal of its adoption by some societies, and there might even be a threshold of social complexity below which wet rice cultivation was avoided (Fuller and Qin 2009). Still more important, however, are the inherent differences in potential carrying capacity that can be estimated in terms of the land necessary for rice cultivation to feed a self-sustaining village community or typical Neolithic community. In order to estimate the amount of land needed to feed populations at Neolithic sites, we have assembled a range of ethnographic and historic data on yield per hectare (ha) for wet rice, dry rice and traditional millet agriculture. This can be converted into a caloric yield and divided by the amount of cereal crop consumed per person per year (assuming grains were the caloric staple) and the population of past communities. It should be noted that population estimates are not meant to be precise, but rather provide an order of magnitude approximation: thus the difference between 50 and 500 is significant, whereas that between 30 and 100 is less meaningful.

For population sizes we have taken empirical values from the size of archaeological sites as well as a few pre-existing estimates of population size. These include Chengtoushan (Hunan) in the Middle Yangtze (6500-6000 BP), at ca. 8 ha, Hemudu (7000-6300 BP), at ca. 4 ha, and Tianluoshan (7000-6300 BP), at ca. 3 ha, in the Lower Yangtze (Zhejiang). All of these sites have quite reliable maximum size estimates from their main periods of occupation. Previous population estimates for Chinese Neolithic habitation sites agree on a ratio of approximately 50 persons/hectare, including an estimate from Hemudu based on building numbers and floor space (Sun 2013: 563). An independent estimate of 53.5 person/ha has also been made for the millet-producing area of northern China, based on house areas and burial numbers from the Early Yangshao site of Jiangzhai (Liu 2004: 79).

Modern data provide estimates of rice consumed per person, with ~250 kg of unhusked rice required for ~2000 calories per person according to Grist (1975: 450), and 160 kg/person/year estimated for traditional Southeast Asia (Hanks 1972: 48). The typical intake observed for traditional coastal Odisha, India of 160kg/person/yr (Smith and Mohanty 2018: 1328) is similar, assuming this number represents dehusked rice, which weighs the equivalent of 60%-70% of unhusked rice. These modern estimates probably account for ca. 80% of total caloric intake (Grist 1975: 450), but we assume that

Neolithic populations ate a more diversified diet, as clearly indicated by the archaeobotanical data from sites like Hemudu, Kuahuqiao and Chengtoushan. These deposits suggest a diet rich in other carbohydrates such as acorns, *Trapa* waterchestnuts (Fuller et al. 2007, 2009; Fuller and Qin 2010), and in some cases millet, as observed at Chengtoushan (Nasu et al. 2007, 2012). We have therefore assumed that rice in this context might account for roughly 50% of the total diet (if, as in the modern diet, grains accounted for 75%-80% then land need estimates would need to be increased by 50%-60%).

Past yields may be difficult to estimate, as they depend directly on land use systems. Nor can modern traditional yields serve as perfect analogues for earlier in prehistory. In general, wet rice is expected to yield better than rainfed rice; thus the lower bounds of reasonable yields draw upon data from dry rice productivity. Dry rice yields range from around 480 kg/ha to as much as some 1500 kg/ha, in some modern systems (Fig. 9.6). The average of our comparative data on dry rice is 1062 kg/ha, although data from Palawan and Borneo swiddens alone average just 578 kg/ha, with yields as low as 229 kg (Barton 2012). The average of our compilation of wet rice yields is 1897 kg/ha, with the lower end of recently reported traditional wet rice yields standing around 1500 kg/ha. Historical data, however, indicate that about 1300 kg/ha was achieved in 10th century Japan, while around 1000 kg/ha was observed in the Han Dynasty, Hangzhou nearly 2000 years ago. Thus the slightly lower yields of 830 and 950 kg, estimated from rice leaf phytolith densities in paleosols of field surfaces around Neolithic Tianluoshan (ca. 6700 BP), might be reasonable for early, unimproved wet rice yields (Zheng et al. 2009). Rounding these down to 800 or 900 kg and taking into account the upper and lower estimates of modern rice consumption per person, we can therefore bracket the land area needed for rice production among a small selection of Chinese Neolithic sites (see Table 9.1).

Based on the above calculations, we estimate that Neolithic rice producing sites need between 6.25 and 9.75 hectares of rice cultivation land for every hectare of settled land (or for every ~50 persons), with a median estimate of about 8 ha of rice cultivation land for each hectare of settlement land (see Table 9.1). Our productivity estimates are also quite low, meaning that if 1000 kg or more rice per hectare were produced, even less land would be needed per person and local carrying capacity would exceed our existing estimates. Historical and ethnographic data indicate that most fields are found within 3 km of settlements, while farm plots over 4 km from settlements appear to have been more or less impossible due to the need for daily travel, on foot, to work in the fields and return home (Chisholm 1968: 43-66; Carlstein 1980: 172). This suggests that about 2800 hectares of land could readily support a local population on the order of 14,000 people.

This relatively high productivity estimate for wet rice can be contrasted with the much lower expected estimates for rainfed rice or millet production (Fig. 9.6, 9.7). Rainfed rice production has been well documented in Southeast Asia, and as summarized by Barton (2012), the productivity of such rice in Borneo was quite low (ranging from 229 to 1000 kg/ha). For Neolithic dry rice these yields would have been, on average, about half that of wet rice, or between 400 and 500 kg/ha. This low rate of productivity would have been further exacerbated by the need to shift fields, as fertility decreased and weed competition with rice increased over time. In other cases rainfed rice is grown in shifting cultivation systems unless an external source of fertilizer can be employed, such as manure from domesticated cattle, In the well-studied case of traditional agriculture amongst the Iban in the Philippines, about 0.33 ha was cleared for rice per person per year, and a long-house village of 140 people required 50 ha per year (Carlstein 1980). Based on these figures the Iban could reside at a single settlement for a maximum of 14 years before needing to move, but ten years was considered a better estimate given the unsuitability of some land in a given catchment as well as the shifting age-sex demographics of the community over time (Carlstein 1980: 174).

The land needs of the Iban are therefore approximately four times those estimated for the Yangtze Neolithic communities (see Table 9.1). This would mean that carrying capacity for a given settlement catchment based on rainfed rice is roughly one quarter what it would be for wet rice. Assuming uniform rates of population growth, this predicts that community fission and migration in search of new space would occur four times as often among dry rice farmers as among wet rice farmers (see Fig. 9.5). Given dry rice farmers' need to shift fields for fallowing, or indeed their need to relocate altogether (e.g., every 10-15 years for a group like the Iban), cultural traditions of mobility and the establishment of new settlements are likely to have encouraged the kind of movement that underpinned long-term sequences of migration. This also suggests that as wet rice productivity increased over time, it allowed for more tightly packed populations.

