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Temperate deciduous broadleaf forest dynamics around the last glacial maximum in a hilly area in the northern Kanto district, central Japan

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ABSTRACT

Research into the geographical distribution of temperate tree refugia and their associated environmental conditions during glacial stages is necessary to understand the processes by which the present vegetation and plant distributions developed. On the basis of pollen and plant macrofossil assemblages deposited in a small valley in a hill in the northern Kanto district in central Japan, we reconstructed the local and regional vegetation changes in and around the distribution range limit of temperate broadleaf trees during the latest stage of marine isotope stage (MIS) 3 (36.2–32.8 ka) and around the late stage of the last glacial maximum (LGM) (23.4–16.6 ka). During the latest stage of MIS 3, the local and regional vegetation in and around the hill was composed of temperate deciduous broadleaf forest dominated by *Quercus* subgen. *Lepidobalanus* and mixed with pinaceous conifers. The proportion of deciduous broadleaf trees in the regional vegetation increased during recurring warm and humid phases that were correlated with Greenland D-O 7, 6, and 5 warming events. During the LGM, coniferous forests composed of *Picea jezoensis* var. *hondoensis*, *Tsuga diversifolia*, *Abies veitchii*, and *Betula ermanii*, which are major components of the present subalpine forests in central and western Japan, expanded in hilly and mountain zones in central Japan. Refugia of temperate broadleaf trees existed at altitudes up to that of the study site and were limited to mesic places along the valley bottom. At the termination of the LGM around 18.8 ka, a biome shift to mixed coniferous and deciduous broadleaf forest dominated by *Betula* occurred in and around the study site. The expansion of deciduous broadleaf trees at ca. 19 ka, which has also been recognized in other localities in central Japan, may have been triggered by an increase in precipitation during the stage wherein summer insolation became greater. The temperate broadleaf trees that have been distributed in hilly-zone refugia were sensitive to warming at the termination of the LGM.

1. Introduction

During the last glacial maximum (LGM), pinaceous conifers were prevalent among the forest vegetation in nearly all areas of Japan (Tsukada, 1985; Takahara, 2011), while refugia of temperate deciduous broadleaf trees were located in lowlands and hilly areas along the Pacific and the Sea of Japan coasts at latitudes below 38°N in northern and central Japan (Nasu, 1980; Ono and Igarashi, 1991; Momohara et al., 2016). The present geographical distribution of forest species and their genetic composition (Tomaru et al., 1998; Fujii et al., 2002; Magri et al., 2006; Hiraoka and Tomaru, 2009) demonstrates the importance of location and environmental conditions in temperate tree refugia during the LGM. The locations of temperate tree refugia at the LGM influenced the pattern of temperate tree expansion after the last glacial period (Takahara, 2011) that finally led to the present distribution. However, most paleovegetation reconstructions from the last glacial period in Japan are based mainly on pollen data, including airborne pollen transported from regional vegetation. The geographical distribution of temperate tree refugia and their environmental conditions have not yet been determined in detail from both pollen and macrofossil records.

Nishiuchi et al. (2015) studied both pollen and macrofossil assemblages deposited during the period of ca. 20,300–16,600 cal BP in Nakazato site, Utsunomiya City, Tochigi Prefecture, in a hilly area in the northern Kanto district (Fig. 1). Based on macrofossil assemblages deposited in a valley with a very limited catchment area, they

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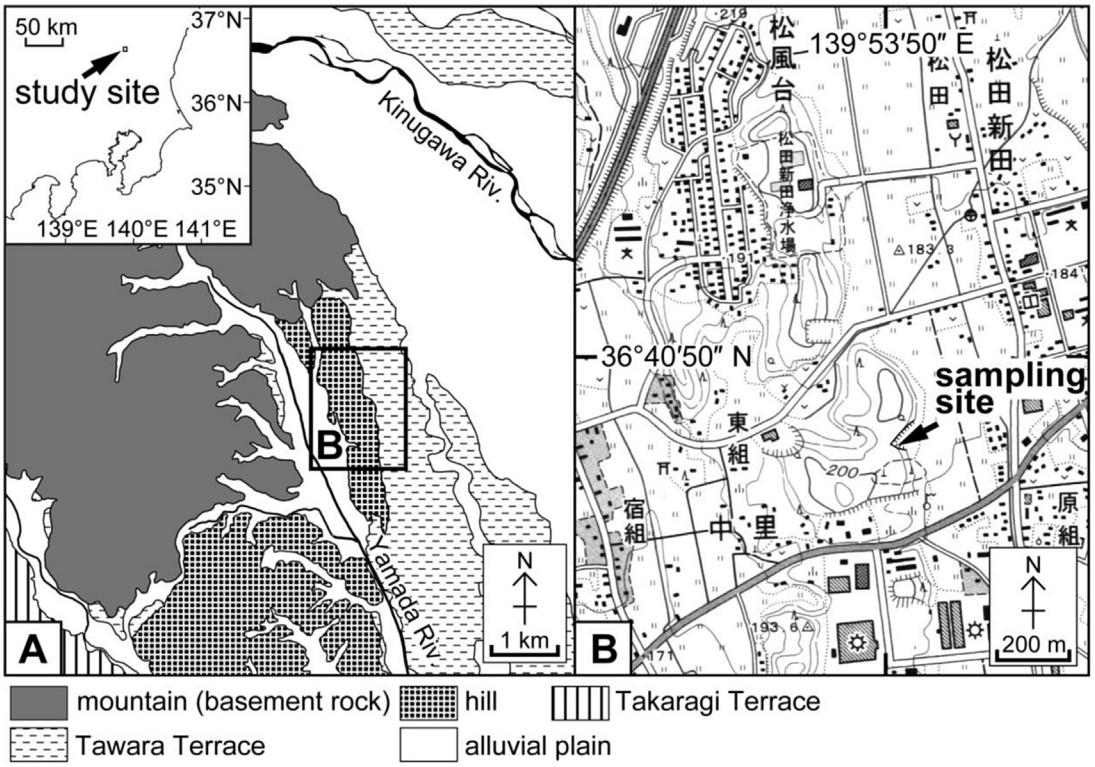

