Review Article

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Water Quality of Lakes Ohrid and Prespa Based on Physical-chemical and Biological Parameters in 2013–2014

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Abstract: The urbanisation of environment and the application of phosphorus detergents and fertilisers with nitrogen and phosphorus as active components, substantially enrich the aquatic ecosystems with nutrients. This results in a disruption of the natural biological balance of the ecosystem, which certainly reflects on the water quality and trophic state of the aquatic ecosystem. The main aim of our study was to make a comparative analysis of nutrient (phosphorus) and organic loading of water in the littoral and pelagic zones of Lakes Ohrid and Prespa, as most important natural lakes in the Republic of Macedonia. The analysis of water quality was based on the results of monitoring of certain physical-chemical parameters (Secchi depth, biochemical oxygen demand, biodegradable organic matter, concentration of total phosphorus) and biological parameters (total number of heterotrophic bacteria, chlorophyll *a* concentration), in the period 2013–2014. According to the numeric values of the Carlson's Trophic State Index (TSI), calculated based on the total phosphorus, Secchi depth and chlorophyll *a* concentration, Lake Ohrid was determined in a stable oligotrophic state, while Lake Prespa was in a mesotrophic state, with a tendency towards an eutrophic state.

Key words: Trophic state, nutrients, oligotrophic, mesotrophic, Lake Ohrid, Lake Prespa

Introduction

The lake systems are highly dependent on their environment, i.e. on the physical, chemical and biological variables of the watershed area. Human impact and the changes caused by human activities that occur in the watershed area contribute to the increased flow of nutrients, which can result in a change in the trophic state of the littoral zone, and consequently affect the pelagic zone of aquatic ecosystems. Lakes Ohrid and Prespa are the largest and most important natural aquatic ecosystems in the Republic of Macedonia. They belong to the Dessarete Lake group and, with the natural rarities and the endemic species that live in them, they are classified within the group of the most important and the oldest freshwater systems in the world.

Comparative studies of the trophic state of Lakes Ohrid and Prespa have shown that Lake Ohrid is in oligotrophic state, without clearly visible signs of eutrophication and the pelagic zone remains immune to the anthropogenic pressures that could threaten these waters in previous decades, while Lake Prespa is in mesotrophic state, with clearly visible signs of eutrophication (Patceva 2005, Veljanoska-Sarafiloska & Patceva 2012). The main aim of our study was to make a comparative analysis of nutrient (phosphorus) and organic loading of water in the littoral and pelagic zones of lakes Ohrid and Prespa, based on original and recent available data (2013–2014) (Lesoski et al. 2015, Lokoska 2015, Vasilevska & Veljanoska-Sarafiloska 2015), in order to determine any changes in the trophic state of the lakes as a consequence of the anthropogenic impact and decline in the water level of Lake Prespa.

Materials and Methods

Study area

Lakes Ohrid and Prespa are the biggest and the most valuable natural water resources in the Republic of Macedonia. They are one of the oldest lakes in the world and with their natural rarities and endemic species attract the attention of scientists. Lakes Ohrid and Prespa form a very unusual lake system. Lake Prespa lies at an altitude, which is about 160 m higher than this of Lake Ohrid. Stable isotope measurements and recent tracer experiments have revealed that water from Lake Prespa is flowing to Lake Ohrid through karst channels (Anovski et al. 1980, Eftimi & Zoto 1997). According to Matzinger et al. (2006), almost the entire outflow of Lake Prespa is found to flow into Lake Ohrid; however, 65% of the transported phosphorus is retained within the aquifer and thanks to this natural filter Lake Prespa does not pose an immediate threat to Lake Ohrid.

The water samples were collected from the following sampling sites in Lake Ohrid: Kalishta littoral (N41°09'025"; E20°39'078"), Grashnica littoral (N41°07'043"; E20°47'260"), Veli Dab littoral (N40°59'237"; E20°47'965"), St. Naum littoral (N40°54'855"; E20°44'499"), and the pelagic zone (central point) at depths of 0.5 and 240 m (N 41°03'730"; E20°45'000") (Fig. 1).

