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OPEN

Ekológia (Bratislava)

Vol. 37, No. 1, p. 1–10, 2018
DOI:10.2478/eko-2018-0001

TROPHIC STATUS OF BLIDINJE LAKE (BOSNIA AND HERZEGOVINA) BASED ON THE DETERMINATION OF THE TROPHIC STATE INDEX (TSI)

ANITA IVANKOVIĆ*, NIKOLINA ĆOSIĆ, ZRINKA KNEZOVIĆ, VIŠNJA VASILJ

Faculty of Agronomy and Food Technology University of Mostar, Biskupa Čule bb, 88000 Mostar, Bosnia and Herzegovina; e-mail: anitaivankovic@gmail.com, nikolinacosic24@hotmail.com, knezovic.zrinka@tel.net.ba, visnjavasilj@yahoo.com

* Author for correspondence

Abstract

Ivanković A., Ćosić N., Knezović Z., Vasilj V.: Trophic status of Blidinje lake (Bosnia and Herzegovina) based on the determination of the trophic state index (TSI). Ekológia (Bratislava), Vol. 37, No. 1, p. 1–10, 2018.

Blidinje lake is an integral part of the Nature Park Blidinje established in 1995. Blidinje lake is largest mountain lake in Bosnia and Herzegovina (B&H) according to the surface and water supplies. Considering the surface, it is surprising to its low depth and large surface changes.
Eutrophication is defined as the 'biological effect of increasing concentrations of plant nutrients in aquatic ecosystems'. Eutrophication results in increased primary production or the production of aquatic plants. It can adversely affect the suitability of the use of water resources for other purposes. Metabolism of shallow lakes is extremely specific such as classical connections; algal biomass with a load of nutrients in shallow lakes can have catastrophic effects.
Nutrients that come directly or indirectly into water lead to increase in the amount of algae as well as changes in the composition of phytoplankton, where there is suppression of diatoms and green algae by cyanobacteria.
The values of parameters assessing trophic index (Trophic State Index [TSI]) are total phosphorus, chlorophyll a and transparency. This method that generalises numerous data using mathematical equations allows the expression of trophic level.
On the basis of earlier studies on physical and chemical parameters of water quality in Blidinje lake, Carlson trophic index was calculated, and based on that assessment, trophic level is given.

Key words: eutrophication, trophic index, total phosphorus, transparency, chl-a.

Introduction

The Blidinje lake is an integral part of Blidinje Nature Park founded in 1995. It is the largest mountain lake in Bosnia and Herzegovina (B&H) (Spahić, 2001) and occupies 364 km^2 of the surface (Šimunović, Bognar, 2005). The main factors influencing the formation of lakes are devastation of forests and anthropogenic flooding of the abyss.

The lake is under strong influence of meteorological conditions. The amount of water in the lake depends on the amount of rainfall and the rate of water sinking (Musa, 2005). The

lake is very shallow with an average depth of 0.3–1.9 m. The ratio of lake surface during high water and surface lakes during low water level is 3.6:2.5 km^2. The transparency of water is 15 cm, because a large amount of suspended particles blurs water (Spahić, 2001).

Blidinje Nature Park is under the influence of the mountain climate, with fresh summers lasting from early June to September. Above 1,700 m above sea level, there are parts with 'everlasting snow'. Precipitation is most prevalent in the fall and early spring, and the mean annual temperatures vary and range from 1.2 to 11.2 °C (Soldo, 2005).

Eutrophication is the biological effect of increasing nutrient concentrations in aqueous ecosystems (Harper, 1992). By increasing the concentration of nutrients, it increases the primary production, that is, the development of phytoplankton. Increased phytoplankton development leads to an increase in the amount of organic substance that is bactericidal, oxygen concentration reduction and increased release of sedimentary nutrients. This nutrient increase allows algae production, resulting in reduced transparency and water staining. This process can be natural or anthropogenic (Welch, 1980).

Nutrients that come directly or indirectly into water lead to an increase in the amount of algae, that is, to increase the amount of cyanobacteria. Carlson (1977) uses algal biomass as the basis for determining the trophic state. The amount of chlorophyll, the transparency and the total phosphorus are three variables that affect each other and algae biomass independently.

On the basis of earlier researches on physicochemical water quality indicators of Blidinje lake and Carlson's TSI, Blidinje lake is classified into certain categories of trophy, as opposed to the OECD (1982) classification which provides only a descriptive estimate of the level of trophy (US EPA, 2000).

