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THE OXYGEN REGIME OF A SHALLOW LAKE

ABSTRACT. The year-round measurement data of water temperature and dissolved oxygen content in a small boreal Lake Vendyurskoe in 2007–2013 were used to explore the hydrophysical prerequisits of anoxia and accumulation and emission of greenhouse gases. Typically, anoxia appears in the bottom layers of lakes in mid-winter and during the summer stagnation. The thickness of the benthic anaerobic zone (dissolved oxygen concentration <2 mg·l^{-1}) reached one meter in the end of the winter and at the peak of the summer stratification, except for the extremely hot summer of 2010, when it reached five meters. Synoptic conditions had a crucial influence on the formation and destruction of the benthic anaerobic zones in summer. The most favorable oxygen dynamics was observed during the cold summers of 2008, 2009, and 2012, when the repeated full mixings of the water column occurred under conditions of the cyclonic weather. In the winter periods, the early dates of ice season resulted in the most pronounced deficiency of oxygen.

KEY WORDS: ice-covered lake, summer stagnation, dissolved oxygen, anoxia, greenhouse gases

INTRODUCTION

Dissolved oxygen (DO) is one of the most important parameters in the lake ecosystem. Oxygen depletion can cause large changes in the population of fish, leading, in extreme cases, to the massive fish kill [Greenbank, 1945; Barica & Mathias, 1979]. The lack of DO leads to the activation of anaerobic processes and to accumulation of harmful greenhouse gases such as carbon dioxide (CO_2) and methane (CH_4) in the bottom layers of the water column and upper bottom sediments [Golosov et al., 2007; McGinnis et al., 2015]. The significant emission of such gases can take place after the full mixing of the water column, for example, as a result of the ice breakup or after erosion of the seasonal thermocline at the end of the summer [Lohila et al., 2015]. Anaerobic conditions occur in the bottom layers of mesotrophic and eutrophic boreal lakes during summer thermal stratification due to insufficient aeration of the water column [Efremova et al., 2015]. In the winter periods, the main cause of the oxygen reduction in shallow lakes is the absence of the gas exchange with the atmosphere and the suppression of photosynthesis. The rate of DO reduction is determined by the intensity of its diffusion in sediments and bacterial consumption in the water column [Hargrave, 1972; Boylen & Brock, 1973; Mathias & Barica, 1980; Brekhovskih, 1988]. The amount of organic matter, initial water temperature at the start of the ice season, and heat flux from the sediments are the factors that have the major influence on the rate of oxygen reduction in a lake during winter [Terzhevik et al., 2009]. In addition, hydrodynamic processes, such as geostrophic circulation, non-linear internal waves, seiches, and seiche-induced convection in upper sediments, can have a significant impact on the rate of oxygen reduction [Mackenthun & Stefan, 1998; Baehr & DeGrandpre, 2002; Lorke et al., 2003; Bernhardt et al., 2014].

To date, the seasonal oxygen regime of the shallow boreal lakes is described in general [Golosov et al., 2007, 2012; Terzhevik et al., 2009, 2010; Zdorovennov et al., 2011]; however, many aspects of its dynamics at a finer scale remain poorly understood.

The aim of the current study is to investigate the thermal and oxygen seasonal dynamics of a shallow boreal lake from the standpoint of the development of favourable conditions for the accumulation and release of greenhouse gases, including anoxia in near-bottom waters as a prerequisite.

MATERIALS AND METHODS

A small mesotrophic Lake Vendyurskoe (southern part of Karelia, Russia, 62°10’N, 33°10’E) was chosen as the object of our study. It is a shallow polymictic lake (surface area 10.4 km^2, volume $54.8 \cdot 10^6$ m^3, maximal and mean depths 13.4 and 5.3 m, respectively) (Fig. 1), a typical representative of the lakes of water-glacial origin widespread in North-Western Russia and Fennoscandia [Terzhevik et al., 2010]. Lake Vendyurskoe is a popular site for fishing used for fish farming and recreational purposes.

