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A revised chronology for the archaeology of the lower Yangtze, China, based on Bayesian statistical modelling

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A B S T R A C T

Bayesian statistical modelling, based on 128 existing radiometric (radiocarbon and thermoluminescence) dates and associated information from a database totalling 252 dates, was used to generate a revised chronological framework for the lower Yangtze, eastern China. The framework covers the period from the terminal Pleistocene through to the mid to late Holocene, and thus the appearance of and subsequent developments in food production in the region, which is marked in the archaeological record by seven cultural phases. Results indicate that the age span of the Shangshan, Kuahuqiao, Hemudu, Majiabang, Songze, Liangzhu, and Maqiao cultural phase were, respectively, ca. 10,800–8600 cal BP, ca. 7900–7200 cal BP, ca. 7100–5200 cal BP, ca. 7200–5200 cal BP, ca. 5700–5200 cal BP, ca. 5500–4000 cal BP, and ca. 3700–3200 cal BP. In addition to providing a basis for a more robust absolute dating of archaeological remains in the lower Yangtze in the future, the results raise important questions deserving of further research. These questions relate to *a priori* assumptions concerning the degree of temporal separation of Neolithic cultural phases on the Yangtze Delta. A coexistence of cultures on the Yangtze Delta evident in the results does not accord with the existing model for the region, which generally assumes a replacement of one cultural phase by the next. Coexistence of cultures could have been supported by a high degree of environmental variability on the Yangtze Delta, or by social factors, such as different levels of preference towards innovations or traditions, or some combination of factors.

1. Introduction

The agriculturally-fertile lower reaches of the Yangtze River, eastern China, are considered one of several regions globally where agriculture developed more-or-less independently (Bellwood, 2005) and have thus been a focus of archaeological research for several decades (Mo et al., 2011; Zong et al., 2012b). The onset of and subsequent developments in food production are also thought to have underpinned the formation of civilisation in the lower Yangtze, in the form of relatively permanent settlements, the accumulation of wealth, a hierarchical division of society, and the acquisition of ritual (Lu and Yan, 2005). The transition in the lower Yangtze from presumably relatively small, mobile groups of hunter-gatherers, thinly dispersed over the landscape, to large concentrations of settled agriculturalists and their food-production infrastructure, dating locally from the latest phase of the Pleistocene through the mid to late Holocene, is often divided into seven cultural phases (Wu et al., 2014) (Fig. 1). Each of the seven phases is titled according to the name of type locations: Shangshan, Kuahuqiao, Hemudu, Majiabang, Songze, Liangzhu, and Maqiao (Table 1).

Each of the seven cultural phases has been distinguished primarily on the basis of characteristic material remains and inferences about livelihoods and the structure of society drawn from the archaeological record (Liu, 2004). The material remains include human burials, lithic tools, decorative objects (e.g. those fabricated from jade), tools (e.g. wooden and bone implements), ceramic remains, and evidence of changes in the ways in which nutritional needs were met and of increasingly sophisticated forms of environmental manipulation, including irrigation and possible flood control (Long et al., 2014). For example, 'hand-made brown/reddish pottery' (Zhang, 2004: p. 201) characterises the early part of the Majiabang, and is distinguishable from the 'wheel-made greyish/black pottery' associated with the Liangzhu (Zhang, 2004: p. 206). Moreover, the cultural phases are generally assumed to be

