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Palaeobotanical records from Rebun Island and their potential for improving the chronological control and understanding human–environment interactions in the Hokkaido Region, Japan

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Abstract

Rebun Island with Hamanaka and Funadomari among the 43 documented archaeological sites and the environmental archive stored in the Lake Kushu sediment proves to be one of the key areas to study the interplay between ecology, climate and human activities. This paper focuses on the potential of palaeobotanical records from Rebun Island for improving the chronological control and understanding of late Quaternary climate changes and habitation environments of northern hunter-gatherers in the Hokkaido Region of Japan. A set of 57 radiocarbon dates of the RK12 core (Lake Kushu) demonstrates that it represents a continuous environmental archive covering the last *c.* 17,000 years. The RK12 pollen record reflects distinct vegetation changes associated with the onset of the lateglacial warming about 15,000 cal. yr BP and the cold climate reversal after *c.* 13,000 cal. yr BP. The onset of the current Holocene interglacial after *c.* 11,700 cal. yr BP is marked by a major spread of trees. The middle Holocene (*c.* 8000–4000 cal. yr BP) is characterized by a major spread of deciduous oak in the vegetation cover reflecting a temperature increase. A decline of oak and spread of fir and pine is recorded at *c.* 2000 cal. yr BP. After *c.* 1100 cal. yr BP, arboreal pollen percentages decrease, possibly linked to intensified usage of wood during the Okhotsk and Ainu culture periods. The results of diatom analysis suggest marshy or deltaic environments at the RK12 coring site prior to *c.* 10,500 cal. yr BP and a brackish lagoon between *c.* 10,500 and 7000 cal. yr BP. A freshwater lake developed after 6500 cal. yr BP, likely reflecting sea level stabilization and formation of the sand bar separating the Kushu depression from the sea. Plant macrofossil analysis shows use of various wild plants and also domesticated barley during the Okhotsk and Ainu periods.

Keywords

Ainu, cultivated barley, Jomon, northern hunter-gatherers, Okhotsk culture, post-glacial environments

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Introduction

The Baikal–Hokkaido Archaeology Project (BHAP: http://bhap.artsrn.ualberta.ca/) gathered together a multidisciplinary team of scholars investigating Holocene hunter-gatherer cultural dynamics and environmental and climate changes in the Lake Baikal Region of Russia and the Hokkaido Region of Japan (Tarasov et al., 2013; Weber et al., 2013). In contrast to the much more recently developed farming and pastoral economies, the hunter-gatherer lifestyle, in its various modes, has sustained humankind during most of its history (Fuentes, 2009; Kelly, 1995). In some places (e.g. the Near East and eastern China), the shift to food production in the early Holocene was followed by farming dispersals and the eventual rise of villages, towns and eventually states. However, in many other areas, prehistoric groups did not switch to farming but first intensified foraging (hunting, fishing and gathering) and only much later adopted agriculture (e.g. central and southern Japan), while other groups (e.g. in Hokkaido,

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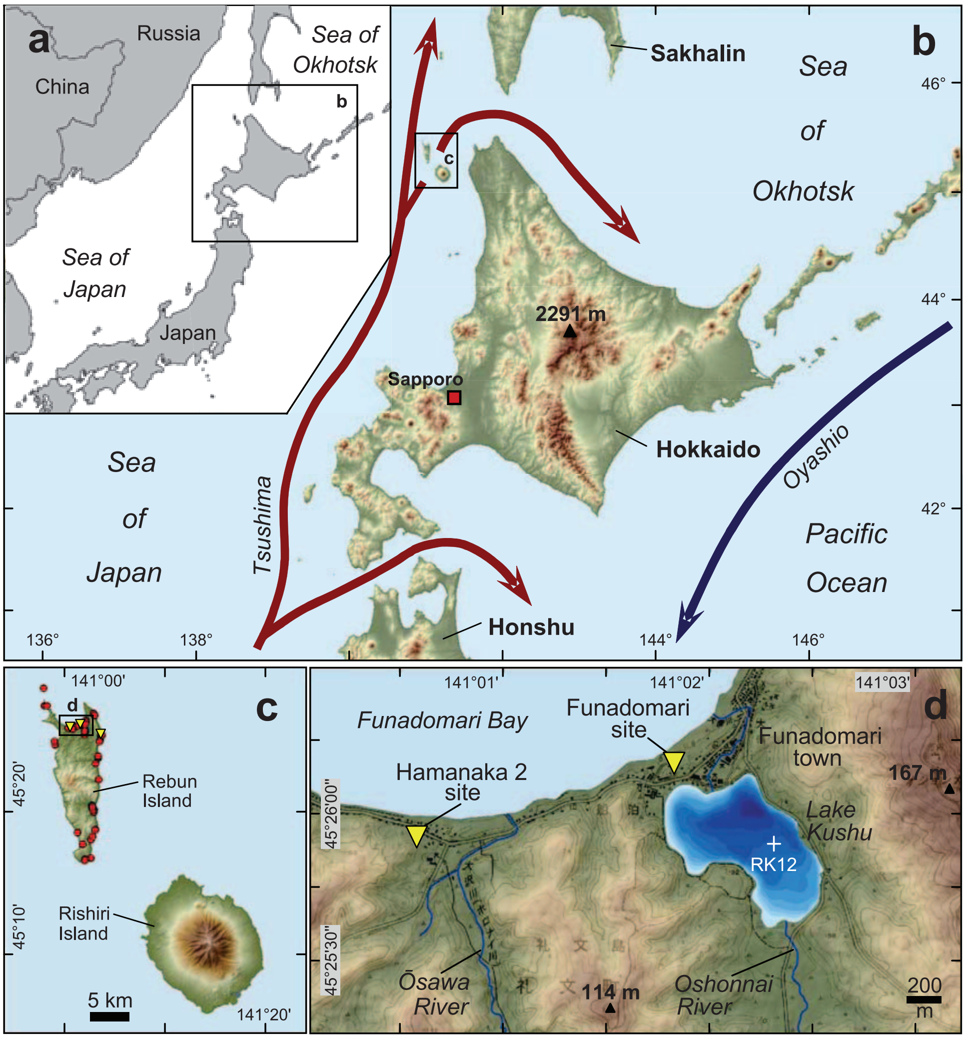

Figure 1. Map compilation showing (a) the northwest Pacific and (b) the Hokkaido Region including the Tsushima warm current (red) and the Oyashio cold current (blue); (c) Rebun and Rishiri islands; and (d) the northern part of Rebun with Lake Kushu (white cross indicates location of the RK12 cores) and Hamanaka 2 and Funadomari archaeological sites (yellow triangles). In (c), yellow triangles indicate locations of the Hamanaka 2, Funadomari and Uedomari archaeological sites and red dots indicate locations of the remaining 40 archaeological sites documented so far on Rebun. Topographic maps are based on elevation Shuttle Radar Topography Mission (SRTM) V4.1 data (Jarvis et al., 2008). Isolines for terrestrial area are drawn from a topographic map (Geospatial Information Authority of Japan, 2012). Bathymetry of Lake Kushu (0.5 m isolines) is based on survey data provided by T Haraguchi (Osaka City University).

Greenland and most of northern Eurasia) remained hunter-gatherers well into the historic period (e.g. Weber et al., 2010, 2013).

Weber et al. (2013), summarizing the substantial progress achieved in hunter-gatherer research during the past few decades and defining the BHAP rationales, noted that 'the understanding of the cultural dynamism, variability, and resilience of Holocene hunter-gatherers in many regions remains rather impoverished'. The Holocene cultural sequence of the Hokkaido Region is characterized by a series of hunter-gatherer populations. Through this time, it represented a cultural and ecological junction between the Neolithic and post-Neolithic populations of warmer latitudes of mainland Asia and central Japan and foragers of the colder regions of Northeast Asia. Recent investigations brought to light that Hokkaido's prehistoric hunter-gatherers (long time regarded as 'static' and 'primitive', e.g. Kobayashi, 1992; Watanabe, 1986) are marked by a complex pattern of inter-regional variability with a number of demographic and cultural transitions distinguished by changes in population size, distribution, organization, socio-political differentiation and degrees of sedentism and mobility (e.g. Habu, 2004; Nomura and Udagawa, 2006a, 2006b, 2006c; Underhill and Habu, 2006). What role unstable environments and climate played in the local and regional cultural dynamics remains an extremely important, although an empirically challenging question (e.g. Weber et al., 2013). Thus, in the northern part of the Japanese Archipelago including Hokkaido and adjacent islands (Figure 1a and b), potentially rich in archaeological and environmental archives, the main challenge remains the scarcity of published environmental and archaeological records with high temporal resolution and adequate dating control (see Igarashi (2013) and Habu (2004) for details and references). These common problems hinder direct correlation between the individual archives and make discussion of regional environmental and societal responses extremely difficult, thus preventing inter-regional comparison and identification of leads and lags in reconstructed changes. A multidisciplinary research started in 2011 on Rebun Island in the north-western Hokkaido Region (Figure 1c), under the umbrella of the BHAP, aiming to fill the existing gap in the current knowledge and to address the causal factors driving cultural processes, including the role of climate and environment (Weber et al., 2013).

