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Physico-chemical characteristics of shallow, high mountain Lake Blidinje (in a karst area of Bosnia and Herzegovina) with emphasis on its trophic status

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Key words: shallow mountain lakes, nutrients, trophic state

Abstract

This paper presents data on the physico-chemical characteristics of lake water from May to November, the period without ice cover. Chlorophyll *a* was monitored over two years from May to November (2006 and 2007). Water was sampled at five locations in the lake's littoral zone. The following parameters were investigated: temperature, dissolved oxygen, oxygen saturation, pH, total dissolved solid (TDS), Secchi depth (transparency), turbidity, suspended matter, conductivity, total hardness, alkalinity (bicarbonates), acidity, concentrations of nitrite (NO_2^-), nitrate (NO_3^-), ammonium (NH_4^+), total nitrogen (TN), sulphate (SO_4^{2-}), total iron (Fe), silica (SiO_2), phosphate (PO_4^{3-}), total phosphorous (TP) and chlorophyll *a*. Data were statistically analyzed.

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INTRODUCTION

Lake Blidinje, with an area of 3.2 km² (Šimunović & Bognar 2005), is the biggest mountain lake in Bosnia and Herzegovina (Spahić 2001) (Fig. 1). The lake is highly variable in volume and surface area. The literature reports Blidinje Lake's area as ranging from 2.5 km² (Slišković et al. 2005) to 6.05 km² (Razdorov et al. 1990, Šimunović and Bognar 2005, Slišković et al. 2005)

The lake is located at an altitude of 1185 m (N 43°36'; E 17°29'). It is very shallow with an average depth of from 0.3 m (Spahić 2001) to 1.9 m (Slišković et al. 2005, Šimunović & Bognar 2005), and is under the strong influence of meteorological conditions. Duration of ice cover depends on weather conditions, but the average duration is four to five months (Fig. 2). Lake Blidinje is an integral part of the Nature Park "Blidinje" founded in 1995 (Fig. 3).

The aim of this study was to increase knowledge of Lake Blidinje (including defining its trophic status), to prevent its further degradation, promote its sustainable management, and contribute to the protection of the wider area. Although Blidinje Lake is the largest mountain lake in Bosnia and Herzegovina, the physico-chemical properties of its water have not been investigated systematically.

MATERIALS AND METHODS

Samples were taken at the surface at five stations located along the shore of the lake. Water sampling from the surface was adequate due to the fact that shallow lakes are frequently mixed and nonstratified (Rocha et al. 2009). Water samples were taken fortnightly during the period from May to November during 2008. Physico-chemical analyses were carried

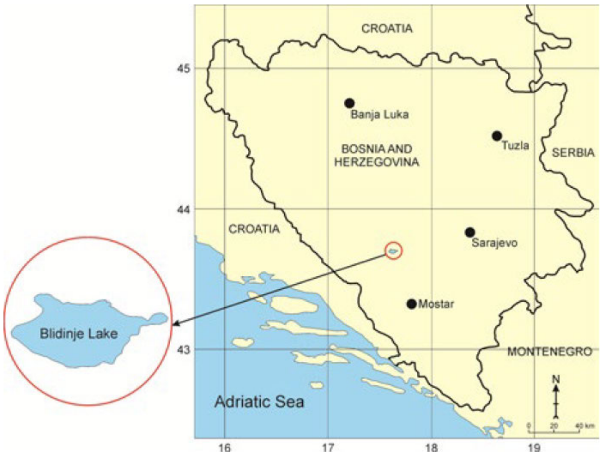

Fig. 1. Map of Bosnia and Herzegovina showing the location of Blidinje Lake.

Fig. 2. Blidinje Lake under ice cover in December 2006.

out using standard methods (APHA 1998). Accuracy of each method is prescribed by the APHA methodology.

Temperature, dissolved oxygen (DO), oxygen saturation, pH, electric conductivity (CND), total dissolved solids (TDS) (using WTW Multi-Parameter Instruments) and Secchi depth (using a Secchi disc) were measured directly at the sampling sites.

A UV-VIS spectrophotometer (Shimatzu) was used for analyzing phosphates, total phosphorous (λ = 690 nm) and inorganic nitrogen: nitrites (λ = 543 nm), nitrates (λ = 220 nm) and ammonium (λ = 630 nm). Other chemical parameters were analyzed using a portable (HACH DR/2010) spectrophotometer.

Total nitrogen was determined by the Kjedahl-method (Gerhardt).

Fig. 3. Nature Park "Blidinje" (Blidinje Lake).

Water samples for determination of chlorophyll *a* were collected fortnightly from May to November over three years (2006, 2007, and 2008). The content of chlorophyll *a* was determined by the fluorometric method (TURNER TD-700, Sunnyvale, CA) at wavelength 365 nm using 90% acetone as the extracting solvent (Jeffrey at al. 1997).

Physico-chemical parameters were analyzed using the following statistical tests:

- Pearson and Spearman correlations for determining the significance of relations between certain parameters.
- ANOVA - Sampling locations were compared with each other using the analysis of variance for all parameters and concentrations of chlorophyll *a*, depending on the year of sampling.
- Multiple regression analysis - Using multiple regression analysis it is possible to predict future states and dynamics of the system according to Rigler (1982), Rigler & Peters (1995), Attayde & Bozelli (1998), Gomes & Miranda (2001) and Pace (2001).

