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Trophic State of Lake Ohrid[#]

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Abstract: Lake Ohrid in southeastern part of Europe is one of the few ancient, long-lived lakes of the world. This is a transboundary lake shared by Macedonia and Albania, situated between mountain ranges to the east and west. It is a deep lake with a large surface area. In order to obtain information about its trophic state were carried out investigations on the basic trophic parameters. The investigative period of this study took place over the years 2001, 2002, 2003. The results obtained during these investigations indicated that Lake Ohrid is in an oligotrophic state without clearly visible signs of eutrophication. The pelagic zone remains immune to the anthropogenic pressures that threatened these waters in previous decades. In Lake Ohrid it was determined that there was a highly significant, strong inverse correlation between Secchi transparency and chlorophyll a; significant, strong correlation between total phosphorus and chlorophyll a and there was a significant inverse correlation between chlorophyll a and TN:TP ratio.

Keywords: *Lake Ohrid, pelagic zone, trophic state, nutrients, chlorophyll-a*

Introduction

Trophic state is a multidimensional phenomenon (Kratzer & Brezonik 1981), and it is generally agreed that no single trophic indicator adequately measures the underlying concept. Classification of the lakes according to the water quality and trophic state is significant subject from the beginnings of limnology (Reckhow & Chapra, 1983; Welch, 1992; Cooke *et al*., 1993). With classification of aquatic ecosystems trophic state it's possible to carry out comparison of the productivity of the ecosystems between different region or to determine the capacity and the speed of cultural eutrophication (Dodds, 2002).

Trophic state the most frequently is mark as oligotrophic, mesotrophic and eutrophic. The fixed boundary system is based on best judgement as to the transition between two neighbouring categories with respect to each parameter specified (OECD, 1982). Lake Ohrid is a transboundary lake shared by Macedonia and Albania, situated between mountain ranges to the east and west. It is deep (max. depth ~ 289 m), large (surface area ~ 358 km^2), and one of the most voluminous lakes (~ 55 km^3) in Europe. It is a lake of tectonic origin and it is one of the oldest lakes in the world.

In this article we present the results from the triennial (2001-2003) investigations of the basic trophic parameters of ancient Lake Ohrid.

Material and Methods

Water samples were collected during 2001-2003 from the pelagic zone of Lake Ohrid on nine depths (0, 10, 20, 30, 40, 50, 75, 100, 150 m) by Niskin bottles, seasonally and with a monthly frequency of sampling in the summer period. In the course of the investigation the ammonia, nitrates, nitrites and total nitrogen have been determined by Kjedahl, among the nitrogen compounds.

The procedure for determining ammonia is performed by binding of the ammonia with hypochlorite in monochloramine, which in reaction with phenol gives p-aminophenol, which in reaction with natrium nitroprusside forms blue-coloured compounds. The values are read using Perkin-Elmer UV-VIS spectrophotometer, wavelength 640 nm.

Nitrates are quantitatively reduced from the water to nitrites by a cadmium-copper couple (Strickland & Parsons, 1968), and as nitrites bind with sulphanilic acid and N- (1-naphthyl ethylene

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diamine - dichloride (III) in the shape of a very intensive diamine compound. The results are read on Specord S-10 UV-VIS spectrophotometer, wavelength 530 nm.

Total phosphorus - by acid digestion of persulphate all forms of phosphates are altered to orthophosphate, which with antimony-molybdate and antimonyl potassium tartarate form the complex antimony-phosphate-molybdate, which is reduced by ascorbic acid thus forming a blue molybdene complex whose intensity is in function of the quantity of total phosphorus. The results can be read on Specord S-10 UV-VIS spectrophotometer, wavelength 885 nm.

The determination of chlorophyll *a* content was carried out spectrophotometrically after extraction in 90% ethanol (ISO 10260, 1992; Meyns et al. 1994).

Results and Discussion

Secchi depth with decades it's use from the limnologists as an index of lake transparency. This is the water quality variable people usually note first. Secchi disk transparency reflects algal biomass as well as water colour and varies between 0 and several meters (Nürnberg, 1996).