The water samples from Lake Prespa were collected from the following sampling sites: north-western (NW) Ezerani littoral (N1°00'131"; E20°56'683"), north-eastern (NE) Ezerani littoral (N41°00'015"; E20°58'656"), Ezerani littoral (N41°00'197"; E20°57'741"), Oteshevo littoral (N40°58'692"; E20°55'016") and the pelagic zone (central point) at depths of 0.5 and 15 m (N40°57'949"; E20°57'513") (Fig. 1).

Data collection and analysis

The results were based on the analysis of water samples collected in four campaigns, in the four different seasons, during the period 2013–2014.

A Ruttner bottle of 2.25 L (Hydro-bios, Kiel, Germany) was used for collecting the water samples from the littoral zone. The water samples from the pelagic zone (at different depths along the water column) were collected with a Niskin bottle (5 L). All sampling procedures were conducted according to the official standard methodology (APHA 2005).

The transparency was measured by a standard Secchi disk. The concentration of dissolved biodegradable organic matter content in the water expressed as permanganate consumption was determined by digestion in acid and by titration (Bether 1953, APHA 1980). The Winkler method was used for the analysis of dissolved oxygen and biochemical oxygen demand for five days (BOD_5) (Bether 1953, APHA 1980).

Standard limnological methods (Bether 1953, Ruttner 1972, Golterman et al. 1978, APHA