The geographic location of Rebun Island at the border between the cool temperate zone and boreal zone makes its vegetation and environments very sensitive to climatic change. The bottom sediment of Lake Kushu (Figure 1d) is a valuable natural archive which stores detailed and high-resolution information about past environmental changes and, possibly, human–environment interactions. As indicated in the title, the aim of this paper is to emphasize the potential of palaeobotanical (i.e. pollen, plant macrofossil and diatom) records from Rebun Island for better understanding environmental and human histories of the study region and for improving the chronological control of the reconstructed changes. Furthermore, the discussion and publication of the first results are of importance for planning future archaeological and environmental research and for selecting priority research questions.

Study area

Site and regional settings

Rebun is located in the northern part of the Sea of Japan (Figure 1a), *c*. 45 km west of Hokkaido (Figure 1b) and *c*. 10 km north-west of volcanic Rishiri Island (highest point at 1721 m a.s.l.). Both islands (Figure 1c) are part of the Rishiri Rebun Sarobetsu National Park, where natural vegetation consists of cool mixed and cool conifer forest associations, shrubs, grasslands and meadows. About 100 km of open seawater separates Rebun from southern Sakhalin and the direct waterway to continental Asia exceeds 240 km.

Rebun Island occupies an area of about 82 km^2 (Schmidt et al., 2016). It extends for over 20 km from north to south and for up to 6–8 km from east to west. The hilly landscape is characterized by steep slopes. The highest point (490 m a.s.l.) is situated in the western part of the island (Figure 1c).

Lake Kushu (Figure 1d) is the only freshwater lake on Rebun (Figure 1c). Located in the northern part of the island (45°25′58″N, 141°02′05″E), about 230–400 m from the modern sea coast, the lake has a kidney bean shape and a maximum length of *c*. 1100 m. The maximum water depth reaches *c*. 6 m in the eastern part of the lake with average depths of about 3–5 m.

Climate

The climate conditions of Rebun and Rishiri islands are mainly controlled by the East Asian monsoon system. The East Asian summer monsoon (EASM) circulation, which is formed by the pressure gradient between the Asiatic Low over Siberia and the Hawaiian High over the northern Pacific Ocean, transports warm and moist air from southern to south-eastern directions. The formation of the Aleutian Low and the Siberian High during autumn is paralleled by the reversal of the ocean–continent pressure gradient which culminates in winter. During this time, the islands are mainly influenced by cold continental air flow from northern to north-western directions controlled by the East Asian winter monsoon (EAWM) circulation.

Another important climatic control in the study region is the Tsushima warm current (TWC) which flows as a branch of the Kuroshio warm current northwards along the eastern margin of the Sea of Japan (Figure 1b). Especially during winter, the TWC promotes moisture uptake by the predominant winter monsoon winds, which results in enhanced snow fall and prevents sea ice formation in the region (Nikolaeva and Shcherbakova, 1990).

A global high-resolution (30 arc seconds) dataset of surface climate variables averaged over the years from 1950 to 2000 (Hijmans et al., 2005) reveals year-round moist conditions around Lake Kushu and on Rebun Island with mean monthly precipitation values reaching ~90–130 mm from July to January. The driest month (March) is still reasonably wet (~55 mm). The mean annual precipitation is ~1100 mm. The summers are relatively mild and winters are cool. The annual mean temperature is 6.1°C. During the warmest month (August) mean temperature reaches 19.4°C. In winter (December–March), mean temperatures drop below 0°C, with the mean temperature of the coldest month (January) as low as −6.4°C.

Vegetation

The combination of cool temperatures and abundant all-year-round precipitation results in dense vegetation cover and predominance of cool temperate and boreal woody plants. Rebun and Rishiri islands are situated within the cool mixed forest biome zone (Nakagawa et al., 2002), which roughly stretches between 48° and 42°30′N, that is, from south-western Sakhalin (Bukhteeva and Reimers, 1967) to the northern limit of the temperate deciduous forest biome (known as Kuromatsunai line) in south-western Hokkaido (Itoh, 1987). The natural forest vegetation is dominated by boreal evergreen conifers including *Abies sachalinensis* (Sakhalin fir), *Picea jezoensis* (Jezo spruce) and boreal and temperate deciduous broadleaf trees including several *Betula* (birch) and *Alnus* (alder) spp., *Salix* (willow) spp., *Quercus crispula* (Mongolian oak), *Sorbus commixta* (Japanese rowan), *Sorbus sambucifolia* var. *pseudogracilis* (Siberian mountain ash), *Acer pictum* subsp. *mono* (painted maple), *Fraxinus* (ash) spp., *Juglans ailantifolia* (Japanese walnut), *Morus australis* (Chinese mulberry), *Phellodendron amurense* (Amur cork tree) and woody vine *Toxicodendron orientale* (syn. *Rhus ambigua*, Asian poison ivy). Japanese botanical literature (Haruki et al., 2004) also reports *Ulmus davidiana* var. *japonica* (Japanese elm), *Ulmus laciniata* (Manchurian elm), *Tilia japonica* (Japanese lime) and *Fraxinus mandschurica* (Manchurian ash). Mild maritime climate and deep snow cover might explain the presence of some warm-temperate taxa such as *Ilex* (holly) spp., *Aralia* (spikenard) spp., *Skimmia japonica* (Japanese skimmia) and *Kalopanax septemlobus* (prickly castor oil tree) on the islands.

Today, large parts of Rebun Island are deforested and mostly covered by dense *Sasa kurilensis* (dwarf bamboo) stands or *Reynoutria sachalinensis* (Sakhalin knotweed), likely hindering the re-establishment of arboreal taxa. Although arboreal plants are less common on Rebun today, occupying mainly valleys in the central and eastern part of the island, interviews with the local villagers in August 2014 suggest that forests played a greater role in the vegetation cover in the first half of the 20th century. Rishiri Island reveals a much better preserved well-developed natural forest belt (e.g. Igarashi, 2008; Sawada et al., 2015). On exposed elevated sites on Rebun Island and above *c*. 400–600 m a.s.l. on Rishiri Island, *Pinus pumila* (Siberian dwarf pine), *Sasa kurilensis* and shrubby forms of *Betula* and *Alnus* are common. *Empetrum nigrum* (black crowberry), *Juniperus chinensis* (Chinese juniper) and *Taxus cuspidata* var. *nana* (dwarf Japanese yew) also grow at these higher elevations.

Archaeology

Within the prehistory of the Japanese Archipelago, the Hokkaido Region played a specific role as a cultural crossroad between mainland Japan and northern territories (i.e. Russian Far East and Siberia). A diverse pattern of cultural shifts is displayed by regional archaeological studies (Figure 2). The oldest traces of human presence in Hokkaido are stone artefacts which date to *c*. 30,000 cal. yr BP (i.e. calibrated or calendar years before present, where 'present' is conventionally taken as 1950) as suggested by Izuho and Sato (2007). Some authors argue that Upper Palaeolithic groups migrated from Siberia (Izuho et al., 2014 and references therein) via a land bridge, which connected Hokkaido with Sakhalin and the northeast Asian mainland during most of the Last Glacial period (Kuzmin et al., 2002). Palaeolithic exchange networks extended at least as far as southern Sakhalin/Hokkaido (Kuzmin et al., 2013). The origin of the Neolithic Japanese Jomon culture is still debated (Adachi et al., 2009). In addition to the traditional view of a southern origin (e.g. Hanihara, 1991; Hudson, 1999), a growing number of anthropological studies stress the role of immigration from northern regions via Hokkaido (e.g. Hanihara and Ishida, 2009; Omoto and Saitou, 1997; Tanaka et al., 2004). Widely accepted is another southward movement of

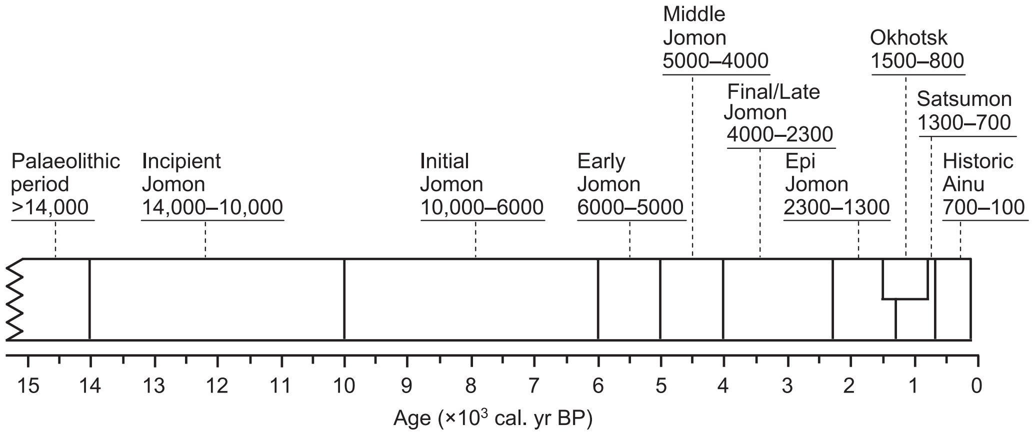

Figure 2. Archaeological culture sequence of the Hokkaido Region (according to Hanihara et al., 2008; Weber et al., 2013).

hunter-gatherer populations around the Last Glacial Maximum (*c*. 20,000 cal. yr BP) into Hokkaido. These groups later (*c*. 15,000 cal. yr BP) introduced microblade tools on Honshu Island (e.g. Imamura, 1996) and likely mixed with local communities (Matsumura and Oxenham, 2013).

