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Results of long-term measurements of particulate matter in Lake Baikal

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ABSTRACT. For the first time, data on average annual particle fluxes in Lake Baikal from the past 22 years are presented. Sampling was carried out using sediment traps, which were installed at a mooring in the deep part of the Southern Basin of the lake (depth 1366 m) from March 1999 to March 2021. The total annual fluxes of sedimentary material during this period varied from 11.5 g $m^{-2} y^{-1}$ to 208 g $m^{-2} y^{-1}$. The peaks of fluxes correspond to the years of massive blooms of diatoms. Average total annual fluxes generally increase in the second half of the study period (since 2010), simultaneously with a change of the dominant diatom genera. We assume that the recent climate warming is responsible for these developments.

Keywords: Lake Baikal, sediment traps, particulate matter, average total fluxes of particles, diatoms, climate warming, terrigenous material

1. Introduction

Over the last decades, significant climate changes have been recorded, which have a sincere impact on the environment of our planet.

The aim of this research is to study the variability of vertical fluxes and material composition of particles in Lake Baikal, using data of sediment trap measurements. Such a study is important for an understanding of processes of recent sedimentation under conditions of climate change.

2. Materials and methods

During 22 years from March 1999 to March 2021, the collection and analysis of sedimentary matter from different depths of the water column of the Southern Baikal was performed. The work was carried out near the Baikal Neutrino Telescope observatory (51°46.076' N 104°24948' E) at a water depth of 1366 m by using a mooring with integrating cylindrical sediment traps (Vologina and Sturm, 2017). Details of the exposure data are given in Table. The sampled material was freeze-dried on an FD ALPHA instrument and weighed on an analytical balance OHAUS Pioneer. The total annual fluxes of particulate matter (TAF) were calculated in grams per square meter per year (g $m^{-2} y^{-1}$). The qualitative composition of the sedimentary matter was determined in smear slides under a SK14 light microscope (PZO WARSZAWA, Poland) with a magnification of 100x and 400x. Preliminary data have been published in (Sturm et al., 2015).

3. Results and discussion

The description of smear slides indicates that the collected material contains biogenic and terrigenic particles. The biogenic part consists mainly of valves of diatom species of the genera *Aulacoseira*, *Synedra*, *Cyclotella* and amphipods (*Gammarus* genus). Additionally sponge spicules are also observed. Allochthonous biogenic material is represented by pollen particles. The terrigenous material consists mainly of mineral particles of clay size with a little content of silt.

TAF varied significantly during the observation period from 11.5 g $m^{-2} y^{-1}$ (2006) to 208 g $m^{-2} y^{-1}$ (2014), with an average value of 89.6 g $m^{-2} y^{-1}$ (Fig.). Average TAF values from March 1999 to March 2010 amount 75.1 g $m^{-2} y^{-1}$, and from March 2010 to March 2021 104 g $m^{-2} y^{-1}$. Thus, the total amount of sedimentary matter that entered Baikal over the past 11 years has distinctly increased. It should be noted that values of the lowest traps (about 15 m above the lake floor) were not taken into account in the weight calculations, in order to exclude effects of sediment resuspension at the water/sediment interface, which took place in almost every year. For example, in 2004 TAF was 79.8 g $m^{-2} y^{-1}$ at a

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Table. Details of the exposure of integrating sediment traps in Southern Baikal between 1999 and 2020.

Years	Dates	Exposure, days	Number of traps	Water depth, m
1999	11.03.1999–06.03.2000	361	15	100–1362
2000	09.03.2000–08.03.2001	364	15	100–1362
2001	09.03.2001–07.03.2002	363	14	100–1350
2002	08.03.2002–09.03.2003	366	14	100–1350
2003	11.03.2003–08.03.2004	363	14	100–1350
2004	11.03.2004–07.03.2005	361	18	50–1350
2005	08.03.2005–06.03.2006	363	18	50–1350
2006	12.03.2006-07.03.2007	360	18	50–1350
2007	11.03.2007-05.03.2008	360	18	30–1350
2008	09.03.2008-05.03.2009	361	18	30–1350
2009	08.03.2009-05.03.2010	361	17	50–1350
2010	14.03.2010–07.03.2011	358	10	100–1350
2011	09.03.2011–09.03.2012	366	10	100–1350
2012	11.03.2012–09.03.2013	363	10	100–1350
2013	10.03.2013–09.03.2014	364	10	100–1350
2014	11.03.2014–15.03.2015	369	10	100–1350
2015	07.03.2015–05.03.2016	364	10	100–1350
2016	07.03.2016–07.03.2017	365	10	107–1359
2017	08.03.2017–06.03.2018	363	10	100–1363
2018	08.03.2018–05.03.2019	362	10	100–1363
2019	06.03.2019–04.03.2020	364	10	100–1363
2020	06.03.2020–17.03.2021	376	10	100–1363

depth of 1350 m, while at depths from 50 to 1200 m this value did not exceed 44.6 g m^{-2} y^{-1}. Obviously, the high TAF values were associated with the resuspension of bottom sediments by currents and the activities of aquatic organisms.

