Short communication

ISSN 2658-3518

LIMNOLOGY FRESHWATER BIOLOGY

www.limnolfwbiol.com

Seasonal sedimentation in saline Lake Shira (Siberia, Russia) and meromixis: implications for regional paleoclimate reconstructions

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ABSTRACT. Detailed studies of processes of sediment record formation are necessary for accurate sediment-derived paleo-environmental reconstructions. We conducted the multi-year seasonal sediment evolution of sediment fluxes of chemical elements, organic and inorganic carbon, total nitrogen, and photosynthetic pigments for a period from 2012 to 2017. In 2013, 2016, 2017, and 2018, we estimated the contents of photosynthetic pigments in the uppermost sediment layers frozen in situ with a freeze-corer. In 2015 and 2016, a rare event of transition from meromixis (i.e. long-term hypolimnetic anoxia) to holomixis was observed, which was accompanied by the temporary disappearance of hydrogen sulfide from the water column in spring and a decrease in hydrogen sulfide in other seasons compared to the meromictic state. We have demonstrated that okenone and Mo in the Lake Shira sediments reflect the presence of hydrogen sulfide in the water column. However, the okenone showed smoothened multi-year dynamics without a pronounced seasonal one. Therefore, the okenone can be a proxy of sulphidic conditions in photic zone and weakly depend on seasons whereas Mo can be used as an indicator of winter periods when analyzed in cores with annual resolution. Sedimentation fluxes of other substances showed typical seasonal dynamics with a minimum in winter and a maximum in late summer and autumn. All chemical elements in the sedimentation flow can be roughly divided into those associated with organic matter and terrigenous-chemogenous. The components of the second group showed a pronounced peak of sedimentation in autumn 2012 and summer 2017 presumably due to the increased amount of precipitation at that time. This demonstrates the relationship between the terrigenous components and the climate humidity for this lake. Besides, it reflects the irregularity of annual varves composition.

Keywords: meromictic lake, sediment traps, stratification, okenone, molybdenum, XRF analysis, holomixis, climate change

1. Introduction

Accurate lake sediment-derived palaeo-environmental reconstructions require in-depth knowledge of sediment record formation processes. This might be achieved only by a combination of comprehensive monitoring and sediment trap study (Apolinarska et al., 2020). Since the change in mixing regime results in the changes of the sediments composition, the alterations between meromixis and holomixis can be reconstructed for the long period of a lake history (Vegas-Vilarrúbia et al., 2018). However indisputable sediment proxies of hypolimnetic anoxia and meromictic conditions are still scarce (Sorrel et al., 2021).

2. Materials and methods

Lake Shira (N 54.30, E 90.11) is located in south of Siberia, in the North-Minusinsk Valley Lake Shira has an elliptical shape, the size of 9.35 × 5.3 km, the water surface area of 35.9 km2, the average depth of 11.2 m, and the maximum depth of 24.5 m (2007-2019). The sediment traps were deployed seasonally from 2012 to 2017 in the central deepest part of the lake at the depth of 20 m. The samples of the uppermost

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Received: May 30, 2022; ***Accepted:*** August 08, 2022;
Available online: September 02, 2022

undisturbed sediments were retrieved using a pump freeze-corer made in the workshop of the Institute of Biophysics (Krasnoyarsk, Russia) after Renberg and Hansson (1993). Freeze-coring was carried out in March 2013, 2016, and 2017 and February 2018 from the ice surface. The carotenoids in the traps and sediments were determined by high-performance liquid chromatography (HPLC). Total carbon and total nitrogen were determined using FlashEA 1112 NC Soil/MAS 200 CN elemental analyzer (ThermoQuest, Italy). The elemental composition was measured in solid blocks of sediment material using micro-XRF analysis by Synchrotron radiation (scan XRF SR) in the Institute of Nuclear Physics (Novosibirsk, Russia) (Kalugin et al., 2013).

3. Results and discussion

During 2012-2014, the lake was meromictic and winter mixing did not reach the bottom. In the spring of 2015, the water column was mixed and reached the bottom, and hydrogen sulfide disappeared completely of the water column but reappeared there in summer. In May 2016, the almost complete mixing was observed again. Thus, during 2015-2016, the lake was holomictic. However, in 2017, the spring mixing did not reach the bottom, so the lake became meromictic again and remained meromictic during 2018 – 2022. The sulfide content in the water column was relatively high in 2012-2014 compared to 2015-2016, when other increasing occurred in 2017. Therefore, the sulfide content reflected the changes of the lake mixing regime.

Principal component analysis showed that the main differences in contents of the traps were associated with the season. Nitrogen, organic components (carotenoids, Chl-*a* and organic carbon), Br, Cu, As, S, Cl, and Zn constitute one large group, whereas other large group consisted of Cr, Pb, Ca, Ni, Zr, Rb, Nb, Ga, Y, Sr, Th, V, K, Ti, Mn, Fe, and inorganic carbon. Molybdenum was a single component that was clearly confined to the winters, while Bchl- *a* and okenone were merged into a separate group. These are specific pigments of purple sulfur bacteria (PSB), so their dynamics reflected the dynamics of PSB described elsewhere (Rogozin et al., 2017). The content of these pigments in the traps was the greatest in 2012 and decreased throughout the entire study period. Organic carbon, Chl-*a*, and carotenoids of oxygen photosynthetic organisms (lutein + zeaxanthin, alloxanthin, beta-carotene) in the traps demonstrated regular seasonal fluctuations - minima in winter and spring and a noticeable increase in summer and autumn. In contrast, neither okenone nor Bchl-*a* demonstrated seasonal dynamics.

In frozen recent sediments, a steady downward trend in the annual okenone content was similarly observed with traps. In contrast, the contents of Chl-*a* and other carotenoids increased slightly from 2016 to 2018. The use of the freeze-corer allowed us to see the structure of the recent sediments changed from laminated to homogeneous after 2013. We assume the decrease in monimolimnetic stability enhanced the movement of bottom water and, hence, led to resuspension of the uppermost sediments. The color transitions in the traps corresponded generally to the typical alternation of light and dark layers described for other lakes. However, using sediment traps, we revealed a violation of the typical alternation of colors: in 2012, the color of the sediment in the autumn trap was light, while in the autumn periods of other years it was dark. The light color in autumn 2012 coincided with a higher content of inorganic carbon and all terrigenous components. Presumably the large amount of terrigenous matter was carried into the lake after abnormally high precipitation in August 2012. Thus, we demonstrate that weather anomalies can cause irregularities in the formation of annual varves.

4. Conclusions

In general, we did not reveal any noticeable differences between the meromictic and holomictic states in the composition of sediments, except okenone. We demonstrated okenone and Mo reflect the presence of hydrogen sulfide in the water column in Lake Shira sediments. However, okenone showed smoothened multi-year dynamics and no distinct seasonal dynamics. Therefore, okenone can be a proxy of sulfidic conditions in the photic zone and is seasonally invariable whereas Mo can be used as an indicator of winter periods when analyzed in cores with annual resolution. The obtained results will be useful for down-core analysis of the bottom sediments aimed to reconstructing the stratification regimes of Lake Shira and climate changes in the south Siberia.

Acknowledgements

This work was supported by the Russian Science Foundation (grant No. 22-17-00185 https://rscf.ru/en/project/22-17-00185/).

Conflict of interest

The authors declare no conflict of interest.

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