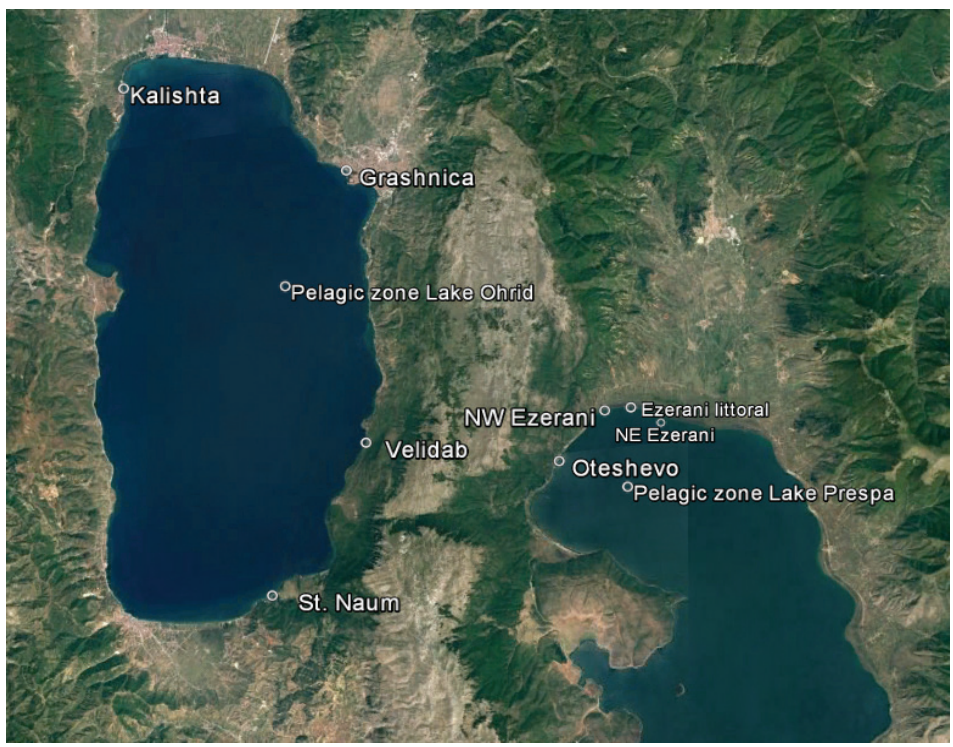

Fig. 1. Sampling sites in Lake Ohrid and Lake Prespa

1980, Wetzel & Likens 2000) were used for all titrimetric analyses. The total phosphorus (TP) was analysed by acid digestion of persulfate (at 121°C, pressure 1 at, and time 1 hour) (Menzel & Corwin 1965, Strickland & Parsons 1972, APHA 1980). The results for total phosphorus were read on a Spectrophotometer Specord, model S–10, Carl Zeiss Jena, 880 nm. The chlorophyll *a* content was measured spectrophotometrically after an extraction in 90% ethanol (ISO 10260 1992, Meyns et al. 1994). The microbiological analyses were made according to standard methods (Rodina 1972, APHA 2005).

The classification of water was done according to the Carlson trophic state index (TSI) (Carlson 1977), classification of the Organization for Economic Co-operation and Development (OECD 1982), and the Decree on classification of waters of the Republic of Macedonia (Official Gazette 1999). The calculation of TSI was done by taking into consideration all water characteristics (physical, chemical and biological) represented by the corresponding parameters: Secchi depth (SD), total phosphorus concentration (TP), and chlorophyll *a* concentration (Chl*a*) (Aizaki et al. 1981, Carlson 1991, Havens 1994, Jarosiewicz et al. 2011).

The microbiological assessment of water quality was made according to Kavka & Poetsch (2002).

The comparison of trophic state between the two lakes was based on the analyses of original data from the present study as well as available data from our previous studies for lakes Ohrid and Prespa (Lesoski et al. 2015, Lokoska 2015, Vasilevska & Veljanoska-Sarafiloska 2015).

Results and Discussion

The graphs on Fig. 2 depict the relationship between average values of BOD_5 and the biodegradable organic matter (permanganate oxidation) for the studied period (2013–2014). The relationship between these two components is positive, i.e. the maximum values of BOD_5 correspond to the maximum content of organic matter in the water samples from the studied sites in lakes Ohrid and Prespa. The highest average values for both parameters were registered at the site Grashnica in Lake Ohrid, and at the littoral sites Ezerani and Oteshevo in Lake Prespa.

The total phosphorous, as an essential nutrient, is one of the most limiting factors in the productivity and the eutrophication processes of aquatic ecosystems (Vollenweider 1965, Reynolds 1992, Carvalho & Kirika 2003). The main parameter in determining the trophic state of an aquatic water body is its phosphorus concentration. Any change in the phosphorus concentration of a freshwater ecosystem can also alter its trophic state (Devi Prasad & Siddaraju 2012). The results for the concentration of total phosphorus (TP) in the water samples from the littoral and pelagic zones in Lake Ohrid (Vasilevska & Veljanoska-Sarafiloska 2015) and Lake Prespa are presented on Fig. 3.

During the summer period, the highest values for total phosphorus (TP) in Lake Ohrid were registered in the water samples from the sites Grashnica littoral, near the mouth of the Velgoshka River (65.01 μg L^{-1} TP) and St. Naum littoral (23.66 μg L^{-1} TP). Generally, most of the TP values during the studied period corresponded to oligotrophic state: at Kalishta, Veli Dab, St. Naum and the

