Quaternary Science Reviews 98 (2014) 45–59

Contents lists available at ScienceDirect

Quaternary Science Reviews

journal homepage: www.elsevier.com/locate/quascirev

# Prehistoric demographic fluctuations in China inferred from radiocarbon data and their linkage with climate change over the past 50,000 years

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ARTICLE INFO

*Article history:*
Received 7 January 2014
Received in revised form
8 May 2014
Accepted 20 May 2014
Available online 17 June 2014

*Keywords:*
Climate change
Prehistoric demography
Radiocarbon
Database
Summed probability distribution
China

ABSTRACT

Historic human–climate interactions have been of interest to scholars for a long time. However, exploring the long-term relation between prehistoric demography and climate change remains challenging because of the absence of an effective proxy for population reconstruction. Recently, the summed probability distribution of archaeological radiocarbon dates has been widely used as a proxy for human population levels, although researchers recognize that such usage must be cautious. This approach is rarely applied in China due to the lack of a comprehensive archaeological radiocarbon database, and thus the relation between human population and climate change in China remains ambiguous. Herein we systematically compile an archaeological $^{14}C$ database ($n = 4656$) for China for the first time. Using the summed probability distributions of the radiocarbon dates alongside high-resolution palaeoclimatic records, we show that: 1) the commencement of major population expansion in China was at 9 ka cal BP, occurring after the appearance of agriculture and associated with the early Holocene climate amelioration; 2) the major periods of small population size and population decline, i.e., 46–43 ka cal BP, 41–38 ka cal BP, 31–28.6 ka cal BP, 25–23.5 ka cal BP, 18–15.2 ka cal BP, and 13–11.4 ka cal BP, correspond well with the dating of abrupt cold events in the Last Glacial (LG) such as the Heinrich and Younger Dryas (YD) events, while the major periods of high-level population in the Holocene, i.e., 8.5–7 ka cal BP, 6.5–5 ka cal BP and 4.3–2.8 ka cal BP, occur at the same times as warm-moist conditions and Neolithic cultural prosperity, suggesting that abrupt cooling in the climate profoundly limited population size and that mild climate episodes spurred a growth in prehistoric populations and advances in human cultures; and 3) populations in different regions experience different growth trajectories and that their responses to climate change are varied, due to both regional environmental diversity and the attainment of different levels of adaptive strategies.



## 1. Introduction

In recent years, the relation between human history and climate change has been intensively studied (Sandweiss et al., 1999; Weiss and Bradley, 2001; deMenocal, 2001; Zhang et al., 2011; McMichael, 2012; Xie et al., 2013; Ziegler et al., 2013). The potential role of climate change in the growth and demise of human societies is a matter of heated debate (Catto and Catto, 2004; Coombes and Barber, 2005; Yancheva et al., 2007; Zhang et al., 2007; O'Sullivan, 2008; Maher et al., 2011; Zong et al., 2012). In spite of some still extant doubts, there is much strong environmental evidence to suggest that catastrophic climate fluctuations, such as drought and cold spells, can be closely associated with societal disintegrations and human crises around the world (Weiss et al., 1993; Cullen et al., 2000; Hodell et al., 2001; Polyak and Asmerom, 2001; Wu and Liu, 2004; An et al., 2005; Zhang et al., 2007; D'Andrea et al., 2011; Hsiang et al., 2011; Kennett et al., 2012; Medina-Elizalde and Rohling, 2012). It has also been suggested that palaeoclimatic–variability transitions may have acted as a trigger for rapid change in the development of humankind in Africa (Donges et al., 2011), and that the global population growth and geographical expansion experienced before the Neolithic was a

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http://dx.doi.org/10.1016/j.quascirev.2014.05.015
0277-3791/

result of rising temperatures after the Last Glacial Maximum (LGM) (Zheng et al., 2011, 2012). With the increasing availability of well-dated, high-resolution climate records, which can be interpreted alongside archaeological data, the future researches would provide more valuable information on past human–climate interactions. However, it remains a challenge to test the correlation between climate change and past human population size or intensity of human occupation accurately, because in many cases it is difficult to obtain long-term, high-resolution approaches for reconstructing prehistoric population trends which can compare with long-term, continuous palaeoclimate archives.

Up to the present, although inevitably drawing on imperfect evidence, scholars have attempted to access information about prehistoric demography in a number of different ways (Chamberlain, 2006; Bocquet-Appel, 2008), summarized by two principal methods: genetic and archaeological. A rapidly increasing body of both modern and ancient genetic data has been used to examine past population size trends on various temporal and spatial scales (Haak et al., 2005; Atkinson et al., 2008; Gignoux et al., 2011; Zheng et al., 2011, 2012; Aimé et al., 2013), but this remains strictly inferential and fraught with technical difficulties (Riede, 2009). In addition, the population trend lines in genetic records are too smooth and monotonic to be scientifically comparable with fluctuating climate curves. Archaeological records are considered much better than genetic data for prehistoric population density reconstruction (Riede, 2009); the time-series analysis of archaeological site numbers, site density, size and distribution has been extensively accepted and applied in many studies to interpret population dynamics and their association with climate change (Li et al., 1993; An et al., 2004; Tarasov et al., 2006; Li et al., 2009; Wagner et al., 2013; Zhuo et al., 2013). However, due to coarse time resolutions and variable age controls, simply converting site numbers to human population size may not provide accurate enough information when comparing these with climate records in a given space and time period (Tarasov et al., 2006). In light of these methodological difficulties, what proxy from archaeological records can we use to track exactly the changes in human population history?

