Earth-Science Reviews 245 (2023) 104552

Contents lists available at ScienceDirect

Earth-Science Reviews

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

Human activities facilitated the decline of forest ecosystem in East Asia after 5000 a BP

Shengfang Zhou [a,b], Hao Long [a,*], Hang Xing [c], Ke Zhang [a], Rong Wang [a], Enlou Zhang [a]

[a] State Key Laboratory of Lake Sciences and Environment, Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences, Nanjing 210008, China
[b] University of Chinese Academy of Sciences, Beijing 100049, China
[c] Key Laboratory of Humid Subtropical Eco-geographical Process (Ministry of Education), School of Geographical Sciences, Fujian Normal University, Fuzhou 350007, China

ARTICLE INFO

Keywords:
Forest ecosystem
Human activity
Anthropogenic impacts
Anthropocene
East Asia
Arboreal pollen

ABSTRACT

Human activities have drastically reshaped global forest ecosystems in recent decades. However, identifying the origins, magnitude, and primary effects of these actions, especially in East Asia (EA), with a long history of human activity, remains challenging. Crucially, unraveling the early anthropogenic impacts on forest ecosystems has substantial implications for characterizing the Anthropocene. In this study, we collated and synthesized Holocene arboreal pollen (AP) sequences from 61 EA lake basins, which demonstrated an overall expansion of forest vegetation during the early to middle Holocene, followed by a retreat from 5 cal. ka BP. The cooling and drying climate during the mid- and late Holocene proved inimical to forest proliferation across EA. Survival imperatives are likely to drive humans to adopt grazing and farming, causing a transformation from forest land to agro-pastoral land. This change further accelerated forest ecosystem degradation. By dividing EA into five subregions, we observed asynchronous declines in forest vegetation from 8 cal. ka BP to 3 cal. ka BP. This trend is primarily attributed to human impacts, given the pronounced coincidence between forest reduction and emergence and prosperity of Neolithic agriculture in each region. Significantly, the positive feedback loop between population growth and agricultural expansion can amplify human impacts. Coupled with climatic effects, these factors resulted in EA's forest vegetation plummeting to its lowest level since 10 cal. ka BP at 2.1 cal. ka BP. Furthermore, the anthropogenic influences on EA forest vegetation mirror land use, soil erosion, and vegetation variability observed globally in terms of timeline. These alterations are driven by human activities, almost coinciding with shifts in atmospheric greenhouse gas levels away from their natural trajectory. We, therefore, argue that the Anthropocene definition should consider the aggregate environmental impact of human activities over millennia, rather than restricting to the most recent centuries.

1. Introduction

Forest ecosystems, accounting for a substantial portion of global biodiversity and playing a pivotal role in the global carbon cycle—most notably, acting as a "carbon sink" (Pan et al., 2011; Crowther et al., 2015; Harris et al., 2021)—are vital. As per Harris et al. (2021), deforestation and other disturbances have led to total carbon emissions of 8.1 $\pm$ 2.5 $GtCO_2e\,yr^{-1}$ between 2001 and 2019, while the global forests' net carbon sink was $-7.6 \pm 49\,GtCO_2e\,yr^{-1}$ during this period. Consequently, in the context of climate warming and escalating greenhouse gases, research into forest ecosystems is essential—particularly to comprehend past shifts in forest vegetation for the effective forecasting of future forest ecosystem changes. The Holocene epoch, the one closest to us, occurred during a warm interglacial period (Steffen et al., 2007). A comparison by Cheng et al. (2018) between the last five interglacial periods showed a marked decline in vegetation by approximately 6 cal. ka BP during the Holocene. This occurred significantly earlier than in previous interglacials, and was associated with high carbon flux. Accumulating evidence suggested that human activities have substantially modified most global ecosystems (e.g., Jenny et al., 2019; Stephens et al., 2019; Ellis et al., 2021; Mottl et al., 2021; Nogué et al., 2021; Thompson et al., 2021), pushing the current interglacial potentially to deviate from its natural trajectory (Steffen et al., 2007). In this era of global change, it becomes imperative to comprehend the repercussions

* Corresponding author.
E-mail address: longhao@niglas.ac.cn (H. Long).

https://doi.org/10.1016/j.earscirev.2023.104552
Received 7 March 2023; Received in revised form 27 July 2023; Accepted 31 August 2023
Available online 3 September 2023

of human interventions on forest ecosystems throughout the Holocene.

Human have acted as a geological force, shaping the earth's surface for millennia (Ellis et al., 2021). Recognizing this unique influence, Crutzen and Stoermer (2000) coined the term "Anthropocene", distinguishing it from the preceding Holocene epoch. There is no doubt that since the onset of the Anthropocene, escalating human activities have imposed substantial impact (Elhacham et al., 2020; Cendrero et al., 2022; Huang et al., 2022; Syvitski et al., 2022). Notwithstanding, the Anthropocene's concept was quickly met with contention across various scientific fields (e.g., Lewis and Maslin, 2015; Bauer et al., 2021; Kunnas, 2021; Head et al., 2022; Gibbard et al., 2022a, 2022b; Waters and Turner, 2022). The questions posed are whether the Anthropocene can be accepted as a new geological epoch and when this epoch commenced. The Anthropocene paradigm assumes that human-induced global environmental change is a recent phenomenon (e.g., Lewis and Maslin, 2015; Head et al., 2022). However, mounting evidence from ecosystem evolution (e.g., Mottl et al., 2021; Nogué et al., 2021; Thompson et al., 2021; Cai et al., 2022; Ding et al., 2022), soil erosion/sediment accumulation rates (e.g., Jenny et al., 2019; Zhang et al., 2022; Dreibrodt et al., 2023; Zhao et al., 2023), and land use change (e.g., Fyfe et al., 2015; Stephens et al., 2019; Ellis et al., 2021), indicates that humans have been influencing the earth's surface for millennia (Ruddiman et al., 2015; Roberts et al., 2021; Gibbard et al., 2022a, 2022b). Nevertheless, the extent to which such profound impacts can be traced back remains uncertain.

Primitive agricultural practices inflicted substantial damage on forest ecosystem (Ruddiman, 2003, 2007; Fyfe et al., 2015; Zheng et al., 2021), leading to possibly irreversible transformations of the land surface. Crowther et al. (2015) assessed global tree density, reporting a reduction of nearly 46% since the dawn of human civilization. By integrating pollen data and sediment accumulation rates from 632 lakes worldwide, Jenny et al. (2019) determined that the shift from natural to human-induced alterations in arboreal pollen (AP) occurred around 4 cal. ka BP. However, their study included a limited number of pollen sequences from East Asia (EA). Given EA as an origin of ancient civilizations, it merits intensive investigation to understand the consequences of human activities. Recently, Cao et al. (2022) integrated pollen data from 254 sites across China, demonstrating significant human disturbance to vegetation and a reduction in plant diversity in eastern China over the last two millennia, however, this study paid less attention to the northeastern Tibetan Plateau, a region recognized for being considerably influenced by early human activities. Additionally, Zhao et al. (2023) compiled data on vegetation, soil erosion, temperature, and precipitation throughout the Holocene from 35 lakes in China to investigate Holocene soil erosion dynamics, yet only treated vegetation as an influencing factor. Consequently, there is a demand for additional studies on forest ecosystems in EA during the Holocene, particularly those combining vegetation reconstruction results with archaeological findings to assess human activity impacts on Holocene forest ecosystems in the region.

Lakes serve as sinks for watersheds, encapsulating information about ecological and environmental changes prompted by human activities within the watershed. This information is often conveyed to lakes through material transport and is ultimately retained in the sediments (Dearing, 2013; Jenny et al., 2019). As such, lake sediments are frequently utilized to uncover indications of early human activities, including deforestation, fire use, land use, and soil erosion (Lageras, 1996; Noël et al., 2001). Furthermore, pollen records in lake sediments can denote the historical vegetation status of the lake and its surrounding catchment area (Shen et al., 2006; Li et al., 2008). We collected AP records from 61 lakes and peatlands in EA during the Holocene, aiming to answer the following questions: (1) How did forest vegetation change in EA lake basins during the Holocene? (2) When did major human activity impacts occur? (3) What implications do the early human impacts on land surface forest ecosystems have in defining the Anthropocene?

2. Data and methods

2.1. Arboreal pollen datasets

To assess the effects of climate change and human activities on Holocene forest alterations in EA, we compiled 61 published tree pollen or arboreal pollen (both abbreviated AP) records from lake and peat sediments across the region (Fig. 1a). These sites span latitudes from 19.95° N to 52.82° N, longitudes from 80.24° E to 134.94° E, and altitudes from 6 m to 5059 m (Table S1). To ensure age reliability, we verified that these records underwent ^{14}C calibration, and recalculated age-depth using the Bayesian model. And we also selected 36 AP records based on the following strict criteria: (1) time span should be ≥10 ka; (2) the record should contain five or more ^{14}C age control points throughout the Holocene for an accurate age framework; (3) the average sample resolution in the record should be within 200 years to guarantee high resolution. To discern regional differences in vegetation changes and human influence, we conducted the statistical analysis on the data for subregions (Fig. 1b). For subregion division, we initially considered geographical divisions and climatic backgrounds, as well as the distribution of early archaeological sites. According to Hosner et al. (2016), early human activity sites are extensively distributed in northeast China, the middle and lower Yangtze River, southwest China, and the northeastern part of the Tibet Plateau, but relatively fewer in northwest China. Consequently, we divided the pollen sites into five subregions for analysis: northeast China (NEC; $n = 17$), middle and lower Yangtze River (MLYR; $n = 6$), northwest China (NWC; $n = 8$), northeastern Tibetan Plateau (NETP; $n = 9$), and southwest China (SWC; $n = 13$). Upon comparing the integrated results of the 36 records with the 61 records, we observed minor differences in the amplitude of the AP records' fluctuations in the NWC and MLYR, with negligible discrepancies in the other records (Fig. S1). Therefore, to provide a comprehensive representation of forest vegetation changes in EA, we chose to analyze the integrated results of the 61 lakes.

2.2. Data processing

Each record in the collected data was linearly interpolated at 100-year intervals, resulting in interpolated AP percentages for 101 time slices between 10 and 0 cal. ka BP. The interpolated data was then calculated for *Z*-Scores, and the average of the 61 Z-Scores records was used to represent changes of AP in East Asia (Fig. 1c). To validate the reliability of the linear interpolation results, we also fitted the Z-Scores of the 61 records and each subregion using a generalized additive model (GAM), and compared these fitted curves with the interpolated curves (Fig. 1c). In order to investigate the driving-response relationship between climate, human activity, and forest vegetation changes, we conducted a correlation analysis between the linearly interpolated AP and the proxy indicators of climate and human activity in EA. Furthermore, to examine how the correlation between AP, climate, and human activity changes over time, we employed a sliding window correlation analysis with a 3000-year window and a 100-year sliding step. All of the aforementioned data analysis was executed using Python code.

2.3. Regime shift detection

To quantify the changes in EA forest ecosystems, we employed the Sequential *t*-test Analysis of Regime Shifts (STARS), a cyclic algorithm based on the *t*-test proposed by Rodionov (2004), to detect regime shifts. The primary advantage of this method is able to dynamically adjust the position and number of regime shifts for optimally fitting the data changes. STARS is primarily implemented in Excel via the STARS package and has been extensively utilized to identify regime shifts in climate and paleoecology (e.g., Rodionov and Overland, 2005; Reid et al., 2016; Huang et al., 2022). We used both of the mean and variance tests to detect the shift points of AP in East Asia and its subregion. At a