Carlson's Trophic State Index (Tidal Index – TSI)

The trophic state is defined as the total mass of living biological material (biomass) in the aquatic area at a given site at a given time. The trophic state arises in response to an increased amount of nutrients (Naumann, 1929). And the amount of nutrients can affect the annual life time, drinking water and mixing water.

Carlson (1977) uses algae biomass as the basis for determining the trophic state. The amount of chlorophyll, the depth and the total phosphorus are three variables that affect algal biomass and thus affect the determination of the trophic state of any aqueous area. Chlorophyll is preferred because it is the most accurate predictor of algal biomass. According to Carlson (1977), total phosphorus can be a better indicator of chlorophyll for predicting the summer trophic state than winter patterns, and transparency should only be used if no other method is available.

The index can be easily calculated and used. Carlson (1977) has formed three equations that mathematically calculate the degree of trophy:

$$\mathrm{TSI\ (SD)} = 10 \times \left(6 - \frac{\ln SD}{\ln 2}\right),$$

where SD is the secchi depth in metres (m)

$$TSI\ (Chl\text{-}a) = 10 \times \left(6 - \frac{2.04 - 0.68 \ln Chl\text{-}a}{\ln 2}\right),$$

where Chl-a is the concentration of chlorophyll a in mg/m^3

$$TSI\ (TP) = 10 \times \left(6 - \frac{\ln \frac{48}{TP}}{\ln 2}\right),$$

where TP is the concentration of total phosphorus in mg/m^3.

Logarithmic data transformation allows the use of statistical parameters (mean, standard deviation and parametric comparison of tests). This makes it easier not only to compare and reduce data but also to communicate because the user does not have to use graphs with logarithmic sections (Carlson, 1977).

In addition to Carlson's equation (1977), he compiled a systematic table according to which the index range is 0–100, although the index does not theoretically have lower and upper bounds.

Carlson defines the trophic index using every doubling of algae biomass as a benchmark for dividing each state, that is, every time the biomass concentration doubles because of a basic scale, a new trophic state emerges. Owing to the reciprocal relationship between the biomass concentration and the transparency measured by the Secchi disk, any duplication of biomass results in a split of transparency values. The zero dot in the table corresponds to the value greater than ever measured by the Secchi disc. The largest transparency of 41.6 m was measured in lake Masyuko in Japan. The next largest integer on the log 2 rank is 64. Then the transparency equation was formed (Table 1).

The scale is presented numerically, not nomenclature. A small number of nomenclature categories leads to loss of information, because a large number of lakes are classified together and susceptible to a change in the trophic state. This scale classifies lakes into more than 100 categories, giving more accurate information on the trophy lake condition (Carlson, 1977).

The trophy index gains value when it can be related to certain events in the water area as shown in the table. Lakes with TSI values of less than 40 are usually classified as oligotrophic, 40–50 as mesotrophic and 50–70 as eutrophic, and if the value is greater than 70, then it is hypertrophic lake. Table 2 shows the classification of the lake according to Carlson's trophic index and the characteristics of a particular category (Carlson 1983, Carlson, Simpson, 1996).

The main advantage of the TSI is that the relationship between the variables can be used to identify certain conditions

Table 1. TSI and its parameters (Carson 1977).

TSI	Secchi disk (SD)	TP	Chl-a
0	64	0.75	0.04
10	32	1.5	0.12
20	16	3	0.34
30	8	6	0.94
40	4	12	2.6
50	2	24	6.4
60	1	48	20
70	0.5	96	56
80	0.25	192	154
90	0.125	384	427
100	0.064	768	1183

Table 2. Lake classification according to Carlson's trophic state index (Carlson, Simpson, 1996).

TSI	Attributes	Water Supply
<30	**Oligotrophy:** Clear water, oxygen throughout the year in the hypolimnion	Water may be suitable for an unfiltered water supply
30–40	Hypolimnia of shallower lakes may become anoxic	
40–50	**Mesotrophy:** Water moderately clear; increasing probability of hypolimnetic anoxia during summer	Iron, manganese, taste, and odour problems worsen. Raw water turbidity requires filtration
50–60	**Eutrophy:** Anoxic hypolimnia, macrophyte problems possible	
60–70	Blue-green algae dominate, algal scums and macrophyte problems	Episodes of severe taste and odour possible
70–80	**Hypereutrophy:** (light limited productivity). Dense algae and macrophytes	
>80	**Oligotrophy:** Clear water, oxygen throughout the year in the hypolimnion	Water may be suitable for an unfiltered water supply

Table 3. Interpretations of deviations of the index values (Carlson, 1983).

