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Macrophyte-dominated Clearwater State of Lake Mogan

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Abstract: In this study, the water chemistry and zooplankton community of Lake Mogan studied between March 1997 and April 1998. Small-scale industries, crop-farming, urban settlement of the municipality of Gölbaşı with the untreated raw sewage effluent and recreational activities are examples of the human impact within the catchment and the lake, leading to high loading of DIN and TP into the lake via the inflows. However, the natural wetland with the dense reedbeds (Çölovası or Çökek Bataklığı), located on the southern end of the lake, appear to act as a sink for these nutrients. Therefore, the in-lake concentartions of DIN and TP were significantly lower than those of the inflows. Lake Mogan appeared to be in a macrophyte-dominated clearwater state with low TP (annual mean: 63 $\mu g\ l^{-1}$) and chlorophyll-a (annual mean: 8.47 mgl^{-1}) concentrations and very high Secchi depth (the bottom of the lake), and with submerged plants covering almost the entire lake. The grazing pressure of the dominant pelagic zooplankton, *Daphnia* sp. and *Arctodiaptomus* sp., did not seem to be significant in determining the low phytoplankton crop expressed as chlorophyll-a. The luxury nutrient uptake of submerged plants and associated epiphytes may have been the dominant stabilising buffer mechanisms suppressing the phytoplankton crop of the lake.

Key Words: Alternative stable states, shallow lake, submerged plant, zooplankton grazing, wetland.

Yoğun Sualtı Bitkileri ve Berrak Su Özelliğiyle Mogan Gölü

Özet: Bu çalışmada Mart 1997-Nisan 98 tarihleri arasında Mogan Gölü'nün su fiziko-kimyasal karakteri ile zooplanktonu çalışılmıştır. Göl havzasında ve göldeki insan etkinlikleri, küçük ölçekli sanayii, tarım, şehirleşme ile arıtılmamış atıksu deşarjı (Gölbaşı Belediyesi) ve rekrasyonel kullanımdır. Mogan Gölü'ne akan derelerde çok yüksek düzeyde çözünmüş inorganik nitrogen (DIN) ve toplam fosfor (TP) bulunmuştur. Gölün güneyinde bulunan sulak alan (Çölovası veya Çökek Bataklığı), derelerden gelen DIN ve TP'yi filtre ederek yoğunluklarını azaltmaktadır. Çölovası Bataklığı bu işleviyle Mogan Gölü'nün temiz su kalitesinin korunmasında çok önemlidir. Mogan Gölü düşük TP (yıllık ortalama 63 $\mu g\ 1^{-1}$) ve klorofil-a (yıllık ortalama: 8.47 $\mu g\ 1^{-1}$) yoğunlukları, yüksek Seki derinliği (göl tabanı) ve tüm gölü kaplayan sualtı bitkileriyle, makrofitlerin baskın olduğu berrak su özelliğinde zengin bir sığ göldür. Pelajik zooplankton olan *Daphnia* sp. ve *Arctodiaptomus* sp'un yoğunlukları düşük ve fitoplankton biyokütlesini kontrol etmedeki rollerinin fazla önemli olmadığı bulgulanmıştır. Makrofitlerin üzerinde yaşayan epifitelerın yüksek besin tuzu kullanımı fitoplankton biyokütlesini sınırlamada önemli bir etmen olabilir.

Anahtar Sözcükler: Alternatif Karalı Durumlar, sığ göl, su için bitkiler, zooplankton beslenmesi, sulakalan.

