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Holocene vegetation, environment and anthropogenic influence in the Fuzhou Basin, southeast China

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ABSTRACT

A ~40 m sediment core (FZ4) was collected from the Fuzhou Basin, near the lower reaches of the Min River, in Fujian Province on the southeast coast of China. The sediment and pollen record contributes to our understanding of Holocene paleogeography, including local changes in vegetation and climate in the context of Neolithic cultural developments. The sediment record reveals a fluvial environment in the Fuzhou Basin during the late Pleistocene, and it demonstrates that a change from fluvial to estuarine conditions at ~9000 cal yr BP resulted from postglacial sea level rise. Evidence of abundant marine diatoms and tidal flat laminations observed in the FZ4 sediments, implies that the Fuzhou Basin was under marine influence between ~9000 and ~2000 cal yr BP. After 2000 cal yr BP, a rapid retreat in coastline associated with fluvial aggradation and coastal progradation produced more shallow water for wetlands and initiated formation of the floodplain landscape. The pollen record reveals the presence of a dense subtropical forest between ca. 9000 and 7000 cal yr BP, representing the Holocene thermal maximum, which is linked with rising sea level and marine transgression in the Fuzhou Basin. Between ca. 5500 and 2000 cal yr BP, the thermophilous forest dominated by *Castanopsis* retreated and coniferous forest expanded, reflecting moderate climatic cooling during this period. Timing of the high frequencies for *Pinus* and ferns correspond with the mid-late Holocene cooling trend recorded in local mountain peatland and coastal regions of the lower Yangtze and Hanjiang deltas. Anthropogenically induced land cover change was negligible prior to the Tanshishan cultural period, which marks the beginning of Neolithic era sedentary village life on the Fujian coast around 5500 BP. The pollen transition at ca. 3000–1500 cal yr BP, distinguished by rising frequencies of Poaceae and taxa (including Cyperaceae and *Artemisia*) closely associated with agricultural land cover, indicates exploitation of newly formed lowlands in the emerging Min River floodplain. The historic era intensification of rice agriculture is reflected in this trend of rising frequencies of Poaceae. After ca. 2000 cal yr BP, we observe the onset of a marine regression followed by evidence for an intensely human-impacted environment characterized by sharp rises in pioneer plants such as Poaceae and *Dicranopteris*. This transition coincides with a rapid retreat of coastline and emergence of the Fuzhou Basin floodplain.

1. Introduction

The major deltas and downstream river basins of southeast China originated during the late Pleistocene, followed by Holocene formation of expansive coastal lowlands and floodplains (Wang and Zheng, 1997; Zheng and Li, 2000; Zong et al., 2013; Innes et al., 2014). Among these are the lowlands and floodplain of the Fuzhou Basin (Lan et al., 1986; Zheng et al., 2005). The Min River, the largest in Fujian, flows through the basin and the capital city of Fuzhou sits on the floodplain. Recent coring of the thick Fuzhou Basin Holocene sediments yielded a series of Holocene records that are suitable for pollen and other proxy studies (Rolett et al., 2011). Our study focuses on one of these cores, FZ4, to present the first high-resolution Holocene pollen record of changes in the Fuzhou Basin regional ecosystem and its sedimentary environment. In addition to documenting a 9000-year long history of Holocene vegetation change, our study also investigates the evolution of coastal

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landscapes in response to sea level changes and anthropogenic influences.

The global expansion of Neolithic cultures is widely associated with anthropogenic land cover change related to activities such as early agriculture and deforestation (Kaplan et al., 2011; Boyle et al., 2011). In China, the Hangzhou Bay area (Zhejiang Province), south of Shanghai and the Changjiang (Yangtze) delta plain, was a center for early rice agriculture (e.g., Fuller et al., 2009; Fuller, 2011; Zong et al., 2007). In the lower Yangtze wetlands region, environmental conditions and other factors related to food resources influenced the choice of Neolithic settlement areas, as well as the migration of Neolithic communities (Zong et al., 2012). This suggests that migration was one of the main Neolithic era strategies for coping with environmental change (Zong et al., 2012). Neolithic cultures spread down the southeast coast of China and across the Taiwan Strait (Bellwood, 2005; Chi and Hung, 2010; Ruddiman et al., 2008). Data from the Pearl River delta shows that the shift to economic dependency on rice agriculture occurred 2500–2200 years ago (Zong et al., 2013). Similarly, for the Fuzhou Basin, although Neolithic cultures were well established by 5000 years ago, it is argued that local environmental factors related to the presence of a large mid-Holocene estuary inhibited the development of intensive food production until after ca. 2000 cal yr BP (Rolett et al., 2011). Here we explore this hypothesis by examining long-term changes in the regional environment, including evidence for anthropogenic influence, from the early Holocene until the modern era.

Palynological studies in the Fuzhou Basin began in the 1980s (Zheng, 1986; Yang et al., 1991), but this early work relied on low-resolution sequences with poor chronological control using thermo-luminescence dating (Zheng et al., 2005). The high-resolution pollen record presented in our study offers a chronology based on Accelerator Mass Spectrometry (AMS) radiocarbon (^{14}C) dating of macro-botanical and other organic remains embedded in the laminated FZ4 core sediments. This makes it possible to more precisely correlate climatic events and Neolithic cultural developments with a regional scale paleoenvironmental reconstruction.

