© by PSP Volume 29 – No. 12A/2020 pages 11129-11135 Fresenius Environmental Bulletin

EVALUATION OF ECOLOGICAL CHANGES IN LAKE HAZAR (ELAZIG, TURKEY) USING DIATOM-BASED PALEOLIMNOLOGICAL TECHNIQUES

Faruk Maraslioglu[1,*], Elif Neyran Soylu[2], Ulas Avsar[3], Aurelia Hubert-Ferrari[4]

[1]Department of Biology, Faculty of Arts and Science, Hitit University, Corum, Turkey
[2]Department of Biology, Faculty of Arts and Science, Giresun University, Giresun, Turkey
[3]Department of Geological Engineering, Middle East Technical University, Ankara, Turkey
[4]Department of Geography, University of Liege, Liege, Belgium

ABSTRACT

Sediment core samples (H002, H003, H005 and H006) recovered from the basin of Lake Hazar located in the South East Region of Turkey. Core samples were collected from the four sampling stations by UWITEC corer to determine diatom flora distribution in Lake Hazar. Diatom counts and identifications were made from the sediments sampled at 1-2 cm intervals. Total of 142 species of diatoms were recorded, most of them were pennate diatoms. *Ulnaria ulna, Nitzschia gracilis, Synedra nana,* and *Cyclotella ocellata* dominated the assemblage in the sampling points. Our objective was to investigate the environmental and ecological history of Lake Hazar, and to recover diatom microfossil profils using paleolimnological techniques.

KEYWORDS:
Paleolimnology, sediment, microfossil, species composition, ecological status

INTRODUCTION

The siliceous valves of diatoms and chrysophyte cysts are generally abundant and well preserved in lake sediments. So, Lacustrine algal remains (e.g. diatoms, pigments and chrysophyte scales) can serve as valuable indicators of past environments and can act as indices of present and past trophic conditions [1]. They are useful for revealing successional changes in glacial and postglacial ecology, limnology and climate, especially changes in aquatic productivity [2].

Diatoms are extremely sensitive to changes in water chemistry, with specific species being adapted to a particular environment. Due to their short life cycle, they quickly respond to changes in their environment. For that reason, they are often used to track pollution and evaluate environmental health of aquatic habitats [3]. When diatoms die, the frustule sinks to the bottom and is added to the sedimentary record. The diatom assemblage preserved at depth in a sedimentary sequence provides information on past water chemistry and environmental conditions [4].

Paleolimnological approaches can be used to define physical, chemical and biological variations (changes) even there is no record of environmental measurements data base [5]. Subfossil diatoms are used as indicators of environmental conditions (e.g. pollution, pH, nutrients, water level) and climate changes. For this reason, they provide a tool for examining environmental change. For decades, diatoms have been used successfully to describe the environmental histories of lake systems [6]. However, the studies on this subject are not sufficent.

MATERIALS AND METHODS

Site Description. The oligotrophic Lake Hazar is the second largest natural lake in Eastern Anatolia. The lake is monomictic, with the incomplete mixing in spring and the complete mixing between autumn and early winter. It is stratified from June to September, forming a thermocline between 10 and 20 meters [7].

Lake Hazar, formed by faulting of the Eastern Anatolia Fault, is a tectonic lake located at 38°31′ N, 39°25′ E. Lake Hazar covers about 100 km^2 of the basin area with an NE-trending elongated-shape along the East Anatolian Fault. According to bathymetrical measurement of the lake, various maximum depths ranging between 80 and 210 m (Figure 1). The bathymetry map shows two distinct areas: an irregular 216 m-deep sub-basin in the northeastern half of the lake and a much flatter and shallower sub-basin occupying its southwestern half. These two main sub-basins have been named the Deep and Flat basins to facilitate the description of the basin [8].