Introduction

Recent studies suggest that shallow lakes with a total phosphorus (TP) concentration of less than 0.05 mgl^{-1} tend to be exclusively clear (except dystrophic lakes). A clearwater state is largely characterised by submerged plants and sufficient piscivorous fish (e.g., pike and predatory perch) biomass to extert strong control on planktivorous fish (e.g., bream, carp, roach, tench) enabling zooplankton (e.g., *Daphnia)* to control phytoplanton and snails to control epiphytes on the plant surfaces (1-4). However, if the nutrient supply increases further, a threshold (>0.150 mgl^{-1} TP) will eventually be reached at which the system breaks down and abrupt changes occur. The lake enters a turbid water state with heavy phytoplankton biomass. In the turbid water state, there are few or no submerged plants, and there is total dominance of the fish community by planktivorous fish (1, 2, 4).

Submerged macrophytes are of great importance for maintaining originally oligo-mesotrophic lakes in clearwater state after a moderate increase in nutrient supply (TP range: 0.05-0.150 mgl^{-1}), at which shallow lakes may have more than one equilibrium (i.e., alternative submerged plant dominated clearwater or phytoplankton dominated turbid water named as alternative stable states) (3,4). Submerged plants

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promote clearwater through several stabilising buffer mechanisms: namely, luxury nutrient uptake (6, 7), reduction of sediment resuspension (8), provision of refuge, especially for *Daphnia* against fish predation (9, 10), improving conditions for micro-macroinvertebrate epiphyton filtraters (11, 12), preference of small perch over roach (13), provision of refuge for small perch and small pike (14), enhancement of denitrification (7), and allelopathic effects on phytoplankton (15).

Lake Mogan has been the topic of many studies within the last two decades. Tanyolaç and Karabatak (16) classified Lake Mogan as eutrophic, due to the low Secchi dept (35 and 107 cm) despite the fact that the nitrate and phosphate concentrations were undetectable. An intensive limnological survey carried out by the State Water Works (DSİ) (17) recorded relatively low nitrate and phosphate concentrations (annual mean: 0.2 mg l^{-1} and 0.06 mg l^{-1}), the presence of over fifty species of phytoplankton belonging to six families, and domination of the zooplankton community of the lake by rotifers (65%) and copepods (29%). The same study also recorded a large expansion of the submerged plants, to 80% of the lake surface area in 1992 (17) from only a littoral belt with a width of 8-10 m during 1971-1973 (16). The recorded submerged plant species in the lake were *Myriophyllum spicatum* L., *Potamogeton* pectinatus L., *Ranunculus saniculifolius* Viv., *Ceratophyllum* sp. and *Chara* sp. (16, 17). A recent study also confirmed the further expansion of the submerged plants to almost the entire lake surface area with the presence of the same species recorded previously (18).

Study site

Mogan Lake is a large shallow lake (area:6.35 km^2, Z_{max}:3.5 m, Z_{mean}:2.1 m) located 20 km south of Ankara (39° 47' N-32° 47'E) within the municipality of Gölbaşı (population: 25123). There are also ten small villages (total population: 3699) within the catchment of the lakes. The sample major inflows to Lake Mogan were Yavrucak, Çölovası and Gölcük brooks, which run into the lake from the southern end through the wetland, called Çölovası or Çökek Bataklığı, and Sukesen brook runs into the lake at the northern end near the outflow of the lake (Figure 1).

Materials and Methods

Water samples were collected at monthly intervals between 26 March 1997 and 17 April 1998. The lake water sample was taken from the deepest point in the lake by using a hose pipe with lead weights on the end. The major inflows, including Sukesen, Gölcük, Yavrucak and Çölovası brooks, and the outflow, called Mogan outflow, were also sampled. Water temperature and dissolved oxygen were measured with a YSI 57 oxygen-meter, with half-meter increments until the bottom of lake was reached. A litre of water samples was taken from the inflows and outflows of the lake. Water for chemical analyses was stored in acid-washed 1-1 Pyrex bottles. Soluble reactive phosphorus (SRP) and total phosphate phosphorus (TP), and nitrite+nitrate-nitrogen (NO_2+NO_3-N) were determined according to Mackereth et al. (19) to a precision of ±3%, ±8% and ±8%, respectively. Ammonium-nitrogen (NH_4-N) was determined according to Chaney and Mormbach (20) to of ±4%. Chlorophyll *a* was extracted in acetone, and the concentration was calculated from the absorbance reading at 663 (21) to a precision of ±5%.

