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The Holocene environmental history of a small coastal lake on the north-eastern Kamchatka Peninsula

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ABSTRACT

A radiocarbon and tephra-dated sediment core from Lifebuoy Lake, located on the north-east coast of Kamchatka Peninsula, was analysed for pollen, spores, diatoms, chironomids and tephra in order to uncover regional environmental history.

The 6500-year environmental history of Lifebuoy Lake correlates with the broad regional patterns of vegetation development and climate dynamics with both diatoms and chironomids showing near-synchronous changes. Between ca. 6300 and 3900 cal yr BP, the lake ecosystem was naturally enriched, with several *Stephanodiscus* species dominating the diatom plankton. This natural eutrophication state is likely to be due to a combination of the base-rich catchment geology, the fertilisation effect of several fires in the catchment, silica input from tephra layers and, possibly, nitrogen input from seabirds. The substantial tephra deposit at about 3850 cal yr BP might have stopped sedimentary phosphorus from entering the lake water thus decreasing the trophic state of the lake and facilitating the shift in diatom composition to a benthic Fragiliariaceae complex.

Both diatoms and chironomids showed simultaneous compositional changes, which are also reflected by statistically significant changes in their rates of change 300–400 years after the arrival of *Pinus pumila* in the lake catchment. The rapid increase in both total diatom concentration and the percentage abundance of the large heavy species, *Aulacoseira subarctica* might be a response to the change in timing and intensity of lake spring turnover due to the changes in the patterns of North Pacific atmospheric circulation, most notably westward shift of the Aleutian Low.

The two highest peaks in *A. subarctica* abundance at Lifebouy Lake occurred during opposite summer temperature inferences: the earlier peak (3500–2900 cal yr BP) coincided with warm summers and the latter peak (300 cal yr BP–present) occurred during the cold summer period. These imply that *A. subarctica* shows no direct response to the changes of summer air temperature. Instead, it appears to thrive during the periods of increased winter precipitation, thicker ice and late spring turn-over periods, i.e., shows indirect response to climate.

The clearest effect of tephra deposition on the lake ecosystem is above 908 cm (ca. 3800 cal yr BP) where the tephra deposit might have caused the shift from *Stephanodiscus*-dominated planktonic assemblages to the Fragilariaceae complex of benthic species. Tephra deposits might have also contributed towards the development of eutrophic plankton from about 6300 cal yr BP. It is not certain if several tephra deposits influenced diatom and chironomid changes during the last 300 years.

1. Introduction

There has been recent interest in the Holocene palaeoenvironmental history of the Kamchatka Peninsula with most studies largely focusing on lakes and peat deposits in the southern and central parts of the

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peninsula (e.g., Dirksen et al., 2011, 2013; Hoff et al., 2012, 2014). The climate model experiments suggest that mid-Holocene climatic changes were time-transgressive in the Kamchatka Peninsula with the Holocene thermal maximum (HTM) being delayed in southern and central Kamchatka by about 2000 years in comparison with northern Kamchatka, Alaska and NE Siberia (e.g., see Fig. 3 in Renssen et al., 2009). It is therefore especially important to provide better insight into Holocene environmental and climate dynamics in northern Kamchatka since there is still little palaeoenvironmental evidence from this region, whereas the Holocene history of Alaska and NE Siberia are comparatively well-documented (e.g., Anderson et al., 2002; Edwards and Barker, 1994; Lozhkin et al., 2001, 2007).

In the last few decades, palaeoecological research in the Kamchatka Peninsula has largely comprised studies of vegetation history (Andreev and Pevzner, 2001; Dirksen et al., 2013), tephrochronology (e.g., Braitseva et al., 1993, 1997; Dirksen et al., 2011; Pevzner et al., 1998; Pevzner, 2006) and glacial dynamics (Savoskul, 1999; Barr and Solomina, 2014). A comprehensive study of the Holocene vegetation history of the Kamchatka Peninsula has been presented by A. Klimaschewski (2010). Climate history during the last 400 years was reconstructed using tree-rings by Solomina et al. (2007) and Sano et al. (2010) and is summarized by Jones and Solomina (in this issue). Quaternary diatom records were studied by Braitseva et al. (1968).

Recently, a diatom sediment record from in the central Kamchatka was used to infer late-Holocene environmental changes (Hoff et al., 2012) and a diatom record from the Sokoch Lake in southern Kamchatka was used to reconstruct the past 9600 years of environmental history (Hoff et al., 2014). Hoff et al. (2011) also described a new diatom species (*Fragilaria flexura*) in Dvuyurtochnoe Lake. A recent paper by Nazarova et al. (2013) presents a chironomid-based climatic reconstruction from Dvuyurtochnoe Lake. Diatom phytoplankton, mainly *Aulacoseira subarctica*, has been studied in detail by Lepskaya et al. (2010) in the large and deep Kurilskoye Lake in southern Kamchatka.

This study presents the Holocene environmental history of the north-eastern coastal area of the Kamchatka Peninsula based on diatom, pollen and chironomid records from the sediment succession of a small coastal lake near the town of Ossora (Fig. 1a). The overall aims of this paper are (1) to qualitatively reconstruct the development of regional vegetation in north-eastern Kamchatka; (2) to assess its influence on the lake development (3) to compare environmental reconstructions with the Holocene environmental history of southern and central Kamchatka, north-eastern Siberia and Alaska and (4) to assess the importance of tephra on lake development.

