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Holocene vegetation and climate history in Baikal Siberia reconstructed from pollen records and its implications for archaeology

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ABSTRACT

Past research has greatly improved our understanding of palaeoenvironmental changes in the Lake Baikal Region, but at the same time has indicated intra-regional variations in this vast study area. Here we present a new AMS-dated late glacial–middle Holocene (ca. 13,500–4000 cal. yr BP) pollen record from Lake Ochaul (54°14′N, 106°28′E; altitude 641 m a.s.l.) situated in the less-studied area of Cis-Baikal and compare reconstructed vegetation and climate dynamics with the published environmental history of Trans-Baikal based on the pollen record from Lake Kotokel (52°47′N, 108°07′E; altitude 458 m a.s.l.). Although both records show comparable major long-term trends in vegetation, there are considerable differences. Around Ochaul the landscape was relatively open during the Younger Dryas stadial, but forest vegetation started to spread at the late glacial/Holocene transition (ca. 11,650 cal. yr BP), thus ca. 1000 years earlier than around Kotokel. While in both regions taiga forests spread during the early and middle Holocene, the marked increase in Scots pine pollen in the Kotokel record after ca. 6800 cal. yr BP is not seen in that from Ochaul, where birch and coniferous taxa, such as Siberian pine, larch, spruce and fir, dominate, indicating different environmental conditions and driving forces in both study regions. However, the pollen data from Ochaul emphasizes that the Cis-Baikal area also saw a continuous increase in forest cover and in the proportion of conifers over birch trees and shrubs during the early–middle Holocene, which may have contributed to a decrease in the number of large herbivores, the main food resource of the Early Neolithic hunter-gatherer groups. This and rather abrupt reorganization of atmospheric circulation, which affected atmospheric precipitation distribution resulting in thicker and longer-lasting snow cover, may have led to a collapse of Early Neolithic Kitoi populations ca. 6660 cal. yr BP followed by a cultural “hiatus” in the archaeological records during the Middle Neolithic phase (ca. 6660–6060 cal. yr BP). The results stress the importance of sub-regional palaeoenvironmental studies and the need for a representative network of well-dated, high-resolution sediment archives for a better understanding of environmental changes and their potential impacts on the hunter-gatherer populations in the archaeologically-defined micro-regions.

1. Introduction

The Baikal Archaeology Project (BAP) is a long-term multi-disciplinary research project running over two decades (Losey and Nomokonova, 2017; Weber, 1995; Weber et al., 2002, 2010, 2013). The new phase of the BAP, which began in 2018, is focused on the detailed reconstructions of individual life histories of Holocene hunter-gatherer culture dynamics in two regions of Northern Eurasia: the Lake Baikal

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Region (LBR) in Siberia and the region around Lake Onega in European Russia (https://baikalproject.artsrn.ualberta.ca/). Such detailed reconstructions of individual life histories require a comprehensive ensemble of bioarchaeological and biogeochemical analytical methods (e.g. Lieverse et al., 2016; Losey and Nomokonova, 2017; Weber et al., 2016a) and high-quality chronological control (e.g. Schulting et al., 2015; Weber et al., 2016b, 2020) but also detailed palaeoenvironmental data (Weber et al., 2013). Therefore, the reconstruction of past climate changes and their possible effects on human population dynamics, cultural traditions and subsistence strategies remains one of the main goals of the long-term geoarchaeological studies in the LBR (Bezrukova et al., 2010, 2013; Müller et al., 2014; Tarasov et al., 2007, 2013b, 2017; Weber and Bettinger, 2010; Weber et al., 2013; White and Bush, 2010). The key questions raised in these archaeological and palaeoecological studies can be summarized as follows (Tarasov et al., 2017): Did climate change directly or indirectly affect hunter–gatherers in the LBR or were changes in the regional archaeological sequence the result of socio-cultural rather than environmental processes? Finding a well-founded answer to this question is particularly important with regard to a documented lack of settlement and mortuary sites in regional archaeological records during the Middle Neolithic. This “hiatus” was dated to *7030–5575* cal. yr BP (Weber et al., 2016b). More recently the age was narrowed down to *6660–6060* cal. yr BP (all archaeological chronological boundaries come from Weber et al., 2020 and are shown in italics, if they were obtained using Bayesian modeling).

In a wide range of methods, which are used for reconstructing the environmental setting and the economy and way of life of past human cultures, pollen analysis ranks very highly (Bryant and Holloway, 1983; Dimbleby, 1985). A relatively high number of Holocene pollen records has been generated in the LBR in recent decades (e.g. Bezrukova et al., 1996, 2000, 2005a, 2005b, 2010; Demske et al., 2005; Tarasov et al., 2017 and references therein). The first regional quantitative estimates of Holocene changes in atmospheric precipitation, temperature of the warmest and coldest month and moisture index were reconstructed from a continuous pollen record recovered from sediment cores extracted from the Bugul'deika site in the southern part of Lake Baikal (Tarasov et al., 2007) and from Lake Kotokel in the area of Trans-Baikal (Tarasov et al., 2009). The authors of these papers came to the conclusion that the environmental reconstructions based on Lake Baikal sediment likely represent a mixed signal of vegetation and climate dynamics from the very large catchment region with complex topography. The pollen records from Lake Baikal and from surrounding coastal plains demonstrate significant spatial variations in vegetation dynamics within the LBR (e.g. see Bezrukova et al., 2013; Demske et al., 2005 for discussion and references), highlighting the need for more investigations across the region.

Weber et al. (2013) emphasized that any interpretation of human-environment relationships requires well-dated proxy records with adequate spatial-temporal resolution and also mentioned some issues that reduce the value of the available palaeoenvironmental records for addressing the archaeological questions in the LBR. The main obstacles are (i) low temporal resolution and (ii) poor dating control of sedimentary archives (see Tarasov et al., 2017 for discussion and references) and (iii) insufficient attention paid to the identification of micro-regional effects from past environmental changes (Weber et al., 2013). These obstacles challenge robust comparisons with recent bioarchaeological records with much higher temporal resolution and an understanding of the potential factors responsible for the spatial-temporal differences in vegetation and climate changes observed between individual palaeoenvironmental records from the LBR (Tarasov et al., 2017).

One way to overcome these obstacles in the ongoing BAP research is to search for high-resolution sediment archives that are representative of each archaeological macro- and micro-region as well as their detailed analysis and robust AMS dating. This strategy was successfully used in the Baikal-Hokkaido Archaeology Project (BHAP: https://bhaparchive.artsrn.ualberta.ca/;Tarasov et al., 2013b; Weber et al., 2013) on Rebun Island, where pollen, diatom and geochemical records of decadal resolution from the Holocene sediment of Lake Kushu along with the high-resolution archaeological and archaeobotanical data of the Hamanaka-2 site next to the lake enabled a solid discussion of past interactions between humans and the local and regional environments (Müller et al., 2016; Leipe et al., 2018).

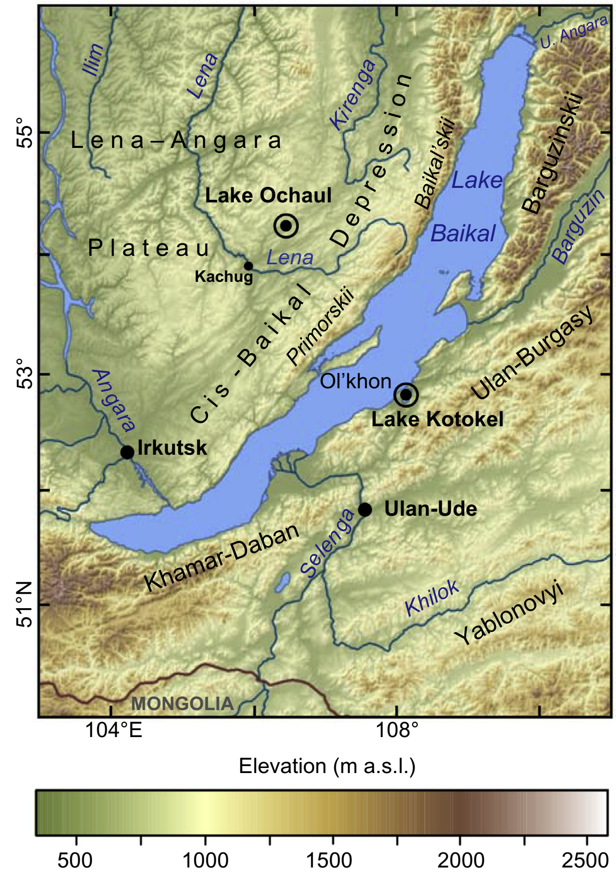

Fig. 1. Topographic map showing the Lake Baikal Region, and locations of Lake Kotokel and Lake Ochaul discussed in the text. Elevation is based on 90-m-resolution Shuttle Radar Topography Mission (SRTM) v4.1 data (Jarvis et al., 2008).