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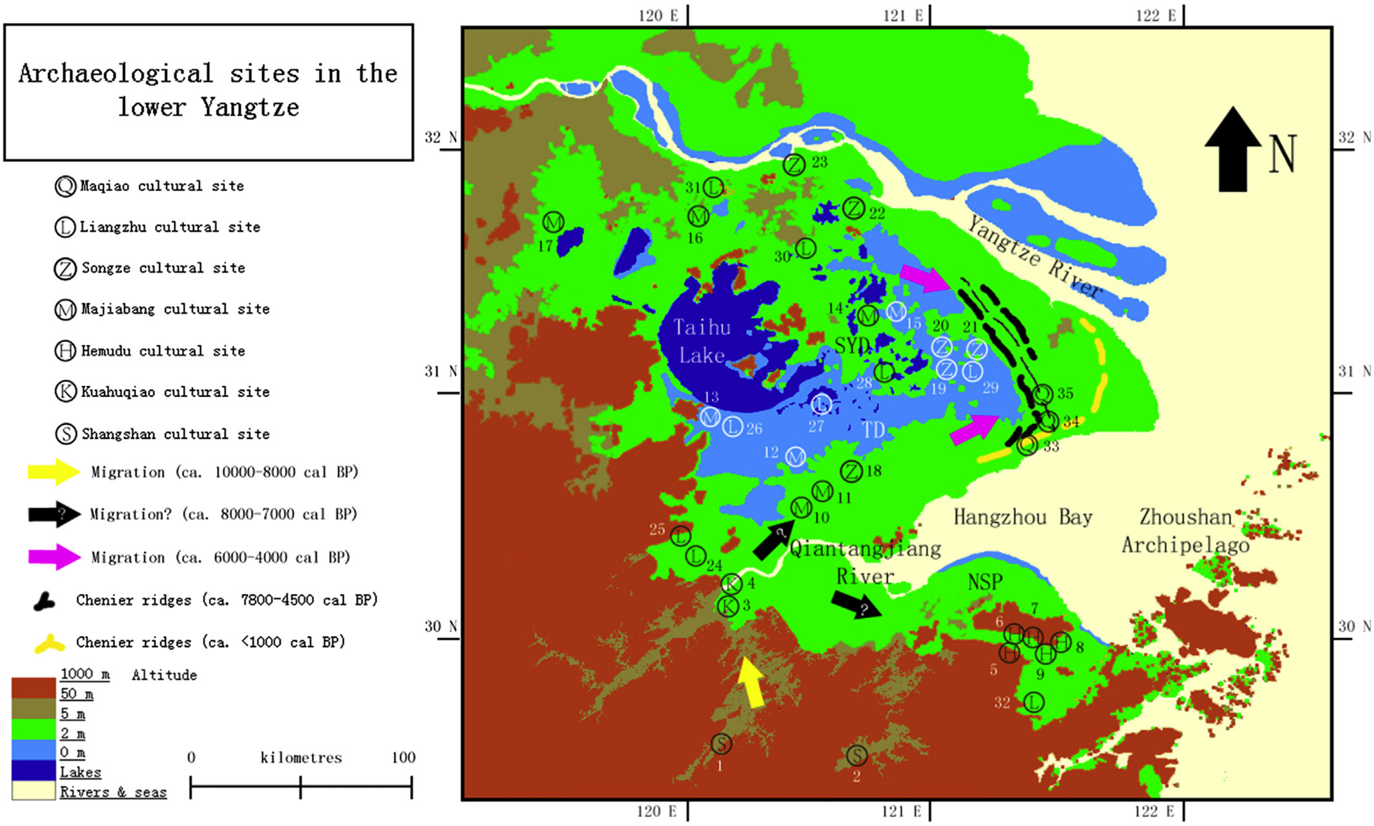

Fig. 1. The geographical distribution of characteristic archaeological sites in the lower Yangtze. A list of the sites in the current study: 1. Shangshan, 2. Xiaohuangshan, 3. Kuahuqiao, 4. Xiasun, 5. Hemudu, 6. Xiangjiashan, 7. Tianluoshan, 8. Xiaodongmen, 9. Cihu, 10. Luojiajiao, 11. Majiabang, 12. Guangfucun, 13. Qiucheng, 14. Caoxieshan, 15. Chuodun, 16. Weidun, 17. Sanxingcun, 18. Nanhebang, 19. Songze, 20. Siqiancun, 21. Fuquanshan, 22. Qiandixiang, 23. Dongshancun, 24. Liangzhu, 25. Wujiabu, 26. Qianshanyang, 27. Longnan, 28. Dianshanhu, 29. Guangfulin, 30. Jialingdang, 31. Sidun, 32. Mingshanhou, 33. Tinglin, 34. Zhashan, 35. Maqiao.

separated chronologically and to an extent geographically, with the causes of transitions from one phase to the next also attracting the attention of researchers (Stanley et al., 1999). Thus the shift from the late Neolithic (Liangzhu) to the Bronze Age (Maqiao) has been linked to environmental change (Chen et al., 2005), reduced temperatures and a weakening East Asian monsoon (Sun and Chen, 1991) as examples. One weakness here, however, is that rarely does a single location preserve evidence of more than one cultural phase, and, critically, evidence for periods of phase shifts (Shen et al., 2004). Moreover, heavy reliance on material remains in defining past cultures can be problematic (Whittaker et al., 1998; Chen, 2012); for example, the same artefact may be recycled and used by several different cultures, with the way in which an artefact was used possibly changing over time (Sullivan, 2008).