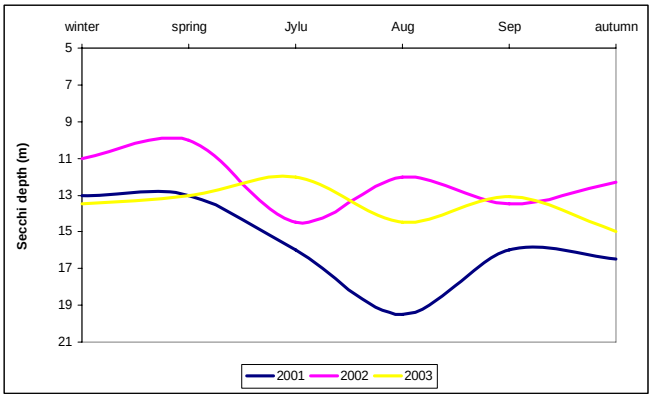

Figure 1. Seasonal distribution of Secchi depth in Lake Ohrid during 2001-2003

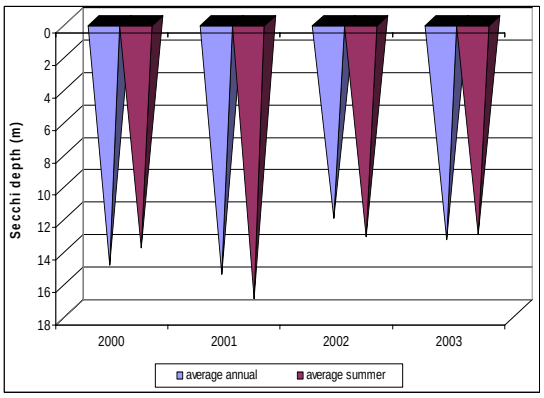

Figure 2. Average annual Secchi depth in Lake Ohrid during 2000-2003

Lake Ohrid is one of the rare lakes in the world which is characterized with an extraordinary tranparency. During the period 2000-2003 in Lake Ohrid was identified high Secchi depth with values that varied between 11 and 20.7 m. There are not observed significant differences depending on the season though, something lower transparency was observed in the spring period when the phytoplankton biomass was the highest (Fig. 1). Average annual Secchi depth in 2000 was 15.1 m, in 2001 - 15.67 m, in 2002 - 12.22 m, and in 2003 was observed Secchi depth of 13.52 m (Figure 2). Average summer values of this parameter were 14 m in 2000, 17.17 m in 2001, 13.33 m in 2002 and 13.2 m in 2003 (Figure 2).

Average annual Secchi depths in Lake Ohrid during the period 1979-1990 varied from 12.43 m in 1986 to 15.71 m in 1982 (Naumoski, 1994). Average value of Secchi depth in Lake Ohrid during the period February 1999-February 2000 was 12.9 m (Patceva, 2001). All of these values indicate that in Lake Ohrid there are not more significant changes in transparency during the last twenty five years.

During the investigated period total phosphorus concentration in the pelagic zone of Lake Ohrid didn't show significant seasonal differences. The concentration was the highest in spring, something lower in the summer and in the winter period, and the lowest in the autumn period (Figure 3).

Average integrated total phosphorus concentration in the water column of Lake Ohrid ranged from 2.48 to 7.38 μg l^{-1} in 2001, from 3.25 to 7.64 μg l^{-1} in 2002 and from 3.27 to 5.99 μg l^{-1} in 2003 (Figure 3). Average annual total phosphorus concentration in 2001 was 5.55 μg l^{-1}, in 2002 was 5.63 μg l^{-1} and in 2003 was observed total phosphorus concentration of 5.09 μg l^{-1} (Figure 4). Average summer total phosphorus concentration in 2001 was 6.68 μg l^{-1}, in 2002 was 5.77 μg l^{-1} and in 2003 was 4.6 μg l^{-1} (Figure 4). In the period June 1988 - June 1989 average total phosphorus concentration in the pelagic zone of Lake Ohrid was 6.58 μg l^{-1} (Naumoski, 1994) and in the period February 1999 - February 2000 was 5.5 μg l^{-1} (Patceva, 2001). Compared with the current values there isn't arguments that indicate eutrophication of Lake Ohrid, but investigations of phosphorus in the sediments by Matzinger *et al*. (2004) indicated that in Lake Ohrid take place quiet process of anthropogenic

eutrophication and phosphorus concentration in the sediments increased 4 times in the last hundred years.