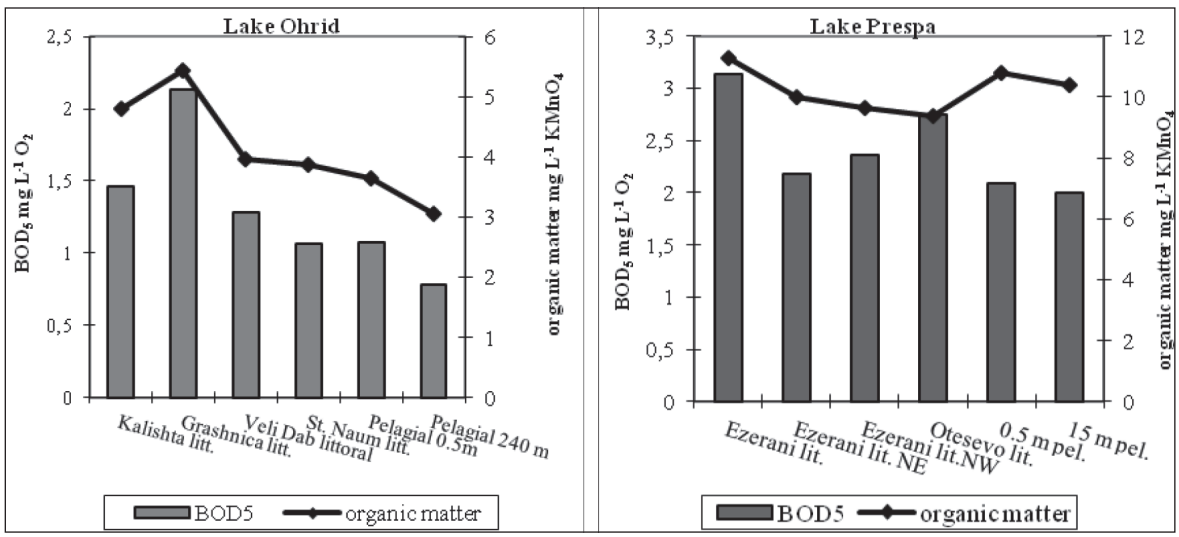

Fig. 2. Correlation between the average values of biochemical oxygen demand for five days (BOD_5) and content of organic biodegradable matter in lakes Ohrid and Prespa (2013–2014)

pelagic zone (0.5 and 240 m), according to the OECD classification (OECD 1982), or to I–II classes according to the Decree on classification of waters of the Republic of Macedonia (Official Gazette 1999). The water sample from Grashnica littoral during the summer period had significantly higher TP values and the site corresponded to IV class or eutrophic state according to the OECD classification (OECD 1982), and IV class according to the Decree on classification of waters of the Republic of Macedonia (Official Gazette 1999).

The maximum values for the TP concentration in Lake Prespa were registered at the sites Ezerani littoral NW (40.08 and 40.89 μg L^{-1} TP during the summer and autumn periods, respectively) and Oteshevo littoral (45.06 μg L^{-1} TP during the winter period) (Fig. 3). During the summer period, the highest TP value was registered at a depth of 15 m in the pelagic zone of Lake Prespa. It is well known that anaerobic conditions above the sediment surface can strongly stimulate the release of phosphorus from the sediment. Due to the fact that during the summer period at a depth of 15 m, at the bottom of Lake Prespa, the concentration of dissolved oxygen was very low (there were anoxic conditions), the TP value in the same period was very high (87.203 μg L^{-1} TP). Generally, based on the TP values, most of the sites in Lake Prespa during our study were in a mesotrophic state (OECD 1982) or of IV–V classes (Official Gazette 1999). Exceptions from this condition were the sampling sites Ezerani littoral NW, the pelagic zone 0.5 and 15 m, and Oteshevo littoral, where the TP values in the different seasons corresponded to the eutrophic state.