In multiple regression analyses the dependent variable was chlorophyll *a*, and the independent variables were:

- Transparency and concentration of total phosphorus as well as variables that describe the chlorophyll *a* trophic status of the lake.
- SO_4^{2-}, Fe, NH_4^+, temperature, hardness, PO_4^{3-} filtered samples (dissolved reactive phosphorus), N/P ratio by Redfield. All abiotic parameters were taken as independent variables, and then gradually left out variables that had the lowest statistical significance. Last seven variables have a statistically significant effect on chlorophyll *a*.
- Temperature, Fe, SiO_2, pH, TN/TP filtered samples. All abiotic parameters that have a statistically significant correlation ($p < 0.05$, $p < 0.01$) with chlorophyll a using Pearson correlation index are taken as independent variables in the first step. Then variables that did not show a statistically significant correlation with chlorophyll *a* in the multiple regression method were gradually omitted until only these five variables remained, all of which have a statistically significant impact on chlorophyll *a*.

Data were analyzed using SPSS 13 (Statistical Package for the Social Sciences).

RESULTS AND DISCUSSION

When analyzing the results it is necessary to note that the ice cover is not studied in this work. Blidinje Lake is a shallow mountain lake with turbid water, which varies throughout the day depending on wind direction and speed. At different locations there are different micro-conditions and it is possible to get different values of the same variables at the same time. Even quite steady and uniform variables such as electrical conductivity can vary in some places from 20 to 50% (Table 1). Daily differences in temperature (Fig. 4) and dissolved oxygen (Fig. 5) between locations are shown graphically.

Temperature had no consistent trend over the study period, but the values oscillated. This situation is not surprising considering that this is a very shallow lake strongly influenced by air temperature and wind, as noted by some other authors (Brancelj et al. 2002, Dobson & Find 2008).

The lowest oxygen saturation amounted to 66.9% with a maximum of 150% in the same day. A difference of 44.9% at two locations in the same day was recorded, which can be explained by the strong impact of wind and waves on the oxygen saturation. Water temperature and dissolved oxygen were negatively correlated (solubility of gases in water; $r = -0.748$; $r_s = -0.788$, $p < 0.01$) (Table 2).

In this study, no correlation was found between temperature and electrical conductivity ($r = 0.086$) because the lake has very low and fairly uniform electrical conductivity, probably because most of the water comes from melted snow, as other authors have demonstrated for similar mountain lakes (e.g. Brancelj et al. 2002).

pH is slightly alkaline with an average value of 8.14 (median 8.19; std. dev. 0.35), with fairly uniform values recorded throughout the study. Uniform and slightly alkaline pH values indicate oligotrophic status of the lake. Brancelj et al. (2002) provide other examples of mountain lakes in the southeastern Alps with similar limestone geology, as described by Spahic (2001) for Blidinje Lake.

Most of the measured values of chlorophyll *a* in all three years show the oligotrophic status of the lake according to OECD (1982) and Dobson and Find (2008) (Figure 6, Table 3). According to Carlson (1977) the amount of chlorophyll *a* fits oligotrophic/mesotrophic waters.

Analysis of variance was performed for values of chlorophyll *a*, depending on years of sampling, and showed no statistically significant differences in the concentrations of chlorophyll *a* between the years 2006, 2007, and 2008 (Table 4).

In multiple regression analysis the dependence of chlorophyll *a* concentration of total phosphorus and transparency showed that the relationship between these parameters is weak ($R = 0.341$), while the coefficient of multiple determination ($R^2 = 0.116$) showed that only 11.6% of the variance of chlorophyll *a* was explained by concentration of total phosphorus and transparency. Thus, this model can not be considered representative even though the total phosphorus, transparency and chlorophyll parameters describe the trophic status of Blidinje Lake.

Multiple regression analysis where the dependent variable is chlorophyll *a* concentrations and independent variables are SO_4^{2-}, Fe, NH_4^+, water temperature, hardness, dissolved reactive phosphorus, N/P ratio (Redfield`s) showed that the relationship between these parameters is very strong ($R = 0.849$), while the coefficient of multiple determination ($R^2 = 0.720$) showed that 72% of the variance of chlorophyll *a* concentrations is explained

Table 1

Descriptive statistics of chemical parameters of water quality.