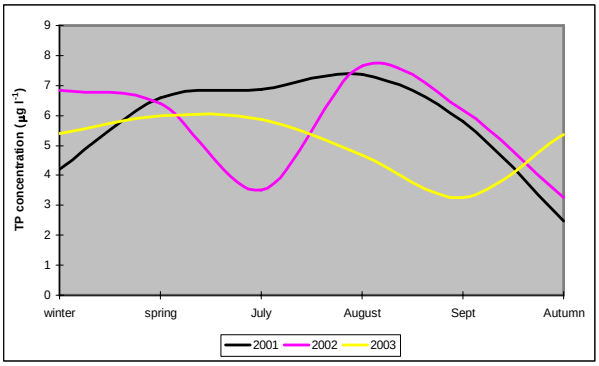

Figure 3. Seasonal distribution of average TP concentration in water column of Lake Ohrid

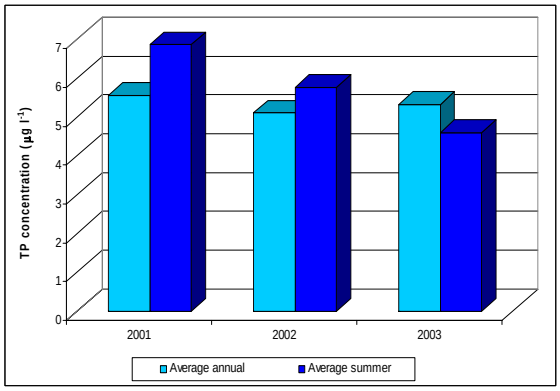

Figure 4. Average annual TP concentration in Lake Ohrid

The largest part of the presented nitrogen forms in Lake Ohrid belonged to total nitrogen whereas nitrate as bio available form of nitrogen were present in low concentration (Figure 5).

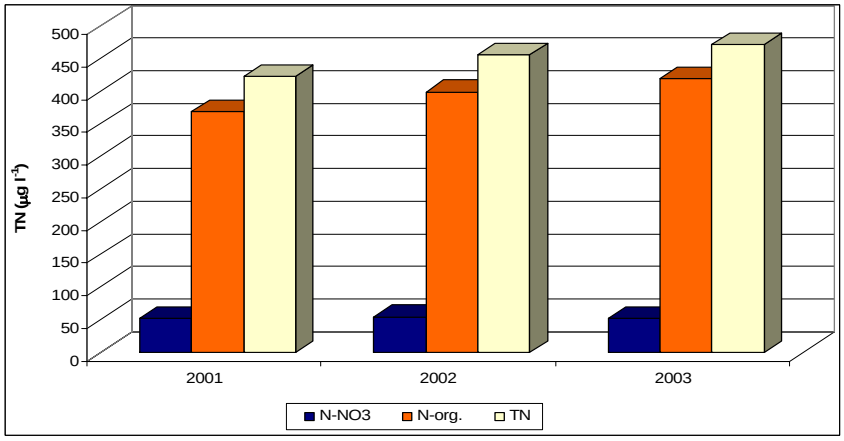

Fig. 5. Average annual concentration of the nitrogen forms in Lake Ohrid

Concentration of nitrate in the water column of Lake Ohrid was ranged from 44.2 to 63.08 µg l^{-1} in 2001, from 38.68 to 47.31 µg l^{-1} in 2002, and from 45.92 to 56.72 µg l^{-1} in 2003.

Average annual concentration of nitrate in 2001 was 52.07 µg l^{-1}, in 2002 was 54.32 µg l^{-1}, and in 2003 was 51.43 µg l^{-1} (Figure 5).

In the water column of Lake Ohrid organic nitrogen concentration was ranged between 187.66 and 757.12 µg l^{-1} in 2001, between 172.48 and 672.28 µg l^{-1} in 2002, and in 2003 ranged between 86.24 and 736.68 µg l^{-1}.

Average annual concentration of organic nitrogen in 2001 was 368.64 µg l^{-1}, in 2002 was 398.67 µg l^{-1} and in 2003 reached 418.88 µg l^{-1} (Fig. 5).

