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Spatio-temporal dynamic of submerged aquatic macrophytes in Lake Sapanca

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Abstract: Aquatic macrophytes are one of the key components of freshwater ecosystems and contribute to ecosystem functioning and environmental sustainability. They are assumed to be an ideal biomonitoring tool in long-term monitoring programs implemented by the EU Water Framework Directive due to their sensitivity to environmental factors. Therefore, this study focuses on the evaluation of the ecological status in Lake Sapanca using macrophyte composition and abundance in order to make future predictions on the health of aquatic ecosystems and to form effective management. Submerged macrophyte assemblages related to environmental parameters were investigated from February to November of 2017. A total of 12 submerged macrophyte species were recorded in the littoral zone of the lake. The main findings on the most dominant 7 species of this community indicated significant differences among stations and seasons. They also revealed that submerged macrophyte density was shaped in relation to environmental variables, particularly temperature and nutrients. Submerged macrophyte assemblages reached their highest species number and biomass value (5312 gm^{-2}) in summer, while no species was recorded in winter. High biomass values of these species corresponded with lower macrophyte diversity. The macrophyte index results demonstrated that Lake Sapanca is at a critical level in terms of nutrient enrichment. More frequent observation of species such as *Ceratophyllum demersum* and *Elodea canadensis*, which indicated "massive" nutrient enrichment, revealed that the ecological status of the lake varies from meso- to eutrophic at the local level.

Key words: Aquatic ecosystem, macrophyte index, ecological quality, Lake Sapanca

1. Introduction

Aquatic macrophytes are one of the key components of freshwater littoral ecosystems (Wetzel, 1983; Jeppesen et al., 1998), contributing to ecosystem functioning and to environmental sustainability (Jones et al., 1983; Takamura et al., 2003; Mulderij et al., 2007; Hilt et al., 2010). Associated with water quality and freshwater ecosystems, both directly and indirectly, macrophytes stabilize the trophic level (Scheffer, 2001; Wetzel, 1983) as a food source and contribute to primary production (Schneider, 2012; Gecheva et al., 2013; Golob et al., 2015). In addition, they prevent coastal erosion with their developed roots and decrease water turbidity, acting as a natural barrier against water movements (Scheffer, 2001; Mulderij et al., 2007; Hilt et al., 2010; Schneider et al., 2012). Moreover, they are considered as a source of biodiversity and constitute ideal habitats for various freshwater communities (Heegaard, 2004). Macrophytes, in terms of water quality, lake ecosystems, and metabolism (Jones et al., 1983; Takamura et al., 2003; Mulderij et al., 2007; Hilt et al., 2010), also contribute to regional public welfare and regional economy by providing the various ecosystem functions and services mentioned above. However, as a consequence of human pressures on aquatic ecosystems, macrophyte habitats are also faced with degradation in water quality. These pressures might transform the composition of macrophytes and stimulate the growth of opportunistic species since they are attached to the substratum and exposed to high levels of nutrients and organic compounds.

The European Union Water Framework Directive (WFD, 2000/60/EC) concentrates on the evaluation of the ecological status of freshwater ecosystems through macrophyte classification methods. Macrophytes are assumed to be an ideal biomonitoring tool in long-term monitoring programs implemented by the WFD due to their long life span (Golob et al., 2015), sensitivity to environmental factors, and rapid response to fluctuations in water quality (Melzer, 1999; Mulderij et al., 2007). Studies conducted on aquatic macrophytes in Turkey mainly focus on their importance at the biodiversity level (Öztürk et al., 1996; Seçmen and Leblebici, 1997; Özen and Korkmaz, 2005; Turna et al., 2010; Kırkağaç et al., 2011; Altınsaçlı et al., 2013; Beishenbekova, 2013; Özçelik et al., 2014). However, studies on submerged plants and their ecological evaluation (Susamlı, 1998; Demir and Köse,

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2004; Beklioğlu et al., 2006; Kırım et al., 2014; Şanal et al., 2015) are limited.

Lake Sapanca, which is located in the eastern part of the Marmara region and used as a source of drinking water, is a deep and temperate lake. Previous studies on the biotic components of the lake have focused on plankton ecology and fisheries (Temel, 1992; Aykulu et al., 2006; Okgerman, 2008). However, to date, no study exists that makes an ecological assessment of macrophytes, which occupy an important place in the lake ecosystem.

It is necessary to monitor water quality by testing the spatio-temporal variations in the composition of macrophytes in order to make future predictions about the health of aquatic ecosystems and to plan effective management (Beck et al., 2010; Søndergaard, 2010).

Therefore, this study focuses on the evaluation of the ecological status of Lake Sapanca by using macrophyte species composition and abundance as important indicators of limnologic ecosystem quality.

2. Material and methods

2.1. Study area

Lake Sapanca (40°43'0.38"N,30°15'37.41"E) is a deep tectonic lake located in the northwestern part of Turkey (Figure 1). It is fed by several creeks/streams and partly by groundwater. The lake has a surface area of 47 km^2 and a maximum depth of 55 m. Initial observations on the limnological properties of the lake show that its shallow shores are covered by a broad vegetation belt and that it is a typical warm-monomictic lake mixed thoroughly from top to bottom in February to March, which provides nutrient enrichment in surface waters, as well as ventilation of bottom waters (Aykulu et al., 2006). As an important local drinking water source, Lake Sapanca contains low concentrations of dissolved inorganic ions. Therefore, its water is adequate for drinking, industrial usage, and irrigation. However, the lake is negatively affected by urbanization, which causes habitat loss on the shores due to the increase in the human population. Although there is no direct discharge of waste, chemical pollutants of both domestic and agricultural origin find their way into the lake through surface run off (Morkoç et al. 1998). Commercial and artisanal fishing and touristic and recreational activities can also be assumed to cause considerable damage to the lake. Signs of deterioration in Lake Sapanca were first observed towards the end of the 1990s with some colour changes indicating water blooms due to *Planktotrix rubescens* (De Candolle ex Gomont) Anagnostidis & Komarek (Aykulu et al. 2006). The frequency and quantity of cyanobacterial blooms has continued to increase since then.