Relationship between TSI Variables	Conditions
TSI(Chl) = TSI(TP) = TSI(SD)	Algae dominate light attenuation; TN/TP = 33:1
TSI(Chl) > TSI(SD)	Large particulates, such as *Aphanizomenon* flakes, dominate
TSI(TP) = TSI(SD) > TSI(Chl)	Non-algal particulates or colour dominate light attenuation
TSI(SD) = TSI(Chl) > TSI(TP)	Phosphorus limits algal biomass (TN/TP > 33:1)
TSI(TP) >TSI(Chl) = TSI(SD)	Algae dominate light attenuation but some factor such as nitrogen limitation, zooplankton grazing or toxics limit algal biomass

in the lake that limit algal biomass growth or affect the measured variables. As the relationships between variables derived from regression relationships and correlations are not perfect, the variability between the index values can be expected. However, in some situations, these variations are not random and the factors that interfere with this empirical relationship can be identified (Carlson, 1981). Table 3 gives some possible interpretations of the index deviation (Carlson, 1983).

Material and methods

Determination of sampling locations

Surface water samples were taken at five stations located along the lakeshore (Fig. 1). Surface water sampling was the appropriate method, given the fact that water in shallow lakes is often mixed and there is no vertical stratification (Rocha et al., 2009). Water samples are taken two weeks in the period May to November in 2008. Some parameters have not been monitored for some months (Ivanković et al., 2011).

All water quality parameters are determined in accordance with the APHA methodology (APHA, 1998). Accuracy of each method is prescribed by the APHA methodology. Dense depth (using Secchi disk) was measured directly at the sampling points. Ultraviolet–visible (Shimatzu) was used for analysing phosphate and total phosphorus content (λ = 690 nm). The chlorophyll content was determined by a fluorimetric method (TURNER TD-700, Sunnyvale, CA) at wavelength of 365 nm using 90% acetone as extraction solvent (Jeffrey et al., 1997).

Data analysis

From the data for chlorophyll, the transparency and total phosphorus according to the research by Ivanković (2010) determined the trophic status of Blidinje lake. The trophic state index (TSI) is obtained by incorporating data for these three parameters into the corresponding Carlson (1977) equation. The obtained results enabled the determination of Blidinje lake trophy category based on the criteria given in Tables 1 and 2. (Carlson, 1977). A certain relationship between individual parameters was observed using Table 3 (Carlson, 1983).

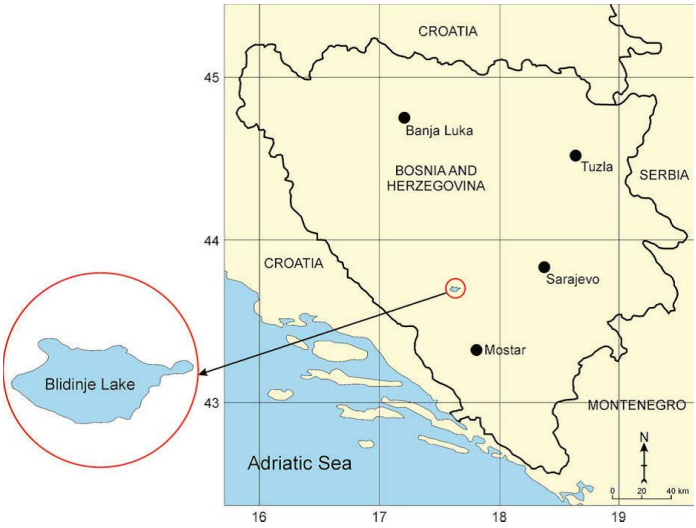

Fig. 1. Location of Blidinje lake on the map of B&H with noticed sampling locations (Ivanković, Hafner, 2012).

Results and discussion

Carlson's Trophic State Index – Secchi Depth

Blidinje lake is a shallow mountain lake of shady water, which varies throughout the day depending on the direction and speed of the wind. At different locations, there are different micro-conditions and different values of the same variables are possible at the same time (Ivanković et al., 2011).

