Ecological Indicators 84 (2018) 738–747

Contents lists available at ScienceDirect

Ecological Indicators

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

Research paper

Evaluating the timing of the start of the Anthropocene from Northeast China: Applications of stratigraphic indicators

Hanxiang Liu[a,b], Chuanyu Gao[a,*], Chunfeng Wei[a], Chunling Wang[c], Xiaofei Yu[a], Guoping Wang[a,*]

[a] Key Laboratory of Wetland Ecology and Environment, Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences, Changchun, 130102, China
[b] University of Chinese Academy of Sciences, Beijing, 100049, China
[c] College of Urban and Rural Construction, ShanXi Agricultural University, Jinzhong, 030801, China

ARTICLE INFO

Keywords:
Sedimentological parameters
Geochemistry
Biological indicator
Historical document records
Sanjiang plain

ABSTRACT

The Earth can be described as having entered a new human-dominated geological epoch that is known as the "Anthropocene", and determining the timing of the start of the Anthropocene has become important. Here, we combined sedimentological parameters (sedimentation rate and mean grain size), geochemical indicators (heavy metal enrichment factors, black carbon fluxes and polycyclic aromatic hydrocarbons concentrations) and a biological indicator (plant macrofossils) in wetland sediment records to assess the start of the Anthropocene. The analysis of five wetlands on the Sanjiang Plain, Northeast China, showed that the major component scores of sedimentological parameters and geochemical features based on principal component analyses had obvious increasing trends after the 1950s. Structural change tests were applied to the plant macrofossil data of one typical peatland to detect the breakpoint of the wetland ecosystem, and the dominant species of the plant community changed from *Carex lasiocarpa* to *Salix myrtilloides* during this period due to intensive human activities and drainage in this region. We can divide the history of anthropogenic activities into five periods among the three phases of exploitations that occurred in the Sanjiang Plain, Northeast China, based on our results and historical document records; the anthropogenic activities increased significantly starting in the New China period. It is suggested that the 1950s can be treated as the start of the Anthropocene on the Sanjiang Plain, Northeast China. Similar studies of stratigraphic indicators that provide estimates of historical human activities in other regions could contribute to the global definition of the Anthropocene.

1. Introduction

Global environment issues, such as climate change, land and atmosphere pollution, and biodiversity loss, are raising concerns about the viability of human civilization. Human activities have become so profound and pervasive that the Anthropocene concept was first proposed by Crutzen and Stoermer (2000) and very soon became widely used. The term Anthropocene suggests that humankind is the main global geological force and the Earth has transitioned out of the Holocene epoch. Since the advent of the Anthropocene concept, it has become widely used in global change research groups and mass media (Steffen et al., 2011) and has brought with it the question of where its boundary should be placed (Zalasiewicz et al., 2015; Brown et al., 2017).

It is necessary to consider some indicators of environmental change and to figure out the stratigraphic signals that can be characterize the Anthropocene (Waters, 2014). The first proposal for the Anthropocene was based on the beginning of the increases in global carbon dioxide and methane trapped in polar ice, and it was suggested that the start of the Anthropocene could be set in the latter part of the eighteenth century, corresponding to the beginning of the Industrial Revolution (Crutzen, 2002). As is well known, stratigraphy provides insights into the dynamics and evolution of the Earth's system over the history of the planet (Steffen et al., 2016). Indicators in sediment that are influenced by humans, such as polycyclic aromatic hydrocarbons (PAHs), heavy metals (Leorri et al., 2014), black carbon (BC), radioactive elements (Waters et al., 2016), and plant macrofossils (Stankevica et al., 2015), among others, can all be used to define the Anthropocene. The Anthropocene can also be defined based on diverse paleontological criteria, such as the mixtures of native and non-native species (Barnosky, 2013), human-impacted speciation rates (Thomas, 2015) and the changes in entire ecological communities (Pennisi, 2015). However, the conclusions that are based on these various indicators regarding the start of the Anthropocene are not consistent (Table 1).

The various start dates need to be systematically assessed against the requirements of a "golden spike" that must correspond to a global

* Corresponding authors.
E-mail addresses: gaochuanyu@iga.ac.cn (C. Gao), wangguoping@iga.ac.cn (G. Wang).

http://dx.doi.org/10.1016/j.ecolind.2017.09.040
Received 2 June 2017; Received in revised form 18 September 2017; Accepted 23 September 2017
Available online 30 September 2017

Table 1
The indicators used to date the Anthropocene over the World.

Location	Indicators	Date time	Reference
Global	CO_2, CH_4	1784 CE (Common Era)	Crutzen (2002)
Global, Eurasia, Northeastern Canada	CO_2, CH_4, agriculture, forest clearance	Thousands of years ago	Ruddiman (2003)
Global	CO_2	1800 CE, stage 1 of Anthropocene	Steffen et al. (2007)
Global	Subsurface structures and fossils	1863 CE	Williams et al. (2007)
Global	Artificial radionuclides	1945 CE	Zalasiewicz et al. (2010, 2015)
America	CH_4	13,400 years BP (Before Present)	Smith et al. (2010)
Global	Sediment flux	3000 years BP	Syvitski and Kettner (2011)
Global	Anthropogenic soil	last c.2000 years of the late Holocene	Certini and Scalenghe, 2011
Global	Palaeontology	1950 CE	Barnosky (2013)
All continents except Antarctica	Sedimentation erosion rate	At least 2300 years BP	Brown et al. (2013)
Global	Ignition of fire	> 1.8 million years ago, early Anthropocene	Glikson (2013)
Remote arctic and alpine lakes	N stable isotope, siliceous microfossil	1850 CE	Wolfe et al. (2013)
Northern Spain	Atmospheric pollution, PAHs, heavy metal	ca. 1800 CE	Leorri et al. (2014)
Yellow River Basin, China	Soil, charcoal, pollen and archaeological data	~11,500–7000 BP, early Anthropocene	Zhuang and Kidder (2014)
Europe	Plant speciation	Not to mention	Thomas (2015)
Global	CO_2, bomb spike	1610 or 1964 CE	Lewis and Maslin (2015)
Global	Species	6000 years ago	Pennisi (2015)
Latvia	LOI, heavy metal, plant macrofossil	Not to mention	Stankevica et al. (2015)
Argentina	Sediment rate	Past two centuries ago	Forte et al. (2016)
Global	Stratigraphic and Earth system	Mid-20th century	Steffen et al. (2016)
Global	Geochemical, carbon, climate	1950 CE	Waters et al. (2016)
Global	Stratigraphical signal	Mid-20th century	Williams et al. (2016)
Global	Geomorphology	Not to mention	Brown et al. (2017)

