

Preliminary Assessment of the Ecological Status of Some Tributaries of Lake Ohrid (Macedonian Part) Based on Diatom Community according to the Water Framework Directive

Tatjana Loshkoska¹, Sasho Trajanovski¹, Konstantin Zdraveski³, Suzana Patceva¹, Lirika Kupe², Elizabeta Veljanoska-Sarafiloska¹, Sonja Trajanovska¹ & Biljana Budzakoska Gjoreska¹

¹ PSI Hydrobiological Institute Ohrid, 50 Naum Ohridski Street, 6000 Ohrid, Republic of Macedonia; E-mail: tloskoska@hio.edu.mk, trajsa@hio.edu.mk, spatceva@hio.edu.mk, elizabetasarafiloska@yahoo.com, sonjat@hio.edu.mk, biljanab@hio.edu.mk

² Agricultural University of Tirana, Koder-Kamez, 1029 Tirana, Albania; E-mail: lirika_kupe@yahoo.com

³ Association for Ecology ECOMENLOG Ohrid, ASNOM zg. 3/1/3, 6000 Ohrid, Republic of Macedonia; E-mail: tincoz@yahoo.com

Abstract: The main aim of our study was to assess the water quality in the Lake Ohrid watershed (Macedonian part) based on diatom indices (Trophic Diatom Index and Saprobic Index) as defined by the EU Water Framework Directive. In addition, dissolved oxygen, dissolved organic matter and total phosphorus were measured. The study was carried out along the following tributaries of Lake Ohrid: Sateska, Koselska, Velgoshka, Rachanska and Cherava rivers and the Canal Studenchishta, as well as the outflow Crni Drim/ Drini River. The Saprobic Index ranged from 1.6 (oligo-β mesosaprobic class) to 1.9 (β mesosaprobic class) registered in the inflow of the Cherava River. The Trophic Diatom Index ranged from 1.6 (mesotrophic class) in the upper flow of the Sateska River and the middle flow of the Koselska River to 2.5 (eutrophic class) in the inflow of the Velgoshka River. The rivers Velgoshka and Cherava showed the highest pollution and negative influence on Lake Ohrid.

Key words: Lake Ohrid watershed, benthic diatoms, Trophic Diatom Index, Saprobic Index, ecological state

Introduction

Diatoms are usually the most abundant and most diverse group of algae in the composition of the phytobenthos (periphyton) of the aquatic ecosystems (BUCZKÓ & ÁCS 1994). The oligotrophic Lake Ohrid represents a unique ecosystem with numerous floristic and faunistic elements, including siliceous algae – diatoms (STANKOVIĆ 1960, ALBRECHT & WILKE 2008). The lake provides numerous services essential for human life (ZDRAVESKI et al. 2015). However, recently, significant loading with organic and inorganic matter of Lake Ohrid, originating from its tributaries, have been reported (VELJANOSKA-SARAFILOSKA 2002, MATZINGER et al. 2007, JORDANOSKI et al. 2008).

The ecological state of rivers is assessed based on long-term monitoring and the evaluation

of biological quality elements, as well as hydromorphological, and physical and chemical parameters, supporting the biological elements (EU 2000). During the last two decades, diatoms have gained considerable popularity throughout the world as a tool to provide an integrated reflection of water quality (ATAZADEH et al. 2007). Most of the diatom indices are designed to give an indication of general water quality (HARDING et al. 2004). LOSHKOSKA (2015) studied benthic diatoms of Lake Ohrid and its watershed and concluded that diatoms may potentially be useful in assessing the trophic state within the waters of the lake and its watershed.

The aim of this study was to assess for the first time the ecological state of some tributaries of Lake

Ohrid (Macedonian part) based on benthic diatoms as defined by the European Union (EU) Water Framework Directive (EU 2000).

Materials and Methods

The topographic watershed of Lake Ohrid comprises an area of 2,393 km², incorporating Lake Prespa (VOGEL et al. 2010). Lake Ohrid has 40 tributaries, 23 in the Albanian and 17 in the Macedonian territory. The largest rivers flowing into the lake are Sateska, Koselska and Cherava (in the Macedonian part) and the rivers Pogradeci and Verdova, with substantially lower flow (in the Albanian part). The outflow of Lake Ohrid is the Crni Drim/ Drini River.