By comparison, yields per year of traditional millet in northern China would have been low, but the high potential fertility of loess soils would have removed the need to allow the fields to lie fallow. Fig. 9.7 illustrates the range of probable yields for millet, combining those of both *Setaria italica* and *Panicum miliaceum* and Indian small millets, as differentiated data are rare. We also assume the productivity differences between early millets were not very significant. For example, Indian experiments found *P. miliaceum* to produce only slightly less, on average (perhaps yielding about 95% as much as *S. italica*), based on the same experimental conditions (drawing on Doggett 1986). As explored by Ho (1975) the loess soils of northern China have high inherent mineral nutrients and are likely limited primarily by their potential to absorb water (49). Ho infers both from deductive principles and through written references to Zhou era agriculture (ca. 2800 BP) that land was likely to be cleared one year, planted in the second and third year, and then left fallow for a year (50-54). Based on this kind of rotation, we estimate that between 30 and 36 hectares of cultivated land would have been needed for 50 people on the most productive loess, about 4 times what was required for Lower Yangtze wet rice (Table 9.2). A 3 km catchment with this level of productivity might support 4,000 people, but a typical Neolithic millet carrying capacity might be closer to half that. For example, less well-watered lands might need to be rested every other year, increasing land needs and lowering carrying capacity. As millet cultivation was taken beyond the loess plateau, and especially into lower fertility soils in the sub-tropics and tropics, lands are likely to have been left fallow for two out of three years, or even more. Thus, as millet cultivation spread to new communities beyond its core area in the loess plateau it required increasing land areas in order to maintain the same levels of productivity.

Table 9.2 Estimated millet consumption, land requirements and carrying capacity for Yellow River Valley

Site	**Est. Population**	**Lower Est. Grain Needs (kg/yr, 68% of diet)**	**Higher Est. Grain Needs (kg/yr, 80% of diet)**	**Lower Est. Land Needs (650 kg/ha, on rich loess, 1/3 fallow)**	**Higher Est. Land Needs (500 kg/ha, on poor soils, 2/3 fallow)**	**Median Millet Land (ha)**
Banpo (Early Yangshao), (5 ha)	250	43,697	51,408	153.95	474.54	314.245
Wangchengang (Longshan), (35 ha)	1750	305,880	359,859	1077.7	3324	2200.8
Hypothetical 1 ha Site	*50*	*8739.44*	*10281.7*	*30.7907*	*94.9079*	*62.8493*
Maximum Size Based on Millet Cultivation within 3 km (~40 ha)	**2000**	**349,577**	**411,267**	**1232**	**3796**	**2514**

Based on the nature of cultivation systems, we can conclude that the wetland rice focused subsistence strategy of the Lower Yangtze (and Middle Yangtze) would have supported high, and increasing, local population densities. Thus, population growth could have been largely absorbed locally, through the expansion and intensification of production. In this sense wet rice agriculture was a factor that drove the creation of larger, more concentrated populations, and also tended to provide for non-subsistence specialists such as those practicing stone working, ceramic production or ritual. The ultimate emergence of urban centers out of this very process can be seen in the mega-sites of Liangzhu, in the Lower Yangtze, and Shijiahe, in the Middle Yangtze. Both of these settlements were supported by local hinterlands of wet rice cultivation, represented by palaeosols and field systems such as those discovered at Masohan, to the northeast of Liangzhu. Population packing, and not migration, was the dominant trend among Neolithic populations focused on wet rice cultivation.

The higher population densities made possible by wet rice agriculture were both a product of and a promoter for engagement with wetlands. Thus, the wetland landscapes of the Lower Yangtze and Taihu lake region included networks of natural water ways that were expanded through rice cultivation, creating a geography that fostered social networks, the capture and transportation of aquatic resources such as fish, and larger, more sustainable populations. Wet rice production required greater investments of labor, but the resulting social and economic organization played a key role in the development of larger social and political units. Thus the development of rice agriculture pulled people together. It also provides a context for understanding how and why earthworks and water control systems such as those discovered at Liangzhu, also known as the Peripheral Water Conservancy System of the Liangzhu City Site, came into existence in this period (Liu et al. 2017). This water control system helped to guarantee the development of the Liangzhu economy, with its specialized jade artwork, as well as the agricultural tool kits that subsequently drove further social complexity and more intensified wet rice agriculture (Qin 2013; Renfrew and Liu 2018).

9.4 Rice and Agricultural Dispersal in East Asia

The following three cases of agricultural dispersal offer a contrast to the above case in Lower Yangzte, illustrating the lack of correlation between the spread of rice agriculture and wet rice cultivation.

9.4.1 Rice as Supplement: Early Farming and Northeast Asian Maritime Cultures

The Northeast Asian regions beyond China, including the Korean Peninsula and the Japanese archipelago, came to agriculture relatively late and received their major agricultural staple crops from China. The millets (*Setaria italica* and *Panicum miliaceum*) and rice (*Oryza sativa*) spread as domesticated species from China to Korea, and later to Japan. Evidence for millets on the Korean peninsula dates back to the Middle Chulmun Period, or 5500 to 5000 BP (Crawford and Lee 2003; Lee 2011). Millet crops of similar date have been found at sites in southeastern Siberia, in the Primorye region of far eastern Russia (Sergusheva and Vostresov 2009). Rice subsequently arrived in Korea later, perhaps around 3500 BP, although some room remains for debating the precise date (Ahn 2010; Lee 2011; Lee 2015).

The migration of farmers was likely part of the process that brought millets and agriculture to these regions. Archaeological evidence suggests a cultural origin in northeastern China (from Jilin or Heiligong in the Chifeng region) (e.g., Miyamoto 2016), while recent research in historical linguistics traces Koreanic and Japonic languages back to a hypothetical Transeurasian language family originating in northeast China (Robbeets 2017a, 2017b). The key point, however, is that these migrations were driven by the lower productivity levels of dry millet crops, not wet rice. Rice as a crop was adopted as an add-on to millet based subsistence and presumably spread through adoption from the Shandong peninsula across to the Liaodong peninsula, then south through the Korean peninsula and eventually to Japan (Ahn 2010; Miyamoto 2016, 2019). Nor does the archaeobotanical evidence from the Shandong and Liaodong peninsulas indicate any regional wet rice farming dominance during the Bronze Age (Liu 2016). The selective adoption of rice cultivation in wet paddy systems only became a characteristic component of Bronze Age agriculture in Korea, alongside millets, soybeans and other crops (Lee 2015). The emphasis on marine food evident in earlier Chulmun ceramics and shell middens moreover indicate that maritime skills were prevalent in the region before this shift began (e.g., Shoda et al. 2017). Indeed, marine foods remained a key part of subsistence through the later Chulmum and Mumun Periods in Korea.

The advent of rice agriculture in Korea therefore took place gradually via adoption. The subsequent transition from foraging to farming may indeed represent a farming dispersal, and has been associated with a language/farming dispersal hypothesis associated with the ancestry of Koreanic and Japonic languages as well as the Transeurasian hypothesis (e.g., Whitman 2011; Miyamoto 2016; Robbeetts 2017a, 2017b). However rice, whether wet or dry, was only adopted later as an add-on crop and not an economic driver of cultural or demographic change.