2.2. Sampling and data analyses

Samples for physico-chemical parameters and quantitative macrophytes analyses were taken seasonally from February to November 2017 at 5 stations which were exposed to different environmental factors (Saski, Eşme, Seka, Kurtköy, and Gölpark) (Figure 1). At each station, submerged macrophytes were collected using a rake and grouped in triplicate from the bounded areas of standardized depths (up to 3 m) (Schloesser and Manny,

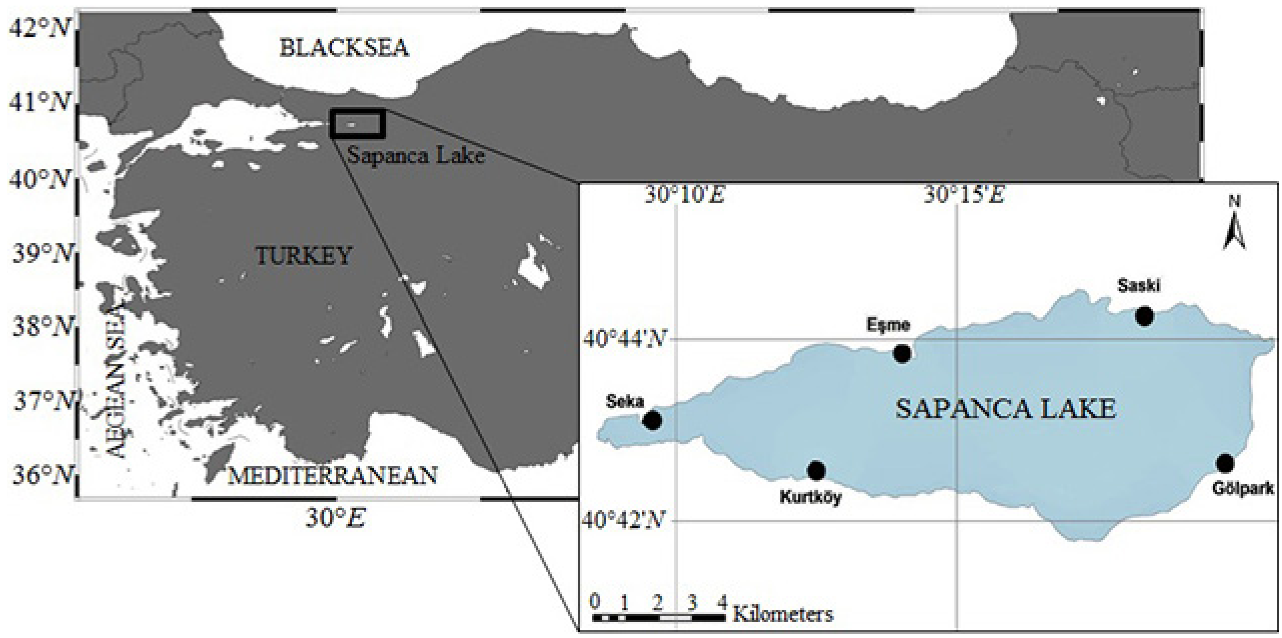

Figure 1. Location of Lake Sapanca and sampling stations.

1984; Johnson and Newman, 2011; Wetzel and Likens, 1991). Furthermore, an additional field study was also conducted during the July–August period, which is known to have the highest biomass. This was carried out along the coastal area of the lake in order to determine macrophyte species composition.

Physico-chemical water quality parameters (temperature, dissolved oxygen, pH, and conductivity) were also measured in situ with a WTW multiparameter probe at all stations. In addition, water samples for determining nutrient concentrations and chlorophyll *a* were collected from the surface water of all stations in 100-mL polyethylene bottles and kept in deep freeze (–20 °C) until analysis was initiated in the laboratory. In the laboratory, nutrient concentrations (nitrate, NO_3-N; nitrite, NO_2-N; ortho-phosphate, and PO_4-P) were measured according to the methods described by APHA-AWWA-WEF (2012), while chlorophyll *a* was measured according to Golterman's method (1978). Macrophyte samples were washed to remove epiphytes and sediments, identified in terms of their species and dried at 105 °C for 24 h (Westlake, 1986; Wetzel and Likens, 1991). They were then weighted to determine macrophyte biomass.

In terms of data management, hierarchical clustering of Bray–Curtis and nonparametrical, multidimensional scaling were used to detect the similarities in macrophyte abundances of the 7 species among seasons and stations. Statistical analyses were applied to quantitative macrophytes data obtained from 5 sampling stations. The Bray–Curtis similarity coefficient (produced with square root-transformed data in order to balance the contributions of very abundant species and rare species) created a matrix for the analysis of similarity, which was used to identify the differences in abundance and for the analysis of similarity of percentages (SIMPER), which was used to detect the species responsible for dissimilarities. Considering macrophyte composition, the Shannon–Weaver (H′) diversity index was calculated (Odum, 1971; Clarke and Warwick, 1994). An analysis of variance (ANOVA with Tukey's HSD) was performed in order to reveal spatial and temporal variations in macrophyte biomass and environmental parameters. Significant levels were tested at $P < 0.05$ and $P < 0.01$. In addition, the relationships between macrophyte metrics and environmental parameters were evaluated with Spearman's correlation analysis.

The macrophyte index was used to estimate the ecological quality of the lake. Macrophyte species at the stations were evaluated according to Kohler ‘s scale (1978), ranging from 1–5. Macrophyte abundance values were cubed to convert them to metric values since the scale was not linear. The macrophyte index was calculated according to Melzer (1999).

3. Results

3.1. Water quality parameters

The results of the main physico-chemical and biological parameters in the surface water of sampling stations are shown in Table 1. Their correlation with macrophytes variables is summarised in Table 3. While the temperature values did not show a significant difference among stations, the temporal difference was statistically significant ($P < 0.01$). The mean value of water temperature was recorded as 17.5 ± 0.4 °C and their dynamics were typically seasonal. While the lowest water temperature (5.8 °C) was recorded in Kurtköy in winter, it started to increase in spring and the highest value (28 °C) was measured in Kurtköy in summer. pH exhibited a noticeable variation among sampling periods and stations (ANOVA, $P < 0.01$). The lowest value (6.86 °C) was recorded in Seka in summer, while the highest value (8.23 °C) in autumn in Gölpark. The maximum concentrations of dissolved oxygen (10.42 mg L^{-1} at the surface) were measured in summer in the middle of the lake, which was selected as a reference station. An intense cyanobacterial increase during this period was

Table 1. Physical, chemical and biological characteristics (mean ± standard deviation) of Lake Sapanca in the study period.

	Winter 2017	Spring 2017	Summer 2017	Autumn 2017
Temperature (°C)	6.2 ± 0.2	20.9 ± 0.9	27.4 ± 0.5	15.8 ± 0.3
Dis. oxygen (mgL^{-1})	9.60 ± 0.33	7.84 ± 0.33	9.51 ± 0.51	7.30 ± 0.67
Conductivity (μScm^{-1})	274 ± 6	264 ± 9	251 ± 4	273 ± 7
pH	7.4 ± 0.1	7.5 ± 0.1	7.1 ± 0.2	8.0 ± 0.2
$(NO_2 + NO_3)$-N(μgL^{-1})	10.62 ± 0.98	2.88 ± 0.50	2.23 ± 0.07	2.42 ± 0.08
PO_4-P(μgL^{-1})	2.29 ± 0.02	2.26 ± 0.01	2.32 ± 0.01	2.53 ± 0.40
N/P	4.6 ± 0.4	1.3 ± 0.2	1.0 ± 0.0	2.0 ± 0.1
Chlorophyll *a* (μgL^{-1})	15.17 ± 4.66	7.34 ± 4.57	6.94 ± 5.81	6.04 ± 2.84