The lake level was about 80 m lower at the start of the Holocene than in 2007 and may have reached its present height only during the last two centuries. These relatively recent lake-level fluctuations appear to be mainly caused by tectonic

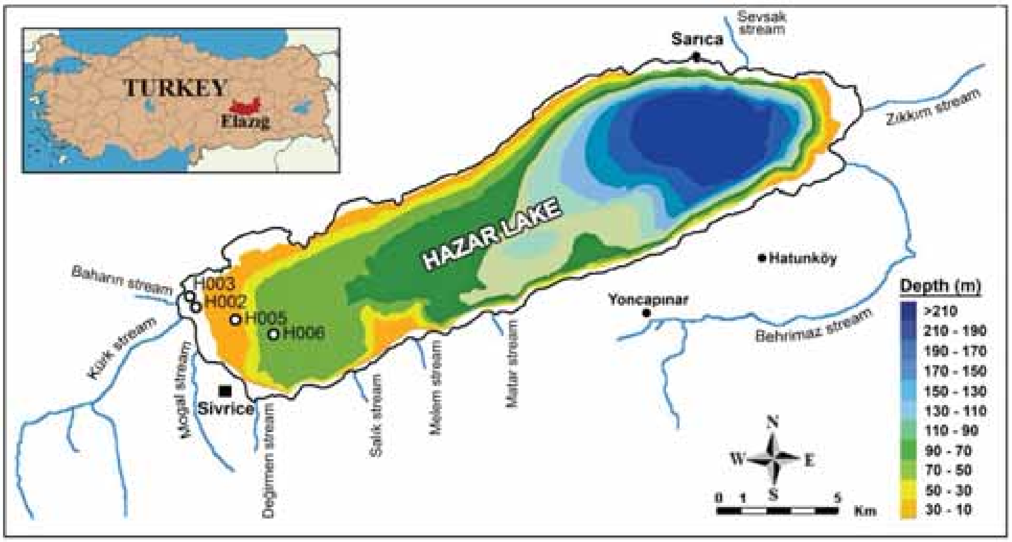

FIGURE 1
The bathymetry map and sediment core locations of Lake Hazar

forcing. However, the main rises of the lake level since the last glacial period are close in time with documented climatic changes in this region. Consequently, the climatic factor may also have contributed to the water-level rise of Lake Hazar during the Holocene period [8].

Core Sampling. Four Gravity Cores were collected in Lake Hazar by a UWITEC corer. The lengths of HZ002, HZ003, HZ005 and HZ006 cores were 84, 92, 68 and 74 cm respectively, and the depths taken were 5.2, 5, 20.4 and 57.2 meters respectively. Diatom valves were separated from the organic matrix of the sediments using standard techniques [9]. Small samples of dry sediment (0.5–1 g) were digested in a solution of 50:50 concentrated sulfiric and nitric acid. Digestion was accelerated by placing the samples in a boiling water bath for 1 h. Digested slurries were rinsed several times in distilled water until neutral pH was reached. On a slide warmer, slurries were dried overnight on coverslips, and then mounted onto microscope slides using Entellan, a permanent mounting medium. Diatom valves were enumerated and identified using an Olympus system microscope (BX53). For each slide, a minimum of 300 valves was counted along a transect. Species identifications were based primarily on the Krammer & Lange-Bertalot [10-13].

RESULTS

Based on the trophic status classification, the surface water of the pelagic zone of Lake Hazar exhibited oligotrophic characteristics in terms of total nitrogen and mean and maximum chlorophyll-*a* concentrations, but it was mesotrophic in total phosphorus. Overall, the main physicochemical characteristics suggest that Lake Hazar is an oligotrophic, hard-water, and alkaline soda lake with to the surface water of the pelagic zone [7].

A total of 142 species of diatoms were recorded in the core samples of Lake Hazar. *Navicula* (31 taxa), *Cymbella* (21 taxa), *Nitzschia* (16 taxa), *Gomphonema* (12 taxa), *Fragilaria* (9 taxa), *Amphora* (8 taxa) and *Epithemia* (8 taxa) were the most common diatom genera in Lake Hazar sediments. Also *Cyclotella ocellata*, *Gomphonema olivaceum*, *Navicula cryptocephala*, *Surirella linearis* and *Ulnaria ulna* species were found in all core samples. But in terms of abundance, *U. ulna*, *Nitzschia gracilis*, *Synedra nana*, and *C. ocellata* were to be remarkable species especially until 69 cm. Diatom assemblage zones were defined by cluster analysis. According to this analysis, four zones were defined as A, B, C, and D in the sediments of Lake Hazar (Figure 2).