The sampling was conducted at three localities (upper flow, middle flow and inflow) along the Crni Drim/Drini River and the Koselska River, and at two localities (upper flow and inflow) along each of the other studied tributaries (the rivers Sateska, Velgoshka, Rachanska, Cherava, and the Canal Studenchishta), in May 2013. In total, 16 samples from the six tributaries and the outflow Crni Drim/ Drini River, all in the Macedonian part, were collected.

The following chemical parameters were analysed: dissolved oxygen, measured according to the Winkler method (APHA 1980); dissolved organic matter (DOM) permanganate consumption, determined by digestion in acid and by titration (BETHEE 1953); and total phosphorus (TP), determined by the persulfuric oxidation method (MENZEL & CORWIN 1965, STRICKLAND & PARSONS 1972).

The basic substrate for diatom analysis was the periphyton on stones. The laboratory treatment,

preparation of permanent slides and identification of species were done according to the method and keys of KRAMMER & LANGE-BERTALOT (1986–1991). The assessment of water quality was conducted according to the requirements of the EU Water Framework Directive (EU 2000), following EN 13946:2003 and EN 14407:2004. Two diatom based indices were used: the Trophic Diatom Index (TI_{DIA}) and the Saprobic Index (SI), calculated by the formula of ZELINKA & MARVAN (1961). The water quality was classified according to ROTT et al. (1997, 1999, 2003). TI_{DIA} represents a useful monitoring tool for site assessments prior to designation of sensitive areas and proved to be generally applicable in the European rivers (KELLY & WHITTON 1995, KELLY et al. 2009); it is in correlation with the presence of inorganic matter in the water. SI classifies water quality based on loading of dissolved organic matter. The statistical analysis of the results was made using the software package IBM SPSS Statistics 19.

Results and Discussion

The waters from all sampling localities were quite well oxygen-saturated; the lowest values were registered at both localities along the Cherava River (8.51 mg l⁻¹ O₂ and 9.31 mg l⁻¹ O₂), while the highest values were along the rivers Sateska and Koselska, which might be due mostly to the higher water velocity of both tributaries, contributing to higher aeration. The dissolved organic matter (DOM) permanganate consumption varied from 2.06 mg l⁻¹ recorded in the Rachanska River (upper flow) to 8.06 mg l⁻¹ in the Velgoshka River (inflow) (Fig. 1). The highest value of total phosphorus was found in the inflow locality

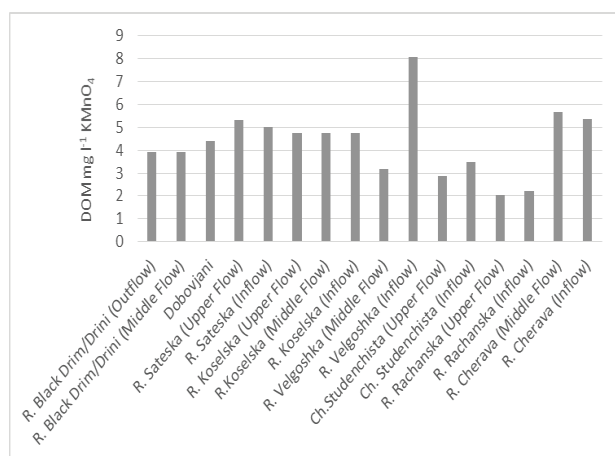


Fig. 1. Concentration of dissolved organic matter (DOM) permanganate consumption in the sampled tributaries and outflow of Lake Ohrid (Macedonian part), in May 2013

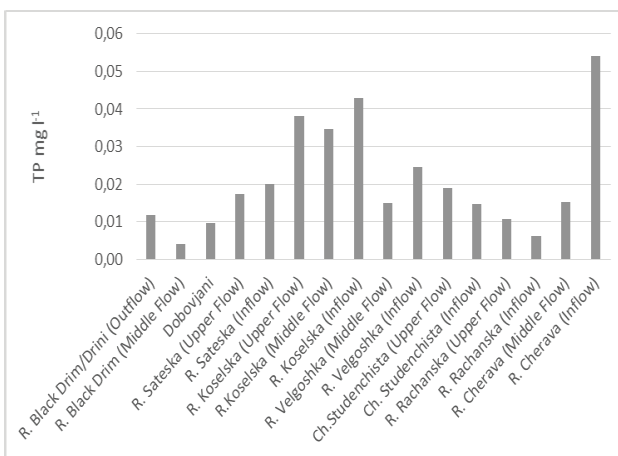


Fig. 2. Concentration of total phosphorus (TP) in the sampled tributaries and outflow of Lake Ohrid (Macedonian part), in May 2013