9.4.2 Low Intensity Millets and the First Cereals in Island Southeast Asia

The origins of agriculture on Taiwan must be understood in relation to what was happening on or near the coast of Fujian. It has long been recognized that the prehistoric cultures on the Island of Taiwan, the nearby Peng-hu archipelago and coastal Fujian are closely connected and regularly interconnect. From the Late Pleistocene until about 6000 BP, people on the island of Taiwan were aceramic and "Palaeolithic," while the first ceramic-making culture is recognized as Tapenkeng Neolithic (Chang and Goodenough 1996; Tsang 2005; Hung and Carson 2014). A number of scholars have suggested that the Tapenkeng Neolithic might represent the arrival of Proto-Austronesian speakers on Taiwan from Eastern Guangdong and perhaps the Pearl River Delta beyond (Tsang 2005; Hung and Carson 2014). For example, the use of stone bark cloth beaters as early at 6800 BP, as well as tooth evulsion in the Pearl River Delta region, provide possible links to later traditions in Taiwain (Hung and Carson 2014). Evidence of the processing of various tubers, sago palm (*sensu lato*) and other wild starchy plant foods has been discovered at a number of sites in the Pearl River catchment (Yang et al. 2013; Denham et al. 2018), indicating that foraging and perhaps some vegeculture was being practiced in this region before rice was introduced around 4600 to 4400 BP (Yang et al. 2017, 2018). Along the Fujian coast near Taiwan, numerous coastal shell middens illustrate the exploitation of marine fish and shell fish, with no evidence for domesticated pigs among the hunted fauna (Jiao 2007; Hung and Carson 2014). Tapenkeng, the first ceramic culture on Taiwan, continued similar traditions of marine and coastal resource use as well as the use of coral, as seen at sites from the Peng-hu Islands as well as Taiwan. These finds illustrate a clear marine focus among early inhabitants of this region.

During the latest Tapenkeng sequence, from 5000 to 4500 BP, the first evidence of grain crops appears in southwest Taiwan, including rice from Nuankuanli and rice and millets from Nuankuanli East (Tsang 2005). Recent systematic archaeobotanical work has confirmed the existence of large quantities of both foxtail millet (*Setaria italica*) and common millet (*Panicum miliaceum*), as well as rice and the wild, weedy yellow foxtail (*Setaria pumila,* syn. *S. glauca* auct. pl.) on Nuankuanli East (Tsang et al. 2017). Millets dominate this assemblage, and based on the apparent absence of clay soils or field systems in the excavated area, rainfed forms of rice cultivation have been suggested. After 4500 BP, four regional Middle Neolithic cultures developed on Taiwan. Recent phytolith evidence from Chaolaiqiao, associted with the southeastern Fushan culture, has confirmed the presence of domesticated rice by ca. 4200 BP (Deng et al. 2018a). This region might therefore constitute a hypothetical launching point for maritime voyages to the Philippines that may have initially brought some rice and millet cultivation to Luzon (Carson and Hung 2018).

In northern Fujian, recent archaeobotanical sampling has revealed the presence of mixed rice-millet agriculture by ca. 4500 BP. In the hilly interior, the Nanshan site in Mangxi County includes a number of occupied caves dating to between 5000 and 4400 BP. Archaeobotanical data that has yet to be published in detail indicates the presence of rice and both millets (ICASS, Fujian Provincial Museum and Mingxi County Museum 2017; Carson and Hung 2018: 810; Yang et al. 2018). In addition, recent excavations at Baitoushan, dated by wood charcoal to between 4800 and 3700 BP, has also yielded phytolith evidence for rice and common millet (Dai et al. 2019). Closer to the Fujian coast, the hilltop sites of Huangguashan (4500-3900 BP) and Pingfengshan (3800-3400 BP) both have direct AMS dates for rice cultivation. Although rice is dominant, both of these sites exhibit clear mixed assemblages of rice, *Setaria* and *Panicum* in charred grains as well as phytoliths (Deng et al. 2018b).

In conclusion, recent research has indicated that rice and the millets, both *Setaria* and *Panicum,* were cultivated together as crops in Southeast China (Fujian) and Taiwan by at least 4500 BP, and perhaps as early as 5000 BP. The limited data on arable weed flora, either from seeds or phytoliths, make it difficult to infer whether this is the evidence of wet or flooded rice or rainfed rice agriculture systems. Still, the locations of Fujian sites in upland zones could be interpreted as consistent with some rainfed rice systems. In any case, the millet crops were consistently present in both cases and appear in significant quantities at Nankuanli East, Taiwan (Deng et al. 2018b; Tsang et al. 2017), indicating the importance of upland, rainfed cultivation systems.

These new data also provide plausible evidence for the dispersal of crops either from the Middle Yangzte (where rice and millets are evident earlier) or via interior upland tracts from Anhui in the north and western Zhejiang into northern Fujian, thus linking Southeast China to the central plains while avoiding the apparently millet-free Lower Yangtze cultures. In either case the dispersal of crops through the interior must have been combined with or adopted into coastal maritime cultural traditions of the Fujian coast. This evidence suggests an alternative hypothesis for the source of agriculture on the Southeast Chinese mainland and on Taiwan, in contrast to the previously proposed maritime sourcing of crops from the Shandong peninsula (e.g., Sagart 2008; Stevens and Fuller 2017).

9.4.3 Mainland Southeast Asian Farming: Millet, Dry Rice and a Late Hydraulic Turn

The dispersal of rice and millet together into the tropical far south of China represents the passage of cereal agriculture, predominately rice with some foxtail millet, into mainland Southeast Asia as early as 4500 to 4000 BP. The earliest directly dated crop in mainland Southeast Asia is foxtail millet (*Setaria italica*) found at Non Pa Wai, in central Thailand, and dated to around 4400 to 4200 BP (Weber et al. 2010). The first evidence for rice, on the other hand, is not yet clearly older than about 4000 BP in Vietnam, Cambodia or Thailand (Castillo 2017; Silva et al. 2015). Nevertheless, controversy remains over when Neolithic and agricultural settlement began in these regions, with the earliest reasonable estimates around 4400 BP and the latest around 4000 BP (cf. Higham and Rispoli 2014). Evidence of colonizers whose skeletons illustrate distinct new physical features began to appear in northern Vietnam around 4300 BP (Matsumura and Oxenham 2014). In southern Vietnam, the coastal site of Rach Nui has produced evidence for rice and foxtail millet together between 3500 and 3200 BP, although both crops are thought to have been imported from a nearby inland region (Castillo et al. 2018a). In the Iron Age, sites in southern Thailand (Khao Sam Kaeo and Phu Khao Thong) dating to 2400-2000 BP have also produced evidence of some foxtail millet alongside rice and other crops of Indian origin (Castillo et al. 2016). The arable weed data from these two Thai sites indicates that the rice encountered there was grown in a rainfed system.

Throughout Southeast Asia, transitions from dry to wet rice occurred in later prehistory or in historical times. Recent research at Ban Non Wot and Non Ban Jak provides a long regional sequence of archaeobotanical data in northeast Thailand between 3000 and 1300 BP (Castillo et al. 2018b). During this period dry rice weeds decline as wet rice weeds appear around 2100 BP. Wet rice subsequently increases and dry rice weeds disappear by 1500 BP. This indicates that in the face of increasing aridity, rice cultivation was bolstered by irrigation; but it also suggests that increasingly hierarchical societies in the region were investing greater labor in more intensive wet rice production. While rainfed rice has persisted in the hills of Southeast Asia into recent times, throughout most of the plains wet rice cultivation has long been the predominant cultivation system, responsible for supporting historically known states and urban systems throughout the region (Scott 2009). This indicates that wet rice cultivation in the Southeast was a secondary development driven by the growth of social complexity and perhaps population growth, rather than the primary force driving regional demographic change in the Early Neolithic.