A Zone. In the deepest part of the core (below 6 cm), the diatom assemblage shows the marked dominance of *Cyclotella* species, mainly *C. ocellata*, a species typical of mesotrophic lakes [14]. This zone is characterized by increased abundance of *C. ocellata* forming 52 % of diatom community. This species was registered as the most abundant species especially in H006 core station and especially at the first 6 centimeters.

B Zone. This zone between 11 and 34 cm was the most important part of the core samples as species abundance and species diversity. This zone is characterized by an initial increase in the abundance of *Nitzschia gracilis* and *Synedra nana*, followed by the sequential appearance of eutrophic species, such as *Nitzschia palea*, *Nitzschia fonticola*, *Navicula cryptocephala*, and *Epithemia turgida*. *N. gracilis* and *S. nana* species became co-dominant species as abundance in this zone forming

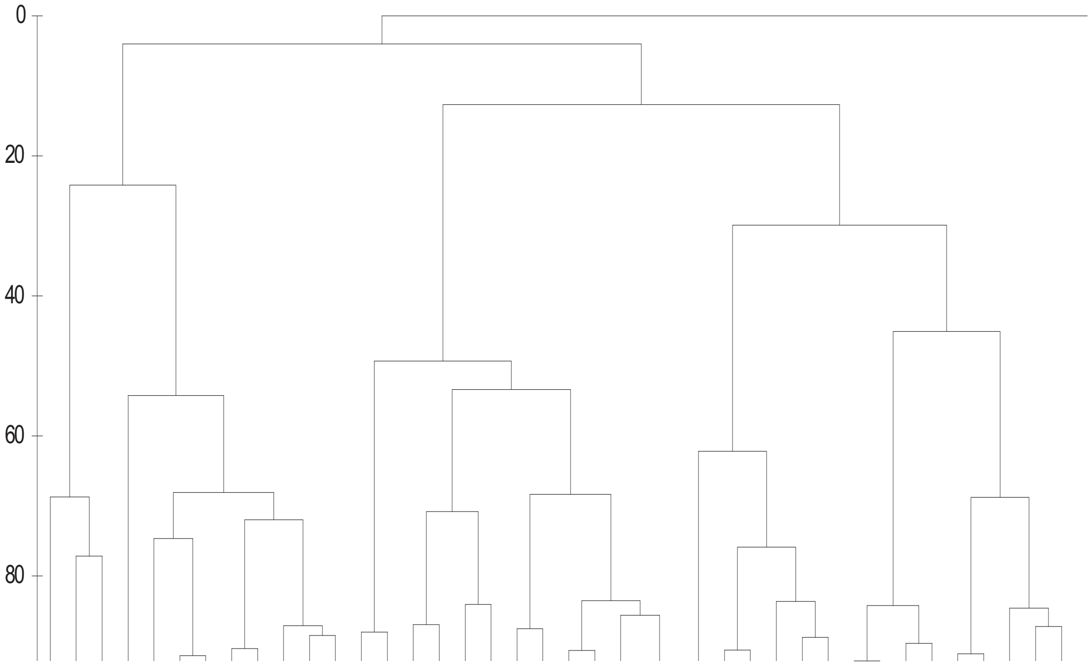

FIGURE 2
Dendrograms using complete linking of Bray-Curtis similarities

32-34 % of total diatoms, respectively. The only difference in the dominance of both species was it that while *N. gracilis* was registered as dominant at 17-18 cm, 19-20 cm, and 29-30 cm, *S. nana* species was found as dominant between 31-32 cm. Additional taxa emerging in increased relative abundance in this zone include *Ulnaria ulna.* This species, characterized by continuous presence in all depths of this part, was subdominant species in this section of the core (Figure 3).

C Zone. *Ulnaria ulna* species was the most important part of this zone. In this zone, *U. ulna*, the subdominant species in B zone, was dominant composing 78 % of total diatoms. This zone is characterized by continuous presence of *U. ulna* in all depths of this part, like in B zone.