also recorded (personal observation, unpublished data). In the littoral stations of the lake, significant differences were found among the stations and sampling periods ($P < 0.01$). The lowest value was recorded in autumn in Eşme (6.58 mg L^{-1}), while the highest (10.19 mg L^{-1}) was recorded in winter in Kurtköy. Conductivity values associated with anion, cation, and temperature values varied between 248–286 µs cm^{-1}, with an average of 266 ± 5 µs cm^{-1}. Significant differences were observed among the stations and sampling periods ($P < 0.01$). During the study period, nitrite + nitrate and orthophosphate concentrations did not show differences among the stations ($P < 0.01$). While the mean nitrite + nitrate concentration was 4.57 + 0.17 µg L^{-1}, it reached the highest value (10.62 ± 0.98 µg L^{-1}) in winter. In the orthophosphate concentrations, no significant difference was observed seasonally ($P < 0.01$). The annual average was recorded as 2.35 ± 0.10 µg L^{-1}. N/P ratios showed a similar trend in relation to these values. Based on the Redfield's ratio, the results indicated that N/P ratios were low. Chlorophyll *a* as an indicator of primary productivity in aquatic environments varied between 1.6 µg L^{-1} (in autumn) and 22.7 µg L^{-1} (in winter) with an average of 8.87 ± 3.43 µg L^{-1}. Significant differences were found among the stations ($P < 0.05$) and sampling periods ($P < 0.01$). Higher values were recorded during the winter period due to an unexpected cyanobacterial increase. Negative significant correlations ($P < 0.05$) were found between chlorophyll *a* and macrophytes biomass and diversity (Table 3).

3.2. Aquatic vegetation and submerged macrophytes community structure

During the study period, a total of 12 different species of submerged aquatic macrophytes were recorded in the coastal areas of Lake Sapanca. Quantitative analysis of 7 species recorded seasonally at the stations was performed among these species. In addition to the submerged macrophytes, information on the aquatic vegetation recorded during the study period in the coastal area of the lake is given in Table 2.

During the study period, submerged macrophyte species composition and their biomass showed differences among the seasons and stations ($P < 0.05$). No submerged macrophyte species was encountered during the winter period (Figure 2). Macrophyte variables correlated positively with temperature ($P < 0.01$) (Table 3). *Potamogeton lucens*, *Chara* sp., and *Ceratophyllum demersum* were recorded as constantly present macrophytes during the spring, summer, and autumn periods (Figure 4). In summer, *Elodea canadensis, P. perfoliatus, Najas minor*, and *Myriophyllum spicatum* were added to the macrophyte flora represented by these 3 species in spring. *N. minor*, recorded only in Kurtköy, dominated in terms of abundance, comprising up to 83% and also constituting 13% of the total submerged macrophytes biomass of the lake during this period. In autumn, 6 of the species, except for *N. minor*, existed. *N. minor* was recorded in the shallow areas of the Kurtköy station (Figure 4).

Table 2. List of macrophytes recorded in Lake Sapanca (the species indicated with an asterisk are those evaluated quantitatively at the intralake stations).

	Family	Species
Submerged macrophytes	*Haloragaceae*	*Myriophyllum spicatum**
	Ceratophyllaceae	*Ceratophyllum demersum**
	Hydrocharitaceae	*Elodea canadensis**
	Najadaceae	*Najas minor**
	Characeae	*Chara* sp.*
		Nitella sp.
	Potamogetonaceae	*Potamogeton lucens**
		*Potamogeton perfoliatus**
		Potamogeton pectinatus
		Potamogeton crispus
		Potamogeton natans
		Vallisneria spiralis
Floating macrophytes	*Lemnaceae*	*Lemna minor*
	Salviniaceae	*Salvinia* sp
		Azolla sp.
	Nymphaeaceae	*Nuphar lutea*
		Nymphea alba
Emergent macrophytes	*Butomaceae*	*Butomus umbellatus*
	Typhaceae	*Sparganium erectum*
		Typha angustifolia
	Cyperaceae	*Schoenoplectus lacustris*
	Poaceae	*Phragmites australis*

The mean total submerged macrophyte biomass was 582 ± 622 gm^{-2} in the lake. Total macrophyte biomass reached 3568 gm^{-2} in spring, and the highest biomass value (5335 gm^{-2}) was recorded in summer. Total macrophyte biomass began to decrease again (2733 gm^{-2}) in autumn. Significant differences in macrophytes biomass were observed among the stations. The highest value (1940 gm^{-2}) was recorded in Gölpark in summer, and *P. lucens* was the most dominant species with a biomass of 1851 gm^{-2}. While no macrophytes were recorded in winter, the lowest biomass value (39 gm^{-2}) was recorded in Eşme in autumn.

Submerged macrophyte species diversity (H′) in the lake was recorded at low values (<1) with an average of 0.40 ± 0.34 (Figure 3). There was no significant difference among the stations, but the seasonal change was significant

Table 3. Correlation between environmental parameters, chlorophyll *a* (Chl.*a*) measured in the water column and macrophytes community structure of Lake Sapanca (r: Spearman correlation coeficient, **: P < 0.01, *: P < 0.05, -: Not significant, Myr spi: *Myriophyllum spicatum*, Cer dem: *Ceratophyllum demersum,* Elo can: *Elodea canadensis*, Naj min: *Najas minor*, Cha sp: *Chara* sp., Pot luc: *Potmaogeton lucens*, Pot per: *Potamogeton perfoliatus*).

		W. temperature	D. oxygen	pH	Conductivity	(NO_2+NO_3)-N	PO_4-P	Chl. *a*
Macrophyte species diversity		0.63**	–0.48*	-	–0.47*	–0.60**	-	–0.54*
Macrophyte species number		0.72**	-	-	–0.54*	–0.82**	0.55*	–0.55*
Total macrophytes biomass		0.74**	-	-	–0.52*	–0.62**	-	–0.48*
Macrophytespecies biomass	Myr spi	-	-	-	-	-	-	-
	Cer dem	-	-	-	-	-	-	-
	Elo can	-	-	-	-	-	-	-
	Naj min	-	-	-	-	-	-	-
	Cha sp.	0.74**	-	-	–0.51*	–0.54*	-	-
	Pot luc	0.56*	-	-	-	–0.49*	-	–0.60**
	Pot per	0.46*	-	-	-	–0.49*	-	-