Seasonal distribution of the average total nitrogen concentration followed the seasonal distribution of organic nitrogen concentration. In Lake Ohrid during the investigated period was observed tendency of nitrogen decrease. Average annual total nitrogen concentration in 2001 reached 877,04 µg l^{-1}, in 2002 reached 815,16 µg l^{-1} and in 2003 reached 528,70 µg l^{-1} (Figure 5).

Chlorophyll *a* as a photosynthetic pigment integrating all type of algae is a measurable parameter for whole algal production.

Chlorophyll *a* concentration in Lake Ohrid during the third investigated years the highest values reached in the spring period and then significantly decreased in the summer months when were observed the lowest chlorophyll *a* concentrations (Figure 6). In the autumn period chlorophyll *a* concentration was lower than in the winter period.

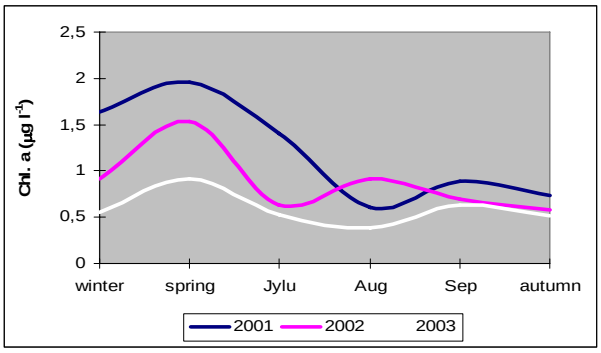

Figure 6. Seasonal distribution of average Chl *a* concentration in water column of Lake Ohrid

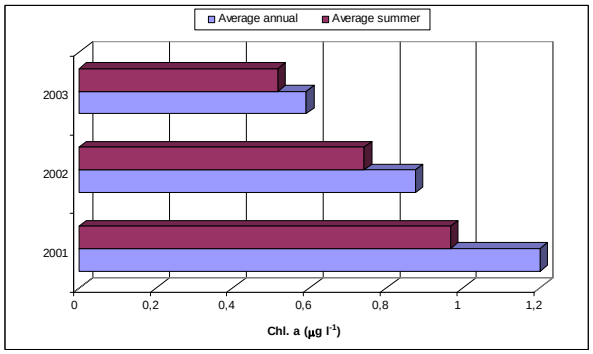

Figure 7. Average annual Chl *a* concentration in Lake Ohrid

Vertical distribution of chlorophyll *a* concentration was identical in the third investigated years what's more the highest average values were observed in 40 m depth and something lower in 30 and 20 m depth (Figure 8).

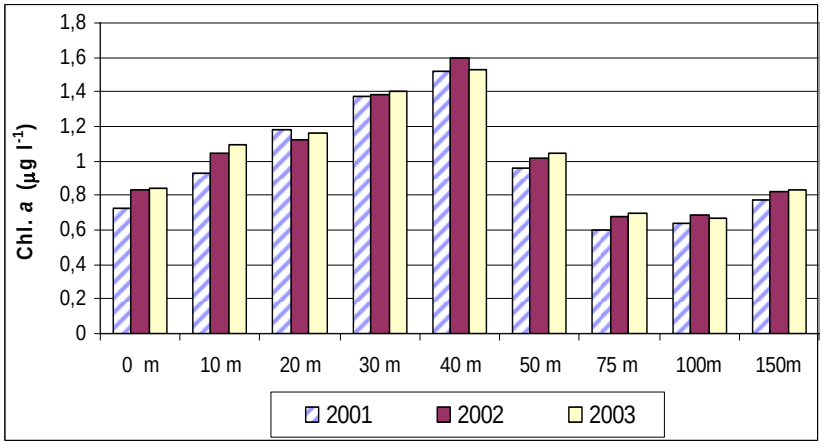

Figure 8. Average annual Chl *a* concentration in each of the investigated depth of Lake Ohrid

Average annual chlorophyll *a* concentration for the investigated water column of Lake Ohrid was the lowest in 2003 (0.52 µg l^{-1}), in 2002 was something higher (0.74 µg l^{-1}) and in 2001 reached value of 0.97 µg l^{-1}. Average summer chlorophyll *a* concentration in 2001 reached value of 1.21 µg l^{-1}, 0.88 µg l^{-1} was in 2002 and 0.59 µg l^{-1} in 2003 (Figure 7).