In most of mainland Japan, foraging became much less important at the end of the Jomon period, during the 3rd millennium BP, when farming was continuously introduced from the Korean Peninsula (Hudson, 2013). In Hokkaido, however, foraging remained fundamental subsistence strategy from the Upper Palaeolithic (*c*. 30,000 cal. yr BP) through to the historic Ainu (*c*. 800–100 cal. yr BP). Also, the Jomon cultural sequence in Hokkaido (*c*. 14,000–1300 cal. yr BP) was extended compared with mainland Japan with the Epi Jomon period dated to *c*. 2300–1300 cal. yr BP. The Epi Jomon communities, who are believed to be direct descendants of the Jomon people, first started to incorporate rice cultivation as an additional food source (e.g. Habu, 2004). However, only insignificant quantities of rice remains are reported from Epi Jomon sites (Crawford, 2011). After the Jomon era, Hokkaido experienced a number of cultural transitions and migrations from the north. People of the Okhotsk culture, probably originating from the lower Amur Region, spread from Sakhalin into the region and occupied Rebun and Rishiri islands and the north-eastern coastline of Hokkaido between *c*. 1500 and 800 cal. yr BP. This culture was highly specialized in marine fishing and hunting sea mammals including *Phoca vitulina* (harbour seal), *Callorhinus ursinus* (fur seal), *Zalophus japonicus* (Japanese sea lion, extinct species), *Eumetopias jubatus* (Steller's sea lion) and whale species (Sato et al., 2007). The Satsumon culture (*c*. 1300–700 cal. yr BP), more or less contemporarily established in the southern and inner parts of Hokkaido, is believed to have developed from the Epi Jomon (Adachi et al., 2009). This culture is marked by plant cultivation (e.g. barley, wheat and millets) at least in the south-western part of Hokkaido (Crawford, 2011). The historical Ainu culture (*c*. 700–100 cal. yr BP) incorporates characteristics of the Okhotsk (e.g. bear cult and marine mammal hunting) and Satsumon (e.g. dry-farming crop cultivation) cultures. Utagawa (2002) and Sato et al. (2007) suggest that the Ainu emerged from the merging of both cultures.

It is plausible that Rebun and Rishiri islands represent an important link in terms of prehistoric human migrations and cultural exchanges between Hokkaido and adjacent regions. A short summary of Rebun archaeology provided by Sakaguchi (2007a, 2007b) points out that the oldest remains of human activities on Rebun Island are Palaeolithic microblades, microcores and tanged projectile points dating to *c*. 22,000–13,000 cal. yr BP. Residential sites cover the period from Middle Jomon to modern Ainu. Most of these sites are concentrated on marine terraces and sand dunes around the Funadomari (Figure 1d) and Kafukai bays. Inui (2000) registered 43 sites on the island. The oldest (so far reported) residential site is Uedomari located on the north-eastern coast of Rebun Island (Figure 1c), which dates to *c*. 4900–4400 cal. yr BP (Middle Jomon period). The number of sites increased during the period *c*. 4400–3200 cal. yr BP. After a decrease in the Final Jomon period, the number of sites increased again during the Epi Jomon, Okhotsk and Ainu periods (Inui, 2000).

Data and methods

Lake Kushu core RK12

Lake Kushu was chosen as a key site for palaeoenvironmental research. It is located in a climatically sensitive region (i.e. the boreal–temperate transition), about 1.5 km east of the Hamanaka 2 site (Figure 1d), and contains a thick sedimentary succession storing diverse palaeoenvironmental information (Kumano et al., 1990). A preliminary survey of the lake to determine the best coring point and to obtain necessary permits from the Wakkanai Nature Conservation Bureau, the Rebun Forest Service, the Rebun Town administration and the local fisherman's union was accomplished by H Yonenobu (Naruto University of Education) and his team in November–December 2011.

In February 2012, when the lake was covered by a thick ice layer, coring was performed in the central part of the lake (Figure 1d) by the commercial company Dokon Co. (Sapporo) using professional equipment for scientific lake coring (e.g. Nakagawa et al., 2012). The composite core RK12 was recovered from two bore holes (i.e. RK12-1 and RK12-2) located within a few metres from each other (Figure 1d). Once coring was completed, the core segments (in thin-wall tubes of 86 mm diameter) were transported to the Graduate School of Environmental Science, Hokkaido University (Sapporo), and stored under cool temperature. In April 2012, the tubes were opened by cutting in two halves, the sediments were photographed, described, documented and sub-sampled for multiproxy analyses using the double-L channel (LL-channel) technique (Nakagawa, 2007; Nakagawa et al., 2012) by a team led by T Irino and M Yamamoto (Hokkaido University).

The composite core revealed a continuous, partly laminated, organic-rich *c*. 19.5-m-long sediment column. The basal unit contains sandy clay with pebbles, likely indicating stronger river influence. Peat (1925–1935 and 1905–1915 cm) and organic-rich clay (1915–1925 and 1895–1905 cm) layers appear in the lower part of the core, suggesting shallow water or marshy environments. The interval between 1895 and 1390 cm is generally characterized by homogeneous, relatively organic-poor clay, which is only interrupted by two short intervals (1790–1815 and 1765–1780 cm) showing a higher amount of coarser grains (i.e. sand). Between 1390 and 850 cm, the clayey material is mostly finely laminated with sections of relatively low to high organic matter concentration. The upper 850 cm of the sediment column consists of homogeneous organic-rich clayey material. The sedimentological comparison with the 16.2-m core (Kumano et al., 1990), recovered from the marshy floodplain at the southern coast of the lake (Figure 1d) and spanning the last *c*. 9000 cal. yr BP, suggests it may represent the entire lateglacial and Holocene time interval at very high temporal resolution.

A subset of the RK12 core material has been shipped to Free University of Berlin where a range of pilot analyses were performed. A total of 57 bulk samples, each representing 1 cm of core material, were sent to the Poznan Radiocarbon Laboratory for age determination. For pollen analysis, sub-samples (each representing 1 cm of core sediment) were processed in the chemical laboratory of the Palaeontology Section at FU Berlin and microscopically analysed (see Demske et al., 2013; Müller et al., 2014 for technical details and references). Fossil samples for diatom analysis have been processed using standard procedures (see Battarbee et al., 2001; Kossler et al., 2011 for details and references). Microscopic analyses revealed high contents and good preservation of diatoms, pollen and spores along the RK12 core.

The Hamanaka 2 archaeological site

Rebun Island is one of the key areas selected for the BHAP research, not least because of its location and the high number of archaeological hunter-gatherer sites spanning an interval from the Palaeolithic to historic Ainu (Inui, 2000). A test survey undertaken by H Kato (Hokkaido University) in 1996 helped to identify Hamanaka and Funadomari as multi-component (habitation and mortuary) and multi-period archaeological sites. Both are located in the northern part of the island close to Lake Kushu (Figure 1d). Sakaguchi (2007a) has suggested that the Hamanaka 2 site was first used by the late Jomon maritime hunter-gatherers as a campsite for intensive hunting and processing, while it was used as a human burial area and dog butchering site during the Okhotsk period. The first BHAP excavations in summer 2011 confirmed the high research potential of the Hamanaka 2 site. Sediment samples representing different cultural layers (e.g. Epi Jomon, Okhotsk/Satsumon and Ainu) and archaeological features (e.g. refuse areas, pits, fire places, and graves) were treated in the field laboratory organized in the old school building in Uedomari. A flotation machine (see Crawford, 1983) was used to isolate the light material (seeds, charcoal etc.) from the sediments. Selected flotation samples from the set obtained during the 2013 campaign were analysed for plant macro-remains. In this paper, we show the analytical results representing the Okhotsk and Ainu cultural layers. Terrestrial plant material of the most representative samples was submitted to Poznan Radiocarbon Laboratory for AMS ^{14}C dating.

Results

RK12 core chronology

Table 1 presents the results of the AMS radiocarbon dating of the RK12 core samples and their calibration to cal. yr BP. The age model (Figure 3a) suggests that the RK12 core sedimentation continued since *c*. 17,000 cal. yr BP. Figure 3a shows rather unambiguous age–depth relation in the upper half of the core accumulated during the past *c*. 6000 years. The accumulation rate is very high, that is, about 1 cm of sediment in *c*. 6 years. In the bottom half of the core, the radiocarbon dates demonstrate several well distinguishable reversals, suggesting contamination of the respective samples by older material. Reversed dates were consistently excluded when constructing the age model for the RK12 core (Figure 3a). The age–depth model also suggests greater variations in sedimentation rates in the lower half of the core and substantially slower sedimentation (i.e. 1 cm in *c*. 20 years) prior to *c*. 9500 cal. yr BP.

RK12 coarse-resolution pollen record

For the purpose of this study, 28 samples have been microscopically analysed in which about 90 different plant taxa could be distinguished. Besides higher plant species of trees, shrubs and herbaceous plants, 15 different species of mosses and ferns were identified. The pollen and spore content of the samples was sufficiently high to allow the counting of a minimum of 400 terrestrial pollen grains per sample. Bisaccate pollen grains of *Abies* and *Pinus* were frequently broken and hampered identification. These counts were grouped to Pinaceae. In addition to pollen, vascular cryptogam spores and green algae colonies (*Pediastrum*, *Botryococcus*) were identified and counted. The preliminary results are summarized in the pollen percentage diagram (Figure 4). For description of the results, we subdivided the diagram into seven chrono-stratigraphic units (i.e. zones Ku-7 to Ku-1) on the basis of the RK12 core chronology and observed changes in plant taxa composition and relative abundance.