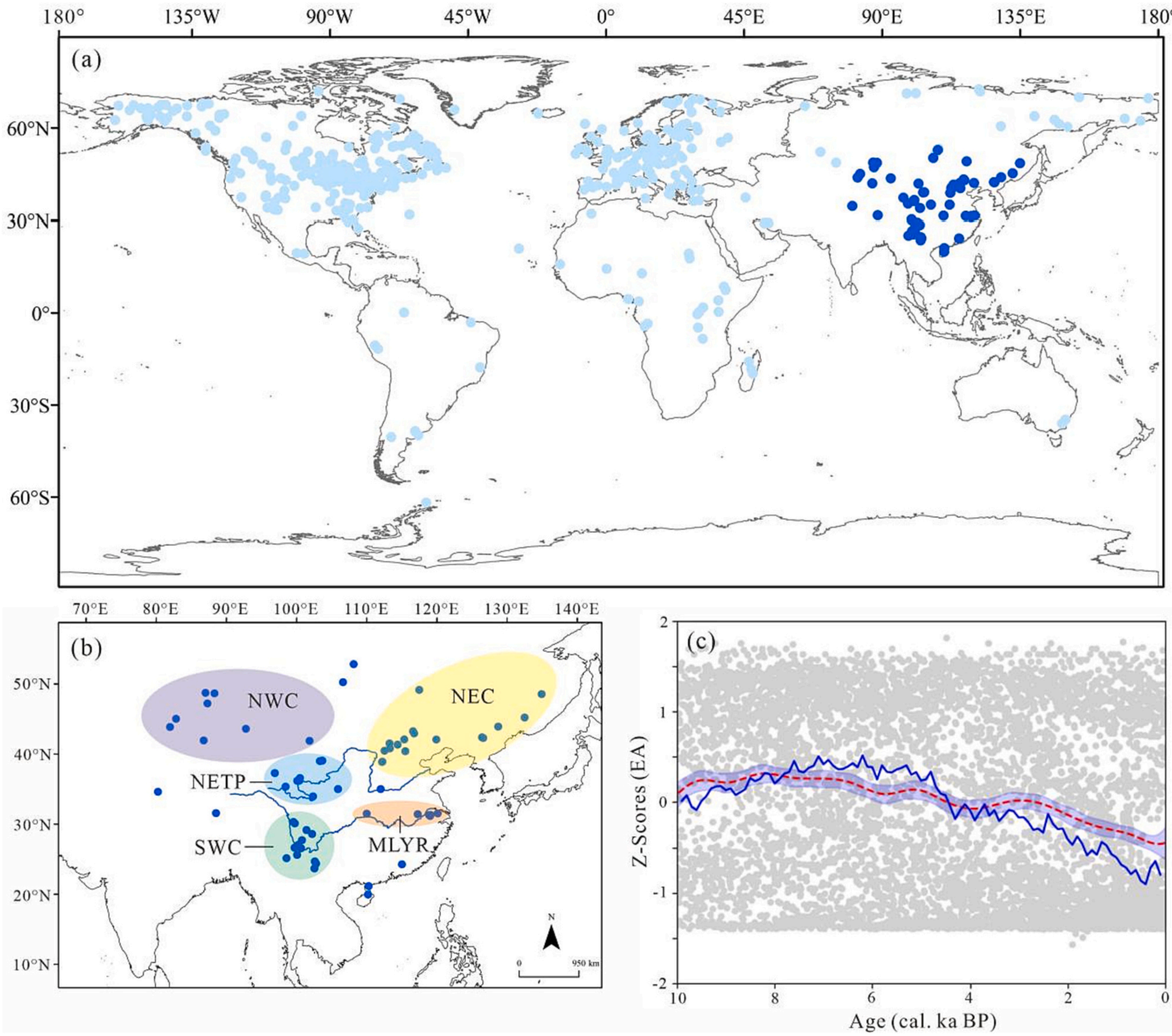

Fig. 1. (a) Distribution of Holocene pollen sequences in Jenny et al. (2019) for the world (light blue dots) and this synthesis study from EA (dark blue dots), respectively; (b) Distribution of Holocene AP sequences in EA lake basins and five subregions; (c) Compilation of 61 AP sequences in EA (light gray dots), and fitting results by generalized additive model (red dashed line) and linear interpolation (blue curve). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

confidence level of 0.01, we tailored the cut-off length to verify the authenticity of our identified regime shifts, designating the cut-off length interval from 5 to 30. With an interval of 1, we employed a sliding method to record regime shifts discerned by both the mean and variance tests for every cut-off length. The frequency of these regime shifts was calculated across EA and its subregions (Fig. S2). To validate the results of the STARS test, we also conducted shift point detection using the Pelt algorithm from the Ruptures library in Python (Table S2). This algorithm, based on the mean-shift model, identifies regime shifts by minimizing a loss function. If the results from the mean and variance tests in STARS align with the results from Ruptures, we consider there to be a high likelihood of a regime shift at that point.

3. Results

3.1. Changes in AP across East Asia and its subregions

The AP pattern in EA displays a gradual increase from the early to mid-Holocene, followed by a consistent decline starting approximately 5 cal. ka BP (Fig. 2a). It is obvious that the forest vegetation in EA exhibited a notable, albeit non-synchronous, decrease during the mid- to late-Holocene periods (Fig. 2c, e, g, i and k). The AP in NEC showed an obvious escalation during the early Holocene and a peak during the early mid-Holocene, followed with a consistent decrease after 5 cal. ka BP and a second drop near 3 cal. ka BP (Fig. 2c). In contrast, the AP alterations in MLYR were negligible between the early and mid-Holocene periods. However, two distinct dips were discerned during the mid to late Holocene, approximately at 5.2 cal. ka BP and 2.2 cal. ka BP (Fig. 2e). NWC registered two significant AP downturns during the Holocene at around 9.5 cal. ka and 6.8 cal. ka BP (Fig. 2g). In NETP, the AP exhibited a rise during the early Holocene and then initiated a continuous fall at about 8 cal. ka BP (Fig. 2i). In SWC, although the AP changes were insignificant from the early Holocene to mid-Holocene, two noticeable declines were identified during the mid to late Holocene at approximately 5.2 cal. ka BP and 1.2 cal. ka BP (Fig. 2k).

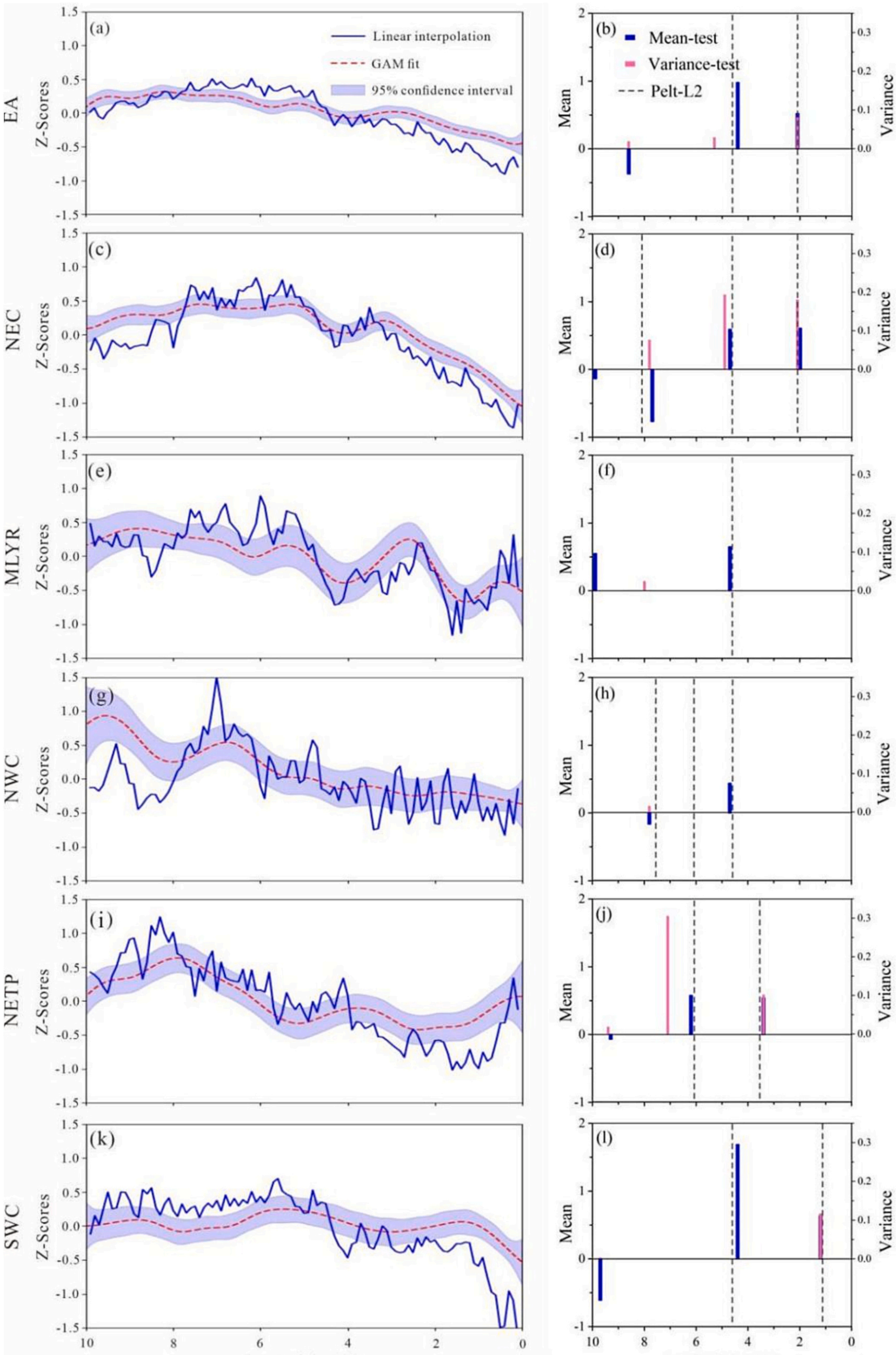

Fig. 2. GAM Fitting and linear interpolation results of AP sequences in East Asia and its subregions (left hand) and its corresponding regime shift detection results (right hand).

3.2. Regime shift detection results

To quantify the degree of forest vegetation decline, we employed a mean and variance test from the STARS to analyze the AP in East Asia and its subregions (Fig. 2b, d, f, h, j and l; Figs. S2 and S3). In our examination of forest vegetation decline, the term "regime shifts" is predominantly used to underscore the transition from a quantitative to a qualitative change. It represents the juncture at which forest vegetation has deteriorated to a state where recovery is nearly unattainable. Subsequently, the Pelt algorithm from the ruptures library was utilized for verification (Table S2). The convergence of these three methods on comparable results significantly enhances the likelihood of a regime shift, such as the shift observed at 2.1 cal. ka BP of AP in East Asia (Fig. 2b). Additionally, the AP changes at 2.1–2 cal. ka BP in NEC, at 3.6–3.4 cal. ka BP in NETP, and at 1.2–1.1 cal. ka BP in SWC were also recognized as regime shifts (Fig. 2d, j and l), because the maximum errors of these methods were only 200 years, a negligible amount. Importantly, both the STARS mean test and the Pelt-based algorithm flagged regime shifts of AP in MLYR, NWC, and SWC at approximately 4.7–4.6 cal. ka BP, while the variance test did not agree (Fig. 2f, h and l). Furthermore, in some regions, including EA (5.3–4.4 cal. ka BP) (Fig. 2b), NEC (8.1–7.7 cal. ka BP and 4.9–4.6 cal. ka BP) (Fig. 2d), and NETP (7.1–6.1 cal. ka BP) (Fig. 2j), all three methods indicated regime shifts of AP but with notable discrepancies. These instances could not be definitively categorized as regime shifts. In summary, through the combination of these three methods, we identified a total of four regime shifts of AP (Text S1).

4. Discussion

4.1. Evolutionary characteristics of forest ecosystems in EA during the Holocene

During the early to mid-Holocene, there was a general trend of forest expansion in NEC, with forest coverage starting to decrease at approximately 5 cal. ka BP (Fig. 3a). It is evident that forest vegetation variation aligns with climate change and paleosol development in this region (Fig. 3b, c and h; Fig. S4). In the early to middle Holocene, the climate leaned towards warmer and wetter conditions (Chen et al., 2016), and paleosol development gradually increased, favoring the expansion of forest vegetation. Conversely, after around 5 cal. ka BP, the climate became cooler and drier (Fig. 3b and c), aeolian sand activities intensified and paleosol development weakened (Fig. 3h), and forest vegetation accordingly retreated. Thus, Holocene forest variation in NEC was primarily driven by climate change. It is important to note, however, that the forest vegetation retreat at approximately 5 cal. ka BP is likely to be involved in anthropogenic factors. Around 7000 years ago, the region witnessed the emergence of the Yangshao culture, a society primarily centered on agriculture (Bao et al., 2018; Zhao, 2014, 2020). The synchronous upsurge in archaeological sites and charcoal concentrations indicated a heightened usage of fire (Fig. 3d and e). This trend may be due to acquiring lands by the Yangshao people with slash-and-burn technique. And the transition from Yangshao to Longshan cultures occurred between 5 and 4 cal. ka BP, during which the cultivation of millet increased significantly (Bao et al., 2018). Moreover, the Yangshao and Longshan cultures are renowned for their pottery production, which necessitated substantial quantities of wood as fuel, potentially contributing to the decline of forest vegetation. Forest vegetation fell sharply again at about 3 cal. ka BP in NEC (Fig. 3a), which we attribute to human activities due to several reasons. First, the population in the Yellow River Basin expanded northward during this period (Zhang et al., 2017); Second, the increased ratio of Cereal-type *Poaceae/Poaceae* (Fig. 3f) and content of *Sporormiella* fungal spores (Fig. 3g) suggest an increase in domesticated plants and intensified grazing activity during this time; Third, relatively high concentrations of charcoal and black carbon were detected during this period (Fig. 3e), implying that human beings