On the basis of the investigated parameters, trophic state of Lake Ohrid was determined. According to the fix boundary system of OECD (1982), Lake Ohrid is in oligotrophic state (Tab. 1). Values of Secchi depth belong to boundary values for ultraoligotrophic water as well as mean chlorophyll *a* concentration in 2002 and 2003 and maximum chlorophyll *a* concentration in 2003.

Table 1. Trophic state of Lake Ohrid in the period 2001-2003 expressed according to fix boundary system of OECD (1982

	Total phosphorus mean	Chl. *a* mean	Chl. *a* max	Secchi depth mean	Secchi depth min	Trophic category
		µg l^{-1}			m	
2001	5.55	1.21	4.18	15.67	13	Oligotrophic
2002	5.63	0.88	3.12	12.22	10	Oligotrophic
2003	5.09	0.59	2.05	13.52	12	Oligotrophic

Table 2. Trophic state of Lake Ohrid in the period 2001-2003 predicated on the average summer values based on Nürnberg (1996) and Forsberg & Ryding (1980) criteria

	Total nitrogen mean	Total phosphorus mean $\mu g\ l^{-1}$	Chlorophyll *a* mean	Secchi depth m	Trophic category
2001	446.67	5.46	0.57	17.17	Oligotrophic
2002	429.88	4.36	0.83	13.33	Oligotrophic
2003	401.22	5.25	0.68	13.2	Oligotrophic

According to the classification of Nürnberg (1996) and Forsberg & Ryding (1980) which are regard to summer period, Lake Ohrid is in oligotrophic state (Tab. 2). According the same classifications, only the values of total nitrogen deviated from the boundary values characteristic for definite trophic category and it probably due to the phosphorus limitation which exists in Lake Ohrid (Patceva et al. 2008).

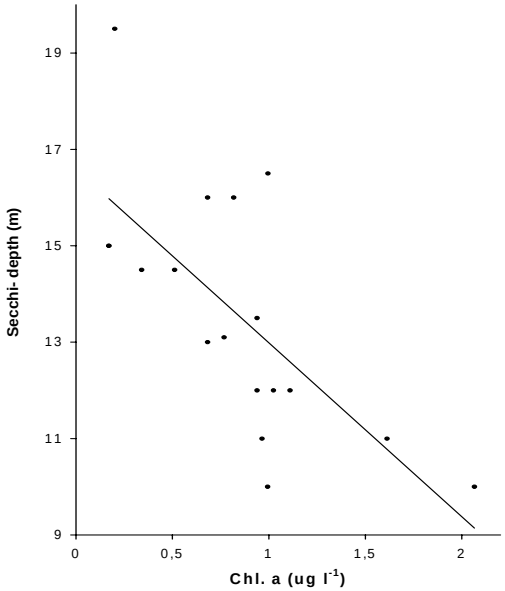

Figure 9. The relationship between Secchi depth and Chl *a* concentration in the surface water of Lake Ohrid ($r = -0{,}69$, $p < 0{,}001$)

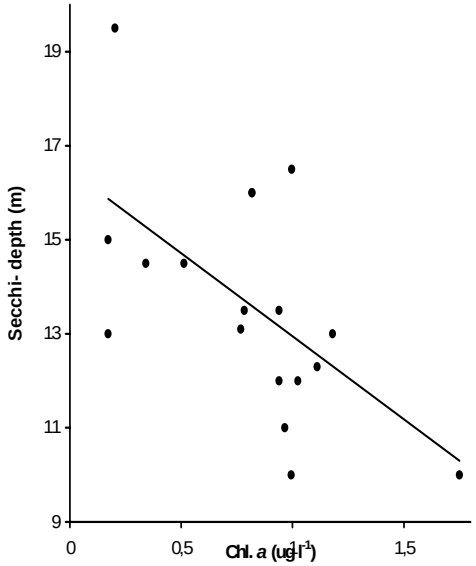

Figure 10. The relationship between Secchi depth and average Chl.a concentration in the water column of Lake Ohrid ($r = -0{,}59$, $p < 0{,}01$)