The lowermost part of the core (Ku-7) is characterized by high amounts of sedges (Cyperaceae) which form up to 60% of the total pollen sum. *Sphagnum* is present with highest values (about 5%) in this zone. Arboreal pollen taxa increase to up to 50% in the following zones (Ku-6 and Ku-5) together with increasing amounts of spores of Lycopodiales and Polypodiales. The percentages of sedges drastically decrease (to 15%) while Poaceae amounts slightly increase (up to 20%). Aquatic plant taxa are rather abundant in zone Ku-5. However, temperate deciduous tree taxa, like *Fraxinus*, *Quercus* and *Ulmus*, which appear in zone Ku-6, disappear again. The following zone Ku-4 is characterized by higher amounts of arboreal pollen taxa (especially Pinaceae, *Alnus*, *Betula* and *Quercus*), which from now on dominate the pollen spectra (up to 90%). Poaceae pollen and spore percentages reach their maxima in this zone. Zone Ku-3 is characterized by high taxonomic diversity and rather stable abundances of arboreal and non-arboreal taxa. In zone Ku-2, *Abies* pollen percentages reach maximum values (about 20%). Noticeably decreasing percentages of arboreal pollen taxa and increasing percentages of Poaceae, *Artemisia*, *Lysichiton camtschatcensis* and spores of Lycopodiales are characteristic for zone Ku-1.

Diatom analysis

A total of 10 selected samples have been analysed (Figure 5) to check the potential of the RK12 core for diatom-based reconstructions. Eight samples show sufficient well-preserved valves allowing for counting of at least 500 valves. Two samples, that is, RK12-02-02_7-8 with 331 counted valves and RK12-02-19_82-83 with 444 counted valves, reveal lower diatom concentrations.

The lowermost analysed sample (RK12-02-19_82-83) shows dominance of benthic *Diploneis subovalis* Cleve 1894 (78%) and *Pinnularia viridis* (Nitzsch) Ehrenberg 1843 (15%) and low taxonomic diversity. No diatoms have been detected between 19 and 16.5 m composite depth. The sample RK12-02-16_16-17 shows high abundance of benthic freshwater *Pseudostaurosira brevistriata* (Grunow) Williams & Round 1987 (31%) and *Pseudostaurosira elliptica* (Schuhmann) Edlund, Morales & Spaulding 2006 (30%). Benthic brackish/marine taxa are represented by *Pinnunavis yarrensis* (Grunow) Okuno 1975 (3.8%), *Rhopalodia acuminata* Krammer 1987 (3.3%) and *Mastogloia elliptica* (Agardh) Cleve 1893 (0.3%). Some planktonic marine *Chaetoceros* spp. appear with less than 5%. The following sample (RK12-02-14_7-8) contains freshwater benthic *Epithemia sorex* Kützing 1844 and *Cocconeis placentula* Ehrenberg 1838 (each 12%) and highest recorded percentages of marine taxa, including *Chaetoceros seiracanthus* Gran 1897 (23%), *Chaetoceros radicans* Schütt 1895 (7.3%), *Chaetoceros diadema* (Ehrenberg) Gran 1897 (0.7%) and *Cyclotella choctawhatcheeana* Prasad 1990 (6.2%). The sample RK12-02-12_9-10 reveals re-increased percentage of benthic freshwater *P. brevistriata* (27%).

Table 1. Summary of radiocarbon dates, and calibrated and modelled ages for the set of 57 AMS-dated samples from the RK12 core of Lake Kushu. Dates shown in *cursive* font are regarded as being too old.

Laboratory number	Composite depth, cm	AMS ^{14}C date, uncal. yr BP	Calendar age (OxCal v4.2.3 Bronk Ramsey, 2013), 95% range		Calendar age (best-fit model)	
			From, cal. yr BP	To, cal. yr BP	Cal. yr BP	Cal. yr AD/BC
Poz-51689	64.5	*470 ± 25*	535	499	350	1600
Poz-51700	96.5	415 ± 30	521	331	499	1451
Poz-51713	126.5	510 ± 35	627	502	615	1335
Poz-51721	164.5	1065 ± 25	1051	929	962	988
Poz-51731	196.5	1290 ± 30	1286	1180	1194	756
Poz-51735	226.5	1445 ± 30	1386	1297	1315	635
Poz-51736	264.5	1520 ± 35	1523	1340	1405	545
Poz-51737	296.5	1745 ± 30	1719	1565	1622	328
Poz-51770	326.5	1765 ± 30	1808	1571	1704	246
Poz-51690	364.5	2070 ± 30	2124	1951	2003	−53
Poz-51691	396.5	2160 ± 30	2308	2058	2149	−199
Poz-51692	426.5	2270 ± 30	2350	2160	2320	−370
Poz-51694	464.5	2420 ± 30	2698	2352	2457	−507
Poz-51695	496.5	2635 ± 30	2837	2730	2753	−803
Poz-51696	527.5	2930 ± 30	3170	2975	3009	−1059
Poz-51697	564.5	2915 ± 35	3166	2958	3134	−1184
Poz-51698	596.5	3190 ± 35	3480	3353	3391	−1441
Poz-51699	626.5	3250 ± 30	3563	3401	3540	−1590
Poz-51703	664.5	3505 ± 35	3876	3651	3774	−1824
Poz-51704	696.5	3670 ± 35	4140	3896	3982	−2032
Poz-51705	726.5	3790 ± 40	4351	3996	4215	−2265
Poz-51706	764.5	4185 ± 30	4839	4619	4660	−2710
Poz-51707	796.5	4300 ± 35	4962	4830	4853	−2903
Poz-51709	826.5	4495 ± 35	5302	4987	5066	−3116
Poz-51710	864.5	4730 ± 35	5585	5327	5340	−3390
Poz-51816	896.5	4735 ± 35	5586	5327	5539	−3589
Poz-51817	926.5	4885 ± 30	5660	5587	5603	−3653
Poz-51711	969.5	5045 ± 35	5906	5665	5749	−3799
Poz-51837	996.5	5770 ± 40	6667	6476	5846	−3896
Poz-51714	1028.5	*6840 ± 40*	7758	7574	5958	−4008
Poz-51838	1064.5	*12,050 ± 70*	14,089	13,750	6084	−4134
Poz-51840	1098.5	*13,030 ± 70*	15,852	15,311	6218	−4268
Poz-51715	1126.5	*14,650 ± 70*	18,027	17,624	6359	−4409
Poz-51716	1165.5	5820 ± 40	6731	6506	6652	−4702
Poz-51717	1196.5	*6850 ± 40*	7787	7609	7072	−5122
Poz-51718	1226.5	6550 ± 40	7565	7418	7435	−5485
Poz-51719	1264.5	6870 ± 50	7827	7611	7686	−5736
Poz-51720	1296.5	*7670 ± 50*	8555	8386	8064	−6114
Poz-51841	1330.5	*7660 ± 50*	8549	8383	8296	−6346
Poz-51723	1364.5	7610 ± 50	8538	8346	8396	−6446
Poz-51724	1397.5	*9080 ± 40*	10,369	10,183	8437	−6487
Poz-51725	1426.5	*8560 ± 50*	9626	9471	8465	−6515
Poz-51726	1464.5	*8180 ± 40*	9263	9021	8520	−6570
Poz-51727	1496.5	7820 ± 50	8766	8456	8594	−6644
Poz-51842	1526.5	*8260 ± 50*	9422	9041	8736	−6786
Poz-51728	1564.5	8070 ± 50	9131	8769	9007	−7057
Poz-51729	1599.5	8300 ± 50	9442	9134	9394	−7444
Poz-51730	1625.5	*10,610 ± 80*	12,718	12,402	10,255	−8305
Poz-51843	1664.5	*11,170 ± 60*	13,146	12,849	11,318	−9368
Poz-51844	1696.5	10,510 ± 60	12,650	12,147	12,250	−10,300
Poz-51733	1726.5	*13,600 ± 80*	16,697	16,133	13,150	−11,200
Poz-51734	1764.5	*15,030 ± 80*	18,491	18,011	14,161	−12,211
Poz-51765	1814.5	*13,220 ± 80*	16,155	15,598	15,215	−13,265
Poz-51766	1832.5	*14,270 ± 90*	17,636	17,096	15,518	−13,568
Poz-51767	1864.5	*14,330 ± 90*	17,722	17,149	15,963	−14,013
Poz-51768	1889.5	13,490 ± 70	16,512	16,012	16,236	−14,286
Poz-51769	1930.5	13,740 ± 100	16,958	16,280	16,591	−14,641

The proportion of marine taxa decreased related to the previous sample RK12-02-14_7-8. Thus, *C. choctawhatcheeana* reaches 5.2% and brackish benthic *M. elliptica* 6.5% of the assemblage.