Transparency of Blidinje lake is very low, especially from June to September. The minimum measured transparency at all locations is 10 cm and the largest is 50 cm, measured at locations 4 and 5. The average transparency is 22.81 cm, according to Harper (1992), indicates the eutrophic/hypertrophic status of Blidinje lake, which according to other relevant The indicators of the trophy are not so. There is no big difference in the measured translucency between individual locations. Everywhere, the transparency is reduced, and the reason is the suspended matter, not the density of phytoplankton (Ivanković et al., 2011).

According to Table 1, based on Carlson's Trophic State Index (TSI) values, the data is greater than 60. By entering the data into the Carlson equation, this is confirmed, so the lowest value of TSI (SD) is 69.99, and the highest is 93.18. The average value of TSI (SD) is 82.71. The differences in TSI (SD) depending on the location are very small.

These values of Blidinje lake are in the category of hypertrophic lake (Fig. 2). From June to September, when the transparency is significantly reduced, the TSI (SD) is very high and points to the hypertrophic state of the lake when it is possible to flourish the algae and eliminate fish, but this does not happen because other relevant indicators do not have hypertrophic values.

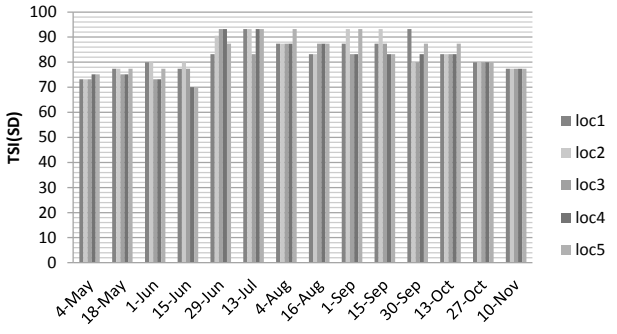

Fig. 2. Trophic state index – secchi depth.

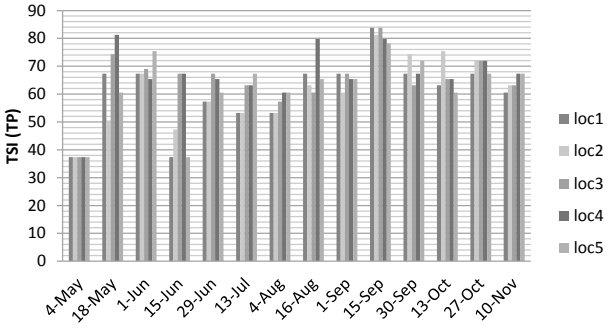

Fig. 3. Trophic state index – total phosphorus (nonfiltered).

Carlson's Trophic State Index – Phosphorus

Values of total phosphorus of non-filtered samples from Blidinje lake vary from 0.01 mg/L (10 μg/L), which is the lowest measured value for all sites at the same time (4 May 2008), up to 0.25 mg/L (250 μg/L), which is the highest measured value at location 3. Values very depending on the location and time in which samples are collected (Ivanković et al., 2011). The highest measured values of total phosphorus of Blidinje lake correspond to hypertrophic waters (>0.1) according to Harper (1992). Most measured values belong to the area of moderately eutrophic waters, whilst some of the least measured values correspond to the mesotrophic waters according to the same classification. According to Brancelj (2002), it is occasionally possible to record high values of total phosphorus even in oligotrophic waters.

According to this data for the total phosphorus of unfiltered samples, the Carlson TSI values for phosphorus is between 30 and 90 (Table 1), which classifies the Blidinje lake in the oligotrophic to hypertrophic (Table 2) categories depending on the location and time of sampling. Owing to the properties of shallow lakes that have a very intense interaction of water–sediment, large variations in total phosphorus values are possible.

By incorporating the data obtained into the Carlson equation for TSI (TP), the lowest value of TSI (TP) was calculated from 37.35 for May 4 at all locations (Chart 2). According to this value, the lake belongs to the category of oligotrophic lake, which occasionally in some locations may remain without oxygen in the summer (Table 2). The highest calculated value for September 15 at locations 1 and 3 is 83.77. This value sets the lake into a group of hypertrophic lakes (Table 2). The average calculated value of the TSI (TP) is 63.29, and according to this, the Blidinje lake belongs to the category of eutrophic lake (Table 2). Carlson›s TSI values for the total phosphorus of unfiltered samples depend on the location and time of sampling.

