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Some factors affecting the abundance of phytoplankton in an unproductive alkaline lake (Lake Hazar, Turkey)

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Abstract: This study aimed to explain the seasonal and vertical distribution of phytoplankton in the pelagic zone of a deep alkaline lake that is characterized by low phytoplankton abundance. Phytoplankton and water samples were collected seasonally from 9 points and 7 depths between the surface and 20 m from December 2004 to September 2005. *Planktolyngbya contorta* was the dominant or subdominant species in all seasons and depths. The dominance of *Gomphonema* species was observed in December, but they were subdominant in September. *Cyclotella meneghiniana* was dominant at 20 m and subdominant in the upper depths during March, June, and September. *Melosira* sp. and *Meridion circulare* were the dominant taxa of the surface phytoplankton in March and June, respectively. A nonparametric test showed the prevalence of cyanobacteria and green algae at a depth of 10 m. Principal component analysis showed the effect of temperature, pH, dissolved solids, nitrate, and silica on the abundance and distribution of phytoplankton. The generalized linear model revealed that high pH and high dissolved solids content seemed to affect the abundance of phytoplankton via limiting nutrient availability.

Key words: Phytoplankton, distribution, external factors, principal component analysis, generalized linear model

1. Introduction

The abundance and distribution of phytoplankton in lakes exhibits spatial and temporal variation. Many allogenic factors (including light, temperature, and nutrients) and autogenic factors under biological control (such as competition, predation, and parasitism) interact to regulate spatial and temporal variations in phytoplankton. Studies explaining these interactions were extensively summarized in the literature (Hutchison, 1967; Round, 1981; Goldman and Horne, 1983; Reynolds, 1984; Harris, 1986; Wetzel, 2001).

There is also a relation between the mixing patterns of the water column and niche diversity. Although phytoplankton may show a high abundance tendency and the highest concentrations of chlorophyll in the mixed deep layers when there is an adequate nutrient supply, the highest biomass of species or divisions in phytoplankton may be expected at different layers according to motility, buoyancy, and size of species (Pinilla, 2006; Mellard et al., 2011). Some species with the buoyancy adaptation of cyanobacteria can regulate their position, while diatoms are positioned on the metalimnion where water density can prevent sinking (Reynolds, 1984). Therefore, provisions in the lake trophic conditions supporting phytoplankton growth should not be constrained to available nutrients; they should also be associated with factors including basin morphometry, mixing dynamics, water clarity, and alkalinity in addition to the size and nature of the nutrient resource (Reynolds, 1998).

Located in East Anatolia, Lake Hazar is a specific ecosystem due to highly alkaline and hard-water characteristics and a high dissolved solids content, which results from carbonate concentrations. The lake is dimictic with complete mixing in spring and autumn; it is stratified from June to September, forming a thermocline below 10 m (Koçer and Şen, 2012). Some studies determined diversity in the littoral algae of the lake (Şen, 1988; Şen et al., 1995; Sönmez and Şen, 2011), and a recent study showed diatom succession in surface phytoplankton (Koçer and Şen, 2012). However, there are limited data on vertical distribution of phytoplankton, and there are many questions to be answered regarding the factors limiting biomass, succession, and distribution. In this study we tried to explain some of the factors affecting abundance

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and distribution of phytoplankton in an unproductive alkaline lake.

2. Materials and methods

2.1. Study site, sampling, and analysis

Lake Hazar, formed by the movement the of East Anatolian Fault, is a tectonic lake located at an elevation of 1238 m in the southeastern Taurus mountain range in the East Anatolia Region of Turkey. The lake has a surface area of 80 km^2 and a basin area of 403 km^2, and it is free of ice the entire year. Different maximum depth records ranging from 80 m to 300 m were proposed in different studies (Koçer and Şen, 2012).

Samples for physicochemical properties and phytoplankton were collected seasonally (December 2004; March, June, and September 2005) from a water column (0, 1, 2, 5, 7, 10, and 20 m) at 9 sampling points representing the near littoral and middle part of the ellipsoid-shaped lake (Figure 1). In total, 53 samples were collected using a Nansen bottle with a volume of 1.5 L at each sampling period. Phytoplankton samples were placed in separate bottles and fixed with Lugol's solution.

Temperature (T), pH, and total dissolved solids (TDS) were measured in situ by using YSI 63 (YSI Inc., Yellow Springs, OH, USA) and Hanna HI9812 (Hanna Instruments, Smithfield, RI, USA) field instruments. Nitrate nitrogen (NO_3^--N), total nitrogen (TN), soluble reactive phosphorus (SRP), total phosphorus (TP), and silica (SiO_2) were determined using a QuickChem 8000 FIA ion analyzer (Lachat Instruments, Loveland, CO, USA). Chlorophyll *a* (Chl-*a*) concentrations were calculated by monochromatic method after extraction with 90% acetone solution, and absorbance was measured by a Helios-α model (Thermo Scientific, Cambridge, UK) spectrophotometer (APHA et al., 1995). Photic zone depth (PZD) was estimated by multiplying 2.79 and the Secchi disk depth (Longhi and Beisner, 2009).