9.5 Conclusion: Contextualizing the Dispersal of Rice

Rice is not simply one thing. As a modern crop it illustrates a vast range of ecological diversity, growing from nearly 40° North in latitude to the equator and from sea level to over 2000 meters above sea level. Genetic evidence indicates the influence of multiple wild populations and numerous trajectories of adaptation and cultural selection over time (e.g., Londo et al. 2006; Castillo and Fuller 2016; Fuller et al. 2016; Choi et al. 2017; cf. Civan et al. 2018). Just as rice was transformed ecologically as it came into new regions and responded to the genetic inputs of local wild populations, the cultures that moved rice are also likely to have been transformed through new cultural adaptations and interactions with local cultural traditions, including hunter-fisher folk and hypothetical tuber cultivators. This means that the challenge for archaeology and archaeobotany through East and Southeast Asia is to understand the beginnings of rice cultivation in its local context, in which both the ecology of rice and its place in subsistence culture may have varied. It is no longer sufficient to use a simplistic proxy like ceramic styles to indicate migration and the spread of rice farming. Different subsistence strategies, including myriad cultivation systems and disparate forms of rice, had variable demographic consequences and impacts on community fission and movement in search of new land.

In terms of understanding the advent of rice agriculture, we can differentiate three major modes. First, we can identify cases where wild rice was brought into cultivation locally and evolved into the domesticated form. The data available from the Lower Yangtze region clearly illustrates this process in which primary domestication takes place, represented clearly in the evolution of non-shattering, and is followed by post-domestication evolution in the form of continuing trends of change in bulliforms and grain shape and size. The evidence from the Lower Yangtze indicates that wet rice cultivation was a *pull* factor that drew local populations towards increased density, increased social complexity and deeper entanglements with inland freshwater wetland habitats. However it did not apparently push groups to migrate outwards.

Second, rice was also brought into new regions as an already domesticated crop. These introductions could have happened in two ways: either it was adopted by local populations as an add-on to existing subsistence systems, or it was carried by migrant farmers. Examples of this form of rice adoption are evident in Northern China, Korea and more broadly in northeastern Asia. In these areas rice was added to local subsistence in places where the cultivation of domesticated millets was already established. The extent to which wet rice or dry rice was adopted would have been constrained by both environmental conditions (e.g., water availability) and social conditions (e.g., labor availability), and these factors would have driven the population's engagement with intensive wet rice systems or low input rainfed systems.

A third possibility is that rice was carried as a part of the migrant culture of food producers. Wet rice is less likely to have spread this way due to its higher local carrying capacity and relatively high labor demands. Instead, in cases where the immigration of farmers with rice did occur, rainfed rice is likely to have been more common. Thus, dry rice tends to *push* populations towards outward migration. This in turn raises a key, unresolved question: "Where, when and how many times dry rice cultivation systems evolve?" It is plausible that rainfed rice developed once in Southeastern Shandong prior to its adoption in Korea, but it is likely to have evolved separately, and perhaps more than once, in the hilly regions south of the Yangtze River. For example, this could have occurred prior to the dispersal of rice into Fujian or Guangdong. These arguments and the current evidence highlight the importance of applying systematic archaeological science to both archaeobotanical macro-remains and phytolith assemblages in order to recover and reconstruct subsistence systems throughout southern China and Southeast Asia.

For too long the transition to rice farming has been a kind of "black box" mechanism for driving population migrations and transforming the demography of eastern Asian Neolithic societies. As we have argued, however, subsistence details matter. Indeed, wet rice cultivation systems appear to have achieved the opposite of what has been supposed, and are actually more likely to underpin local population growth and the intensification of freshwater wetland exploitation rather than promote Neolithic migration. Instead, the transition from the original wetland rice cultivation systems to rainfed rice and/or the integration of rice with rainfed lower intensity millet crops are much more likely to have driven the demographic dynamics that underpin early farmer migrations and crop dispersal. This is supported by rich archaeological evidence from the Hangzhou Bay region and the Lower Yangtze, which indicates a decidedly inward, freshwater wetland focus rather a maritime turn. It is also substantiated by recent data highlighting the importance of millets alongside rice in the Neolithic traditions of Fujian, Taiwan and mainland Southeast Asia.

Thus, in Thailand the turn to intensive wet rice agriculture was late, dating to the Iron Age, and is more likely to have been instrumental in urbanization rather than in establishing Neolithic populations. The non-dispersing character of early wet rice and the need for lower intensity dry rice and/or millet farming to become established in sub-tropical South China prior to major Neolithic dispersals help to explain the long lag time between early rice cultivation (>8000 BP), rice domestication (by 6000 BP) and the beginnings of the cereal-based Neolithic phase in Southeast Asia (<4500 BP). We have offered some explanatory factors, based on the productivity of different cropping systems, that help to explain these patterns and suggest that the lower intensity rainfed rice crop systems are more likely to support community fission and Neolithic migration than the more productive wet rice systems. Ultimately the less productive, rainfed cultivation of rice and millet could be characterized as centrifugal forces that push populations outwards in search of more land, in contrast to the more centripetal pull of wet rice agriculture.

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Figure Captions

Fig. 9.1 Map of Lower Yangtze River

Fig. 9.2 Paddy fields and agricultural tools of the Lower Yangtze River [IN TEXT THERE IS A 9.2A, 9.2B, 9.2C AND 9.2D; SHOULD THESE BE CALLED OUT SEPARATELY IN CAPTION?]

Fig. 9.3 Material culture reflects wetland management of the Lower Yangtze River

Fig. 9.4 Different forms of landscape engagement are reflected in dietary stable isotopes, in which 5 different types can be recognized. Type 1 (lower left) is the Lower Yangtze type characterized by C3 wild plants, freshwater wetland resources and terrestrial mammals. Type 2 (lower middle) is a mixed rice, millet and pig based subsistence strategy represented by the Neolithic Qiujiling culture in Hubei. Type 3 (lower right) is the typical Northern Chinese Neolithic diet focused on millets (C4) and terrestrial mammals like pigs, which are represented here by a Shandong Dawenkou period site and, at its western extreme, the Zongri site of the Longshan Period in Qinghai. Type 4 (top left) is a maritime hunter-gatherer diet represented here by Liyudun on the south coast of Gaungdong and typical of much of Jomon, Japan. Type 5 (upper right) is a maritime millet agriculture signature represented by the Dawenkou Neolithic Period in the Changdao Archipelago of the Bohai Sea, between Shandoong and Liaodong. [add citations of sources] [AUTHORS NEED TO ADDRESS THIS EDIT]