	No. meas.	Min	Max	Aver. value	Median	Std. dev.
Chlorophyll *a* 2006, (µg dm^{-3})	65	0.08	5.17	1.65	1.37	1.05
Chlorophyll *a* 2007, (µg dm^{-3})	65	0.34	2.97	1.49	1.35	0.63
Chlorophyll *a* 2008, (µg dm^{-3})	70	0.24	2.73	1.15	1.105	0.65
SO_4^{2-} (mg dm^{-3})	70	0.00	9.00	2.57	1.5	2.56
Fe (mg dm^{-3})	70	0.00	2.60	0.12	0.065	0.31
NO_3^- (mg dm^{-3})	70	0.00	3.20	0.99	1.1	0.72
NO_2^- (mg dm^{-3})	70	0.00	0.04	0.02	0.02	0.01
NH_4^+ (mg dm^{-3})	70	0.00	0.45	0.17	0.14	0.11
SiO_2 (mg dm^{-3})	70	0.00	0.50	0.06	0.04	0.08
Turbidity (FAU)	70	6.00	106.00	29.79	27	20.91
Secchi depth (cm)	70	10.00	50.00	22.81	20	10.06
Suspended matter (mg dm^{-3})	70	11.00	412.00	67.16	32	79.52
Temperature (°C)	70	6.00	28.90	16.31	15.2	6.64
Dissolved oxygen (mg dm^{-3})	70	7.13	11.70	9.14	9.125	1.11
Oxygen saturation (%)	70	66.90	150.00	102.96	101.05	13.13
Conductivity (µS cm^{-1})	70	79.00	307.00	116.50	113.5	31.64
TDS (ppm)	70	39.00	105.00	57.16	56	11.28
pH	70	6.72	8.62	8.14	8.185	0.35
Total hardness (mg dm^{-3} $CaCO_3$)	65	32.50	67.50	53.81	55	9.39
Acidity (mg dm^{-3})	70	4.40	22.00	9.94	8.8	4.63
Alkalinity (mg dm^{-3})	70	67.10	183.00	103.49	85.4	37.94
Total N no filtered (mg dm^{-3})	70	0.56	3.99	2.22	2.17	0.96
Total N filtered (mg dm^{-3})	70	0.42	3.71	1.81	1.89	0.89
Phosphates no filtered (mg dm^{-3})	70	0.00	0.16	0.04	0.03	0.03
Phosphates filtered (mg dm^{-3})	70	0.00	0.03	0.01	0.01	0.01
Total P no filtered (mg dm^{-3})	70	0.01	0.25	0.08	0.07	0.06
Total P filtered (mg dm^{-3})	70	0.00	0.23	0.03	0.03	0.046
TN/TP ratio no filtered	70	5.67	280	45.79	35.875	50.70
TN/TP ratio filtered	70	4.87	301	73.52	61.83	55.21
N/P ratio (Redfield)	70	2	273	80.22	71	63.29

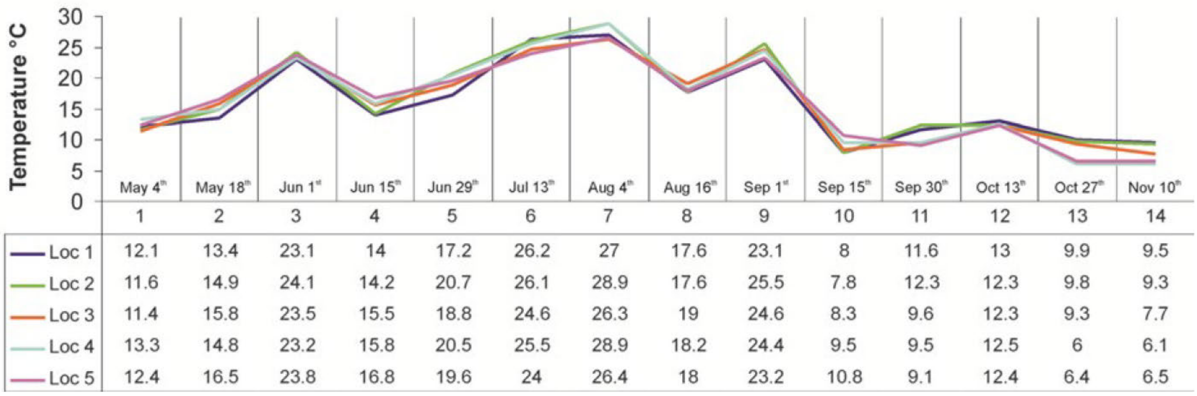

Fig. 4. Differences in temperature between locations.

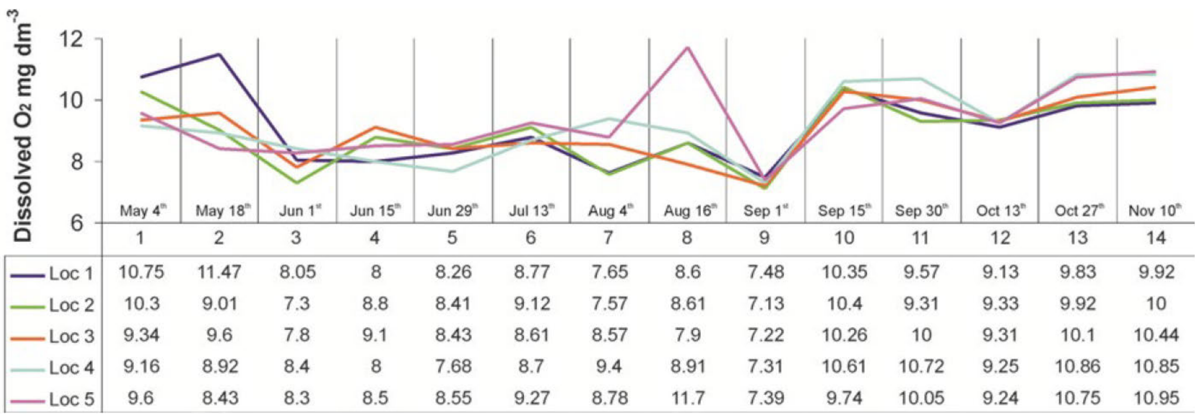

Fig. 5. Differences in dissolved oxygen between locations.

Table 2

Pearson correlation (lower triangle), Spearman correlations (upper triangle) - the physical-chemical parameters of water.