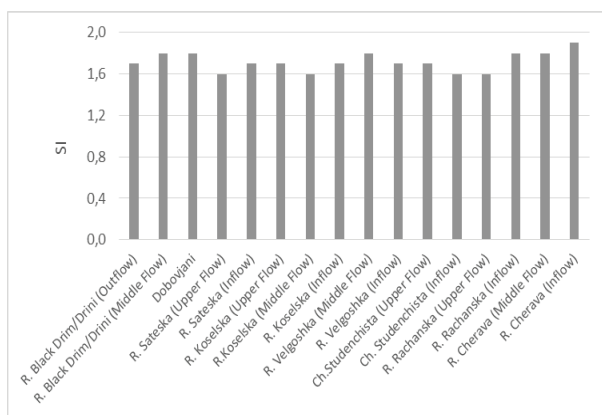


Fig. 3. The Saprobiic Index (SI) in the sampled tributaries and outflow of Lake Ohrid (Macedonian part), in May 2013

of the Cherava River (0.05 mg l^{-1}) followed by the sampling localities along the Koselska River, while the lowest value was in the middle flow locality of the Crni Drim/ Drini River (Fig. 2).

A total of 115 taxa of diatoms were recorded at the studied localities. Most of the species found at the localities in the Sateska River (upper flow) and the Koselska River (middle flow), such as: *Diatoma ehrenbergii* (Kützing, 1844), *Diatoma hyemalis* ((Roth) Heiberg, 1863), *Diatoma mesodon* (Ehrenberg) Kützing, 1844, *Gomphonema pumilum* ((Grunow) Reichardt & Lange-Bertalot, 1991), and *Navicula radiosa* (Kützing, 1844) are known as oligotrophic. Some mesotrophic to eutrophic species were registered as well: *Cocconeis pediculus* (Ehrenberg, 1838) in the Velgoshka River (middle flow and inflow); *Diatoma vulgaris* (Bory, 1824) at Dobovjani, the Crni Drim/ Drini River (middle flow), and the rivers Sateska (inflow) and Cherava (inflow); *Gomphonema olivaceum* ((Hornemann) Brébisson, 1838) in the Koselska River (upper flow) and the Canal Studenchishta (inflow); and *Rhoicosphaenia abbreviata* ((Agardh) Lange-Bertalot, 1980) at Dobovjani, the Crni Drim/ Drini River (middle flow), and the rivers Velgoshka (middle flow) and Cherava (inflow). The species *Nitzschia palea* ((Kützing) W. Smith, 1856) accompanied by other tolerant species as *Fragilaria ulna* ((Nitzsch) Lange-Bertalot, 1980) and *Gomphonema parvulum* ((Kützing) Kützing, 1849) were found at the localities along the rivers Velgoshka and Cherava.

The values of the Saprobiic Index (SI) were characterised by much lower variation, compared to the Trophic Diatom Index (TI_{DIA}), which values were more diverse across the sampling localities. The highest value of SI (1.9) was calculated for the Cherava River (inflow), while the lowest (1.6) for

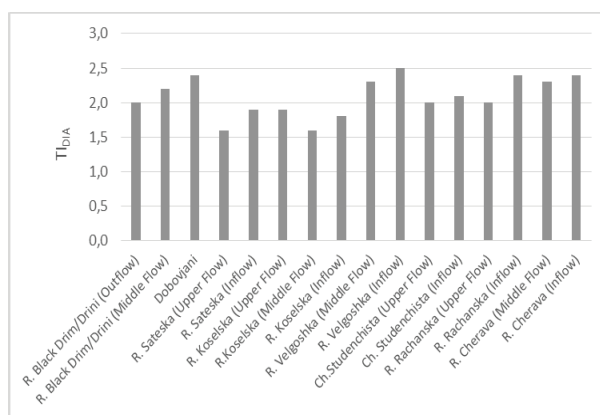


Fig. 4. The Trophic Diatom Index (TI_{DIA}) in the sampled tributaries and outflow of Lake Ohrid (Macedonian part), in May 2013

the upper flows of the rivers Sateska and Rachanska, the middle flow of the Koselska River and the inflow of the Canal Studenchishta (Fig. 3). The Saprobiic Index was estimated as 1.8 at the following localities: Dobovjani, the middle flow of the Crni Drim/ Drini River, Velgoshka, Cherava, and the inflow of the Rachanska River; all the respective localities were classified as β mesosaprobic. The values of TI_{DIA} varied from 1.6 in the upper flow of the Sateska River and the middle flow of the Koselska River to 2.5 in the inflow of the Velgoshka River (Fig. 4).