Fig. 9.5 Population growth and fission model

Fig. 9.6 Traditional and historical rice yields, contrasting predominantly rainfed/dry (tan, at left) and wet/irrigated (blue, at right). Where multiple values are reported from the same study the mean and standard deviation are shown. Sources, from left to right: 1. Barton 2012; 2, 4, 5. Ruthenberg 1976: 52; 3, 20. Geddes 1954: 68; 6, 7. Saitou et al. 2006; 8, 9, 24, 32. Sherman 1990: 131; 10, 14, 26, 31, 33. Bray 1986; 11. Grigg 1974: 97; 12. Heston 1973; 13. Randhawa 1958; 15. Vincent 1954; 16, 17. Zheng et al 2009; 18, 34. Ellis and Wang 1997; 19. Latham 1998: 22; 21, 22, 23, 29. Boomgaard and Kroonenberg 2015; 25, 27. Watabe 1967; 28. Leonard and Martin 1930; 30. Xxxx [SOURCE NEEDED]

Fig. 9.7 Traditional and historical rice yields, including data from South Asia (blue) and East Asia (red). Where multiple values are reported from the same study the mean and standard deviation are shown. Sources, from left to right: 1, 8. Weber 1991; 2. ICAR 1980: 828; 3. Randhawa 1958; 4, 5, 15. Rachie 1975: 16; 6. CSIR 1966: 226; 7. Heston 1973; 9, 10. ICAR 1980: 835-837; 11, 12. King 1927; 13, 14. Bray 1981

Fig. 9.8 Map of the spread of millet-rice agriculture in Southeast Asia

Table Captions

Table 9.1 Estimated rice consumption, land requirements and carrying capacity for Yangtze River Valley. Intake (kg/year/settlement) is calculated for representative Yangtze Valley Middle and Lower Neolithic sites, including a low and high estimate of productivity, and from these a low and high estimate of needed land area is provided, as well as a median estimated land requirement (all assuming between 68%-80% of calories were coming from rice). In the lower rows a hypothetical 1 ha wet rice site is shown, along with an estimated maximum carrying capacity, as well as a contrasting 1 ha dry rice site

Table 9.2 Estimated millet consumption, land requirements and carrying capacity for Yellow River Valley. Intake (kg/year/settlement) is calculated for representative Yellow River Valley Neolithic sites, including a low and high estimate of productivity, and from these a low and high estimate of needed land area is provided, as well as a median estimated land requirement (all assuming between 68%-80% of calories were coming from rice). In the lower rows a hypothetical 1 ha wet rice site is shown, along with an estimated maximum carrying capacity

Figure Captions

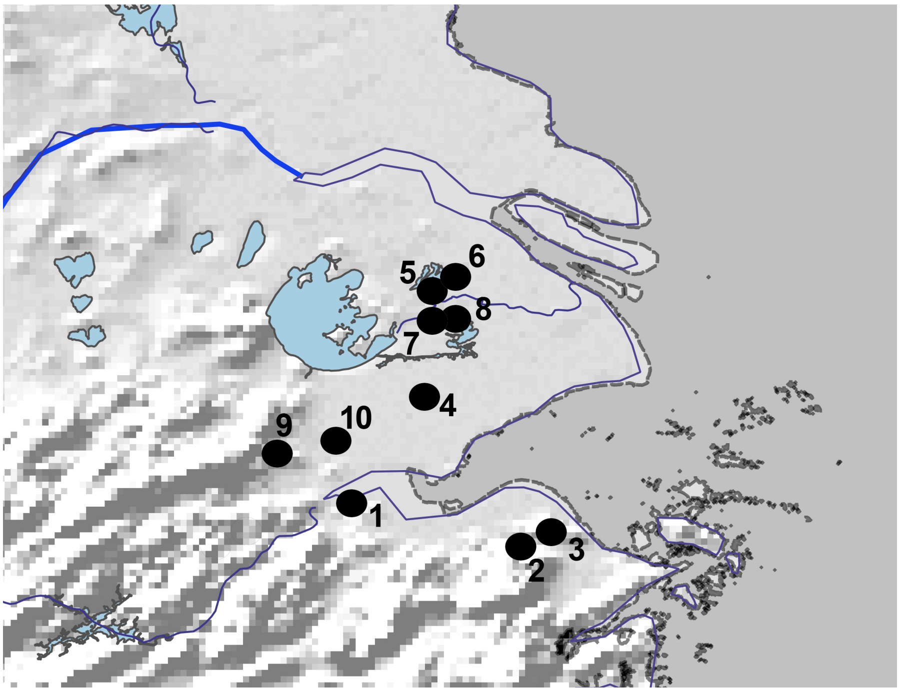

Fig. 9.1 Map of Lower Yangtze River

Archaeological sites mentioned in this article:

1.Kuahuqiao, 2.Hemudu, 3.Tianluoshan, 4.Majiabang, 5.Caoxieshan, 6,Chuodun, 7,Chenghu, 8.Jiangli, 9.Liangzhu ancient city, 10.Maoshan

