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Vegetation responses to the warming at the Younger Dryas-Holocene transition in the Hengduan Mountains, southwestern China

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ABSTRACT

The Younger Dryas (YD) is one of the most abrupt climatic events in Earth's recent history. The warming at the end of the YD, in particular, is considered to be comparable to the global warming seen in the 21st century. However, the YD termination has received little attention, particularly in the Hengduan Mountains of Southwestern China, a low latitude temperate biodiversity hotspot. Here we present evidence for a rapid response in the diversity and composition of vegetation to the warming at the YD termination, based on a continuous, well-dated pollen sequence and loss-on-ignition data (12.9–9.2 cal. ka BP) from Haligu wetland in the Hengduan Mountains. Our data indicate that variations in plant diversity were correlated with relative humidity during this period, and suggest a distinct shift from *Pinus-Abies-Picea* forest to *Pinus*-dominated forest at the YD-Holocene transition, accompanied by an increase in coverage of generally temperate taxa such as *Salix* and *Betula*. This finding provides insights that may be of relevance to biodiversity conservation under future warming scenarios in similar mountain ecosystems worldwide.

1. Introduction

The Younger Dryas (YD, ca. 12.8–11.5 cal. ka BP (before present, 0 BP = 1950 AD)) is the most recent abrupt climatic event recognized during the transition from the last glaciation to the Holocene (Jomelli et al., 2014; Partin et al., 2015) and has been very widely observed in marine and continental sediments in the North Atlantic, North Pacific, Asia, North America, tropical regions, and the Southern Hemisphere (e.g., Johnsen et al., 1992; Dansgaard et al., 1993; Bond et al., 1993; Clark et al., 2002; Shakun and Carlson, 2010). At middle and high latitudes in North America and Europe, changes in the biota, including humans and other terrestrial mammals, have been observed in response to the YD event. For example, in regions of Southwestern North America the YD climate change was accompanied by significant changes from Clovis to Folsom cultures marked by a shift from hunting mammoth to bison (Ballenger et al., 2011). In North America, large mammals such as *Mammuthus*, *Arctodus* and *Smilodon* became extinct during this period (Barnosky et al., 2004). In Romania, diatom responses to the YD have been recorded from lake sediments, including changes in the relative abundance of *Staurosira venter* (Ehr.) Cleve & Moeller and *Stauroforma exiguiformis* (Lange-Bertalot) Flower, along with an overall decrease in diversity (Buczkó et al., 2012). However, few studies are available at low latitudes (e.g., Rull et al., 2010; Ivory et al., 2012). Specifically, the abrupt warming at the YD termination received significantly little attention.

The temperate Hengduan Mountains of Southwestern China are located at the southeastern margin of the Qinghai-Tibet Plateau (Fig. 1a) and form one of 34 designated global biodiversity hotspots (Boufford and van Dijk, 2004). Climatic oscillations within Quaternary glacial and interglacial periods are inferred to have had significant effects on plant diversity and distributions in the north

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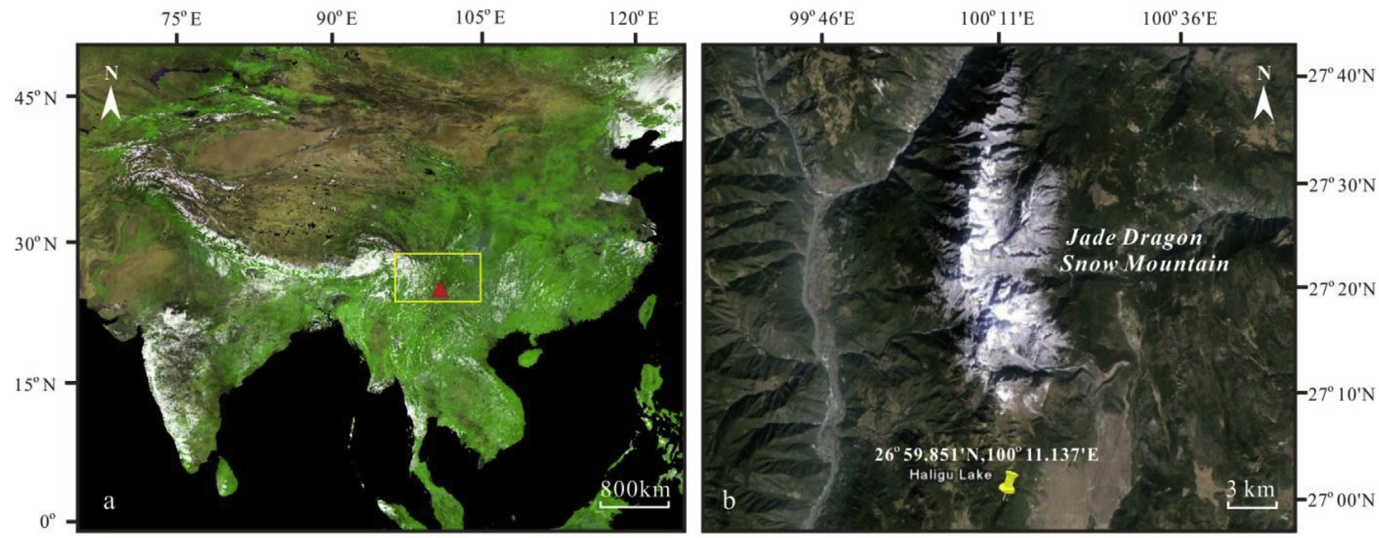