Zooplankton samples were collected at the same time and depth as for those used in chemical analyses. Zooplankton samples were collected by vertical tows to the water surface using a 45μm mesh-size, nylon plankton net. The samples were promptly narcotised with chloroform water (22) and preserved in a formaldehyde solution to yield a final concentration of 4%. The samples were normally subsampled with a wide-bore pipette and counted under a stereo microscope. When samples were subsampled, at least 100 of the most common species were counted (23). Animals were identified to species level whenever possible using standard reference works (24, 25).

Results

Lake Mogan did not undergo stable thermal and oxygen stratifications, and the lake water was mixed throughout the study. Temperature increased in the spring and summer from winter temperatures of 1-2°C (Dec. 1997 to Feb. 1998), reaching a maximum of 22°C in July and August 1998. The dissolved oxygen concentrations were much higher in spring and summer, with a maximum of 13.2 μg l^{-1} recorded in July 1997, than in winter, with a minimum of 2.8 μg l^{-1} recorded in 1997.

The TP concentrations of the inflows of Lake Mogan were higher than that of the in-lake concentrations (annual mean: 63 μg l^{-1}) (Figure 2a), except Çölovası brook, in which the annual mean TP concentration (annual mean: 67 μg l^{-1}) was close to that of Lake Mogan. The annual mean TP concentrations of Sukesen, Gölcük and Yavrucak brooks were 1438 μg l^{-1} , 198 μg l^{-1} and 336 μg l^{-1}, respectively. The annual mean TP

