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# Modern changes in the ecosystem of Lake Onego with climate warming

Filatov N.N.*, Kalinkina N.M., Tekanova E.V.

*Northern Water Problems Institute of the Karelian Research Centre of the Russian Academy of Sciences, Aleksander Nevsky Str., 50, Petrozavodsk, Republic of Karelia, 185030, Russia*

**ABSTRACT.** We have shown the changes in the ecosystem of Lake Onego[1] with climate warming over the past 30 years. Due to climate warming in winter, the river runoff increases, as well as the flow of allochtonic substances into the lake. With the increased runoff of the Shuya River, the main tributary of the Petrozavodskaya Guba (Bay), there is an additional influx of iron and phosphorus to the lake combined with the humus substances. Deep-water benthic communities in the lake become depressed. Therefore, in the past three decades the role of climate warming in the aquatic ecosystem has increased in comparison with anthropogenic impacts, which differs significantly from the changes in previous decades.

***Keywords***: Anthropogenic impact, climate changes, Lake Onego, eutrophication, warming, ecosystem, benthic communities

## 1. Introduction

Assessing the contribution of anthropogenic and climatic factors to the changes in the ecosystem of lakes is fundamental for understanding the causes and consequences of these changes and making management decisions. Lake Onego is a relatively young water body of a glacial-tectonic origin, in which the formation of flora and fauna continues at present time; there are relict forms of crustacean. Studies have shown that the changes in the hydrological regime of Lake Onego due to the regulation of the water level in the lake in the late 50s of the 20th century by the Upper Svir Hydroelectric Station are only a few tens of centimetres, and they had a little effect on the ecosystem of the lake. At the same time, increase in biogenic load and pollutants discharge caused eutrophication and pollution of the lake (The largest lakes-reservoirs..., 2015; Ladoga and Onego, 2010). The transformation process of the lake ecosystem is a sequence of stages during which the ecosystem was transformed in different ways depending on the external influences and intra-aquatic processes. The increase in the trophicity of the most contaminated bays of Lake Onego, such as Petrozavodskaya and Kondopogskaya, was accompanied by a decrease in the stability of phytoplankton and its restructuring aimed at change in balance of the ration of large and small cell species towards increase in the latter (*r-strategists*) having more opportunities for adaptation to changing environmental conditions. In 2000, with a decrease in anthropogenic load the stability of phytoplanktonic community increased (The largest lakes-reservoirs..., 2015).The zooplankton community in the central oligotrophic areas of Onego is in a dynamic equilibrium and stable. However, with a sharp decrease in anthropogenic load after 1991 ecosystem of the lake is restored very slowly (Rukhovets et al., 2011). In the past 20 years, new scattered sources of pollution of Onego have appeared. They are trout farms concentrated in the north-western bays, where more than 30% of all trout in Karelia are grown. Decrease in the total load of phosphorus and organic matters from these farms is possible by transferring them to the sea, as in the Scandinavian countries.

The spontaneous introduction of an alien species, Baikal amphipod *Gmelinoides fasciatus* Stebbing, in the littoral zone of the lake can be regarded as an indirect anthropogenic impact on the Onego ecosystem. In areas with higher aquatic vegetation, it determines up to 80% of the number and biomass of macrozoobenthos. This species acts as a new factor of mineralization in the water body destroying up to 300 tonnes of organic matter per year. The perch nutrition includes the new species; thereby it becomes included in food chains (Sidorova and Kalinkina, 2015).

The current state of biocoenoses in Onego generally reflects the consistent changes under the influence of anthropogenic factors, from the initial increase in productivity to their complete destruction in the upper part of Kondopogskaya Bay. In recent decades, the in-

[1] Hereinafter we will also use the short name Onego

*Corresponding author.
E-mail address: nfilatov@rambler.ru (N.N. Filatov)

fluence of climatic factors on the lake ecosystem and its catchment area has been increasing.

## 2. Materials and methods

We used the data on observations at meteorological stations of Russian hydrometeorological service for a period of instrumental measurements from 1900 to 2017, measurements of water balance elements (river runoff, precipitation and evaporation) and water temperature from 1955 to 2016, as well as information about changes in the water level and characteristics of the ice cover from 1900 to 2017 at hydrometeorological stations located in the catchment area of the lake.

A probabilistic analysis of these data on hydrometeorological observations was carried out to study the pattern of variability in the time scales from decades to intra-annual fluctuations. Trends and quasi-cyclical fluctuations were identified.

It was also used data on the content of the total iron and phosphorus in water of the Shuya River in different seasons of 1992–2018 obtained by researchers from Northern Water Problems Institute of Karelian Research Centre of the Russian Academy of Sciences (Analytical…, 2018). To study dynamics of the state of biological parameters, in particular, macrobenthos of Onego, the database (Polyakova, 2012) was used, as well as data on regular observations on the network of stations in Onego over a period of more than 40 years (Kalinkina and Belkina, 2018). Macrozoobenthos was sampled according to standard methods (Guidelines…, 2005).