	SO_4^{2-}	Fe	NO^{3-}	NO^{2-}	NH_3	SiO_2	Turb	Secch	Susp	Chl *a*	Temp	DO	% O_2	CND	TDS	pH	Hard	Aci	Alk	TN (nf)	TN (f)	PO_4^{3-} (nf)	PO_4^{3-} (f)	TP (nf)	TP (f)	Inorg N
SO_4^{2-}	1.000	0.467**	-0.002	-0.001	-0.078	0.033	-0.114	0.307**	-0.311**	0.067	0.095	-0.144	-0.099	0.152	0.102	-0.249*	-0.174	0.472**	0.609**	-0.581**	-0.521**	-0.368**	-0.493**	-0.115	-0.203	-0.022
Fe	0.371**	1	-0.109	-0.048	0.185	0.415**	0.248*	0.128	-0.015	0.268*	-0.031	-0.010	-0.076	-0.018	-0.047	-0.033	-0.052	0.305*	0.344**	-0.158	-0.166	-0.217	-0.392**	-0.044	0.045	-0.059
NO^{3-}	-0.042	0.092	1	0.360**	0.053	0.012	-0.069	-0.064	0.038	0.013	-0.355**	0.364**	0.125	-0.202	-0.202	0.212	-0.181	-0.143	-0.357**	0.420**	0.491**	0.353**	0.037	0.130	0.132	0.974**
NO^{2-}	0.030	0.065	0.434**	1	0.336**	0.155	0.014	-0.234	-0.007	0.111	-0.188	0.176	0.111	-0.180	-0.154	0.159	-0.145	-0.020	-0.073	0.160	0.231	0.413**	0.193	0.179	0.307**	0.419**
NH_3	0.031	0.251*	0.056	0.349**	1	0.475**	0.365**	-0.390**	0.340**	0.112	-0.238*	0.204	0.112	0.150	0.175	0.125	-0.242	0.186	-0.045	0.157	0.141	0.423**	0.236*	0.288*	0.396**	0.259*
SiO_2	-0.057	0.118	0.218	0.266*	0.395**	1	0.470**	-0.272*	0.205	0.369**	0.004	-0.010	0.023	-0.078	-0.073	0.052	-0.026	0.338**	0.229	0.000	0.010	0.043	-0.153	0.064	0.341**	0.141
Turb	-0.021	0.108	0.049	0.081	0.484**	0.277*	1	-0.665**	0.759**	0.528**	0.477**	-0.343**	0.114	-0.165	-0.162	0.463**	-0.045	0.098	0.114	0.139	0.183	0.092	0.010	-0.037	0.334**	0.039
Sechi	0.267*	-0.078	-0.130	-0.212	-0.425**	-0.275*	-0.485**	1	-0.780**	-0.384**	-0.370**	0.206	-0.146	0.108	0.065	-0.473**	0.044	0.157	0.213	-0.306*	-0.328**	-0.347**	-0.308**	-0.029	-0.460**	-0.176
Susp	-0.039	-0.017	-0.072	-0.028	0.377**	0.082	0.542**	-0.588**	1	0.415**	0.349**	-0.158	0.160	-0.043	-0.019	0.581**	-0.001	-0.144	-0.192	0.390**	0.389**	0.176	0.193	-0.020	0.329**	0.140
Chl *a*	0.147	0.314**	0.113	0.093	0.100	0.225	0.340**	-0.341**	0.244*	1	0.456**	-0.281*	0.202	-0.135	-0.126	0.329**	-0.064	-0.002	0.138	0.036	0.038	0.103	-0.054	0.060	0.405**	0.072
Temp	0.114	0.016	-0.357**	-0.233	-0.198	-0.167	0.328**	-0.329**	0.388**	0.457**	1	-0.788**	0.104	-0.069	-0.074	0.223	0.204	0.110	0.358**	-0.375**	-0.386**	-0.405**	-0.104	-0.336**	-0.006	-0.348**
DO	-0.184	-0.041	0.357**	0.253*	0.204	0.161	-0.201	0.152	-0.271*	-0.228	-0.748**	1	0.262*	0.024	0.030	0.066	-0.306*	-0.280*	-0.348**	0.303*	0.301*	0.362**	0.081	0.257*	0.162	0.360**
$\%O_2$	-0.129	-0.117	0.050	0.070	0.048	-0.013	0.120	-0.169	0.106	0.204	0.235	0.260*	1	-0.200	-0.168	0.339**	-0.104	-0.317**	-0.136	-0.068	-0.072	0.031	-0.139	0.217	0.287*	0.151
CND	0.222	0.248*	-0.179	-0.014	0.125	-0.127	-0.104	0.079	-0.055	-0.013	0.086	-0.138	-0.159	1	0.982**	-0.336**	-0.007	0.147	0.160	-0.172	-0.183	-0.248*	0.057	-0.192	-0.179	-0.161
TDS	0.197	0.336**	-0.233	-0.073	0.134	-0.172	-0.146	0.133	-0.028	-0.026	0.040	-0.101	-0.136	0.924**	1	-0.301*	0.007	0.117	0.106	-0.124	-0.152	-0.199	0.112	-0.183	-0.139	-0.161
pH	-0.245*	-0.040	0.334**	0.081	0.179	0.076	0.284*	-0.405**	0.267*	0.318**	0.151	0.140	0.203	-0.231	-0.287*	1	-0.033	-0.203	-0.156	0.368**	0.325**	0.217	0.060	0.098	0.270*	0.274*
Hard	-0.168	-0.280*	-0.137	-0.154	-0.224	-0.059	0.079	-0.069	0.098	-0.071	0.184	-0.248*	-0.078	-0.112	-0.121	-0.053	1	0.056	0.201	0.069	-0.016	-0.215	-0.032	-0.186	-0.087	-0.225
Aci	0.497**	0.014	-0.231	-0.042	0.058	0.029	0.030	0.366**	0.022	-0.058	0.121	-0.304*	-0.362**	0.241*	0.176	-0.325**	0.049	1	0.542**	-0.466**	-0.446**	-0.299*	-0.323**	-0.312**	-0.348**	-0.098
Alk	0.703**	0.261*	-0.286*	-0.053	-0.043	0.011	0.007	0.381**	-0.060	0.107	0.224	-0.285*	-0.194	0.361**	0.354**	-0.348**	0.016	0.665**	1	-0.528**	-0.544**	-0.499**	-0.457**	-0.265*	-0.256*	-0.348**
TN (nf)	-0.566**	-0.051	0.463**	0.182	0.163	0.257*	0.130	-0.356**	0.086	0.062	-0.348**	0.275*	-0.109	-0.282*	-0.276*	0.476**	0.129	-0.487**	-0.547**	1	0.873**	0.576**	0.373**	0.317**	0.319**	0.413**
TN (f)	-0.502**	-0.006	0.556**	0.294*	0.162	0.297*	0.120	-0.389**	0.105	0.063	-0.361**	0.256*	-0.129	-0.243*	-0.260*	0.421**	0.014	-0.504**	-.518**	0.892**	1	0.576**	0.330**	0.235	0.286*	0.483**
PO_4^{3-} (nf)	-0.227	-0.016	0.492**	0.435**	0.418**	0.426**	0.085	-0.304*	-0.046	0.175	-0.390**	0.365**	-0.016	-0.283*	-0.343**	0.268*	-0.230	-0.259*	-.392**	0.550**	0.585**	1	0.465**	0.487**	0.500**	0.428**
PO_4^{3-}(f)	-0.500**	-0.002	-0.039	0.143	0.260*	-0.128	0.129	-0.334**	0.024	-0.061	-0.092	0.065	-0.106	0.111	0.119	0.201	-0.002	-0 .291*	-.409**	0.354**	0.306**	0.153	1	0.063	0.309**	0.092
TP (nf)	-0.084	0.006	0.313**	0.256*	0.233	0.425**	-0.010	-0.128	-0.093	0.062	-0.307**	0.245(*)	0.070	-0.291*	-0.324**	0.211	-0.151	-0.291*	-.357**	0.356**	0.331**	0.611**	-0.067	1	0.439**	0.187
TP (f)	0.055	0.176	0.374**	0.249*	0.267*	0.262*	0.157	-0.208	0.018	0.183	-0.160	0.191	0.100	-0.173	-0.220	0.199	-0.090	-0.231	-.260*	0.330**	0.296*	0.572**	-0.075	0.683**	1	0.204
Inor N	-0.036	0.131	0.987**	0.480**	0.228	0.283*	0.130	-0.196	0.017	0.144	-0.358**	0.369(**)	0.072	-0.165	-0.219	0.373**	-0.163	-0.192	-.285*	0.462**	0.553**	0.543**	-0.016	0.341**	0.402**	1