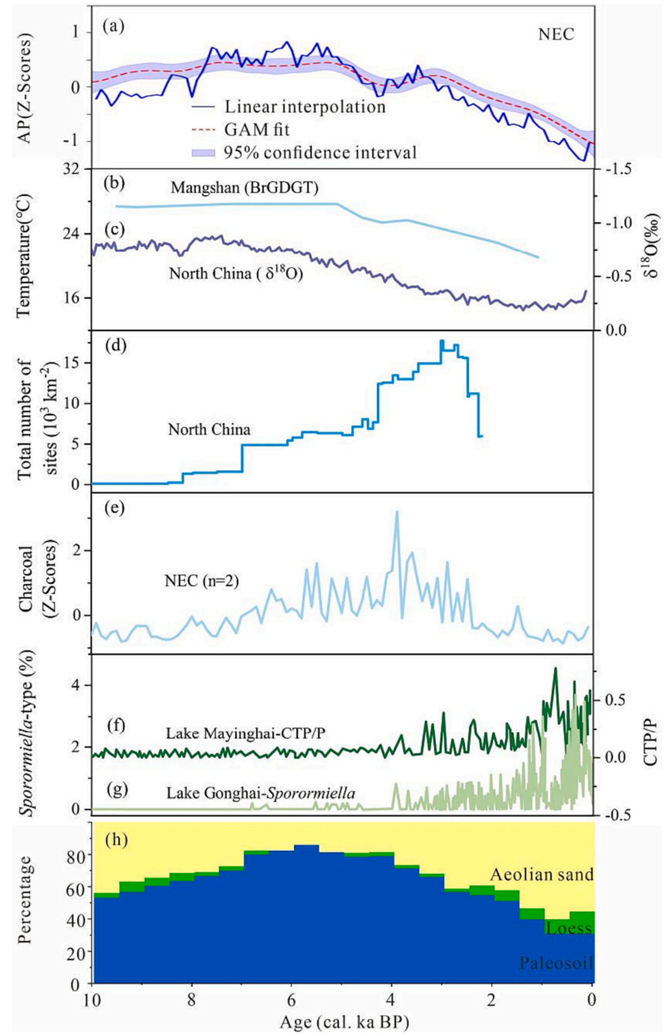

Fig. 3. Comparison of AP with other proxies in NEC: (a) GAM Fitting and linear interpolation results of AP in NEC; (b) Temperature changes in Mangshan based on BrGDGT (Peterse et al., 2011); (c) $\delta^{18}O$ in North China (Yang et al., 2019); (d) Total number of sites in north China (Wagner et al., 2013); (e) *Z*-Scores of charcoal records in NEC (Wang et al., 2013; Ren et al., 2022); (f) Cereal-type *Poaceae/Poaceae* (CTP/P) in lake Mayinghai (Ren et al., 2022); (g) *Sporormiella*-type in lake Gonghai (Huang et al., 2021); (h) Loess-paleosol change in northern China (Li et al., 2014).

employed fire to clear forests and establish plantations, which could have led to a decline in forest vegetation. Furthermore, as the forest vegetation continued to diminish, the forest ecosystem in this region underwent a regime shift approximately at 2.1 cal. ka BP (Fig. 2d). This shift probably catalyzed a transformation of the regional landscape from forest to grassland. This is due to that most lakes and their surrounding catchments in NEC witnessed a shift from temperate broadleaf and deciduous forests to temperate grasslands around that time (Liu et al., 2002; Tarasov et al., 2006; Tian et al., 2020; Ren et al., 2022), when the regional vegetation type was already close to the modern vegetation type.

In the MLYR subregion, two significant retreats of forest vegetation occurred during the Holocene, with the first taking place around 5.2 cal. ka BP (Fig. 4a). This event coincided with decreases in temperature and precipitation (Fig. 4b and c) and an increase in charcoal content (Fig. 4d). Except this period in which AP aligns with temperature and precipitation, there seems minimal correlation between AP and climate change (Fig. S4). Neolithic sites in MLYR began proliferating around 7.5 cal. ka BP (Fig. 4e), when Majiabang/Hemudu (7.5–5.9 cal. ka BP),

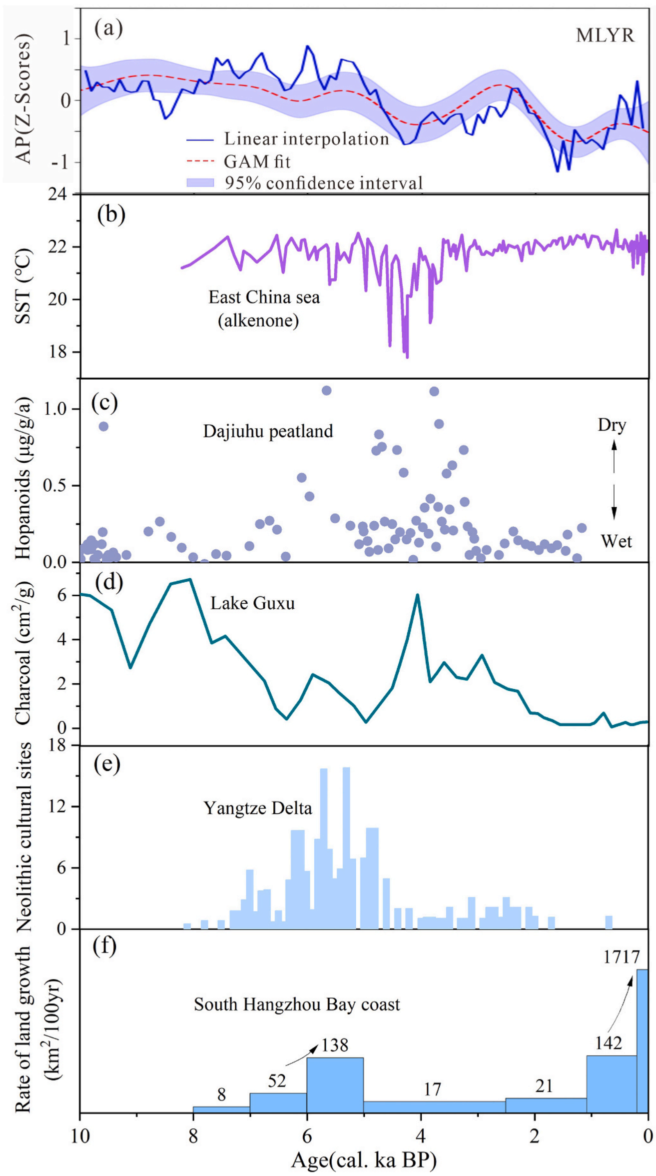

Fig. 4. Comparison of AP with other proxies in MLYR (a) GAM Fitting and linear interpolation results of AP in MLYR; (b) Alkenone temperature in East China sea (Kajita et al., 2018); (c) Hopanoids in Dajiuhu peat (Xie et al., 2013); (d) Charcoal records from Guxu lake (Qiu et al., 2020) (e) Frequency of dates for Neolithic cultural sites (Zhang et al., 2005); (f) The rate of land growth in the south Hangzhou Bay coast (Liu et al., 2021).

Songze (5.9–5.2 cal. ka BP), and Liangzhu (5.2–4.2 cal. ka BP) cultures developed sequentially (Wu et al., 2012; Kajita et al., 2018). These predominantly agricultural Neolithic cultures likely prompted the expansion of agricultural land use and consequent forest vegetation retreat. Interestingly, we observed that AP decrease was not prominent during the Majiabang/Hemudu and Songze periods, potentially due to the rapid expansion of land in southern Hangzhou Bay from 52 km^2/100 yr to 138 km^2/100 yr (Fig. 4f). As land expansion towards the sea took place during this period, less forest area was utilized by humans, which is potentially the reason for the slight AP decrease in MLYR. However, with the onset of the Liangzhu culture at ~5.2 cal. ka BP, AP experienced a dramatic decline, far exceeding that of previous millennia. We also attribute this AP drop at ~5.2 cal. ka BP to the flourishing of the Liangzhu culture. Given that archaeological sites from the Liangzhu period expanded significantly (Fig. 4e) and rice cultivation matured considerably compared to previous cultural periods (Fuller et al., 2009), yet the extent of land expansion towards the sea decreased markedly (Fig. 4f). This forced humans to recede back into the forest, leading to clearing land and significantly increasing charcoal concentrations (Fig. 4d). Moreover, in a climate that increasingly became colder and drier, the likelihood of humans burning wood for heat greatly escalated. Around 4.2 cal. ka BP, a sudden temperature drop led to the lowest AP levels since the early to mid-Holocene (Fig. 4a and b), which coincided with the extinction of the Liangzhu culture (Wu et al., 2012; Kajita et al., 2018). The notable reduction in archaeological sites in the region during this period facilitated a brief vegetation recovery. However, AP plummeted again during the 2.2–1.7 cal. ka BP period, and reached a Holocene minimum around 1.7 cal. ka BP before hitting a turning point (Fig. 4a). Nevertheless, the climate was exceptionally warm and humid during this period, with human activities being the primary driver for the decline in forest vegetation. During the unification of the Six Kingdoms by Qin dynasty around 2.2 cal. ka BP, the region of MLYR was strategically significant and required large quantities of timber for war supplies and post-war reconstruction. Hence, we attribute the sharp decline in trees between 2.2 cal. ka BP and 1.7 cal. ka BP to the wars during this period. The rise in AP after 1.7 cal. ka BP can be attributed to the significant addition of land to the coastal lowlands after 2 cal. ka BP (Fig. 4f) and the gradual population migration to these lowlands. Afterward, human deforestation substantially decreased, allowing for gradual forest recovery.

In the SWC sub-region, AP exhibited minor changes from the early Holocene to early mid-Holocene, but manifested a noticeable downward trend after 5.2 cal. ka BP (Fig. 5a), with the significant decrease of the cold-tolerant *Tsuga* (Fig. 5b). This decline was likely attributable to selective logging by humans, which is evident from the significant increase in *Poaceae* content (Fig. 5c) and insignificant temperature variation during the same period (Fig. 5d). Following 5 cal. ka BP, the region experienced a marginal temperature alteration and continuous precipitation decrease (Fig. 5d and e). It is evident that climate exerted minimal influence on forest vegetation in this region (Fig. S4). Significantly, rice cultivation proliferated in SWC around 5–4 al. ka BP (Lv, 2017), alongside the flourishing of Neolithic cultures, including the Baiyangcun (5–3.7 cal. ka BP) and Baodun (4.8–4 cal. ka BP) cultures (Wu et al., 2012). Concurrently, high carbon flux was observed in SWC lake sediments post 5.2 cal. ka BP (Fig. 5f). Thus, the expansion of rice cultivation may have facilitated the regional forest vegetation decline. Significantly, the AP in the southwest exhibits a precipitous decline, or even a regime shift, after 1.2–1.1 cal. ka BP (Figs. 2l and 5a), implying a substantial ecological reorganization during this period. The considerable population increase (Fig. 5g), augmented lake sediment accumulation rates (Fig. 5h), and a marked uptick in magnetic mineral input into the lake (Fig. 5i), are all associated with increased anthropogenic soil erosion (Dearing et al., 2008; Wu et al., 2015; Hillman et al., 2019; Yang et al., 2022) and a shift in the lake's trophic state (Hillman et al., 2019). These phenomena as well as AP significant drop occurred after 1.2–1.1 cal. ka BP. This period aligns with the Tang and Song Dynasties in China when terrace agriculture advocating higher elevation expansion was gradually instituted (Guedes et al., 2013). This development led to the deforestation of high-altitude forests. Coupled with increased precipitation during this period (Wu et al., 2018), soil erosion in the region was exacerbated.

The forest vegetation in NETP demonstrated a steady decline from ~8 cal. ka BP until a sudden shift in the region's forest ecosystem at ~3.6–3.4 cal. ka BP (Figs. 2j and 6a). Notably, there was a pronounced negative correlation between the AP of this region and precipitation, with little and even no correlation with temperatures (Fig. 6b and c; Fig. S4). Hunter-gatherers in the NETP began planting *Panicum miliaceum* and *Setaria italica* at ~8 cal. ka BP (Bettinger et al., 2010). Subsequently, human activities began to influence the forest vegetation in the region. Around 6 cal. ka BP, there was a significant increase in the influx of *Sporormiella* fungal spores and in diversities of the fungal spores (Fig. 6d), indicating an enhancement of grassland nomadic activities.

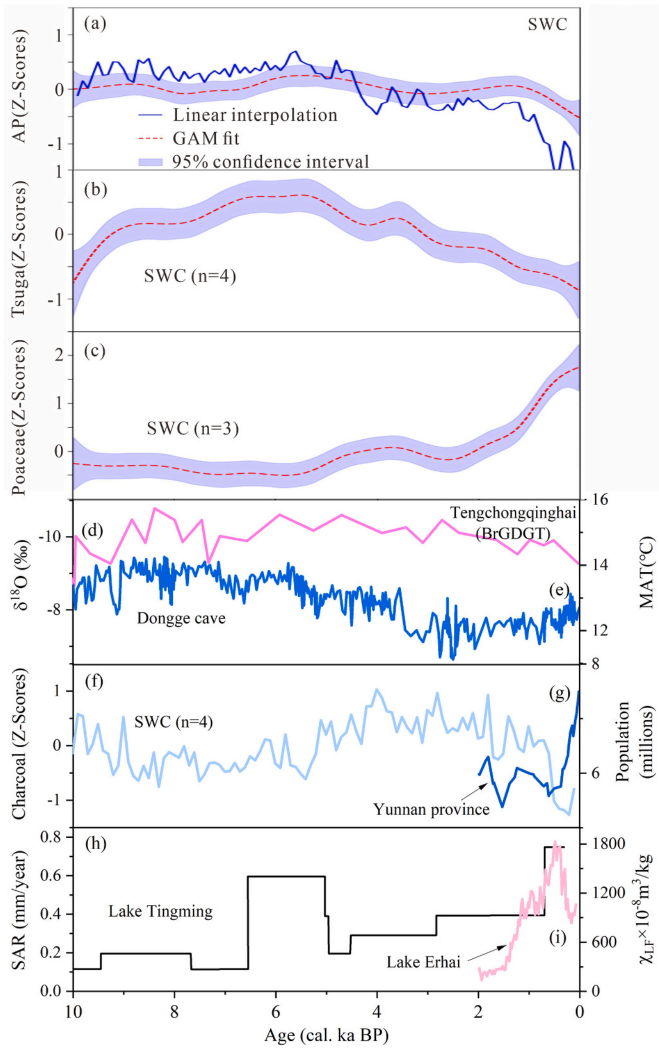

Fig. 5. Comparison of AP with other proxies in SWC (a) GAM Fitting and linear interpolation results of AP in SWC; (b) Compilation of *Tsuga* in SWC (Shen et al., 2006; Xiao et al., 2014, 2020; Wang et al., 2016); (c) Compilation of *Poaceae* in SWC (Shen et al., 2006; Xiao et al., 2014; Zhang et al., 2020); (d) Reconstruction of MAT based on BrGDGT (Zhang et al., 2020); (e) $\delta^{18}O$ from Dongge cave (Dykoski et al., 2005); (f) Compilation of charcoal records in SWC (Xiao et al., 2015, 2018, 2020; Zhang et al., 2020); (g) Population of Yunnan province (Zhao and Xie, 1988); (h) Sedimentation rate from Tingming lake (Sun et al., 2021); (i) χ_{LF} from Erhai Lake (Dearing et al., 2008).