stratotype section and point (GSSP) (Lewis and Maslin, 2015), and the best global standard stratigraphic age (GSSA) to date the start of the Anthropocene should be determined via site sampling in regional perspective. The anthropogenic change throughout China, Korea, the Russian Far East, and Japan became increasing pervasive was mainly driven by global warming near the end of Pleistocene time (Aikens and Lee, 2013). Both the history of the Yellow River region (Zhuang and Kidder, 2014; Kidder and Zhuang, 2015; Rosen et al., 2015) and Yangtze River region (Yang et al., 2002; Shu et al., 2010; Dearing et al., 2012) of China were mainly shaped by the human modification of the environment. The anthropogenic changes of the Yellow River region start slowly based on the soil, charcoal, pollen and archaeological data in the Early Holocene (~11,500–7000 before present), which can be called "the Early Anthropocene" (Zhuang and Kidder, 2014). Unlike the time framework above, Dearing et al. (2012) focused on that the recent rapid economic growth and population increases of Yangtze River region, which were strongly coupled to environmental degradation. The lake ecosystem has significantly shifted since the 1950s based on diatom records (Dong et al., 2015) and paleolimnological data (Xu et al., 2017) in this region.

Wetland sediments are readily and economically accessible geological archives for the study of climate changes and human activities, and their autochthonous mode of accumulation renders them less susceptible to redeposition (Chambers and Charman, 2004). Regional human activities in the Sanjiang Plain, Northeast China started to influence the amount and characteristics of biomass burning residuals (i.e., BC fluxes and PAHs) about a thousand years ago based on Cong et al. (2016)'s study of wetland sediments. These patterns were followed by an even sharper increase in BC fluxes during the last 150 years (Gao et al., 2014c), in conjunction with the enrichment factors (EFs) of heavy metals (Gao et al., 2014b). However, increasing concentrations of heavy metals cannot cause obvious changes to the ecological balance of wetland systems because of the resilience of those ecosystems. "Resilience" is the capacity to recover from a disturbance even though the biomes and ecological processes have been diminished (Holling, 1973; Müller et al., 2015). It is therefore necessary to include some biological indicators to detect when human activities break the balance of a wetland ecosystem. The start of human-modified ecological characteristics in wetland ecosystems could be regarded as the start of the Anthropocene (Dong et al., 2015; Xu et al., 2017).

Here, we conduct a comprehensive analysis of sedimentological parameters (sedimentation rate and grain size), geochemical features (heavy metals, BC fluxes and PAHs) and a biological indicator (plant macrofossils) that accumulated about a two hundred year period on the Sanjiang Plain, Northeast China. Combining these data with the historical human activities that are recorded in historical documents, the transition from the Holocene to the Anthropocene can be identified. In all, the objectives of this study are to (1) reveal the sedimentological parameters and geochemical features influenced by human activities, (2) detect the breakpoint in the plant community, and (3) evaluate the timing of the beginning of the Anthropocene in this region.

2. Material and methods

2.1. Study area and sampling

The Sanjiang Plain is a low and flat alluvial plain crossed by the Heilong River, Songhua River and Wusuli River (Fig. 1). The Heilong River and Wusuli River are the boundary rivers between China and Russia, and the southern Wusuli River originates from Xingkai Lake and flows north to merges into the Heilong River near Boli city. The Songhua River is one of the major rivers in China, and it originates in the Changbai Mountain and merges with the Heilong River near Tongjiang County. On account of the unique topography and climate, a large number of wetlands have developed in this area. During the last 150 years, there were three phases of exploitations of the Sanjiang Plain (Fig. 7d) (Fang et al., 2005). During the first phase, some areas of wasteland were turned into farmland with the gradual lifting from 1840 onward of executive limits previously imposed by the Qing dynasty. The second exploitation began in 1898 as a result of Russia's construction of the "Mid-east" Railway, during which a large number of forests were cut down and some minerals were exploited. Even after the second phase, at the beginning of New China phase, the Sanjiang Plain remained famous as "the great northern wildness" due to the large number of wetlands in this area. However, owing to the rapid increases in population and land exploitation that were encouraged and financed by the government, the wetland areas have decreased by more than 3/4 between 1954 and the present during the third phase of exploitation (Wang et al., 2009).

Four well-preserved wetlands surrounding the rivers and one wetland nearby the city were found on the Sanjiang Plain (Fig. 1). The Heixiazi (HXZ, 134°44′45″ E, 48°19′51″ N) wetland is located in a delta