The site at Shangshan, which has yielded the earliest evidence to date for human occupation of the lower Yangtze (Cohen, 2011), is located inland of the Ningshao Plain, a ca. 4800 km^2 of sub-aerially exposed alluvium (Liu et al., 2007a) to the south of Hangzhou bay and fringed by relatively undulating, upland topography to the south and west (Fig. 1). The lower Yangtze is thought to have been first populated from these upland areas (Zong et al., 2012b). The earliest evidence of permanent occupation of the low-lying part of the region, around the delta area, has been found at Kuahuqiao on the Ningshao Plain, which is the type site for the Kuahuqiao cultural phase (Nakamura, 2010). Following the decline of the Kuahuqiao cultural phase, the Hemudu and the Majiabang cultural phases emerged to, respectively, the south and north of Hangzhou Bay (Wang et al., 2010). The Hemudu and Majiabang cultural phases are regarded as being more or less contemporaneous (Nakamura, 2010). However, whereas the Ningshao Plain seems to have been something of a backwater for the remainder of the Neolithic (Zheng and Chen, 2005), following the decline of the Hemudu culture (Li et al., 2010), the same was not the case north of Hangzhou Bay, where, in addition to the early Neolithic Majiabang, the (Neolithic)

Table 1
Summary of previously proposed chronology and currently modelled chronology for the Neolithic/Bronze-aged cultures in the lower Yangtze.

Cultural phase	Previously proposed chronology (ca. cal BP)	References	Modelled chronology in the current study (ca. cal BP)	Modelled median duration (ca. years)
Shangshan	11000–9000	(Liu et al., 2007b)	10800–8600	2200
Kuahuqiao	8200–6900	(Zhejiang Provincial Institute of Cultural Relics and Archaeology, 2004)	7900–7200	600
Hemudu	7000–5200	(Ruddiman et al., 2008)	7100–5200	2000
Majiabang	7500–5900	(Itzstein-Davey et al., 2007)	7200–5200	2100
Songze	5900–5200	(Itzstein-Davey et al., 2007)	5700–5200	500
Liangzhu	5200–4200	(Itzstein-Davey et al., 2007)	5500–4000	1500
Maqiao	3900–3200	(Itzstein-Davey et al., 2007)	3700–3200	500

Songze and Liangzhu cultural phases are also represented (Chen et al., 2008).

Notwithstanding the problems inherent in distinguishing cultural phases from material remains in the first place, absolute dating, based on techniques that utilise radioactive isotopes such as radiocarbon (^{14}C), ought to be able to assist the process by testing whether different cultural phases are chronologically distinct, and, if not, the extent of any overlap. One challenge of using any kind of radiometric dates in a largely alluvial setting such as the lower Yangtze is the possibility of sediment reworking (or secondary deposition) effects (Brown, 1997). Such effects may be produced, for example, by flood events and have the potential to introduce old carbon from upper and middle reaches of a river system (Stanley and Chen, 2000). A second challenge is that in reality radiometric dating of material remains has been used within the context of *a priori* knowledge, and generally to confirm rather than to test assumptions regarding the chronological ordering of the seven cultural phases (e.g. Archaeology Institute of Zhejiang Province (2005) rejected some ^{14}C dates because they did not fit *a priori* knowledge concerning the presumed age-span of particular cultural phases in the lower Yangtze).

Bayesian chronological models can provide a robust means of using absolute dating information to create chronologies that are relatively free of subjectivity (Steier and Rom, 2000). The effectiveness of a Bayesian model is first related to its capability of processing all input dates together as a time series (Bayliss et al., 2007). Second, other known information (e.g. stratigraphy, sedimentological data) associated with a particular set of dates can be incorporated into a Bayesian model as boundary information to refine the chronology (Finkelstein and Piasetzky, 2010), because Bayesian techniques can generate *posteriori* knowledge from *priori* information mathematically (Bronk Ramsey, 2009a).

The current research establishes a new chronology for the seven cultural phases associated with the introduction of, and early developments in, agriculture in the lower Yangtze on the basis of existing radiometric dates and the use of Bayesian modelling. The revised chronology reveals that the different cultural phases in the lower Yangtze may not have been as distinct, chronologically, as previously assumed. The possible significance of more than one cultural phase existing contemporaneously on the lower Yangtze is discussed.

2. Data and methods

2.1. Data sources

A new database comprising 252 published and unpublished radiometric dates (212 ^{14}C and 40 thermoluminescence) and associated information from sites in the lower Yangtze was created (Supporting Information 1) by compiling information from existing databases for the lower Yangtze, such as Gao (2003) and Pan (2011). The database was used as the basis for Bayesian analysis.