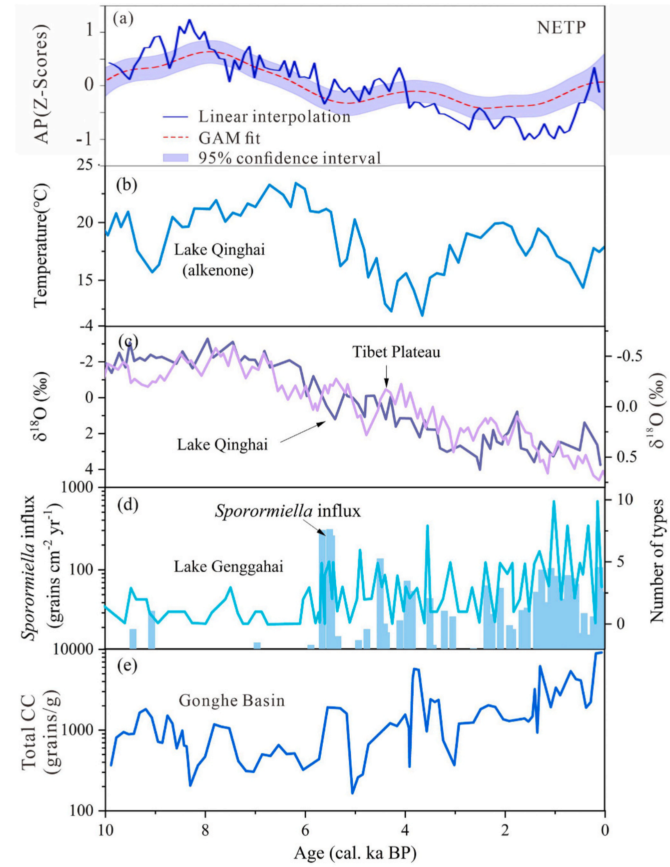

Fig. 6. Comparison of AP with other proxies in NETP (a) GAM Fitting and linear interpolation results of AP in NETP; (b) Reconstruction of alkenone temperature in lake Qinghai (Hou et al., 2016); (c) Synthesis of lacustrine $\delta^{18}O$ and δD records for the entire Tibet Plateau (Chen et al., 2020) and $\delta^{18}O$ records of lake Qinghai (Liu et al., 2007); (d) *Sporormiella* fungal spores influx and diversities of the fungal spores in lake Genggahai (Huang et al., 2020); (e) Total charcoal records from Gonghe Basin (Miao et al., 2017).

Given the continuous decrease in forest vegetation, it is plausible that by ~3.6–3.4 ka, the forest vegetation in the area might have reduced to a level which is challenging to restore. Several recent studies have identified three phases (20–5.2 cal. ka BP, 5.2–3.6 cal. ka BP and after 3.6 cal. ka BP, respectively) of prehistoric human encroachment on the Tibetan Plateau (e.g., Guedes et al., 2014, 2015; Chen et al., 2015, 2016; Zhang et al., 2016; Dong et al., 2017). Between 5.2 and 3.6 cal. ka BP, societies predominantly engaging in millet and corn cultivation expanded to inhabit low-altitude valleys (<2500 m) on the northeastern edge of the Tibetan Plateau. This expansion coincided with a noticeable increase in archaeological sites during 5–4 cal. ka BP (Chen et al., 2015; Hosner et al., 2016; Huang et al., 2017). Moreover, agro-pastoralists extensively migrated and settled at higher elevations (>3000 m) after 3.6 cal. ka BP. These human agricultural activities might have contributed to a decline in forest vegetation, especially after 3.6 cal. ka BP, when human habitation at higher elevations and forest vegetation transition occurred synchronously. It is worth noting that decreasing precipitation yet increasing temperature was observed after 3.6 cal. ka BP (Fig. 6b and c). Simultaneously, there was a significant population increase (Chen et al., 2015; Huang et al., 2017), accompanied by high-altitude grassland degradation (Huang et al., 2017) and an increased frequency of fires (Fig. 6e). Considering these circumstances, it is likely that ecological deterioration in the NETP region compelled prehistoric humans to move to high-altitude areas around ~3.6 cal. ka BP.

In the NWC subregion, desert grasslands primarily characterized the vegetation during the early Holocene, followed by the emergence of grassland vegetation in the mid-Holocene (Tao et al., 2010; Li et al., 2011). This development coincided with the region's warm and humid climate during the mid-Holocene, which was favorable for tree growth. However, due to environmental constraints, early human activities were relatively scarce in this area, yet the prehistoric population surged during the Holocene climatic optimum (Xiang et al., 2023). Seemingly, for NWC subregion, where climate change significantly influences forest vegetation and population distribution, alterations in forest vegetation may not sensitively reflect human-vegetation interaction.

In sum, excluding NWC, the relationship between Holocene AP fluctuations, climate changes, and human activities in each EA subregion can be delineated as presented in Fig. 7. The primary factors to influence forest vegetation in NEC were climate change and human activities. During the Yangshao and Longshan periods, agriculture and pottery production significantly caused forest vegetation decline. Since ~5 cal. ka BP, forest vegetation has been continuously declining, with the landscape transition from forest to grassland at ~2.1 cal. ka BP (Fig. 7a). Compared to evolution patterns of NEC, the forest vegetation

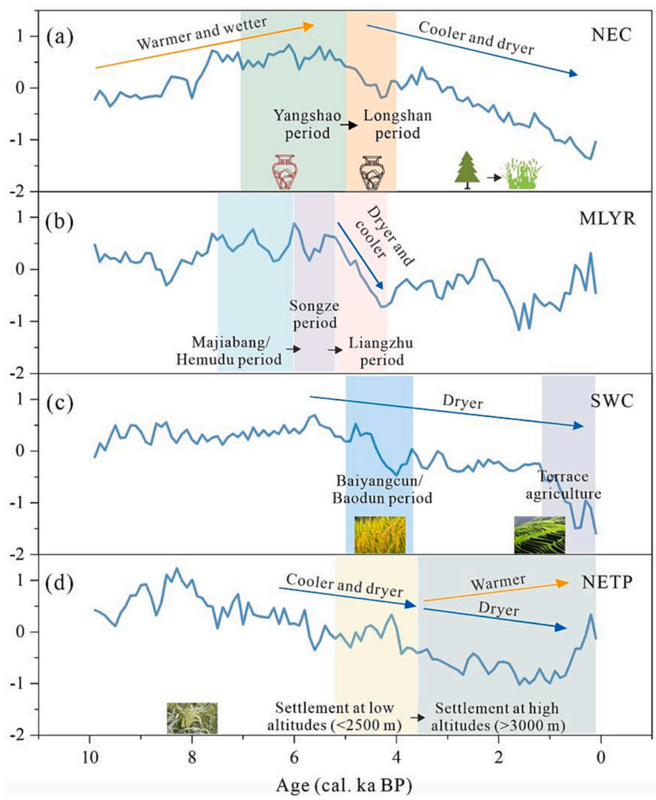

Fig. 7. Relationship between AP and climate change and human activities in the EA subregions (The blue curve represents the *Z*-Scores of AP in each subregion; yellow and blue arrows represent change trends of temperature and precipitation, respectively; The shaded part represents the transformation of different cultural stages or the change of prehistoric human settlement from low altitude to high altitude). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

in MLYR is more profoundly affected by human activities, especially after ~2 cal. ka BP when changes in forest vegetation seem decoupled from climate fluctuations (Fig. 7b). This may be attributed to NEC's positioning at the edge of monsoons, where forest vegetation is more sensitive to climatic change. In the SWC, two significant declines occurred in the forest vegetation sequence, one with the spread of rice cultivation and the other with the advent and prosperity of terraced agriculture (Fig. 7c). Moreover, due to the continuous decline of forest vegetation, the ecosystem of SWC underwent a significant reorganization around 1.2 cal. ka BP. The decline in the forest vegetation of the NETP region began as early as 8 cal. ka BP, reaching a near-irreversible state by ~3.6 cal. ka BP, which was accompanied by grassland degradation and triggered the migration of prehistoric humans to higher altitudes (Fig. 7d). Therefore, the forest vegetation across all subregions have experienced different amplitudes in human's impacts due to the Neolithic agricultural expansion.

4.2. Anthropogenic impacts on forest of East Asia since the mid-Holocene

During the mid to late Holocene, forest vegetation in EA lake basins demonstrated a declining trend (Fig. 8a), corresponding with cooling and drying climatic conditions (Fig. 8b and c). This decline was closely linked to the prevalent climatic shifts of this period (Figs. S5a-S5c). However, an increasing body of research proposes that anthropogenic influences on vegetation became increasingly dominant during the mid- to late Holocene (e.g., Ren, 2000; Cheng et al., 2018; Jenny et al., 2019; Mottl et al., 2021; Thompson et al., 2021; Zheng et al., 2021; Cao et al., 2022; Ren et al., 2022). The mid- and late Holocene climate was generally cold and dry, an environment unfavorable for tree growth. This condition also led to a diminished food supply for hunting and gathering, compelling humans to domesticate plants and animals. Consequently, agriculture and livestock cultivation saw a swift development, and the increased food supply stimulated population growth. Drawing on the correlation between human activities and forest vegetation evolution in different subregions of EA, we postulate that human encroachment on forests, driven by the development of agriculture and pastoralism since the Neolithic era, which in turn led to a significant decline in regional forest vegetation. At 7–6 cal. ka BP, Neolithic sites in China began to emerge (Hosner et al., 2016), followed with a significant growth in the number of archaeological sites and population recorded after approximately 5 cal. ka BP (Fig. 8d and e). This period marked the advent of widespread farming and animal husbandry activities in the MLYR and NEC regions (Li et al., 2020), resulting in more than a twofold expansion in rice farming (Fig. 8d). A pronounced negative correlation between AP and population/archaeological sites in EA was observed (Figs. S5d and S5e). As populations grew, the lifestyle transition from hunting-gathering to settled agriculture invariably led to an expansion of agricultural land. Additionally, for the purpose of settlement, heating and farming, human were likely to clear and burn adjacent vegetation, rendering fire a crucial instrument of human impact on vegetation (Thompson et al., 2021). A significant surge in charcoal concentration occurred after 4.5 cal. ka BP, maintaining a high carbon flux for thousands of years subsequent to 2 cal. ka BP (Fig. 8f), may demonstrate that humans use fire to clean forests. And there is a significant negative correlation between AP and concentration of charcoal (Fig. S5f).

It is noteworthy that the methane concentration in the atmosphere began an upward trajectory after 5 cal. ka BP (Fig. 8g). This trend corresponds with a substantial decrease of AP in East Asia (Fig. 8a) and a significant increase in population, rice distribution area and charcoal concentration (Figs. 8d-8f), alongside surges in deposition rates (Fig. 8f). However, the correlation between AP and methane concentration during the Holocene was not significant (Fig. S5g). Ruddiman (2007) pinpointed human activities (including livestock and human waste emissions, biomass burning, and irrigation), with irrigation identified as the chief factor, for the anomalous rise in methane concentrations during the late Holocene. Contrarily, according to the records from successive interglacials, methane concentrations should have continued to decline in a naturally evolved state (Steffen et al., 2006). Importantly, a significant negative correlation exists between AP and CO_2 (Fig. S5h). Forests serve a critical role in carbon sequestration. Consequently, human activities such as deforestation and slash-and-burn agriculture could release significant amount of CO_2, contributing to a rise in atmospheric CO_2 levels. Moreover, forest vegetation aids in soil stabilization and water conservation; thus, its reduction can lead to severe soil erosion. As the watershed's sink, a lake reflects the basin-wide sediment flux; an increase in sediment accumulation rates, therefore, denotes escalating soil erosion within the basin (Zhang et al., 2022). Cendrero et al. (2022) noted that sediment discharge is even 41.7 times greater in areas where human activities considerably influence vegetation, suggesting that the impacts of human activities on sediment transport substantially surpassed the natural conditions. The sediment accumulation rate in Chinese lakes began to rise around 4.8 cal. ka BP (Fig. 8f), coinciding with the decline of AP in East Asia, and a significant negative correlation exists between the two changes (Fig. S5i). Sediment accumulation rates surged after 2 cal. ka BP and, notably, significantly exceeded the rates of the preceding 40 ka under natural conditions (Zhang et al., 2022).