D Zone. There is a serious decline in number of organisms to the topmost 23 cm. This zone is characterized for all species by the low abundance. This zone is the nearest to the benthic area. The most important species of this zone was *Synedra nana* and *Nitzschia palea* whose relative abundance however didn't reach the values found in the B zone of the core. It was the first time for all depths that these species were seen in such a low abundance.

Significant increases were registered in the abundance of diatoms after 13 cm. *Ulnaria ulna, Nitzschia gracilis, Synedra nana,* and *Cyclotella ocellata* were found to be important diatoms in the sampling areas (Figure 3). The dominance of Fragilariaceae family may be related to the high surface-to-volume ratio of small cells. The other importance of this group is higher specific growth rates. So, this may be a competitive advantage to small taxa under low nutrient conditions [15]. Furthermore, these taxa may quickly form blooms and outcompete larger and/or planktonic diatoms during the short growing season [16].

Ulnaria ulna, Nitzschia gracilis, Synedra nana, and *Cyclotella ocellata* were found to be the most important species in the Lake Hazar core samples (Figure 4). Although planktonic diatoms were occasionally dominant in some lakes [17], benthic diatoms base on epilithic, epipelic, epipsammic, epiphytic species were found dominant in most lakes same as Lake Hazar. However, planktonic diatoms were found commonly in Saint-Louis and Saint Francois Lakes's core samples [18].

DISCUSSION

Algal remains provide an internally consistent record of ecosystem response to several well-defined natural and anthropogenic events, reaffirming the close interrelationship within this trophic level. It is clear from the figures presented here that there is remarkable coherence across a diverse range of biotic and abiotic proxy records recorded in the sediments, which demonstrates the inter-dependence of the entire lake-catchment system as it responds to environmental change.

Paleolimnological analyses based on diatoms aid to determine at present day degredation of water quality and the timing of the events that cause the changes of great ecosystem. At each zone of core