** - Correlation is significant at the 0.01 level; * - Correlation is significant at the 0.05 level

Table 3

Comparative table showing limit values of parameters that describe the trophic status of lakes according to different authors and the values obtained in Blidinje Lake.

	Author													
	Carlson 1977			OECD 1982					Dobson and Find 2008					
Trophic status	Chl *a* (μg dm^{-3})	SD (m)	TP (mg dm^{-3})	mean TP (mg dm^{-3})	mean chl *a* μg (dm^{-3})	max. chl *a* μg (dm^{-3})	mean SD (m)	min. SD (m)	TP (mg dm^{-3})	mean chl *a* μg (dm^{-3})	max. chl *a* μg (dm^{-3})	mean SD (m)	max. SD (m)
Ultra-oligotrophic									<0.004	<1	<2.5	>12	>6
Oligotrophic	<0.95	>8	<0.006	< 0.01	< 2.5	< 8	> 6	> 3	0.004-0.01	1-2.5	2.5-8	6-12	3-6
Oligotrophic/mesotrophic	0.95-2.6	8-4	0.006-0.012										
Mesotrophic	2.6-7.3	4-2	0.012-0.024	0.01-0.035	2.5-8	8-25	6-3	3-1.5	0.01-0.035	2.5-8	8-25	3-6	1.5-3
Mesotrophic/eutrophic													
Eutrophic	7.3-20	2-1	0.024-0.048	> 0.035	> 8	> 25	< 3	< 1.5	0.035-0.1	8-25	25-75	1.5-3	0.7-1.5
Eutrophic/hipertrophic	20-56	0.5-1	0.048-0.096										
Hipertrophic	56-155	0.25-0.5	0.096-0.192						>0.1	>25	>75	<1.5	<0.7
Blidinje Lake	TP (mg dm^{-3})			Chl *a* (ug dm^{-3})			SD (m)						
	min.	max.	mean	min.	max.	mean	min.	max.	mean				
	0.01	0.25	0.08	0.24	2.73	1.15	0.1	0.5	0.23				

Table 4

p-probability analysis of variance (ANOVA) for concentration of chlorophyll *a* between the years 2006, 2007, and 2008.

