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Climatic factors as risks of recent ecological changes in the shallow zone of Lake Baikal

T.G. Potemkina *, V.L. Potemkin, A.P. Fedotov

Limnological Institute, Siberian Branch of the Russian Academy of Sciences, ul. Ulan-Batorskaya 3, Irkutsk, 664033, Russia

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Abstract

Eutrophication processes have been recorded in many world's freshwater reservoirs, which are sources of drinking water. More and more investigations show that global warming is the main natural factor that causes eutrophication. In recent years, signs of eutrophication have also been recorded in Lake Baikal containing 20% of the world's freshwater reserves. Therefore, we performed the first comprehensive analysis of long-term changes in climatic parameters capable to provoke negative changes in the shallow zone. The largest number of anomalies of climatic indices has been recorded in the 21st century. Moreover, the current decade has been the most favorable for the emergence of negative processes in the lake (outbreak of the mass growth of algae and aquatic vegetation, rotting of their remains at the bottom and on the shores of the lake, changes in the structure and zoning of biocoenoses, etc.). The main natural conditions favoring the emergence of negative signs are elevated temperatures of the air and lake shore water, reduced amount of precipitation, reduced inflow of river waters into Baikal and lowering of its water level, low-water season, and weakening of wind currents, water exchange processes, and, as a result, water self-purification. In the period of continuing global warming, it is necessary to study the climate effect on the processes in the shallow zone and to carry out long-term monitoring for elucidation of recent and expected changes in the ecological state of Lake Baikal and for their valid interpretation.

Keywords: global warming; climatic factors; eutrophication; Lake Baikal

Introduction

Baikal is the Earth's largest reservoir of high-quality fresh water. It contains about 20% of the world's freshwater reserves, which already run short. Since 1996, Baikal has been a natural UNESCO World Heritage Site. This means that protection of the lake waters from pollution and depletion and their rational use are a priority task for the Russian Federation, which is liable for the preservation of the Baikal nature to the world. At present, special attention is paid to the ecological state of the shallow zone of the lake. There are local negative ecological processes within it, such as outbreaks of the water bloom (rapid growth of cyanobacteria) and mass growth of filamentous algae (earlier scarce alga of the *Spirogyra* genus); intensive overgrowth of the shore shoals by algae and aquatic vegetation and clogging of the beaches by their remains washed ashore; appearance of an unpleasant odor because of the rotting of these remains; local accumulation of dead mollusks on the beaches; disease of the endemic Baikal sponge, a natural filter of the lake water; and fecal pollution of the shore waters (Belykh et al., 2015a,b; Itskovich et al., 2015; Kalyuzhnaya and Itskovich, 2015; Kravtsova et al., 2012, 2014; Timoshkin et al., 2015, 2016).

Outbreaks of the mass growth of cyanobacteria (blue-green algae) capable to produce life-threatening toxins and of filamentous algae, an increase in their productivity, a rapid overgrowth of the shore shoals, accumulation of algal and higher aquatic vegetation remains on the beaches, their rotting, and changes in the structure of biocoenoses are among the main generally recognized indicators of eutrophication of water reservoirs, which affect negatively the quality of water, the ecology of the aquatic ecosystem as a whole, water supply, recreation, etc. (Bondarenko and Logacheva, 2016; Hallegraeff, 1993; Izmest'eva et al., 2015; Kravtsova et al., 2014; Le et al., 2010; Schindler, 2006; Selezneva et al., 2014; Timoshkin et al., 2016; Zaitseva, 2014; Zilov, 2016). Under recent conditions of unstable climate and rapidly growing man-induced impact on the environment, more than 40% of the world's water reservoirs experience moderate or severe eutrophication (Xia et al., 2016). For example, intensive bloom of blue-green algae producing toxins is a threat to the world's

* Corresponding author.
E-mail address: tat_pot@lin.irk.ru (T.G. Potemkina)

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large water reservoirs being sources of drinking water (Fig. 1). These are lakes such as Zurich in Switzerland, Victoria in Africa, Erie and Okeechobee in the USA, Winnipeg in Canada, Taihu and Chaohu in China, Kinneret in Israel, Biwa and Kasumigaura in Japan, etc. Eutrophication in Lake Baikal (Fig. 1, Nos. 7–8) is of local character (Izmest'eva, 2015; Kravtsova et al., 2012, 2014; Zilov, 2016).