The current article is a review and research paper that contributes to the *Archaeological Research in Asia* journal's special issue entitled “Middle Holocene hunter–gatherers of Lake Baikal: Integrating individual life histories and high-resolution chronologies”. Here, we focus on the postglacial vegetation and climate dynamics in the LBR based on a new unpublished pollen record from Lake Ochaul in Cis-Baikal (Fig. 1). These results are then discussed together with the published vegetation and climate archive from Lake Kotokel (Bezrukova et al., 2010; Tarasov et al., 2017) in Trans-Baikal. So far, both records have reliable chronological controls and are representative of two major subregions of the LBR rich in archaeological sites. Comparing the well-dated record from the Trans-Baikal side with the record from the Cis-Baikal side of Lake Baikal we are going to address some of the above-mentioned challenges (Tarasov et al., 2017; Weber et al., 2013). Different archaeological sites were found on the terrace surface north of Lake Ochaul. Several archaeological surveys conducted there between 1913 and 2016 (Aksyonov, 2009; Peskov, 2016) suggest that the sites were used by Mesolithic and Neolithic hunter-gatherer groups, which typologically range between around 8000 and 5000 years ago. The proximity between the archaeological site and the environmental archive of Lake Ochaul offers great potential for the correlation of the respective archaeological and palaeoecological records in future studies and thus for the discussion of human-environmental interactions at a local to regional level.

2. Modern environments of the LBR

We start with a brief description of the regional environment, focusing on topography, hydrology, vegetation and climate, as these factors (and their changes in the past) have played an important role in the lifestyle and subsistence strategies of hunter-gatherers. The LBR occupies the southern part of Eastern Siberia in the Russian Federation north of the border with Mongolia (Fig. 1). The vast area is shared between the Irkutsk Region (*Irkutskaya oblast*) to the northwest and the Republic of Buryatia to the southeast of Lake Baikal. The LBR is characterized by a complex geology and topography, which strongly affect macro- and micro-scale climate and environments (Alpat'ev et al., 1976).

Lake Baikal (455 m a.s.l.) is located in the central part of the region (Fig. 1). The lake occupies a rift basin, which belongs to the seismically active Baikal Rift Zone (Alpat'ev et al., 1976) and is surrounded by a number of mountain ranges with steep slopes and maximum elevations over 1600 m. Of them, the Primorskii (1658 m a.s.l.), Baikal'skii (2588 m), Khamar-Daban (2371 m) and Barguzinskii (2840 m) ranges are the most prominent (Galaziy, 1993). Most of the prominent topographic features (both mountains and intermountain valleys) are oriented parallel to Lake Baikal and this has an impact on the inter-regional atmospheric circulation.

The regional climate is very continental with relatively warm but short summers and cold long winters, which may vary from ca. 180 days in the southern part to over 200 days in the northern part of Lake Baikal (Galaziy, 1993). Mean temperatures of the warmest month (July) vary between 12.5 and 17.5 °C across most of the LBR (Fig. 2a) but may reach up to 20 °C in the southern depressions and fall below 10 °C in the mountains. Mean temperatures of the coldest month (January) vary between −19 and −30 °C (Fig. 2b), with the coldest temperatures (below −30 °C; Galaziy, 1993) being registered in the river valleys, where a layer of cold air at the surface is overlain by a layer of warmer air – the so called "temperature inversion" (Alpat'ev et al., 1976). The Lake Baikal waterbody strongly affects microclimate of the coastal region (Galaziy, 1993), where relatively cool summers (14–16 °C) are associated with relatively mild winters (−16 to −23 °C). The location of the LBR in the center of Eurasia predetermines relatively low atmospheric precipitation (ca. 400–500 mm/yr) across the region (Fig. 2c). More than half of all precipitation falls in the summer months (Alpat'ev et al., 1976). Lowest values (200–300 mm/yr) are registered at the coasts of Lake Baikal, including Olkhon Island, in the valley of the rivers Selenga and Uda in the south and in the Cis-Baikal (*Predbaikal'skaya*) Depression. At the same time, the mountain ranges (i.e. Khamar-Daban, Barguzinskii, Baikal'skii) get much higher precipitation, up to 1000–1200 mm/yr (Galaziy, 1993). High amounts of rainfall in the mountains feed the well-developed river network of the region. The Selenga and Barguzin are the main rivers in Trans-Baikal and the Cis-Baikal territory is drained by the rivers Angara, Lena and their tributaries (Fig. 1).

The elevated terrain (ca. 400–2800 m a.s.l.), complex topography and variable climatic conditions determine the distribution of plant and animal species in the LBR (Galaziy, 1993). Different types of boreal coniferous forests (broadly known in the Russian literature as 'light and dark taiga') are the most widespread in the region and include mainly larch (*Larix sibirica* and *L. dahurica*), Scots pine (*Pinus sylvestris*), Siberian pine (*Pinus sibirica*), spruce (*Picea obovata*) and fir (*Abies sibirica)*. Among the broadleaved deciduous trees, birches (*Betula platyphylla, B. pubescens*), chosenia (*Chosenia macrolepis*), poplar (*Populus suaveolens*) and aspen (*Populus tremula*) are very common. Shrubby birches (*B. fruticosa*) and diverse members of the heath family (Ericaceae) are often found in the undergrowth, along with mosses, lichens and grasses (Belov et al., 2002), particularly abundant in swampy areas, at lake shores and along rivers.

Although, boreal evergreen conifer and cold deciduous forests (Belov et al., 2002; Bezrukova et al., 2010) are the dominant vegetation types in the LBR, the map of the satellite-based vegetation cover (Fig. 2d) shows substantial variations in the modern tree cover percentages within the region. The predominantly open landscapes are a characteristic feature of the alpine zone, which is situated at elevations above 1700 m in the south and above 1800 m in the north of the region (Demske et al., 2005 and references therein). The alpine areas are characterized by a diversity of mosses, lichens, grasses and shrubs (Bezrukova, 1996; Kozhova and Izmest'eva, 1998). At the upper forest limit in the Barguzinskii and Khamar-Daban Ranges, shrub alders (*Alnus fruticosa*), willows (*Salix*), shrub and dwarf shrub birches (*Betula* sect. *Fruticosae* and *B.* sect. *Nanae*) and scrub pine (*Pinus pumila*) form various communities, intermingled with meadows and fern thickets (Demske et al., 2005). Alpine communities also comprise scrub pine and *Rhododendron aureum* (up to ca. 2000 m a.s.l.), dwarf shrub tundra with *Salix*, *Betula nana* and Ericaceae (Belov et al., 2002; Demske et al., 2005). The low-elevated intermountain depressions and river valleys with low precipitation also demonstrate low percentages of wood cover (Fig. 2d). Particularly in the Angara valley and around human settlements, this feature is frequently reinforced by human activities. However, natural steppe and forest–steppe vegetation occur within the Selenga River basin in the Trans-Baikal sub-region. Further north, patches of steppe are limited to the Barguzin River basin, Olkhon Island and the neighboring region (Belov et al., 2002). Patches of steppe and rock-–steppe vegetation dominated by grasses, forbs and Rosaceae shrubs, often with *Selaginella sanguinolenta* or *Selaginella rupestris*, frequently occur on east- and south-facing slopes within the entire region (Demske et al., 2005).

3. Study site, core material and analytical methods

3.1. Lake Ochaul

Lake Ochaul (641 m a.s.l.) is a small, i.e. ca. 2.7 km long and ca. 1.2 km wide, freshwater lake (Fig. 3) located in the Upper Lena micro-region, ca. 100 km northwest of Lake Baikal (Fig. 1). The water surface is about 2.6 km^2 and the catchment area of the lake is about 170 km^2 (Boyarkin, 2007). The maximum water depth measured in summer 2018 was about 2.5 m in the central part of the lake (Fig. 3). The bottom of the lake was densely covered with aquatic vegetation that grows on a thick layer of sapropel (or gyttja) that smells strongly of hydrogen sulfide. The banks of Ochaul are low and marshy, especially those in the southwest and northeast. In contrast to Lake Kotokel (52°47′N, 108°07′E; 458 m a.s.l.), which is under the influence of Lake Baikal, cryogenic processes play an important role in the formation of the microrelief in the valley. A series of 2–3-m-high palaeoshoreline features that surround the lake in the east, ca. 100–300 m from its modern coastline, indicate that the lake occupied a larger area and was deeper in the past.