The water from the upper flow of the Sateska River was classified as mesotrophic, while the inflow part as meso-eutrophic. The studied localities are characterised by a great variation in the local living conditions, especially in regards to the origin and type of the sediments, as well as the chemical composition of water, which are important factors affecting the composition of the benthic diatom flora. The assessment of the changes in the natural habitats has indicated a decreased share of the benthic fauna from Lake Ohrid in the total fauna exchange with the waters from its watershed and a tendency of change in the correlation between endemic and cosmopolitan species (TRAJANOVSKI et al. 2015). Furthermore, the Sateska River has a developed hydrographic network and passes through a number of settlements and agricultural areas. The sediments, which precipitate in the littoral region of Lake Ohrid, represent the main problem of the river; most of the suspended particles are deposited in the river estuary, thus creating a small island.

Based on the TI_{DIA} , the water of the Koselska River was classified as mesotrophic in the middle flow and inflow to meso-eutrophic in its upper flow (1.9). These results can be explained by the landfill and the lower level of the river in its upper flow, the

water growing turbid due to the erosive sediments, and intake of different municipal and industrial waste along the river. The highest value of the TI_{DIA} was recorded in the Velgoshka River (inflow); all sampling localities along the rivers Velgoshka and Cherava were classified as eutrophic. The water supply of the Velgoshka River varies throughout the year depending on the weather conditions. Its basin in the lower reaches is a recipient of waste water from the sewage and the households in the area. Its trophic state reflects the uncontrolled disposal of different waste materials, use of fertilisers and pesticides in the surrounding agricultural areas, sediment load due to the low discharge during the summer period and the formation of temporal marshy waters. Most of the localities in Lake Ohrid watershed were classified as meso-eutrophic to eutrophic based on the TI_{DIA} .

Different diatom indices in Europe generally correlate with each other (SCHNEIDER et al. 2013). The correlation between TI_{DIA} and SI was significant at the 0.01 level, the Pearson coefficient (r) had the value of 0.729, $p=0.001$. There was a positive insignificant correlation between the values of SI and dissolved organic matter, $r = 0.070$, $p = 0.797$ (Fig. 5). The correlation of the obtained values for TI_{DIA} and TP indicated an inverse or negative insignificant correlation, $r = -0.218$, $p = 0.416$ (Fig. 6).

The diatoms are recommended as a monitoring tool in the rivers in the Republic of Macedonia (LEVKOV & KRSTIC 2002) and have also been used as bioindicators in the neighbouring countries (MIHO & LANGE-BERTALOT 2003, MIHO et al. 2006, KUPE & MIHO 2009, KRIZMANIĆ et al. 2015). The assessment of water quality based on diatoms in

the Albanian part of Lake Ohrid shows that the TI_{DIA} varies from 1.5 recorded in Tushemishti to 2.5 in Driloni (MIHO & LANGE-BERTALOT 2003). The results are explained as a direct consequence of potential high content of nutrients from urban settlements, agriculture and industry in the Driloni River. According to POULÍČKOVÁ et al. (2004), the assessments based on littoral diatoms may be useful for the evaluation of specific trophic situations and variations along the shores of lakes (point-pollution sources). The studies in Lake Ohrid suggest meso- to slightly eutrophic littoral ecosystem conditions where the total phosphorus (TP) concentrations are generally low. Three biotic metrics from three different organism groups (diatoms, macrophytes and macroinvertebrates) indicate at least some degree of eutrophication in the lake littoral, but none of those three biotic metrics correlate with the measured water TP concentrations (SCHNEIDER et al. 2014). According to the same authors, this is neither a discrepancy nor a sign of ‘poorly working biological indices’, but a consequence of ecosystem processes in the lake littoral.