Fig. 1. Location of the study site. a. Location of the Hengduan Mountains (yellow rectangle) and position of coring site (red triangle). Map obtained by European Space Agency satellite Proba-V (June 2013). b. Location of coring site at Haligu on the Jade Dragon Snow Mountain. Image from Google Earth. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

and south of this region (Wu, 1988; Sun, 2002). In the Hengduan area itself, previous studies have mostly concentrated on vegetation succession, climate change and the evolution of the monsoon during the late Quaternary (e.g., Shen et al., 2006; Kramer et al., 2010; Xiao et al., 2014a, 2014b; Rawat et al., 2015; Zhang et al., 2015; Yao et al., 2015, 2017), but little is known about how plant communities responded to the YD event, particularly the rapid warming at the YD termination, which is regarded as providing a potential analog for predicted future global warming (Rull et al., 2015). Here, we present a high-resolution pollen and loss-on-ignition (LOI) record from a wetland site at Haligu (3218 m a. s. l.), and use it to investigate the impacts of abrupt climate shifts at the YD-Holocene transition on plant community composition in the Hengduan Mountains. The study aims to 1) improve understanding of the YD climatic reversal and late glacial-Holocene transition in the Hengduan Mountains, and 2) provide a past analog for biotic responses to potential climatic developments similar to the rapid climatic shifts seen in the YD-Holocene under near-future global warming caused by anthropogenic activity. This may facilitate the formulation and adoption of present and future biodiversity conservation policies.

2. Materials and methods

2.1. Study site

The floristically diverse Jade Dragon Snow Mountain is located in the Hengduan Mountains, within the subtropical South Asian monsoon zone, which is influenced by heat and water sources from the South China Sea and the Indian Ocean. Thus the summers are warm and humid and the winters cool and dry. At the nearest official weather station in Lijiang (about 17 km far from the Jade Dragon Snow Mountain, 2200 m a. s. l.), the mean annual precipitation is 935 mm and more than 90% of the annual precipitation falls in summer, from June to October. The mean annual temperature is 12.8 °C, and the warmest month is July, with a mean temperature of 17.9 °C; the coldest month is January, with a mean temperature of 5.9 °C (Feng et al., 2006). The local vegetation displays a distinct vertical zonation. Between 2400 m a. s. l. and 3000 m a. s. l., the vegetation is dominated by semi-humid evergreen broad-leaved forest-pine forest. From 3000 m a. s. l. to 3300 m a. s. l., the vegetation succeeds to needle- and broad-leaved mixed forest-sclerophyllous evergreen broad-leaved forest. From 3300 to 4200 m a. s. l., it comprises cold-temperate coniferous forest, and above 4200 m the vegetation changes to alpine shrub meadow (Yao et al., 2015). The present-day vegetation of the study area is dominated by needle-leaved trees (such as *Pinus yunnanensis* Franch.) and evergreen oak (*Quercus aquifolioides* Rehd. et Wils.) along with deciduous broad-leaved trees such as *Populus davidiana* Dode., *Acer davidii* Franch., and *Rhododendron* spp., especially *R. mucronatum* (Blume) G. Don, *R. racemosum* Franch., *R. yunnanense* Franch. and *R. delaveyi* Franch. At higher elevations important tree species comprise *Abies delavayi* Franch., *Picea likiangensis* (Franch.) Pritz., and *Tsuga dumosa* (D. Don) Eichler (Wang et al., 2007).

2.2. Sampling and dating

In October 2008, a sediment core 730 cm in length was obtained using a Russian corer at Haligu (26°59.851′ N, 100°11.137′ E, 3218 m a. s. l., Fig. 1b) on the southern end of the Jade Dragon Snow Mountain. The core was documented and wrapped in PVC tubes in the field. The present study focuses on the lower part of the core (730–510 cm), which comprises black and grey-brown clays. In total, nine AMS (Accelerator Mass Spectrometry) radiocarbon dates were obtained from the core by the Scottish Universities Environmental Research Centre (SUERC) in Glasgow, Scotland and Beta Analytic Radiocarbon Dating Laboratory in Florida, USA, at depths of 100 cm, 200 cm, 300 cm, 400 cm, 500 cm, 550 cm, 600 cm, 700 cm, and 730 cm. Because there are no fragments of plant material suitable for analysis in the core, bulk samples were used. The ^{14}C age is quoted in conventional years BP; age calibration was achieved using OxCal v3.10 (Baillie and Reimer, 2004; Bronk, 2005). Errors are expressed at the two sigma level of confidence (95% probability), the end points of the dates were rounded to the nearest 10 years, and dates are quoted in calibrated years BP (Mook, 1986; Foster et al., 2008). Radiocarbon dating results are shown in Table 1.