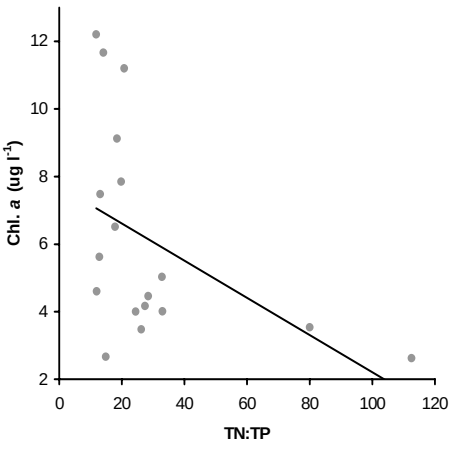

Figure 11. The relationship between average Chl.a concentration and TN:TP ratio in the water column of Lake Ohrid ($r = -0{,}48$, $p < 0{,}05$)

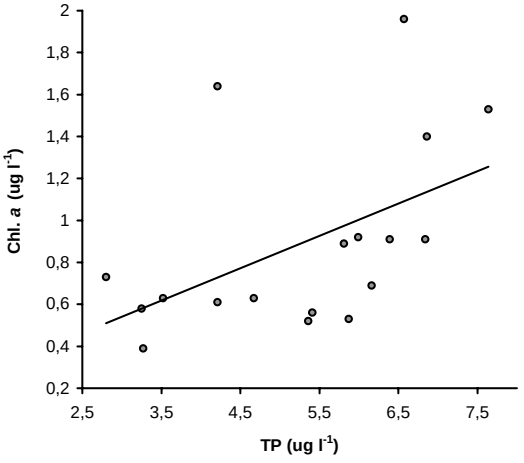

Figure 12. The relationship between average Chl *a* and total phosphorus concentrations in the water column of Lake Ohrid ($r = 0{,}50$, $p < 0{,}05$)

Chlorophyll *a* concentration and Secchi depth are both measures of trophic state in lakes. In many lakes Secchi depths are inversely proportional to Chlorophyll *a* concentration, reflecting the importance of phytoplankton in light absorbance and scattering (Carlson, 1977). This relationship was observed in Lake Ohrid. During the investigated period it was determined a highly significant, strong inverse correlation between Secchi depth and chlorophyll *a* concentration in the surface water of Lake Ohrid (Fig. 9). Also, it was determined a significant, strong inverse correlation between Secchi depth and average chlorophyll *a* concentration in the water column of Lake Ohrid (Fig. 10). It indicated that lake transparency mostly depend on chlorophyll *a* content in other words on phytoplankton biomass. In Lake Ohrid was determined a significant, strong correlation between average Chl *a* concentration and average TP concentration (Fig. 11) and a significant good inverse correlation between chlorophyll a and TN:TP ratio (Fig. 12). Forsberg & Ryding (1980) found identical relationship between those parameters in the investigated lakes. It indicate that in Lake Ohrid phosphorus is limiting nutrient of the phytoplankton growth and main factor of eutrophication process and TN:TP ratio is related with the lakes trophic state.

Conclusions

According to the results obtained during these investigations Lake Ohrid is in an oligotrophic state without clearly visible signs of eutrophication. The pelagic zone remains immune to the anthropogenic pressures that threatened these waters in previous decades.

According to the fix boundary system of OECD values of Secchi depth belong to boundary values for ultraoligotrophic waters as well as mean chlorophyll *a* concentration in 2002 and 2003 and maximum chlorophyll *a* concentration in 2003.

During the investigated period it was determined a highly significant, strong inverse correlation between Secchi depth and chlorophyll *a* concentration. It indicated that lake transparency mostly depend on chlorophyll *a* content in other words on phytoplankton biomass.

In Lake Ohrid was determined a significant, strong correlation between Chl *a* concentration and TP concentration and a significant good inverse correlation between chlorophyll *a* and TN:TP ratio.
It indicate that in Lake Ohrid phosphorus is limiting nutrient of the phytoplankton growth and main factor of eutrophication process and TN:TP ratio is related with the lakes trophic state.

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