The climate of the study area can be characterized as temperate continental with some marine features. Winters are long and relatively mild, and summers are short and cool. The weather during the year is highly variable due to the frequent cyclones approaching the area from the west. Cloudy weather occurs on more than half of the days each year. In winter, thawing often occurs, and in spring and sometimes in early summer, short frosty periods are normal.

Previous studies of the oxygen regime of the lake were carried out in 2000-2006 based on the field measurements of DO content made in the vertical sounding regime at 22 stations in April and October. Estimates of winter DO consumption rate were obtained [Terzhevik et al., 2009, 2010]. However, such sporadic surveys could not describe the annual course of DO dynamics.

The year-round measurements with 1-min intervals during 2007–2013 allowed filling this gap. We measured the water temperature and DO content within the water column using chains equipped with sensors TR-1060 (range –5…+35 °C, accuracy ± 0.002 °C, resolution < 0.00005 °C) and DO-1050 (range 0–150 %, accuracy ±1 %FS) (RBR Ltd., Canada), which were spaced on a rope at the intervals of 0.5–1 m, the top sensor being located at the depth of 2.5 m. The rope was stretched between the anchor and the buoy.

RESULTS AND DISCUSSION

The seasonal dynamics of the thermal regime of Lake Vendyurskoe included spring and

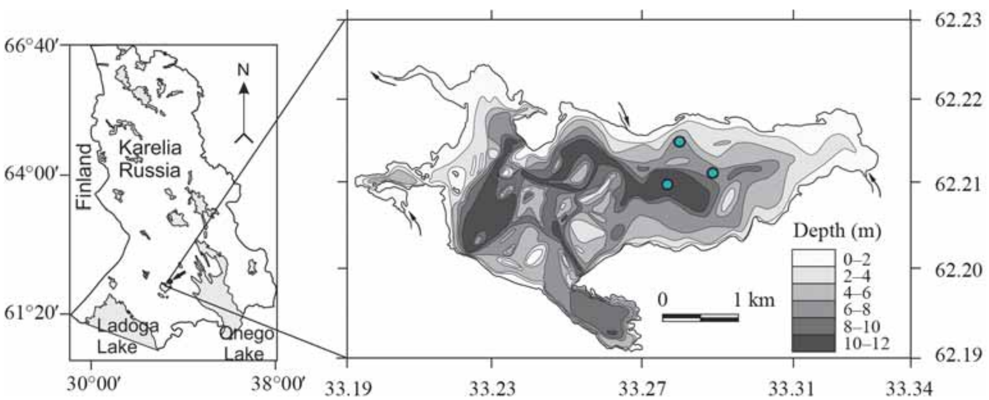

Fig. 1. Scheme of Lake Vendyurskoe with the location of the measurement sites (circles).

summer heating (2.5–3.5 months), autumn cooling (3–4.5 months), winter heating (5–6 months) and spring under-ice convection (one month). The water column was inversely stratified during winter with temperature and density increasing with depth, it was homothermal after the ice breakup and during autumn cooling, and it was unstable or had a mild thermal stratification during summer heating.

Ice season. The period started in mid-November to early December and ended in the first half of May, thus lasting five to six months [Zdorovennov et al., 2013]. The bottom water temperature in the central part of the lake rose to 4.5–5.5 °C by the end of winter [Zdorovennov et al., 2011] due to the heat exchange with bottom sediments and redistribution of heat [Malm, 1998; Palshin et al., 2009]. The reduction of the DO concentration throughout the water column started in the first days of the ice season. The oxygen deficit appeared in the bottom layers of the central basin during the first month. The thickness of the anaerobic zone gradually increased and reached one meter by the end of winter. Maximal thickness of the anaerobic zone was observed in years with early start of the ice-covered period (winters of 2007–2008 and 2010–2011). The data of our field measurements confirmed the results of the numerical modeling [Golosov et al., 2007; Terzhevik et al., 2009]: colder autumns and earlier dates of freeze-up contribute to the earlier formation of the anaerobic zone and an increase in its thickness. Warmer autumns and later dates of freeze-up contribute to the favorable oxygen regime in the lake: anaerobic conditions appear much later, if any, and the thickness of the anaerobic zone is significantly reduced.