Phytoplankton was quantified by the sedimentation method. Individuals (colonies, filaments, and cells) were counted at the species level in random fields, and, whenever possible, 100 individuals of the most commonly occurring species were counted. The diatoms were identified according to Patrick and Reimer (1966, 1975), Hustedt (1985), and Krammer and Lange-Bertalot (1986, 1988, 1991a, 1991b); other algal groups were identified with the help of Prescott (1982), John et al. (2002), and Wehr and Sheath (2003). Pennate diatoms that were represented with a few dominant species in the same periods were evaluated on the genus level.

2.2. Data analysis

Normality of data was tested using the Shapiro–Wilk test. Since the data were nonnormally distributed, water quality parameters and species abundance were compared using a signed rank test (Kruskal–Wallis) followed by a post hoc test (Student's t-test). Since there were no significant differences among the sampling depths at 9 different stations in terms of species abundance and water quality parameters, data from the 9 sampling stations were combined as means for each particular sampling depth (0, 1, 2, 5, 7, 10, and 20 m) to conduct the multivariate analysis.

Relationships between species and environmental variables were determined using multivariate analysis. In the first step of the analysis, an unconstrained ordination to select linear or unimodal methods was calculated: detrended correspondence analysis (DCA). Data were transformed logarithmically [log (a × y + b)]. Through detrending by segments in DCA and Hill's scaling, the

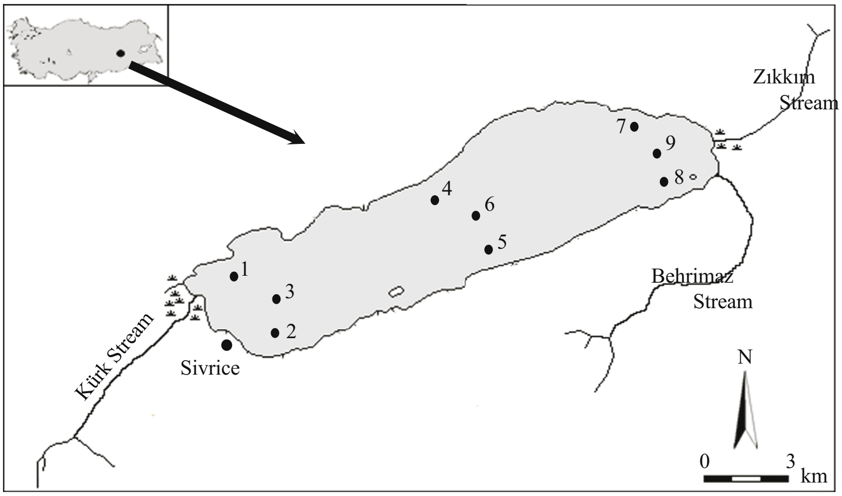

Figure 1. Lake Hazar and sampling points.

length of the longest axis provided an estimate of the beta diversity in the data set. Since DCA showed short gradient lengths (<1.2 SD), a linear model was appropriate for our data (ter Braak, 1995; Lepš and Šmilauer, 2003). Principal component analysis (PCA), scaling in interspecies relations and dividing species scores by the standard deviation, was then used. Logarithmically transformed data were centered (ter Braak, 1995; ter Braak and Verdonschot, 1995; Lepš and Šmilauer, 2003).

The generalized linear model (GLM) is an advantageous univariate analysis method because it allows for nonlinear and nonnormal responses. It was performed to simulate the response of species abundance to predictor variables that prefer logarithmic link functions and Poisson distributions (Lepš and Šmilauer, 2003). Multivariate analyses and the GLM were performed using CANOCO version 4.5, while nonparametric and other statistical tests were carried out using JMP 8.0.

3. Results

Temperatures between the surface and 20 m during the sampling period ranged from 4.6 to 23.7 °C. There was a significant difference ($P < 0.05$) among the upper depths of the water column and 20 m (Table 1). Temperature measurements at 10 m showed similarity both with the upper depths and 20 m, indicating metalimnion

Table 1. Summary of some physicochemical properties in the water column of 9 sampling stations during the study period (parameters not sharing the same letter in the same line are significantly different; $P < 0.05$).