Parameter		p-probability
chlorophyll *a*	2006	0.602
	2007	0.951
	2008	0.166

Table 5

Multiple regression, dependent variable chlorophyll *a*.

A

Model	R	R^2	Adjusted R^2	Std. Error of the Estimate
1	0.849	0.720	0.670	0.36331

B

Model	Unstandardized coefficients		Standardized coefficients	t	Sig
	B	Std. Error	Beta		
1 (Constant)	-0.179	0.466		-0.384	0.703
SO_4^{2-}	-0.067	0.030	-0.257	-2.224	0.032
Fe	0.418	0.169	0.248	2.470	0.018
NH_4^+	1.779	0.596	0.327	2.987	0.005
Temperature	0.084	0.010	0.923	8.752	0.000
Hardness	-0.018	0.006	-0.262	-2.770	0.009
PO_4^{3-} filtered	23.354	11.486	0.237	2.033	0.049
N/P ratio (Redfield)	0.003	0.001	0.272	2.602	0.013

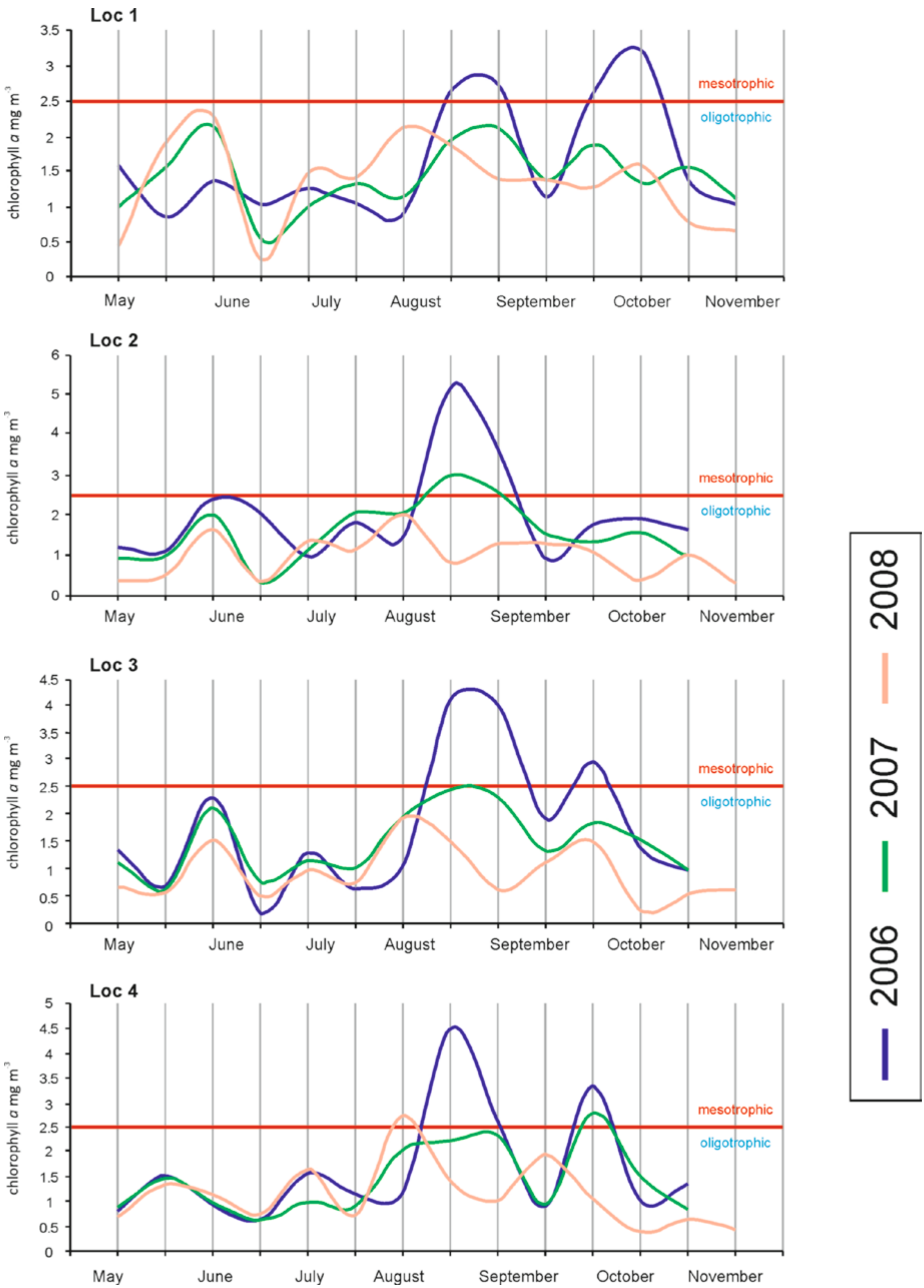

Fig. 6. Seasonal variations of chlorophyll *a* at different sampling locations during 2006, 2007 and 2008. Limiting degrees of trophic status according to the OECD (1982) and Dobson and Find (2008) classifications.