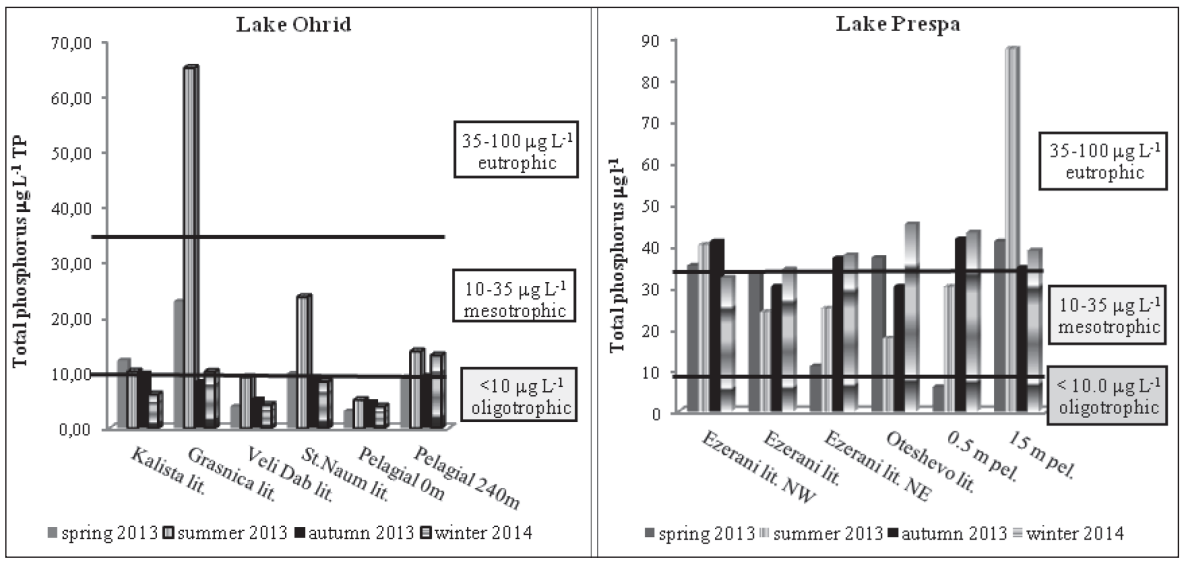

Fig. 3. Seasonal changes in total phosphorus concentrations and corresponding trophic state in lakes Ohrid and Prespa (2013–2014)

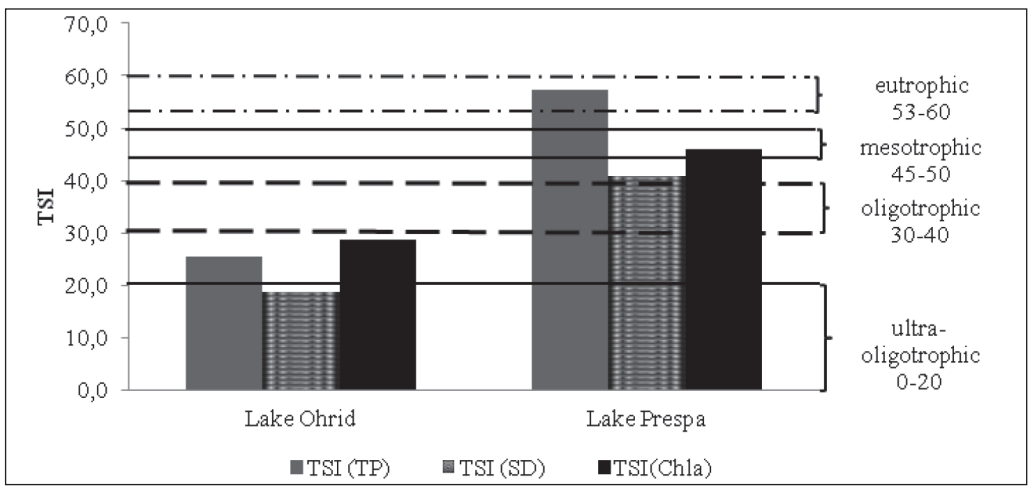

Fig. 4. Trophic state index (TSI) calculated on the basis of average values of total phosphorous (TP), Secchi depth (SD), and chlorophyll *a* concentration (Chl*a*), in lakes Ohrid and Prespa (pelagic zones, 0.5 m) (2013–2014)