Estimates of the total rate of DO consumption γ for the winter seasons of 2007–2013 were calculated in accordance with the approach outlined in [Terzhevik et al., 2010]:

$$\frac{\partial C}{\partial t} = -\gamma C,$$

where C is DO concentration, γ is the total rate of oxygen consumption; $[\gamma] = s^{-1}$, t time. This equation has an analytical solution:

$$C_t = C_0 e^{-\gamma t},$$

where C_0 is the initial DO concentration at the very beginning of the ice season.

Evolution of relation C_t/C_0 shows that DO concentration in the lake decreased by more than one-third during the winter, compared with the initial value (Fig. 2A). The reduction of oxygen concentration lasted from 140 to 170 days every winter. The maximal values of the total rate of oxygen consumption γ reached $0.5–1.5 \cdot 10^{-7}$ s^{-1} in the first week of ice period and then rapidly dropped, not exceeding $0.5 \cdot 10^{-8}$ s^{-1} from the third month until the end of winter (Fig. 2B). The greatest variation in the range of γ was observed in the first month of ice period, while later the rate of oxygen consumption became comparable across different years. As shown previously [Golosov et al., 2007, 2012; Terzhevik et al., 2009, 2010], the rate of oxygen consumption is determined by several factors, i.e. (1) the initial freezing temperature of the lake, (2) the magnitude of the heat flux from the sediments and (3) the amount of the organic matter accumulated in waters of the lake. Our estimates of γ for winters of 2007–2013 are in a good agreement with the estimates done for the winter seasons of 2001–2002 and 2003–2006 [Terzhevik et al., 2010].

Thus, anaerobic conditions may exist in the bottom layers of Lake Vendyurskoe for four-five months of each winter, and the probability of a significant accumulation of greenhouse gases in the bottom layers of the lake at the end of winter is high. A decrease of the ice-covered period leads to the less pronounced deficiency of oxygen in the bottom layers of lakes and a reduced risk of large greenhouse gases emissions after the ice breakup.

Ice breakup lasts for several days accompanied with a complete mixing of the water column and vertical uniform distribution of the water