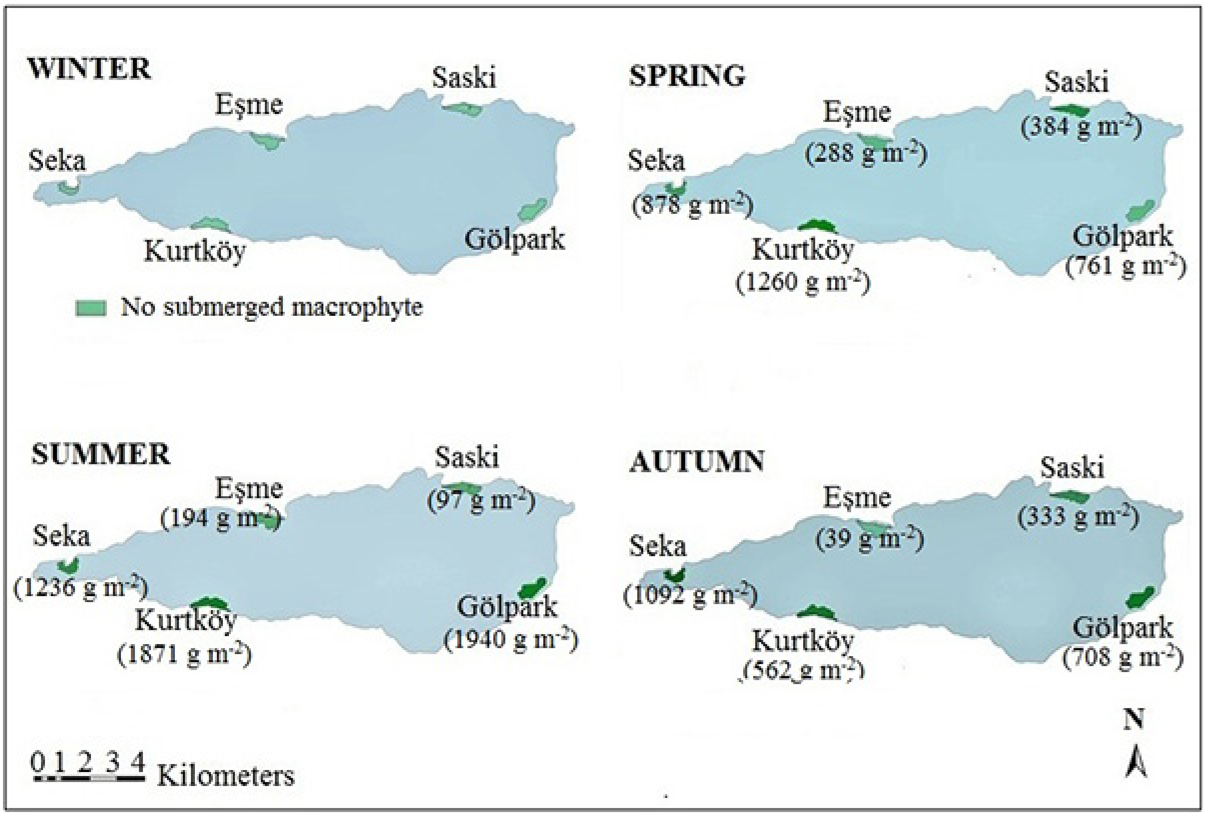

Figure 2. Temporal variations in the total submerged macrophyte biomass at the sampling stations of Lake Sapanca.

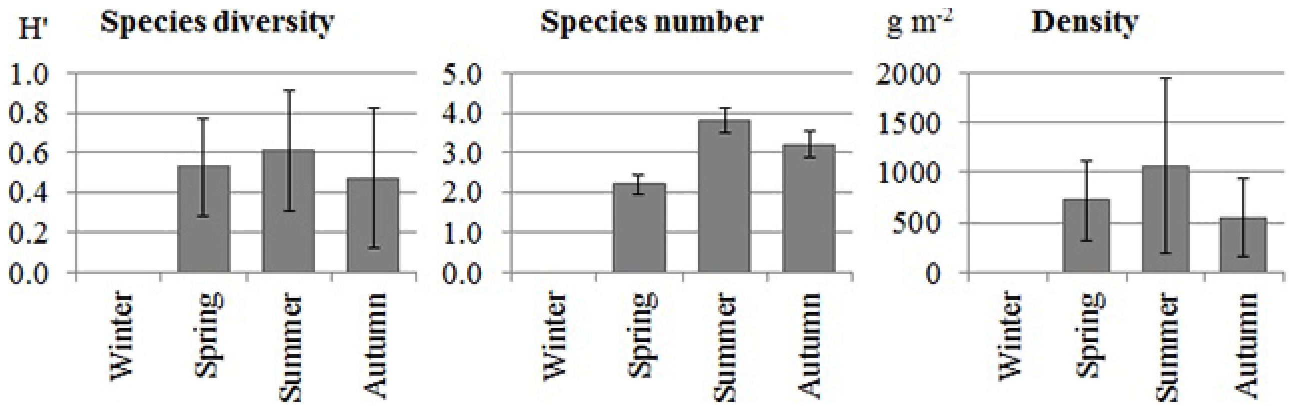

Figure 3. Temporal variations in submerged macrophyte species richness, biomass, and diversity (H′) in Lake Sapanca

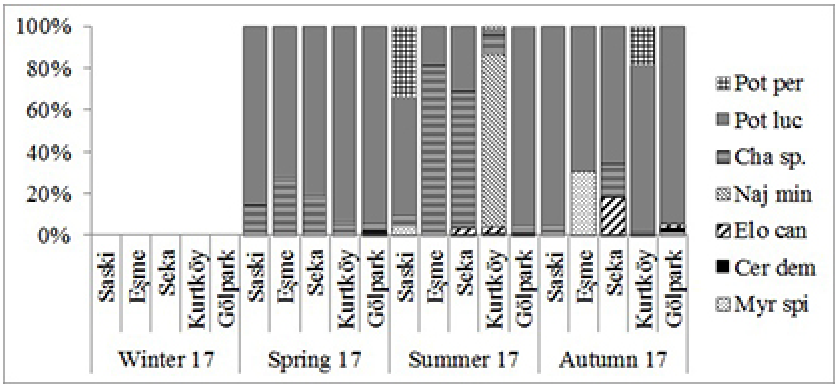

Figure 4. Temporal variation in the relative contribution of total submerged macrophyte biomass in Lake Sapanca.

($P < 0.05$). The highest average diversity (0.57 ± 0.43) was recorded in Seka (with a maximum value of 1.02 in autumn) and the lowest (0.29 ± 0.28) in Kurtköy.

The results of nonparametric multidimensional scaling analysis based on macrophyte biomass (gm^{-2}) data in Lake Sapanca are given in Figure 5, and a Bray–Curtis similarity dendrogram is presented in Figure 6. According to the data analysis results, the structure of species communities differed seasonally and regionally, and seasonal conditions became more determinative in general. Cluster analyses identified 2 main groups. Group I was characterized by data from the winter period, which had no macrophyte biomass and data from the summer period in Kurtköy, which had maximum species number and biomass.

The most frequent species were *P. lucens* and *Chara* sp., and they continued to dominate throughout the year (Figure 7). *P. lucens, Chara* sp., and *C. demersum* emerged in spring and reached the highest biomass in summer and decreased in autumn. *P. perfoliatus, M. spicatum*, and *E. canadensis* were recorded initially in summer and continued to exist in autumn but with low biomass values. The contribution of these species to total macrophyte biomass was 4% in summer and 13% in autumn. *N. minor* was found only in Kurtköy in summer and reached the highest biomass during this season. It presented its maximum contribution to total biomass with 82%. The relative contribution of macrophyte species to total macrophytes biomass is given in Figure 4.