Lake Ochaul is drained by the Malaya Anga River, which meanders freely along the flat valley floor and forms a swampy delta as it enters the lake. Malaya Anga is a right tributary of Bol'shaya Anga, which flows into the Lena River near the city of Kachug ca. 50 km southwest of the lake (Fig. 1). The valley is part of the larger Cis-Baikal Depression (Fig. 1). It opens to the Lena valley in the southwest and to the Kirenga River in the northeast. The slopes of the valley around Ochaul do not exceed 850–900 m a.s.l. (that is 200–250 m above the lake level) and are covered with boreal coniferous forest consisting of larch, birch and Siberian pine, with admixture of spruce and fir. The undergrowth is represented by shrubs of the heath family (*Ledum palustre, Vaccinium vitis-idaea, V. uliginosum*) as well as various grass and moss species. Larch forests with abundant birch shrubs (*ernik*) in the undergrowth dominate in the catchment area of the lake (Belov et al., 2002), while

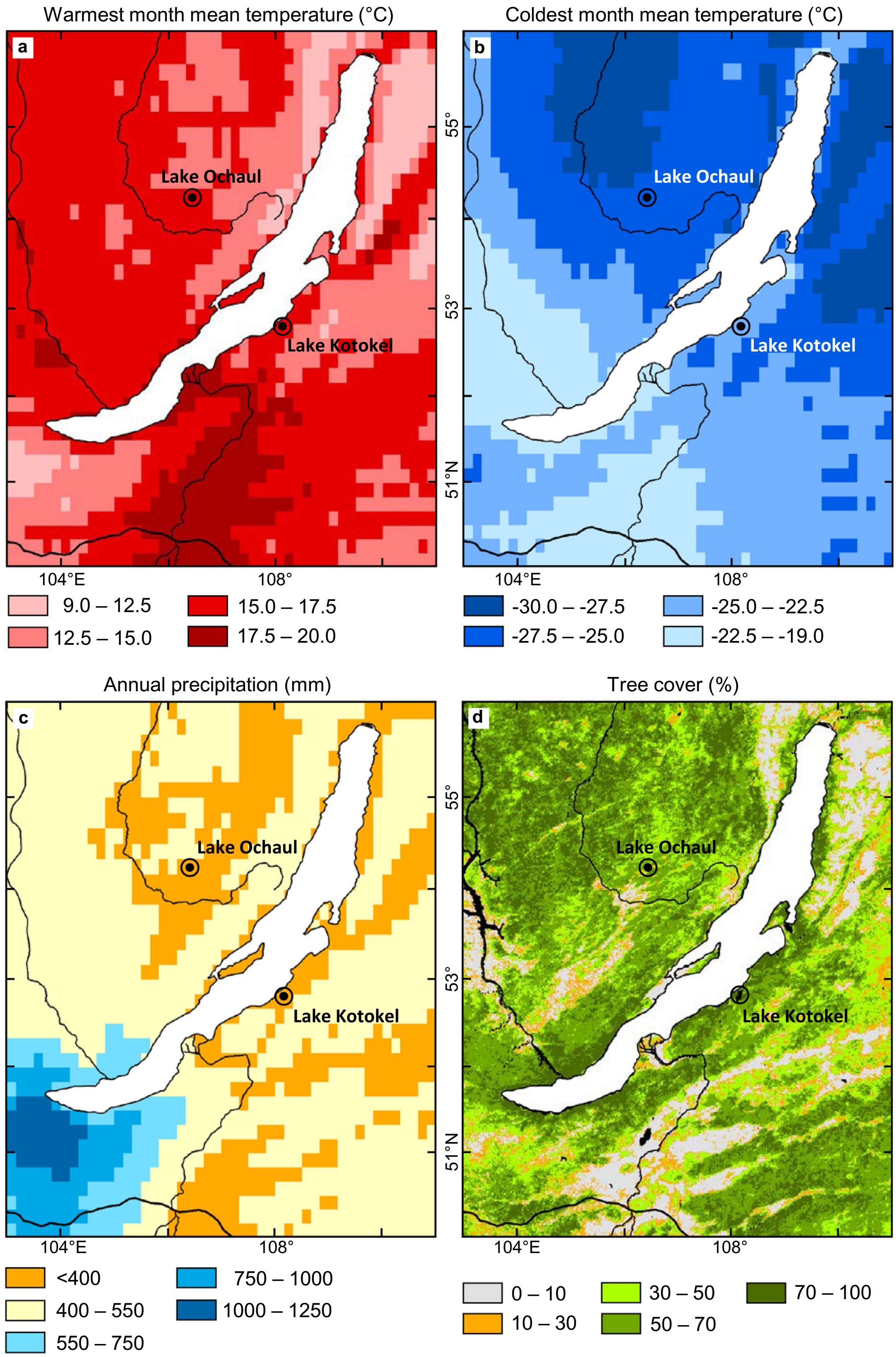

Fig. 2. Map compilation showing modern patterns of mean temperature of the (a) warmest and (b) coldest month (Hijmans et al., 2005), (c) modern mean annual precipitation (New et al., 2002); and (d) AVHRR-derived percentage values of modern tree cover (DeFries et al., 2000) in the Lake Baikal Region of Eastern Siberia.

Scots pines appear seldom in the catchment and are not as common as around Lake Kotokel in the Trans-Baikal sub-region. The climate averages from Kachug show a mean temperature of −25.5 °C in January, 17.1 °C in July, an annual precipitation of 339 mm (https://ru.climate-data.org/) and a period of continuous snow cover of 167 days (Galaziy, 1993).

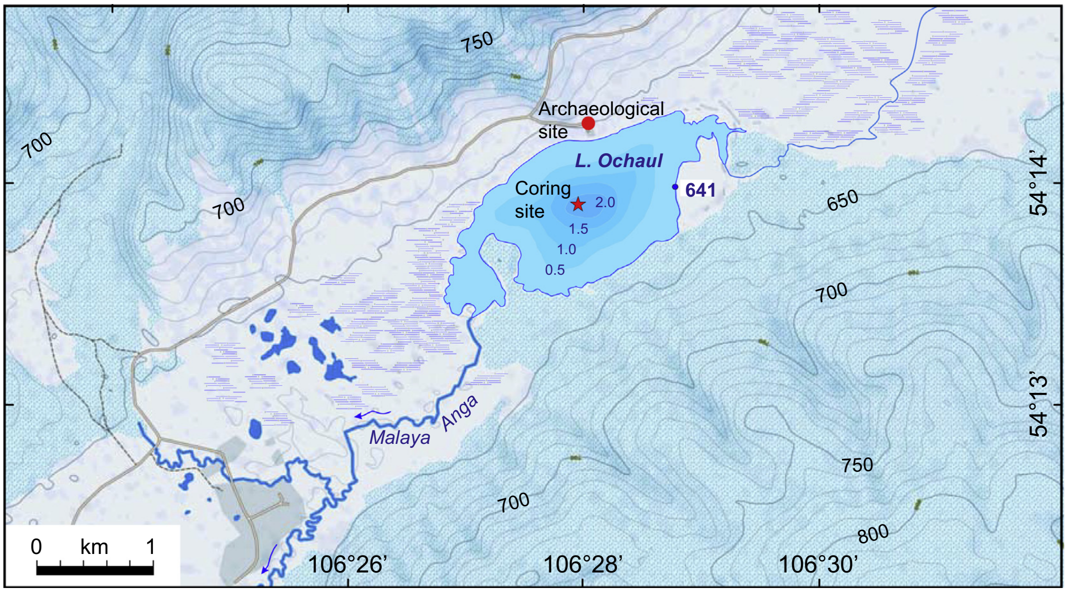

Fig. 3. Topographic map showing Lake Ochaul and surrounding area. Location of the Och18 coring site is indicated by a star and the archaeological site is indicated by a closed circle.