2. Site description

Regional descriptions of northern Kamchatka Peninsula are presented in several papers in this volume, e.g., Self et al. and Andrén et al. Lifebuoy Lake (unofficial name; 59°06′593″N, 163°09′141″E) is a small lake (area is approximately 0.8 ha), which is located on a narrow peninsula between two coastal bays, Karaga Bay and Ossora Bay about 200 m from the Pacific coast, in north-eastern Kamchatka. It is situated about 20 km south of Pechora Lake (Andrén et al., in this issue), approximately 730 km to the north of Petropavlovsk and about one km from a small settlement of Karaga (Fig. 1a and b).

The lake lies about 6 km from the mountains to north-west, which reach altitudes of 385 m. The lake has an open hydrology with a well-defined outlet and at least one surface inlet with some diffuse leakage (recharge) through marginal fens. There are narrow peat margins around the lake, partly with small palsas (permafrost mounds). At the time of sampling the lake was stratified, with the thermocline occurring at about 3.5 m (the sampling depth was 5.1). It is likely that the lake is dimictic, with winter stratification occurring after the autumn ice sets in November–December. On the day of the sampling, in August 2005, the lake water was circum-neutral, with pH 7.82, conductivity 95.0 mS and the surface water temperature 16.9 °C (Dan Hammarlund, pers. comm).

Sphagnum bogs prevail in the catchment, together with low-lying shrubby *Pinus pumila*, *Alnus fruticosa* and *Betula ermanii*, generally similar to the vegetation at Pechora Lake (Andrén et al., in this issue). Bushes of Siberian dwarf pine (*P. pumila*) grow on the higher ground near the lake. Birch (*B. ermanii*) covers the mountain slopes (Fig. 1c).

Summers are relatively cold (July mean T is about 12 °C) with a short growing season and cold winters (mean January T is about −17 °C) (meteorological data from Ossora weather station, 1983–2005, http://kamchatka-meteo.ru/).

The main bedrock type is of Eocene origin (Klimaschewski, 2010), the lake catchment is dominated by till with high peat coverage.

Shiveluch is the nearest active volcano, which is located approximately 300 km south of Lifebuoy Lake. Eight visible tephra layers, predominantly from Shiveluch, occur in the Lifebuoy Lake sediments (Plunkett et al., in this issue).

3. Materials and methods

3.1. Sampling techniques

The core segments were sampled with a 1-m long, 5 cm diameter piston corer (Wright et al., 1984), deployed from a rubber boat at the lake centre from 5.10 m of water in August 2005. Sediments were wrapped in plastic, aluminium foil, thick plastic and modified plastic drain pipes, and stored in wooden boxes in a cold room at 4 °C. The upper ca. 30 cm of the lake sequence was sampled with a gravity corer, subsampled at 1-cm intervals and stored in separate plastic bags.

3.2. Laboratory methods

Pollen slide preparation followed standard methods (Fægri and Iversen, 1993; Moore et al., 1991; Bennett and Willis, 2001); *Lycopodium* spores were used to enable quantitative analysis (Stockmarr, 1971). Where possible, a minimum of 500 pollen grains were counted. Pollen percentages are based on the total terrestrial pollen sum. Percentages of obligate aquatics, non-arboreal pollen and charcoal, *Pediastrum*, snow algae are based upon the total pollen sum plus the count of the taxon in question.

For identification, the pollen reference collection at the School of Geography, Archaeology and Palaeoecology, Queen's University Belfast was used together with Moore et al. (1991), Reille (1992), Fægri and Iversen (1993) and Beug (2004). The palynological nomenclature generally follows Beug (2004). *Betula nana* pollen was not separated from *Betula alba*. Pollen grains of *P. pumila* were identified using the handbook of Hesse et al. (2009). Fungi and algae remains were determined following van Geel (1976).

Diatom slide preparation followed standard methods (Battarbee et al., 2001) using the water-bath technique (Renberg, 1990). Slides were mounted using Naphrax®. The diatom concentration was estimated by adding microsphere markers (Battarbee and Kneen, 1982). Between 300 and 400 valves were counted where possible at 1000 times magnification. Diatom nomenclature followed Krammer and Lange-Bertalot (1986–1991). Counts of *Pseudostaurosira brevistriata* and *Staurosira construens* v *venter* were combined into *Pseudostaurosira*–*Staurosira* group as these species are particularly difficult to separate, especially in girdle view. These taxa also show very similar stratigraphic changes within the Lake Lifebuoy sediment sequence.

Chironomid sub-fossils were prepared and slides mounted following standard techniques (Brooks et al., 2007) at sample intervals of between 2 and 14 cm. Chironomids were identified with reference to Wiederholm (1983), Rieradevall and Brooks (2001) and Brooks et al. (2007). Chironomids were absent or occurred at very low abundance at the base of the core (1204–1188 cm). These samples were excluded from the diagram and assemblages analysed at 3–8 cm intervals from

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