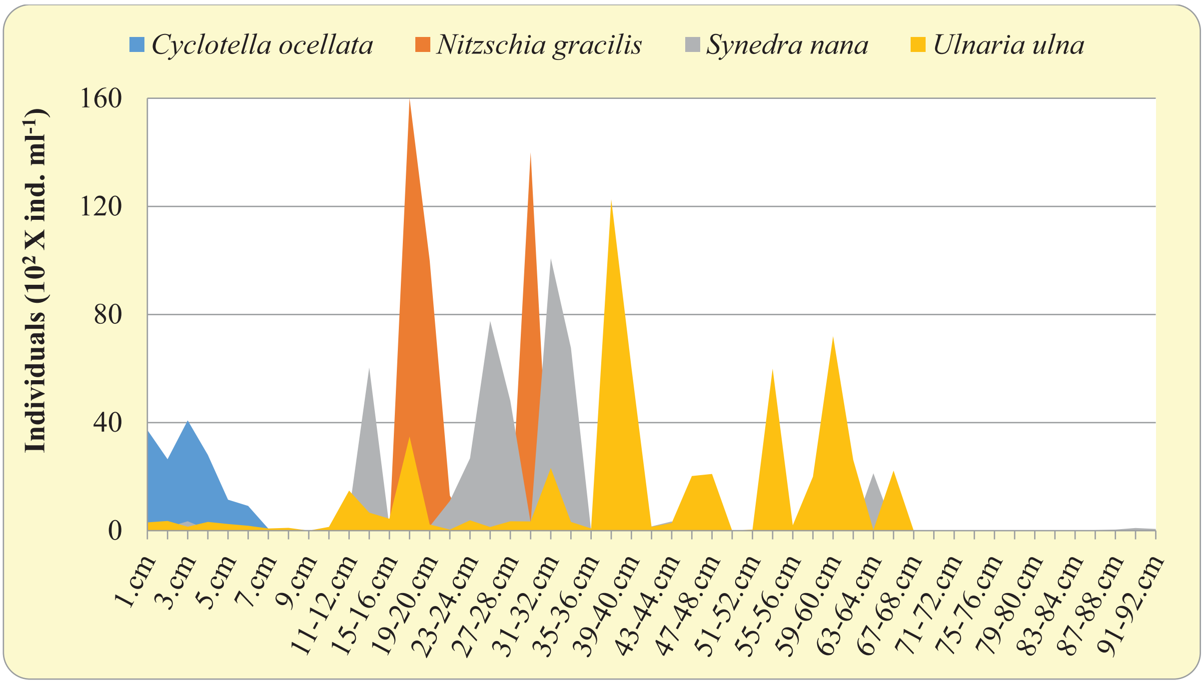

FIGURE 3
Depth-based distributions of common species in the core samples of Lake Hazar

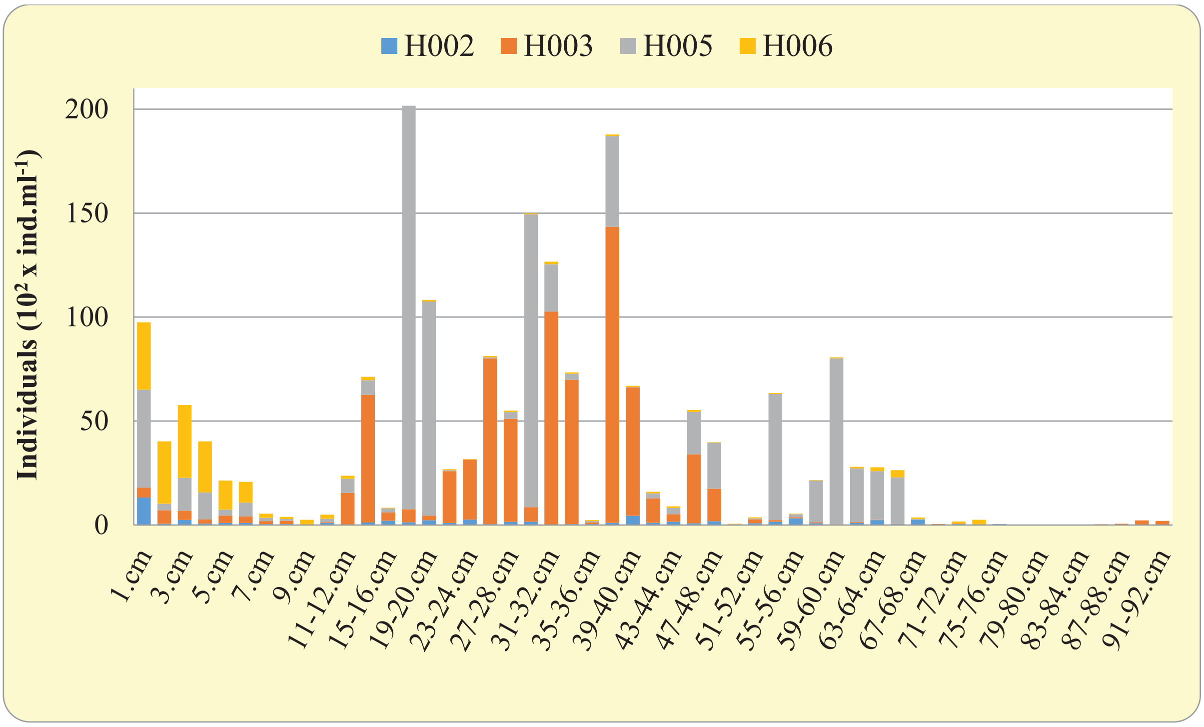

FIGURE 4
Depth-based variations of total organisms at four core sampling stations (H002, H003, H005, H006)

samples the differences have been observed in the number and variety of paleolimnetic diatoms in Lake Hazar. These changes are reflected by modifications of diatom assemblages in the lake, specially in the dominant species. The changes in organic matter and dominant species in the sedimentary diatom assemblages of Lake Hazar indicate that changes in the silica content, modifying the nutrient availability in the water. According to Barker and his colleagues [19], fluctuating of the diatoms abundance associates with the silica content in the water. By this expression it is likely that while the silica availability at the last 23 cm is rather low with falling diatoms abundance, the silica content between 11-69 cm is partially high with increasing diatoms abundance in our study area.