3.2. Sediment cores and chronological control

Lake Ochaul was cored in summer 2018 using an UWITEC percussion piston corer and coring platform acquired via the BAP. The 7.24-m-long core Och18-II (54°13′58.4″N, 106°27′53.8″E) was retrieved from the central and deepest part of the lake (Fig. 3). To roughly estimate the age of the core 7 sediment samples from the top and bottom parts of the individual core sections were sent to the Poznan Radiocarbon Laboratory for AMS dating. The obtained dates suggested accumulation of the recovered core sediment during the past ca. 32,000 years and helped choosing section 2 of the Och18-II core (further called Och18-II-2) for denser radiocarbon (^{14}C) dating and for detailed pollen and geochemical analyses, aiming to address the current goals of the BAP and to contribute new knowledge to this special issue. The Och18-II-2 section represents the interval from 100 to 260 cm of the composite core depth. Altogether 9 AMS dates from this interval (Table 1) demonstrate ^{14}C ages, which vary between 4430 ± 30 and 12,180 ± 50 ^{14}C yr BP, thus covering the late glacial and the early and middle Holocene interval. Considering that the dated lake sediments are calcareous, a reservoir effect could be an issue in Lake Ochaul. The AMS dating of the topmost sample from the Och18-II core to 615 ± 30 ^{14}C yr BP and the modern age of this sample obtained using down-core profiles of short-lived ^{210}Pb and ^{137}Cs isotopes confirm this assumption. When constructing the age model, we subtracted the supposed reservoir age of 600 years from all radiocarbon dates prior to their calibration to calendar ages using OxCal v4.3 (https://c14.arch.ox.ac.uk/oxcal.htmlBronk Ramsey, 1995) and the IntCal13 curve (Reimer et al., 2013). The obtained age model was applied to the Och18-II-2 pollen record. However, this reported age model should be viewed as preliminary until more robust modeling of an appropriate correction factor can be applied.

3.3. Material and methods

The Och18-II-2 section analyzed in the current study (Fig. 4) is represented by soft biogenic gyttja rich in freshwater mollusk shells (0–113 cm) underlined by a transitional layer of gyttja and laminated silty clay olive-gray to blackish in color between 113 and 136 cm, and by massive viscous clay (136–160 cm). Extraction of pollen, fern spores and other non-pollen palynomorphs (NPPs) from the Ochaul core sediment was performed according to the protocol described in Leipe et al. (2019). The protocol includes treatment of 1 g of sediment with 10% HCl, 10% KOH, dense media separation using sodium polytungstate (SPT) at a density of 2.1 g/cm^3, and acetolysis. In order to estimate pollen and NPP taxa concentrations, a known quantity of exotic *Lycopodium clavatum* marker spores was added to each sample (Lyco Batch No 483216: 18,583 spores per tablet) prior to laboratory preparation following Stockmarr (1971). Pollen and NPPs were counted using a light microscope with magnification ×400 and taxonomically identified with the help of regional pollen atlases (Beug, 2004; Demske

Table 1
AMS ^{14}C dates and calibrated ages based on sediment bulk samples for the Och18–II-2 core segment from Lake Ochaul (this study). Calibration was performed using OxCal v4.3 (Bronk Ramsey, 1995) and the calibration curve IntCal13 (Reimer et al., 2013).

Lab ID	Depth, cm	Radiocarbon date / Corrected date, ^{14}C yr BP	Calibrated 68% range, cal. yr BP	Calibrated 95% range, cal. yr BP	Modeled age, cal. yr BP
Och18-II-2	Lake Ochaul				
Poz-114413	4–5	4430 ± 30 / 3830 ± 30	4286–4155	4405–4101	4180
Poz-114415	24–25	5930 ± 35 / 5330 ± 35	6186–6016	6263–5996	5971
Poz-114416	44–45	6655 ± 35 / 6055 ± 35	6954–6808	6996–6797	7495
Poz-114417	64–65	8790 ± 50 / 8190 ± 50	9244–9032	9287–9015	8821
Poz-114571	84–85	9550 ± 50 / 8950 ± 50	10,202–9941	10,225–9914	9994
Poz-114518	104–105	8630 ± 50 / 8030 ± 50	9012–8780	9031–8658	11,047
Poz-114419	118–119	10,410 ± 50 / 9810 ± 50	11,250–11,197	11,317–11,166	11,724
Poz-114420	137–138	11,070 ± 50 / 10,470 ± 50	12,545–12,242	12,562–12,135	12,577
Poz-114421	158–159	12,180 ± 50 / 11,580 ± 50	13,465–13,355	13,540–13,291	13,443

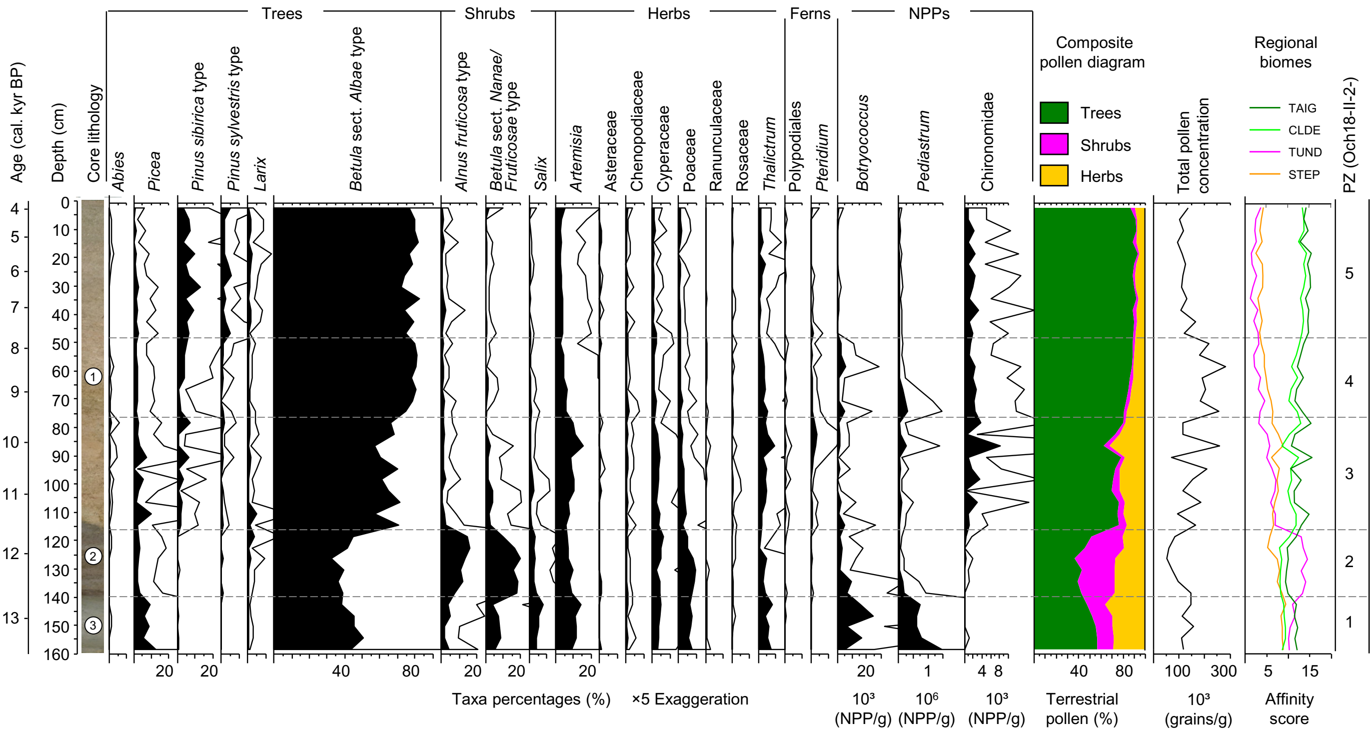

Fig. 4. AMS-based chronology, the core lithology and pollen percentage diagram of the most abundant arboreal and non-arboreal taxa, the representative NPPs and the pollen derived biome scores of the Och18-II-2 core from Lake Ochaul plotted against the core depth and age axes (this study). Numbers in the lithology column indicate: (1) soft biogenic gyttja rich in freshwater mollusk shells; (2) transitional layer of gyttja and laminated silty clay olive-gray to blackish in color; and (3) massive viscous gray clay.

et al., 2013; Reille, 1992, 1995, 1998; Savelieva et al., 2013) and the institute's reference collection.

For all analyzed fossil pollen samples, calculated pollen taxa percentages refer to the sum of terrestrial pollen grains. Other counted taxa percentages, including pollen of aquatic plants, spores of ferns were calculated using the total terrestrial pollen sum plus the sum of palynomorphs in the respective group. Tilia version 1.7.16 software (Grimm, 2011) was used for calculating taxa percentages and drawing the diagrams.