The analyses of data revealed increased nutrient concentrations in both lakes: in the littoral zones at Grashnica (near the mouth of the Velgoshka River) and Ezerani (near the mouth of the Golema River), and in the pelagic zones (especially in Lake Prespa). These conditions have resulted from the high influence of the surface tributaries in the watersheds of the lakes. The tributaries collect waste communal and industrial waters, as well as drainage waters from the surrounding agricultural areas (Patceva et al. 2006, Veljanoska-Sarafiloska et al. 2006, Jordanoski & Veljanoska-Sarafiloska 2008, Veljanoska-Sarafiloska et al. 2008). The river waters of deteriorated water quality flow entirely into the littoral zone of the lakes, which is to be considered as their end recipients and prime danger for these aquatic ecosystems (Veljanoska-Sarafiloska 2002, Veljanoska-Sarafiloska et al. 2004). According to James & Barko (1991), the phosphorus released in the littoral zone can be transported to the deep pelagic lake waters, as a result of the convective night movements and lake mainstreams. Especially alarming conditions have been reported in the littoral zone of Lake Prespa, near the riverbeds of the Golema and Kranska rivers (Shemo et al. 2008), and in the littoral zone of Lake Ohrid, near the riverbed of the Velgoshka River (Veljanoska-Sarafiloska 2002).

According to the numeric values of the trophic state index (TSI), calculated on the basis of the Secchi depth (average values), Lake Ohrid was assessed in the ultra-oligotrophic state, while Lake Prespa belonged to oligo-mesotrophic state (Fig. 4).

According to the numeric values of TSI, based on TP (average values) in the pelagic zone (samples collected from 0.5 m), during the studied period Lake Ohrid was classified in stable oligotrophic state, while Lake Prespa belonged to meso-eutrophic state (Fig. 4).

According to the numeric values of TSI, as calculated on the basis of the chlorophyll *a* concentration (average values) in the pelagic zone (samples collected from 0.5 m), Lake Ohrid was in stable oligotrophic state, while Lake Prespa was assessed in mesotrophic state (Fig. 4).

The trophic state of Lake Prespa during 1992 in line with the studied parameters (TP and total nitrogen, TN) was between mesotrophic and oligotrophic (Naumoski et al. 1997). Long-term studies conducted in Lake Prespa during the period 2000–2012, have revealed that the trophic state has substantially changed (from mesotrophic to eutrophic according to TP and chlorophyll *a*), and the human influence is visible in the littoral as well as in the pelagic zone of the lake (Matzinger et al. 2004, 2006, Veljanoska-Sarafiloska & Patceva 2012). Other studies have also confirmed that Lake Prespa is under an intense process of eutrophication, which is strengthened by the natural processes of decline in water level and human impact (Peveling et al. 2015).

The values of TSI in the littoral zone of Lake Ohrid (Kalishta, Grashnica, Veli Dab and St. Naum) based on the concentrations of total phosphorus (Vasilevska & Veljanoska-Sarafiloska 2015) indicated a great seasonal variability (Fig. 5). During the summer period, higher TSI values were evident for all sampling sites. According to these results, the littoral zone of Lake Ohrid (Kalishta, Veli Dab, St. Naum) belonged mainly to the oligotrophic state. An exception from this condition was the site Grashnica littoral, where the TSI values during the spring and summer periods belonged to the mesotrophic and eutrophic state. During the summer period, the TSI value at St. Naum littoral was assessed in mesotrophic state as well.

According to the numeric values of TSI, calculated on the basis of total phosphorus during the studied period, the littoral zone of Lake Prespa (Ezerani, Ezerani NW, Ezerani NE and Oteshevo) was assessed in the meso-eutrophic state (Fig. 5).

The total numbers of heterotrophic bacteria at the studied sites in Lake Ohrid (Lokoska 2015) and Lake Prespa, in the period 2013–2014, are presented on Fig. 6.