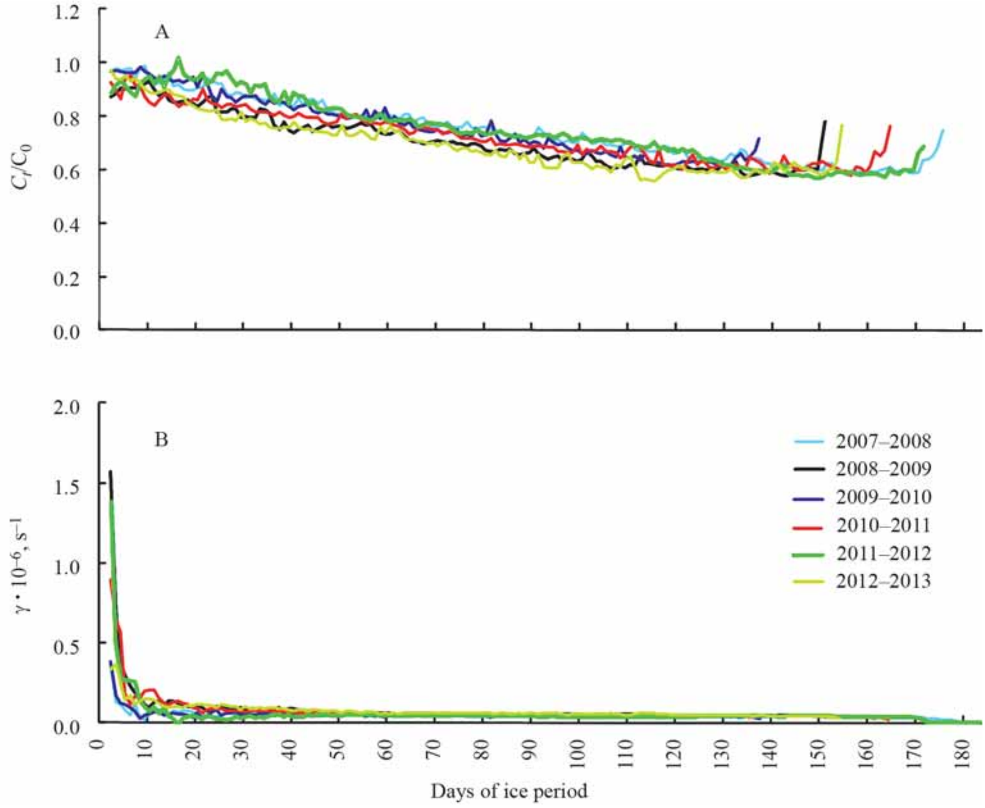

Fig. 2. Evolution of relation C_t/C_0 (A) and γ (B) during the ice season.

temperature and dissolved oxygen content [Gavrilenko et al., 2014]. The near-bottom anaerobic zone usually disappears after the ice breakup; at this moment, a substantial release of greenhouse gases into the atmosphere may occur.

Measurements carried out in small and medium-size boreal lakes show that concentration of greenhouse gases changes significantly during the ice-covered period. Greenhouse gas concentrations change little in the under-ice layer, while in the bottom layers there is rapid growth at the beginning of winter, taking place against the backdrop of a sharp reduction of oxygen [Denfeld et al., 2015]. The sharp increase of greenhouse gases concentration in the surface layer of small boreal lakes in late winter during ice and snow melting may occur due to inputs from the catchment area [Denfeld et al., 2015], and from the bottom layers involved into convective mixing [Huotari et al., 2009; Baehr & DeGrandpre, 2004; Miettinen et al., 2015]. The spring peak in greenhouse gas emissions can reach 30 % of the total annual emissions [Miettinen et al., 2015], but in most cases the autumn peak prevails [Huotari et al., 2011].

Summer heating. After ice breakup, the surface temperature increased due to radiation heating. The concentration of DO increased to 10–11.5 mg·l^{-1} (saturation of 80–90 %) during the first week of open water. The weather in the study area is usually unstable in May and June, and thermal stratification of Lake Vendyurskoe is slight or moderate. The thermocline was observed only in mid-May 2010 following a long period of hot windless weather. The oxygen regime was usually favorable in May and early June as the water column was periodically mixed and phytoplankton bloomed. The saturation of dissolved oxygen in the daytime in the upper layer of the water column often exceeded 100 % (103–106 % – 23–30 May 2009, 105–113 % – 15–22 May 2010) [Gavrilenko et al., 2014]. However, the total oxygen content decreased within the water column along the amplification of thermal stratification due to the increased biochemical oxygen demand and reduced photosynthesis.

The water temperature rose during July [Efremova et al., 2015]. Observational data for six years (2007–2013) show that the DO concentration decreased to 8–9 mg·l^{-1} (80–100 % saturation) in the surface layer with the water temperature increasing to 15–20 °C. With the water temperature above 20 °C, the oxygen concentration dropped to 6–7 mg·l^{-1} (70–80 % saturation).