The pollen-based vegetation and climate reconstruction methods, their rigorous tests using extensive surface reference pollen data sets from the LBR and northern Asia and application to the fossil pollen data from Lake Kotokel are described and discussed in the respective publications (e.g. Tarasov et al., 2009; Bezrukova et al., 2010) to which readers are referred to for further details and references. For convenience, we provide a brief summary of the biome and landscape openness reconstruction techniques applied in the current study to the Och18-II-2 pollen record.

Pollen-based 'biomization' is a quantitative approach, which was first designed and tested using a limited number of key pollen taxa digitized from the 0 and 6 ka pollen spectra from Europe (Prentice et al., 1996). The method has been further adapted for reconstructing the main vegetation types (biomes) present in northern Eurasia (Tarasov et al., 1998, 2000, 2013a). Pollen taxa found in the sediments from Lake Kotokel and Lake Ochaul and their assignments to the respective biomes are presented in Table 2. By calculating the difference between the maximal forest biome score and the maximal open biome score, a qualitative assessment of landscape openness can be achieved with a higher confidence compared to a more traditional approach using arboreal and non-arboreal pollen percentages (Tarasov et al., 2013a).

The results of biome score calculation are further used to subdivide the pollen diagram (Fig. 4) into local pollen zones (PZ). This approach considers the ecology of pollen-producing plants (Prentice et al., 1996) and does not entirely rely upon a statistical similarity between pollen assemblages composed of numerous taxa representing ecologically different plant functional types as demonstrated by Bezrukova et al. (2010).

4. Pollen record and vegetation reconstruction

The results of the pollen analysis of the Och18-II-2 section are summarized in Fig. 4. The pollen diagram is divided into five pollen zones, which can be briefly described as follows.

PZ Och18-II-2-1 (160–140 cm) shows moderately high values for trees, shrubs and herbaceous pollen taxa, suggesting a patchy character of vegetation. The age model places this assemblage between ca. 13,500 and ca. 12,790/12,620 cal. yr BP, which corresponds to the late-glacial warm interval in the Greenland ice records (Svensson et al., 2008). The biome reconstruction suggests dominance of shrubby tundra followed by taiga/cold deciduous forest. The steppe scores are lower than for tundra and forest biomes, though herbaceous communities played a significant role in the vegetation, as indicated by the highest percentages of *Artemisia* and Poaceae pollen.

PZ Och18-II-2-2 (140–116 cm) is characterized by the highest percentages of shrubby taxa (such as *Alnus fruticosa*, *Betula* sect. *Nanae/Fruticosae* and *Salix*) of the entire record. The non-arboreal pollen (NAP) percentages are still moderately high and the AP percentages decrease to 35–40%. This zone is dated to ca. 12,790/12,620–11,720/11,540 cal. yr BP and corresponds well to the Younger Dryas (YD) late-glacial cold oscillation. The biome reconstruction reveals highest scores for the tundra biome.

PZ Och18-II-2-3 (116–76 cm) highlights a sharp increase in arboreal pollen (AP) percentages, mainly represented by birch (60–70%) and to a lesser extent by spruce, larch, Siberian pine and fir. This change in the pollen assemblages indicates major climate amelioration, which is in agreement with the early Holocene age of this zone, i.e. between ca. 11,720/11,540 and 9660/9420 cal. yr BP. The tundra biome lost its

Table 2
Terrestrial pollen taxa identified in the pollen records from Lake Kotokel (Bezrukova et al., 2010; Tarasov et al., 2009) and from Lake Ochaul (this study) and their assignments to the respective biomes.

Biome	Taxa included
Tundra	*Alnus fruticosa*, *Betula* sect. *Nanae/Fruticosae*, Cyperaceae, Ericales, Poaceae, *Polemonium*, *Polygonum*, *Rumex*, *Salix*, Saxifragaceae, *Valeriana*
Cold deciduous forest	*Alnus* (tree), *Betula* sect. *Albae*, Ericales, *Larix*, *Pinus sylvestris* (subgen. *Diploxylon*-type), *P. pumila* (subgen. *Haploxylon*-type), *Salix*
Taiga	*Abies sibirica*, *Alnus* (tree), *Betula* sect. *Albae*, Ericales, *Larix*, *Picea obovata*, *Pinus sylvestris* (subgen. *Diploxylon*-type), *P. sibirica* (subgen. *Haploxylon*-type), *Ribes*, *Salix*
Cool conifer forest	*Abies sibirica*, *Alnus* (tree), *Betula* sect. *Albae*, Ericales, *Corylus*, *Larix*, *Picea obovata*, *Pinus sylvestris*, *P. sibirica* (subgen. *Haploxylon*-type), *Ribes*, *Salix*, *Ulmus*
Steppe	Apiaceae, *Artemisia*, Asteraceae subfam. Asteroideae, A. subfam. Cichorioideae, Brassicaceae, Cannabaceae, Caryophyllaceae, Chenopodiaceae, Fabaceae, Lamiaceae, Liliaceae, *Plantago*, Poaceae, *Polygonum*, Ranunculaceae, Rosaceae, Rubiaceae, *Rumex*, Scrophulariaceae, *Thalictrum*, *Urtica*, *Valeriana*
Desert	*Artemisia*, Boraginaceae, Chenopodiaceae, *Ephedra*, *Polygonum*

dominant role in the vegetation and the landscape became more forested, though still rather open, as suggested by the results of biomization.

PZ Och18-II-2-4 (76–48 cm) shows further increase in AP to 80–88% and minimal contribution of shrub taxa to the pollen assemblage. The pollen concentrations are the highest in this zone, suggesting favorable growth conditions for the boreal taiga and cold deciduous forests around the lake. The NAP percentages decline to 10–15%, indicating a reduction of the steppe/meadow-covered areas between ca. 9660/9420–7910/7640 cal. yr BP. This trend is visible in the biome reconstruction result.

PZ Och18-II-2-5 (48–0 cm) demonstrates the highest values of AP (over 90%) and the lowest values of all other pollen taxa. Among the AP taxa, birch, still dominant, is followed by *Pinus sibirica*, *Pinus sylvestris*, *Larix*, *Picea* and *Abies*. This and the results of the biome reconstruction suggest a fully forested landscape in the study area between 7910/7640 and 4000/3730 cal. yr BP.

5. Discussion and conclusions

In this chapter, we discuss the postglacial vegetation and climate dynamics in the LBR (Fig. 5) based on the newly generated pollen record from Lake Ochaul in Cis-Baikal and the published vegetation and climate record from the sedimentary archive of Lake Kotokel situated on the opposite side of Lake Baikal (Fig. 1). Both records have a number of similarities and strengths, which make them useful for the BAP research. The analyzed core sediments were dated using the AMS dating facility at the Poznan Radiocarbon Laboratory. However, the Lake Kotokel sediments have a better potential for high-resolution studies, as one centimeter of the KTK2 core, for example, covers a 20–24-year interval (Bezrukova et al., 2010) in contrast to 55–60 years of environmental history stored in one centimeter of the Och18-II core (this study). Though, the resolution of Holocene records, the number of proxies analyzed, and thus the overall quality of proxy-based environmental reconstructions can be significantly improved during ongoing BAP studies, this paper provides an important base for future research.

5.1. Regional vegetation history: Forest on the march

The pollen record from Lake Ochaul presented here (Fig. 4) helps in the reconstruction of environmental changes in the Upper Lena microregion of Cis-Baikal during ca. 13,500–4000 cal. yr BP. This interval includes a late glacial warm climate oscillation, known as the Allerød (AL) interstadial, and the YD cold climate oscillation (stadial), as well as the early and middle parts of the Holocene interglacial, including the Holocene climate optimum. The pollen spectra composition shows significant participation of boreal trees (i.e. about 50%) in the vegetation cover between 13,500 and 12,650 cal. yr BP, i.e. during the AL interstadial (Fig. 5c). The biome score calculations (Fig. 5a) demonstrate that the taiga biome predominates closely followed by tundra and cold steppe, which indicates a patchy character of the vegetation cover. The landscape openness curve (Fig. 5b) also shows a comparatively open boreal woodland landscape around the lake. The published vegetation records from Lake Kotokel (Bezrukova et al., 2010; Tarasov et al., 2009, 2017) show great similarities between the regions of Cis-Baikal and Trans-Baikal (Fig. 5d-f) at that time.