In the middle part of the RK12 core (sample RK12-02-10_40-41), the ratio of benthic to planktonic taxa (b/p-ratio) shifts significantly, reflecting the dominance of planktonic *Stephanodiscus*

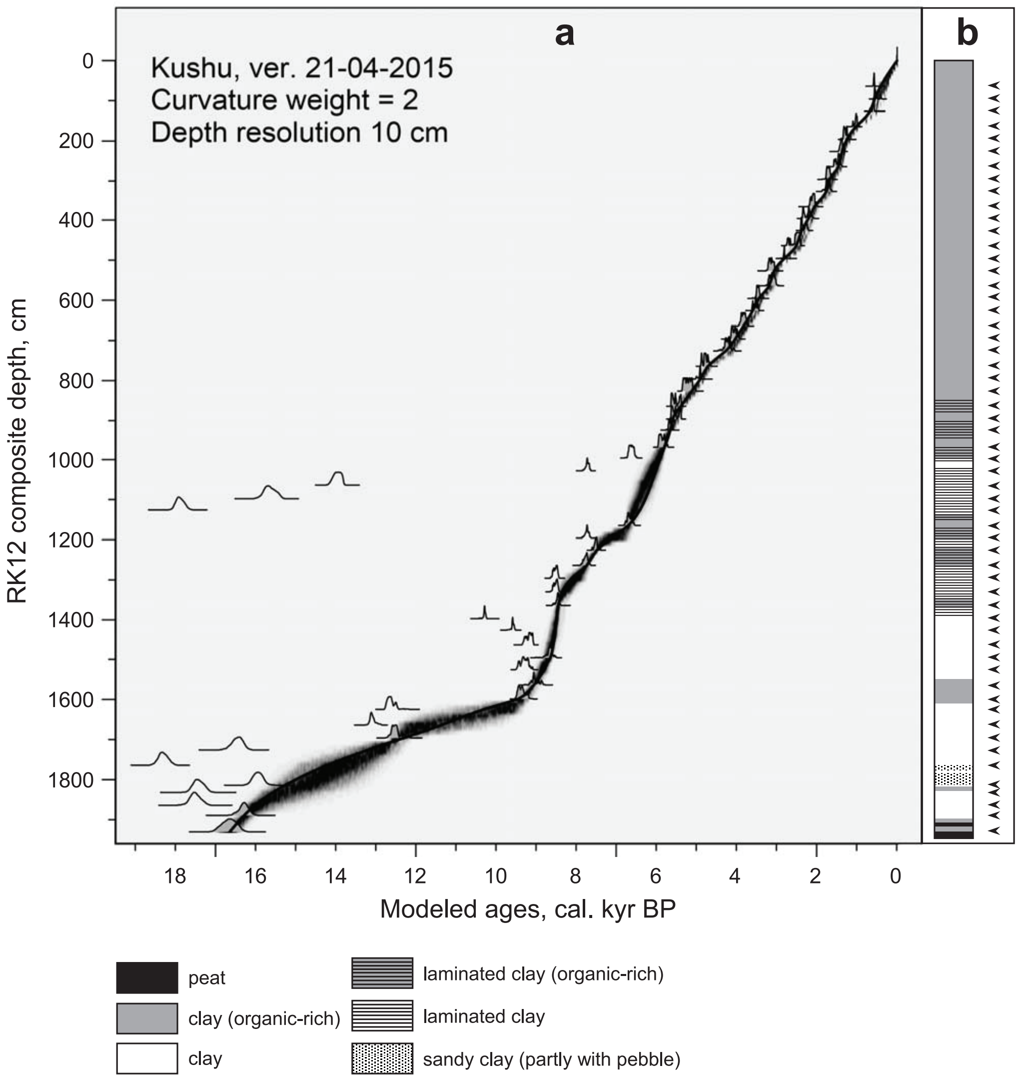

Figure 3. (a) The age–depth model (best-fit line with uncertainty ranges) applied to the RK12 sediment core (b) from Lake Kushu. Radiocarbon dates (dated levels are indicated by the horizontal arrows in b) were calibrated against the calibration curve Intcal13 (Reimer et al., 2013), and the model was constructed using the free-shape algorithm (Goslar et al., 2009). The grey silhouettes along the best-fit line (a) represent calibrated ^{14}C dates taken into account by the model, while the non-filled silhouettes left of the best-fit line represent older ^{14}C dates rejected by the model.

hantzschii Grunow 1880 (53%), *Aulacoseira ambigua* (Grunow) Simonsen 1979 (15%), *Aulacoseira granulata* (Ehrenberg) Simonsen 1979 (11%) and *Asterionella formosa* Hassall 1850 (8.6%). The overlying sample (RK12-02-07_9-10) is also mainly composed of planktonic diatoms including *A. ambigua* (16%), *A. granulata* (16%), *Aulacoseira islandica* (Müller) Simonsen 1979 (18%) and *S. hantzschii* (18%). The sample RK12-02-06_21-22 shows the dominance of *A. ambigua* (33%) and *A. granulata* (31%), whereas *A. islandica* still accounts for 18%. Marine taxa are represented by *Cyclotella choctawhatcheeana* (5.4%).

In the upper part of the core, the sample RK12-02-03_73-74 is dominated by *Aulacoseira granulata* (65%), *Aulacoseira ambigua* (19%) and *Aulacoseira islandica* (9.7%). In the sample RK12-02-02_7-8, *A. islandica* becomes the dominant taxa reaching 56% of the assemblage. A noticeable increase in benthic freshwater diatoms, including *Gomphonema grovei* var. *lingulatum* (Hustedt) Lange-Bertalot 1985 (6.9%), *Pseudostaurosira elliptica* (9.3%) and other minor taxa (i.e. other benthic <5%) is recorded in this sample. The uppermost analysed sample RK12-02-01_1-2 is dominated by planktonic freshwater diatoms including *A. ambigua* (64%), *A. granulata* (15%) and *A. islandica* (7.8%). *P. elliptica* (Schuhmann) Edlund, Morales & Spaulding 2006 accounts for 9.3%.

Plant macrofossil analysis

Our results demonstrate that all 30 flotation samples from the sediment layers I, IIa–c, IIIa–c and VII of the Hamanaka 2 site (Figure 6) contain plant macrofossils, but abundance and diversity of remains vary between the samples. Dark, organic-rich cultural layers (i.e. I and IIIb) contain generally more abundant and diverse plant material than the less organic-rich, sandy layers IIa–c, IIIc, VII and the pure shell midden layers IIIa, IIId. Seeds from wild plants such as *Rumex*, *Aralia*, *Sonchus*, *Chenopodium* and other Caryophyllales were found in all studied layers. In this study, we focus on the cultural layers I and IIIb (both are characterized by greater amounts of identifiable plant material) to demonstrate the potential for the plant macrofossil analysis.

The layer IIIb is rich in charred seeds of wild plants (Figure 6), although a few charred *Hordeum vulgare* (barley) grains were also identified. AMS ^{14}C dating performed on charred seeds from three different samples of the cultural layer IIIb shows similar ages (Table 2) ranging between *c*. 1150 and 1250 cal. yr BP (i.e. *c*. AD 700–800). Based on typological characteristics of stone tools and pottery, the cultural layer IIIb is assigned to the Okhotsk period. The radiocarbon dating results confirm the archaeological classification, but allow narrowing down the deposition time of the layer IIIb.

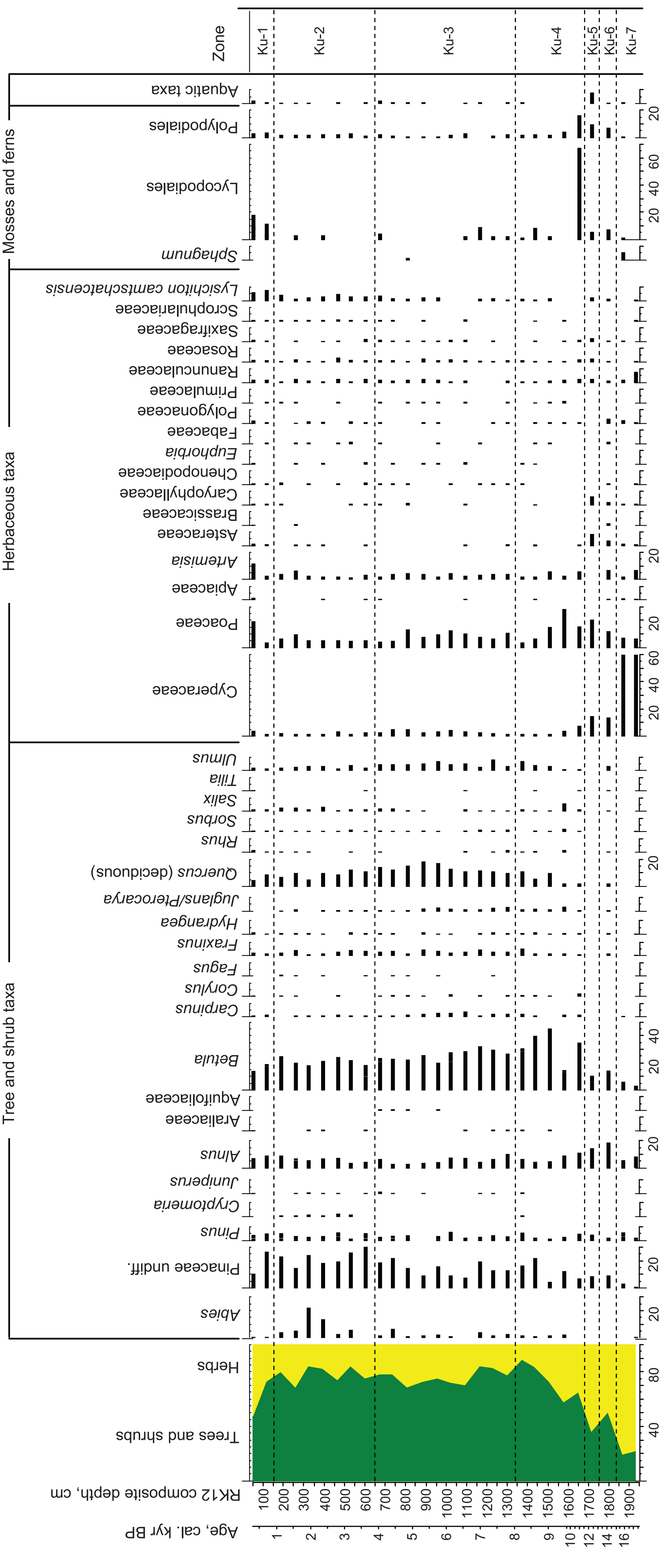

Figure 4. Simplified percentage pollen diagram presenting results of the coarse-resolution pollen analysis of the RK12 core from Lake Kushu along the composite depth and age axes.