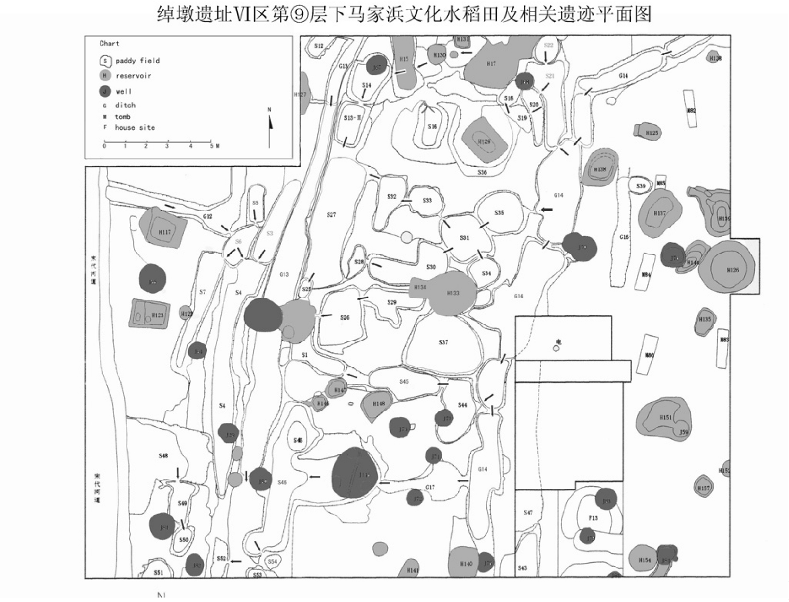

Fig. 9.2a

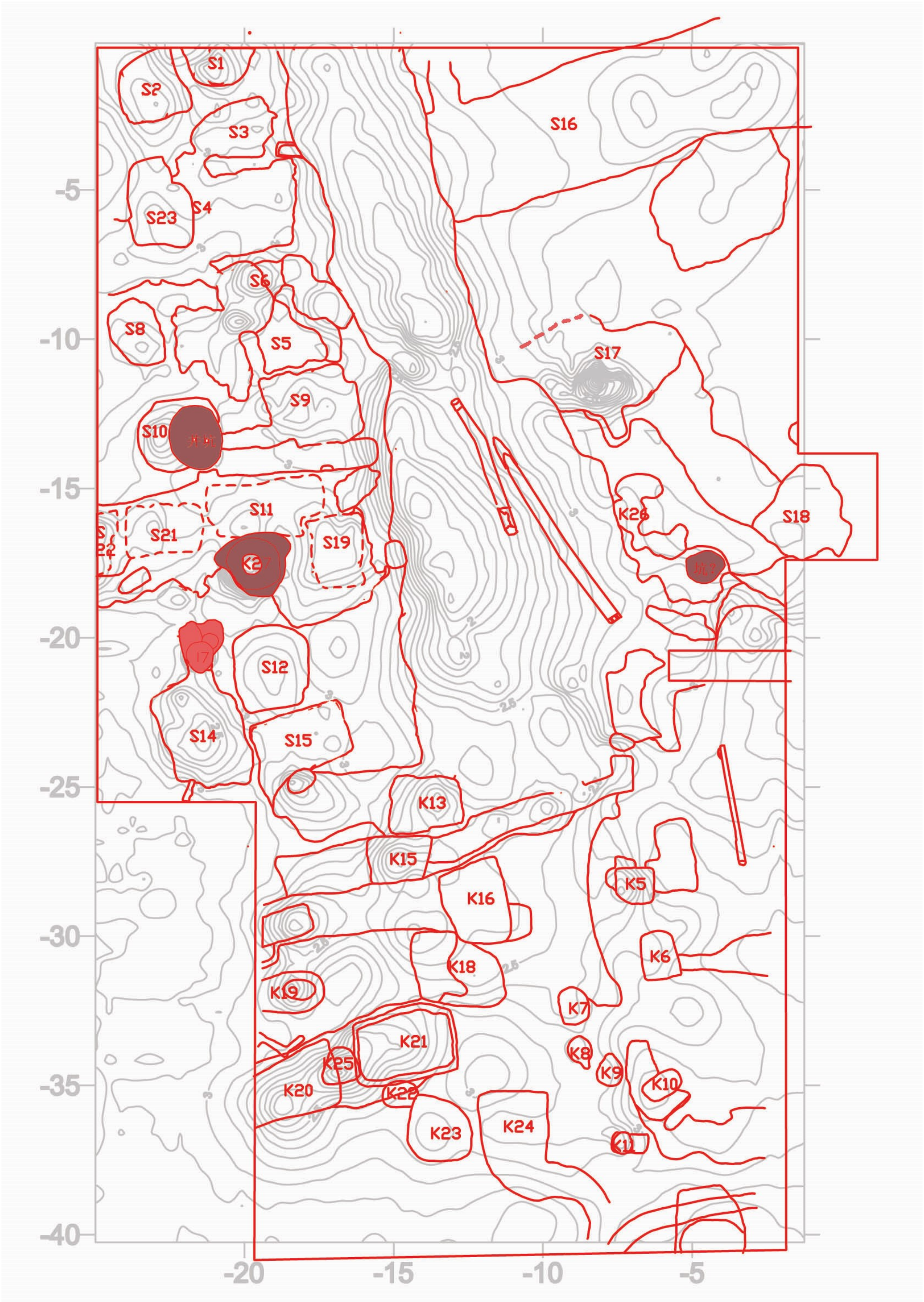
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fig9.2b


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居住区
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墓葬
古河道
堤岸兼通道
堤岸兼通道
稻田口活动场地
灌溉水渠
田埂
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灌溉水渠

Fig9.2c

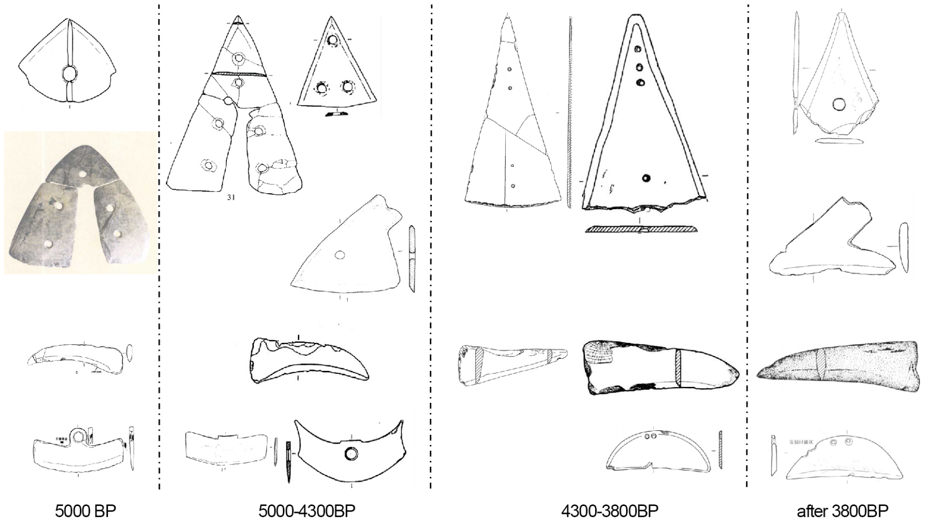

Fig 9.2d

Fig. 9.2 Paddy fields and agricultural tools of the Lower Yangtze River

9.2a: paddy fields of Chuodun site (Fuller et al. 2009)

9.2b: paddy fields of lower layer of Maoshan site (Illustrated by Qin, L.)

9.2c: paddy fields of top layer of Maoshan site (Zhuang, Y. et al. 2014)

9.2d: agricultural tools of the Lower Yangzte (Illustrated by Qin, L)

fig 9.3a

fig 9.3b

fig 9.3c

Fig. 9.3 Material culture reflects wetland management of the Lower Yangtze River

9.3a animal images from Liangzhu jades and pottery decoration （from exhibition at Liangzhu Museum）

9.3b canoe from Kuahuqiao site （Zhejiang Provincial Institute of Archaeology and Culture Relics et al. 2004）

9.3c canoe from Maoshansite (lower layer) (photoed by Qin, L.)

