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Human activity induced asynchronous dune mobilization in the deserts of NE China during the late Holocene

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ABSTRACT

Studies of dune mobilization during the last 3 kyr in the deserts of NE China indicate that the area of desert expanded, and associated dust storms increased in the affected regions downwind. However, uncertainty about the timing and origin of episodes of late Holocene dune mobilization has resulted in the failure to provide information about dust-related processes that can be used in atmospheric dust models. Here, we present a detailed regional compilation of dune mobilization and human activity in the deserts of NE China and the adjacent regions spanning the last 3 kyr. The results show that human activity and dune mobilization intensified synchronously at ~2.5 ka in the Mu Us and Hobq deserts, at ~1.5 ka in the deserts of NE China, and at ~0.5 ka in the Horqin and Hulun Buir deserts. A comprehensive analysis indicates that a northward trend of intensified human activity, with the main contribution from cultivation and a secondary contribution from grazing, was responsible for the asynchronous pattern of dune mobilization in these deserts during the late Holocene.

1. Introduction

The deserts of NE China are a dust source area of global significance (Sun et al., 2001). In spring, abundant dust derived from the region is transported downwind and the resulting dust storms have substantial implications for human welfare because they likely cause a substantial increase in lagged non-accidental and cardiovascular mortality (Crooks et al., 2016). Successful prediction of future dust storm occurrences in the affected areas requires comprehensive knowledge of the processes of dust emission, transport and deposition. Xu et al. (2018) suggested that periods of increased dust occurrence in lake sediment records were consistent with episodes of dune mobilization within the dust source area during the late Holocene, and that dust transport was related to the Siberian High. Understanding the episodes of late Holocene dune mobilization in these deserts, and its driving mechanisms, is important for the development of atmospheric dust models capable of evaluating possible future dust storm occurrences in the affected areas downwind (Shao and Dong, 2006).

Multiple mechanisms are responsible for Holocene dune mobilization in the deserts of NE China, including early Holocene aridity (Mason et al., 2009; Lu et al., 2011), an irreversible regional hydrological event at ~4.2 ka (Yang et al., 2015), climatic deterioration at ~4.0 ka (Guo et al., 2018), the combination of climatic deterioration and intensified human activity since ~2.3 ka (Sun, 2000; Li and Sun, 2006; Huang et al., 2009; Yang et al., 2017), and intensified human activity since ~2.0 ka (Yang et al., 2016). The driving mechanisms of early to middle Holocene dune mobilization can be established using continuous high-resolution sedimentary records with well-constrained chronologies, together with a comprehensive compilation of dune activity in the region. However, conclusions regarding the occurrence and causes of late Holocene dune mobilization are limited by the fact that data on dune activity are typically only available for a single desert. Although late Holocene records indicating climate change are of relative abundance in the region, there is limited documentary evidence of changes in human activities. This lack of knowledge of dust-related processes hinders the development of computer models that can predict future climate trends (Shao and Dong, 2006; Zhao et al., 2006). Thus, an increased number of reliable late Holocene records of dune activity and intensified human activity are needed in the region.

Here, we present a detailed regional compilation of dune activity in the deserts of NE China over the last 3 kyr, which we compare with contemporaneous records of human activity in the deserts and the