During our study, the Saprobic Index in the tributaries and outflow of Lake Ohrid (Macedonian part) ranged from 1.6 (oligo-β mesosaprobic class) to 1.9 (β mesosaprobic class) in the inflow of the Cherava River, while the Trophic Diatom Index ranged from 1.6 (mesotrophic class) in the upper flow of the Sateska River and the middle flow of the Koselska River to 2.5 (eutrophic class) in the inflow of the Velgoshka River. According to our preliminary results of the assessment of ecological state based on diatom indices, the rivers Velgoshka and Cherava

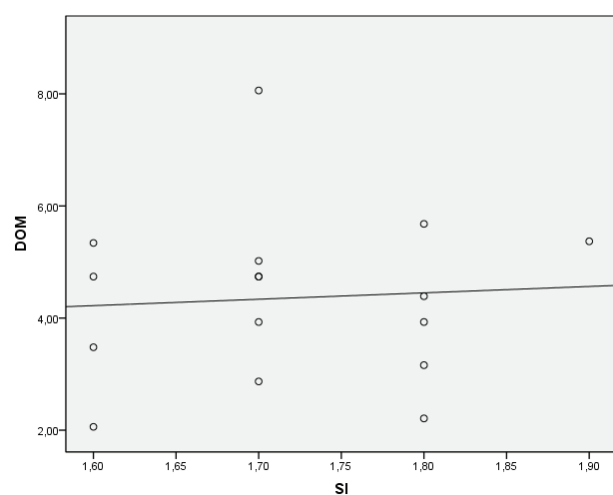


Fig. 5. Correlation between the Saprobic Index (SI) and the concentration of dissolved organic matter (DOM) in the sampled tributaries and outflow of Lake Ohrid (Macedonian part), in May 2013

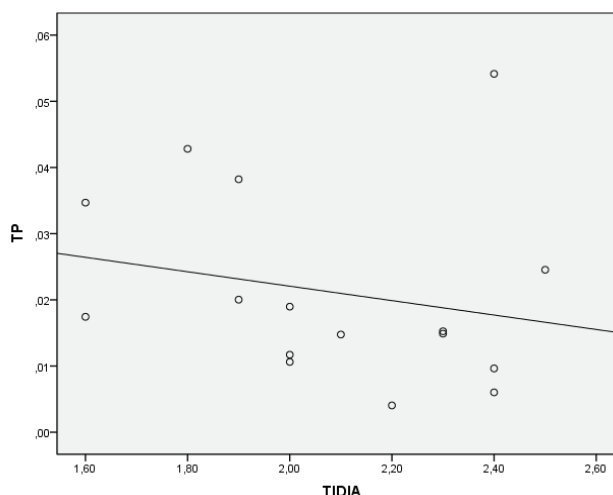


Fig. 6. Correlation between the Trophic Diatom Index (TI_{DIA}) and concentration of total phosphorus (TP) in the sampled tributaries and outflow of Lake Ohrid (Macedonian part), in May 2013

showed the highest pollution and negative influence on Lake Ohrid (Macedonian part). Both rivers are the end recipients of different liquid and solid waste. Our results also showed that more inorganic matter was entrained and transported along the tributaries compared to organic matter.

Further use of the benthic diatoms as sensitive bio-indicators and enhancement of the research methods for diatoms and diatom indices are recommended for monitoring of the water quality in the Lake Ohrid watershed.