Depth (m)		T (°C)	pH	TDS (mg/L)	NO_3^--N (mg/L)	TN (mg/L)	SRP (µg/L)	TP (µg/L)	SiO_2 (mg/L)	Chl-*a* (µg/L)
0	min	5.1	8.5	1001	0.100	0.160	8.7	8.9	1.70	0.41
	max	23.7	9.3	1191	1.280	1.643	53.1	73.0	5.00	2.16
	mean	13.3^{a}	9.0	1109	0.446	0.618	13.8	18.6	3.08	1.33^{ab}
	SD*	7.9	0.2	53	0.298	0.362	8.5	11.8	0.99	0.43
1	min	4.9	8.6	1040	0.075	0.150	5.5	6.8	1.40	0.58
	max	23.7	9.3	1211	1.220	1.556	30.0	41.3	6.00	2.01
	mean	13.1^{a}	9.0	1114	0.421	0.597	12.8	17.2	2.95	1.25^{abc}
	SD	7.9	0.2	50	0.293	0.361	5.2	7.3	1.09	0.38
2	min	4.7	8.6	1033	0.100	0.150	3.9	5.3	1.73	0.51
	max	23.7	9.3	1180	1.070	1.381	40.0	55.0	8.40	2.64
	mean	13.0^{a}	9.0	1112	0.364	0.507	14.3	20.1	3.00	1.36^{a}
	SD	7.8	0.2	46	0.255	0.319	7.9	11.1	1.35	0.52
5	min	4.7	8.6	1039	0.100	0.160	7.8	10.7	1.40	0.68
	max	23.4	9.3	1175	1.550	1.962	30.0	41.3	7.80	1.74
	mean	12.8^{a}	9.0	1110	0.423	0.595	13.2	18.1	3.17	1.16^{bc}
	SD	7.7	0.2	46	0.334	0.439	6.4	8.9	1.30	0.27
7	min	4.7	8.6	1040	0.100	0.156	4.2	5.7	0.70	0.39
	max	23.3	9.3	1173	2.110	2.622	85.0	89.5	8.00	2.05
	mean	12.6^{a}	9.0	1108	0.425	0.588	15.2	20.8	3.11	1.09^{c}
	SD	7.5	0.2	47	0.386	0.471	13.7	15.6	1.56	0.36
10	min	4.6	8.6	1011	0.100	0.150	4.2	5.8	0.26	0.41
	max	22.7	9.3	1165	0.618	0.856	40.0	55.0	6.00	2.14
	mean	11.6^{ab}	9.0	1100	0.305	0.447	15.3	21.3	2.85	1.12^{c}
	SD	6.8	0.2	52	0.158	0.197	9.4	12.8	1.24	0.42
20	min	4.7	8.6	883	0.100	0.170	8.6	11.8	1.94	0.55
	max	10.5	9.3	1161	0.960	1.271	30.0	41.3	6.40	2.00
	mean	7.2^{b}	9.0	1066	0.377	0.536	13.6	19.1	3.09	1.03^{c}
	SD	2.2	0.2	90	0.290	0.367	6.4	8.6	1.23	0.42

*: SD, ±standard deviation.

formation among these depths as proposed by Koçer and Şen (2012). During the study period pH was almost the same throughout the water column, and a mean pH value of 9.0 was calculated. TDS concentrations in the water column were measured between 883 and 1211 mg/L (mean: 1066–1114 mg/L). Although there was a decreasing trend with depth, the difference in TDS concentrations between depths was not statistically significant ($P > 0.05$). The absence of a clear trend in the vertical distribution of nutrients (NO_3^--N, TN, SRP, TP, and SiO_2) led us to deduce homogeneity in the water column. Although the Chl-*a* concentrations at different depths in the water column were very close to each other, concentrations were significantly higher in surface layers in comparison to depths between 10 m and 20 m ($P < 0.05$). PZD was between 4.5 and 11.7 m (average 7.7 m) depending on Secchi disk depth measurements between 1.6 m and 4.2 m. Higher PZD estimates were recorded in the middle parts of the lake compared to near littoral sites.

During the sampling period, the phytoplankton community of the pelagic zone in Lake Hazar included 50 species of Bacillariophyta, which were reported by Koçer and Şen (2012), who described the qualitative changes of the diatom community in the surface water. In addition to the diatoms reported by Koçer and Şen (2012), *Chlorella vulgaris*, *Closteriopsis acicularis*, *Oocystis apiculata*, *Oocystis pusilla*, *Planctonema* sp., *Chroococcus dispersus*, *Chroococcus minor*, *Chroococcus minutus*, *Chroococcus turgidus*, *Planktolyngbya contorta*, and *Peridinium cinctum* were identified as species belonging to divisions Chlorophyta, Cyanophyta, and Pyrrophyta in the present study.

Seasonal changes in mean algal abundance were not significant according to analysis of variance ($P > 0.05$). However, vertical distribution of mean algal abundance was significantly different ($F = 5.44$, $P < 0.05$) and was detected at the highest and lowest numbers at 10 m and 20 m, respectively (Figure 2).