by the above mentioned independent variables. Therefore, this model can be considered representative. Individual testing of the significance of the regression model showed that all selected independent variables have a statistically significant effect on the concentration of chlorophyll *a* (Table 5a-b). The relationship between sulfate and hardness as independent variables and chlorophyll *a* as a dependent variable were inversely proportional, while the relationship between other independent variables of this model and the chlorophyll *a* were directly proportional. An inversely proportional relationship with chlorophyll *a* and sulfate does not necessarily mean that sulfates affect the concentration of chlorophyll *a* concentrations because the sulfate is higher in the spring after the melting of snow regardless of the chlorophyll. Also, the relationship between hardness and chlorophyll *a* can be interpreted as a coincidence. The proportional relationship of orthophosphate and ammonium to chlorophyll *a* is expected.

Multiple regression analysis where the dependent variable is chlorophyll *a* concentration and the independent variables are Fe, SiO_2, pH, and the TN/TP ratio of filtered water samples showed that the relationship between these parameters is strong ($R = 0.705$), while the coefficient of multiple determination ($R^2 = 0.497$) showed that 49.7% of the variance of chlorophyll *a* concentrations can be explained by the above mentioned independent variables. Therefore, this model can be considered representative. Individual tests of the significance of the regression model showed that all selected independent variables have a statistically significant effect on the concentration of chlorophyll *a* (Table 6a-b). The relationship between the TN/TP ratio of filtered samples as independent variables and chlorophyll *a* as the dependent variable is inversely proportional, while the relationship between other independent variables of this model and chlorophyll *a* are proportional. SiO_2 has a proportional relationship with chlorophyll *a* as expected, since SiO_2 can be a limiting nutrient for diatoms' growth.

Both the representative models of multiple regression analysis showed, as expected, that the temperature is proportional to chlorophyll *a*. Fe also has a proportional relationship with chlorophyll *a* in both representative models of multiple regression, because iron is necessary for the synthesis of chlorophyll as well as micronutrients.

The two representative models of multiple regressions can be used to predict the concentration of chlorophyll *a* in future research. Such models for predicting the concentration of chlorophyll *a* have already been described by certain authors (e.g. Rocha et al. 2009).

Table 6

Multiple regression, dependent variable chlorophyll *a*.

A

Model	R	R^2	Adjusted R^2	Std. Error of the Estimate
1	0.705	0.497	0.453	0.47476

B

Model	Unstandardized coefficients		Standardized coefficients	t	Sig
	B	Std. Error	Beta		
1 (Constant)	-3.744	1.540		-2.431	0.018
Temperature	0.039	0.009	0.413	4.082	0.000
Fe	0.534	0.186	0.273	2.879	0.006
SiO_2	1.747	0.809	0.213	2.160	0.035
pH	0.527	0.194	0.263	2.722	0.009
TN/TP ratio fil	-0.003	0.001	-0.226	-2.235	0.029

Phosphates of filtered samples were not recorded on several occasions during May, June, July and September. The maximum value was 0.03 mg dm^{-3}. It is the only form of phosphorus available for algae photosynthesis. All values of dissolved reactive phosphorus corresponded to oligotrophic and mesotrophic lakes according some classifications (OECD 1992, Dobson and Find 2008).

Most values of total phosphorus match eutrophic waters (>0.035 mg dm^{-3}) according to the OECD (1982) and the Dobson and Find (2008) classifications. According Brancelj et al. (2002), it is occasionally possible to find high values of total phosphorus, even in oligotrophic lakes. According to the concentration of total phosphorus the lake is mesotrophic/eutrophic, which does not correspond to the concentration of chlorophyll *a* on the basis that the lake is oligotrophic/mesotrophic. This is probably the result of large amounts of reactive phosphorus bonding to solid particles of suspended matter and thus inhibited. According to Scheffer (2004), total phosphorous is not the best choice for a parameter to use to classify the trophic status of shallow lakes where the sediment-water interactions are more intensive. The concentration of dissolved reactive phosphorus (SRP) strongly depends on the interaction of water and sediment. Understanding this interaction is crucial in understanding the dynamics of phosphorus in shallow lakes.

Transparency of the lake is extremely low, especially from June to September, and ranged from a minimum of 10 cm to a maximum of 50 cm. In earlier research transparency was 15 cm (Spahić 2001). These values of transparency suggest a eutrophic/hypertrophic status for the lake. The other relevant parameters for trophic status are not in agreement. Suspended matter contributes more to reduced transparency than phytoplankton density. The correlation between transparency and suspended matter was very negative and statistically very significant ($r = -0.588$; $r_s = -0.780$, $p<0.01$), and transparency is expected to have a very negative and statistically significant correlation with turbidity ($r_s = -0.665$, $p<0.01$). The correlation between transparency and chlorophyll *a* was negative but weak ($r = -0.341$; $r_s = -0.348$, $p<0.01$). This relationship between transparency and chlorophyll *a* is common in the limnology of shallow lakes of varying volume where the surface is strongly influenced by wind resuspension of sediment (Engel and Nicholas 1994).

Although macrophytes Blidinje Lake have not been systematically studied, it is evident that the lake is poor in macrophytes. According to Scheffer (2004) the lack of macrophytes contributes to turbidity, reduced transparency and increased sediment resuspension. Long, cold winters with ice cover also contribute to the lack of macrophytes in Blidinje.