2.2. Data selection

^{14}C dates included in the database are from a range of types of material, including charcoal, macrofossils (e.g. seeds), microfossils (e.g. concentrated pollen), timber used in construction, and bulk sediment samples (Supporting Information 1). All dates included in the database were subjected to quality assurance (Blockley and Pinhasi, 2011), with any dates that were thought suspect (e.g. not clearly associated with a cultural phase, of uncertain provenance, with a large statistical uncertainty, or generated pre-1990 on bone material, etc.) removed prior to analysis. The same selection criteria were applied to thermoluminescence dates included in the database (Supporting Information 1).

2.3. Age modelling

2.3.1. Calibration

^{14}C dates were input to the programme OxCal v.4.2 (Bronk Ramsey, 1995), calibrated according to the IntCal13 curve (Reimer et al., 2013), and presented as calibrated years before present (i.e. 1950 AD) (Reimer et al., 2009). Thermoluminescence dates do not need calibrating in order to correspond with calendrical ages (Walker, 2005). Consequently thermoluminescence dates were input to OxCal v.4.2 using the command 'C_Date()' (Bronk Ramsey, 1995). This command converts the thermoluminescence date to a calendrical age and uses the uncertainty measure provided by the laboratory carrying out the original dating to estimate the uncertainty of the calendrical age (Lienkaemper and Bronk Ramsey, 2009).

2.3.2. Bayesian chronological models

The current study involved establishing the beginning and termination for the seven cultural phases based on Bayesian modelling of all radiometric dates included in the database that met the quality assurance criteria applied. Here a phase comprises a population of dates that does not have an internal structure; the actual measured dates used in the analysis are a set of samples of this population (Blockley and Pinhasi, 2011). A phase can be confined by upper (oldest) and lower (youngest) boundaries (Alberti, 2013) (Fig. 2).

Each of the seven cultural phases was processed separately in a sub-model to permit, if necessary, the existence of possible gaps and overlaps between different sampled populations of dates, as we considered that the possibilities should be objectively determined by the dataset itself and that the analysis is weakened by artificially excluding these possibilities. Furthermore, no dates were rejected on the basis that they disagreed with *a priori* knowledge, and no preconceived age ranges were input in the Bayesian models. All assessment and modelling processes were solely based on the quality of the dates themselves.

All sub-models were run with model convergence measurements higher than 95%. If difficulty arose in convergence or numerical definition of any parameter in a model, then an explicit prior should be added to the parameter to constrain its sampling interval. However, as it is aimed to free the model from unverified *a priori* knowledge on the age of archaeological cultures, the prior we chose was an age constraint covering the entire Holocene (presented as an interval from 11,600 cal BP (Barrows et al., 2007) to 0 cal BP), in which all the dates should be well covered. This constraint can effectively promote convergence but also avoid introduction of unverified *a priori* information.

Conventions of reporting radiocarbon-based modelling were followed in the current study: 95.4% range, 68.2% range, and median-to-median range were all presented (Millard, 2014). The median-to-median range (e.g. Dee et al., 2013) was also adopted here as the major approach to define the age range for the different cultural phases. This type of range, which is less accurate but more precise than 68.2% range and 95.4% range (cf. Walker, 2005), provides a basis for highlighting and assessing possible overlaps amongst different cultures with a high level of precision.

2.3.3. Outlier models

One major reason accounting for dating outliers (i.e. dates that are assumed to be inaccurate) is that the age of the material dated is not equivalent to the age of the event being dated (Bronk Ramsey, 2009b). Every date included in the analysis has the potential to be an outlier, as the age of the dated material could conceivably differ