The subsequent phase in the regional vegetation development is characterized by a noticeable decrease in the pollen content of boreal trees and a parallel increase in the percentages of boreal shrubs in the records of Ochaul (Fig. 5c) and Kotokel (Fig. 5d). This phase is dated to ca. 12,650–11,650 cal. yr BP and corresponds well to the YD stadial. The results of the biome reconstruction (Fig. 5a, e) show that the tundra biome was dominant and the landscape was therefore more open than during the previous phase (Fig. 5b, f), although trees played a greater role in the vegetation cover than during the last glacial maximum interval (Bezrukova et al., 2010; Müller et al., 2014; Tarasov et al., 2019a). Although the trends in vegetation development in Cis-Baikal and Trans-Baikal are similar, there are also some differences. The reduction of tree pollen is more pronounced in the Kotokel record, which indicates a greater spread of open vegetation types (i.e. shrubby and herbaceous tundra) there.

The early Holocene pollen assemblages of Lake Ochaul show a rapid increase in the percentages of boreal trees to above the interstadial level (Fig. 5c), which indicates a rapid spread of forest vegetation in the region after ca. 11,650 cal. yr BP. However, the area around Lake Kotokel remains poorly forested for another 1000 years, which is suggested by the relatively low pollen percentages of boreal trees (Fig. 5d) and the comparatively high openness of the landscape (Fig. 5f). Although the rapid expansion of forests marks the beginning of the Holocene interglacial in many temperate and boreal regions of the Northern Hemisphere (Khotinskii, 1977; Kobe et al., 2019; Litt et al., 2009; Stebich et al., 2015; Tarasov et al., 2019b), this is often not the case in the continental regions of Northern Asia (Binney et al., 2017; Andreev and Tarasov, 2013). Pollen analysis of sediment cores from Hoton-Nur Lake in the semiarid Mongolian Altai, shows that boreal forests replaced the predominantly open landscape in northwest Mongolia about 10,000 years ago (Rudaya et al., 2009; Tarasov et al., 2000). This and the fact that the internationally recognized date of the YD/Holocene boundary (ca. 11,650 cal. yr BP; Walker et al., 2009) is well defined by the two AMS dates 11,890 ± 110 and 11,470 ± 130 cal. yr BP in the sediment records of Lake Kotokel (Bezrukova et al., 2010) suggest that the reconstructed delay in forest spread in Trans-Baikal is real.

The interval between ca. 10,600 and 6800 cal. yr BP in the pollen records from Ochaul (Fig. 5a-c) and Kotokel (Fig. 5d-f) reveals very similar trends, such as a continuous increase in the pollen percentages of boreal trees, which reflects progressive expansion of forest and the strengthening position of the taiga biome in the LBR. This trend is in line with many other pollen records from across Eurasia (Binney et al., 2017).

The Ochaul record demonstrates highest values for tree pollen (over 90%) and lowest values for shrub and herbaceous pollen taxa after ca.

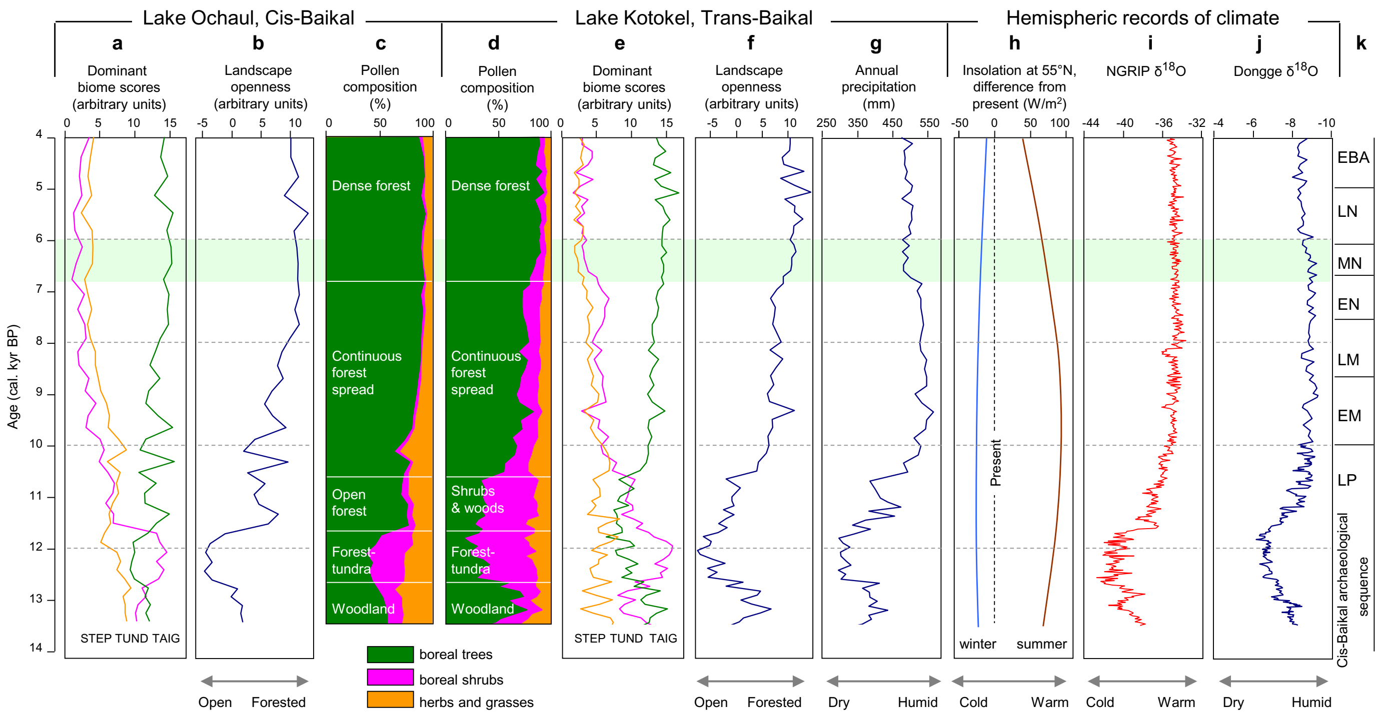

Fig. 5. Summary chart showing selected results derived from the pollen records of (a-c) Lake Ochaul (this study) and (d-g) Lake Kotokel (Bezrukova et al., 2010; Tarasov et al., 2009); selected records of the Northern Hemisphere climate showing (h) the computed mean summer (June–August) and winter (December–February) insolation at 55°N (as differences from the modern values), as indicator of climate seasonality (Laskar et al., 2004); (i) the $\delta^{18}O$ ice core records from Greenland, as indicator of the Northern Hemisphere air temperature (Svensson et al., 2008); (j) the $\delta^{18}O$ records from Chinese stalagmites, as indicator of the Pacific summer monsoon intensity (Yuan et al., 2004); and (k) archaeological cultures of the Lake Baikal Region (Weber et al., 2020). Light green horizontal band indicates the transition from a more open to a densely forested environment in the LBR that coincides with the Middle Neolithic "hiatus" in archaeologically visible mortuary sites. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

6800 cal. yr BP (Fig. 5c), which reflects a well forested landscape. The same, but more pronounced shift to highest percentages of tree pollen taxa can be seen in the Kotokel record (Fig. 5d). In both records, the taiga biome scores are noticeably higher than the steppe and tundra biome scores. The differences between the Ochaul and Kotokel records are more pronounced when one looks at the taxa composition of the tree pollen, which reflects composition of the surrounding forests. In the Ochaul record (Fig. 4), birch pollen, most common in the early Holocene, remains dominant, although the contribution of coniferous taxa such as Siberian pine, larch, spruce and fir has to be considered. Scots pine pollen does not exceed 5% and is likely to indicate long-distance air transport. By contrast, the published pollen diagrams from Kotokel (Bezrukova et al., 2010; Shichi et al., 2009; Tarasov et al., 2009) show a marked increase in the percentages of *Pinus sylvestris*, indicating a wide spread of Scots pine in the area around the lake between ca. 6800 and 6000 cal. yr BP.

The key pollen records and the pollen-based vegetation reconstructions summarized here show a vegetation change in the Cis-Baikal and Trans-Baikal areas of the LBR between ca. 13,500 and 4000 years ago. This interval represents a long transition from the last glacial interval characterized by herbaceous tundra and cold steppe associations and the virtual absence of trees (Bezrukova et al., 2010; Müller et al., 2014; Tarasov et al., 2019a) throughout the late glacial phase with a limited woody cover and stronger role of shrubby and herbaceous vegetation to the densely forested Holocene landscapes as we see them today.