The results indicate the continuous presence of heterotrophic bacteria in the collected water samples throughout the studied period. Increased numbers of heterotrophic bacteria in the littoral and pelagic zones of the two lakes was observed during the summer period, which is in correlation with the increased nutrient concentrations (TP) and content of biodegradable organic matters in the water. The maximum number of heterotrophic bacteria in Lake Ohrid was registered at Grashnica littoral, estimated at 19,560 CFU ml^{-1}, while the maximum number of such bacteria in Lake Prespa was registered at Ezerani littoral NE, estimated at 5,520 CFU ml^{-1} (Fig. 6). The maximum values of BOD_5 and biodegradable organic substances were recorded at the same sites: Grashnica littoral and Ezerani littoral, which indicated intensive processes of mineralisation, i.e. great presence of organic matter. These results confirm the assumption that the maximum and minimum values of BOD_5 are often in a positive correlation with the maximums and minimums of the bacterial population. Similar conditions have been reported for the littoral zone of

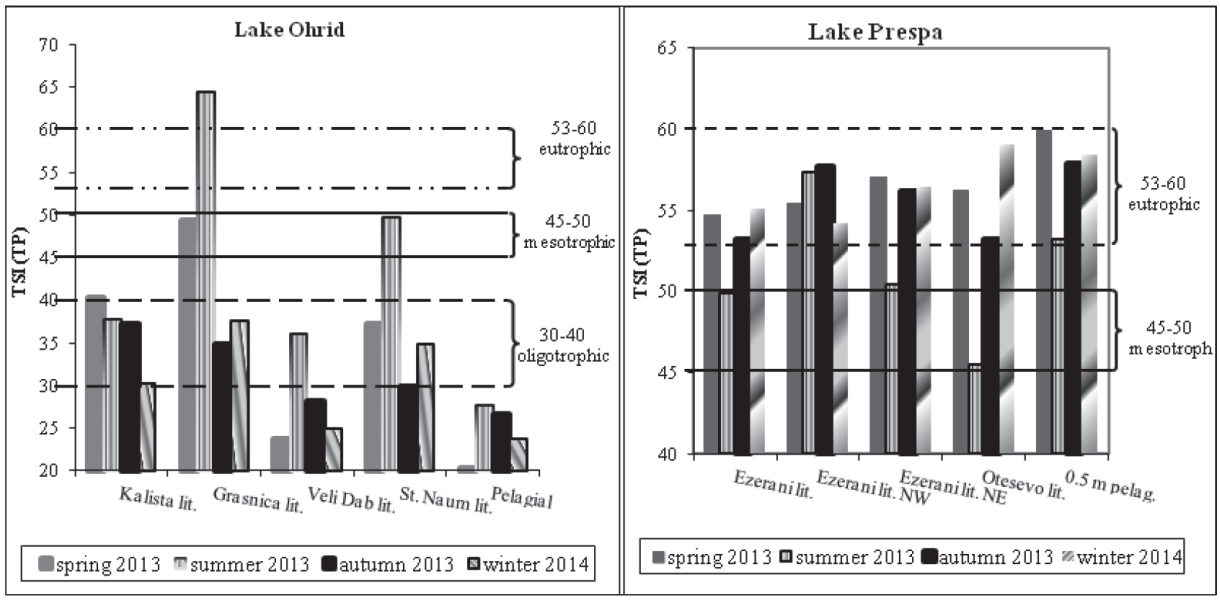

Fig. 5. Trophic state index calculated on the basis of average values of total phosphorous (TSI–TP) in the littoral and pelagic (0.5 m) zones of lakes Ohrid and Prespa (2013–2014)