Weather has a decisive influence on the oxygen regime of the lake in summer. Weak stratification or homothermia was observed in July of 2007–2009 and 2012 due to frequent cyclones. For example, the water column was completely mixed at least five times during May–July 2012. Under those conditions, the oxygen regime of the lake was favorable. A decrease of the oxygen content in the bottom layers of deeper locations was less pronounced than in other years of research

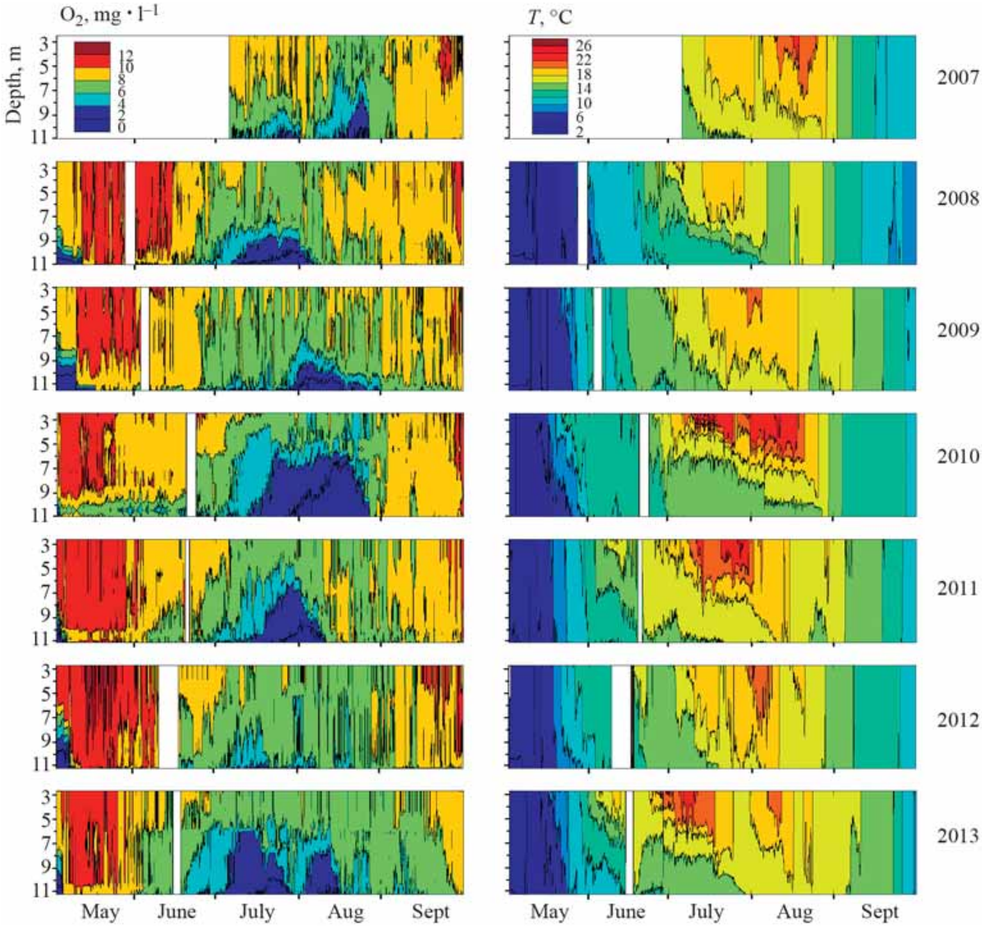

Fig. 3. Seasonal dynamics of DO concentration (left panels) and water temperature (right panels) in the deep-water central part of Lake Vendyurskoe in May-September of 2007–2013.

(Fig. 3). The thickness of the anaerobic zone did not exceed one meter, and its lifespan was not more than two-three weeks. A danger of the accumulation of greenhouse gases was minimal.

In contrast, a pronounced thermal stratification occurred during a period of hot windless weather in July and early August of 2010, 2011 and 2013 (Fig. 3).