Species contributing to seasonal differences were analysed with the SIMPER test. Choosing the seasonal grouping as a factor, the most significant species contributing to the similarity among the macrophyte communities was recorded as *P. lucens*. Its contribution during spring (intragroup similarity was 88%) and autumn (intragroup similarity was 71%) was also confirmed with the SIMPER test. Intragroup similarity was recorded as 52% during the summer season. *P. lucens* was recorded as the main species contributing to the similarity, with a contribution rate of 42%, and was followed by *Chara* sp. with a contribution rate of 30%.

The macrophytes index based on abundance data of 7 species varied between 3.23 and 3.42, with an annual average of 3.30. Significant differences were observed among stations but not in the temporal profile.

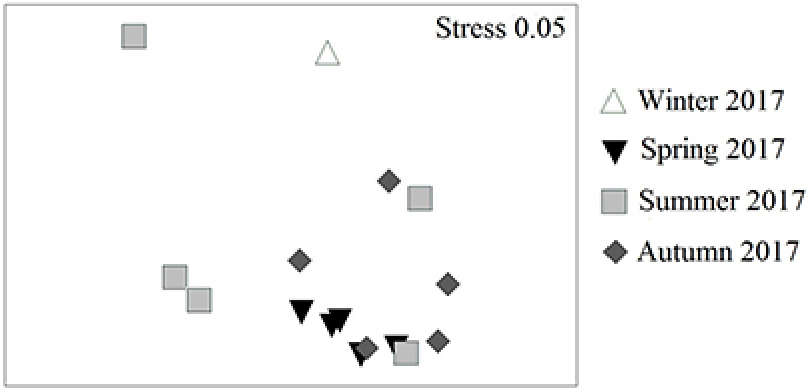

Figure 5. Nonparametric, multidimensional scaling analysis clusters based on Bray–Curtis similarity, derived from log-transformed submerged macrophyte biomass data.

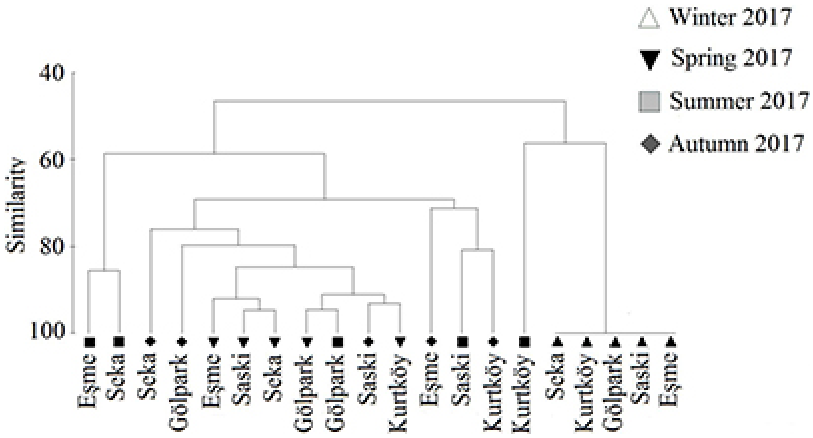

Figure 6. Bray–Curtis similarity dendogram, based on submerged macrophyte biomass data.

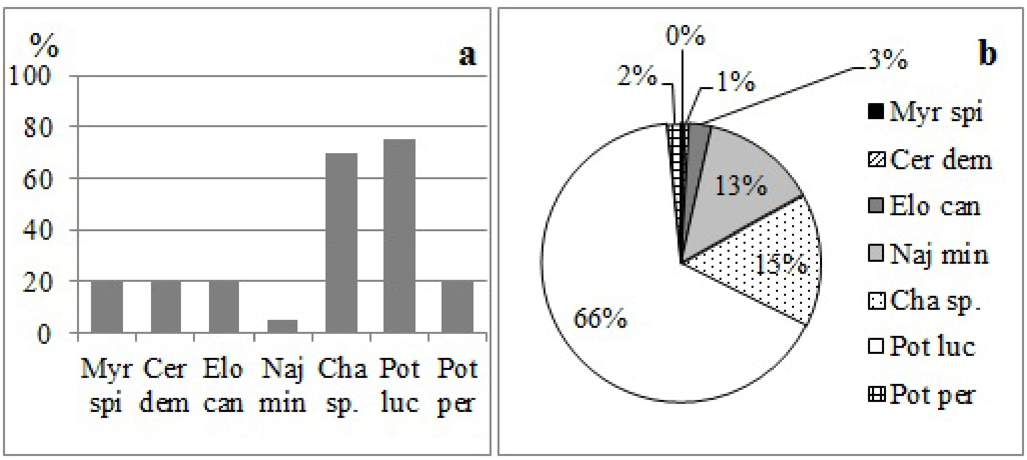

Figure 7. Submerged macrophyte species frequency (a) and relative abundance (b) in Lake Sapanca (Myr spi: *Myriophyllum spicatum*; Cer dem: *Ceratophyllum demersum*; Elo can: *Elodea canadensis*; Naj min: *Najas minor*; Cha sp: *Chara* sp.; Pot luc: *Potmaogeton lucens*; Pot per: *Potamogeton perfoliatus*).

Macrophytes Index values increased towards the southern shores of the lake, and the highest value (4.89) were recorded at Gölpark, which attracted attention because of the presence of *E. canadensis* and *C. demersum*.

4. Discussion

A total of 12 submerged macrophytes species were identified along the littoral area of Lake Sapanca with low species diversity. The main findings based on quantitative analysis of 7 species (*Myriophyllum spicatum, Ceratophyllum demersum, Elodea canadensis, Najas minor, Chara* sp.*, Potamogeton perfoliatus*, and *Potamogeton lucens*) at the stations revealed that the submerged macrophytes community of the lake showed spatio-temporal differences. *P. lucens* and *Chara* sp. were the most important species in terms of frequency and abundance. The high biomass values of these species corresponded with lower macrophyte diversity. Macrophyte composition and the general trends of their dynamics were similar to those found in other lakes in Turkey (Seçmen and Lebleci, 1997; Turna et al., 2010; Şanal et al. 2015). pH, which regulates the acidic characteristics of water, is one of the most significant factors affecting the species composition of macrophytes (Bornette and Puijalon, 2011). The species recorded in the submerged macrophyte flora of alkaline Lake Sapanca have been mentioned in the literature as the species favouring neutral or alkaline waters (Kadono, 1982). Considering that the findings from other lakes of Turkey, studied in terms of macrophytes, were alkaline, it can be inferred that the recorded species shows similarity.