The seasonal succession of the phytoplankton in the pelagic zone of Lake Hazar was mainly governed by several dominant and subdominant taxa. *Gomphonema* species in December and *Cyclotella meneghiniana* and *Melosira* sp. in March were the dominant taxa. When total algal abundance decreased highly in June, *Meridion circulare* was dominant in surface waters. The dominance of *Planktolyngbya contorta* and *Cyclotella meneghiniana* at the other depths during June held in September. Only diatoms and *Planktolyngbya contorta* were dominant in all seasons and depths. *Fragilaria* and *Nitzschia* species, *Chlorella vulgaris*, *Closteriopsis acicularis*, and *Planctonema* sp. were subdominant taxa in different seasons and depths (Figure 3).

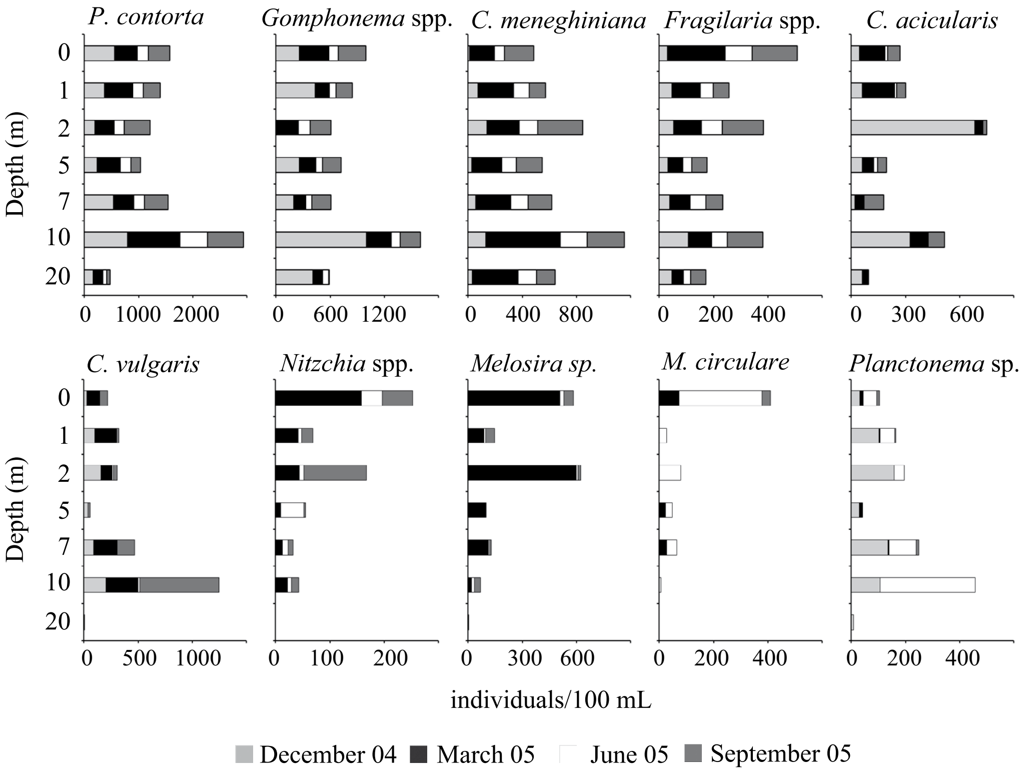

Figure 2. Seasonal and vertical changes in abundance of algal groups in phytoplankton.

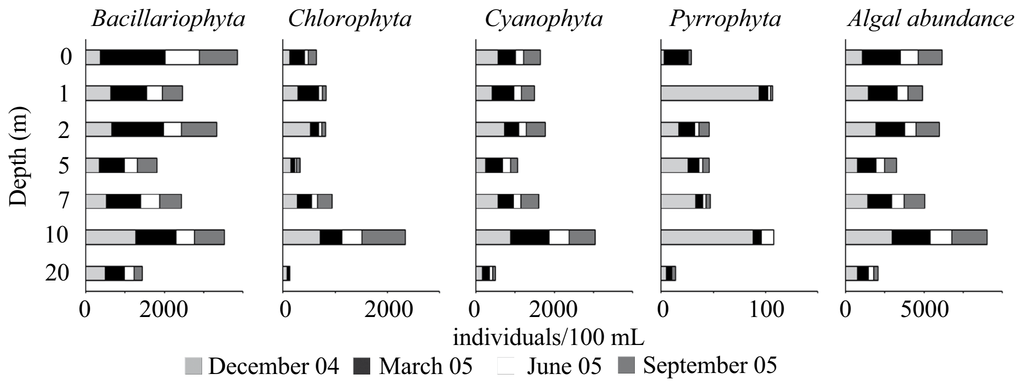

Figure 3. Seasonal and vertical changes in abundance of dominant and subdominant taxa in phytoplankton.