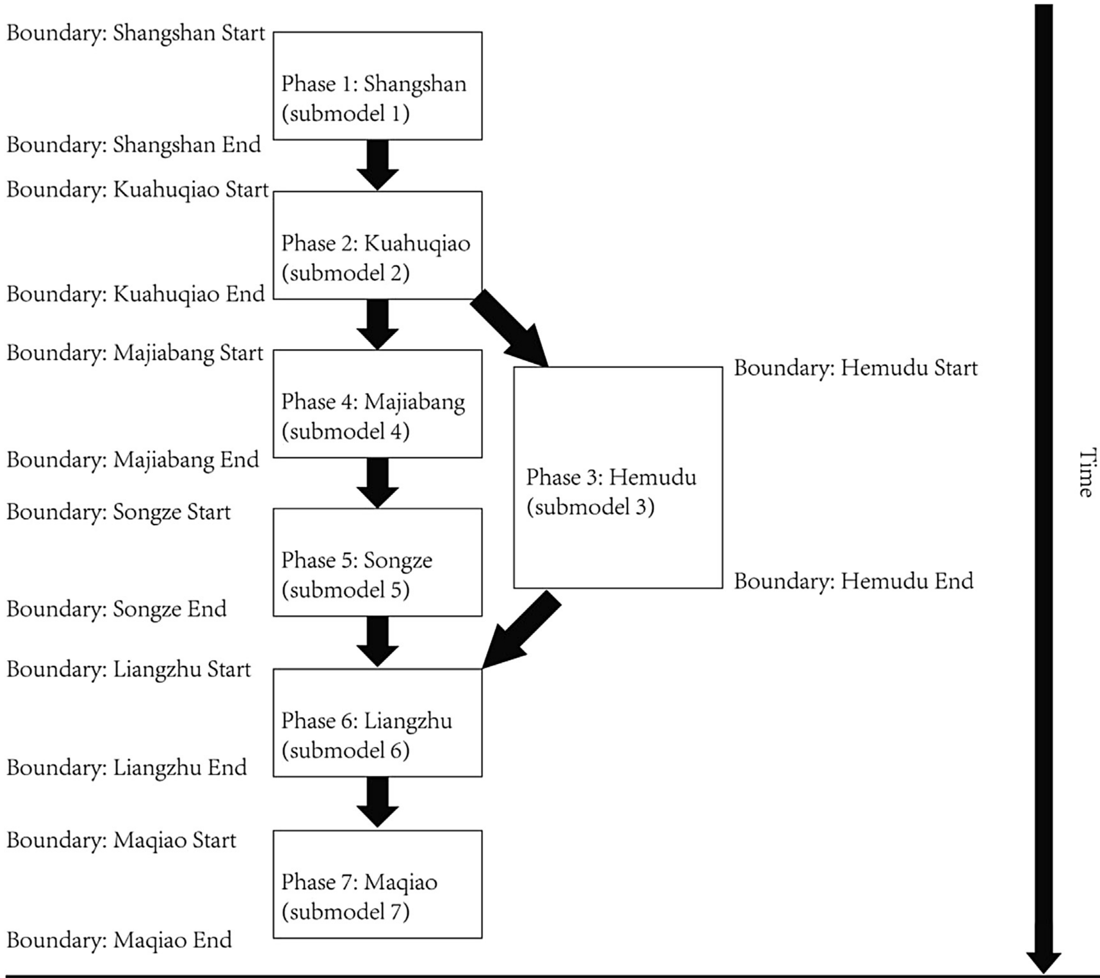

Fig. 2. The schematic Bayesian chronological model for the lower Yangtze archaeology.

significantly from its date of deposition. The current study used built-in outlier models in the OxCal programme to analyse potential outliers (Bronk Ramsey, 2009b). Thus, ^{14}C dates in the database were classified into two categories: *short time lag* materials (e.g. plant macrofossils), which are deposited in sediments or in the archaeological record soon after they have been produced, and are therefore generally considered more reliable in indicating the time of deposition (Bronk Ramsey et al., 2010); and those materials (e.g. fragments of charcoal and timber used in construction) where there is a potentially *long time lag* between production and final deposition, and that therefore often require greater caution when used in archaeological studies (van der Plicht and Bruins, 2001). Dates falling into the latter of the two categories were allocated an outlier probability value of 1 (Supporting Information 2 and 'OW' in Supporting Information 3) (Bronk Ramsey, 2009b) prior to analysis (e.g. Lorentzen et al., 2014). A second outlier model was applied to the dates on material classed as *short time lag*. A typical value for *a prior* probability value by which such material leads to a dating outlier is suggested to be 0.05, since statistically there is a 1 in 20 chance that a radiocarbon measurement needs to be offset in some way (Bronk Ramsey, 2009b). The offset in this situation, however, can be random statistically, the dates being either younger or older than the dated event (Bronk Ramsey, 2009b). Therefore a longer-tailed t-distribution (Supporting Information 2), which can minimise possible influences from any individual dating anomaly that conflicts with the overall sequence, is appointed in OxCal programming (Dee et al., 2013). The model was abbreviated as 'SL' for programming (Supporting Information 3). The same t-distribution outlier model is also widely applied to thermoluminescence dates (e.g. Leighton et al., 2013), as in the current study. As the model is equivalent to the above mentioned 'SL' model, the code 'SL' was recycled here (Supporting Information 3).