Both planktonic and benthic diatoms occurred in these sediments. The majority of the diatom flora is typical of oligo-mesotrophic and eutrophic lakes.

While oligo-mesotrophic species were common at first period, eutrophic species peaked at later periods (B and C zone). For the trophy of final phase we can't say an obvious expression because of lowing diatoms abundance.

At the initial period of the lake's existence (A Zone, especially lower part of H006) the frequency of open-water diatoms increased. The genus *Cyclotella* often dominates species assemblages in paleolimnology and can cause difficulties or loss of information in paleoenvironmental reconstructions due to the ongoing taxonomic uncertainty in the family of Stephanodiscaceae [20]. The development of planktonic *Cyclotella ocellata* and the low frequency of benthic *Ulnaria ulna* and *Nitzschia fonticola* indicate higher water level. The dominant taxa in this part of the core point to a mesotrophic environment. Accordingly, the development of *Cyclotella* spp. suggest a lower trophic status of the lake; the ecological amplitude of *C. ocellata* has not been entirely clarified, however. This taxon is found in shallow as well as deep ultra-oligotrophic [21], oligo-mesotrophic [22] and mesotrophic lakes [23]. According to Haworth and Hurley [24], *Cyclotella* spp. grows in habitats with high silica availability and, in many cases, the distribution of this species is related to a volcanic horizon with high silica content. Also, Reynolds and his colleagues [14] stated that *C. ocellata* lives generally in mesotrophic small medium lakes and is sensitive to Si depletion and pH rise. The increase of *C. ocellata* at the fist 6 cm in core samples may be explained with the high silica availability at these santimeters.

In the next parts of core samples (B and C Zones, especially medium parts of H003 and H005) was dominated by benthic and epiphytic diatoms such as *Nitzschia gracilis, Synedra nana* and *Ulnaria ulna*. This suggests a shallow water level and turbid water. *N. gracilis* population growth in Lake Hazar was apparently controlled by certain physical features. The role of nutrients in *N. gracilis* population dynamics easily understood, since this diatom appears to thrive in environments with widely varying N:P and Si:P ratios. Phosphorus appeared to be inversely related to *N. gracilis* length in E1 Porcal lake. This has been expressed by Cobelas and Garcia-Morato [25] as a side effect of the phosphorus effect on population growth. In our core samples (H002, H003, H005, H006), *N. gracilis* had peak only in H005 sampling point in the ranges of 17-18, 19-20 and 29-30 cm. So, we can't say for zone B, silica and phosphorus had been low level in the past. However, Reynolds and his colleagues [14] stated that *U. ulna* and *Nitzschia* spp. prefer to enriched turbid waters as habitat and are sensitive to nutrient depletion. However, Sienkiewicz [17] stated that *U. ulna* (*Synedra ulna)* have wide trophy tolerance and can live in oligo-eutrophic waters. Unlike the eutrophic-featured benthic species mentioned above, some diatoms preferring eutrophic conditions occurred at low frequency in this period of the Lake Hazar (e.g. *Epithemia turgida*, *Gomphonema olivaceum*, *Navicula cryptocephala*, *N. veneta*, *Nitzschia fonticola*, *N. palea*, *N. paleaceae*, *Surirella linearis*). This result shows that the lake at this time probably had good habitat conditions for promoting benthic algal growth: warmer seasonal temperature and nutrient-rich surface water. Consequently, the diatom assemblages indicate that the lake had an eutrophic environment at the later period of lake's development (B and C Zone).

For the final phase of the lake's existence (D Zone, upper parts of core samples) we can't comment owing to low diatom abundance. If we need necessarily to make a comment on trophic status of lake's these layers, it can be expressed that according to the available species in a small number (*Nitzschia fonticola, N. palea, Synedra nana*), this period of the lake was eutrophic. The frequency of both mezotrophic and eutrophic species fell suddenly especially *Cyclotella ocellata*, *Ulnaria ulna*, *Synedra nana* that were commonly present in other zones, perhaps due to occuring of tectonic movements in the last part of sediment. Thus, it is likely that changes in hydrological and/or climatic conditions derived from tectonic movements may have caused instantaneous decrement of the diatom abundance and diversity.