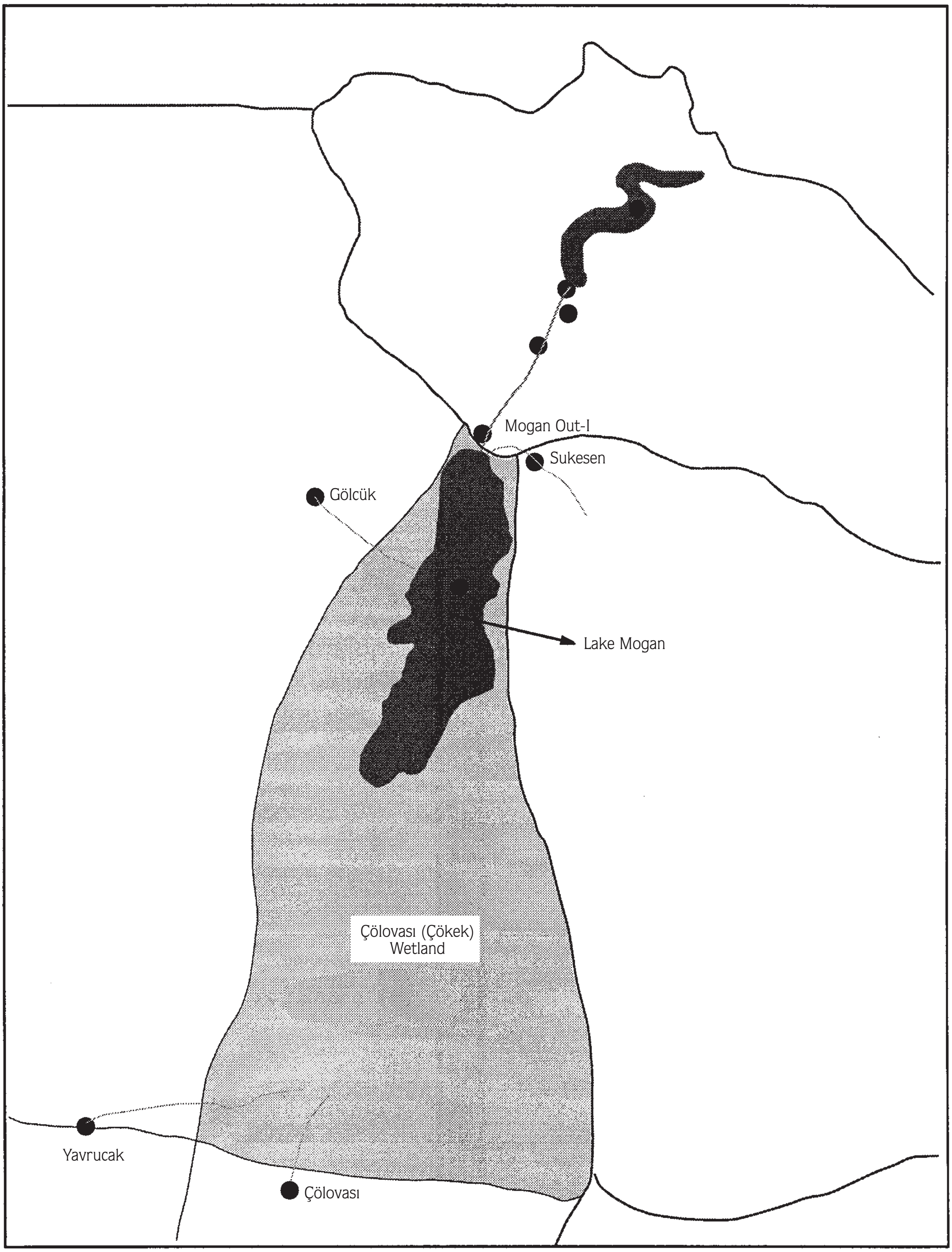


Figure 1. Map of Lake Mogan and its catchment (the sampling sites pointed).

concentration of Mogan outflow (93 µg l^{-1}) was slightly higher than that of Lake Mogan (Figure 2a). The DIN concentrations of the inflows were also higher than those of the in-lake concentrations (Figure 2b), except Çölovası brook (annual mean: 32 µg l^{-1}). The annual mean DIN concentrations of Sukesen, Gölcük and Yavrucak brooks were 3489 m, 3110 µg l^{-1} 2877 µg/l, respectively. The annual mean DIN concentrations of Mogan outflow was 101 µg l^{-1}, which was lower than that of the lake concentration (Figure 2b).