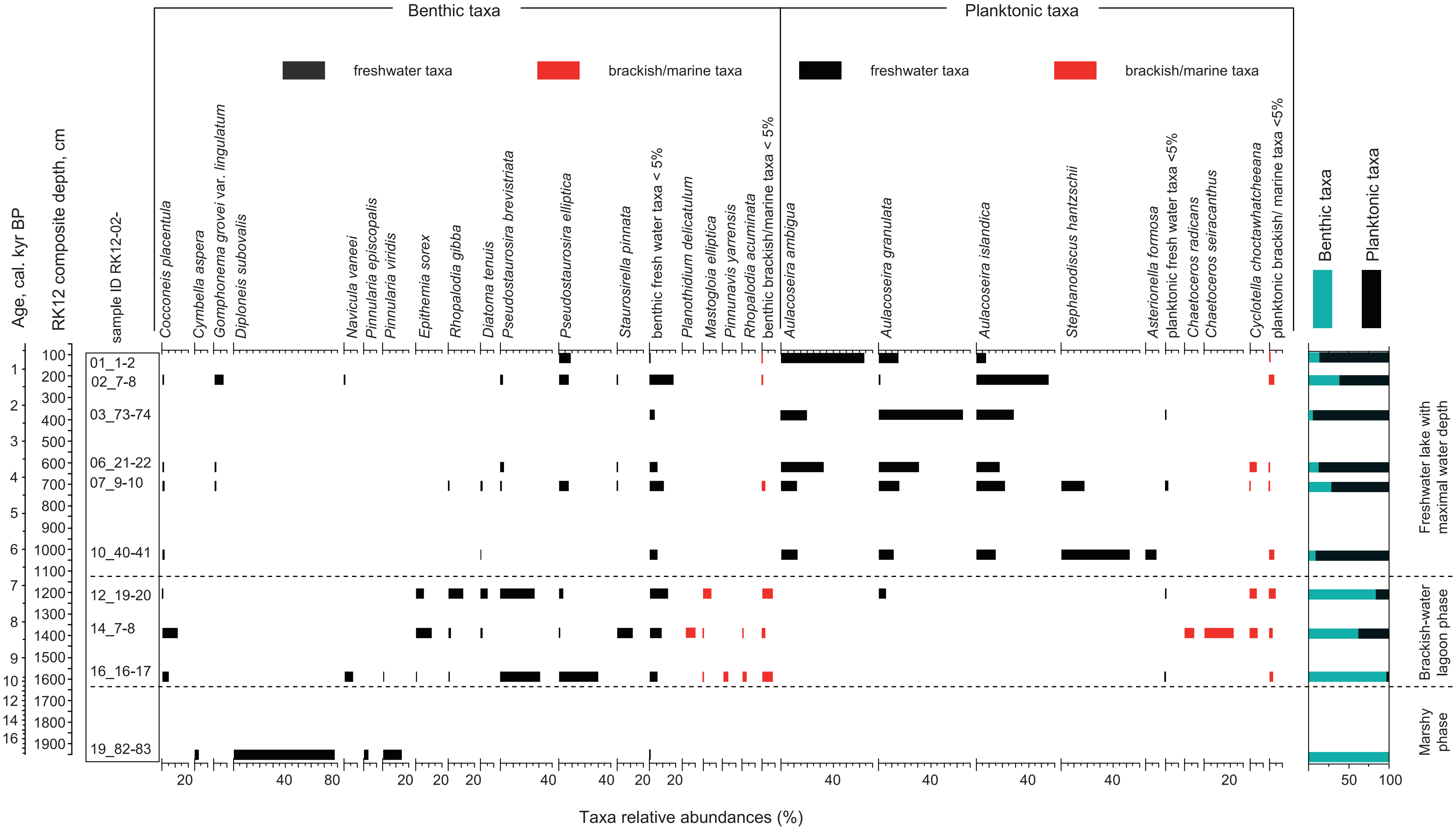

Figure 5. Diatom percentage diagram presenting analytical results for 10 selected samples of the RK12 core. All taxa exceeding 5% of the particular assemblage are shown individually and minor taxa (<5%) are combined into the following groups: other benthic freshwater taxa, other benthic brackish/marine taxa, other planktonic freshwater taxa and other planktonic brackish/marine taxa. The proportion of benthic and planktonic forms is interpreted as an indicator for relative water depth. Diatom analyst: M. Schmidt.

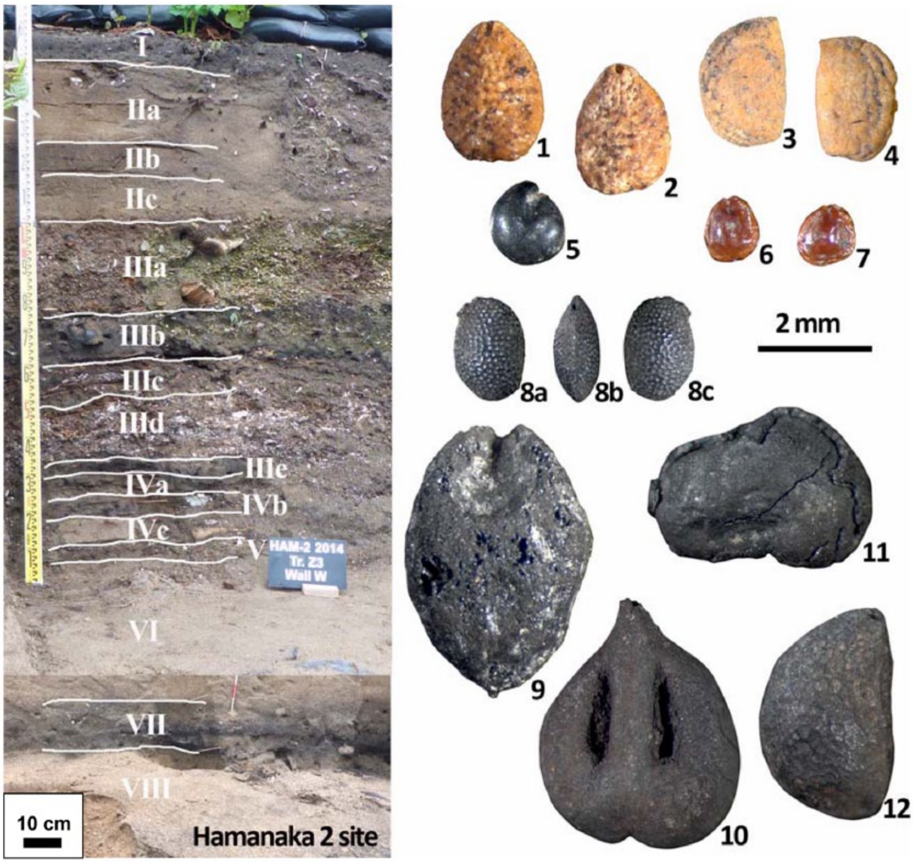

Figure 6. Composed photo of the sedimentary succession (left) of the archaeological site Hamanaka 2 with cultural layers I–VIII (August 2014). Images of selected plant macro-remains (right) representing the cultural layer I (1–7: non-charred seeds): *Sambucus sieboldiana* (1, 2), *Aralia cordata* (3, 4), *Chenopodium album* (5), *Amaranthus* sp. (6, 7) and cultural layer IIIb (8–12: charred seeds): *Actinidia arguta* (8a–c), *Hordeum vulgare* (9), *Vitis coignetiae* (10), *Toxicodendron* sp. (11) and *Phellodendron amurense* (12).

Table 2. Summary of radiocarbon dates and calibrated ages for the set of AMS-dated samples from the Okhotsk and Ainu cultural layers of Hamanaka 2, Rebun Island.