Aquatic macrophytes are highly sensitive to the changes in physico-chemical parameters, and their dynamics change depending on the environmental factors (Melzer, 1999; Hopson and Zimba, 1993; Bornette and Puijalon, 2011). While lake morphology and littoral zone width play a significant role in the distribution of submerged macrophytes, the physical and chemical properties of water directly affect the composition and biomass of macrophytes (Wetzel, 1983, Padial et al., 2008, Silva et al., 2014). The results from Lake Sapanca show that macrophyte variables correlated strongly with temperature and nutrients (especially nitrite + nitrate) (Table 3). Temperature is a significant factor in determining the rate of metabolic processes in plants (Feldman, 2012). While the seasonal biomass of macrophytes increases at the beginning of spring as a result of sprouting due to the increase in temperature and the effect of positive environmental conditions, it decreases as a result of deaths due to the decrease in water temperature in autumn (Wetzel, 1983; Hilt et al., 2010). In this study, water temperature changed in line with seasonal norms and while no macrophyte was recorded in winter, macrophyte biomass increased in spring and reached its highest biomass rate in summer. The highest rates of nitrite + nitrate concentrations were also reached in winter when no aquatic macrophyte was recorded. Nitrite + nitrate concentrations showed a significant negative correlation with macrophyte biomass (Table 3). Nutrients are important due to their influence on the structuring of submerged macrophyte communities in lake ecosystems (Szoszkiewicz et al., 2014). Also, the presence of macrophytes has an effect on the nutrient cycle. During the study period, the average N/P ratio was 6:1 and N was limiting. The N/P ratio reached its lowest value (<2) during the spring, summer, and autumn periods when macrophyte biomass was recorded as being high.

Macrophytes compete with phytoplankton for nutrients. It is known that submerged macrophytes support lower chlorophyll *a* concentrations as an indicator of biological productivity in aquatic environments (Takamura et al., 2003), and phytoplankton biomass generally tends to be lower in the littoral zone where macrophytes are densely populated (Wetzel, 1983). In some studies of shallow lakes, it was concluded that periods with intensive macrophyte growth were characterized by low phytoplankton density (Scheffer, 1998). In the present study, chlorophyll *a* showed remarkable statistical differences and negatively correlated with macrophyte growth. While the values were low in spring, summer, and autumn, when macrophyte growth increased, the highest value (22.7 $\mu g\ L^{-1}$), characterized by an unexpected cyanobacterial bloom, was recorded in winter when no macrophyte growth was recorded.

Macrophytes are sensitive to environmental parameters. The decrease in water quality due to natural and human pressure causes changes in macrophyte species composition and dominance of species. Macrophyte flora varies from sensitive to tolerant species (Melzer, 1999). When the lake was examined in terms of macrophyte community structure, low species diversity (<1) was recorded. The seasonal contribution of species to intragroup similarity was confirmed with a SIMPER test, and *P. lucens* was determined as the main species, comprising 66% of the total biomass. It was followed by *Chara* sp., with a rate of 15%. There are numerous studies on the dominance of charophytes in lake ecosystems, their role in indicating clean water status, and their relationship with the degradation in water quality (Van den Berg et al., 1998; Scheffer et al., 2001; Mulderij et al., 2007; Hilt et al., 2010). In these studies, lower nutrient and higher transparency values were associated with charophyte production and charophytes, together with some sensitive *Potamogeton* species, were regarded as the characteristic species of an aquatic environment with “high ecological quality” (Melzer, 1999). On the other hand, the presence of *C. demersum* and *E. canadensis* was recorded in low abundance and frequency on the southern shores of the lake. These species were reported as indicator species in massive nutrient enrichment. It was stated that *C. demersum*, which is mentioned as a characteristic type of highly polluted lakes, also grows well in Europe's oligomesotrophic lakes (Melzer, 1999).

In theory, it is known that the shift from submerged macrophytes (especially charophytes) to floating-leaved form is caused by light, which is the most significant factor in the degradation of water quality and bathymetric distribution of submerged macrophytes, which then becomes a restricting factor (Moss et al. 2003). In this study, no data was collected related to the bathymetric distribution of macrophytes. However, the observations conducted at the Saski and Eşme stations in the north and northwest regions of the lake, which have relatively lower biomass, showed that the widespread presence of floating-leaved species (*Nuphar lutea* and *Nymphea alba*) restricted the growth of submerged macrophytes.

There are studies which show that degradation in water quality and in the eutrophication process in aquatic areas affected by human intervention cause changes in aquatic macrophyte communities (Silva et al., 2014), decrease species diversity (Thomaz et al., 2003), and lead free-floating semisubmerged species to replace lake plants (Hilt et al., 2010). The studies conducted about the main limnological properties of Lake Sapanca before 1980 showed that the lake had an oligotrophic character and that its water was suitable for drinking, industrial use, and irrigation (Morkoç et al., 1998). Taking earlier findings on lake phytoplankton composition into consideration, the lake is characterized by a flora typical for oligotrophic lakes (Temel, 1992). However, the lake has developed an oligomesotrophic character in time (Aykulu et al., 2006) and has shown frequent and prolonged cyanobacterial blooms in recent years. As a result, the water quality has degraded, and the threat of eutrophication has appeared.

The Macrophyte Index, which was calculated on the basis of the macrophyte abundance values of 7 species reported at the stations, had a seasonal average of 3.26, and this demonstrates that Lake Sapanca is at an "immense" critical level in terms of nutrient enrichment. The results showed regional differences, and the highest value (4.89) was at Gölpark. More frequent observation of species, such as *C. demersum* and *E. canadensis*, which indicated "massive" nutrient enrichment, revealed that the ecological status of the lake varied from meso- to eutrophic at the local level.

An important finding obtained as a result of this study is also the presence of *Elodea canadensis* in the lake. The presence of nonnative species included in the inland water ecosystem under natural and anthropogenic influence and their uncontrolled dispersion due to the change in water quality has been one of the most salient problems in inland water ecosystems in recent years. The presence of *Elodea canadensis*, which is a nonnative and invasive species, in Lake Sapanca was first reported during the study period (Ersoy and Aktan, 2019), and it reached its highest biomass value (56 gm^{-2}) in summer. As reported by Ersoy and Aktan (2019), the first report of the species in Turkey was in the Thrace region by Davis (1984). The species is known to have advantages such as easy distribution in inland waters (Huotari and Korpelainen, 2013), high tolerance for changing environmental factors (Kolada and Kutila, 2016), and fast vegetative reproduction ability (Kočić et al., 2014). These studies showed that the eutrophication process and increases in nutrient rates contributed to the mass growth and distribution of the species (Collins et al., 1987). Because of its dispersion in European inland waters and fast colonisation success, it is important to evaluate the effects of its presence on the ecological status of the lake.

Resource management is the most significant step in preserving the biodiversity of aquatic ecosystems, which is in constant change due to natural and anthropogenic pressures. Macrophytes contribute to biodiversity and productivity in the littoral zones of inland waters and influence ecosystems by taking part in physical, chemical, and biological processes and, in turn, they are directly influenced by the changes in the ecosystem. Since macrophytes have an indicating role in inland water ecosystems, they have a core role in the studies on environmental monitoring and water quality estimation and, thereby, in management and preservation endeavours (Padial et al., 2008). The WFD reported that macrophytes are the main biological indicator in evaluating the ecological quality of water (Penning et al., 2008a; Sondergaard et al., 2010). Therefore, intense monitoring programs are encouraged in order to fill the information gap on submerged macrophyte flora in inland waters (Bolpagni, 2013). This study will fill the information gap on submerged macrophytes in Lake Sapanca, contribute to the necessary steps needed to be taken for the lake's preservation and management, and also lead to a more comprehensive evaluation of the results provided by the limnological studies of the lake.

