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Terrestrial plant macrofossil records; possible indicators of past lake-level fluctuations in north-eastern European Russia and Finnish Lapland?

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ABSTRACT. Four lake-sediment sequences from north-eastern European Russia and one from Finnish Lapland were studied for plant macrofossils. Basal ages of sediment sequences varied between ca. 12 800 and 6000 radiocarbon years. Plant macrofossil records of terrestrial and telmatic taxa showed a clear declining trend in terrestrial species richness and the relative amount of remains from mid to late Holocene. When these data are examined together with evidence provided by other available proxies (Cladocera, diatom, pollen, chironomid, lithology, LOI), it seems that the declining trend, in addition to reflecting the general vegetation development (e.g. shifts in treelines), might also reflect a change in the distance between the sampling point and the shoreline, i.e. changes in past lake levels. Variations detected in the species richness and abundance records are discussed against previous climate reconstructions available from nearby areas.

KEY WORDS: terrestrial plant macrofossils, species richness, lake-level fluctuations Holocene, north-eastern European Russia, Finnish Lapland

NTRODUCTION

The five sediment sequences discussed here were originally examined to reconstruct general regional and local vegetation history, mainly Holocene-time tree line movements (Kultti et al. 2003, 2004, Sarmaja-Korjonen et al. 2003, Väliranta et al. 2005, 2006). As an additional outcome, all the records seem to reveal similar and clear pattern of decrease in the amount of terrestrial macroscopic remains (including telmatic taxa) as well as a decline in species richness towards modern times. Because additional aquatic proxy evidence was available for three studied lakes (Mezhgornoe, Vankavad and Njargajavri), it is worthwhile to speculate, whether the declining trend through the Holocene could also be due to factors other than actual changes in vegetation composition and density, like past lake-level changes (i.e. changes in the distances between the sampling points and the shoreline).

Plant macrofossil analysis has proved to be a useful tool when reconstructing past lake-level fluctuations (Hannon & Gaillard 1997, Yansa & Basinger 1999, Birks 2001). The plant macrofossil assemblage in lake sediments consists of two components: terrestrial macrofossils are exogenic, originating from the catchment, whereas aquatic remains represent an endogenic compound derived from the lake itself (Birks & Birks 1980). In both cases local vegetation dominates because macroscopic particles are seldom transported far, and vegetative parts of aquatics are normally not transported at all (Birks & Birks 1980, Vance & Mathewes 1993). Plant remains do not readily reach the centres of large and/or deep lakes (Birks 1973, 2001, Wainman

& Mathewes 1990), hence a high abundance of terrestrial remains usually implies a close proximity to the shoreline, whereas an abrupt disappearance of terrestrial remains (sometimes with a concurrent increase in aquatic remains) implies a rising/higher water level at the sampling point (and development of the littoral zone). Similarly, disappearance of terrestrial remains and concurrent disappearance of limnophyte remains suggest deep water and a remote location from the shoreline (Birks 1973, Birks & Birks 1980, Vance & Mathewes 1993, Hannon & Gaillard 1997, Last et al. 1998, Dieffenbacher-Krall & Halteman 2000, Cohen 2003, and references therein, Magny & Bégeot 2004). Because in this study only one core per site was examined it is not, however, possible to quantify past water level changes (Gaillard 1984, Digerfeldt 1986, Digerfeldt et al. 1997, Hannon & Gaillard 1997).

The water balance of a lake is dependent on such factors as precipitation, evaporation and evapotranspiration at the catchment, the area of the lake and catchment, runoff from the catchment, outflow from the lake, and groundwater flow (Street-Perrott & Harrison 1985, Dearing & Foster 1986). Models developed by Vassilev et al. (1998) suggest that especially changes in precipitation are needed to cause significant lake-level changes; shifts in temperature alone are not sufficient. Changes in permafrost conditions affect soil permeability and moisture retention capacity, complicating historical water balance interpretations in arctic and subarctic areas (MacDonald et al. 2000a, van den Linden et al. 2003, Smith et al. 2005). The natural infilling process leads to the shallowing of lakes and shorelines and to an increase in the extent of littoral habitats (Hannon & Gaillard 1997). Regional differences in historical moisture-balances in some areas can also depend on the past geographical position in relation to, for instance; 1) the melting Scandinavian ice-sheet, which influenced regional climate conditions along the edge of the ice-sheet (Subetto et al. 2002, Wohlfarth et al. 2002); 2) the historical Barents Sea coastline, which affected the oceanic/continentality rate (Andreev & Klimanov 2000); and 3) the Atlantic Ocean, the climatic influence weakening eastwards (Velichko et al. 1997, Wohlfarth et al. 2004). In addition, the early Holocene changes in insolation (COHMAP members 1988) may have had a strong regional impact on moisture regimes (MacDonald et al. 2000a, Miousse et al. 2003). Here plant macrofossil-derived interpretations are compared to existing climate reconstructions available from nearby areas: northern Fennoscandia and north European Russia.