3. Results

3.1. Results of data selection

A total of 128 radiometric dates were retained and subjected to Bayesian modelling. Of these dates, 125 were from ^{14}C analysis and 3 were thermoluminescence dates. Dates in the *long time lag* category comprised the majority of the ^{14}C dates, with 105 dates in the total assemblage of 125 dates falling into this category, whereas the remaining 20 dates were based on material classified as *short time lag*. The majority of the thermoluminescence dates from sites in the lower Yangtze are associated with large dating uncertainties, and hence were not included in the Bayesian analysis.

3.2. Model outputs

Although there were high percentages of outliers (Supporting Information 4 and 5) associated with both *long time lag* and *short time lag* dates, none of the sub-models have a problem with convergence (with all convergence measurements higher than 95%). Fig. 3 summarises the revised chronology generated through the current research, based on the median-to-median range approach, and shows both the 68.2% and 95.4% limits of each boundary for comparative purposes. According to the revised chronology, the Shangshan cultural phase commenced about ca. 10,800 cal BP and terminated at ca. 8600 cal BP. The median duration of the cultural phase was a little over 2000 years. The Kuahuqiao cultural phase was established in the lower Yangtze ca. 7900 and lasted until ca. 7200 cal BP, with a median length of about 600 years. The Kuahuqiao appeared to have been followed by the Hemudu cultural phase (ca. 7100 to ca. 5200 cal BP, with a median duration of almost 2000 years). The results also confirmed an overlap between the Hemudu and Majiabang cultural phases, with the latter dated between ca. 7200 cal BP and ca. 5200 cal BP. Similar to the Hemudu cultural phase, the median duration of the Majiabang cultural phase was about 2100 years.

The results of Bayesian modelling also highlighted a potential overlap between the later stages of the Hemudu and Majiabang cultural phases and the Songze cultural phase (the latter commenced at ca. 5700 cal BP, terminated at ca. 5200 cal BP, and had a median duration of approximately 500 years). Moreover, there also appeared to be some overlaps between the Hemudu, Majiabang, and Songze cultural phases and the Liangzhu, at least according to the analysis that underpins this paper. Thus, according to the Bayesian analysis of dates, the Liangzhu cultural phase lasted from ca. 5500 to ca. 4000 cal BP, and had a median duration of about 1500 years. Moreover, results presented here seem to confirm the presence of a gap between the end of the late Neolithic Liangzhu and the beginning of the Bronze Age Maqiao cultural phase – based on the currently available and valid dates, with the Maqiao commencing at ca. 3700 cal BP and terminating at ca. 3200 cal BP (median duration of a little over 500 years). However, the 95.4% ranges of the two phases, ca. 5700–3700 cal BP for the Liangzhu and ca. 4100–2700 cal BP for the Maqiao, overlap.

4. Discussion

Results of the current study, although in general agreement with the existing chronology for the seven cultural phases in the lower Yangtze, show some notable and potentially critical differences in detail (Table 1). For example, the modelled age range (ca. 10,800–8600 cal BP) generally agrees with previously proposed range for the Shangshan cultural phase but showed younger *terminus post quem* (start) and *terminus ante quem* (end) dates (cf. Liu et al., 2007b). The age span of the Kuahuqiao cultural phase, previously suggested to have been ca. 1300 years from ca. 8200 to ca. 6900 cal BP (e.g. Zhejiang Provincial Institute of Cultural Relics and Archaeology, 2004), is here found to be significantly shorter in duration (ca. 7900–7200 cal BP, median length of ca. 600 years).

Another important feature in the revised chronology is the evidence of temporal overlap between the later parts of the Majiabang and the Songze cultural phases and the Liangzhu cultural phase. These overlaps may be an artefact of the conservative approach to Bayesian modelling adopted, and therefore not real. However, of note is the fact that 10 of the 32 ^{14}C dates forming the