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References

Altınsaçlı S, Altınsaçlı S, Temel M (2013). Species composition and qualitative distribution of macrophytes in four lakes (Karasu, Adapazarı, Turkey). Phytologia Balcanica 19 (1): 67-75.

APHA, AWWA, WEF (2012). Standard methods for examination of water and wastewater. 22nd ed. Washington, DC, USA: American Public Health Association, pp. 1360.

Aykulu G, Albay M, Akçaalan R, Tüfekçi H, Aktan Y (2006). Species composition, abundance and seasonality of phytoplankton in a moderately deep Turkish lake. Nova Hedwigia 130: 325-338.

Beck MW, Hatch LK, Vondracek B, Valley RD (2010). Development of a macrophyte-based index of biotic integrity for Minnesota lakes. Ecological Indicators 10: 968-979. doi: 10.1016/j.ecolind.2010.02.006

Beishenbekova A (2013). Balıkdamı Gölü makrofit florası (Sivrihisar/Eskişehir). Ankara Üniversitesi Çevrebilimleri Dergisi 3 (1): 65-72 (in Turkish).

Beklioğlu M, Altınayar G, Tan CO (2006). Water level control over submerged macrophyte development in five shallow lakes of Mediterranean Turkey. Archiv für Hydrobiologie166 (4): 535–556. doi: 10.1127/0003-9136/2006/0166-0535

Bolpagni R (2013). Macrophyte richness and aquatic vegetation complexity of the lake Idro (Northern Italy). Annali di Botanica 3: 35-43. doi: 10.4462/annbotrm-10207

Bornette G, Puijalon S(2011). Response of aquatic plants to abiotic factors: a review. Aquatic Sciences 73: 1-14. doi: 10.1007/s00027-010-0162-7

Clarke KR, Warwick RM (1994). Changes in Marine Communities: An Approach to Statistical Analysis and Interpretation. Plymouth, UK: PRIMER-E Ltd, pp. 144.

Collins CD, Sheldon RB, Boylen CW (1987). Littoral zone macrophyte community structure: distribution and association of species along physical gradients in Lake George, New York, USA. Aquatic Botany 29: 177-194. doi: 10.1016/0304-3770(87)90095-7

Davis PH (1984). Flora of Turkey and the East Aegean Islands, Vol. 8. 1st ed. Edinburgh, Scotland: Edinburgh University Press.

Demir N, Köse B (2004). Göllerde sualtı makrofit biyokütlesini etkileyen faktörler. In: I. Ulusal Limnoloji Çalıştayı; Kocaeli, Turkey. p. 16 (in Turkish).

Ersoy S, Aktan Y(2019). First report on the occurrence of invasive macrophytes *Elodea canadensis* Michx. in Sapanca Lake. European Journal of Biology 78 (2): 105-109. doi: 10.26650/EurJBiol.2019.0018

Feldmann T (2012). The structuring role of lake conditions for aquatic macrophyte. PhD, Estonian University of Life Science, Tartu, Estonia.

Gecheva G, Yurukova L, Cheshmedjıev S (2013). Patterns of aquatic macrophyte species composition and distribution in Bulgarian rivers. Turkish Journal of Botany 37: 99-110. doi: 10.3906/bot-1112-35

Golob A, Gabersick A. Germ M(2015). Presence and abundance of macrophytes in Lake Slivniško jezero. Acta Biologica Slovenica 58: 23-34.

Goltermann HL, Clymo RS, Ohnstad MAM (1978). Method for Physical and Chemical Analysis of Freshwaters. IBP.8. Oxford, UK: Blackwell Scientific Publications.

Heegaard E (2004). Trends in aquatic macrophyte species turnover in Northern Ireland - which factors determine the spatial distribution of local species turnover? Global Ecology and Biogeography 13: 397-408. doi: 10.1111/j.1466-822X.2004.00119.x

Hilt S, Henschke I, Rücker J, Nixdorf B (2010). Can submerged macrophytes ınfluence turbidity and trophic state in deep lakes? Suggestions from a case study. Journal of Environmental Quality 39: 725-733. doi: 10.2134/jeq2009.0122

Hopson MS, Zimba PV (1993). Temporal variation in the biomass of submersed macrophytes in Lake Okeechobee, Florida. Journal of Aquatic Plant Management 31: 76-81.

Huotari T, Korpelainen H (2013).Comparative analyses of plastid sequences between native and introduced populations of aquatic weeds *Elodea canadensis* and *E. nuttallii.* PLoS One 8 (4): e58073. doi: 10.1371/journal.pone.0058073

Jeppesen E, Sondergaard M, Christoffersen K (eds.) (1998). The structuring role of submerged macrophytes in lakes. Ecological Studies 131. New York, NY, USA: Springer Science Business Media.

Johnson JA, Newman RM (2011). A comparison of two methods for sampling biomass of aquatic plants. Journal of Aquatic Plant Management 49: 1-8.

Jones RC, Walti K, Adams MS (1983). Phytoplankton as a factor in the decline of the submersed macrophyte Myriophyllum spicatum L. in Lake Wingra, Wisconsin, USA. Hydrobiologia 107 (3): 213-219. doi: 10.1007/BF00036690

Kadono Y (1982). Occurrence of aquatic macrophytes in relation to pH, alkalinity, Ca, Cl, and conductivity. Japanese Journal of Ecology 32: 39-44.

Kırım B, Çoban D, Güler M, (2014). Floating aquatic plants and their impact on wetlands in Turkey. In: 2nd International Conference, Water resources and wetlands; Tulcea, Romania. pp. 102-109.

Kırkağaç M, Demir N, Topçu A, Fakıoğlu Ö, Zencir Ö (2011). Porsuk Çayı'nda (Eskişehir) sucul makrofitler, zooplankton ve bentik makroomurgasızların incelenmesi. Ankara Üniversitesi Çevrebilimleri Dergisi 3 (1): 65-72 (in Turkish).

Kočić A, Horvatić J, Jelaska SD (2014). Distribution and morphological variations of invasive macrophytes *Elodea nuttallii* (Planch.) H. St. John and *Elodea canadensis* Michx in Croatia. Acta Botanica Croatica 73 (2): 437-446. doi: 10.2478/botcro-2014-0011

Kohler A (1978). Methoden der Kartierung von Flora und Vegetation von Susswasserbiotopen. Landschaft und Stadt 10: 73-85 (in German).