References

- ALBRECHT C. & T. WILKE 2008. Ancient Lake Ohrid: biodiversity and evolution. *Hydrobiologia* 615: 103-140.
- APHA 1980. Standard methods for the examination of water and wastewater. 15th Edition Washington DC: APHA, AWWA, WPCF, 1134 p.
- ATAZADEH I., SHARIFI M. & KELLY M. G. 2007. Evaluation of the Trophic Diatom Index for assessing water quality in River Gharasou, western Iran. *Hydrobiologia* 589 (1): 165-173.
- BETHER G. 1953. Practical manual for determination of chemical composition of water. Belgrade: Institute of Hygiene of Serbia, No. 3, 78 p. (In Serbian)
- BUCZKÓ K. & ÁCS É. 1994. Algological studies on the periphyton in the branch-system of the Danube at Cikolasziget (Hungary). *Internationale Vereinigung für Theoretische und Angewandte Limnologie: Verhandlungen* 25 (3): 1680-1683.
- EU 2000. Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000, establishing a framework for Community action in the field of water policy. *Official Journal of the European Communities* 327, pp. 1-73.
- EN 13946:2003. Water quality. Guidance standard for the routine sampling and pretreatment of benthic diatoms from rivers. 14 p. Available at: http://standards.mackido.com/en-standards24_view_3175.html
- EN 14407:2004. Water quality. Guidance standard for the identification, enumeration and interpretation of benthic diatom samples from running waters. 12 p. Available at: http://www.standardsdirect.org/standards/standards1/Standards Catalogue 24_view_11733.html
- HARDING W. R., ARCHIBALD C. G. M., TAYLOR J. C. & MUNDREE S. 2004. The South African Diatom Collection: An Appraisal and Overview of Needs and Opportunities. WRC Report No. TT242/04. Water Research Commission, Pretoria.
- JORDANOSKI M., VELKOVA-JORDANOSKA L. & VELJANOSKA-SARAFILOSKA E. 2008. Ecological effects of River Sateska and its tributaries on ancient Lake Ohrid. *Natura Montenegrina* 7 (2): 541-547.
- KELLY M. G. & WHITTON B. A. 1995. The Trophic Diatom Index: a new index for monitoring eutrophication in rivers. *Journal of Applied Phycology* 7: 433-444.
- KELLY M. G., BENNETT C., COSTE M., DELGADO C., DELMAS F., DENYS L., ECTOR L., FAUVILLE C., FERREOL M., GOLUB M., JARLMAN A., KAHLERT M., LUCEY J., NÍ CHATHÁIN B., PARDO I., PFISTER P., PICINSKA-FALTYNOWICZ J., ROSEBERY J., SCHRANZ C., SCHAUMBURG J., VAN DAM H. & VILBASTE S. 2009. A comparison of national approaches to setting ecological status boundaries in phytobenthos assessment for the European Water Framework Directive: results of an intercalibration exercise. *Hydrobiologia* 621 (1): 169-182.
- KRAMMER K. & LANGE-BERTALOT H. 1986-1991. Bacillariophyceae. Bd 2/1: Naviculaceae, Bd 2/2: Bacillariaceae, Epithemiaceae, Surirellaceae, Bd 2/3: Centrales, Fragilariaceae, Eunotiaceae, Bd 2/4: Achnantheaceae. In: Ettl H., Gerloff J., Heynig H. & Mollehnauer D. (Eds.), *Süßwasserflora von Mitteleuropa*, Bd 2/1-2/4. Jena: Gustav Fischer.
- KRIZMANIĆ J., SUBAKOV SIMIĆ G., VIDAKOVIĆ D. & MARJANOVIĆ P. 2015. Water quality assessment of Vrutci Reservoir tributaries based on diatom indices. In: Poleksić V. & Marković Z. (Eds.), VII International Conference 'Water & Fish' Conference Proceedings, Belgrade, Serbia: University of Belgrade, Faculty of Agriculture, pp. 318-322.
- KUPE L. & MIHO A. 2009. Impact of urban pollution on the benthic diatom communities from Gjanica and Ishmi rivers. *Journal of International Environmental Application & Sciences* 4 (3): 272-277.
- LEVKOV Z. & KRSTIC S. 2002. Use of algae for monitoring of heavy metals in the River Vardar, Macedonia. *Mediterranean Marine Science* (3) 1: 99-112.
- LOSHKOSKA T. 2015. Benthic diatoms as a tool for assessment of the trophic status of Lake Ohrid and its watershed. MSc Thesis. Ohrid: PSI Hydrobiological Institute, University 'St. Kliment Ohridski', Bitola, 131 p. (In Macedonian, English summary)
- MATZINGER A., SCHMID M., VELJANOSKA-SARAFILOSKA E., PATCEVA S., GUSESKA D., WAGNER B., MÜLLER B., STURM M. & WÜEST A. 2007. Eutrophication of ancient Lake Ohrid: Global warming amplifies detrimental effects of increased nutrient inputs. *Limnology and Oceanography* 52 (1): 338-353.
- MENZEL D. & CORWIN N. 1965. The measurement of total phosphorus in seawater based on the liberation of organically bound by persulfate oxidation. *Limnology and Oceanography* 10 (2): 280-282.
- MIHO A. & LANGE-BERTALOT H. 2003. Considerations on biodiversity and trophic state of lake Ohrid (Albanian part) from a microscopic algae point of view. *Journal of Environmental Protection and Ecology* 4 (3): 543-549.
- MIHO A., ÇULLAJ A., LAZO V., HASKO A., KUPE L., SCHANZ F., BRANDL H. & BACHOFEN R. 2006. Assessment of water quality of some Albanian rivers using diatom-based monitoring. *Albanian Journal of Natural and Technical Sciences*, Academy of Sciences, Tirana, Albania, 19 (20): 94-105.
- POULÍČKOVÁ A., DUCHOSLAV M. & DOKULIL M. T. 2004. Littoral diatom assemblages as bioindicators of lake trophic status: A case study from perialpine lakes in Austria. *European Journal of Phycology* 39 (2): 143-152.
- ROTT E., HOFMANN G., PALL K., PFISTER P. & PIPP E. 1997. Indikationslisten für Aufwuchsalgen in Österreichischen Fließgewässern. Teil 1: Saprobienle Indikation. Wien: Wasserwirtschaftskataster, Bundesministerium für Land- und Forstwirtschaft, 73 p.
- ROTT E., PIPP E., PFISTER P., VAN DAM H., ORTLER K., BINDER N. & PALL K. 1999. Indikationslisten für Aufwuchsalgen in