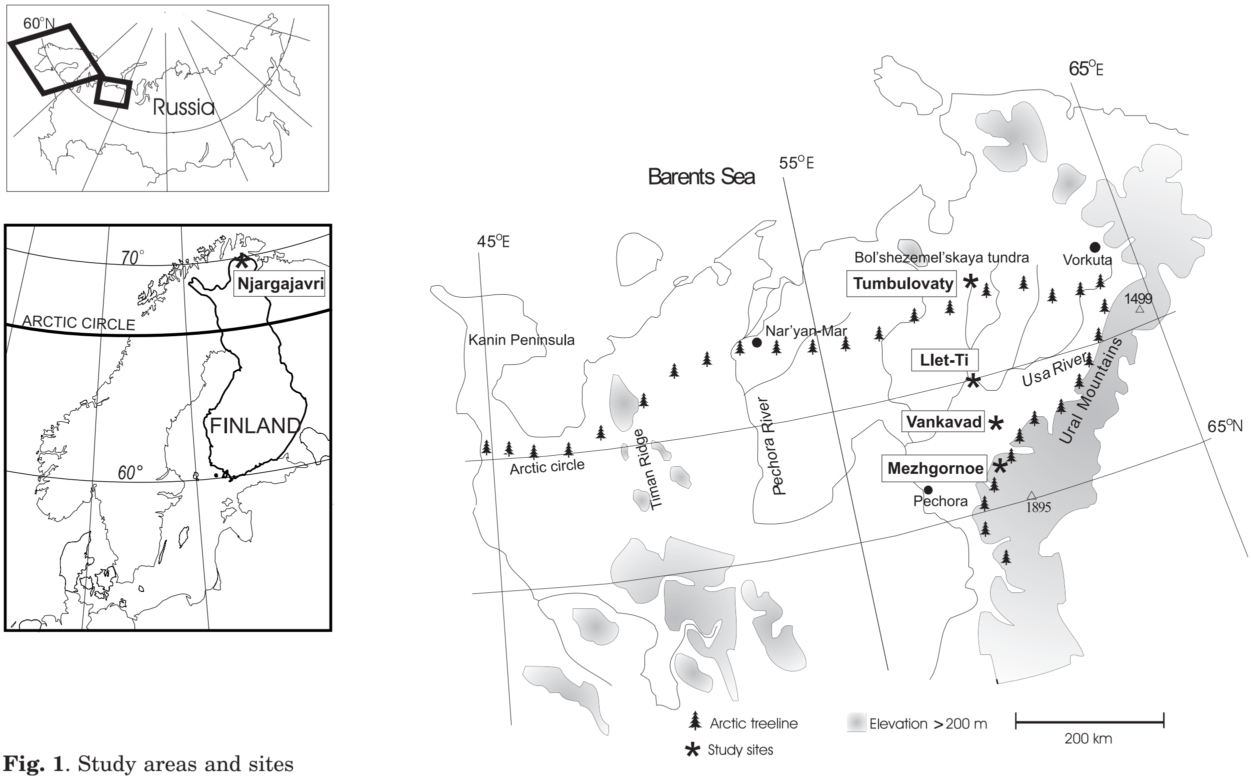

Fig. 1. Study areas and sites

STUDY SITES AND SAMPLING

Four of the study sites, lakes Llet-Ti, Vankavad, Mezhgornoe and Tumbulovaty, are located in the Pechora area, north-eastern European Russian and one in eastern Finnish Lapland (Fig. 1).

Lake Llet-Ti (ca. 75 ha) is situated at the northern boundary of the extreme northern taiga zone (67°50′N, 58°50′E, 50 m a.s.l.). The lake has one inlet that probably functions only seasonally. The vegetation around the lake consists of mixed spruce forest and open mires. The area belongs to the discontinuous permafrost zone. A 500-cm-long sediment sequence was collected through lake-ice with a Russian peat corer in 1999, less than 100 m from the shore. The water depth at the sampling point was 1.5 m.

Lake Vankavad (ca. 46 ha) is situated inside the extreme northern taiga zone (65°N, 59°E, 56 m a.s.l.). The lake has no inlets or outlets. The surrounding vegetation consists mainly of spruce mixed with birch. The area belongs to the sporadic permafrost zone. A 220-cm-long sediment sequence was collected through lake-ice from the middle of the lake (ca. 200 m from the shore) with a Russian peat corer in 1998. The water depth at the sampling point was 5.6 m.

Lake Mezhgornoe (ca. 6 ha) is situated at the alpine treeline on the western side of the Ural Mountains (65°N, 59°E, 550 m a.s.l.). The lake has one inlet and one outlet. Rich meadows occupy mesic terrestrial habitats, and shrubby tundra vegetation or bare rocks are found on drier sites. A 320-cm-long sediment sequence was collected in summer 1998 with a Russian peat corer ca. 20 m from the shore, where the water depth was 2 m.

Lake Tumbulovaty (ca. 43 ha) is located on an upland plateau near the arctic treeline (67°N, 59°E, 115 m a.s.l.). The lake has one outlet. The catchment is characterized by dwarf-shrub tundra and some peat deposits. The area belongs to the discontinuous permafrost zone. A 280-m-long sediment sequence was collected through lake-ice with a Russian peat corer in 2000, from the middle of the lake ca. 300 m from the shore. The water depth at the sampling point was 1.6 m.

Lake Njargajavri (ca. 14 ha) is located above the present treeline on a gently sloping mountain plateau in northernmost eastern Finnish Lapland (ca. 70ºN, 27ºE, 355 m a.s.l.). The lake has one, probably only seasonally functioning outlet. The surrounding vegetation consists of subarctic heath plants. A 120-cm-long sediment sequence was collected with a Russian peat corer in 2001 through lake-ice from the middle of the lake (ca. 150 m from the shore), where the water depth was 2 m.

ANALYSIS OF PLANT MACROFOSSILS

All sites were analysed for plant macrofossil remains. Sample sizes and intervals varied as follows (the most common volume in bold): Llet-Ti (20–**30** cm^3, 5-cm interval), Vankavad (20–**30** cm^3, 10–cm interval), Mezhgornoe (5–**20–30** cm^3, 5-cm interval), Tumbulovaty (25–**30–**50 cm^3, 5-cm interval) and Njargajavri (10–**20** cm^3, 1-to 4-cm interval). Pollen data are available from all study sites. In addition, diatom and Cladocera data are available from lakes Mezhgornoe, Vankavad and Njargajavri, and chironomid data from Njargajavri lake. All of the dates in the text are calibrated radiocarbon ages cal yr BP (Stuiver & Reimer 1993, CALIB 4.4, version intcal98). Based on calibrated radiocarbon ages, a liner age-depth model was applied for each sediment sequence. In the case of Njargajavri, the model was created separately for the sequences below and above the hiatus.

