Ecological Indicators 97 (2019) 120–129

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Relations between variations in the lake bacterioplankton abundance and the lake trophic state: Evidence from the 20-year monitoring

B.V. Adamovich[a,*], A.B. Medvinsky[b], L.V. Nikitina[a], N.P. Radchikova[c], T.M. Mikheyeva[a], R.Z. Kovalevskaya[a], Yu.K. Veres[a], A. Chakraborty[d], A.V. Rusakov[b], N.I. Nurieva[b], T.V. Zhukova[a]

[a] Belarusian State University, Faculty of Biology, 220030, Nezavisimosti Ave., 4, Minsk, Belarus
[b] Institute of Theoretical and Experimental Biophysics, 142290, Institutskaya Str., 3, Pushchino, Moscow, Russia
[c] Pirogov Russian National Research Medical University, 117997, Ostrovityanova Str., 1, Moscow, Russia
[d] School of Mathematics, Statistics and Computational Sciences, Ajmer 305801, Central University of Rajasthan, NH-8, Bandar-Sindri, Rajasthan, India

ARTICLE INFO

Keywords:
Trophic state index
Lake ecosystems
Bacterioplankton
Long-term monitoring

ABSTRACT

Trophic state is a key biological characteristic of water body that integrates the main hydroecological factors. However, the character of the interrelation between bacterioplankton dynamics and the lake trophic state remained obscure. The long-term (1995–2015) monitoring data were carried out to examine the relations between bacterial parameters (abundance, biomass, and cell biovolume) and main hydroecological factors (chlorophyll, phosphorus, nitrogen, organic matter) in three water bodies: Lake Batorino, Lake Myastro, and Lake Naroch, which differ by trophic state. The results of the analysis of the data show that the growth of the chlorophyll-based trophic state index (TSI_{Chl}) as well as dissolved organic carbon (DOC), total phosphorus (TP) and 5-day biochemical oxygen demand (BOD_5) in the chain Lake Naroch – Lake Myastro – Lake Batorino is accompanied by a linear increase in the bacterioplankton abundance, while fluctuations of bacterioplankton abundances and trophic state parameters in each of the Naroch Lakes are not correlated with each other. It is shown that temperature is the factor, which impacts seasonal bacterioplankton dynamics. The ratio of the time-averaged abundance of bacteria in July to the time-averaged abundance of bacteria in May remains virtually unchanged compared to the ratio between July and October. However, similar ratios for chlorophyll-*a* undergo significant changes. This result leaves room for further investigation of the factors, which can influence trophic state of the lakes, on the assumption that bacterial abundance is considered as an invariant measure.

1. Introduction

The concept of the trophic state was introduced in order to classify lake ecosystems in terms of productivity (Nauman, 1927). The trophic classification of lake ecosystems classically distinguishes three types of lakes: oligotrophic, mesotrophic and eutrophic. For introducing a numerical measure of the trophic state, trophic state indices (TSI), such as the chlorophyll (TSI_{Chl}), total phosphorus (TSI_{TP}), total nitrogen (TSI_{TN}), and Secchi depth (TSI_{SD}) (Carlson, 1977; Kratzer and Brezonik, 1981) indices were put forward. Among these four indices, TSI_{Chl} probably yields the most certain measures, as it is the most accurate predictor of the phytoplankton biomass (Carlson, 1977). However notice that the bacterioplankton abundances, even being related to trophic states (Wetzel, 2001; Nixdorf and Jander, 2003; Jekatierynczuk-Rudczyk et al., 2014), have not been directly related with numerical values of any TSI.

Among several environmental factors exerting potential on TSI, temperature (which, for example, essentially drives seasonal changes in the phytoplankton abundance; see Scheffer, 2009; Quinn et al., 2013; Tammert et al., 2015) exhibits most critical effects. It is worth noting in this context that fluctuations of the bacterioplankton abundance have been shown to be phase-locked by oscillations in the water temperature (Medvinsky et al., 2017). In order to assess relative values of the temperature and TSI changes as the potential factors that may be related to the bacterioplankton dynamics, long-term monitoring of the lakes that are in close proximity to each other but differ in their trophic states is

* Corresponding author.
E-mail addresses: belaqualab@gmail.com (B.V. Adamovich), medvinsky@iteb.ru (A.B. Medvinsky), nikitina@bsu.by (L.V. Nikitina), nataly.radchikova@gmail.com (N.P. Radchikova), mikheyeva@tut.by (T.M. Mikheyeva), lakes@tut.by (R.Z. Kovalevskaya), veres.julia.naroch@gmail.com (Y.K. Veres), amitc.envsc@yahoo.com (A. Chakraborty), rusakov_a@rambler.ru (A.V. Rusakov), nailya.nurieva@mail.ru (N.I. Nurieva), tvzhukova@tut.by (T.V. Zhukova).

https://doi.org/10.1016/j.ecolind.2018.09.049
Received 13 April 2018; Received in revised form 6 August 2018; Accepted 25 September 2018
1470-160X/

needful. The long-term monitoring can assist in sustainable management allowing long-term maintenance of their functionalities and services.

The Naroch Lakes consist of three water bodies, Lake Batorino, Lake Myastro and Lake Naroch, which are in close proximity to each other. These lakes have a common catchment area but differ in their trophic states; namely, the time-averaged values of TSI consistently decrease in the chain Lake Batorino – Lake Myastro – Lake Naroch (Adamovich et al, 2016). The Naroch Lakes were monitored intensively during the last fifty years. Throughout this time, these lakes underwent a set of conversions in their structural and functional structure. In the end of 1970s, the increased nutrient load on the catchment area was followed by eutrophication of the Naroch Lakes. Later, due to a reduction of the nutrient load, the concentrations of nitrogen and phosphorus in these water bodied decreased significantly. Besides, the Naroch Lakes were affected by the invasion of zebra mussel *Dreissena polymorpha* Pallas (Burlakova et al., 2006; Ostapenya et al., 2012; Mikheyeva et al., 2017). The stabilization of biological and hydrochemical characteristics of these water bodies came in the mid-1990s (Ostapenya et al., 2012; Adamovich et al., 2015; Zhukova et al., 2017).