During the investigation period it cannot be concluded that transparency is primarily dependent on the biomass of phytoplankton. It is, in fact, more influenced by weather and wind. There was a weak negative correlation between chlorophyll *a* and transparency ($r = -0.341$, $p<0.01$).

The presence of ammonia salts indicates recent water pollution, which is not unexpected since the lake is used to water up to 3000 sheep per day (Spahic 2001). The maximum values of nitrate (3.2 mg dm^{-3}), nitrite (0.04 mg dm^{-3}) and ammonia salts (0.45 mg dm^{-3}) correspond to a moderately eutrophic lake. Values of total nitrogen are high and Blidinje Lake is phosphorus limited despite the fact that most of the phosphorus is in a form that is inaccessible for primary producers. Total nitrogen of filtered samples showed a strong correlation between the high level of 99% of the total inorganic nitrogen ($r = 0.553$, $p<0.01$). Similar results are found in some previous studies of mountain lakes (Kamenik et al. 2001).

According to Johannessen and Henriksen (1978) sulphates in mountain lakes mainly originate from melted snow. These results were confirmed in this study. Sulphates showed a strong and significant positive correlation with alkalinity ($r = 0.703$: $r_s = 0.609$, $p<0.01$), which is consistent with similar studies (Barbieri et al. 2001), and a strong negative correlation with total nitrogen ($r = -0.566$; $r_s = -0.521$, $p<0.01$).

The total water hardness is fairly uniform. Alkalinity was slightly higher in spring than in summer. According Brancelj et al. (2002) lakes like Blidinje with a limestone geology have slightly higher alkalinity in spring.

Most values of the TN/TP ratio were greater than 7, indicating an oligotrophic status for the lake (Schindler 1977, Elser et al. 1990). According to these values the limiting factor of phytoplankton growth was phosphorus. In temperate zone lakes, phytoplankton growth is limited more by phosphorus than nitrogen (Schindler 1977, Elser et al. 1990, Diaz & Pedrozo 1996).

The N/P ratio $(NO_3 + NO_2 + NH_4)/PO_4$ ranged from 2 to 273, with most values exceeding Redfield's ratio of 16:1 (Redfield et al. 1963). The most limiting element in the growth of phytoplankton and phytobenthos in Blidinje Lake was phosphorus.

Forsberg and Ryding (1980) showed on a series of lakes that the TN/TP ratio negatively correlated with the chlorophyll *a* concentration. In this study, there was no correlation between TN/TP of filtered samples and chl *a* ($r = -0.077$) while the TN/TP ratio of filtered samples showed a week negative correlation with chl *a* ($r = -0.372$, $p<0.01$).

According to results of the ANOVA test there were no significant differences between stations, although some differences were found in measured parameters during the same sampling days (Table 7). These results can be explained by the fact that the lake is influenced by diffuse pollution sources (cattle, air pollution, roads), and heavily influenced by climatic conditions, especially wind, which often mixes the water. Although at first glance the lake appears to be horizontally stratified according Dobson and Find (2008), analysis of variance did not confirm this.

Table 7

p-probability analysis of variance (ANOVA) at sampling stations.

Parameter	p-probability	Parameter	p-probability
SO_4^{2-}	0.693	CND	0.386
Fe	0.482	TDS	0.259
NO_3^-	0.794	pH	0.829
NO_2^-	0.301	Hardness	0.999
NH_4^+	0.991	Acidity	0.827
SiO_2	0.762	Alkalinity	0.779
Turbidity	0.677	TN(nf)	0.991
Secchi depth	0.865	TN(f)	0.971
Susp. matter	0.689	PO_4^{3-}(nf)	0.868
Chl *a*	0.689	PO_4^{3-}(f)	0.234
Temperature	0.999	TP(nf)	0.747
Dissolved O_2	0.885	TP(f)	0.750
Saturation O_2	0.886	TN/TP(nf)	0.949

CONCLUSIONS

Wind, the geological background and mountain character are factors with special impact on the physical and chemical properties of the lake. The lake is shallow and exposed to wind causing very restrictive conditions for recreation and sport, except for fishing. Blidinje Lake has very low transparency, and is hypertrophic in terms of transparency, as other relevant parameters are not shown. Namely, the concentration of chlorophyll *a* and dissolved phosphate (the only form of phosphorus available to plants for metabolic processes) in the lake suggest that it is oligotrophic/mesotrophic. Concentrations of total phosphorus are high, suggesting eutrophic status, so there is a possibility of ,the release of phosphorus which is adsorbed on particles of suspended matter. Because it is a shallow lake this would change fast. Slowing down the process of eutrophication are factors such as altitude, the mountain climate and abundant rainfall.

Since the ANOVA test did not show statistically significant differences in the concentration of chlorophyll in 2006, 2007 and 2008, it can be concluded that there was no trend of increasing primary production.

Since the analysis of variance showed no statistically significant differences between sampling locations the authors' propose further sampling at the surface and bottom of the deepest part of the lake.

Assessment of water quality can be used for different purposes. For example, trophic status can be useful for warning, monitoring and forecasting, and sustainable development of the region. Potential data and information have specific relevance for forecasting models. The gradual accumulation of data from the monitoring of water quality will allow determination of the facts, from simple to very important additional information.

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