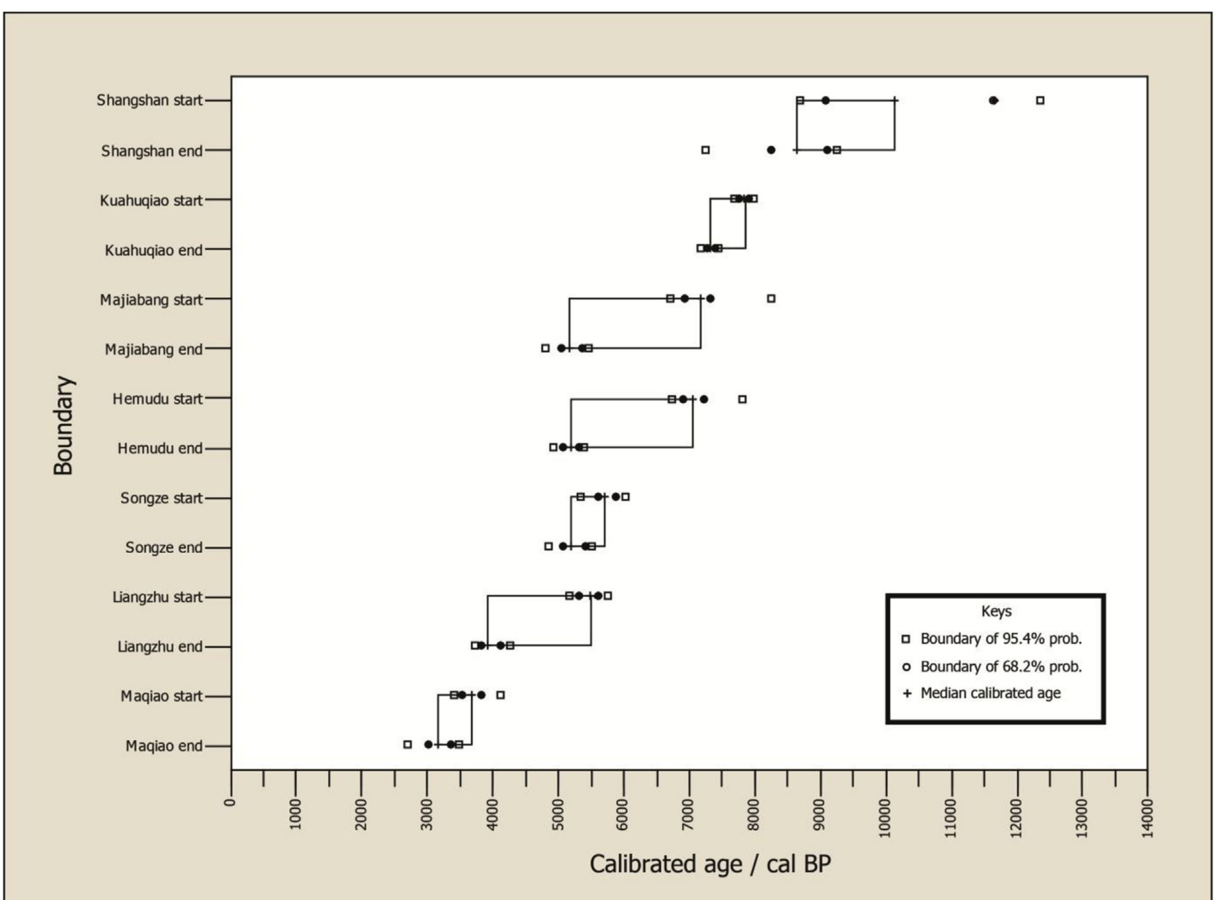

Fig. 3. The modelled age spans of the seven archaeological cultural phases in the lower Yangtze. Here the median-to-median range is used to determine age ranges of these cultural phases.

Majiabang sub-model have their calibrated medians younger than 5900 cal BP (Supporting Information 1), the previously assumed date of termination of the Majiabang cultural phase. Also, calibrated medians of 20 of a total of 48 ^{14}C dates in the Liangzhu dataset (Supporting Information 1) are older than the previously suggested age range for the cultural phase (ca. 5200 to ca. 4200 cal BP).

Aside from the above overlaps being a possible artefact of the approach and methods adopted, there is a possibility that material remains might, in fact, represent the contemporaneous occupation of the Yangtze Delta by a diversity of cultures. Such a representation seems to conflict with the more accepted interpretation, which, as having already been criticised in e.g. Chen (2006), views the archaeological record on the delta as representing a step-by-step, time-dependent progression of increasingly sophisticated cultural phases. The possibility that several different cultural phases could have co-existed on the Yangtze Delta during the later part of the Neolithic period and the transition to the Bronze Age is not without precedent in other parts of the world, or in the lower Yangtze. For example, Flannery (1965) described the use of different food production strategies by people living in close proximity in Southwest Asia at ca. 6000 cal BP, long after the introduction of agriculture to the area. Even today in parts of Africa, cultivators, pastoralists, and hunter-gatherers are found in relative close proximity, particularly where environmental gradients are relatively steep (Spielmann and Eder, 1994). Moreover, archaeological evidence from the lower Yangtze indicates that two distinctive cultural phases dating to the early Neolithic existed contemporaneously to the north and south of Hangzhou Bay (the Majiabang and Hemudu). If indeed the different cultural phases recognised equate to genuine cultural differences, the difference could have been due to variations in environmental conditions on the Yangtze Delta and fringing more upland areas (Zong et al., 2012a), which are likely to have supported the co-existence of more than one expression of human culture. Alternatively, or additionally, different groups of people might have chosen to adopt or retain their own characteristic strategies and tools regardless of their neighbours and/or environmental conditions, thereby displaying a diversity of preferences to traditions and innovations.