PCA analysis revealed that the first 2 axes explained 68% of variation in species–environment relationships (Table 2). Factor 1, negatively graded with species abundance data, explained 51% of species variation and 34% of total variation. Factor 2 explained 34% of total variation and was positively loaded with T, pH, TDS, NO_3^--N, SRP, and Chl-*a* and negatively loaded with D, PZD, and SiO_2 (Figure 4). PCA clearly showed that variation of algal abundance in the phytoplankton of Lake Hazar was mainly graded with *Planktolyngbya contorta* and *Gomphonema* as well as variation in total algal abundance. The loads of water quality parameters suggested that while D, SRP, and Chl-*a* have correlations near zero with the ordination axis, parameters T, pH, PZD, TDS, NO_3^--N, and SiO_2 have higher correlations. The latter variables may indicate significant impacts on the abundance and distribution of phytoplankton in spite of their weak loads on the axis plain. Therefore, univariate analysis of these external factors may supply an extended understanding of community structure in the pelagic zone of the alkaline and unproductive Lake Hazar.

The GLM simulated the seasonal succession based on the abundance response of the taxa to temperature changes in the water column of Lake Hazar (Figure 5). Algal abundance was defined by high numbers around 10 °C, which was near the annual mean temperature

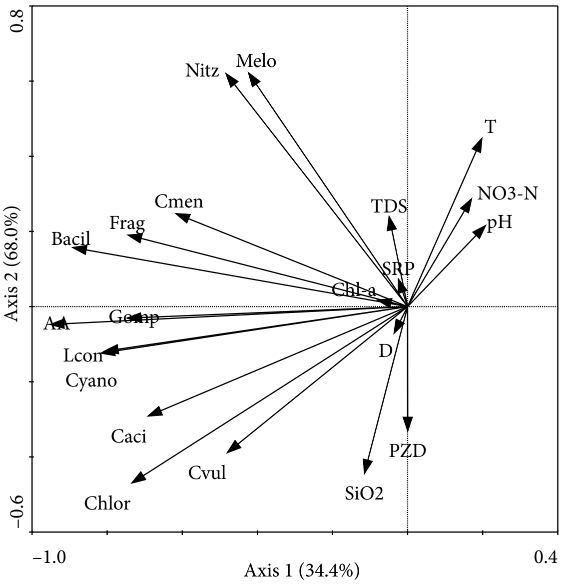

Figure 4. PCA plot of environmental variables and abundance data. AA, algal abundance; Bacil, Bacillariophyta; Caci, *Closteriopsis acicularis*; Chlor, Chlorophyta; Cmen, *Cyclotella meneghiniana*; Cvul, *Chlorella vulgaris*; Cyano: Cyanophyta; Frag, *Fragilaria* spp.; Gomp, *Gomphonema* spp.; Lcon, *Planktolyngbya contorta*; Melo, *Melosira* sp.; Nitz, *Nitzschia* spp.; T, temperature; D, depth; PZD, photic zone depth; TDS, total dissolved solids; NO3-N, nitrate nitrogen; SRP, soluble reactive phosphorus; SiO2, silica; Chl-*a*, chlorophyll *a*.

Table 2. Total variance explained with PCA.

Axes	1	2	3	4	Total variance
Eigenvalues	0.514	0.115	0.096	0.071	1.000
Species–environment correlations	0.269	0.562	0.230	0.262	
Cumulative percentage variance					
of species data	51.4	62.9	72.4	79.5	
of species–environment relationships	34.4	68.0	72.8	77.3	

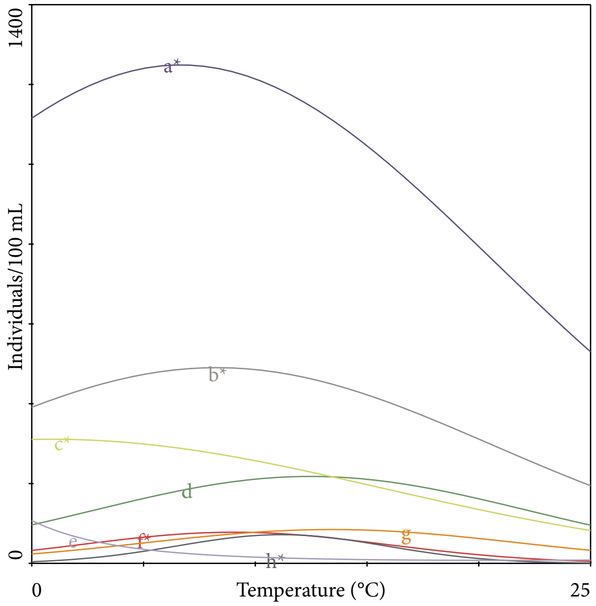

Figure 5. GLM fits of abundance response to temperature (°C) predictor (distribution: Poisson; link function: log). a- algal abundance; b- *Planktolyngbya contorta*; c- *Gomphonema* spp.; d- *Cyclotella meneghiniana*; e- *Melosira* sp.; f- *Closteriopsis acicularis*; g- *Fragilaria* spp.; h- *Chlorella vulgaris*; *: P < 0.05.