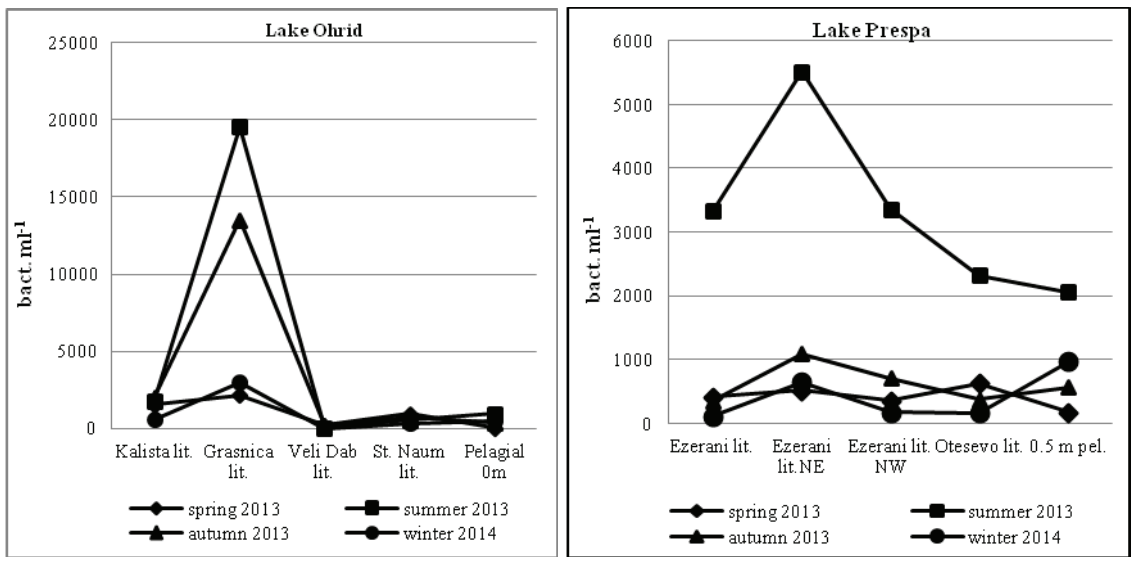

Fig. 6. Seasonal fluctuations in heterotrophic bacteria in lakes Ohrid and Prespa (2013–2014)

Lake Ohrid in 2002, when the maximum value of the total number of heterotrophic bacteria at Grashnica littoral was estimated at 82,240 CFU ml^{-1}, while the BOD_5 value was 7.21 mg L^{-1} O_2 (Veljanoska-Sarafiloska et al. 2004).

Based on the number of heterotrophic bacteria, the water quality in the pelagic zone of Lake Ohrid (0.5 m depth) and Veli Dab littoral was assessed as I class (little pollution), while at St. Naum littoral it was mostly II class (moderate pollution), except in winter – I class. At the site Kalishta littoral, the water quality was II class, while at the site Grashnica littoral, it was in the range from II to III classes, which corresponded to moderate and critical organic pollution. According to the number of heterotrophic bacteria, the water quality in Lake Prespa (pelagial and littoral) was classified in I and II classes (Kavka & Poetsch 2002).

Conclusions

According to all analysed indicators in Lake Ohrid, the worst trophic conditions were recorded at Grashnica littoral, where the water was mainly mesotrophic, changing to eutrophic in some periods.

The microbiological parameters indicated: good water quality at the pelagial, Veli Dab littoral and St. Naum littoral; moderate organic pollution at Kalishta littoral; and critical contamination by bacteria in all seasons, with a maximum in summer, at the Grashnica littoral. The Velgoshka River, which inflow is located near Grashnica, has been considered as the main cause of organic pollution, since it is the end-recipient of waste, drainage and household waters. In summer (the touristic season), the organic loading is more intense and high values of nutrients (especially concentrations of total phosphorus, which has maximum values) were recorded at the studied sites in Lake Ohrid. These conditions have resulted from the increased number of people and touristic facilities in that period, which seriously contribute to the pollution of the ecosystem.

Our results confirm the ongoing processes of eutrophication in Lake Prespa. They are strengthened by the natural processes of decline in water level and the human impact. The changes in the volume of the lake have a direct effect on the concentrations of dissolved nutrients. The intensive negative influence of the rivers, which flow into Lake Prespa, is manifested in the littoral zone, but also poses a potential risk for deterioration of the trophic state and water quality in the pelagic zone. The worst trophic conditions were recorded in the littoral zone near the mouth of the Golema River.

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