Here, we present the results of statistical analysis of the data obtained during the monitoring of the Naroch Lakes under conditions of the stabilization, i.e. in 1995–2015. We show that even though the dynamics of bacterioplankton abundances and chlorophyll concentrations in each of the Naroch Lakes are not statistically correlated with each other, the Naroch Lakes system as a whole manifests a distinct linear relationship between the temporal variations in the TSI_{Chl} values assessed for each of the Naroch Lakes, and the corresponding variations in bacterioplankton abundances. This result implies that the bacterioplankton abundance is inextricably associated with lake trophic state. Moreover, the bacterioplankton oscillations are shown to be under a tangible temperature control.

2. Materials and methods

2.1. Study site

The system of Naroch Lakes is situated in the Northwestern Belarus in the Neman River basin and includes the following water bodies: Lake Batorino, Lake Myastro and Lake Naroch. Lake Naroch consists of two parts, Small Stretch and Large Stretch. Lakes are interconnected by channels (Fig. 1). Main characteristics of the Naroch Lakes are given in Table 1. The Naroch Lakes have different surface area but similar morphometric features, including the relatively small average depth, resulting in intense mixing of waters. The surface of the Naroch Lakes is completely frozen during the period from the late November to April. In 1995–2015, Secchi depth (SD) was 0.5–2.4 m in Lake Batorino, 2.0–7.5 m in Lake Myastro and 3.6–10.7 m in Lake Naroch, respectively.

Table 1
The major characteristics of the Naroch Lakes.

Characteristics	Naroch	Myastro	Batorino
Surface area, km^2	79,6	13,1	6,3
Water volume, mln. m^3	710,0	70,1	18,7
Depth (average/maximum), m	8,9/24,8	5,4/11,3	2,4/5,5
Water retention time, yr	10–11	2.5	1.0
Trophic state	oligotrophic-mesotrophic	mesotrophic	eutrophic

2.2. Field sampling

Water samples were collected monthly in the period between 1995 and 2015 at specific monitoring points of the pelagic zones of the Naroch Lakes during the vegetative season (from May to October) using two-liter Ruttner sampler. The samples were collected from six different depths (0.5, 3, 6, 8, 12 and 16 m) in both the Small Stretch (54°53′10.56″N, 26°43′12.12″E) and Large Stretch (54°51′10.92″N, 26°46′44.52″E) of Lake Naroch, from four depths (0.5, 4, 7 and 9 m) in Lake Myastro (54°52′0.91″N, 26°52′49.86″E), and from three depths (0.5, 3 and 5 m) in Lake Batorino (54°50′47.94″N, 26°58′3.36″E). The water samples from all depths were mixed. Volumes of samples collected from different depths were proportional to the total estimated volume of the water in this horizon in the lake (according to bathymetry tests). Temperature was measured at all tested depths using a mercury deep-water thermometer with a scale resolution of 0.1 °C.

2.3. Water chemistry

The magnitude of SD was determined with the use of a white Secchi disc (d = 30 cm). The suspended matter for determination of chlorophyll content (without correction for the presence of pheopigments) was collected on the nuclear membrane filters with a pore diameter of 1.5 µm. The analysis of chlorophyll content was carried out by standard spectrophotometry. Pigments were extracted using 90% acetone. The chlorophyll concentration was calculated as described in (SCOR-UNESCO Working Group No 17, 1966). The 5-day biochemical oxygen demand (BOD_5) was determined as the decrease of dissolved oxygen level measured by the standard Winkler technique (Methods for Studying Organic Matter…, 1980). The total concentration of organic carbon (TOC) was determined by wet potassium dichromate oxidation of lake water samples, evaporated in a water bath (Maciolek, 1962, Ostapenia, 1965). It was assumed that 1 g of O_2 is equivalent to 0.375 g of C (Vinberg, 1960). Particulate organic carbon (POC) concentrations were estimated from the seston ash content. Lake water was filtered on nuclear membrane filters with pore size 1.5 µm, which were combusted under 450 °C for 6 h in a muffle furnace (Semenov, 1977; Wetzel and Likens, 2000). Dissolved organic carbon (DOC) concentrations were calculated using TOC and POC differences. The concentration of the total nitrogen (TN) was assessed after oxidation of raw water samples

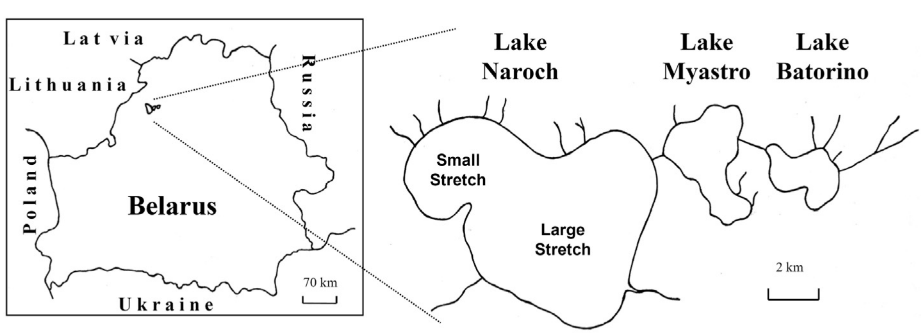

Fig. 1. Geographical location of the Naroch Lakes.