Sliding correlation analysis results suggest a significant intensification in the impacts of both climate and human activities on forest vegetation since the mid-Holocene (Figs. S6a-S6d). Notwithstanding, the influence of precipitation on forest vegetation markedly diminished over the following 5 cal. ka BP (Fig. S6b). Relative to temperature and precipitation, mean effective moisture exerted a more profound impact on forest vegetation. It is noteworthy that the correlation between AP and regional population growth has remained high since the mid-

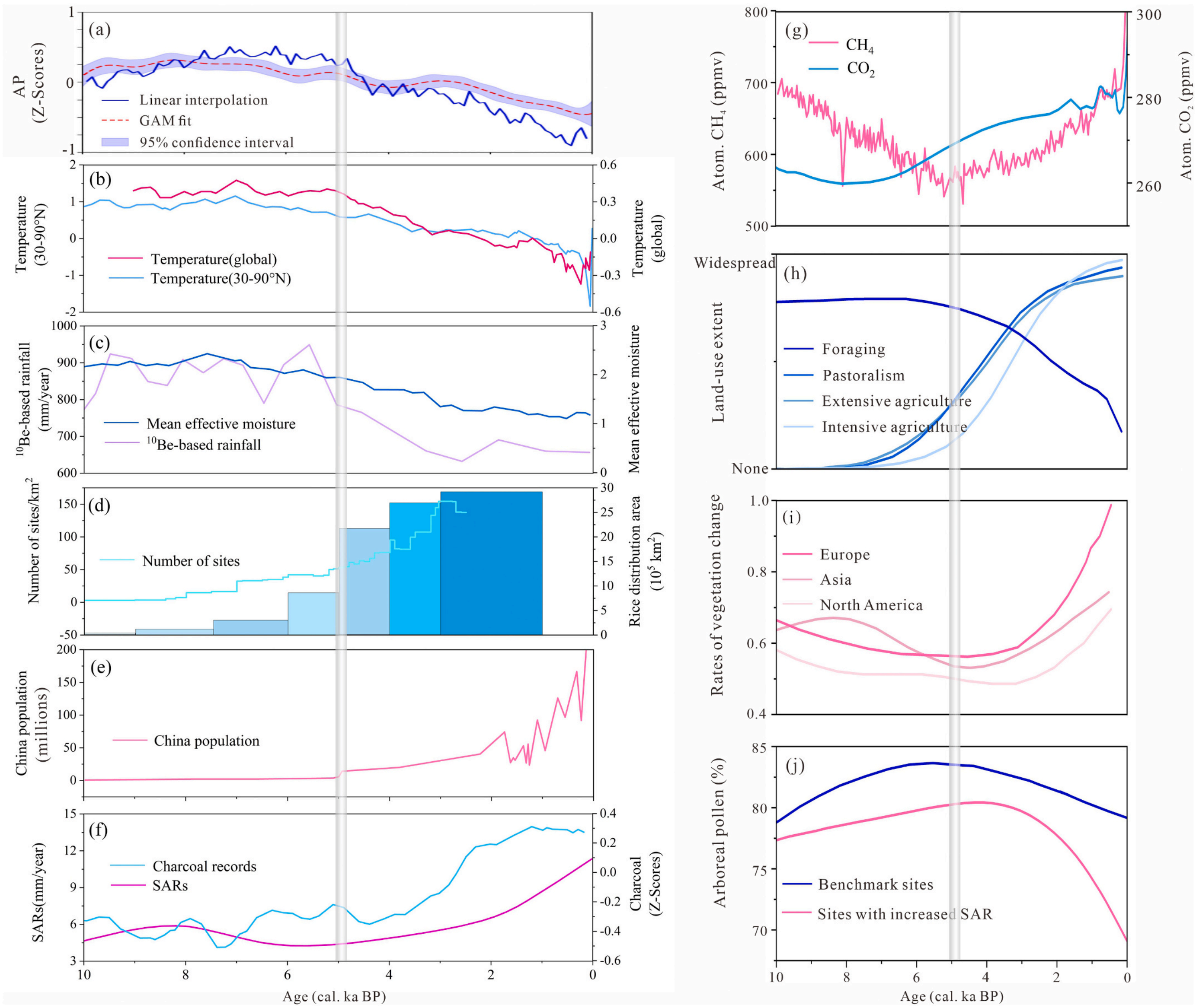

Fig. 8. (a) GAM Fitting and linear interpolation results of AP in EA; (b) Reconstruction of paleo-temperature in global (Shakun et al., 2012) and at 30–90° N (Marcott et al., 2013) based on multiple indicators; (c) Reconstruction of Holocene mean effective moisture in China based on multiple indicators (Herzschuh, 2006) and rainfall based on ^{10}Be (Beck et al., 2018); (d) Reconstruction of archaeological sites (Hosner et al., 2016) and rice distribution area (Li et al., 2009); (e) Reconstruction of population in China (Li et al., 2009); (f) Charcoal records (Xu et al., 2021) and lake deposit accumulation rates (Zhang et al., 2022) in China; (g) Global CH_4 and CO_2 reconstruction (Köhler et al., 2017); (h) Global land-use extent (Stephens et al., 2019); (i) Global vegetation change rates (Mottl et al., 2021); (j) Global arboreal pollen (Jenny et al., 2019).

Holocene (Fig. S6d), underscoring the growing influence of human activities on forest vegetation. Thus, the persistent decline of forest vegetation since 5 cal. ka BP can be attributed to both climatic and anthropogenic modifications. Cheng et al. (2018) conducted a comparative study of vegetation changes over the last five interglacials, and found that the Holocene vegetation exhibited an early downward trend compared to its predecessors. This suggests that the evolution of Holocene vegetation diverged from the trajectory observed in successive interglacials. Importantly, as forest vegetation in EA continue to decline, a regime shift has occurred at ~2.1 cal. ka BP in the region (Fig. 2b). Notably, an exponentially growing population (Fig. 8e), substantial expansion of cropland and pasture (Klein Goldewijk et al., 2017; Li et al., 2020), a peak in charcoal concentration (Fig. 8f), forest fragmentation (Zheng et al., 2021), a significant reduction in vegetation biodiversity (Mottl et al., 2021; Cao et al., 2022), and a marked increase in soil erosion (Dearing et al., 2008; Wu et al., 2015; Hillman et al., 2019; Yang et al., 2022; Zhang et al., 2022; Zhao et al., 2023), also ensued after 2.1 cal. ka BP. It is acknowledged that increased human activity led to a tremendous reorganization of the ecological environment in EA. Therefore, it is plausible to conclude that the forest vegetation retraction to a near-irreversible state was a direct consequence of intensified human activities, given the continuous shift towards colder and drier climatic conditions.

On a global scale, we observed an expansion in agricultural and pastoral lands commencing around 7 cal. ka BP. Despite this, the primary activities of our forebears remained hunting and gathering until approximately 5 cal. ka BP (Fig. 8h), a timeline that corresponds with the onset of forest vegetation decline in East Asia (Fig. 8a). Between ~7 and 2 cal. ka BP, the footprint of agricultural and pastoral lands underwent a significant increase, reaching extensive global distribution by 2 cal. ka BP (Fig. 8h). Concurrently, the forest vegetation in East Asia experienced a decline to near irreversible levels. By 10 cal. ka BP, agriculture and livestock rearing had taken root across the globe, and between 10 and 4 cal. ka BP, agro-pastoral practices spread widely in Asia, Europe, Africa, and South America. These practices, however, were scarcely prevalent in North America and Oceania during the initial years (Stephens et al., 2019). In regions such as North America and Oceania, where agro-pastoral activities were limited, the rate of vegetation change started to increase much later than in other continents (Mottl et al., 2021). Furthermore, global changes in vegetation composition underwent a significant acceleration from 4.6 to 2.9 cal. ka BP, a trend that is unprecedented in both magnitude and extent over the past 18,000 years (Mottl et al., 2021). We note that the decline of East Asian forest vegetation coincides with a period of rapid vegetation changes across Asia. Interestingly, compared to Europe and North America—both situated in the Northern Hemisphere—the initiation of these rapid changes in vegetation transpired significantly earlier (Fig. 8i). This observation suggests that the swift vegetation alterations during the mid-late Holocene were unlikely to have been driven by broad-scale climatic factors. In addition, the global soil erosion transitioned from natural to human-induced forces at approximately 4 cal. ka BP, just consistent with a decline in arboreal pollen (Fig. 8j).

4.3. Implications for "Anthropocene"

The most striking feature of climate changes during the Quaternary is the glacial-interglacial cycle. Even though each cycle varies, the overall evolutionary path remains constant (Hays et al., 1976; Past Interglacials Working Group of PAGES, 2016). The Holocene, an interglacial period lasting over 12,000 years, is comparable in duration and warmth to interglacials of the past 1.2 million years. However, the swift evolution of the climate system over the past half century, compounded by human technological entrenchment and socioeconomic inertia, has driven the earth system rapidly moving out of the glacial-interglacial cycle (Steffen et al., 2007). In light of the present research on global change, Crutzen and Stoermer (2000) introduced the concept of the Anthropocene. This new geological epoch signifies the period of modernization post-industrialization, underscoring humans' unique role in geology and ecology, and setting it apart from the post-glacial Holocene. In recent times, scholars from various disciplines have increasingly engaged in discussions about the Anthropocene. Some argue that while the Anthropocene should be recognized as a geologic event, it should not be situated within a geologic chronology (e.g., Bauer et al., 2021; Kunnas, 2021; Gibbard et al., 2022a, 2022b). Additionally, debates continue regarding the precise onset of the Anthropocene. The prevailing Anthropocene paradigm posits that "human-induced global environmental change is a recent phenomenon" (e.g., Macfarling Meure et al., 2006; Lewis and Maslin, 2015; Head et al., 2022). Several researchers have proposed differing onsets for the Anthropocene. These include the fusion of the 'Old World' and 'New World' populations ca. 1610 CE (Macfarling Meure et al., 2006), the Industrial Revolution in the 1800s (Steffen et al., 2007; Ellis et al., 2013; Lewis and Maslin, 2015), and the global nuclear explosion of 1964 (Rakowski et al., 2013). However, to officially classify the Anthropocene as a geological epoch, it necessitates the identification of a "golden spike" within stratigraphy. The Anthropocene Working Group recently put forth a proposal identifying the mud of Crawford Lake, Canada, as this stratigraphic "golden spike", which catalogues the "great acceleration" commencing in the 1950s (Voosen, 2023; Witze, 2023). Obviously, numerous perspectives identify the inception of the Anthropocene within the past several centuries. However, Ruddiman (2003) postulated that anthropogenic emissions of greenhouse gases began altering atmospheric concentrations thousands of years ago. Subsequent work supported this claim with additional evidence (Ruddiman, 2007), demonstrating that human influences on greenhouse gases and global climate commenced millennia ago, incrementally intensifying until the rapid growth instigated by the industrial era. Moreover, a reconstruction of historical population and land use spanning the past 12,000 years, conducted by Ellis et al. (2021), suggests that human activity significantly altered the terrestrial environment much earlier than previously recognized. This contested temporal boundary has led certain scientists to object to the formal recognition of the Anthropocene as a stratigraphic unit, arguing that a centennial-scale Anthropocene has primarily social implications, and its scientific feasibility and necessity remain ambiguous (e.g., Gibbard et al., 2022a, 2022b).

In reality, human-induced modifications of ecosystems have accompanied the development of civilizations throughout the entire Holocene. A mounting body of evidence suggests that human activities have reshaped surface landscapes and vegetation over millennia (e.g., Giguet-Covex et al., 2014; Fyfe et al., 2015; Jenny et al., 2019; Ellis et al., 2021; Mottl et al., 2021; Nogué et al., 2021; Thompson et al., 2021; Roberts et al., 2021; Gibbard et al., 2022a, 2022b; Zhang et al., 2022; Dreibrodt et al., 2023; Zhao et al., 2023), leading to irreversible effects on the land surface (Stephens et al., 2019). Based on sediment accumulation rates and pollen records from 632 global lakes, Jenny et al. (2019) posited that the initial increase in lake sedimentation took place around 4 cal. ka BP, attributing most of the associated surface soil erosion to human activity. Stephens et al. (2019) conducted a comprehensive archaeological assessment of global land use over the past 10,000 years, suggesting that by 3 cal. ka BP, the Earth's surface had been significantly modified by hunter-gatherers, and intensive agropastoralism began to replace hunter-gathering, resulting in largely irreversible long-term changes. Mottl et al. (2021) analyzed 1181 global-scale pollen data sets and found that between 4.8 and 2.9 cal. ka BP, the impacts of human on the terrestrial system surpassed those of climate change. Thompson et al. (2021) examined the paleoenvironment in the past 600 cal. ka BP in Malawi in central and southern Africa, and then proposed that the period of ecological transformation could be lengthy, complex, and iterative. They further posited that modern human have significantly altered ecosystems, though identifying the origins or early outcomes of these changes remains challenging.