To produce “species richness” data, each record was first divided into 1000-year intervals and the number of terrestrial taxa (including telmatics) present within these intervals was then calculated (Fig. 2). The term “species richness” is here used to refer to the number of taxa representing any taxonomic level, not only remains identified to species level. For instance, birch bark is considered to represent a taxonomic unit if no other birch remains were present. Accordingly, if birch finds included birch bark, tree-type and dwarf-type birch seeds and/or catkin scales, these were counted as representing two taxonomic units (tree birch and dwarf birch). To depict general historical trends, mean values of the number of species for 1000-years intervals were used (see Allen & Huntley 1999).

INTERPRETED LAKE LEVEL FLUCTUATIONS BASED ON CHANGES IN TERRESTRIAL PLANT MACROFOSSIL RECORDS

Macrofossil records (Figs 2, 3) show that a maximum in the abundances (i.e. relative amount of finds) of remains as well as species richness often corresponds to the initial phase when the sampling points, which at present have a mid-lake position (except in Mezhgornoe lake), were situated close to the shoreline. In the case of Vankavad lake, the high abundance of remains is probably, at least partly, due to a markedly higher sedimentation rate between ca. 6000 and 5000 cal yr BP. Otherwise, the sedimentological records (lithology or sedimentation rates) show quite minor changes after the initiation phases and the changes are

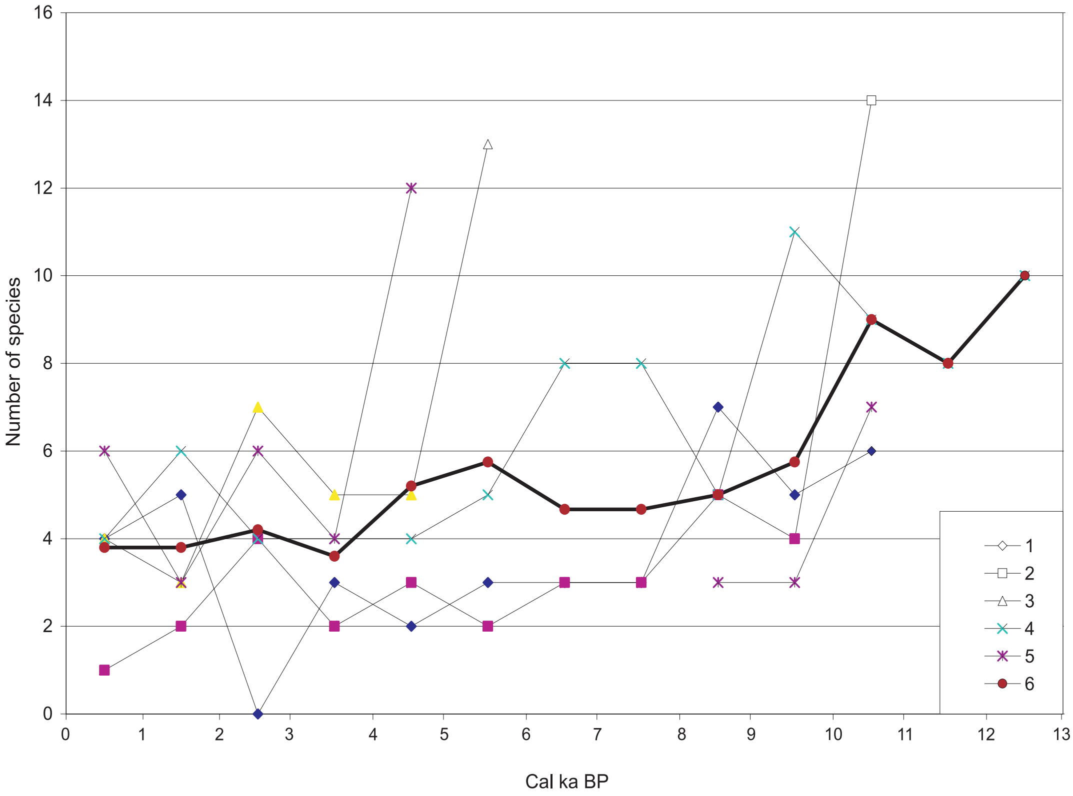

Fig. 2. Past changes in species richness of terrestrial and telmatic taxa. A mean value of number of taxa within 1000 year periods was used to illustrate the long-term trend. **1** – Tumbulovaty lake, **2** – Mezhgornoe lake, **3** – Vankavad lake, **4** – Liet-Ti lake, **5** – Niargajavri lake, **6** – Mean

not interrelated with the abundance-pattern. The data suggest low lake-levels in lakes Llet-Ti and Vankavad until ca. 5000 cal yr BP, in Mezhgornoe lake at first until ca. 10 000 cal yr BP and then again between ca. 8000 and 4000 cal yr BP (see, however, text below), in Tumbulovaty lake until 3000 cal yr BP and in Njargajavri lake until the lake dried out possibly around 8000 cal yr BP. The macrofossil-based interpretation in terms of the low water levels during the early to mid Holocene, receives support from other available proxies: a small relative share of planktonic Cladocera and the presence of diatoms thriving in shallow waters (Kultti et al. 2003, Sarmaja-Korjonen et al. 2003, 2006) and also the presence of shallow-water chironomid taxa in Njargajavri lake (Sarmaja-Korjonen et al. 2006). According to macrofossil and Cladocera assemblages the sampling point in Mezhgornoe lake was situated further from the shoreline and beyond the littoral zone between 10 000 and 8000 cal yr BP. After ca. 8000 cal yr BP, the shoreline was located nearer to the sampling point again, i.e. the water level probably dropped. Fig. 4 illustrates the interpretations in terms of shifts in the position of the sampling points in relation to the shorelines based on plant macrofossil records and other available proxy data.