Kolada A, Kutyła S (2016). *Elodea canadensis* (Michx.) in Polish lakes: a non-aggressive addition to native flora. Biological Invasions 18: 3251-3264. doi: 10.1007/s10530-016-1212-4

Melzer A. (1999) Aquatic macrophytes as tools for lake management. In: Harper DM, Brierley B, Ferguson AJD, Phillips G (eds.). The Ecological Bases for Lake and Reservoir Management. Developments in Hydrobiology, Vol. 136. Dordrecht, Netherlands: Springer. doi: 10.1007/978-94-017-3282-6-17

Morkoç E, Tuğrul S, Öztürk M, Tüfekçi H, Egesel L et al. (1998). Trophic characteristics of the Sapanca lake (Turkey). Croatica Chemica Acta 71 (2): 303-322.

Moss B, Stephen D, Alvarez C, Bécares E, BundWVD et al. (2003). The determination of ecological status in shallow lakes-a tested system (ECOFRAME) for implementation of the European Water Framework Directive. Aquatic Conservation 13 (6): 507-549. doi: 10.1002/aqc.592

Mulderij G, Nes EHV, Donk EV (2007). Macrophyte–phytoplankton interactions: the relative importance of allelopathy versus other factors. Ecological Modelling 204 (1-2): 85- 92. doi: 10.1016/j.ecolmodel.2006.12.020

Odum P (1971). Fundamentals of Ecology. Philadelphia, PA, USA: WB Saunders Company, pp. 574.

Okgerman H. 2008. Sapanca Gölü zooplanktonu. In: Okgerman H, Altuğ G (editors). Sapanca Gölü'ne Bilimsel Açıdan Bakış. TÜDAV Yayınları No. 28. İstanbul, Turkey: Türk Deniz Araştırmaları Vakfı (TÜDAV), pp. 65-74.

Özçelik H, Çinbilgel İ, Muca B, Koca A, Tavuç İ et al. (2014). Burdur ili karasal ve iç su ekosistem çeşitliliği, koruma ve izleme çalışmaları. Süleyman Demirel University Faculty of Arts and Science Journal of Science 9 (2): 12-43.

Özen AS, Korkmaz Ö (2005). Yedigöller (Kütahya) ekosisteminde biyolojik çeşitlilik ve kirlilik üzerine bir araştırma. Dumlupınar Üniversitesi Fen Bilimleri Enstitüsü Dergisi 9: 15-26 (in Turkish).

Öztürk M, Seçmen Ö, Leblebici E (1996). Eber Gölü (Afyon) bitki örtüsü ve kirlenme ilişkileri. Ekoloji Çevre Dergisi 20: 15-26 (in Turkish).

Padial AA, Bini LM, Thomaz SM (2008). The study of aquatic macrophytes in Neotropics: a scientometrical view of the main trends and gaps. Brazilian Journal of Biology 68 (4): 1051-1059. doi: 10.1590/S1519-69842008000500012

Penning WE, Dudley B, Mjelde M, Hellsten S, Hanganu J et al. (2008a). Using aquatic macrophyte community indices to define the ecological status of European lakes. Aquatic Ecology 42 (2): 253-264. doi: 10.1007/s10452-008-9183-x

Scheffer M (2001). Alternative attractors of shallow lakes. The Scientific World 1: 254-263. doi: 10.1100/tsw.2001.62

Schneider SC, Lawniczakb AE, Faltynowiczc P, Szoszkiewiczb K (2012). Do macrophytes, diatoms and non-diatom benthic algae give redundant information? Results from a case study in Poland. Limnologica - Ecology and Management of Inland Waters 42 (3): 204-211. doi: 10.1016/j.limno.2011.12.001

Seçmen Ö, Leblebici E (1997). Türkiye Sulak Alan Bitkileri ve Bitki Örtüsü. Ege Üniversitesi, Fen Fakültesi Yayın No: 158. İzmir, Turkey: Ege Üniversitesi Basımevi, p. 450 (in Turkish).

Schloesser DW, Manny BA (1984). Rapid qualitative method for estimating the biomass of submersed macrophytes in large water bodies. Journal of Aquatic Plant Management 22: 102-104.

Silva SCA, Cervi AC, Bona C, Padial AA (2014). Aquatic macrophyte community varies in urban reservoirs with different degrees of eutrophication. Acta Limnologica Brasiliensia 26 (2): 129-142. doi: 10.1590/S2179-975X2014000200004

Sondergaard M, Johansson SL, Lauridsen TL, Jorgensen TB, Liboriussen L et al. (2010). Submerged macrophytes as indicators of the ecological quality of lakes. Freshwater Biology 55: 893-908. doi: 10.1111/j.1365-2427.2009.02331.x

Susamlı S (1998). Mogan Gölü'nde (Ankara) su altı makrofitlerinin balık-zooplankton ilişkisine ve tatlı su kalitesine etkileri. Master's thesis, Gazi University, Ankara, Turkey (in Turkish).

Szoszkiewicz K, Ciecierska H, Kolada A, Schneideet SC (2014). Parameters structuring macrophyte communities in rivers and lakes – results from a case study in North-Central Poland. Knowledge and Management of Aquatic Ecosystems 415 (8)08p1-08p16. doi: 10.1051/kmae/2014034

Şanal M, Köse B, Coşkun T, Demir N (2015). Mogan Gölü'nde sucul makrofitlere göre ekolojik kalitenin tahmini. Iğdır Üniversitesi Fen Bilimleri Enstitüsü Dergisi 5 (4): 51-55 (in Turkish).

Takamura N, Kadono Y, Fukushima M, Nakagawa M, Kim B (2003). Effects of aquatic macrophytes on water quality and phytoplankton communities in shallow lakes. Ecological Research 18: 381-395. doi: 10.1046/j.1440-1703.2003.00563.x

Temel M (1992). Phytoplankton of Lake Sapanca. Su Ürünleri Dergisi 1: 25-40 (in Turkish).

Thomaz SM, Souza, DC, Bini LM (2003). Species richness and beta diversity of aquatic macrophytes in a large subtropical reservoir (Itaipu Reservoir, Brazil): the influence of limnology and morphometry. Hydrobiologia 505: 119-128. doi: 10.1023/B:HYDR.0000007300.78143.e1

Turna II, Yıldırım UG, Durucan F (2010). Eğirdir Gölü'nün görsel su altı flora ve faunası. In: Isparta ili Değerleri ve Değer Yaratma Potansiyeli Sempozyumları; Isparta, Turkey (in Turkish).

Van den Berg MS, Scheffer M, Van Nes E, Coops H (1998). The role of characean algae in the management of eutrophic shallow lakes. Journal of Phycology 34: 750-756. doi: 10.1046/j.1529-8817.1998.340750.x

Wetzel RG (1983). Limnology. 2nd ed. Philadelphia, PA, USA: Saunders College Publishing.

Wetzel RG, Likens GE (1991). Limnological Analyses. 3rd ed. New York (NY):Springer Science + Business Media Inc. p. 429.

Westlake DF (1986). The Direct Determination of Biomass of Aquatic Macrophytes and Measurement of Underwater Light. London, UK: Her Majesty's Stationery Office, p. 45.