In our study, we observed a continuous decline in East Asian forest vegetation after 5 cal. ka BP, closely associated with agricultural development displacing natural vegetation. We propose a potential mechanism to depict human activity's influence on forest vegetation (Fig. 9). The cooling and drying climate may have altered EA's intact forests during the mid- and late Holocene. As a result, changes in climate could have led to a decline in natural food supply, potentially inciting a food crisis that may have compelled humans to domesticate plants and animals, replacing hunting and gathering, and initiating settled agriculture. With the expansion of agriculture, humans primarily gained agricultural land by clearing and burning intact forests, resulting in a forest decline. Undoubtedly, there exists a significant positive feedback effect between population growth and agricultural development. Obviously, with the continuous expansion of population, the area of forest decreases accordingly. In this way forest recovery within a brief period becomes unfeasible; if the forest reduction surpasses a particular threshold, restoration may not be possible. Furthermore, escalating populations also lead to increased wood consumption for construction and heating. Therefore, under the continuing cooling and drying climate, the strengthening human activities could have accelerated the decline in forest vegetation since 5 ka ago. It is worth noting that the present forest vegetation in EA appears to have reached a Holocene minimum (Fig. 8a), and it is likely that the forest vegetation in the region has been destroyed to an irrecoverable state at ~2 cal. ka BP. Consequently, contrary to the Anthropocene paradigm's viewpoint, we assert that the human impact on the Earth's surface should be evaluated on a millennial scale rather than a centennial one. Recognizing that human impacts on the ecological environment accumulate gradually across different time scales—a process transitioning from quantitative to qualitative change—it would be unsuitable to overlook thousands of years of accumulated quantities just because qualitative changes manifested in the last few centuries. When defining the Anthropocene, it is essential to clarify whether its onset coincides with the initial human

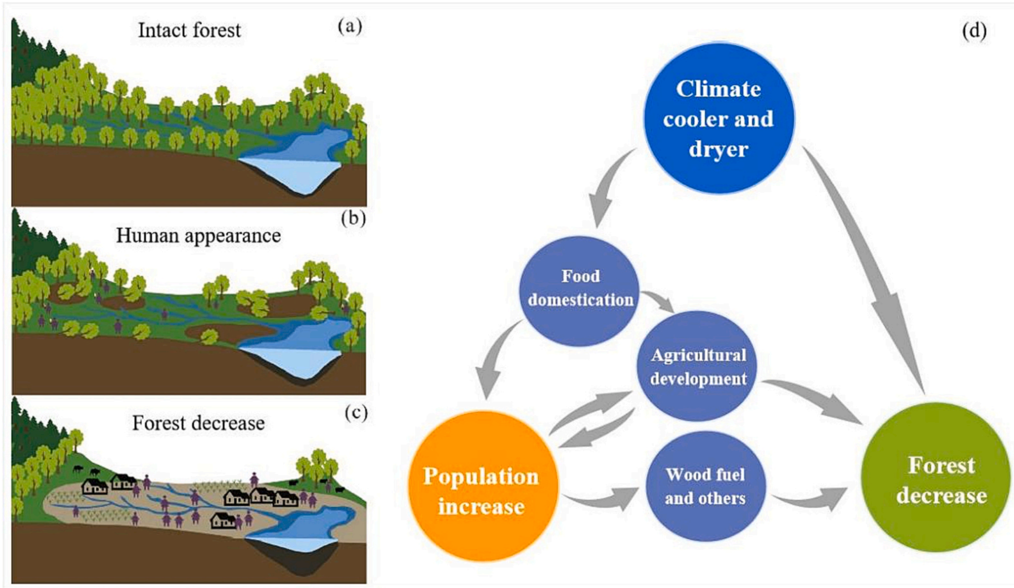

Fig. 9. Influencing and feedback mechanisms of climate change and human activities on forest vegetation.

influence or with the point at which anthropogenic impact supersedes natural forces and becomes dominant.

5. Conclusion

Our synthesis of the Holocene pollen record from 61 lake basins in EA disclosed a steady AP increase from the early to mid-Holocene, succeeded by a consistent decline starting approximately at 5 cal. ka BP. We partitioned EA into five subregions (NEC, MLYR, NWC, NETP, and SWC) to analyze the relationship between forest evolution, climate change and human activities. Each subregion demonstrated an asynchronous forest vegetation decline during the mid- and late Holocene, coinciding significantly with the emergence and progression of Neolithic agriculture and pastoralism. Obviously, there is a significant intensification in the impacts of human activities on forest vegetation since the mid-Holocene. During the mid- and late Holocene, the cold and dry climate of EA hindered forest expansion. Concurrently, the shift towards grazing and cultivation from hunting and gathering led to an upswing in land utilization for agricultural and pastoral purposes, progressively supplanting forest areas. This transition likely resulted in a significant decline of forest vegetation in the region. Additionally, a strong positive feedback between population growth and agricultural expansion can amplify human impacts, which combined with climatic effects, accelerated a reduction of EA's forest vegetation to its lowest level around 2.1 cal. ka BP since 10 cal. ka BP. We also identified that the timing of human impacts on forest reduction in East Asia aligns with global trends in land use, soil erosion, vegetation variability, and other surface environmental shifts. This synchronicity even corresponds with timing of deviations from natural trajectories in changes to atmospheric greenhouse gas content. Finally, we propose that the definition of Anthropocene should underscore the cumulative environmental effects of human activities spanning thousands of years, rather than focusing solely on the last few centuries.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

I have shard the link to my data at the Attach File step

Acknowledgments

We thank all those who made their pollen data available in datasets for reanalysis in this research. This research was supported by the National Key Research and Development Program of China (2022YFF0801103), the Strategic Priority Research Program of Chinese Academy of Sciences (No. XDB40010200), the National Natural Science Foundation of China (No. 41977381), Youth Innovation Promotion Association CAS (grant No. Y201959), the Science and Technology Planning Project of NIGLAS (grant No. NIGLAS2022GS01).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.earscirev.2023.104552.

References

Bao, Y.G., Zhou, X.Y., Liu, H.B., Hu, S.M., Zhao, K.L., Atahan, P., Li, X.Q., 2018. Evolution of prehistoric dryland agriculture in the arid and semi-arid transition zone in northern China. PLoS One 13 (8), e0198750. https://doi.org/10.1371/journal.pone.0198750.

Bauer, A.M., Edgeworth, M., Edwards, L.E., Ellis, E.C., Gibbard, P., Merritts, D.J., 2021. Anthropocene: event or epoch? Nature 597 (7876), 332. https://doi.org/10.1038/d41586-021-02448-z.

Beck, J.W., Zhou, W.J., Li, C., Wu, Z.K., White, L., Xian, F., An, Z.S., 2018. A 550,000-year record of East asian monsoon rainfall from 10Be in loess. Science 360 (6391), 877–881. https://doi.org/10.1126/science.aam5825.

Bettinger, R.L., Barton, L., Morgan, C., 2010. The origins of food production in north China: A different kind of agricultural revolution. Evol. Anthropol.: Issues, News, and Reviews: Issues, News, and Reviews 19 (1), 9–21. https://doi.org/10.1002/evan.20236.

Cai, Y., Zhang, J.R., Yang, N., Zhang, C., Zhao, C., Long, H., 2022. Human impacts on vegetation exceeded the hydroclimate control 2 ka ago in the Qinghai Lake basin revealed by n-alkanes of loess. Palaeogeogr, Palaeoclimatol, Palaeoecol 607, 111269. https://doi.org/10.1016/j.palaeo.2022.111269.

Cao, X.Y., Tian, F., Herzschuh, U., Ni, J., Xu, Q.H., Li, W.J., Chen, F.H., 2022. Human activities have reduced plant diversity in eastern China over the last two millennia. Glob. Chang. Biol. 28 (16), 4962–4976. https://doi.org/10.1111/gcb.16274.

Cendrero, A., Remondo, J., Beylich, A., Cienciala, P., Forte, L., Golosov, V., Płaczkowska, E., 2022. Denudation and geomorphic change in the Anthropocene; a global overview. Earth Sci. Rev. 104186 https://doi.org/10.1016/j.earscirev.2022.104186.

Chen, F.H., Dong, G.H., Zhang, D.J., Liu, X.Y., Jia, X., An, C.B., Jones, M.K., 2015. Agriculture facilitated permanent human occupation of the Tibetan Plateau after 3600 BP. Science 347 (6219), 248–250. https://doi.org/10.1126/science.1259172.

Chen, F.H., Liu, F.W., Zhang, D.J., Dong, G.H., 2016. The process and driving force for peopling the Tibetan Plateau during prehistoric periods. Chinese J. Nat. 38 (4), 235–240. https://doi.org/10.3969/j.issn.0253-9608.2016.04.001.

Chen, J.H., Rao, Z.G., Liu, J.B., Huang, W., Feng, S., Dong, G.H., Chen, F.H., 2016. On the timing of the East Asian summer monsoon maximum during the Holocene—Does the speleothem oxygen isotope record reflect monsoon rainfall variability? Sci. China Earth Sci. 59, 2328–2338. https://doi.org/10.1007/s11430-015-5500-5.

Chen, F.H., Zhang, J.F., Liu, J.B., Cao, X.Y., Hou, J.Z., Zhu, L.P., Yang, K., 2020. Climate change, vegetation history, and landscape responses on the Tibetan Plateau during the Holocene: a comprehensive review. Quat. Sci. Rev. 243, 106444. https://doi.org/10.1016/j.quascirev.2020.106444.

Cheng, Z.J., Weng, C.Y., Steinke, S., Mohtadi, M., 2018. Anthropogenic modification of vegetated landscapes in southern China from 6,000 years ago. Nat. Geosci. 11 (12), 939–943. https://doi.org/10.1038/s41561-018-0250-1.

Crowther, T.W., Glick, H.B., Covey, K.R., Bettigole, C., Maynard, D.S., Thomas, S.M., Bradford, M.A., 2015. Mapping tree density at a global scale. Nature 525 (7568), 201–205. http://doi-org-443.bjmu.ilibs.cn/10.1038/nature14967.

Crutzen, P.J., Stoermer, E.F., 2000. The 'Anthropocene'. In: Springer International Publishing, pp. 19–21. https://doi.org/10.1007/978-3-030-82202-6_2.

Dearing, J.A., 2013. Why Future Earth needs lake sediment studies. J. Paleolimnol. 49, 537–545. https://doi.org/10.1007/s10933-013-9690-1.

Dearing, J.A., Jones, R.T., Shen, J., Yang, X., Boyle, J.F., Foster, G.C., Elvin, M.J.D., 2008. Using multiple archives to understand past and present climate–human–environment interactions: the lake Erhai catchment, Yunnan Province, China. J. Paleolimnol. 40, 3–31. https://doi.org/10.1007/s10933-007-9182-2.

Ding, G.Q., Chen, J.H., Yan, H.Y., Zhang, S.R., Liu, Y., Zhou, A.F., Chen, F.H., 2022. Late Holocene transition from natural to anthropogenic forcing of vegetation change in the semi-arid region of northern China. Quaternary Science Reviews 287, 107561. https://doi.org/10.1016/j.quascirev.2022.107561.

Dong, G.H., Yang, Y.S., Han, J.Y., Wang, H., Chen, F.H., 2017. Exploring the history of cultural exchange in prehistoric Eurasia from the perspectives of crop diffusion and consumption. Sci. China Earth Sci. 60, 1110–1123. https://doi.org/10.1007/s11430-016-9037-x.

Dreibrodt, S., Langan, C.C., Fuchs, M., Bork, H.R., 2023. Anthropogenic impact on erosion, pedogenesis and fluvial processes in the central european landscapes of the eastern Harz mountains forelands (Germany). Quat. Sci. Rev. 303, 107980 https://doi.org/10.1016/j.quascirev.2023.107980.

Dykoski, C.A., Edwards, R.L., Cheng, H., Yuan, D., Cai, Y., Zhang, M., Revenaugh, J., 2005. A high-resolution, absolute-dated Holocene and deglacial asian monsoon record from Dongge Cave,China. Earth Planet. Sci. Lett. 233 (1–2), 71–86. https://doi.org/10.1016/j.epsl.2005.01.036.

Elhacham, E., Ben-Uri, L., Grozovski, J., Bar-On, Y.M., Milo, R., 2020. Global human-made mass exceeds all living biomass. Nature 588 (7838), 442–444. https://doi.org/10.1038/s41586-020-3010-5.

Ellis, E.C., Gauthier, N., Klein Goldewijk, K., Bliege Bird, R., Boivin, N., Díaz, S., Watson, J.E., 2021. People have shaped most of terrestrial nature for at least 12,000 years. Proc. Natl. Acad. Sci. 118 (17), e2023483118 https://doi.org/10.1073/pnas.2023483118.

Ellis, E.C., Kaplan, J.O., Fuller, D.Q., Vavrus, S., Klein Goldewijk, K., Verburg, P.H., 2013. Used planet: a global history. Proc. Natl. Acad. Sci. 110 (20), 7978–7985. https://doi.org/10.1073/pnas.1217241110.

Fuller, D.Q., Qin, L., Zheng, Y., Zhao, Z., Chen, X., Hosoya, L.A., Sun, G.P., 2009. The domestication process and domestication rate in rice: spikelet bases from the lower Yangtze. Science 323 (5921), 1607–1610. https://doi.org/10.1126/science.1166605.

Fyfe, R.M., Woodbridge, J., Roberts, N., 2015. From forest to farmland: pollen-inferred land cover change across Europe using the pseudobiomization approach. Glob. Chang. Biol. 21 (3), 1197–1212. https://doi.org/10.1111/gcb.12776.

Gibbard, P.L., Bauer, A.M., Edgeworth, M., Ruddiman, W.F., Gill, J.L., Merritts, D.J., Ellis, E.C., 2022a. A practical solution: the Anthropocene is a geological event, not a formal epoch. Episodes J. Int. Geosci. 45 (4), 349–357. https://doi.org/10.18814/epiiugs/2021/021029.