Phosphates of filtered samples were not recorded on several occasions during May, June and July. The lowest recorded value was 0.01 mg/L (10 μg / L) on several occasions at all sites, and the highest was recorded on May 18 at site 2 and August 15 at site 3 and was 0.23 mg/L (230 mg/L) (Ivanković et al., 2011). The mean value is 0.0384 mg/L (38.4 μg/L). This form of phosphorus is the only form available for algae for photosynthesis processes (Brancelj, 2002). All measured values of dissolved reactive phosphorus correspond to the mesotrophic category (Harper, 1992), except the values obtained for March 18 at location 2 and July 15 at locations 1, 3 and 4, belonging to the hypertrophic category according to Harper (1992).

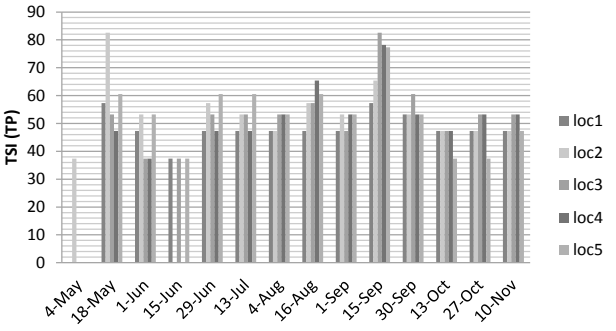

Fig. 4. Trophic state index – total phosphorus (filtered).

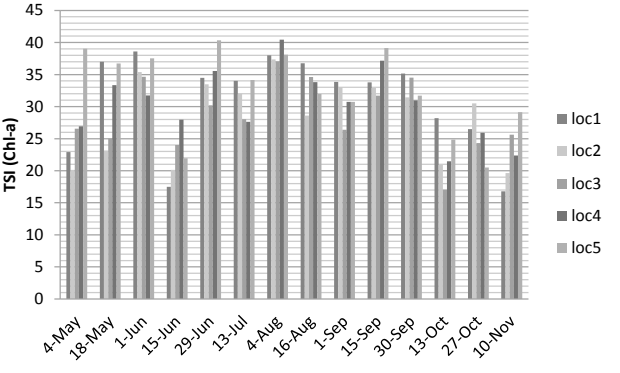

Fig. 5. Trophic state index – chlorophyll a.

According to the concentrations of total phosphorus, Blidinje lake is mesotrophic/eutrophic. This is probably due to the large amount of reactive phosphorus that binds solid particles of suspended matter and is thus inhibited.

According to Table 1, the obtained total phosphorus concentrations mostly correspond to TSI (TP) values from 40 to 70, which belong to a mesotrophic/eutrophic category (Table 2). The TSI (TP) calculated using Carlson's equation ranges from 37.35 to 82.56. The average value is 52.35. According to Figures 3 and 4, there is enough oscillation of the TSI (TP) depending on the location and time of sampling. However, most of the calculated TSI (TP) values at all lake locations are in the mesotrophic category (TSI) (TP) is 40–50) or eutrophic (TSI (TP) is 50–60) of lakes (Table 2). Only a couple of times during the year, high TSI (TP) (>70) was calculated at certain locations according to which the lake would fall into the category of hypertrophic lakes (Table 2).

Carlson's Trophic State Index – Chlorophyll a

The chlorophyll concentration ranges from 0.24 to 2.73 mg/m^3. The mean value is 1.15 mg/m^3. Although there is a large difference between concentrations measured at the same time

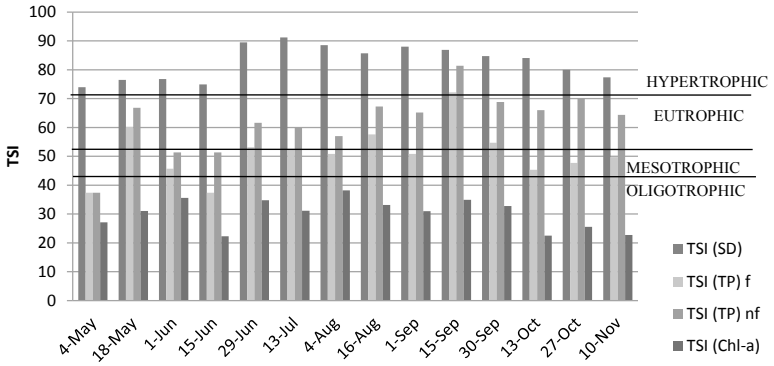

Fig. 6. Average TSI values for trophic indicators over the observed period.

at different locations, most of the measured values point to the oligotrophic status of lakes by many authors (Ivanković et al., 2011).