CONCLUSION

Evaluating the trophic structure of the Lake Hazar on the basis of diatom from the present to the past about 100 years, it is seen that the lake's trophic structure has changed from oligotroph to eutroph in the past although the Lake Hazar is an oligotrophic structure in nowadays. Contrary to many other studies [17], planktonic and benthic diatoms in Lake Hazar have been distributed throughout all zones. The changes in the water level of the lake from past to present changed the trophic structure of the lake and the distribution ratios between planktonic and benthic diatoms. The abundance of planktonic diatoms in the community suggests that the lake was oligo-mesotrophic at the beginning of its development. Possibly the best conditions for growth of the diatom flora were the later period of lake's development (B and C zones), marked by the highest development of diatoms based on bentic area, nutrient-rich. The majority of diatoms were alkaliphilous and alkalibiontic taxa, confirming the high trophic status of Lake Hazar. As seen in Lake Hazar, the best conditions for the diatoms were found to be second period (the Boreal and early Atlantic) in Lake Skaliska [17]. But, dominant diatom species in this period of the lake were generally open-water diatoms such as *Cyclotella ocellata*, *Aulacoseira* spp., *Stephanodiscus* spp. that differs from Lake Hazar.

Finally a change in sediment lithology took place at the beginning of D zone (69 cm).

ACKNOWLEDGEMENTS

This study was financially supported by the European Commission Marie Curie Excellence Grant Project "Understanding the irregularity of seismic cycles: A case study in Turkey" (MEXT-CT-2005-025617: Seismic Cycles), hosted by the Seismology Section of the Royal Observatory of Belgium.

REFERENCES

[1] Leavitt, P.R. (1993) A review of factors that regulate carotenoid and chlorophyll deposition and fossil pigment abundance. Journal of Paleolimnology. 9, 109-127.

[2] Sanger, J.E. (1988) Fossil pigments in palaeoecology and palaeolimnology. Palaeogeography Palaeoclimatology Palaeoecology. 62(1-4), 343-359.

[3] Ivanov, P., Chipev, N., Temniskova-Topalova, D. (2003) Diatoms of the river Iskar (Sofia plane) and their implication for water quality assessment. Part 1. The diatom flora, ecology and community structure. Journal of Environmental Protection and Ecology. 2(4), 301-310.

[4] Rosén, P., Hall, R., Korsman, T., Renberg, I. (2000) Diatom transfer-functions for quantifying past air temperature, pH and total organic carbon concentration from lakes in northern Sweden. Journal of Paleolimnology. 24(2), 109-123.

[5] Smol, J.P. (1992) Paleolimnology: An important tool for effective ecosystem management. J. Aquat. Ecosyst. Health. 1, 49-58.

[6] Dixit, S., Cumming, B.F., Smol, J.P., Kingston, J.C. (1992) Monitoring environmental changes in lakes using algal microfossils. In: McKenzie, D.H., Hyatt, D.E., MacDonald, V.J. (Eds.) Ecological Indicators. Amsterdam. Elsevier Applied Science. 1135-1155.

[7] Koçer, M.A.T., Şen, B. (2012) The seasonal succession of diatoms in phytoplankton of a soda lake (Lake Hazar, Turkey). Turkish Journal of Botany. 36, 738-746.

[8] Moreno, D.G., Hubert-Ferrari, A., Moernaut, J., Fraser, J.G., Boes, X., Daele, M.V., Avşar, U., Çağatay, N., Batist, M.D. (2011) Structure and recent evolution of the Hazar Basin: A strike-slip basin on the East Anatolian Fault, Eastern Turkey. Basin Research. 23(2), 191-207.

[9] Batterbee, R.W. (1986) Diatom analysis. In: Berglund, B.E. (Ed.) Handbook of Holocene paleoecology and paleohydrology. London. Wiley and Sons Ltd. 527-570.