The rapid spread of Scots pine, apparently, is one of the most fundamental changes in the Trans-Baikal vegetation during the Holocene interval (Bezrukova et al., 2010; Tarasov et al., 2017). Previous publications referring to pollen records from Yakutia north of Lake Ochaul (Müller et al., 2010), the Southern Urals, Western Siberia and Kazakhstan (Andreev and Tarasov, 2013 and references therein) suggested that this spread of Scots pine between 7000 and 6000 years ago represents an event of sub-continental scale (Tarasov et al., 2017). The results from Lake Ochaul presented in the current study show that this thesis cannot be applied to the entire LBR without further investigations. The new results emphasize the importance of local studies and the need for a more representative network of reliably dated and high-resolution sediment archives for a better understanding of environmental changes and their possible impacts on the human population in every archaeologically-defined micro-region (Losey and Nomoknova, 2017).

5.2. Climate drivers of vegetation change in the LBR: The role of the local environment

Understanding the drivers of vegetation change is crucial for any project that deals with the interactions between humans and the environment and traditional research methods try to determine the causal relationships among humans, climate and vegetation, which leads to ongoing debates (Robinson et al., 2018). This problem appears to be less severe in the cold boreal and arctic regions with a very low population of hunters and gatherers and little pressure on the native vegetation over the past millennia. This assumption suggests that the changes in vegetation around Ochaul and Kotokel presented here were caused by climatic factors. To reconstruct the climate of the past, it is necessary to find a way to convert changes in the vegetation cover, which are reflected in the results of pollen analysis, into climate parameters (Guiot, 1990; Prentice et al., 1996; Tarasov et al., 2005).

Despite the large number of potentially continuous ecological archives stored in the postglacial lake sediments of the LBR, the number of quantitative climate reconstructions based on pollen (as well as on other proxies) remains very limited. Among the factors that impede this important work are the problems of coring lake sediments and establishing an accurate chronology, which is crucial for any reliable palaeoclimate record (Nakagawa et al., 2012; Schlolaut et al., 2012), but also the lack of reference surface pollen data, representing the vast region north of Lake Baikal (Binney et al., 2017), which is necessary for pollen-based reconstructions and verification of reconstruction methods. Another problem of a more complex nature is that almost all pollen/plant taxa identified in the LBR records have relatively wide bioclimatic ranges (Prentice et al., 1996), which leads to a relatively large uncertainty of the reconstructed climatic variables (Litt et al., 2009; Tarasov et al., 2005). In such situations, climate reconstructions obtained from proxies other than pollen can significantly improve the final results (Kostrova et al., 2013, 2014) or even revise previous long-standing results (Tarasov et al., 2019a). Such multi-proxy analyses are planned in the current project and will be applied to recently obtained sediment cores from Ochaul and Kotokel lakes.

A review paper by Tarasov et al. (2017) noted that both general trends and centennial variability in scores of taiga and steppe biome derived from the Kotokel pollen record (Bezrukova et al., 2010; Tarasov et al., 2009) demonstrate significant synchronism with changes in air temperature in the Northern Hemisphere, archived in the oxygen isotope record from Greenland ice cores (Svensson et al., 2008), and with summer monsoon intensity recorded in the stalagmites from China (Yuan et al., 2004). The idea that both the climatic system of the North Atlantic and the North Pacific Ocean in the past influenced the LBR environment (Bezrukova et al., 2010; Tarasov et al., 2009, 2017) was supported by a study based on oxygen-isotope analysis of diatoms preserved in the bottom sediments of Lake Kotokel (Kostrova et al., 2013, 2016). Their results indicate that southeastern moisture transport played a more significant role in the LBR during the early Holocene, controlled by a higher than present level of summer insolation (Fig. 5h) and intensified monsoon circulation (Fig. 5j), while westerly moisture transport was weaker in the middle latitudes of Eurasia in the early Holocene and became stronger in the late Holocene (Kleinen et al., 2011; Rudaya et al., 2009). A recent study of moisture origin and stable isotope characteristics of atmospheric precipitation in Baikal Siberia (Kostrova et al., 2020), which analyzed the seasonal distribution of backward trajectories for 284 single precipitation events from June 2011 to April 2017, confirmed the leading role of westerly moisture transport in the study region throughout the year, a typical feature of the late Holocene described in meteorological and palaeoenvironmental publications. However, moisture from the Pacific region was also traced in the stable isotope data of modern precipitation, which confirms the plausibility of the early Holocene scenario. This conclusion is extremely important for palaeoclimate reconstructions using proxy-based interpretations of moisture origin in southeast Siberia (Kostrova et al., 2020).

A pollen-based climate reconstruction for the area around Lake Kotokel (Tarasov et al., 2009) shows moderately high annual precipitation during the AL interstadial, low precipitation during the YD stadial and an increase in precipitation values in the early Holocene (Fig. 5g) reflecting the major climate changes in the North Atlantic (Fig. 5i) and the North Pacific (Fig. 5j) regions. The highest summer temperatures and precipitation reconstructed between ca. 10,600 and 6800 years ago (Fig. 5g; Tarasov et al., 2009) fall in the interval of higher-than-present summer insolation in the middle latitudes of the Northern Hemisphere (Fig. 5h), which in turn promoted a stronger-than-present summer monsoon (Fig. 5j) and intensified south-easterly moisture transport to the LBR during the early Holocene summers. However, this increase in precipitation was offset by high summer temperatures (and higher evaporation). At the same time, lower-than-present winter insolation (Fig. 5h) stimulated a stronger winter anticyclone, which blocked the westerly flow and caused dry winter conditions. This scenario, which was adequately reproduced in climate modeling experiments (Braconnot et al., 2004; Kleinen et al., 2011), can satisfactorily explain relatively low percentages for tree pollen and above-average openness of the landscape around Lake Ochaul in Cis-Baikal (Fig. 5a-c) in the early Holocene, as suggested in earlier publications (Bezrukova et al., 2010; Tarasov et al., 2009, 2017) for Lake Kotokel in Trans-Baikal (Fig. 5d-f). The much faster spread of forest vegetation in the Ochaul area (Fig. 5b) compared with the area around Kotokel (Fig. 5f), revealed in this study, likely reflects differences in topography and environmental conditions of the two micro-regions. Located at higher elevations and better provided with moisture, the intermountain valley of Lake Ochaul provided better conditions for the rapid spread of trees with the onset of Holocene warming.

A pollen-based climate reconstruction (Tarasov et al., 2009) shows a decrease in precipitation around Lake Kotokel that began ca. 7000–6800 cal. yr BP (Fig. 5g). This trend is parallel to a decrease in summer insolation and an increase in winter insolation (Fig. 5h), which led to a weakening of both the activity of the summer monsoon (Fig. 5j) and the winter anticyclone and a strengthening of the westerly circulation, bringing rain and snow precipitation to the middle latitudes of Eurasia stretching from Germany (Litt et al., 2009) to Kazakhstan (Tarasov et al., 2012), the Altai Mountains (Rudaya et al., 2009) and the LBR (Bezrukova et al., 2010; Kostrova et al., 2020; Tarasov et al., 2017). Numerous vegetation records from this middle latitudinal belt of Eurasia show the expansion of Scots pine during the middle and late Holocene (see MacDonald et al. (2000) and Müller et al. (2010) for discussion and references).

The question raised in the current study is why the sharp increase in the percentages of *Pinus sylvestris* pollen from less than 10 to more than 50%, which occurred in the Kotokel record (Bezrukova et al., 2010; Tarasov et al., 2009) during only a few hundred years is not visible in the Ochaul record (Fig. 4), located ca. 200 km to the north? The answer to this question must be sought in the ecology of Scots pine and in the local conditions of these two micro-regions. Geobotanical studies of *Pinus sylvestris* in the LBR show that the natural distribution of this eurythermic coniferous tree is limited by permafrost (Shumilova, 1960). Indeed, Scots pine can withstand cold winter temperatures, relatively low precipitation and poor soils (Gunin et al., 1999; Kremenetski et al., 1998; MacDonald et al., 2000), but does not grow in environments where the permafrost layer is too close to the surface and can cause damage to the roots (Müller et al., 2010; Tarasov et al., 2017). It was suggested (MacDonald et al., 2000; Andreev and Tarasov, 2013 and references therein) that higher than present summer insolation during the first half of the Holocene contributed to the degradation of permafrost and to the spread of Scots pine in Eastern Siberia, where it quickly occupied sandy river terraces and rocky habitats in central and southern Yakutia, along the Angara River and in Trans-Baikal. However, the Lake Ochaul micro-region of Cis-Baikal, where surface permafrost processes play an important role to this day, remained unsuitable for Scots pine, although other coniferous taxa there could also benefit from the less continental climate conditions and thicker snow cover during the second half of the Holocene, as suggested by the Ochaul pollen record and pollen-based reconstructions (Fig. 5a-c).