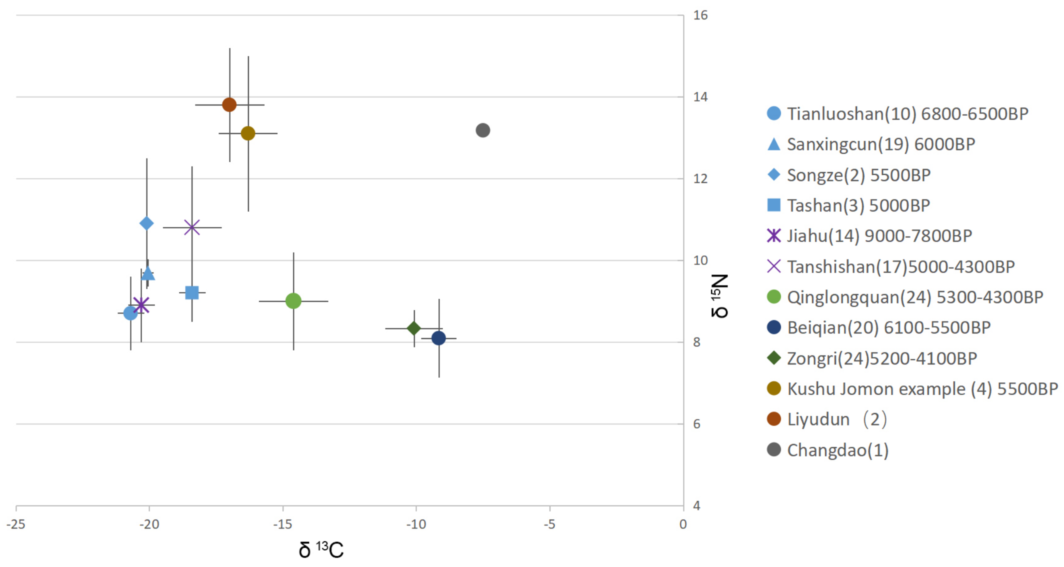

Fig. 9.4 Different forms of landscape engagement are reflected in dietary stable isotopes, in which 5 different types can be recognized. Type 1 (lower left) is the Lower Yangtze type characterized by C3 wild plants, freshwater wetland resources and terrestrial mammals (Tianluoshan, Minagawa et al. 2011; Sanxingcun, Hu et al. 2007; Songze, Zhang 2003; Tangshan, Zhang et al. 2015; as well as Jiahu (Hu et al. 2006), an inland early gathering-cultivating settlement and Tanshishan (11 adults data, Wu et al. 2016), a late neolithic site along southeast coast in Fujian province . Type 2 (lower middle) is a mixed rice, millet and pig based subsistence strategy represented by the Neolithic Qujialing culture in Hubei (Qinglongquan site, Guo et al. 2011). Type 3 (lower right) is the typical Northern Chinese Neolithic diet focused on millets (C4) and terrestrial mammals like pigs, which are represented here by Bianqian, a Shandong Dawenkou period site(Wang et al. 2012) and, at its western extreme, the Zongri site of the Longshan Period in Qinghai(Cui et al. 2006). Type 4 (top left) is a maritime hunter-gatherer diet represented here by Liyudun (Hu et al. 2010) on the south coast of Gaungdong and typical of much of Jomon, Japan (Minagawa et al. 2011). Type 5 (upper right) is a maritime millet agriculture signature represented by the early Dawenkou Neolithic Period in the Changdao Archipelago of the Bohai Sea, between Shandoong and Liaodong（Zhang 2003）.

The number in brackets refers to the sample numbers.

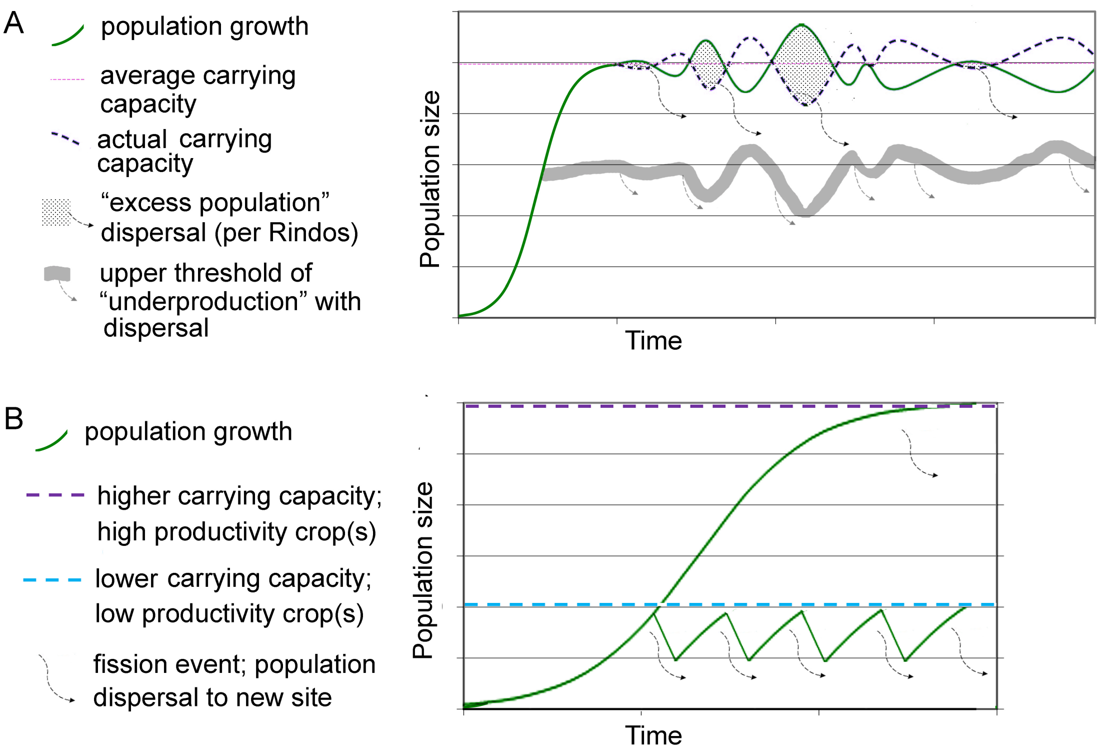

Fig. 9.5 Population growth and fission model

Schematic representation of population growth and dispersal through fission. A. indicates population growth towards carrying capacity with dispersal of "excess" population as carrying capacity is breached, or, alternatively in a scenario of underproduction as rapid growth rates cross a threshold into decreasing returns. B. Population growth and dispersal scenarios given two contrasting productivity regimes with different carrying capacity.

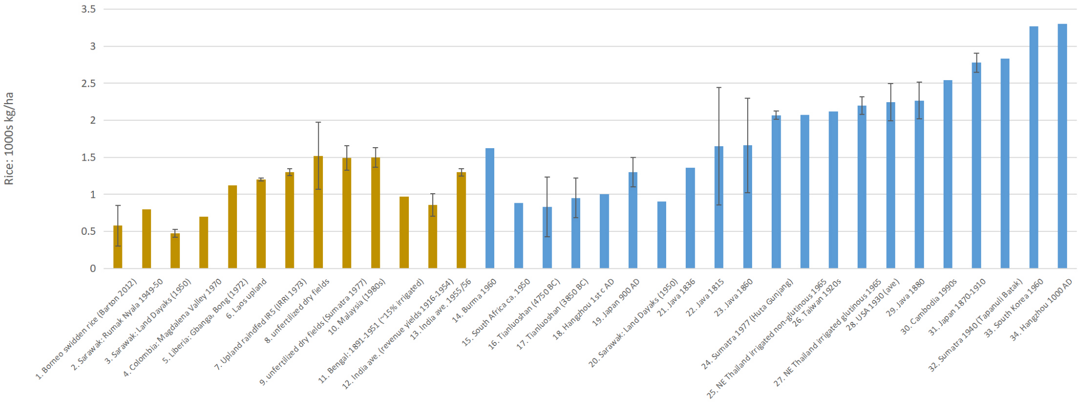

Fig. 9.6 Traditional and historical rice yields, contrasting predominantly rainfed/dry (tan, at left) and wet/irrigated (blue, at right). Where multiple values are reported from the same study the mean and standard deviation are shown. Sources, from left to right: 1. Barton 2012; 2, 4, 5. Ruthenberg 1976: 52; 3, 20. Geddes 1954: 68; 6, 7. Saitou et al. 2006; 8, 9, 24, 32. Sherman 1990: 131; 10, 14, 26, 31, 33. Bray 1986; 11. Grigg 1974: 97; 12. Heston 1973; 13. Randhawa 1958; 15. Vincent 1954; 16, 17. Zheng et al 2009; 18, 34. Ellis and Wang 1997; 19. Latham 1998: 22; 21, 22, 23, 29. Boomgaard and Kroonenberg 2015; 25, 27. Watabe 1967; 28. Leonard and Martin 1930; 30.