The lately dominated academic concept of eutrophication explained this process by man-induced pollution, mainly by the high contents of nitrogen and phosphorus in urban, agricultural, and industrial waste water entering water bodies (Kravtsova et al., 2012; Moss et al., 2011; Timoshkin et al., 2015; Whitehead et al., 2009). In recent years, however, more attention has been paid to the role of the climatic factor in the eutrophication of water bodies. Studies have shown that climate warming is the natural factor that can stimulate eutrophication in freshwater ecosystems (Bar-Yosef et al., 2010; Cohen et al., 2016; Moss et al., 2011; Paerl and Otten, 2013; Paerl and Paul, 2012; Posch et al., 2012; Qin et al., 2010; Selezneva et al., 2014; Zaitseva, 2014; Zhang et al., 2012). For example, in May–September 2010, the growth of blue-green algae in the Volga water reservoirs increased twice to nine times because of the anomalous natural conditions (high air and water temperatures, reduced amount of precipitation, low water level, windless weather, and weakening of water dynamics) as compared with the same season in 2009 (Selezneva et al., 2014). According to the World Meteorological Organization, 2010 was one of the hottest years ever recorded. In the same year, the total population of blue-green algae reached its maximum in the largest water reservoirs of Udmurtia (Izh and Votka ones) for the same reasons (Zaitseva, 2014). The increased outbreaks of cyanobacterial growth in European lakes are associated with a decrease in the temperature gradient between surface and bottom waters and a weakening of the spring mixing of water masses because of warmer winters. Cold winters and strong winds would prevent water bloom (Posch et al., 2012). In recent two decades, the active growth of cyanobacteria in Lake Taihu (China) has begun earlier and has lasted longer, with an increase in temperature and sunshine duration and a decrease in wind speed. Wind speed and sunshine duration are regarded as the climatic factors that make the greatest contribution (84.6%) to water bloom (Zhang et al., 2012). In lakes Zurich and Kinneret, outbreaks of the mass growth of cyanobacteria continue, despite the long-term improvements of waste treatment plants and the decrease in nutrients in waste water, which is associated with climatic changes (Bar-Yosef et al., 2010; Posch et al., 2012).

The effect of climate changes on the emergence of eutrophication in the Baikal shallow zone was not studied. There are only a few works partly or indirectly concerned with this issue. For example, the appearance of toxin-producing cyanobacteria in the shallow zone near Turka Village on Middle Baikal in August 2010 is explained by the increase in air temperature and the warming of shore waters, as well as man-induced impact (Belykh et al., 2015a,b). Structural changes in shore phytoplankton in some Baikal areas are evident of eutrophication of the shallow zone and are also associated with the climatic effect (Bondarenko and Logacheva, 2016). Analysis of the material collected throughout the Baikal water area for 1977–2003 showed changes caused by warming (increase in water surface temperature and water transparency, changes in biocoenosis structures), but there is no widespread eutrophication in the pelagic area of the lake (Izmest'eva et al., 2015). Zilov et al. (2016) generalized observation data on the state of plankton in a 800 m deep water column in South Baikal, located 2.7 km offshore, which have been obtained since 1945. They drew the conclusion about its stable state in general but noted some plankton structure trends. These trends are, most likely, due to either natural fluctuations or some long-term auto-oscillations in the lake ecosystem, or global climate changes. Another, less probable, cause is regional pollution (Zilov et al., 2016). Other researchers (Kravtsova et al., 2012; Timoshkin et al., 2015, 2016) associate the eutrophication (significant increase in benthos, abundance of algae, changes in biocoenosis zoning, etc.) in the local Baikal shallow zones with the discharge of poorly cleaned sewage into the lake. At the same time, the hydrochemical studies performed in recent years have not revealed significant changes in biogenic impact as compared with the 1950s and 1960s, except for the sites near human settlements, estuaries of some rivers, some bays and sors (Bondarenko and Logacheva, 2016; Sakirko et al., 2016; Tomberg et al., 2012).

Climate warming and its influence on the eutrophication of freshwater ecosystems occur all over the world. Signs of this process are also observed in Baikal. The goal of this work is to analyze the long-term changes in the most sensitive climatic parameters that can stimulate eutrophication in the Baikal shallow zone, taking into account the regional climate warming specifics. Such an analysis is important for future research, revealing of current and expected changes in the ecological state of Baikal, and their substantiated interpretation.

Materials and methods

We analyzed data of long-term hydrometeorological monitoring at 15 Roshydromet network stations in the Baikal basin (Fig. 2). Monitoring of the main hydrological and climatic parameters at the Roshydromet stations is performed regularly at fixed time (so-called "urgent" observations, i.e., several measurements a day). The measurement results are used to determine the monthly, seasonal, and annual values of the parameters.

Since eutrophication in Baikal was observed in the warm period (May–October), analysis of hydrometeorological data obtained in this season was based on the time series of the monthly and seasonal average values of hydrological and climatic parameters: air temperature and wind speed measured at stations at heights of 2 and 10–12 m from the ground surface, respectively, water temperature in the surface (50 cm thick) layer in the shallow zone, atmospheric precipitation, and direct solar radiation. The long-term changes in these parame-