Laboratory number	Sample number	Dated material	AMS radiocarbon date, uncal. yr BP	Calendar age (OxCal v4.2.3 Bronk Ramsey, 2013), 95% range		Best-fit date (http://www.calpal-online.de/), 68% range	
				From, cal. yr BP	To, cal. yr BP	Cal. yr BP	Cal. yr AD
Poz-60766	F2013/129	*Toxicodendron* seeds	1305 ± 30	1292	1181	1240 ± 40	710 ± 40
Poz-60767	F2013/147	*Vitis coignetiae* seeds	1265 ± 30	1284	1087	1221 ± 36	729 ± 36
Poz-60768	F2013/145	*Toxicodendron* seeds	1215 ± 30	1256	1061	1151 ± 56	799 ± 56
Poz-60760	F2013/31	*Sambucus* seeds	165 ± 30	288	1	146 ± 117	1804 ± 117
Poz-60761	F2013/39a	*Aralia* seeds	115 ± 30	270	11	142 ± 97	1808 ± 97
Poz-60762	F2013/39b	Charred twig piece	210 ± 30	304	1	221 ± 69	1729 ± 69

The uppermost cultural layer I is characterized by mainly non-charred and few charred macro-remains (including barley and some unidentified plant material). The composition of plant remains differs significantly from layer IIIb. Especially seeds of *Sambucus sieboldiana* (elderberry, '*ezo-niwatoko*'), *Aralia cordata* ('*udo*') and *Chenopodium album* occur in greater quantities. Additional identified herbs are edible *Amaranthus* (amaranth), *Anthriscus* cf. *sylvestris* and *Solanum* sp. (nightshade). Three samples from this layer sent for AMS ^{14}C dating also show compatible ages (Table 2) ranging between *c*. 50 and 250 cal. yr BP (i.e. *c*. AD 1700–1900). All three dates confirm archaeological attribution of cultural layer I to the historical Ainu period.

Interpretation and discussion

Since the introduction of pollen analysis by Lennart von Post in 1916, pollen records serve as a valuable proxy for reconstruction and interpretation of post-glacial vegetation, climate change and human activities (e.g. Dolukhanov et al., 2002; Litt et al., 2009; Tarasov et al., 2007) and, more recently, for data–model comparison aiming in improving climate predictability (e.g. Kageyama et al., 2001; Kleinen et al., 2011; Wanner et al., 2008; White and Bush, 2010).

Particularly in situations when archaeological data suggest that major changes in population size and distribution, subsistence strategy, and social complexity were rapid rather than gradual, high-resolution pollen and diatom records may provide detailed information about gradual and short-term changes in the local to regional environments and help improve interpretation and better understanding of the archaeological results. Such environmental archives are rare and seldom occur in combination with archaeological material from the boreal forest zone of eastern Eurasia (e.g. Weber et al., 2013). The most recent synthesis of available pollen records from the Hokkaido Region (Igarashi, 2013 and references therein) shows a good number of pollen diagrams representing (entirely or partly) the post-glacial time interval at centurial- to millennial-scale temporal resolution. However, none of them could serve for decadal-scale reconstructions of climate and vegetation of the entire Holocene.

The intensive radiocarbon dating and coarse-resolution pollen and diatom analyses of the RK12 core demonstrate that it represents a continuous environmental archive covering the last *c*. 17,000 years. Due to the changes in sedimentation rate, temporal resolution of this sedimentary archive may vary along the record, that is, from about 20 yr/cm in the lower part to about 6 yr/cm in the upper part of the core. However, the overall potential of the Lake Kushu sediment for high-resolution environmental reconstructions over the entire post-glacial period remains very high. The RK12 record could serve as a link between the high-resolution and accurately dated records from central (i.e. Lake Suigetsu: Nakagawa et al., 2012) and northern Honshu (i.e. Lake Megata: Yamada et al., 2010; Lake Ogawara: Ikeda et al., 1998), on one hand, and the decadal-resolution pollen records from China (i.e. Sihailongwan Maar Lake: Stebich et al., 2009, 2015) on the other hand.

The pilot results of pollen analysis presented here (Figure 4) clearly demonstrate changes in vegetation and climate, such as the onset of the lateglacial warming around 15,000 cal. yr BP, the cold climate reversal after *c*. 13,000 cal. yr BP and the lateglacial/Holocene transition around 11,650 cal. yr BP. This result is consistent with a formal definition and dating of the base of the Holocene interglacial obtained from an array of physical and chemical parameters within the Greenland ice cores, including an abrupt shift in deuterium excess values, accompanied by more gradual changes in $\delta^{18}O$, dust concentration and annual layer thickness (Walker et al., 2009).

The transition from the glacial (Ku-7 in Figure 4) to the lateglacial (Ku-6) environments on Rebun is characterized by a shift from herbaceous (predominantly sedge) to tree and shrub (pine, alder and birch) dominated vegetation. Spread of woody vegetation interrupted by the lateglacial cold reversal (Ku-5) continues during the early Holocene phase (Ku-4). The observed transition to colder (and more open) vegetation communities during the lateglacial cold reversal – commonly referred to as Younger Dryas/Greenland Stadial 1 cold phase in the European and North Atlantic records (Walker et al., 2009) and Pollen Stadial 1 in the Lake Suigetsu record from central Japan (Nakagawa et al., 2005) – is not pronounced in the RK12 sediment column characterized by relatively organic-poor, homogeneous clay (Figure 3b). However, a higher amount of sand grains in the layers dated to *c*. 15,200–14,750 and *c*. 14,500–14,150 cal. yr BP likely reflects intensified fluvial erosion activity during the lateglacial climate amelioration phase. The pollen-based climate reconstruction from Lake Suigetsu (Nakagawa et al., 2005) suggests a pronounced increase in the mean annual temperature from *c*. 4–8°C prior to *c*. 15,000 years ago to *c*. 8–12°C after this time. This deglacial warming accompanied by more gradual increase in atmospheric precipitation (Nakagawa et al., 2002) led to a replacement of the cool mixed forest vegetation that consisted of coniferous and deciduous broadleaf trees, such as *Picea*, *Abies*, *Tsuga*, *Betula*, *Quercus* and *Fagus crenata*, by *Fagus*-dominated temperate deciduous forest in the region of Lake Suigetsu (Gotanda et al., 2002; Nakagawa et al., 2005), *c*. 1175 km south of Lake Kushu.

The middle Holocene phase (between *c*. 8000 and 4000 cal. yr BP) is well distinguishable in the composite core sediment characterized by mostly organic-rich and finely laminated clayey material after *c*. 8430 cal. yr BP and in the pollen record (Ku-5) suggesting a major spread of deciduous oak trees in the vegetation, with the highest percentages of oak pollen registered between 6000 and 5000 cal. yr BP. A noticeable increase in *Quercus* pollen percentages occurred in many regions of Hokkaido by about 8000 cal. yr BP, when cold-tolerant *Larix* disappeared from the pollen records (Igarashi, 2013), indicating middle Holocene climatic optimum with slightly increased precipitation and improved thermal conditions. This is well in line with a major spread of cool mixed and cool conifer forests in the Hokkaido Region and in the southern part of Sakhalin which is reflected by maximum pollen percentages for *Ulmus*, *Quercus*, *Fraxinus*, *Juglans*, *Corylus* and *Acer* (Igarashi, 2013 and references therein). Middle Holocene optimum climate conditions are also reported for the lower Amur River region (Mokhova et al., 2009) and for the Kuril Archipelago (Razjigaeva et al., 2013).

The Khoe pollen record from Sakhalin Island, *c*. 650 km north of Lake Kushu (Igarashi and Zharov, 2011), and the pollen-based climate reconstruction (Leipe et al., 2015) demonstrate most favourable climate conditions on the island between *c*. 8700 and 5200 cal. yr BP. Compared with the early Holocene part of the Khoe record, the reconstructed mean January and July temperature and mean annual precipitation values were higher by about 2.5°C, 0.5°C and 70 mm, respectively, during the middle Holocene interval (Leipe et al., 2015).

The late Holocene part of the RK12 record demonstrates homogeneous organic-rich clay sedimentation and reveals highest percentages of fir and pine pollen by *c*. 2000 cal. yr BP (Ku-2), suggesting an increase in coniferous forest cover in the regional vegetation. In the topmost part of the Khoe record, from *c*. 5200 cal. yr BP to present, the pollen analysis also shows a dominance of coniferous (e.g. *Picea* and *Abies*) pollen, whereas percentages of temperate woody taxa decrease (Igarashi and Zharov, 2011), suggesting a slight deterioration of the climate conditions on Sakhalin Island (Leipe et al., 2015). Analogous late Holocene climate trends are inferred on the basis of palynological investigations from the wider study region including the lower Amur River basin (Mokhova et al., 2009) and the Kuril Islands (Razjigaeva et al., 2013). However, late Holocene climate deterioration is less obvious in the fossil pollen records from Hokkaido, as suggested by the migration history of *Fagus crenata* (Igarashi, 2013) and a recent quantitative climate reconstruction derived from a *c*. 5500-year-old pollen record from southwest Hokkaido (Leipe et al., 2013). These results and the Holocene vegetation and climate reconstruction based on the pollen record from Sihailongwan Maar Lake in northeast China (Stebich et al., 2015) suggest that hydrology of the Sea of Japan, particularly the re-intensified TWC, had a stronger influence on the regional and local climate conditions during the late Holocene than the progressively weakening summer insolation. Forthcoming high-resolution pollen and sedimentary analyses of the RK12 core from Rebun will provide missing information helping to address this problem.

The uppermost zone of the RK12 pollen record (Ku-1) shows decrease in arboreal pollen after *c*. 1100 cal. yr BP, but more pronouncedly after *c*. 750 cal. yr BP. If the older part of the record primarily reflects natural, that is, climatically driven, changes in vegetation, this upper zone most likely reflects human activities, that is, intensive use of wood during the Okhotsk and particularly during the Ainu period. The pollen diagram (Figure 4) also reveals several troughs in the arboreal pollen curve dated to around *c*. 1500, 2800, 3600, 4800 and 6600 cal. yr BP. However, an important task of the further in-depth environmental (including high-resolution pollen analysis) and archaeological research on Rebun would be to establish whether these and earlier drops in the arboreal pollen percentages reflect human presence on the island or natural climate variability or both. Another important question to be addressed by the continued archaeological excavations is whether consecutive peaks in the arboreal pollen curve correspond to the intervals with limited human activities or even absence of human settlements on Rebun Island during the earlier Jomon interval. In answering these questions and searching for possible connections between Holocene hunter-gatherer culture change and environmental/climatic conditions, high-resolution pollen and other palaeorecords (including diatoms and plant macrofossils) will play an important role.