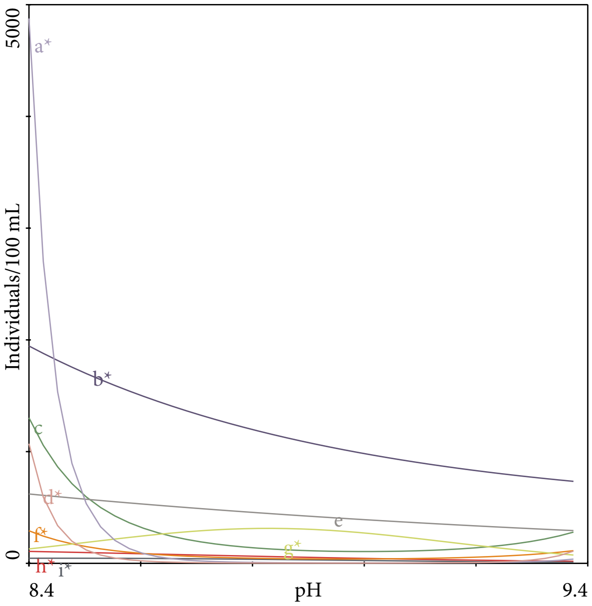

Figure 6. GLM fits of abundance response to pH predictor (distribution: Poisson; link function: log). a- *Melosira* sp.; b- algal abundance; c- *Cyclotella meneghiniana*; d- *Nitzschia* spp.; e- *Planktolyngbya contorta*; f- *Fragilaria* spp.; g- *Gomphonema* spp.; h- *Chlorella vulgaris*; i- *Closteriopsis acicularis*; *: P < 0.05.

in the water column. The GLM roughly classified *Gomphonema* species as dominant below 10 °C, while *Planktolyngbya contorta* and *Cyclotella meneghiniana* were dominant around 10 °C and above 15 °C, respectively. The model explained maximum growth under the higher temperature conditions in spring and autumn for species such as *Fragilaria* sp., *Chlorella vulgaris*, and *Closteriopsis acicularis*.

In addition to highlighting temperature change as a means for understanding the seasonal succession, GLM results showed that the abundance response of taxa to pH change was also highly significant (Figure 6). The GLM modeled that the abundance of species dramatically decreased with linear and polynomial trends above pH 8.5, with the exception of *Gomphonema* species. Similarly, the model showed the negative impact of increasing dissolved solids on the growth of species, with the exception of *Planktolyngbya contorta* and *Cyclotella meneghiniana* (Figure 7). The model results led us to consider that increasing TDS concentrations may restrict phytoplankton growth by limiting the nutrient availability via the processes of adsorption, dissolution, and precipitation.

The response of species abundance to PZD change did not produce meaningfully interpretable results. However, the GLM described the vertical distribution patterns of species (Figure 8). It simulated that while *P. contorta* dominated between 5 m and 10 m, *Gomphonema* and *Fragilaria* species exhibited vertically linear increasing and decreasing trends. *C. meneghiniana* showed a concentration pattern between 10 m and 15 m.

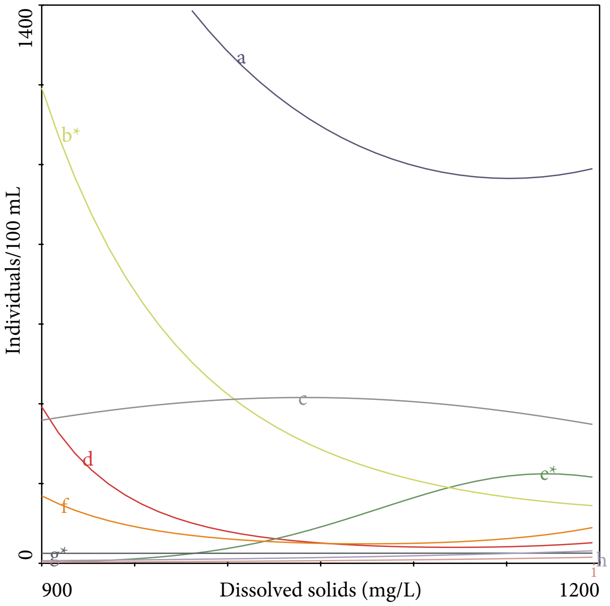

Figure 7. GLM fits of abundance response to TDS predictor (distribution: Poisson; link function: log). a- algal abundance; b- *Gomphonema* spp.; c- *Planktolyngbya contorta*; d- *Closteriopsis acicularis*; e- *Cyclotella meneghiniana*; f- *Fragilaria* spp.; g- *Chlorella vulgaris*; h- *Melosira* sp.; i- *Nitzschia* spp.; *: P < 0.05.