Fig. 1. Location of the study site in Nakazato, Tochigi Prefecture, central Japan (Nishiuchi et al., 2015): A, map showing geomorphology in and around the study site (after Koike and Suzuki, 2000); B, map showing location of the sampling site, made from the 1:25,000 topographic map of "Uziie" published by the Geospatial Information Authority of Japan (2009).

reconstructed the local paleo-vegetation in the area. Their study described the geographical distribution of temperate tree taxa and subalpine conifers in inland and coastal areas near the Pacific in central Japan. Based on the geographical distribution of macrofossil assemblage compositions, they concluded that the Nakazato site represents the distribution boundary between subalpine coniferous trees and temperate broadleaf trees. They also clarified that the onset of the expansion in temperate tree taxa occurred at the termination of the LGM at ca. 19 k cal BP (hereinafter ka) and suggested that the boundary of temperate tree distribution was sensitive to climatic changes. Because the time span covered by their research is limited to the latest stage of the LGM, further analysis of fossil assemblages from earlier stages is necessary to understand how the distribution limit of temperate trees changes with climate.

We conducted drill core sampling next to the outcrop studied by Nishiuchi et al. (2015) and obtained organic sediments with ages of ca. 36.2–32.8 ka, corresponding to the last part of marine isotope stage (MIS) 3, and ca. 23.5–22.9 ka, which represents the late stage of the LGM. In this study, we analyzed pollen and macrofossils in the core samples along with additional samples from the outcrop studied by Nishiuchi et al. (2015) to investigate the response of vegetation to climatic changes since the latest stage of MIS 3. We compared these data with pollen profiles from other areas and with oxygen isotope records from the Greenland ice core (Andersen et al., 2006), stalagmite calcite in Hulu Cave in southern China (Wang et al., 2001), and summer insolation curves (Berger, 1992) to demonstrate the sensitivity of vegetation to climate change.

2. Regional setting

The study site (36°40′43″N, 139°53′49″E, 183 m a.s.l.) in Nakazato, Tochigi Prefecture, central Japan, is located at the eastern foot of a ridge of Utsunomiya Hill (alt. 200–210 m) that extends from north to south (Fig. 1). The hill is composed of Neogene tuffaceous rocks and is rimmed by middle and high terraces consisting of late Pleistocene gravel deposits. A lower terrace known as the Tawara Terrace (Yamamoto, 2006) occupies a wide area along the eastern and southern border of the hill. The Tawara Terrace was formed by the accumulation of fluvial deposits from the Kinugawa River to a height of 170–180 m above sea level during MIS 3 to 2 (Yamamoto, 2006). Alluvial plains with a height of about 170 m above sea level occur along the Kinugawa River to the east of the Tawara Terrace and along the Yamada River to the west of Utsunomiya Hill. The annual mean temperature of the site is 12.3 °C, the coldest month mean temperature is 1.1 °C, and annual precipitation is 1427 mm (JMA, 2011). The potential vegetation of the hilly zone below ca. 400 m is warm temperate evergreen broadleaf forests dominated by *Quercus* subgen. *Cyclobalanopsis* (Miyawaki, 1986). Deciduous broadleaf forests dominated by *Castanea*, deciduous *Quercus,* and *Fagus* are located between ca. 400 m and 1500–1600 m, whereas subalpine coniferous forests consisting of *Abies veitchii*, *Tsuga diversifolia*, and *Picea jezoensis* var. *hondoensis* occur at altitudes above 1500 m (Miyawaki, 1986).

The outcrop we studied is ca. 6 m high and 60 m wide and faces NNE, and was exposed by the excavation of a middle terrace along the Utsunomiya Hill. In the western part of the outcrop, a buried valley incising the middle terrace deposit and loam is observed (Fig. 2, Nishiuchi et al., 2015). The deposits at the base of the eastern part of the outcrop are composed of a subrounded gravel layer that corresponds to the Takaragi Terrace deposit that emerged from below the water during MIS 4 (Yamamoto, 2006). The gravel is covered by a loam layer approximately 3.5 m thick, which is intercalated with the Kanuma pumice bed (Ag-KP: Akutsu, 1957) consisting of a ca. 70-cm-thick deposit of 1–2-cm-size yellowish pumice, and the ca. 15-cm-thick Ogawa lapilli bed (Nt-Og: KLRG,

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