The rise in water level, resulting in an increase in distance between sampling points and the shorelines seems to have occurred in Russian taiga lakes around 5000 cal yr BP and in Tumbulovaty lake around 3000 cal yr BP. In the case of Njargajavri the rise in water level, around 5000 cal yr BP, is indicated by a re-formation of the lake, after which the sampling point was situated close to the shore for one thousand years, until ca. 4000 cal yr BP. In Mezhgornoe lake the macrofossil record shows a less straight-forward signal. In Mezhgornoe lake the distance between the sampling point and the shore is currently only about 20 m and still the modern sediment samples contained very few macroscopic remains. The rarity of macroscopic remains from ca. 4000 cal yr BP until modern times is probably a false notion and is due to relatively small sample sizes (<20 cm^3) between 150 and 0 cm (= ca. 4000 cal yr BP and modern). Before that the sample size was mainly 20–30 cm^3. So, the interpretation of the phase of a higher water level between ca. 11 000 and 8000 cal BP, based on small amounts of macroscopic remains, and

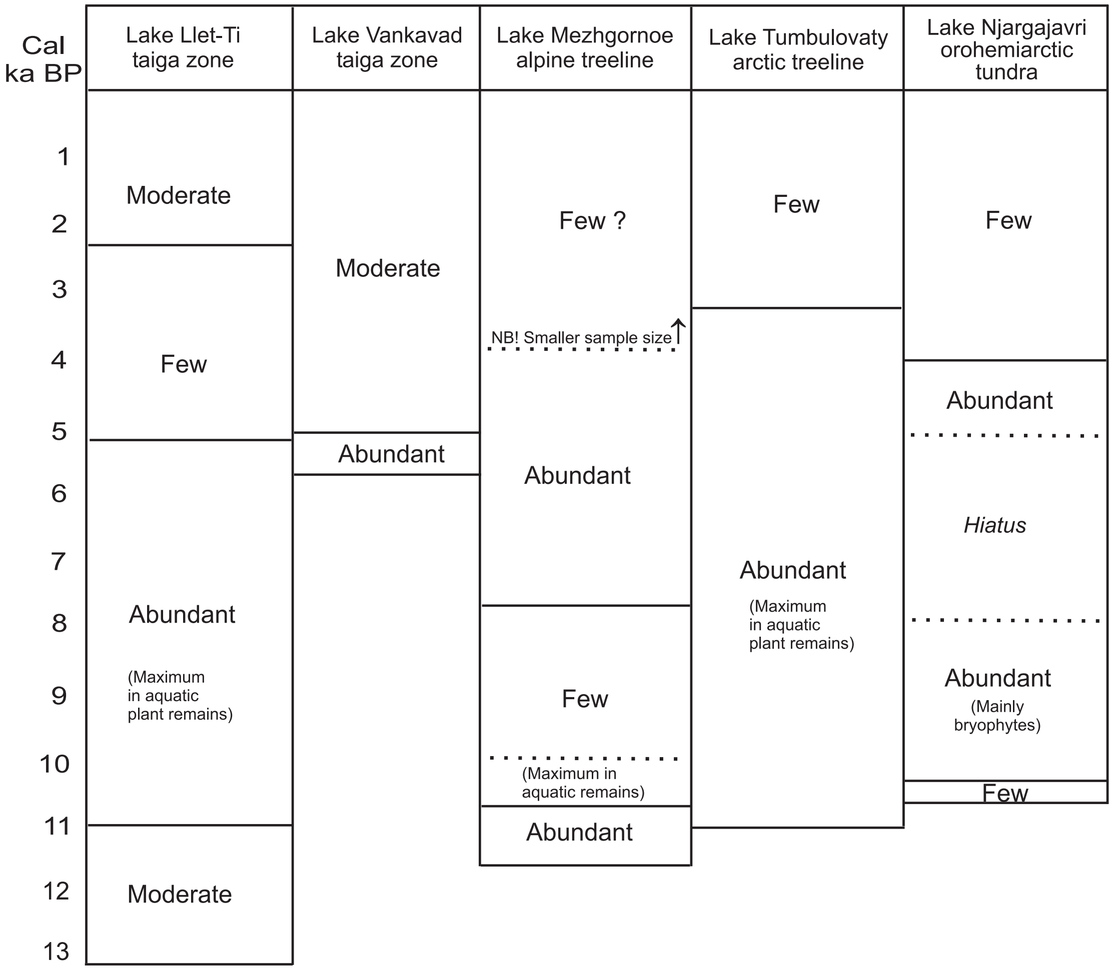

Fig. 3. A summary of the changes in the numbers of finds of terrestrial plant remains indicated by a relative tripartite scale: few, moderate and abundant. Phases with the maximum presence of aquatic plant remains, indicating littoral conditions, are also shown

the absence of aquatic plant remains can be considered reliable, but after 4000 cal yr BP low values probably reflect the sample size, not a change in lake level. In all other cases, the scarcity of macroscopic remains in modern samples can be interpreted to be a result of the sampling points being currently located relatively far from the shoreline (100–300 m).