TSI (Chl-a) ranges from 16.78 to 40.44. The average value is 30.19 (Fig. 5). All calculated values at all locations rank Blidinje lake in the category of oligotrophic lakes with extremely clear water (Table 2).

Comparison and interpretation of results (relation between individual variables)

By comparing the mean values of the calculated TSI for transparency, total phosphorus and chlorophyll, it is apparent that each determines the trophic status of the lake and is not about the same or dependent on each other. Low TSI (Chl), High TSI (TP) and Highly High TSI (SD) (Fig. 6) cannot blend the Blidinje lake into the same category of trophy.

Considering that this is a shallow lake with a large amount of suspended matter (Ivanković, 2010) located on a limestone base, it cannot be classified into a given category for the value comparison shown in Table 3. However, most of the values are closest to the TSI (TP) = TSI (SD)> TSI (CHL) → no algae or colouring particles and light reduced to what has been the case with previous research (Ivanković, Hafner, 2012).

The TSI (Chl-a) is in the oligotrophic range throughout the test period, whilst TSI (TP) is mostly in mesotrophic and eutrophic waters and TSI (SD) is in hypertrophic waters (Table 2), Very low TSI (Chl-a) corresponds to a very high transparency up to a few metres of depth, and a low concentration of total phosphorus, but in the case of Blidinje lake, there are no such conglomerates.

According to Scheffer (2004), total phosphorus as a traditionally applied indicator for describing the level of trophy is not the best choice for shallow lakes where the water–sediment interaction is more pronounced. The dissolved reactive phosphor binds itself to solid suspended particles and is thus inhibited, algae cannot be used for the photosynthesis process, and this is the reason for its high concentration in samples, that is, high TSI (TP). And this also contributes to the reduction of transparency.

TSI (Chl-a) is low all the time during the test and indicates the oligotrophic state of the lake. This state of affairs should correspond to a clear transparency, that is, a low TSI (SD). In Blidinje lake, this is not the case, and the reason for the high TSI (SD) is a large amount of suspended matter rather than the phytoplankton density. Such a relationship between transparency and chlorophyll is common in limnology of shallow lakes of varying volumes, where the surface is subject to strong wind influences which constantly leads to resuspension of the precipitate (Engel, Nichols, 1994). Although there is no data on the macrophytes of Blidinje lake, it is evident that the lake is not rich in macrophytes (Ivanković, Hafner, 2012). According to Scheffer (2004), the lack of macrophytes contributes to blurredness, reduced transparency and increased resuspending of the sediment. Long, cold winter with ice cover also contribute to the lack of macrophytes in Blidinje lake (Ivanković et al., 2011).

The TSI (Chl-a) is low and fairly uniform all the time (Fig. 6) and at all locations (Fig. 5), indicating that Blidinje lake has no trend of increase in primary production and does not affect other trophies.

Conclusion

Wind, geological base and mountain character are the factors that affect the physical and chemical properties of the lake. The lake is shallow and exposed to the wind making it suitable not only for fishing but also for recreation and sport.

Blidinje lake has very low transparency, respectively, high TSI (SD), which would place it in hypertrophic lakes, whilst other relevant parameters do not show it. The reason for such a high TSI (SD) is the large amount of suspended particles, not the high TSI (Chl). TSI (Chl-a) and TSI (TP) (soluble phosphorus is the only phosphorus form that can be used by photosynthesis algae) in the lake indicate that it is oligotrophic/mesotrophic. Such a relationship between transparency and chlorophyll is common in limnology of shallow lakes of varying volumes, where the surface is subject to strong wind influences that constantly leads to resuspension of the precipitate. TSI (Chl-a) is all the time consistent, indicating that the lake has no trend of increasing primary production.

TSI (TP) is high, indicating eutrophic status, the reason being the separation of phosphorus that is absorbed from particles of suspended matter. Because the lake is shallow, this condition can be quickly changed. TSI (Chl) can be taken as the most relevant indicator for determining the status of Blidinje lake trophy. The slowdown of the eutrophication process is influenced by factors such as altitude, mountain climate and very rainy area. The trophic status of the lake may be useful for warning, monitoring and prediction. Data and information obtained by monitoring have a particular importance for the formation of different prognostic models and ecological modelling.