Gibbard, P., Walker, M., Bauer, A., Edgeworth, M., Edwards, L., Ellis, E., Ruddiman, W., 2022b. The Anthropocene as an event, not an Epoch. J. Quat. Sci. 37 (3), 395–399. https://doi.org/10.1002/jqs.3416.

Giguet-Covex, C., Pansu, J., Arnaud, F., Rey, P.J., Griggo, C., Gielly, L., Taberlet, P., 2014. Long livestock farming history and human landscape shaping revealed by lake sediment DNA. Nat. Commun. 5 (1), 3211. https://doi.org/10.1038/ncomms4211.

Guedes, J., Jiang, M., He, K., Wu, X., Jiang, Z., 2013. Site of Baodun yields earliest evidence for the spread of rice and foxtail millet agriculture to south-West China. Antiquity 87 (337), 758–771. https://doi.org/10.1017/S0003598X00049449.

Guedes, J.A., Lu, H., Hein, A.M., Schmidt, A.H., 2015. Early evidence for the use of wheat and barley as staple crops on the margins of the Tibetan Plateau. Proc. Natl. Acad. Sci. 112 (18), 5625–5630. https://doi.org/10.1073/pnas.1423708112.

Guedes, J., Lu, H., Li, Y., Spengler, R.N., Wu, X., Aldenderfer, M.S., 2014. Moving agriculture onto the Tibetan plateau: the archaeobotanical evidence. Archaeol. Anthropol. Sci. 6, 255–269. https://doi.org/10.1007/s12520-013-0153-4.

Harris, N.L., Gibbs, D.A., Baccini, A., Birdsey, R.A., De Bruin, S., Farina, M., Tyukavina, A., 2021. Global maps of twenty-first century forest carbon fluxes. Nat. Clim. Chang. 11 (3), 234–240. https://doi.org/10.1038/s41558-020-00976-6.

Hays, J.D., Imbrie, J., Shackleton, N.J., 1976. Variations in the Earth's Orbit: Pacemaker of the Ice Ages: for 500,000 years, major climatic changes have followed variations in obliquity and precession. Science 194 (4270), 1121–1132. https://doi.org/10.1126/science.194.4270.1121.

Head, M.J., Zalasiewicz, J.A., Waters, C.N., Turner, S.D., Williams, M., Barnosky, A.D., Summerhayes, C.P., 2022. The proposed Anthropocene Epoch/Series is underpinned by an extensive array of mid-20th century stratigraphic event signals. J. Quat. Sci. 37 (7), 1181–1187. https://doi.org/10.1002/jqs.3467.

Herzschuh, U., 2006. Palaeo-moisture evolution in monsoonal Central Asia during the last 50,000 years. Quat. Sci. Rev. 25 (1–2), 163–178. https://doi.org/10.1016/j.quascirev.2005.02.006.

Hillman, A.L., Yao, A., Abbott, M.B., Bain, D.J., 2019. Two millennia of anthropogenic landscape modification and nutrient loading at Dian Lake, Yunnan Province,China. The Holocene 29 (3), 505–517. https://doi.org/10.1177/0959683618816504.

Hosner, D., Wagner, M., Tarasov, P.E., Chen, X., Leipe, C., 2016. Spatiotemporal distribution patterns of archaeological sites in China during the Neolithic and Bronze Age: an overview. The Holocene 26 (10), 1576–1593. https://doi.org/10.1177/0959683616641743.

Hou, J.Z., Huang, Y.S., Zhao, J.T., Liu, Z.H., Colman, S., An, Z.S., 2016. Large Holocene summer temperature oscillations and impact on the peopling of the northeastern Tibetan Plateau. Geophys. Res. Lett. 43 (3), 1323–1330. https://doi.org/10.1002/2015GL067317.

Huang, S.X., Zhang, K., Lin, Q., Liu, J.B., Shen, J., 2022. Abrupt ecological shifts of lakes during the Anthropocene. Earth Sci. Rev. 227, 103981 https://doi.org/10.1016/j.earscirev.2022.103981.

Huang, X.Z., Liu, S.S., Dong, G.H., Qiang, M.R., Bai, Z.J., Zhao, Y., Chen, F.H., 2017. Early human impacts on vegetation on the northeastern Qinghai-Tibetan Plateau during the middle to late Holocene. Prog. Phys. Geogr. 41 (3), 286–301. https://doi.org/10.1177/0309133317703035.

Huang, X.Z., Zhang, J., Ren, L.L., Zhang, S.R., Chen, F.H., 2021. Intensification and driving forces of pastoralism in northern China 5.7 ka ago. Geophys. Res. Lett. 48 (7) https://doi.org/10.1029/2020GL092288 e2020GL092288.

Huang, X.Z., Zhang, J., Storozum, M., Liu, S.S., Gill, J.L., Xiang, L.X., Grimm, E.C., 2020. Long-term herbivore population dynamics in the northeastern Qinghai-Tibetan Plateau and its implications for early human impacts. Rev. Palaeobot. Palynol. 275, 104171 https://doi.org/10.1016/j.revpalbo.2020.104171.

Jenny, J.P., Koirala, S., Gregory-Eaves, I., Francus, P., Niemann, C., Ahrens, B., Carvalhais, N., 2019. Human and climate global-scale imprint on sediment transfer during the Holocene. Proc. Natl. Acad. Sci. 116 (46), 22972–22976. https://doi.org/10.1073/pnas.1908179116.

Kajita, H., Kawahata, H., Wang, K., Zheng, H., Yang, S., Ohkouchi, N., Zheng, B., 2018. Extraordinary cold episodes during the mid-Holocene in the Yangtze delta: Interruption of the earliest rice cultivating civilization. Quat. Sci. Rev. 201, 418–428. https://doi.org/10.1016/j.quascirev.2018.10.035.

Klein Goldewijk, K., Beusen, A., Doelman, J., Stehfest, E., 2017. Anthropogenic land use estimates for the Holocene-HYDE 3.2. Earth Syst. Sci. Data 9 (2), 927–953. https://doi.org/10.5194/essd-9-927-2017.

Köhler, P., Nehrbass-Ahles, C., Schmitt, J., Stocker, T.F., Fischer, H., 2017. A 156 kyr smoothed history of the atmospheric greenhouse gases CO2, CH4, and N2O and their radiative forcing. Earth Syst. Sci. Data 9 (1), 363–387. https://doi.org/10.5194/essd-9-363-2017.

Kunnas, J., 2021. Anthropocene event idea is empowering. Nature 598 (7880), 257. https://doi.org/10.1038/d41586-021-02753-7.

Lageras, P., 1996. Farming and forest dynamics in an agriculturally marginal area of southern Sweden, 5000 BC to present: a palynological study of Lake Avegöl in the Småland Uplands. The Holocene 6 (3), 301–314. https://doi.org/10.1177/095968369600600305.

Lewis, S.L., Maslin, M.A., 2015. Defining the anthropocene. Nature 519 (7542), 171–180. https://doi.org/10.1038/nature14258.

Li, F.R., Gaillard, M.J., Cao, X.Y., Herzschuh, U., Sugita, S., Tarasov, P.E., Jia, X., 2020. Towards quantification of Holocene anthropogenic land-cover change in temperate China: A review in the light of pollen-based REVEALS reconstructions of regional plant cover. Earth-Sci. Rev 203, 103119. https://doi.org/10.1016/j.earscirev.2020.103119.

Li, Q., Wu, H.B., Yu, Y.Y., Sun, A.Z., Marković, S.B., Guo, Z.T., 2014. Reconstructed moisture evolution of the deserts in northern China since the last Glacial Maximum and its implications for the East Asian Summer Monsoon. Glob. Planet. Chang. 121, 101–112. https://doi.org/10.1016/j.gloplacha.2014.07.009.

Li, X.Q., Dodson, J., Zhou, J., Zhou, X.Y., 2009. Increases of population and expansion of rice agriculture in Asia, and anthropogenic methane emissions since 5000 BP. Quat. Int. 202 (1–2), 41–50. https://doi.org/10.1016/j.quaint.2008.02.009.

Li, X.Q., Zhao, K.L., Dodson, J., Zhou, X.Y., 2011. Moisture dynamics in Central Asia for the last 15ákyr: new evidence from Yili Valley, Xinjiang,NW China, 30 (23–24), 3457–3466. https://doi.org/10.1016/j.quascirev.2011.09.010.

Li, Y.Y., Zhou, L.P., Cui, H.T., 2008. Pollen indicators of human activity. Chin. Sci. Bull. 53 (9), 1281–1293. https://doi.org/10.1007/s11434-008-0181-0.

Liu, H.Y., Xu, L.H., Cui, H.T., 2002. Holocene history of desertification along the woodland-steppe border in northern China. Quat. Res. 57 (2), 259–270. https://doi.org/10.1006/qres.2001.2310.

Liu, X.Q., Shen, J., Wang, S.M., Wang, Y.B., Liu, W.G., 2007. Southwest monsoon changes indicated by oxygen isotope of ostracode shells from sediments in Qinghai Lake since the late Glacial. Chin. Sci. Bull. 52 (4), 539–544. https://doi.org/10.1007/s11434-007-0086-3.

Liu, Y., Deng, L.J., He, J., Zhao, X.S., Wang, H., Feng, D., Sun, Q.L., 2021. Holocene geomorphological evolution and the Neolithic occupation in South Hangzhou Bay, China. Geomorphology 389, 107827. https://doi.org/10.1016/j.geomorph.2021.107827.

Lv, H.Y., 2017. New methods and progress in research on the origins and evolution of prehistoric agriculture in China. Sci. China Earth Sci. 60, 2141–2159. https://doi.org/10.1007/s11430-017-9145-2.

Macfarling Meure, C., Etheridge, D., Trudinger, C., Steele, P., Langenfelds, R., Van Ommen, T., Elkins, J., 2006. Law Dome CO2, CH4 and N2O ice core records extended to 2000 years BP. Geophys. Res. Lett. 33 (14) https://doi.org/10.1029/2006GL026152.

Marcott, S.A., Shakun, J.D., Clark, P.U., Mix, A.C., 2013. A reconstruction of regional and global temperature for the past 11,300 years. Science 339 (6124), 1198–1201. https://doi.org/10.1126/science.1228026.

Miao, Y.F., Zhang, D.J., Cai, X.M., Li, F., Jin, H.L., Wang, Y.P., Liu, B., 2017. Holocene fire on the northeast Tibetan Plateau in relation to climate change and human activity. Quat. Int. 443, 124–131. https://doi.org/10.1016/j.quaint.2016.05.029.

Mottl, O., Flantua, S.G., Bhatta, K.P., Felde, V.A., Giesecke, T., Goring, S., Williams, J.W., 2021. Global acceleration in rates of vegetation change over the past 18,000 years. Science 372 (6544), 860–864. https://doi.org/10.1126/science.abg1685.

Noël, H., Garbolino, E., Brauer, A., Lallier-Vergès, E., De Beaulieu, J.L., Disnar, J.R., 2001. Human impact and soil erosion during the last 5000 yrs as recorded in lacustrine sedimentary organic matter at Lac d'Annecy, the French Alps. J. Paleolimnol. 25, 229–244. https://doi.org/10.1023/A:1008134517923.

Nogué, S., Santos, A.M., Birks, H.J.B., Björck, S., Castilla-Beltrán, A., Connor, S., Steinbauer, M.J., 2021. The human dimension of biodiversity changes on islands. Science 372 (6541), 488–491. https://doi.org/10.1126/science.abd6706.

Pan, Y., Birdsey, R.A., Fang, J., Houghton, R., Kauppi, P.E., Kurz, W.A., Hayes, D., 2011. A large and persistent carbon sink in the world's forests. Science 333 (6045), 988–993. https://doi.org/10.1126/science.1201609.

Past Interglacials Working Group of PAGES, 2016. Interglacials of the last 800,000 years. Rev. Geophys. 54 (1), 162–219. https://doi.org/10.1002/2015RG000482.

Peterse, F., Prins, M.A., Beets, C.J., Troelstra, S.R., Zheng, H., Gu, Z., Damsté, J.S.S., 2011. Decoupled warming and monsoon precipitation in East Asia over the last deglaciation. Earth Planet. Sci. Lett. 301 (1–2), 256–264. https://doi.org/10.1016/j.epsl.2010.11.010.

Qiu, Z.W., Jiang, H.G., Ding, L.L., Shang, X., 2020. Late Pleistocene-Holocene vegetation history and anthropogenic activities deduced from pollen spectra and archaeological data at Guxu Lake, eastern China. Sci. Rep. 10 (1), 1–14. https://doi.org/10.1038/s41598-020-65834-z.

Rakowski, A.Z., Nadeau, M.J., Nakamura, T., Pazdur, A., Pawełczyk, S., Piotrowska, N., 2013. Radiocarbon method in environmental monitoring of CO2 emission. Nucl. Instrum. Methods Phys. Res., Sect. B 294, 503–507. https://doi.org/10.1016/j.nimb.2012.07.017.

Reid, P.C., Hari, R.E., Beaugrand, G., et al., 2016. Global impacts of the 1980s regime shift[J]. Glob. Chang. Biol. 22 (2), 682–703. https://doi.org/10.1111/gcb.13106.

Ren, G.Y., 2000. Decline of the mid-to late Holocene forests in China: climatic change or human impact? J. Quat. Sci. Published for the Quaternary Research Association 15 (3), 273–281. https://doi.org/10.1002/(SICI)1099-1417(200003)15:3<273::AID-JQS504>3.0.CO;2-2.