2. Regional setting

The Fuzhou Basin is a Quaternary fault-depression basin attaining widths of more than 20 km. The bedrock consists mainly of Jurassic volcanic rock and later granite formations (Fig. 1). Formation of the basin is linked with the East Fujian tectonic faults, and mainly controlled and cut by the faults of Bayishuiku-Shangan (F1), Gushan piedmont (F2), Tongkou-Hongshanqiao (F3), Hutou-Miaopu (F4), Wuhushan (F5) and Minhou-Nanyu (F6) (Min et al., 2002) (Fig. 1). Quaternary sediments filling the Fuzhou Basin are up to 64 m thick and they consist mainly of Pleistocene terrestrial sands and silts overlaid by Holocene marine and terrestrial sediments (Lan et al., 1986; Zheng et al., 2005). The Min River, the largest river in Fujian Province, flows through the basin. It is more than 577 km long, originating in the Wuyi Mountains ranges on the border of Fujian and Jiangxi Provinces. Annual mean runoff is about 6.2×10^{10} m^3, draining a catchment area of ca. 61,000 km^2 that includes much of northern and central Fujian (Lu, 2004). This is significant because proxy records from the estuarine geological archives of large river drainage basins tend to capture a broad regional signal, making them valuable for studying long-term environmental change (e.g., Strong et al., 2012).

The Min River is narrow in its upper reaches but it becomes much broader as it flows through the Fuzhou Plain. At present, maximum inland reach of the tides is to Fuzhou City. The modern landscape is vastly different from that which existed during the early and mid-Holocene eras, as shown by a paleoenvironmental reconstruction based on Fuzhou Basin sediment cores (Rolett et al., 2011). This reconstruction shows that early Holocene sea-level rise flooded the basin, and continued sea-level rise during the mid-Holocene created a large paleoestuary that reached 75 km inland from the modern coast. The fall in sea-level from a mid-Holocene highstand to near modern levels occurred close around 1900 cal yr BP. As the ocean retreated, the regional landscape was transformed from an estuary-dominated to a mainly fluvial environment. Sedimentation after ca. 1900 cal yr BP created the first lowlands suitable for irrigated rice agriculture in Fuzhou Basin (Rolett et al., 2011; Rolett, 2012).

The geographical position of core FZ4 is ideal for investigating the interconnected roles of climate change and anthropogenic influence in the evolution of southeast China landscapes. One reason is that the Fuzhou Basin has been an important center for human settlement from the Neolithic era (beginning 5000–6000 years ago in this region) until the present. In addition, the FZ4 sequence provides a precisely dated, highly resolved pollen record that allows evaluation of hypothesized climatic shifts which potentially influenced the monsoon regime, including events such as a strengthening of the summer monsoon around 9000 cal yr BP and the abrupt lowering of its intensity around 4400 cal yr BP (e.g. Wang et al., 2005). The high resolution FZ4 sequence thus allows the correlation of climatic events with changes in regional vegetation and developments in the Neolithic culture. This is based on well-preserved pollen assemblages extracted from laminated deposits, and a chronology established with direct AMS ^{14}C dating of macro-botanical and other organic remains.

The regional climate is strongly influenced by the East Asian Monsoon, with frequent typhoons originating from the southwest Pacific. Annual mean temperature is 19–20 °C, with annual precipitation varying from 1200 to 1600 mm and an average annual humidity of ca. 76 percent. The zonal vegetation is monsoonal broad-leaved evergreen forest dominated by species of Fagaceae and Lauraceae (Wu, 1980; Lin, 1990). Upstream in the eastern Wuyi Mountains, four vegetation belts are present: (1) cultivated land, brush and secondary *Pinus* forest at <450 m; (2) broad-leaved evergreen forest at 400–1200 m, consisting mostly of *Castanopsis, Lithocarpus, Cyclobalanopsis, Schima, Ternstroemia, Symplocos, Ilex, Euscaphis, Platycarya,* and *Fagus*; (3) coniferous and broad-leaved mixed forest at 1200–1900 m, consisting primarily of *Fagus*, *Quercus*, *Tsuga*, and *Pinus*; and (4) subalpine meadows of *Miscanthus* and *Arundinella* on the summits (Wu, 1980).

Native forests in the study region have been almost totally destroyed by human activity. Present day local forests are mostly planted, dominated by *Pinus massoniana*, *Cunninghamia lanceolata*, *Acacia confusa*, *Casuarina*, and *Ficus*, with a limited range of mangrove in the coastal mud flat zone. Coastal areas and alluvial plains are under intensive cultivation. Within the highly human impacted landscapes, certain taxa, including *Dicranopteris*, herbs such as *Artemisia* and some secondary trees (*Pinus* and Taxodiaceae) are indirectly but closely associated with agriculture. A study of modern rice cultivation areas along a transect of southeast China revealed that, in addition to Poaceae, other pollen and spore taxa such as *Dicranopteris*, Cruciferae, *Artemisia* and *Pinus* are rather common in the areas surrounding rice fields (Yang et al., 2012). *Dicranopteris* is a heliophilous fern of tropical–subtropical hilly areas where it thrives in areas disturbed by forest clearance and which have been repeatedly burned. *Dicranopteris* is closely linked with land clearing for agriculture and human disturbance in general. It is well adapted to acidic soils such as those common in Fujian, and it often grows in association with planted *P. massoniana* and other pioneer vegetation. *Artemisia*, a dry-land herb, is a taxon indicator of anthropogenic landscapes, especially in temperate floodplain zones (Zheng et al., 2007). *Artemisia* pollen percentages decrease gradually from north to south, before falling off rapidly to