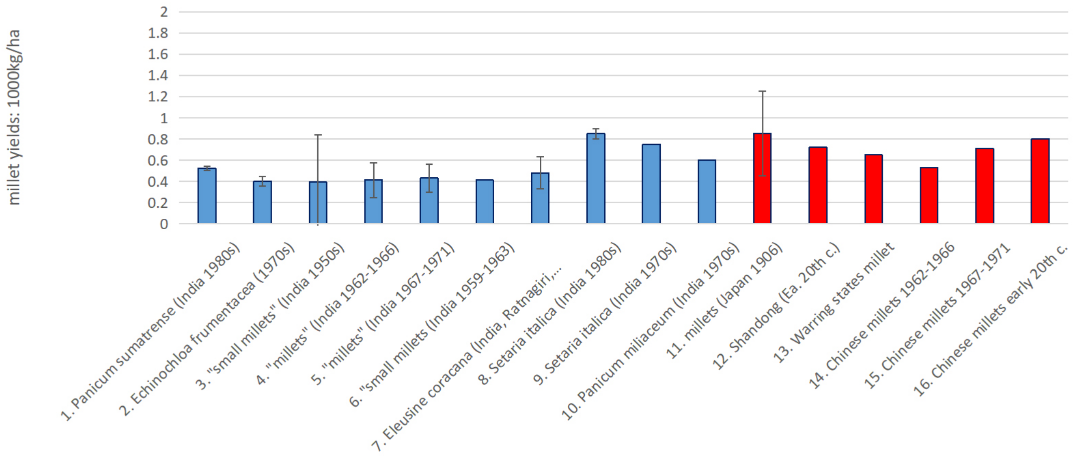

Fig. 9.7 Traditional and historical rice yields, including data from South Asia (blue) and East Asia (red). Where multiple values are reported from the same study the mean and standard deviation are shown. Sources, from left to right: 1, 8. Weber 1991; 2. ICAR 1980: 828; 3. Randhawa 1958; 4, 5, 15. Rachie 1975: 16; 6. CSIR 1966: 226; 7. Heston 1973; 9, 10. ICAR 1980: 835-837; 11, 12. King 1927; 13, 14. Bray 1981

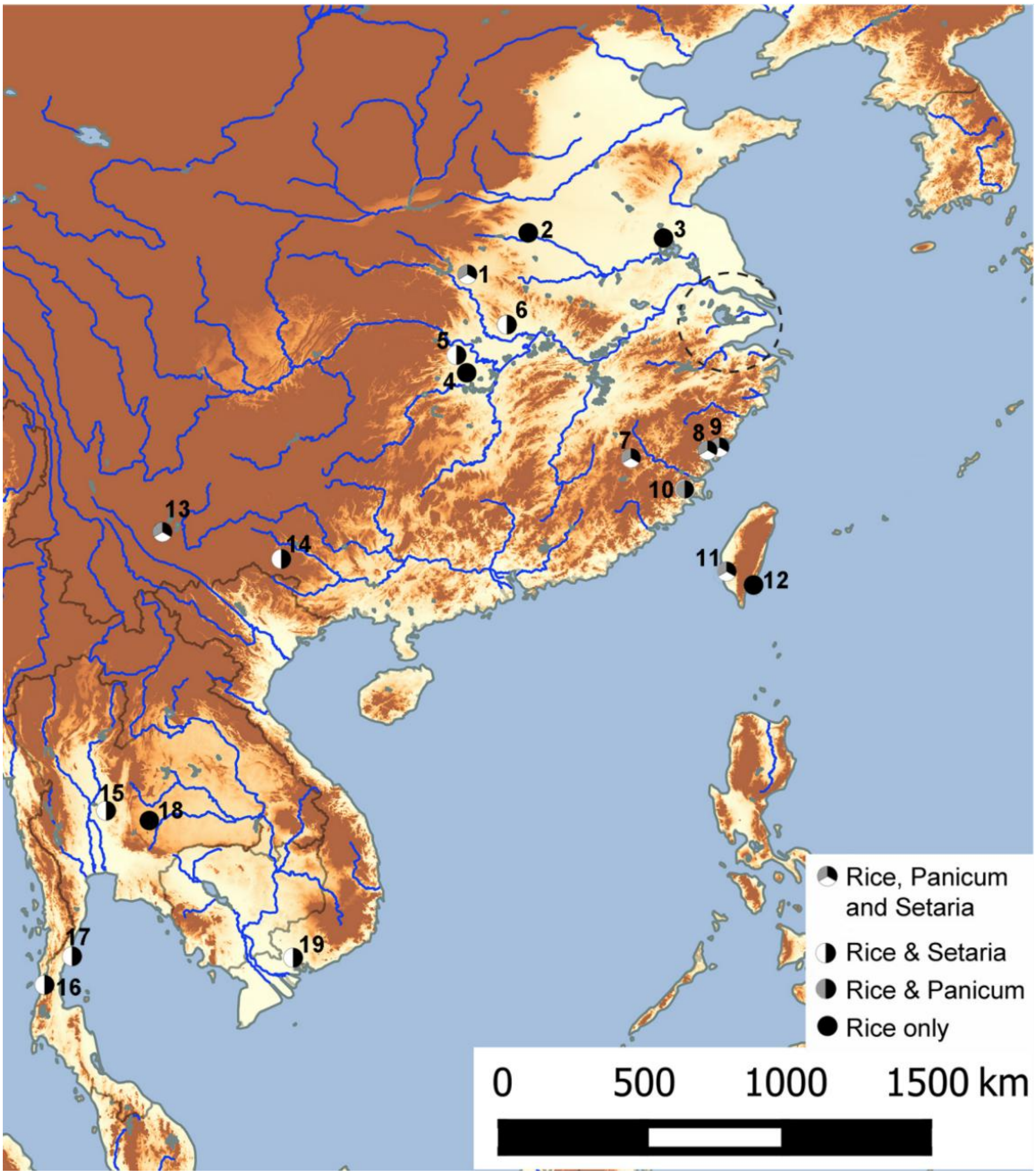

Figure 9.8 Map of sites with archaeobotanical evidence mentioned in the text or relevant to the southward dispersal of rice and millets.

Sites numbered: 1. Baligang; 2. Jiahu; 3. Shuanshanji; 4.Pengtoushan; 5.Chengtoushan; 6. Shijiahe; 7. Nanshan; 8. Pingfengshan; 9. Huangguashan; 10. Baitoushan; 11. Nankuanli East; 12. Chaolaiqiao;13. Baiyangcun; 14. Gantuoyan; 15. Non Pa Wai; 16. Phu KhaoThong; 17. Khao Sam Kaeo; 18. Ban Non Wat & Non Ban Jak ; 19. Rach Nui.

*dash line in lower Yangzte: the area only with rice agriculture. See Figure 1 for the details.