COMPARISON OF PLANT MACROFOSSIL-BASED INTERPRETATIONS OF LAKE LEVEL CHANGES WITH THE EXISTING ENVIRONMENTAL RECONSTRUCTIONS

In general, the initiation of the lakes in north-eastern European Russia is linked to the warming that started ca. 13 000 cal yr BP, leading to a gradual melting of the permafrost (Sidorchuk et al. 2001, Henriksen et al. 2003). Earlier studies on Holocene-time changes in lake-levels are not available from the north-eastern part of European Russia. Yet, some reconstructions exist for north-western European Russia and Russian Karelia. Harrison et al. (1996) synthesized data derived from various proxy records and applied a rough lake-level reconstruction to the western part of the north European Russia. The reconstruction shows a somewhat contradictory pattern to the one indicated by my data (Fig. 4). It suggests that in north-western Russia higher than present lake-levels prevailed around 10 500 cal yr BP, and higher or similar lake levels ca. 8000 and 3000 cal yr BP, respectively. In addition, according to Harrison et al. (1996) lake levels were lower than present in the north-eastern European Russia ca. 3000 years ago. The records presented here indicate that after the initial phase the lake levels were not high, but they remained relatively low (except in Mezhgornoe lake). Wohlfarth et al. (2004) report more congruent results from Russian

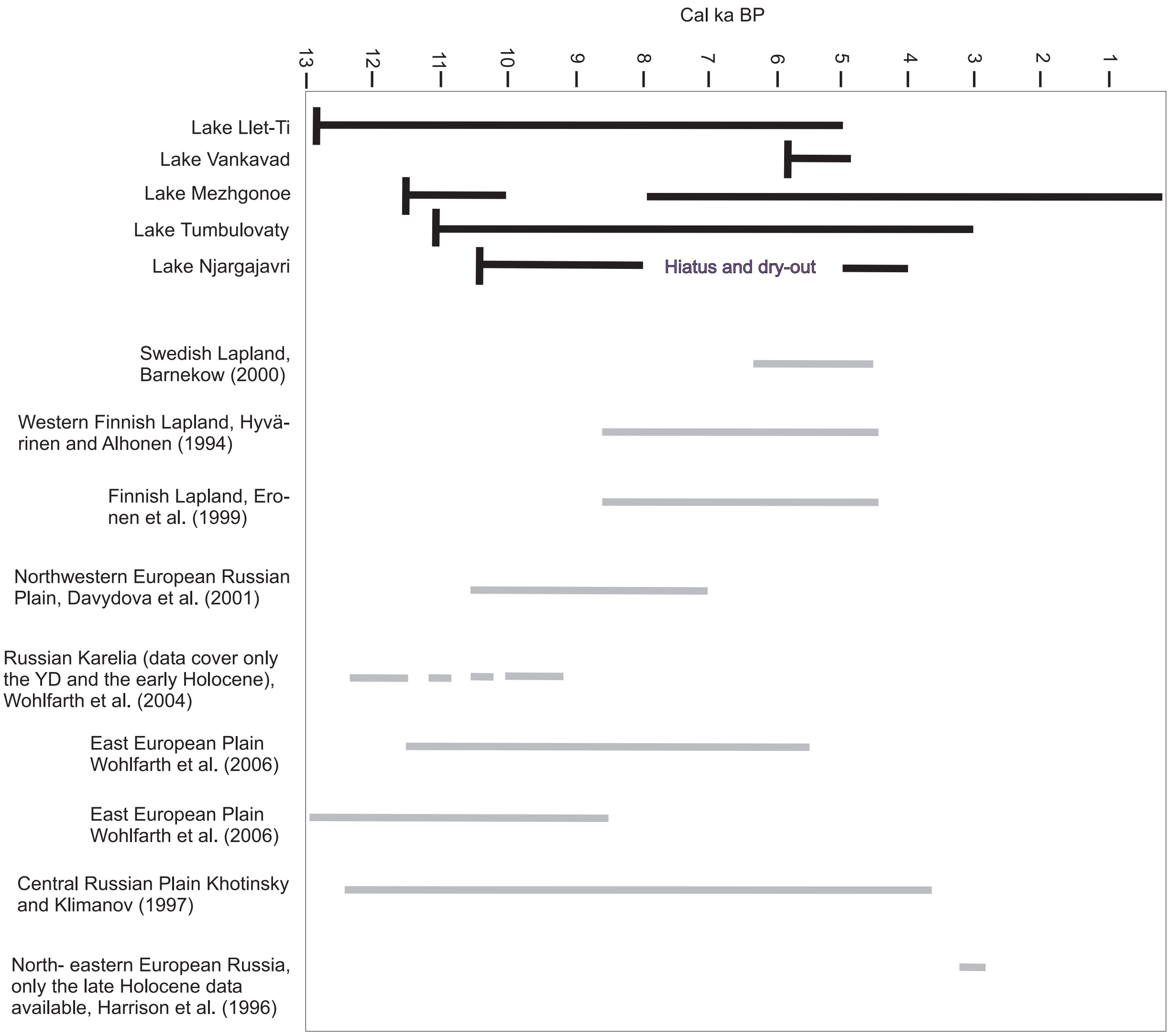

Fig. 4. A plant macrofossil-based interpretation of the time periods when the sampling point is located near the shore (i.e. low water level). For comparison some examples of reconstructed periods with dry climate and/or low lake-levels in northern Fennoscandia and northern European Russia are shown

Karelia and conclude that during the early Holocene several periods of negative effective moisture occurred (see also Wohlfarth et al. 2006). Moreover, their results are in fairly good agreement with some previously published palaeoecological studies from northern Russia (Khotinsky 1984, Khotinsky & Klimanov 1997, Arslanov et al. 1999), suggesting intermittent warm and cool periods during the early Holocene. In addition, Davydova et al. (2001) report low lake levels in the Russian Karelian area during the early Holocene.

In the light of these reconstructions, the suggestion of low lake levels until the mid Holocene, based on plant macrofossil records of four Russian lakes, is reasonable. The reason for the higher water level period detected between 10 000 and 8000 cal yr BP for Mezhgornoe lake remains unclear. It might, for instance, be related to dynamics of local cirque glaciers.