The most dramatic situation was observed in the summer of 2010 as a result of the stationary anticyclone which blocked the western transfer of air masses [Trenberth & Fasullo, 2012]: the average monthly temperature in July 2010 at the meteorological station Petrozavodsk was 22.3 °C, which exceeded the average value (16.5 °C) for the period of 1953–2011 by 3.1 standard deviations, and was higher than the basic norm (1961–1990) by 6.2 °C [Efremova et al., 2015]. A sharp thermocline was developed in Lake Vendyurskoe: the temperature gradient reached 5 $°C \cdot m^{-1}$at depth of 3–5 m in the middle of July 2010; by mid-August, it was 3–4 $°C \cdot m^{-1}$ and dropped to the depths of 5–7 m. The thermocline prevented aeration of the bottom layers of the water column, so the oxygen conditions were much worse. The concentration of DO did not exceed 4 $mg \cdot l^{-1}$ at depth of 6 m and sharply decreased to values close to zero at depth greater than 7–8 m from the end of July to mid-August. The thickness of the anaerobic zone reached 3–4 m from August 1 to August 20, 2010. The data for 2011 and 2013 have also shown that anaerobic conditions quickly develop in bottom layers of the lake on the background of hot windless weather, creating a base for the accumulation of greenhouse gases.

Numerous measurements on boreal lakes show that during the summer stratification, oxygen deficiency develops and accumulation of greenhouse gases occurs in the bottom layers [Huotari et al., 2009; Kankaala et al., 2013]. Wind and cooling moderate the gas transfer to the air-water interface [Heiskanen et al., 2014].

Autumn cooling. The surface temperature (20–25 °C) and heat content of the water column reached its annual maximum during the last ten days of July and the first part of August, 2007–2013. Autumn cooling starts when the heat loss prevails. Wind convection leads to deepening and destruction of the seasonal thermocline. At this point, the benthic anaerobic zone is destroyed, and a large greenhouse gas emission is possible. As shown by Lohila et al [2015], a significant CO_2 peak was observed at the stage of the autumn cooling after complete mixing of Lake Pallasjärvi. Mixing promotes the uniform temperature and oxygen distribution in the water column. At the stage of the autumn cooling the lake is nearly homothermal; the water temperature gradually decreases, and the oxygen content increases with the growth of its solubility. At this stage, the oxygen saturation occurs at the bottom layers, and there is no risk of the accumulation of greenhouse gases.

CONCLUSIONS

Throughout the year, the ice season and long periods of warm windless weather during summer are potentially dangerous in terms of the accumulation of greenhouse gases. The greatest risk of greenhouse gas emissions exists for several days after the ice breakup and at the time of the erosion of the seasonal thermocline at the end of the summer. The observational data suggest that oxygen consumption is much faster in summer than in winter. This is evidenced by a more rapid increase in the thickness of the anaerobic zone in the bottom layers: just one month of summer thermal stratification leads to anaerobic zone thickness greater than three meters, while the five months of winter stagnation translate into the one-meter anaerobic zone. Consequently, the risk of accumulation of the large amounts of greenhouse gases in summer is also pronounced, even when the periods of hot windless weather are short. At the same time, cold summers are favorable for the oxygen saturation of the water column and do not present a risk in terms of the accumulation of greenhouse gases in the lake.

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REFERENCES

1. Baehr, M.M., DeGrandpre, M.D. (2002) Under-ice CO_2 and O_2 variability in a freshwater lake. Biogeochemistry, V. 61, pp. 95–113.

2. Baehr, M.M., DeGrandpre, M.D. (2004) In situ pCO_2 and O_2 measurements in a lake during turnover and stratification: observations and modeling. Limnol. Oceanogr., N 49, pp. 330–340.

3. Barica, J., Mathias, J.A. (1979) Oxygen depletion and winterkill risk in small prairie lakes under extended ice cover. J. Fish. Res. Board Can., N 36, pp. 980–986.

4. Bernhardt, J., Kirillin, G., Hupfer, M. (2014) Periodic convection within littoral lake sediments on the background of seiche-driven oxygen fluctuations. Limnology and Oceanography: Fluids and Environment, N 4, pp. 17–33.

