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Diatoms from Lake Kushu: A pilot study to test the potential of a Late Quaternary palaeoenvironmental archive from Rebun Island (Hokkaido Region, Japan)

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ABSTRACT

Rebun Island is a key research area for the Baikal-Hokkaido Archaeology Project to better understand the dynamics of the Neolithic hunter–gatherers in the NW Pacific region. Hence, the ca. 19.5 m sediment core RK12 spanning the last ca. 16.6 cal. kyr BP was obtained from Lake Kushu. Our aim is to test its potential as a high-resolution multi-proxy archive. Here, we used diatoms to investigate the modern ecosystem of Lake Kushu and its surrounding area on Rebun Island and of Hime-numa Pond on Rishiri Island and selected core samples for comparison. Modern diatom and stable isotope analyses show well-mixed freshwater bodies with eutrophic, alkaline conditions. The fossil diatom and geochemical sediment analyses display three phases that represent major changes in the lake development: (i) a marshy phase (ca. 16.6–10 cal. kyr BP); (ii) a brackish water lagoon phase (ca. 10–6.6 cal. kyr BP); and (iii) a freshwater lake phase (since ca. 6.6 cal. kyr BP). This shows the major role of the post-glacial climate amelioration, global sea-level rise and marine transgression in the development of this landscape. Further analyses will provide a palaeolimnological record at (sub-)decadal resolution that will facilitate the interpretation of the hunter–gatherer dynamics.

1. Introduction

An increasing number of archaeological sites of the hunter–gatherer cultures in the Hokkaido Region are being investigated (Weber et al., 2013 and references therein). Main research foci are to outline the differences between the Japanese and Okhotsk civilizations and the origin and geographical distribution of the Okhotsk people (Ohyi, 1975) that led to cultural heterogeneity (Moiseyev, 2008), which is also reported in characteristic pottery types (Deryugin, 2008).

The Baikal-Hokkaido Archaeology Project (BHAP) enlarged its study area from the Baikal Region (Siberia) towards the Hokkaido Region to improve the understanding of Holocene hunter–gatherers, their cultural dynamism, variability and lifestyle (Weber et al., 2013). In fact, the driving factors for cultural changes, e.g. environmental and climate changes or epidemic diseases, are not fully understood. Because numerous remains of the Middle Jomon (5–4 cal. kyr BP), Late to Final Jomon (4–2.3 cal. kyr BP), Epi Jomon (2.3–1.3 cal. kyr BP), Okhotsk (1.5–0.8 cal. kyr BP), and Historic Ainu (0.7–0.1 cal. kyr BP; Müller et al., 2016) cultures that were recently found on Rebun Island, this area is of special interest for the BHAP research. So far there are 43 sites on Rebun Island, with the oldest residential sites dated to ca. 4.9–4.4 cal. kyr BP (see Müller et al., 2016 and references therein).

The need for a nearby high-resolution archive for reconstructing local and regional climate as well as environmental changes resulted in the Lake Kushu coring campaign in February 2012. Two parallel, overlapping sediment cores (RK12-01 and RK12-02) were taken in the central part of the ice-covered lake. The obtained ca. 19.5 m composite sediment core is a potentially high-resolution environmental archive, which will be investigated using a multi-proxy approach that includes a ^{14}C-inferred chronology, pollen, tephra, and geochemical analyses.

Various proxies have been used to reconstruct the Holocene climate and vegetation of Hokkaido and central Japan. Pollen-based reconstructions are among the most numerous during the last few decades, resulting in a number of articles concerning past

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vegetation or biome dynamics and its climatic and human-impact implications (e.g. Nakagawa et al., 2002, 2005; Gotanda et al., 2002, 2008; Igarashi et al., 2011; Tarasov et al., 2011; Hase et al., 2012; Igarashi, 2013; Leipe et al., 2013; Kigoshi et al., 2014).

Like terrestrial pollen, diatoms have been successfully used as a palaeoenvironmental proxy in Europe, North America and Africa (e.g. Gasse, 1986; Round et al., 1990; Smol and Stoermer, 2010). A considerable amount of studies has been published in local journals and in the Japanese language. Nevertheless, an increasing number of internationally accessible studies describing taxonomy, geographical distribution, and ecology of lacustrine, riverine, and coastal marine diatom taxa appeared during the last two decades. In Hokkaido, several water bodies have been analysed including Lake Akan (Tuji et al., 2003), Hii River (Ohtsuka, 2002), and Lake Tokotan (Sawai, 2002). Diatom-inferred environmental reconstructions for the Holocene were obtained from coastal plains including the Tokoro Region (Hamano et al., 1985), Akkeshi Estuary (Kumano et al., 1990a), Kushiro Moor (Ihira et al., 1985; Kumano et al., 1990b), and Kutcharo Lake (Kumano et al., 1984).

On Rebun Island, Kumano et al. (1990a) and Sato et al. (1998) analysed a 16.25 m sediment core spanning the last ca. 9000 years as suggested by the four ^{14}C dates given in their studies. Their core was obtained from the peat moor on the southern margin of Lake Kushu. These papers provide a relatively coarse-resolution diatom record with repeated occurrences of brackish-water environments, suggesting multiple phases of marine influence on Lake Kushu during the Holocene. Sato et al. (1998) mention taxonomic problems, which could be addressed by a high-resolution diatom analysis and would improve the understanding of the environmental history of Lake Kushu and its catchment. Until now, no study has focused on the modern diatom assemblages of Rebun Island and neighbouring Rishiri Island. Our paper is a pilot study and presents the first results on modern diatom assemblages from the Rebun and Rishiri islands in order to discuss the potential of fossil diatom assemblages as regional palaeoenvironmental indicators in a new sediment core from Lake Kushu representing the last 16,600 years.