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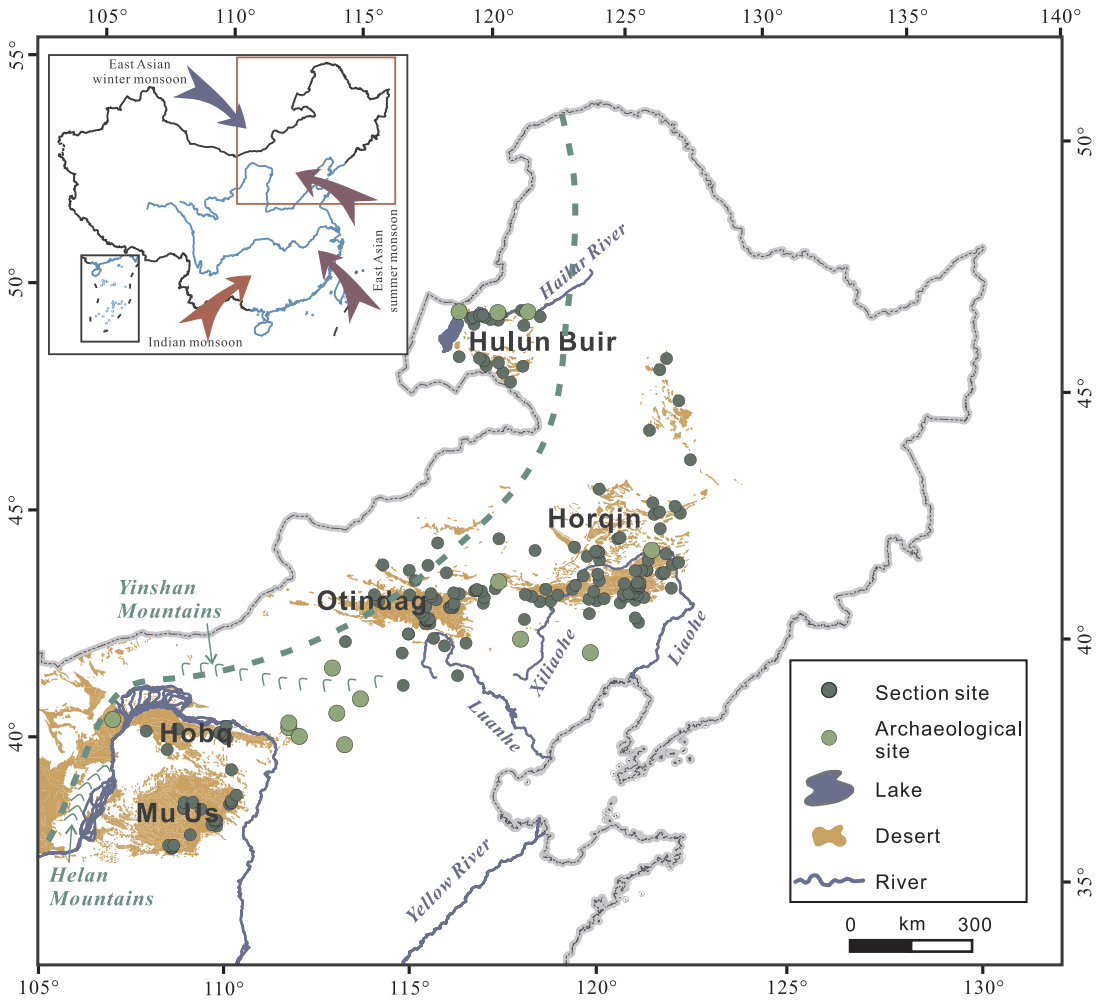

Fig. 1. Distribution of deserts (Hulun Buir, Horqin, Otindag, Hobq and Mu Us) and study sites (sections and archaeological sites) in NE China. The green dashed line indicates the front of the East Asian summer monsoon. The desert data set is provided by the Environmental and Ecological Science Data Center for West China, National Natural Science Foundation of China, http://westdc.westgis.ac.cn.

adjacent regions. Our regional compilation of dune activity and human activity is based on previously published data. Our principal aim is to explore the timing of the episodes of late Holocene dune mobilization in the region and to determine the main causal mechanisms.

2. Study region

The deserts of NE China are located on the northern margin of the region of influence of the East Asian summer monsoon (EASM) and consist of the Hulun Buir, Horqin, Otindag, Hobq and Mu Us deserts (Fig. 1). The modern climate of these deserts is semi-arid, with mean annual precipitation increasing from 200 mm in the northwest to 400–500 mm in the southeast (Ren et al., 1985). East Asian summer monsoon precipitation accounts for 65–75% of total annual precipitation (Liu, 2010). The dunes in the region are mainly stabilized and semi-stabilized at present, except for the dunes in the Hobq desert that are mainly active and semi-stabilized.

Grasses, mainly Needlegrass (*Stipa* sp.), Chinese wild rye (*Aneurolepidium chinense*) and *Cleistogenes squarrosa*, comprise the predominant natural vegetation, and they are favored by grazing animals. In addition, water from several rivers enables the relative flourishing of irrigation agriculture in cultivated areas, especially in riparian zones and inter-dune lowlands. Local agricultural activity can be traced back to the Hongshan culture (the middle Holocene), when agriculture from the Central Plain spread to the region (Han, 2012; Liu and Chen, 2012).

3. Data and methods

Previous research has documented the history of agricultural activity in the deserts of NE China and the adjacent regions (e.g., Han, 2012; Zhang et al., 2015a), and the findings are relevant to the present study. In addition, a regional compilation of dated Holocene records from sub-aerial sedimentary deposits in the desert can be used to characterize the spatiotemporal pattern of dune activity (Li and Yang, 2016; Guo et al., 2018). Paleosols, lacustrine, and peat deposits are the sources of dated records indicating a stable dune state, while eolian sand and loess are the sources of dated records for a mobile dune state (Guo et al., 2018). In practice, a mobile dune state is characteristic of a dry climate, mainly due to the increased aridity resulting from a deficit of EASM precipitation, and/or from the intensification of human activity. By contrast, abundant EASM precipitation favors plant growth and the development of paleosols and lakes, corresponding to a stable dune state.

The localities on the northern margin of the agro-pastoral ecotone, which have existed for the last 3 kyr, and which are described in Han (2012), are a major concern of the present study. These localities are plotted in Fig. 2, and environmental changes in these areas mainly resulted from local human activity. The nature of the paleodiet of the ancient inhabitants during the interval of 3–0 ka has been investigated using a compilation of stable isotope data from animals (cattle, sheep and horses) and humans from 15 archaeological sites in NE China (Fig. 1; Zhang, 2006; Zhang et al., 2006, 2008, 2012a,b, 2015a,b, 2018;