5. Boylen, C., Brock, T. (1973) Bacterial decomposition processes in Lake Wingra sediments during winter. Limnol. Oceanogr., N 4 (18), pp. 628–634.

6. Brekhovskih V.F. (1988) Gidrofizicheskie faktory formirovaniya kislorodnogo rezhima vodoemov [Hydrophysical factors of water bodies oxygen regime formation]. Moscow: Nauka, 166 p. [in Russian].

7. Denfeld, B.A., Wallin, M.B., Sahlée, E., Sobek, S., Kokic, J., Chmiel, H.E., Weyhenmeyer, G.A. (2015) Temporal and spatial carbon dioxide concentration patterns in a small boreal lake in relation to ice-cover dynamics. Boreal Env. Res., N 20 (6), pp. 679–692.

8. Efremova, T.V, Palshin, N.I., Zdorovennova, G.E., Terzhevik, A.Yu. (2015) Effect of extreme hot summer of 2010 on the water temperature and oxygen distribution in Karelian lakes. Meteorology and Hydrology, N 9 (40), pp. 67–76.

9. Gavrilenko, G., Zdorovennova, G., Zdorovennov, R. (2014) Termicheskij i kislorodnyj rezhimy melkovodnogo ozera posle vzloma l'da [Thermal and oxygen regimes of shallow lake after breaking the ice]. In: Geography: traditions and innovations in science and education. SPb.: Herzen State Pedagogical University, Publishing, pp. 142–144. [in Russian].

10. Golosov, S., Maher, O.A., Schipunova, E., Terzhevik, A., Zdorovennova, G., Kirillin, G. (2007) Physical background of the development of oxygen depletion in ice-covered lakes. Oecologia, N 151 (2), pp. 331–340.

11. Golosov, S., Terzhevik, A., Zverev, I., Kirillin, G., Engelhardt, C. (2012) Climate change impact on thermal and oxygen regime of shallow lakes. Tellus A, N 64, 17264.

12. Greenbank, J. (1945) Limnological conditions in ice-covered lakes, especially as related to winter-kill of fish. Ecological Monographs, N 4 (15), pp. 343–392.

13. Hargrave, B. (1972) A comparison of sediment oxygen uptake, hypolimnetic oxygen deficit and primary production in Lake Esrom, Denmark. Vehr. Int. Ver. Limnol., N 18, pp. 134–139.

14. Heiskanen, J.J., Mammarella, I., Haapanala, S., Pumpanen, J., Vesala, T., MacIntyre, S., Ojala, A. (2014) Effect of cooling and internal wave motions on gas transfer coefficients in a boreal lake. Tellus B, 66, 22827, http://dx.doi.org/10.3402/tellusb.v66.22827.

15. Huotari, J., Ojala, A., Peltomaa, E., Pumpanen, J., Hari, P., Vesala, T. (2009) Temporal variations in surface water CO_2 concentration in a boreal humic lake based on highfrequency measurements. Boreal Env. Res., N 14 (Suppl. A), pp. 48–60.

16. Huotari, J., Ojala, A., Peltomaa, E., Nordbo, A, Launiainen, S., Pumpanen, J., Rasilo, T., Hari, P., Vesala, T. (2011) Longterm direct CO_2 measurements over a boral lake: five years of eddy covariance data. Geophys. Res. Lett. 38: L18401, doi: 10.1029/2011GL048753.

17. Kankaala, P., Huotari, J., Tulonen, T., Ojala, A. (2013) Lake-size dependent physical forcing drives carbon dioxide and methane effluxes from lakes in a boreal landscape. Linmol. Oceanogr. N 58 (6), pp. 1915–1930.