Additional support can be found from regional vegetation and climate reconstructions for north-eastern European Russia. These reconstructions show that early Holocene climate warming led to the rapid immigration of different trees to previously treeless areas as well as to denser vegetation in areas formerly occupied by sparse vegetation (Kremenetski et al. 1998, Andreev & Klimanov 2000, Kaakinen & Eronen 2000, MacDonald et al. 2000b, Kultti et al. 2003, 2004, Paus et al. 2003, Väliranta et al. 2006). Such a succession would have resulted in an increase in the evapotranspiration and had a negative effect on the catchments' moisture balance (Lockwood 1979, Bosch & Hewlett 1982, Yu & McAndrews 1994, Zhang et al.

2001). This was also interpreted to be the case in Njargajavri lake, in Finnish Lapland (Väliranta et al. 2005). The Njargajavri record, which indicated that the water level started to drop already around 10 000 cal yr BP, was not in total harmony with earlier records from Fennoscandia, which reported humid climate and higher-than-present lake-levels during the early Holocene (Seppä & Hammarlund 2000, Korhola & Weckström 2004, Korhola et al. 2005). Apparently, the drying effect resulting from the immigration of tree birch was enhanced because of a small catchment/lake relation (5:1). The mid Holocene dry-out of the lake is, however, in accordance with other historical Fennoscandian lake-level data that show low lake levels in the mid-Holocene (Hyvärinen & Alhonen 1994, Eronen et al. 1999, Sarmaja-Korjonen & Hyvärinen 1999, Barnekow 2000, Korhola & Weckström 2004).

The interpreted, relatively concurrent, mid-Holocene rise in lake levels (and the initiation of Vankavad lake) coincides with climate reconstructions indicating widespread cooling and a more humid climate after the mid Holocene (Fennoscandia: Rosén et al. 2001, Seppä & Birks 2001, Bigler et al. 2003, Korhola & Weckström 2004 and Northern Russia: Davydova & Servant-Vildary 1996, Kremenetski et al. 1998, Arslanov et al. 1999, MacDonald et al. 2000b, Kaakinen & Eronen 2000, Oksanen et al. 2001, Andreev et al. 2002, Kultti et al. 2003, 2004, Paus et al. 2003).

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REFERENCES

ALLEN J.R.M. & HUNTLEY B. 1999. Estimating past floristic diversity in montane regions from macrofossil assemblages. J. Biogeogr., 26: 55–73.

ANDREEV A.A. & KLIMANOV V.A. 2000. Quantitative Holocene climatic reconstruction from Arctic Russia. J. Paleolim., 24: 81–91.

ANDREEV A.A, SIEGERT C., KLIMANOV V.A., YU.A., SHILOVA D., SHILOVA G.N. & MELLES M. 2002. Late Pleistocene and Holocene vegetation and climate on the Taymyr lowland, northern Siberia. Quat. Res., 57: 138–150.

ARSLANOV K.H.A., SAVELJEVA L.A., GEY N.A., KLIMANOV V.A., CHERNOV S.B., CHERNOVA G.M., KUZMIN G.F., TERTYCHNAYA T.V., SUBETTO D.A. & DENISENKOV V.P. 1999. Chronology of vegetation and paleoclimatic stages of northwestern Russia during the Late glacial and Holocene. Radiocarbon, 41: 25–45.

BARNEKOW L. 2000. Holocene regional and local vegetation history and lake-level changes in the Torneträsk area, northern Sweden. J. Paleolim., 23: 399–420.

BIGLER C., GRAHN E., LAROCQUE I., JEZIORSKI A. & HALL R. 2003. Holocene environmental change at Lake Njulla (999 m a.s.l.), northern Sweden: a comparison with four small nearby lakes along an altitudinal gradient. J. Paleolim., 29: 13–29.

BIRKS H.H. 1973. Modern macrofossil assemblages in lake sediments in Minnesota: 173–189. In: Birks H.J.B. & West R.G. (eds) Quaternary Plant Ecology. Blackwells Scientific Publications, Oxford.

BIRKS H.H. 2001. Plant macrofossils: 49–74. In: Smol J.P., Birks H.J.B. & Last, W.M. (eds) Tracking environmental change using lake sediments. Vol. 3: Terrestrial, algal and siliceous indicators. Kluwer Academic Publishers, Dordrecht, The Netherlands.

BIRKS H.J.B. & BIRKS H.H. 1980. Quaternary Palaeoecology. Edward Arnold, London.

BOSCH J.M. & HEWLETT J.D. 1982. A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration. J. Hydrol., 55: 3–23.

COHEN A.S. 2003. Paleolimnology. Oxford University Press, New York.

COHMAP MEMBERS 1988. Climatic changes of the last 18,000 years: observations and model simulations. Science, 241: 1043–1052.

DAVYDOVA N. & SERVANT-VILDARY S. 1996. Late Pleistocene and Holocene history of the lakes in the Kola Peninsula, Karelia and North-western part of the East European Plain. Quat. Sci. Rev., 15: 997–1012.

DAVYDOVA N.N., SUBETTO D.A., KHOMUTOVA V.I. & SAPELKO T.V. 2001. Late-Pleistocene-Holocene paleolimnology of three northwestern Russian lakes. J. Paleolim., 26**:** 37–51.

DEARING J.A. & FOSTER I.D.L. 1986. Lake sediment and paleohydrological studies: 67–90. In: Berglund B.E. (ed.) Handbook of Holocene Palaeoecology and Palaeohydrology. John Wiley & Sons. Ltd., Chichester, New York.

DIEFFENBACHER-KRALL A.C. & HALTEMAN W. 2000. The relationship of modern plant remains to water depth in alkaline lakes in New England, USA. J. Paleolim., 24: 213–229.