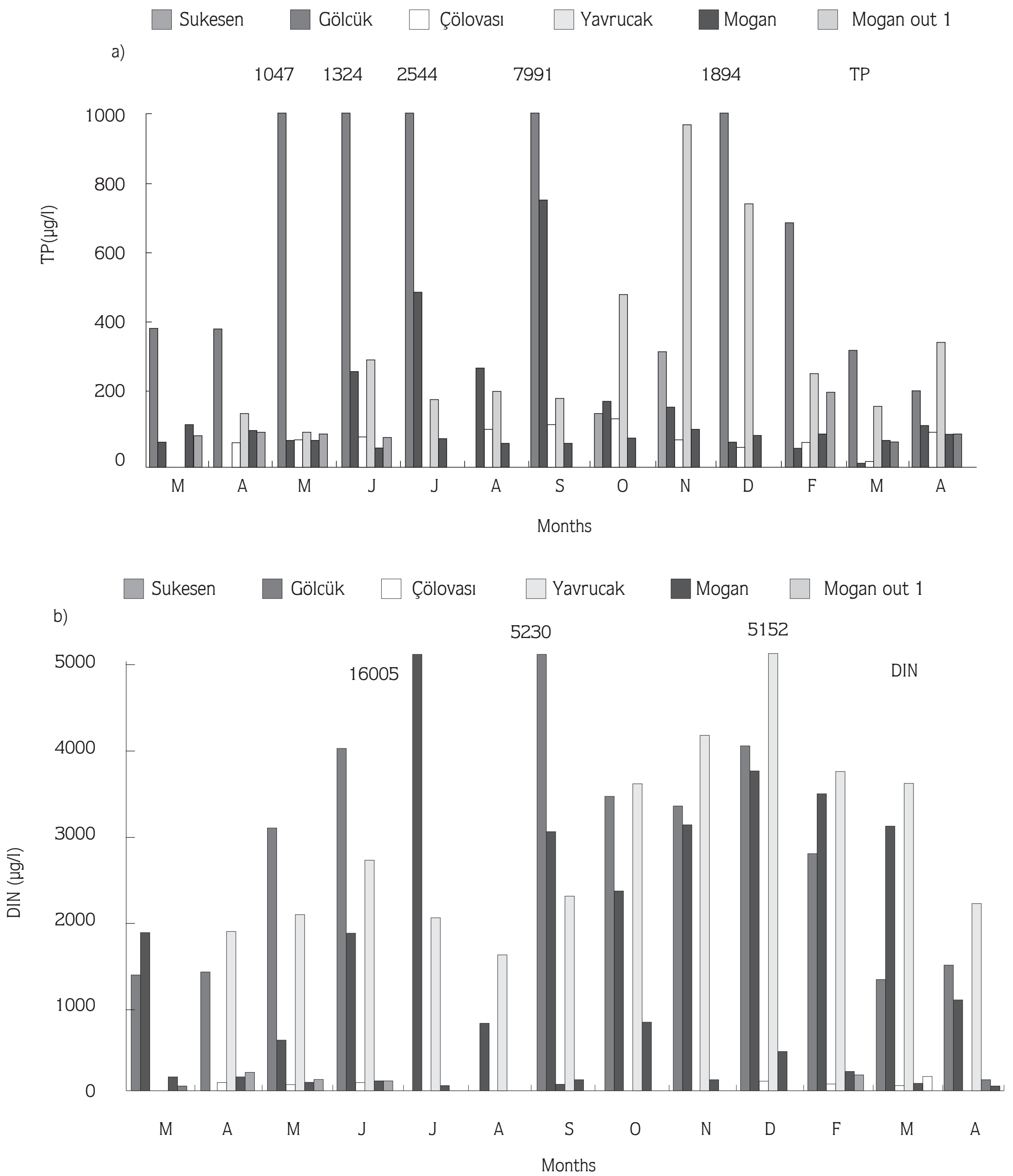
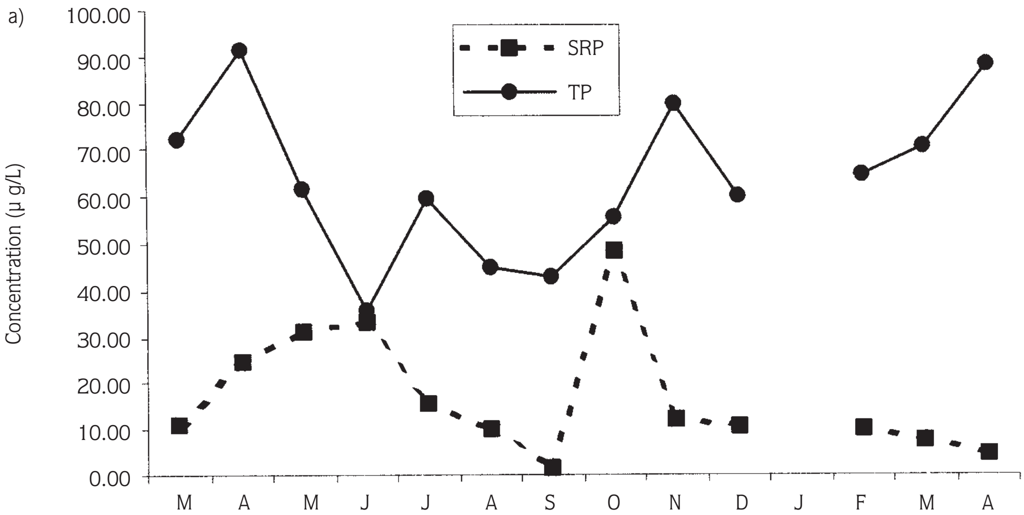


Figure 2. Changes in a) total phosphorus (TP) and b) dissolved inorganic nitrogen (DIN), concentrations (given in µg/l) of the inflows to Lake Mogan, the lake and the outflow measured between March 97 and April 98.