## 3. Modern ecosystem changes with climate warming

According to the analysis of hydrometeorological observations in the Onego catchment area for 1900-2017, there is a positive trend in the change of the average annual air temperature, which is 0.20-0.34°C per 10 years. Almost in all years, since 1988, the average annual air temperature exceeded the climatological normal calculated for 1961-1990 (Filatov et al., 2014). With climate warming, the duration of the ice-free period at Onego increased on average from 215 days per year at the end of the 19$^{th}$ century to 227 days per year at the beginning of the 21$^{st}$ century. In the intra-annual course, the change in the average air temperature per month occurs unevenly for different seasons of the year. Notably, there is warming in winter (March) of up to +0.45 …+0.6°C per ten years. In 1951-2017, there was an increase in the annual air temperature by 1.2$^{o}$C, total evaporation – by 70-80 mm and total precipitation – by 60-90 mm. Despite the significant interannual variability of the total river inflow into Onego, there are no trends over 60 years (1951-2010), since the increase in the total evaporation offsets the annual total precipitation. There is an evidence that the duration of the 'biological summer' for 60 years has increased more than by 15 days (Nazarova, 2015). At the same time, the share of spring-spawning species of fish tended to increase relative to autumn-spawning ones (Georgiev and Nazarova, 2015). Climate changes have affected the state of the catchment area: there is an increase in the number of thaws and in the proportion of liquid precipitation over the solid one, as well as a decrease in soil freezing (Nazarova, 2015).

## 4. Results and discussion

Almost 10 years ago, based on the data on mathematical modelling (Ladoga and Onego…, 2010) and field observations N.A. Petrova with colleagues (see in Rukhovets et al., 2011) noted that anthropogenic factors mainly contribute to the changes in the ecosystems of Ladoga and Onego, and climate plays a secondary role. Changes in the phytoplankton development caused by warming are visible only in autumn, while the heterogeneous development of zooplankton is more obvious, but it also does not exceed the fluctuations resulted from changes in the biogenic load.

With climate warming and increased runoff in winter for the past 30 years, the iron runoff to Onego with waters of the Shuya River has increased by 35%, and phosphorus – by 25% due to winter and spring months (Kalinkina et al., 2018). During the winter months, the water runoff increased, and there was its intra-annual redistribution, which corresponds to the general tendency to the change in the water runoff in the north-western regions of Russia (Dzhamalov et al., 2017). In winter and spring months, the concentration of iron and phosphorus in the river waters increased, and the consistency of changes in the iron and phosphorus concentrations indicates their terrigenous nature (Kalinkina et al., 2018). The change in runoff into the Petrozavodsk Bay caused an increase in the content of iron and phosphorus in its waters. In the same period, there was the iron accumulation in bottom sediments of the Petrozavodsk Bay and a 4-fold decrease in the biomass of macrozoobenthos, *Oligochaeta* and *Amphipoda* (Kalinkina and Belkina, 2018) (Fig. 1).

The changes identified in the Onego ecosystem in terms of the geochemical characteristics of the region (Tekanova et al., 2018) decrease its productivity and resistance to external influences.

The process of transformation of the lake ecosystem is a sequence of stages during which the external factors of influence changed. The first stage of

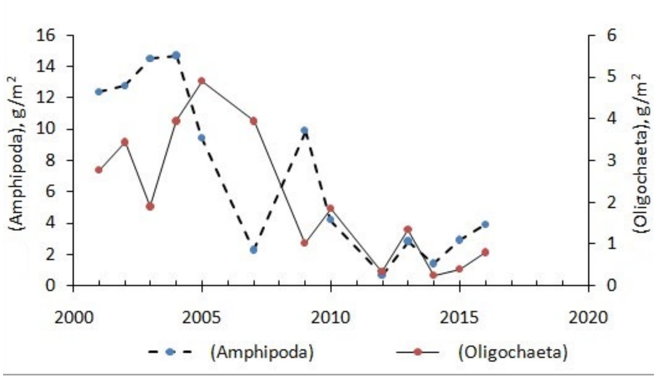


**Fig.1.** Biomass dynamics of the main macrozoobenthos groups in the Petrozavodsk Bay of Onego Lake (2001-2016).

anthropogenic changes in the water body was due to timber rafting and a significant deterioration of the water quality in the mouth areas of large tributaries. The intensive work of the main industrial centres on the Onego Bays (Petrozavodskaya and Kondopogskaya) and the centralized wastewaters discharge into the lake outlined the next stage of the ecosystem transformation, which is local anthropogenic eutrophication. At different times and in different parts of the lake, anthropogenic eutrophication had different types: heterotrophic or autotrophic (Timakova et al., 2011). The economic recession in 1990s led to a decrease in the ecological stress in the areas adjacent to the industrial centres, Petrozavodskaya and Kondopogskaya Bays. However, the role of the intra-aquatic processes increased, and there was an obvious influx of nutrients and slowing down the restoration of the ecosystem. In recent years, the most obvious changes in the ecosystem have been due to climate warming.

## 5. Conclusion

In the late 1990s and early 2000s, the role of climate warming in the changes of the Lake Onego ecosystem increased. Currently, an increase in the surface water temperature and change in the vegetation period reflect the impact of climate warming. Due to climate warming and increase in the runoff from the catchment area in winter time, formation of the hydrochemical regime change leading to an increase in colour of water, content of iron and phosphorus in humus complexes, as well as the abundance and structure of aquatic communities.

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