DIGERFELDT G. 1986. Studies on past lake-level fluctuations: 127–141. In: Berglund B.E. (ed.) Handbook of Holocene Palaeoecology and Palaeohydrology, John Wiley & Sons Ltd.

DIGERFELDT G., BEAULIEU DE J-L., GUIOT J. & MOUTHON J. 1997. Reconstruction and paleoclimatic interpretation of Holocene lake-level changes in Lac de Saint-Léger, haute-Provence, southeast France. Palaeogeogr., Palaeoclimatol., Palaeoecol., 136: 231–258.

ERONEN M., HYVÄRINEN H. & ZETTERBERG P. 1999. Holocene humidity changes in northern Finnish Lapland inferred from lake sediments and submerged Scots pines dated by tree-rings. The Holocene, 9: 569–580.

GAILLARD M-J. 1984. A palaeohydrological study of Krageholmssjön (Scania, South Sweden). Lundqua Rep., 25: 1–40.

HANNON G. & GAILLARD M-J. 1997. The plant macrofossil record of past lake-level changes. J. Paleolim., 18: 15–28.

HARRISON S., YU G. & TARASOV P.E. 1996. Late Quaternary lake-level record from Northern Eurasia. Quat. Res., 45: 138–159.

HENRIKSEN M., MANGERUD J., MATIOUCHKOV A., PAUS A. & SVENDSEN J.I. 2003: Lake stratigraphy implies an 8000 yr delayed melting of buried dead ice in northern Russia. J. Quat. Sci., 18: 663–679.

HYVÄRINEN H. & ALHONEN P. 1994. Holocene lake level changes in the Fennoscandian tree-line region, western Finnish Lapland: diatom and cladoceran evidence. The Holocene, 4: 251–158.

KAAKINEN A. & ERONEN M. 2000. Holocene pollen stratigraphy indicating climatic and tree-line changes derived from a peat section at Ortino, in the Pechora lowland, northern Russia. The Holocene, 10: 611–620.

KHOTINSKY N.A. 1984. Holocene climatic change: 305–309. In: Velichko A.A. (ed.) Late Quaternary environments of the Soviet Union. Translated from Russian, Minneapolis: University of Minnesota Press.

KHOTINSKY N.A. & KLIMANOV V.A. 1997. Alleröd, Younger Dryas and Early Holocene palaeo-environmental stratigraphy. Quat. Int., 41/42: 67–70.

KORHOLA A. & WECKSTRÖM J. 2004. Paleolimnological studies in arctic Fennoscandia and the Kola Peninsula (Russia): 381–418. In: Pienitz R., Douglas M.S.V. & Smol J.P. (eds) Long-term Environmental Change in Arctic and Antarctic Lakes. Kluwer Academic Publishers.

KORHOLA A., TIKKANEN M. & WECKSTRÖM J. 2005. Quantification of the Holocene lake-level changes in Finnish Lapland by means of a cladocera-lake depth transfer model. J. Paleolim., 34: 175–190.

KREMENETSKI C.V., SULERZHITSKY L.D. & HANTEMIROV R. 1998. Holocene history of the northern limits of some trees and shrubs in Russia. Arct. Alp. Res., 30: 317–333.

KULTTI S., OKSANEN P. & VÄLIRANTA M. 2004. Multiproxy record of Holocene environmental change in the Nenets region, East-European Russian arctic. J. Can. Earth Sci., 41: 1141–1158.

KULTTI S., VÄLIRANTA M., SARMAJA-KORJONEN K., SOLOVIEVA N., VIRTANEN T., KAUPPILA T. & ERONEN M. 2003. Palaeoecologial evidence of changes in vegetation and climate during the Holocene in the pre-Polar Urals, northeast European Russia. J. Quat. Sci., 18: 503–520.

LAST W.M., VANCE R.E., WILSON S. & SMOL J.P. 1998. A multi-proxy limnologic record of rapid early-Holocene hydrologic change on the northern Great Plains, southwestern Saskatchewan, Canada. The Holocene, 8: 503–520.

LINDEN van der S., VIRTANEN T., OBERMAN N. & KUHRY P. 2003. Sensitivity analysis of discharge in the arctic Usa basin, east-European Russia. Clim. Chang., 57: 139–161.

LOCKWOOD J.G. 1979. Water balance of Britain, 50,000 B.P. to present day. Quat. Res., 12: 297–310.

McDONALD G.M., FELZER B., FINNEY B.P. & FORMAN S.L. 2000a. Holocene lake sediment records of Arctic hydrology. J. Paleolim., 24: 1–14.

McDONALD G.M., VELICHKO A.A., KREMENETSKI V., BORISOVA O.K., GOLEVA A.A., ANDREEV A.A., CWYNAR L.C., RIDING R.T., FORMAN S.L., EDWARDS T.W.D., ARAVENA R., HAMMARLUND D., SZEICZ J.M., & GATTAULIN V.N. 2000b. Holocene treeline history and climate change across northern Eurasia. Quat. Res., 53: 302–311.

MAGNY M. & BÉGEOT C. 2004. Hydrological changes in the European midlatitudes associated with freshwater outburst from Lake Agassiz during the Younger Dryas event and the early Holocene. Quat. Res., 61: 181–192.

MIOUSSE L., BHIRY N. & LAVOIE M. 2003. Isolation and water level fluctuation of Lake Kachishayoot, Northern Québec, Canada. Quat. Res., 60: 149–161.

OKSANEN P.O., KUHRY P. & ALEKSEEVA R.N. 2001. Holocene development of the Rogovaya River peat plateau, East-European Russian arctic. The Holocene, 11: 25–40.

PAUS A., SVENDSEN J.I. & MATIOUCHKOV A. 2003. Late Weichselian (Valdaian) and Holocene vegetation and environmental history of the northern Timan Ridge, European Arctic Russia. Quat. Sci. Rev., 22: 2285–2302.