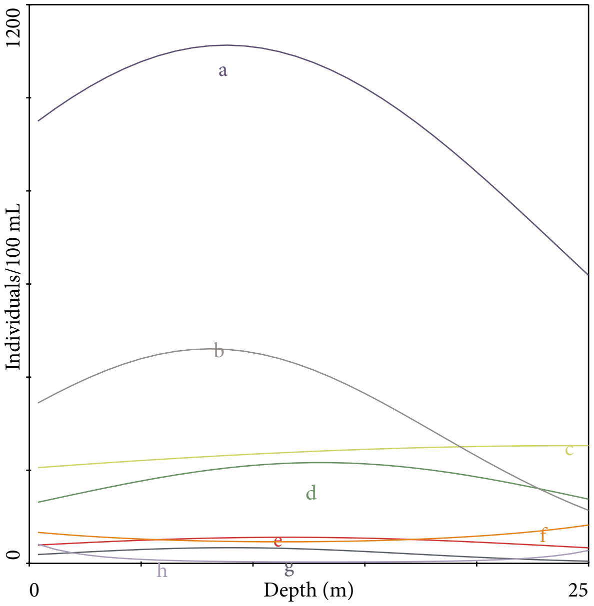

Figure 8. GLM fits of abundance response to depth predictor (distribution: Poisson; link function: log). a- algal abundance; b- *Planktolyngbya contorta*; c- *Gomphonema* spp.; d- *Cyclotella meneghiniana*; e- *Closteriopsis acicularis*; f- *Fragilaria* spp.; g- *Chlorella vulgaris*; h- *Melosira* sp.

4. Discussion

The results of the nonparametric test pointed to a prevalence at 10 m especially for cyanobacteria and green algae, while diatoms did not exhibit such a clear vertical distribution pattern. Multivariate analysis also indicated that the variables T, pH, PZD, TDS, NO_3^--N, and SiO_2 may have significant impacts on the abundance and distribution of phytoplankton in Lake Hazar.

Nutrients have been invoked as one of the main factors controlling phytoplankton community structure and biomass, and numerous studies demonstrated that phosphorus, nitrogen, and silicon are limiting resources (Tilman et al., 1982). Hecky and Kilham (1988) proposed that nutrient limitation occurs at concentrations not analytically detectable. Therefore, dissolved nutrient data cannot be interpreted in terms of growth limitation but can be used to calculate nutrient fluxes to aquatic ecosystems. However, the measured nutrient concentrations may be used to determine the trophic state, and their ratios may indicate whether a particular nutrient is limiting (Guildford and Hecky, 2000; Dodds, 2003). The concentration ranges of TN and TP may help to evaluate the trophic status of Lake Hazar as mesotrophic (OECD, 1982; Hakanson and Jansson, 1983; Nürnberg, 1996). Additionally, data on N:P and Si:P ratios (about 100Si:30N:1P) may partially explain diatom dominance in Lake Hazar, as shown in experimental studies (Tilman et al., 1982). However, these approaches cannot easily explain low Chl-*a* concentrations and nominal algal abundance in the pelagic zone despite the high littoral phytoplankton contribution (Koçer and Şen, 2012).

These queries suggest that Lake Hazar has a sufficient nutrient pool. Therefore, questions should focus on external factors other than nutrients for a good understanding of spatial and temporal variation in phytoplankton. Temperature is one of the major external factors impacting maximum growth rates and convection currents (Tilman et al., 1982; Wetzel, 2001). The modeling approach showed the effects of temperature on seasonal succession in the pelagic zone of Lake Hazar, classifying the taxa response to temperature variation into 3 ranges.

The GLM also simulated a dramatic decrease in biomass above pH 8.5. Obvious dominance of neutral/alkaliphilic diatom taxa (Håkansson, 1993; Van Dam et al., 1994) in the littoral and pelagic zones of Lake Hazar, from the point of diversity and abundance (Şen, 1988; Şen et al., 1995; Sönmez and Şen, 2011; Koçer and Şen, 2012), supports this projection. Higher relative abundance of alkaliphilic/alkalibiontic *Gomphonema olivaceum* (Håkansson, 1993; Solak et al., 2012), which was also reported as dominant in phytoplankton by Koçer and Şen (2012), may explain the estimated growth trend of *Gomphonema* species between pH 8.6 and 9.0. The results may suggest that pH is a major limiting factor for phytoplankton biomass and diversity, taking into account the mean pH value of 9.0 in the pelagic area of Lake Hazar.