Beginning with the pioneering work done by Rick (1987), investigators have increasingly used the data derived from archaeological radiocarbon dating to reconstruct trends in regional prehistoric populations (e.g. Gamble et al., 2004, 2005; Barton et al., 2007; Shennan and Edinborough, 2007; Riede, 2009; Hinz et al., 2012; Williams, 2012). Such research has been based on the reasonable assumption that frequency distributions of archaeological radiocarbon ages can act as a proxy for prehistoric demography since a larger population will result in greater production and deposition of cultural carbon, therefore providing more determinations (Holdaway and Porch, 1995; Surovell and Brantingham, 2007; Munoz et al., 2010; Peros et al., 2010). This method's supposition that, with sufficient numbers of radiocarbon dates from large regions, numerous sites and investigators, the changes in their frequency distributions are a reliable indicator of the population fluctuations, has been widely approved (Kuzmin and Keates, 2005; Peros et al., 2010; Anderson et al., 2011). Moreover, the main advantage of radiocarbon is that it provides a more precise chronological framework than the molecular clock and the use of phases as a cultural measure of time (Gamble et al., 2005). Although the reliability of this approach can encounter problems such as a taphonomic bias in site; archaeological sampling and/or dating biases; variable sample sizes; a varied quality of the dates themselves; and the artificial effect arising from radiocarbon calibration curve (Surovell et al., 2009; Steele, 2010; Ballenger and Mabry, 2011; Bamforth and Grund, 2012; Williams, 2012), there are several strategies which have been proposed to handle these problems and improve the use of radiocarbon data, thus making population estimates more reliable (Williams, 2012).

Temporal radiocarbon frequency distributions, which are commonly presented as summed probability plots or frequency histograms of calibrated $^{14}C$ dates, have been extensively used to explore demographic change and its relation to climate change in North America (Buchanan et al., 2008; Munoz et al., 2010; Peros et al., 2010; Anderson et al., 2011; Kelly et al., 2013; Miller and Gingerich, 2013); Europe (Gkiasta et al., 2003; Gamble et al., 2005; Turney et al., 2006; Shennan and Edinborough, 2007; González-Sampériz et al., 2009; Hinz et al., 2012; Tallavaara and Seppä, 2012; Shennan et al., 2013; Wicks and Mithen, 2014); Siberia and the Russian Far East (Dolukhanov et al., 2002; Kuzmin and Keates, 2005; Fiedel and Kuzmin, 2007); Australia (Turney and Hobbs, 2006; Smith et al., 2008; Williams et al., 2008, 2010; Williams, 2013); West Asia (Maher et al., 2011); the Sahara (Kuper and Kröpelin, 2006); and South America (Delgado Burbano, 2012; Bueno et al., 2013; Martínez et al., 2013; Méndez Melgar, 2013; Prates et al., 2013; Rademaker et al., 2013). Most of these studies argue that there is a correlation between climatic and demographic changes, but some find no evidence to support the relation (e.g. Buchanan et al., 2008; Maher et al., 2011; Shennan et al., 2013), indicating the necessity of further research into many other regions along similar lines and using the same methods.

Some scholars, using the existing methodology, have argued that the summed probability curves of radiocarbon ages are a more rigorous indicator of population history than simple frequency plots (Holdaway and Porch, 1995; Smith et al., 2008), because the process of accumulation of the probability distributions of a large number of dates gives a high degree of chronological precision for exploring population changes in considerable detail (Shennan, 2013). Radiocarbon probability curves are also continuous time series records that permit the investigation of large-scale temporal population changes within a region, and a direct comparison with paleoclimate records (Smith et al., 2008; Williams, 2012). Thus, the summed probability distributions of calibrated radiocarbon ages are used as the mainstay of population history reconstruction to explore whether its history may be associated with climate change (Williams, 2012; Shennan, 2013).

However, in China, the technique has rarely been applied until now. The few existing applications either focused merely on single site or narrow areas or were based on small sample sizes and short timescales (Barton et al., 2007, 2009; Ma et al., 2012a; Dong et al., 2013). Thus, neither prehistoric population fluctuations throughout China nor how they respond to climate change over long timescales are explicitly delineated. This situation may be due to the lack of an available archaeological $^{14}C$ database in China such as the Canadian Archaeological Radiocarbon Database (CARD) in Canada (Morlan, 2005), the S2AGES database in Europe (Gamble et al., 2004) and the AustArch database in Australia (Williams, 2012), alongside detailed analysis of these radiocarbon data. In this paper, we report on the synthesis and compilation of a database of $^{14}C$ dates from archaeological sites in China, and then use an analysis of summed probability distributions of these radiocarbon data to reconstruct the broadly long-term population history at a regional to country-scale based on critically assessing the effects of biasing factors, finally testing whether this correlates with records of climatic variability in China over the past 50 ka.

## 2. Regional setting

### 2.1. Environmental setting

Situated in the eastern part of Eurasia and on the west coast of the Pacific, mainly between latitudes 20°and 54°N and between