[10] Krammer, K., Lange-Bertalot, H. (1991a) Freshwater flora of Central Europe. Bacillariophyceae, Part 3. Centrales, Fragillariaceae, Eunotiaceae. Germany, Stuttgart. Gustav Fischer Verlag. 576pp. (in German).

[11] Krammer, K., Lange-Bertalot, H. (1991b) Freshwater flora of Central Europe. Bacillariophyceae, Part 4. Achnanthaceae, Critical additions to *Navicula* (Lineolate) and *Gomphonema* complete literature. Germany, Stuttgart. Gustav Fischer Verlag. 436pp. (in German).

[12] Krammer, K., Lange-Bertalot, H. (1999a) Freshwater flora of Central Europe. Bacillariophyceae, Part 1. Naviculaceae. Germany, Berlin. Spectrum Academicher Verlag. 876pp. (in German).

[13] Krammer, K., Lange-Bertalot, H. (1999b) Freshwater flora of Central Europe. Bacillariophyceae, Part 2. Bacillariaceae, Epithemiaceae, Surirellaceae. Germany, Berlin. Spectrum Academicher Verlag. 610p. (in German).

[14] Reynolds, C.S., Huszar, V., Kruk, C., Naselli-Flores, L., Melo, S. (2002) Towards a functional classification of the freshwater phytoplankton. Journal of Plankton Research. 24, 417-428.

[15] Westover, K.S., Fritz, S.C., Blayakharchuk, T.A., Wright, H.E. (2006) Diatom paleolimnological record of Holocene climatic and environmental change in the Altai Mountains, Siberia. Journal of Paleolimnology. 35(3), 519-541.

[16] Smol, J.P. (1988) Paleoclimate proxy data from freshwater arctic diatoms. SIL Proceedings. 23(2), 837-844.

[17] Sienkiewicz, E. (2013) Limnological record inferred from diatoms in sediments of Lake Skaliska (north-eastern Poland). Acta Palaeobotanica. 53(1), 99-104.

[18] Reavie, E.D., Smol, J.P., Carignan, R., Lorrain, S. (1998) Diatom paleolimnology of two fluvial lakes in St. Lawrence River: A reconstruction of environmental changes during the last century. Journal of Phycology. 34(3), 446-456.

[19] Barker, P., Telford, R., Merdaci, Q., Williamson, D., Taieb, M., Vincens, A. (2000) The sensitivity of a Tanzanian crater lake to catastrophic tephra input and four millennia of climate change. The Holocene. 10(3), 303-310.

[20] Häkansson, H. (2002) A compilation and evaluation of species in the genera *Stephanodiscus*, *Cyclostephanos* and *Cyclotella* with a new genus in the family Stephanodiscaceae. Diatom Research. 17, 1-139.

[21] Cremer, H., Wagner, B. (2003) The diatom flora in the ultra–oligotrophic El'gygytgyn, Chukotka. Polar Biology. 26, 105–114.

[22] Reavie, E.D., Smol, J.P. (2001) Diatom-environmental relationships in 64 alkaline southeastern Ontario (Canada) lakes: A diatom-based model for water quality reconstructions. Journal of Paleolimnology. 25, 25-42.

[23] Maraşlıoğlu, F., Gönülol, A. (2014) Phytoplankton Community, Functional Classification and Trophic State Indices of Yedikır Dam Lake (Amasya). Journal of Biological and Environmental Sciences. 8(24), 133-141.
[24] Haworth, E., Hurley, M. (1986) Comparison of the Stelligeroid Taxa of the Centric Diatom Genus *Cyclotella*. In: Ricard, M. (Ed.) Proceedings of the 8th International Diatom Symposium. Koenigstein, Koeltz Scientific Books. 43-58.
[25] Cobelas, M.A., Garcia-Morato, C.R. (1990) Population Dynamics of *Nitzschia gracilis* (Bacillariaceae) in a Hypertrophic Lake. British Phycological Journal. 25(3), 263-273.

Received: **14.11.2019**
Accepted: **23.04.2020**

CORRESPONDING AUTHOR

Faruk Maraslioglu
Hitit University
Faculty of Arts and Science
Department of Biology
Çorum – Turkey

e-mail: farukmaraslioglu@hitit.edu.tr