pH is the master variable in the chemistry of aquatic ecosystems due to impacts on the kinetics of nutrient uptake and the chemical forms of the required nutrient ions for algae (Tilman et al., 1982). The extent of complexing and chelation between phosphate forms and micronutrient metal depends upon the pH as well as the relative concentrations of these ions. Moreover, increasing pH leads to the formation of calcium carbonate, which coprecipitates phosphate with the carbonate. When pH increases above 8.5, a considerable reduction in carbon dioxide concentration occurs, and equilibrium concentrations of dissolved carbon dioxide become inadequate to saturate photosynthesis. In this case, many algae are capable of utilizing bicarbonates as a carbon source (Wetzel, 2001). In addition, high alkaline conditions (pH > 9) enhance the dissociation of silicic acid where the saturation level of sodium carbonate is maximal (Fritz et al., 1999). Reflecting a positive correlation between TDS and T, the GLM showed the negative impact of increasing dissolved solids content on the growth of all species except the alkaliphilic *C. meneghiniana* (Solak and Kulikovskiy, 2013) and the brackish water species *P. contorta*. The model results suggest that increasing carbonate concentrations increase TDS and pH and, thus, may be limiting to phytoplankton growth by decreasing carbon dioxide, SRP, and SiO_2 availability via the processes of adsorption, dissolution, and precipitation. This hypothesis, which produces many new questions regarding the dynamics of the lake, remains to be proven.

The main physical factors affecting vertical distribution are light gradients and thermal stratification (Longhi and Beisner, 2009). However, GLM simulation of responses of species abundance to PZD changes did not provide significant evidence defining the impact of light on the vertical distribution of phytoplankton. On the other hand, the model described the vertical distribution patterns of species as a result of a combined impact of external factors, although there was no statistical significance. The domination trend of *P. contorta* over the metalimnion, as a shade-adapted cyanobacteria, was similar to its vertical distribution pattern between 6 m and 10 m in the saline Lake Shira, depending on the percent ratio of surface irradiance (Degermendzhy and Gulati, 2002; Degermendzhy et al., 2002; Gaevsky et al., 2002; Kopylov et al., 2002). The centric diatom *C. meneghiniana* concentrates in the metalimnion and was responsible for deep chlorophyll maxima in Lake Tahoe as a result of light and buoyancy adaptations (Winder and Hunter, 2008). The vertically linear increasing trend of the *Gomphonema* species is in harmony with the experimental results of Reynolds, who found that fast-sinking diatoms were replaced by buoyant and motile taxa (Reynolds, 1984).

From a different viewpoint, the dominant and subdominant taxa in the phytoplankton of Lake Hazar have also been indicators of different habitat conditions. According to the functional classification of phytoplankton, *C. meneghiniana* were more often associated with mesotrophic and mixed waters (Kruk et al., 2002; Moura et al., 2009) as well as eutrophic small- and medium-sized lakes (Padisak et al., 2009). *Fragilaria* species and *Melosira* sp. were indicative of eutrophic lakes with continuous or semicontinuous mixed layers, while *P. contorta*, *C. vulgaris*, *C. acicularis*, and *Nitzschia* species were common among the turbid mixed waters of eutrophic shallow lakes (Reynolds, 1998; Reynolds et al., 2002; Moura et al., 2009; Padisak et al., 2009). The meroplanktonic species, including *Gomphonema*, *Epithemia*, and *Cymbella* species, drifted from metaphytic, periphytic, and epilithic habitats into the phytoplankton, and they were also dominant among diatoms in the surface phytoplankton of Lake Hazar (Koçer and Şen, 2012); they are probably associated with frequently stirred-up, inorganically turbid, shallow lakes (Padisak et al., 2009). In fact, it has been proposed that many diatom species enter into the phytoplankton, detaching from the benthic habitats of the littoral zone by wind-driven currents (Koçer and Şen, 2012). Keeping in mind the adaptations of species regarding light niches and buoyancy, the functional classification approach denotes that distribution and biomass of the phytoplankton in Lake Hazar were highly associated with mixing processes.

The importance of sampling frequency in understanding spatial and temporal variations in phytoplankton is well known (Interlandi and Kilham, 2001). Despite a low sampling frequency, this study revealed the significance of a few key factors on phytoplankton biomass and distribution in unproductive Lake Hazar, which possesses highly alkaline and hard water characteristics. High pH and dissolved solids content appear to be limiting factors for nutrient availability in spite of a sufficient nutrient pool in mesotrophic conditions. Indeed, pH, dissolved solids (as salinity), and temperature were suggested as major factors controlling the distribution and abundance of the phytoplankton community in a saline and a soda lake (Girgin et al., 2004; Kazancı et al., 2004).

Therefore, the findings of the present study indicate that high pH and dissolved solids seem to be major factors controlling growth and biomass of phytoplankton as well as species diversity in Lake Hazar. A seasonal succession of phytoplankton in which meroplanktonic species are dominant is mainly governed by temperature, while mixing and water movement may be driving factors in spatial and temporal variation. Long-term field studies with more frequent sampling and laboratory experiments focusing on these major factors and their mechanisms would allow us to better understand phytoplankton biomass, diversity, and distribution in Lake Hazar.

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