References

APHA (American Public Health Association) (1998*). Standard methods for the examination of water and wastewater.* Washington.

Brancelj, A. (Ed.). (2002). *High-mountain lakes in the eastern part of the Julian Alps*. Ljubljana: Založba ZRC.

Carlson, R.E. (1977). A trophic state index for lakes. *Limnol. Oceanogr*., 22(2), 361–369. DOI: 10.4319/lo.1977.22.2.0361.

Carlson, R.E. (1981). Using trophic state indices to examine the dynamics of eutrophication. In *Proceedings of the International Symposium on Inland Waters and Lake Restoration* (pp. 218–221). U.S. Environmental Protection Agency.

Carlson, R.E. (1983). Discussion on "Using differences among Carlson's trophic state index values in regional water quality assessment". *Water Resour. Bull.*, 19, 307–309. DOI: 10.1111/j.1752-1688.1983.tb05335.x.

Carlson, R.E. & Simpson J.A. (1996). *Coordinator's guide to Volunteer lake monitoring methods*. North American Lake Management Society.

Engel, S. & Nichols S.A. (1994). Aquatic macrophyte growth in a turbid windswept lake. *J. Freshw. Ecol.*, 9, 97–109. DOI: 10.1080/02705060.1994.9664436.

Harper, D. (1992). *Eutrophication of freshwaters*. London: Chapman & Hall.

Ivanković, A. (2010). *Physico-chemical and biological characteristics of Blidinje lake.* Faculty of Agronomy and Food Technology, University of Mostar, Doctoral Thesis.

Ivanković, A., Velagić Habul, E. & Knezović Z. (2011). Physico-chemical characteristics of shallow, high mountain lake Blidinje (in a karst area of Bosnia and Herzegovina) with emphasis on its trophic status. *Oceanological and Hydrobiological Studies*, 40(3), 19–27. DOI: 10.2478/s13545-011-0025-4.

Ivanković, A. & Hafner D. (2012). Water quality assessment of the Blidinje shallow high mountain lake in Bosnia and Herzegovina, based on its biological properties. *Ekológia (Bratislava)*, 31(3), 295–308. DOI: 10.4149/ekol_2012_03_295.

Jeffrey, S.W., Mantoura, R.F.C. & Wright S.W. (1997). *Phytoplankton pigments in oceanography: guidelines to modern methods*. Paris: UNESCO Publishing.

Musa, S. (2005). Geomorphological specifications of Blidinje Nature Park (in Croatian). In *International Scientific Symposium Blidinje* (pp. 93–120). Mostar: Faculty of Civil Engineering.

Naumann, E. (1929). The scope and chief problems of regional limnology. *International Revue der Gesamten Hydrobiologie und Hydrographie*, 22(1), 423–444. DOI: 10.1002/iroh.19290220128.

OECD (1982). *Eutrophication of waters. Monitoring, assessment and control*. Paris.

Rocha, R.R.A., Thomaz, S.M., Carvalho, P. & Gomes L.C. (2009). Modeling chlorophyll-α and dissolved oxygen concentration in tropical floodplain lakes (Paraná River, Brazil). *Braz. J. Biol.*, 69(Suppl. 2), 491–500. DOI: 10.1590/S1519-69842009000300005.

Scheffer, M. (2004). *Ecology of Shallow lakes*. Dordrecht, Boston, London: Kluwer Academic Publishers.

Soldo, V. (2005). Research on habitat conditions and establishment of economic capacity for the cultivation of wild game species in Blidinje Nature Park (in Croatian). In *International Scientific Symposium Blidinje* (pp. 211–260). Mostar: Faculty of Civil Engineering.

Spahić, M.I. (2001). *Natural lakes of Bosnia and Herzegovina (in Bosnian).* Limnological monograph. Tuzla: Harfo-Graf.

Šimunović, V. & Bognar A. (2005). Geomorphological features of Blidinje Nature Park (in Croatian). In *International Scientific Symposium Blidinje* (pp. 25–40). Mostar: Faculty of Civil Engineering.

US EPA (2000). *Nutrient criteria technical guidance manual lakes and reservoirs*. EPA-822-B00-001. Washington: U.S. Environmental Protection Agency, Office of Water, Office of Science and Technology.

Welch, B.E. (1980). *Ecological effects of waste water*. Cambridge: Cambridge University Press.