ROSÉN P., SEGERSTRÖM U., ERIKSSON L., RENBERG I. & BIRKS H.J.B. 2001. Holocene climatic change reconstructed from diatoms, chironomids, pollen and near-infrared spectroscopy at an alpine lake (Sjuodjijaure) in northern Sweden. The Holocene, 11: 551–562.

SARMAJA-KORJONEN K. & HYVÄRINEN H. 1999. Cladoceran and diatom stratigraphy of calcareous lake sediments from Kuusamo, NE Finland. Indications of Holocene lake-level changes. Fennia, 177: 55–70.

SARMAJA-KORJONEN K. KULTTI S., SOLOVIEVA N. & VÄLIRANTA M. 2003. Mid-Holocene palaeoclimatic and palaeohydrological conditions in northeastern European Russia; a multi-proxy study of Lake Vankavad. J. Paleolim., 30: 415–426.

SARMAJA-KORJONEN K. NYMAN M., KULTTI S. & VÄLIRANTA M. 2006. Palaeolimnological development of Lake Njargajavri, northern Finnish Lapland, in changing Holocene climate and environment. J. Paleolim., 35: 65–81.

SEPPÄ H. & BIRKS H.J.B. 2001. July mean temperature and annual precipitation trends during the Holocene in the Fennoscandian tree-line area: pollen-base climate reconstruction. The Holocene, 11: 527–539.

SEPPÄ H. & HAMMARLUND D. 2000. Pollen stratigraphical evidence of Holocene hydrological change in northern Fennoscandia supported by independent isotopic data. J. Paleolim., 24: 69–79.

SIDORCHUK A., BORISOVA O. & PANIN A. 2001. Fluvial response to the LateValdai/Holocene environmental change on the East European Plain. Glob. Planet. Chang., 28: 303–318.

SMITH L.C., SHENG Y., MACDONALD G.M. & HINZMAN L.D. 2005. Disappearing arctic lakes. Science, 308: 1429–1433.

STREET-PERROTT F.A. & HARRISON S.P. 1985. Lake levels and climate reconstruction. In: Reconstructing climate from lake level changes. Offprints from paleoclimate analysis and modelling, Lundqua Thesis, 21.

STUIVER M. & REIMER P.J. 1993. Extended ^{14}C database and revised CALIB radiocarbon calibration program. Radiocarbon, 35: 215–230.

SUBETTO D.A., WOHLFARTH B., DAVYDOVA N.N., SAPELKO T.V., BJÖRKMAN L., SOLOVIEVA N., WASTEGÅRD S., POSSNERT G. & KHOMUTOVA V.I. 2002. Climate and environment on the Karelian Isthmus, northwestern Russia, 13000–9000 cal. yrs BP. Boreas, 31: 1–19.

VÄLIRANTA M., KULTTI S. & SEPPÄ H. 2006. Vegetation dynamics during the Younger Dryas – Holocene transition in the extreme northern taiga zone, north-eastern European Russia. Boreas, 35: 201–212.

VÄLIRANTA M., KULTTI S., NYMAN M. & SARMAJA-KORJONEN K. 2005. Holocene development of aquatic vegetation in shallow Lake Njargajavri, Finnish Lapland, with evidence of water level fluctuations and drying. J. Paleolim., 34: 203–215.

VANCE R.E. & MATHEWES R.W. 1993. Deposition of modern pollen and plant macroremains in a hypersaline prairie lake basin. Can. J. Bot., 72: 539–548.

VASSILJEV J., HARRISON S.P. & GUIOT J. 1998. Simulating the Holocene lake-level record of Lake Bysjön, Southern Sweden. Quat. Res., 49: 62–71.

VELICHKO A.A., ANDREEV A.A. & KLIMANOV V.A. 1997. Climate and vegetation dynamics in the tundra and forest zone during the Late glacial and Holocene. Quat. Int., 41/42: 71–96.

WAINMAN N. & MATHEWES R.W. 1990. Distribution of plant macroremains in surface sediments of Marion lake, southwestern British Columbia. Can. J. Bot., 68: 364–373.

WOHLFARTH B,. TARASOV P., BENNIKE O., LACOURSE T., SUBETTO D., TORSSANDER P. & ROMANENKO F. 2006. Late glacial and Holocene palaeoenvironmental changes in the Rostov-Yaroslavl' area, West Central Russia. J. Paleolim., 35: 543–569.

WOHLFARTH B., FILIMONOVA L., BENNIKE O., BJÖRKMAN L., BRUNNBERG L., LAVROVA N., DEMIDOV I. & POSSNERT G. 2002. Late-glacial and early Holocene environmental and climatic change at Lake Tambichozero, Southeastern Russian Karelia. Quat. Res., 58: 261–272.

WOHLFARTH B., SCHWARK L., BENNIKE O., FILIMONOVA L., TARASOV P., BJÖRKMAN L., BRUNNBERG L., DEMIDOV I. & POSSNERT G. 2004. Unstable early-Holocene climatic and environmental conditions in northwestern Russia derived from a multidisciplinary study of a lake-sediment sequence from Pichozero, southeastern Russian Karelia. The Holocene, 14: 732–746.

YANSA C. & BASINGER J.F.1999. A postglacial plant macrofossil record of vegetation and climate in southern Saskatchewan. Geol. Surv. Can. Bull., 534: 139–172.

YU Z. & McANDREWS J.H. 1994. Holocene water levels at Rice Lake, Ontario, Canada: sediment, pollen and plant macrofossil evidence. The Holocene, 4: 141–152.

ZHANG L., DAWES W.R. & WALKER G.R. 2001. Response of mean annual evapotranspiration to vegetation changes at catchment scale. Water Resour. Res., 37: 701–708.