- Österreichischen Fließgewässern. Teil 2: Trophieindikation sowie geochemische Präferenzen, taxonomische und toxikologische Anmerkungen. Wien: Bundesministerium für Land- und Forstwirtschaft, Wasserwirtschaftskataster, 248 p.
- ROTT E., PIPP E. & PFISTER P. 2003. Diatom methods developed for river quality assessment in Austria and a cross-check against numerical trophic indication methods used in Europe. *Algological Studies* 110 (1): 91-115.
- SCHNEIDER S. C., KAHLERT M. & KELLY M. G. 2013. Interactions between pH and nutrients on benthic algae in streams and consequences for ecological status assessment and species richness patterns. *Science of The Total Environment* 444: 73-84.
- SCHNEIDER S. C., CARA M., ERIKSEN T. E., BUDZAKOSKA GORESKA B., IMERI A., KUPE L., LOSHKOSKA T., PATCEVA S., TRAJANOVSKA S., TRAJANOVSKI S., TALEVSKA M. & VELJANOSKA SARAFILOVSKA E. 2014. Eutrophication impacts littoral biota in Lake Ohrid while water phosphorus concentrations are low. *Limnologica – Ecology and Management of Inland Waters* 44: 90-97.
- STANKOVIĆ S. 1960. The Balkan Lake Ohrid and its living world. *Monographiae Biologicae*, Den Haag: Dr. W. Junk Publishers, 357 p.
- STRICKLAND H. D. J. & PARSONS T. R. 1972. A practical handbook of seawater analysis. Ottawa: Fisheries Research Board of Canada, Bulletin No. 167 (2nd edition), 311 p.
- TRAJANOVSKI S., BUDZAKOSKA GJORESKA B., TRAJANOVSKA S. & ZDRAVESKI K. 2015. Habitat change-driving force for endemic/cosmopolitan ratio perturbation in the benthic fauna of ancient Lake Ohrid and its watershed. Review, PSI Hydrobiological Institute Ohrid, University 'St. Kliment Ohridski' Bitola, Republic of Macedonia, 43 (1): 116-130.
- VELJANOSKA-SARAFILOSKA E. 2002. Nitrogen and phosphorus loading in lake Ohrid influenced by rivers Velgoska and Koselska. MSc Thesis. Skopje: Faculty of Technology and Metallurgy, University 'Ss. Cyril and Methodius'. (In Macedonian, English summary)
- VOGEL H., WESSELS M., ALBRECHT C., STICH H.-B. & WAGNER B. 2010. Spatial variability of recent sedimentation in Lake Ohrid (Albania/Macedonia). *Biogeosciences* 7 (10): 3333-3342.
- ZDRAVESKI K., TRAJANOVSKI S., BUDZAKOSKA GJORESKA B. & TRAJANOVSKA S. 2015. The nature of ecosystem services valuation: Lake Ohrid – theory vs. reality. Review, PSI Hydrobiological Institute Ohrid, University 'St. Kliment Ohridski' Bitola, Republic of Macedonia, 43 (1): 147-156.
- ZELINKA M. & MARVAN P. 1961. Zur Präzisierung der biologischen Klassifikation der Reinheit fließender Gewässer. *Archiv für Hydrobiologie* 57: 389-407.