The results seem to provide further evidence for a temporal gap – at least based on the median-to-median range approach adopted in the current research – between the end of the Liangzhu and the beginning of the Maqiao cultural phases. According to the revised chronology, the duration of the gap is about 300 years (from ca. 4000 to ca. 3700 cal BP), and thus similar in length to the previously proposed range but showing a younger start and termination. However, in the last decade or so, a new archaeological feature (notably in pottery style) has been separated from the latest phase of the Liangzhu and the onset of the Maqiao; the Guangfulin cultural phase is thought by some researchers to represent distinct cultural phase (Qu, 2006). The Guangfulin cultural phase is suggested to have bridged the Liangzhu and Maqiao (Song, 2006). Yet it is not clear whether, if it existed, the proposed cultural phase was represented throughout the lower Yangtze or was restricted to a small number of sites such as Guangfulin. Perhaps most critically for the research described here, for the time being at least the cultural phase lacks well reported radiometric dates, and hence a secure basis for chronological control (cf. Qu, 2006).

The overlap between 95.4% ranges of the Liangzhu and the Maqiao, conversely, requires further explanation. Although the very conservative 95.4% ranges often lead to overly wide intervals (a major reason why a median-to-median range was adopted consistently in the current research), thereby resulting in overlaps between ranges and blanket possible gaps, it reveals that a temporal gap between the Liangzhu and Maqiao cultural phases cannot be guaranteed when this relatively high confidence level (95% confidence level) is adopted. Clearly, more high-resolution dates for the period of transition between the Liangzhu and Maqiao will be needed to resolve the issue.

While every effort has been made to circumvent problems associated with the dating of material accumulating in active deltaic environments, data presented here are believed to provide a more reliable master chronology for the development of food production and associated activities and populations in the lower Yangtze than the existing model that it aims to replace. Moreover, the revised model provides a basis for a more rigorous approach to the absolute dating of archaeological remains in the region in the future, while at the same time raising important questions, deserving of further research, relating to *a priori* assumptions concerning the degree of temporal separation of Neolithic cultural phases on the Yangtze Delta. However, the limited number of dates available to the current study is a major limitation. This is particularly the case for the early Neolithic Shangshan (with only six valid dates included in the analysis) and the Maqiao sub-model (again with only six valid dates). The dating of both cultural phases requires further work, and in particular a greater number of reliable radiometric dates, in order to establish firm chronological control.

5. Conclusion

Results from the current research provide a more reliable master chronology for the development of food production and associated activities and populations in the lower Yangtze than the existing model that it aims to replace. Thus results of Bayesian modelling indicate that the age span of the Shangshan, Kuahuqiao, Hemudu, Majiabang, Songze, Liangzhu, and Maqiao cultural phases in the lower Yangtze were, respectively, ca. 10,800–8600 cal BP, ca. 7900–7200 cal BP, ca. 7100–5200 cal BP, ca. 7200–5200 cal BP, ca. 5700–5200 cal BP, ca. 5500–4000 cal BP, and ca. 3700–3200 cal BP. Moreover, the revised chronology provides a basis for a more rigorous and robust absolute dating of archaeological remains in the region in the future, while at the same time raising important questions, deserving of further research. In particular, these questions relate to *a priori* assumptions concerning the degree of temporal separation of Neolithic cultural phases on the lower Yangtze. According to results presented here, the Majiabang, Songze, and Liangzhu cultural phases may have overlapped temporally, rather than being chronologically entirely separate. Such a coexistence of cultures in a relatively small geographic area, recorded in other parts of the world, may reflect a high degree of environmental variability on the Yangtze Delta, or social factors, such as the level of preference of different groups of people either to traditions or innovations, or some combination of factors. The model represents the first attempt to generate a quantitative chronological framework for the archaeology of the lower Yangtze. The model can be added to (and presumably improved) in future through the acquisition of additional radiometric dates of acceptable quality.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jas.2015.08.019.

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