18. Lohila, A., Tuovinen, J.-P., Hatakka, J., Aurela, M., Vuorenmaa, J., Haakana, M., Laurila, T. (2015) Carbon dioxide and energy fluxes over a northern boreal lake. Boreal Env. Res., 20, pp. 474–488.

19. Lorke, A., Muller, B., Maerki, M., Wuest, A. (2003) Breathing sediments: The control of diffusive transport across the sediment-water interface by periodic boundary-layer turbulence. Limnol. Oceanogr., N 48 (6), pp. 2077–2085.

20. Mackenthun, A.A., Stefan, H.G. (1998) Effect of flow velocity on sediment oxygen demand: Experiments. J. Environ. Eng., N 124, pp. 222–230.

21. Malm, J. (1998) Bottom buoyancy layer in an ice-covered lake. Water Resources Research, 34 (11), pp. 2981–2993.

22. Mathias, J., Barica, J. (1980) Factors controlling oxygen depletion in ice-covered lakes. Can. J. Fish. Aquat. Sci., N 37, pp. 185–194.

23. McGinnis, D.F., Kirillin, G., Tang, K.W., Flury, S., Bodmer, P., Engelhardt, C., Casper, P., Grossart H.-P. (2015) Enhancing Surface Methane Fluxes from an Oligotrophic Lake: Exploring the Microbubble Hypothesis. Environmental Science & Technology, N 49 (2), pp. 873–880.

24. Miettinen, H., Pumpanen, J., Heiskanen, J.J., Aaltonen, H., Mammarella, I., Ojala, A., Levula, J., Rantakari, M. (2015) Towards a more comprehensive understanding of lacustrine

greenhouse gas dynamics – two-year measurements of concentrations and fluxes of CO_2, CH_4 and N_2O in a typical boreal lake surrounded by managed forests. Boreal Env. Res. 20 (1): 75–89.

25. Palshin, N.I., Efremova, T.V., Zdorovennov, R.E., Zdorovennova, G.E. (2009) Perenos tepla v malom ozere v period ledostava [Heat transfer in a small lake during ice-covered period]. Proceedings of the VII Conference of "Dynamic and thermal regime of rivers, reservoirs and coastal seas" Moscow: People's Friendship University, pp. 200–207. [in Russian].

26. Terzhevik, A., Golosov, S., Palshin, N., Mitrokhov, A., Zdorovennov, R., Zdorovennova, G., Kirillin, G., Shipunova, E, Zverev, I. (2009) Some features of the thermal and dissolved oxygen structure in boreal, shallow ice-covered Lake Vendyurskoe, Russia. Aquatic Ecology, N 43 (3), pp. 617–627.

27. Terzhevik, A.Y., Palshin, N.I., Zdorovennov, R.E., Zdorovennova, G.E., Mitrokhov, A.V., Potakhin, M.S., Golosov, S.D., Shipunova, E.A., Zverev, I.S. (2010) Hydrophysical aspects of oxygen regime formation in a shallow ice-covered lake. Water Resources, N 37 (5), pp. 662–673.

28. Trenberth, K.E., Fasullo, J.T. (2012) Climate extremes and climate change: The Russian heat wave and other climate extremes of 2010. J. Geophys. Res, V. 117, pp. 1–12, D17103, doi:10.1029/2012JD018020.

29. Zdorovennov, R.E., Zdorovennova, G.E., Palshin N.I., Terzhevik A.Yu. (2011) Izmenchivost' termicheskogo i kislorodnogo rezhimov melkovodnogo ozera zimoj [Variation of the temperature and oxygen regimes of a shallow lake in winter]. Transactions of Karelian Research Centre of Russian Academy of Science, N 4, Northern Water Problems, pp. 57–63. [in Russian].

30. Zdorovennov, R., Palshin, N., Zdorovennova, G., Efremova, T., Terzhevik, A. (2013) Interannual variability of ice and snow cover of a small shallow lake. Estonian Journal of Earth Sciences, N 61 (1), pp. 26–32.

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