5.3. Implications for archaeology

Intensive archaeological and bioarchaeological research conducted by the BAP team over the past two decades provided rich archaeological material on Holocene hunter–gatherers in several micro-regions of Cis-Baikal and constructed a robust chronology for this archaeological sequence (Fig. 5k and Weber et al., 2020), starting from the Late Paleolithic (LP) to Early Mesolithic (EM) transition around 10,000 years ago. Other cultural and chronological units are Late Mesolithic (LM: ca. *8630–7560* cal. yr BP), Early Neolithic, (EN: ca. *7560–6660* cal. yr BP), Middle Neolithic (MN: ca. *6660–6060* cal. yr BP), Late Neolithic (LN: *6060–4970* cal. yr BP) and Early Bronze Age (EBA: *4970–3470* cal. yr BP).

A key objective of the BAP research formulated by Weber et al. (2020) is to find out what drives the processes of culture change and evolution of the Holocene hunter-gatherers in the study region. To achieve this major task is hardly possible without testing the hypothesis whether "gradual, perhaps even imperceptible on a generational scale, climate and environmental trends can effect cumulative changes in hunter-gatherers adaptive strategies leading, in turn, to tipping points at which rapid system overhaul occurs" (Weber et al., 2020). To discuss all pro and contra of this hypothesis, high-resolution (i.e. generational scale) environmental archives are needed that represent each archaeologically defined micro-region, the acquisition of which is the task of the upcoming BAP research. The following is a preliminary attempt based on the available information.

A close look at the vegetation and climate records summarized in Fig. 5a-j shows that significant fluctuations in global and regional environments occurred by the end of the LP (Fig. 5k). The EM and LM can be regarded as a transition phase to a climatically relatively stable interval, which covers the entire Neolithic and Early Bronze Age in the LBR. The most notable changes (discussed in sections 5.1 and 5.2) that characterize this relatively stable interval of the middle Holocene occurred during the MN, which follows the collapse of the EN Kitoi culture and is marked by the complete absence of bioarchaeological data and formal cemeteries (Weber et al., 2020; Weber et al., 2016b).

A review of archaeological and environmental publications on the final stage of the late Pleistocene in the southern part of Eastern Siberia (Tarasov et al., 2017 and references therein) provided evidence that the cold climate did not cause depopulation of the region even during the coldest phase of the last glacial, explaining this phenomenon by the productive steppe vegetation and very thin snow cover, which secured year-round grazing grounds for large herbivores, which served as a stable source of food for Paleolithic hunter-gatherers. Based on the Kotokel records, it was further suggested that an early Holocene environment with a thin snow cover and relatively open landscape could have allowed the early Holocene hunter-gatherers to lead a lifestyle that was largely similar to that of many previous generations (Tarasov et al., 2017). A comparable situation has developed in the Upper Lena region of Cis-Baikal, as evidenced by the vegetation records from Lake Ochaul presented here, although the distribution of boreal trees occurred earlier and was more noticeable there than in the Kotokel region. However, changes in the geographical distribution of larger mammals in Northern Eurasia, including the LBR, over the past 50,000 years show that the number and diversity of species of herbivores representing the mammoth steppe megafauna significantly decreased during the late glacial-early Holocene transition due to climate change and partly due to anthropogenic pressure (Kuznetsova et al., 2019; Markova et al., 2015; Puzachenko et al., 2017).

The hunter-gatherer population of the EN Kitoi culture (ca. *7560–6660* cal. yr BP) was probably the first to live in an entirely 'new world' characterized by a predominantly forest environment and a limited number and variety of big game. The results of zooarchaeological research in the LBR, summarized by Losey and Nomokonova (2017), indicate that roe deer and red deer were the most economically significant mammals during this period, which means strong anthropogenic pressure on the deer population, on the one hand, and the need to cope with limited food resources and look for alternatives, on the other hand. Archaeological finds representing the material culture of the Kitoi people show a broad spectrum of technological innovations, including the bow-and-arrow, clay pots, fishing nets, new types of leisters and harpoons, fish lures, composite fishhooks, green nephrite tools and a range of spearheads, daggers and knives morphologically more variable than during the LM phase (Weber et al., 2020; Weber et al., 2002, 2010). These innovations undoubtedly helped Kitoi groups coping with the above problems for almost 900 years, but were not able to prevent the collapse of the Kitoi culture.

The reasons for the disappearance of Kitoi from archaeological records and the subsequent cultural "hiatus" marked by the lack of settlements and burial sites during the MN phase (ca. *6660–6060* cal. yr BP) are still under discussion (Tarasov et al., 2007, 2017; Weber et al., 2020; Weber et al., 2002; White and Bush, 2010). Growing stress well confirmed by intensive bioanthropological studies (see Weber et al. (2020) for discussion and references) under rapidly changing environmental conditions in the Baikal region was proposed as a possible driving factor (see Tarasov et al. (2017) for discussion and references). Vegetation reconstructions based on published and recently obtained pollen records (e.g. Figs. 4, 5; Tarasov et al., 2017) show that the mosaic vegetation of the early Holocene, which was dominated by tree and shrub birches, was replaced in the middle Holocene by a forest-dominated landscape, which experienced a rapid spread of two species of pine in the interval between ca. 7000 and 6500 cal. yr BP (Bezrukova et al., 2005a, 2010, 2013; Demske et al., 2005; Shichi et al., 2009; Tarasov et al., 2007). Based on the modern analogue principle, it was suggested that a mosaic of birch forests and shrubs with productive grasslands and swampy meadows was likely to be a significantly more favorable environment for feeding larger populations of herbivores, including roe deer and red deer (Hofmann, 1989; Torres et al., 2011, 2012), than closed coniferous forests (Tarasov et al., 2017). Proxy-based climate reconstruction (Kostrova et al., 2013, 2016; Tarasov et al., 2007, 2009, 2017) and climate modeling experiments (Braconnot et al., 2004; Kleinen et al., 2011; White and Bush, 2010) help explain the reconstructed changes in vegetation in the LBR by the orbitally-induced gradual changes in solar insolation, which led to changes in seasonality and rather abrupt reorganization of atmospheric circulation. The latter affected atmospheric precipitation distribution, resulting in thicker and longer-lasting snow cover than during the late Neolithic and Mesolithic period. Tarasov et al. (2007) hypothesized that keeping their traditional life-style, Kitoi people were not able to survive this period of rapid changes in regional climate, with which they (and their ancestors) had no experience. In the absence of high-resolution climatic records and regional climate models, we can only speculate about the challenges, which occurred in the life of Kitoi by the end of the EN interval. More frequent cases of extreme weather events and deeper and longer snow cover, which made winter hunting difficult and caused hunger and disease - these are just a few examples of what could have happened. By contrast, the LN inhabitants of the region, who lived in smaller and very mobile groups, keeping contact with each other and making better use of the existing aquatic food resources were better adapted to these environments and even experienced population growth during the LN/EBA interval (Weber et al., 2002, 2010).

From the current period of global warming (Pachauri and Meyer, 2014), we learn that even relatively small changes in temperatures on a global scale magnitude can lead to much more significant changes in temperature and atmospheric circulation on a regional scale, which in turn lead to weather conditions and extreme events that have never been experienced by the local population or documented by instrumental records. These extreme weather events, repeated for several years in a row, can endanger the life and economy of both highly developed industrial countries and the poor countries of the world. Palaeoclimate proxy records show that during the Holocene epoch some shifts in global temperature occurred, comparable in magnitude to that observed in the last 50 years. To understand how these changes affected the environment and the people around Lake Baikal on a regional and micro-regional scale is the task of further geoarchaeological research on human-environmental interactions in the LBR. In this research, the palaeoecological team still lags behind the archaeologists in the quality of environmental archives and in the number of proxies analyzed. The results presented in the current study indicate the complexity of the task at hand, but advocate for a causal relationship between changes in the global and regional environment and the archaeological culture sequence of the LBR.

Declaration of Competing Interest

None.

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