Peaks of TAF were observed in 2000, 2002, 2007, 2010, 2012, 2014, 2017 and 2020 (Fig.) and correspond to years mass blooms of diatoms. Diatoms of the genus *Aulacoseira* dominated in the sedimentary material sampled in 2000. *Aulacoseira* together with *Synedra* dominated in 2002 and 2007. Then, starting from 2010, species of the genus *Synedra* were the predominant diatoms (peaks recorded in 2010, 2012, 2014, 2017 and 2020; Fig.).

It is known that the abundance and biomass of diatoms vary in different years and seasons (Votintsev et al., 1975; Popovskaya, 1977; 2000; Jewson and Granin, 2014). This explains the significant fluctuations in TAF over the past 22 years. The literature describes the so-called “*Melosira* years”, when there was a significant increase in the bloom of species of the genus *Melosira* (now renamed as the genus *Aulacoseira*) (Kozhova, 1961; Kozhov, 1962; Antipova, 1963; Evstafyev et al., 2010). According to published data, 2000 was a “*Melosira* year” (Evstafyev et al., 2010; Jewson and Granin, 2014). This phenomenon was also recorded by us in the study of sedimentary matter taken by sediment traps from March 2000 to March 2001 (Vologina and

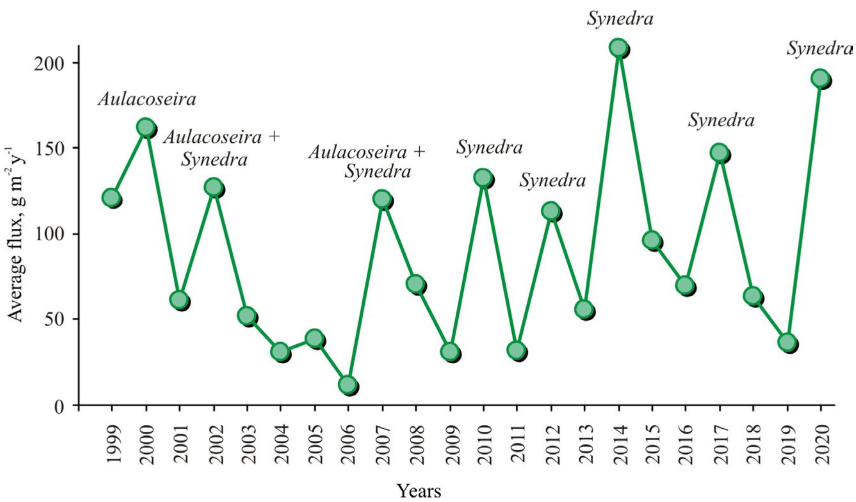

Fig. Total annual fluxes (g m^{-2} y^{-1}) in Southern Baikal between March 1999 and March 2021. Predominant genera of diatoms are indicated.

Sturm, 2017). *Aulacoseira* was the predominant diatom genus in 2000. In 2002 and 2007 *Aulacoseira* and *Synedra* were the two main genera. The composition of diatoms in 2010, 2012, 2014, 2017 and 2020 was dominated by *Synedra* (Fig.). This period (2010–2021) was also associated with increased average TAF values.

It is noteworthy that species of the genus *Aulacoseira* are cold-loving diatoms (Votintsev et al., 1975; Chernyaeva et al., 2008). The dominance of the genus *Synedra*, observed in recent years, both in the water column and in the surface bottom sediments of Southern Baikal (Roberts et al., 2018; Vologina et al., 2019; Bondarenko et al., 2020; Vologina et al., 2020) is probably associated with climate warming. This is also revealed by an increased pelagic eutrophication of Southern Baikal (Izmest'eva et al., 2016). This conclusion is indirectly confirmed by results of the BDP-96 drill core from underwater Akademichesky Ridge of Lake Baikal, where the abundance peaks of *Synedra* are associated with warm isotopic stages (Khursevich et al., 2001).

4. Conclusions

Monitoring of vertical particle fluxes carried out over the past 22 years using sediment traps in South Baikal allows us to reach the following main conclusions. The total annual flux of particulate material that settled on the lake floor of Baikal varied significantly during the study period. Maximum TAF values occur in years with massive diatom blooms. Between 1999-2021 a change in the dominant species of diatom genera has been observed: *Aulacoseira* prevailed in 2000; *Aulacoseira* together with *Synedra* in 2002 and 2007; *Synedra* dominated since 2010 (2010, 2012, 2014, 2017, 2020). Simultaneously, the average TAF has increased over the past 11 years. This and the decrease of cold-adapted diatoms are believed to have been caused by climate warming during the last years.

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Conflict of interest

The authors declare no competing interest.

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