Supporting the first results of diatom analysis obtained from the Lake Kushu basin (Kumano et al., 1990), our pilot results (Figure 5) also demonstrate that marine/brackish-water diatom taxa were abundant in the sediment between *c*. 10,500 and 7000 cal. yr BP, and freshwater taxa became dominant after that time. Presence of exclusively benthic freshwater diatom taxa near the core base is in line with the shallow water, marshy or deltaic environments suggested by the sedimentological (Figure 3b) and pollen (Figure 4) records. Both, the proxy-based reconstructions (Waelbroeck et al., 2002) and ICE-5G (VM2) model simulations (Peltier and Fairbanks, 2006) indicate that relative global sea level was about 110–115 m below present level at that time (i.e. around 17,000 cal. yr BP). Since then, global sea level rose steadily and reached *c*. 40 m below modern level *c*. 10,500 years ago. The diatom record (Figure 5) suggests that marine water penetrated into the Kushu depression at about this time and turned it to a brackish-water lagoon, which existed until about 7000–6500 cal. yr BP. The diatom assemblage composition indicates that Kushu became a freshwater lake between *c*. 6500 and 6000 cal. yr BP, when global seas basically reached modern levels (Peltier and Fairbanks, 2006; Waelbroeck et al., 2002) and the sand bar separating Kushu lagoon from the sea has been formed. Greater environmental stability over the last 6000 years (in comparison with the early Holocene interval) is also supported by the results of radiocarbon dating of the RK12 core, stable sedimentation rates, and pollen composition.

However, four peaks in brackish/marine diatoms registered in the upper freshwater part of the floodplain core (Kumano et al., 1990) may indicate short-term transgressions of seawater into the lake, which could be associated with catastrophic storms or palaeo-tsunami events. The diatom analysis of the RK12 core supports findings of earlier investigations demonstrating small but variable presence of marine taxa in the freshwater lake diatom assemblage. The diatom and sedimentary records from the Kiritappu marsh in eastern Hokkaido helped to identify 13 tsunami sands. Two of these lie within a peat bed above a historical tephra dated to AD 1739, and underlying are 11 prehistoric tsunami sand beds deposited during the past 4000 years (Nanayama et al., 2007). Ongoing high-resolution diatom and geochemical analyses of the upper RK12 core sediment accumulated during the last 6000–7000 years will help in deciphering the interactions within the lake–sea system on Rebun and contribute to the regional discussion of tsunamis and their possible impact on the prehistoric populations.

Complementing the pollen and diatom data, the analysis of plant macro-remains from the archaeological layers of Hamanaka 2 provides more detailed information about the plants used by ancient hunter-gatherers. The first results demonstrate that most of the identified remains belong to edible plants. The Okhotsk culture layer contains seeds of wild ruderal herbs and a great quantity of charred seeds of edible plants, that is, *Actinidia arguta* (kiwi berry, '*sarunashi*'), *Vitis coignetiae* (grape, '*yama-budō*') and *Empetrum nigrum* (black crowberry, '*gankouran*'). Few charred grains of *Hordeum vulgare* (barley) give evidence for the usage of this cereal. The presence of several charred seeds of *Toxicodendron* (sumac) and *Phellodendron amurense* ('*karafuto-kihada*') requires more attention. Sun et al. (2014) reported seeds of *P. amurense* from an early Neolithic cave site in Shandong, China. Medicinal qualities of this plant and its edible bast were mentioned by Sun et al. (2014), and Crawford (1983) reported that the Ainu used its berries for food. The sumac seeds are well-known from the older Jomon archaeological sites on Hokkaido (Crawford, 2011; Noshiro et al., 2007), but no use of sumac by the Ainu people has been reported so far (Crawford, 1983). The woody vine *Toxicodendron orientale* found in the modern vegetation on Rebun is a toxic plant. Other *Toxicodendron* ('*Rhus*') species from Japan are known to be used for wax and lacquer production (Wan et al., 2007). However, species-level identification of the Rebun seeds requires more work.

Our results indicate that the Hamanaka 2 site was not only used during summertime but during autumn as well, because fruits of *Vitis* and *Actinidia* become ripe on Rebun not until October. Edible plants such as *Vitis coignetiae*, *Sambucus sieboldiana*, *Actinidia arguta*, *Aralia cordata* and *Empetrum nigrum* are abundant in the natural vegetation on Rebun and the fossil record suggests their use in the past, as has been shown by the records from Neolithic sites in China (e.g. Wu et al., 2014). Despite some differences between the examined layers, our results suggest that plants could have played an important supplementary role in the diet of the local inhabitants during the Okhotsk and Ainu periods. Particularly for the Okhotsk culture, highly specialized in marine fishing and hunting (e.g. Sato et al., 2007), our results from Rebun indicate a more complex subsistence. The roughly contemporaneous Satsumon culture (Figure 2) identified in the southern and inner parts of Hokkaido had a stronger focus on plant cultivation (Adachi et al., 2009).

The utilization of barley has been proven for different Satsumon sites (Crawford, 2011). There is also evidence that the Okhotsk people cultivated barley, which was probably mainly used for rituals (Yamada, 1996). Barley remains associated with Okhotsk sites exhibit a different morphology compared with barley grown by the Satsumon, who introduced this crop from mainland Japan. It is believed that the barley cultivated by the Okhotsk was brought from the lower Amur Region (Yamada and Tsubakisaka, 1995). The barley grains currently recovered from the Okhotsk cultural layers of the Hamanaka 2 site open a new page in the study of agriculture spread across Eurasia.

While there is a long history of debate over the origin of barley and the possibility of an East Asian domestication (see Dai et al., 2012 for reasons why the Tibetan origin theory has recently been rejected), it is generally accepted that the crop originated from a wild progenitor in the Fertile Crescent about 10,000 years ago (Harlan and Zohary, 1966). A rapidly growing body of data from across Asia are illustrating how this crop, in unison with free-threshing wheat, traversed the entire continent and became established as an important cultigen in East Asia (for a discussion, see Spengler, 2015). Crawford (1992) noted that East Asian archaeobotanical finds of hexaploid wheat and barley from Korea date to *c*. 3000 cal. BP and Japanese finds date to the beginning of the 1st millennium AD (see also Crawford and Lee, 2003). Crawford et al. (2005) further noted the importance of wheat in the economy of peoples in north-eastern China, specifically discussing finds of wheat from the Liangchengzhen site in Rizhao City, Shandong. They were also quick to point out that rice and millet (broomcorn and foxtail) were the main crops throughout the archaeological record of northeast Asia, with barley playing a minor role. Crop cultivation was known in Japan at least as far back as the Late Jomon period (Figure 2) (D'Andrea et al., 1995). Crawford (1992) also pointed out that, historically speaking, both hulled and naked forms of barley were traditionally grown in the warmer zones of southern Korea and southern Japan as a winter crop and in northern Japan as a summer crop. However, as long as the morphotype of the barley from the Okhotsk layers on Rebun is not further distinguished, trade with people from southern Hokkaido or other regions cannot be excluded.

Conclusion

The BHAP research strategy successfully introduced in the Lake Baikal Region strongly relies on the individual life history approach and multi-proxy environmental and climatic reconstructions for better understanding Neolithic and Bronze Age hunter-gatherer life ways (see Bezrukova et al., 2013; Weber et al., 2013 and references therein). However, compatible (both bioarchaeological and palaeoenvironmental) datasets are still to be generated for the Hokkaido Region in order to revisit its past from this new evolutionary perspective. The pilot results from Rebun Island, northwest Hokkaido, presented in the current work demonstrate that forthcoming high-resolution pollen and diatom analyses of the Lake Kushu sedimentary archive are able to provide environmental records of high quality and temporal resolution required to address three main scientific goals: (1) generating objective environmental reconstructions of the shifts in climate, vegetation, ocean currents and sea levels; (2) validating regional proxy- and model-based climatic scenarios; and (3) evaluating their potential effects on the Hokkaido cultural sequence, including resource availability and foraging strategies, settlement and population dynamics. The third goal, however, requires strong contribution from the archaeological research in the region and implies interdisciplinary cooperation. Examples of detailed analysis of plant macro-remains preserved in the cultural layers of the Hamanaka 2 site emphasize the benefits of such cooperation. On one hand, the AMS ^{14}C dating of the identified terrestrial plant remains allows a well-founded age determination of the excavated cultural layers and improved correlation between the environmental and archaeological datasets. The latter often becomes a serious problem in coastal environments, where the ages of excavated animal and human bones are affected to varying degrees by the marine reservoir effect. On the other hand, identification of plant remains allows detailed insights into the living condition and use of plant resources by ancient human populations. Recent discovery of cultivated barley grains in the cultural layers of the Hamanaka 2 site provides new information for discussion of spread of agriculture (or agricultural products) into northern Japan during the Okhotsk and Ainu periods.

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