Ren, X.X., Huang, X.Z., Huang, C., Wang, T., Shen, Z.W., Zhang, X.S., Chen, X.M., 2022. Effects of human activities on mountain forest in northern China during the middle Holocene. Quat. Sci. Rev. 288, 107580 https://doi.org/10.1016/j.quascirev.2022.107580.

Roberts, P., Hamilton, R., Piperno, D.R., 2021. Tropical forests as key sites of the "Anthropocene": past and present perspectives. Proc. Natl. Acad. Sci. 118 (40), e2109243118 https://doi.org/10.1073/pnas.2109243118.

Rodionov, S.N., 2004. A sequential algorithm for testing climate regime shifts. Geophys. Res. Lett. 31 (9) https://doi.org/10.1029/2004GL019448.

Rodionov, S., Overland, J.E., 2005. Application of a sequential regime shift detection method to the Bering Sea ecosystem. ICES J. Mar. Sci. 62 (3), 328–332. https://doi.org/10.1016/j.icesjms.2005.01.013.

Ruddiman, W.F., 2003. The anthropogenic greenhouse era began thousands of years ago. Clim. Chang. 61 (3), 261–293. https://doi.org/10.1023/B:CLIM.0000004577.17928.fa.

Ruddiman, W.F., 2007. The early anthropogenic hypothesis: challenges and responses. Rev. Geophys. 45 (4) https://doi.org/10.1029/2006RG000207.

Ruddiman, W.F., Ellis, E.C., Kaplan, J.O., Fuller, D.Q., 2015. Defining the epoch we live in. Science 348 (6230), 38–39. https://doi.org/10.1126/science.aaa7297.

Shakun, J.D., Clark, P.U., He, F., Marcott, S.A., Mix, A.C., Liu, Z., Bard, E., 2012. Global warming preceded by increasing carbon dioxide concentrations during the last deglaciation. Nature 484 (7392), 49–54. https://doi.org/10.1038/nature10915.

Shen, J., Jones, R.T., Yang, X.D., Dearing, J.A., Wang, S.M., 2006. The Holocene vegetation history of Lake Erhai, Yunnan province southwestern China: the role of climate and human forcings. The Holocene 16 (2), 265–276. https://doi.org/10.1191/0959683606hl923rp.

Steffen, W., Crutzen, P.J., McNeill, J.R., 2007. The Anthropocene: are humans now overwhelming the great forces of nature. Ambio-J. Hum. Environ. Res. Manag. 36 (8), 614–621. https://doi.org/10.18574/nyu/9781479844746.003.0006.

Steffen, W., Sanderson, R.A., Tyson, P.D., Jäger, J., Matson, P.A., Moore III, B., Wasson, R.J., 2006. Global Change and the Earth System: A Planet Under Pressure. Springer Science & Business Media.

Stephens, L., Fuller, D., Boivin, N., Rick, T., Gauthier, N., Kay, A., Ellis, E., 2019. Archaeological assessment reveals Earth's early transformation through land use. Science 365 (6456), 897–902. https://doi.org/10.1126/science.aax1192.

Sun, X.S., Zhao, C., Zhang, C., Feng, X.P., Yan, T.L., Yang, X.D., Shen, J., 2021. Seasonality in Holocene temperature reconstructions in southwestern China. Paleoceanogr. Paleoclimatol. 36 (1) https://doi.org/10.1029/2020PA004025 e2020PA004025.

Syvitski, J., Ángel, J.R., Saito, Y., Overeem, I., Vörösmarty, C.J., Wang, H., Olago, D., 2022. Earth' s sediment cycle during the Anthropocene. Nat. Rev.Earth Environ. 3 (3), 179–196. https://doi.org/10.1038/s43017-021-00253-w.

Tao, S.C., An, C.B., Chen, F.H., Tang, L.Y., Wang, Z.L., Lü, Y.B., Zhao, J.J., 2010. Pollen-inferred vegetation and environmental changes since 16.7 ka BP at Balikun Lake, Xinjiang. Chin. Sci Bull. 55, 2449–2457. https://doi.org/10.1007/s11434-010-3174-8.

Tarasov, P., Jin, G., Wagner, M., 2006. Mid-Holocene environmental and human dynamics in northeastern China reconstructed from pollen and archaeological data. Palaeogeogr. Palaeoclimatol. Palaeoecol. 241 (2), 284–300. https://doi.org/10.1016/j.palaeo.2006.03.038.

Thompson, J.C., Wright, D.K., Ivory, S.J., Choi, J.H., Nightingale, S., Mackay, A., Gomani-Chindebvu, E., 2021. Early human impacts and ecosystem reorganization in southern-Central Africa. ScienceAdvances 7 (19), eabf9776. https://doi.org/10.1126/sciadv.abf9776.

Tian, F., Wang, Y., Zhao, Z.L., Li, Y., Dong, J., Liu, J., Ye, M.N., 2020. Holocene vegetation and climate changes in the Huangqihai Lake region,Inner Mongolia. Acta Geol. Sin. Engl. Ed. 94 (4), 1178–1186. https://doi.org/10.1111/1755-6724.14565.

Voosen, P., 2023. Anthropocene's emblem may be Canadian pond. Science (New York, N.Y.) 381 (6654), 114–115.

Wagner, M., Tarasov, P., Hosner, D., Fleck, A., Ehrich, R., Chen, X., Leipe, C., 2013. Mapping of the spatial and temporal distribution of archaeological sites of northern China during the Neolithic and Bronze Age. Quat. Int. 290, 344–357. https://doi.org/10.1016/j.quaint.2012.06.039.

Wang, Q., Yang, X.D., Anderson, N.J., Dong, X.H., 2016. Direct versus indirect climate controls on Holocene diatom assemblages in a sub-tropical deep, alpine lake (Lugu Hu, Yunnan, SW China). Quat. Res. 86 (1), 1–12. https://doi.org/10.1016/j.yqres.2016.03.003.

Wang, X., Xiao, J.L., Cui, L.L., Ding, Z.L., 2013. Holocene changes in fire frequency in the Daihai Lake region (north-Central China): indications and implications for an important role of human activity. Quat. Sci. Rev. 59, 18–29. https://doi.org/10.1016/j.quascirev.2012.10.033.

Waters, C.N., Turner, S.D., 2022. Defining the onset of the Anthropocene. Science 378 (6621), 706–708. https://doi.org/10.1126/science.ade2310.

Witze, A., 2023. This quiet lake could mark the start of a new Anthropocene epoch. Nature 619 (7970), 441–442. https://doi.org/10.1038/d41586-023-02234-z. PMID: 37433944.

Wu, D., Chen, X.M., Lv, F.Y., Brenner, M., Curtis, J., Zhou, A., Chen, F.H., 2018. Decoupled early Holocene summer temperature and monsoon precipitation in Southwest China. Quat. Sci. Rev. 193, 54–67. https://doi.org/10.1016/j.quascirev.2018.05.038.

Wu, D., Zhou, A.F., Liu, J.B., Chen, X.M., Wei, H.T., Sun, H.L., Chen, F.H., 2015. Changing intensity of human activity over the last 2,000 years recorded by the magnetic characteristics of sediments from Xingyun Lake, Yunnan, China. J. Paleolimnol. 53, 47–60. https://doi.org/10.1007/s10933-014-9806-2.

Wu, L., Li, F., Zhu, C., Li, L., Li, B., 2012. Holocene environmental change and archaeology, Yangtze River Valley, China: Review and prospects. Geosci. Front. 3 (6), 875–892. https://doi.org/10.1016/j.gsf.2012.02.006.

Xiang, L.X., Huang, X.Z., Sun, M.J., Panizzo, V.N., Huang, C., Zheng, M., Chen, F.H., 2023. Prehistoric population expansion in Central Asia promoted by the Altai Holocene Climatic Optimum. Nat. Commun. 14 (1), 3102. https://doi.org/10.1038/s41467-023-38828-4.

Xiao, X.Y., Haberle, S.G., Li, Y., Liu, E.F., Shen, J., Zhang, E.L., Wang, S.M., 2018. Evidence of Holocene climatic change and human impact in northwestern Yunnan Province: high-resolution pollen and charcoal records from Chenghai Lake, southwestern China. The Holocene 28 (1), 127–139. https://doi.org/10.1177/0959683617715692.

Xiao, X.Y., Haberle, S.G., Shen, J., Yang, X.D., Han, Y., Zhang, E.L., Wang, S.M., 2014. Latest Pleistocene and Holocene vegetation and climate history inferred from an alpine lacustrine record, northwestern Yunnan Province, southwestern China. Quat. Sci. Rev. 86, 35–48. https://doi.org/10.1016/j.quascirev.2013.12.023.

Xiao, X.Y., Shen, J., Haberle, S.G., Han, Y., Xue, B., Zhang, E.L., Tong, G.B., 2015. Vegetation, fire, and climate history during the last 18 500 cal a BP in South-Western Yunnan Province,China. J. Quat. Sci. 30 (8), 859–869. https://doi.org/10.1002/jqs.2824.

Xiao, X.Y., Yao, A., Hillman, A., Shen, J., Haberle, S.G., 2020. Vegetation, climate and human impact since 20 ka in Central Yunnan Province based on high-resolution pollen and charcoal records from Dianchi, southwestern China. Quat. Sci. Rev. 236, 106297 https://doi.org/10.1016/j.quascirev.2020.106297.

Xie, S.C., Evershed, R.P., Huang, X.Y., Zhu, Z.M., Pancost, R.D., Meyers, P.A., Zhu, J.Y., 2013. Concordant monsoon-driven postglacial hydrological changes in peat and stalagmite records and their impacts on prehistoric cultures in Central China. Geology 41 (8), 827–830. https://doi.org/10.1130/G34318.1.

Xu, X., Li, F., Lin, Z.D., Song, X., 2021. Holocene fire history in China: responses to climate change and human activities. Sci. Total Environ. 753, 142019 https://doi.org/10.1016/j.scitotenv.2020.142019.

Yang, R., Wu, D., Li, Z.H., Yuan, Z.J., Niu, L.L., Zhang, H., Zhou, A.F., 2022. Holocene-Anthropocene transition in northwestern Yunnan revealed by records of soil erosion and trace metal pollution from the sediments of Lake Jian, southwestern China. J. Paleolimnol. 68 (1), 91–102. https://doi.org/10.1007/s10933-021-00193-x.

Yang, X.L., Yang, H., Wang, B.Y., Huang, L.J., Shen, C.C., Edwards, R.L., Cheng, H., 2019. Early-Holocene monsoon instability and climatic optimum recorded by chinese stalagmites. The Holocene 29 (6), 1059–1067. https://doi.org/10.1177/0959683619831433.

Zhang, D.J., Dong, G.H., Wang, H., Ren, X.Y., Ha, P.U., Qiang, M.R., Chen, F.H., 2016. History and possible mechanisms of prehistoric human migration to the Tibetan

Plateau. Sci. China Earth Sci. 59, 1765–1778. https://doi.org/10.1007/s11430-015-5482-x.

Zhang, F., Li, S.H., Sun, C.P., Li, W.P., Zhao, X., Chen, Z.Y., Li, X.X., 2022. Human impacts overwhelmed hydroclimate control of soil erosion in China 5,000 years ago. Geophys. Res. Lett. 49 (5) https://doi.org/10.1029/2021GL096983 e2021GL096983.

Zhang, Q., Zhu, C., Liu, C.L., Jiang, T., 2005. Environmental change and its impacts on human settlement in the Yangtze Delta,PR China. Catena 60 (3), 267–277. https://doi.org/10.1016/j.catena.2004.12.001.

Zhang, X., Zheng, Z., Huang, K.Y., Yang, X.Q., Tian, L.P., 2020. Sensitivity of altitudinal vegetation in Southwest China to changes in the indian summer monsoon during the past 68000 years. Quat. Sci. Rev. 239, 106359 https://doi.org/10.1016/j.quascirev.2020.106359.

Zhang, Y., Li, J.W., Zhao, Y.B., Wu, X.Y., Li, H.J., Yao, L., Zhou, H., 2017. Genetic diversity of two Neolithic populations provides evidence of farming expansions in North China. J. Hum. Genet. 62 (2), 199–204. https://doi.org/10.1038/jhg.2016.107.

Zhao, H.F., Lin, Y.H., Zhou, J., Sun, Q.L., Yang, L.H., Delang, C.O., He, H.M., 2023. Quantifying the dynamic processes of soil erosion and lake sediment deposition in the Holocene in China. Quat. Sci. Rev. 304, 107993 https://doi.org/10.1016/j.quascirev.2023.107993.

Zhao, W., Xie, S.C., 1988. Population History of China. People's Press, Beijing (in Chinese).

Zhao, Z.J., 2014. The process of origin of agriculture in China: Archaeological evidence from flotation results. Quat. Sci. 34 (1), 73–84.

Zhao, Z.J., 2020. Origin of agriculture and archaeobotanical works in China. Agric. History China 39, 3–13.

Zheng, Z., Ma, T., Roberts, P., Li, Z., Yue, Y.F., Peng, H.H., Saito, Y., 2021. Anthropogenic impacts on late Holocene land-cover change and floristic biodiversity loss in tropical southeastern Asia. Proc. Natl. Acad. Sci. 118 (40), e2022210118 https://doi.org/10.1073/pnas.2022210118.