2. Study area

2.1. Environments

Rebun and Rishiri islands are located 45 km and 19 km, respectively, northwest off the coast of Hokkaido in the northeastern part of the Sea of Japan (Fig. 1a and b). The islands are – as with the entire Japanese Archipelago – located in a tectonically active zone with volcanism, earthquake and tsunami activities (e.g. Hashimoto, 1991; Kimura, 1997; Mandal et al., 2011). The formation of Rebun Island started with the subaqueous volcanic dome growth in the Cretaceous (Kimura, 1997; Goto and McPhie, 1998). Accordingly, the main units on Rebun Island exhibit Cretaceous volcanic rocks of the Rebun Group overlain by Late Miocene sedimentary formations with several basaltic to dacitic intrusions (Goto and McPhie, 1998). The highest point of the island is named Mount Rebun and reaches 490 m a.s.l. (Geospatial Information Authority of Japan, 2012). Rebun Island has an elongated shape and extends for ca. 20 km along the north–south axis and ca. 6 km along the east–west axis, spanning an area of ca. 82 km^2 (Fig. 1d).

Rishiri Island, situated ca. 9 km southeast of Rebun Island (Fig. 1c), is composed of the main strato-volcano called Mount Rishiri, reaching 1721 m a.s.l. (Kuritani and Nakamura, 2006), and several small surrounding volcanoes attached to the main volcano (Mandal et al., 2011). Volcanic activity started ca. 200 kyr BP and deformed the Tertiary basement rocks (Mandal et al., 2011). The island has a more or less circular shape, measures ca. 14–18 km in diameter and spans an area of ca. 183 km^2. Distance and area calculations for Rebun and Rishiri islands were performed based on ASTER GDEM 2 data (METI and NASA, 2011) applying a projected coordinate system (EPSG projection 2623) using ArcGIS v10.2 (ESRI, 2014).

The Tsushima Warm Current (TWC) flowing along the west coast of Hokkaido also influences Rebun and Rishiri islands. Its one branch, called the Soya Warm Current, flows through the Soya (or La Perouse) Strait and into the Sea of Okhotsk (Fig. 1a and b). The TWC affects the regional climate significantly (Igarashi, 2013), particularly during the cold season (November to May; see Leipe et al., 2013 for details and references therein) when the region is strongly influenced by the East Asian Winter Monsoon. Cold and dry air masses from Siberia passing over the relatively warm Sea of Japan collect its ascending moisture and heat resulting in heavy snowfalls in the western Hokkaido Region from November to April with highest amounts recorded in December (Igarashi, 2013; Leipe et al., 2013 and references therein). The Okhotsk High over the Sea of Okhotsk and the Ogasawara High in the northwestern subtropical Pacific control climatic conditions of the warm season. In years with a strong Okhotsk High, linked to the positive mode of the Winter North Atlantic Oscillation, summers are cool; by contrast, the Ogasawara High is connected to La Niña and results in relatively warm summers (Ogi et al., 2004; Igarashi et al., 2011; Igarashi, 2013). The following climatic data for Rebun and Rishiri islands were derived from a global high-resolution interpolated (30 arc seconds or 1-km spatial resolution) climate surface dataset for land areas (Hijmans et al., 2005) averaged over a fifty-year (1950–2000) period and based on meteorological station data (Fig 2a). The mean monthly air temperature on Rebun Island varies from −6.4 °C in January to 19.4 °C in August with a mean annual precipitation of 1102 mm, with highest amounts falling from September (131 mm) to December (106 mm).

Nakagawa et al. (2002) and Leipe et al. (2013) described the predominant natural vegetation type (biome) of Rebun and Rishiri islands (as well as most of Hokkaido) as cool mixed forest. The vegetation on Rebun Island was severely impacted by human activities during the last century. The modern landscape is considerably deforested and *Sasa* spp. (bamboo grass from the Poaceae family) became widespread on the entire island (Müller et al., 2016). Patchy forests and shrubs occupy the river and spring valleys. The vegetation on Rishiri Island consists of a mixture of boreal conifers and cool-temperate broad-leaved trees (Igarashi, 2013). In the volcanic deposition area below 400 m a.s.l., *Sasa* spp. are very frequent as well, but their distribution decreases with higher altitude and under the forest cover.

2.2. Hydrology

Lake Kushu (45°25′58″ N, 141°02′05″ E, 4 m a.s.l.) is a relatively shallow coastal freshwater lake in the northern part of Rebun Island. The distance to Funadomari Bay is about 200 m (Fig. 1e). The lake is separated from the sea by sand barriers with dune ridges reaching up to 15 m a.s.l. that were formed by strong winter winds (Sato et al., 1998). The lake catchment spans an area of ca. 10 km^2. The lake surface area covers about 0.53 km^2 with a total shoreline length of 3.4 km. The maximum water depth of 5.8 m occurs in the northern part of the lake and the average water depth is ca. 3.5 m (bathymetry data provided by T. Haraguchi, Osaka City University). Lake Kushu has two inflows and one outflow that connects with the sea. The major inflow, called Oshonnai River, enters the lake from the south. The second inflow is a small stream that reaches Lake Kushu from the southeast. The outflow in the north is canalised and flows through Funadomari town and into Funadomari Bay. The lake is surrounded by a ring of dense aquatic vegetation (mainly *Phragmites* and *Typha*) followed by a ring of trees