In Lake Mogan, the annual mean ± standard error of TP and SRP concentrations were 63±5 µg l^{-1} and 17±3.77 µg l^{-1}, respectively that the concentrations were lower throughout the summer than in the spring and winter (Figure 3a). The SRP and NH_4-N concentrations were significantly correlated (r=0.69; p=0.0097). The annual mean DIN concentration, which is the sum of the nitrite, nitrate and ammonium concentrations, was 166±58 µg l^{-1} (Figure 3b). Of the two forms of inorganic nitrogen analysed, NO_3+NO_2-N was dominant, with an annual mean of 95+26 µg l^{-1}, and the concentrations peaked in winter (Figure 3b). The NH_4-N concentrations were low (annual mean ±SE: 71±55 µg l^{-1}) and undetectable several times throughout the sampling period, except October 1997 (maximum: 723 µg l^{-1}, which coincided with the rotting of the submerged plants (Figure 3b). The NO_3+NO_2-N concentrations of Lake Mogan significantly correlated with the inflows, Sukese and Yavrucak brooks (r=0.61; p=0.0348; r=0.70; p=0.0106, respectively).

The Secchi depth was measured as the bottom of the lake several times in the summer (max: 315 cm and min: 82 cm) (Figure 4). The Secchi dept was found to be ≤ 1m in spring, autumn and winter when the submerged plants



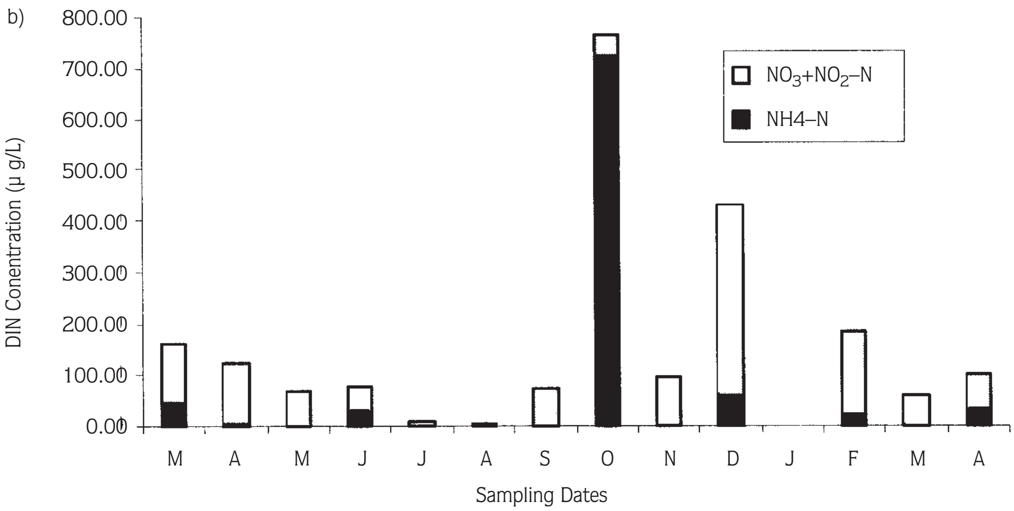


Figure 3. Changes in a) soluble reactive phosphorus (SRP) and total phosphorus, and b) dissolved inorganic nitrogen (DIN) concentrations of Lake Mogan measured between March 97 and April 98.

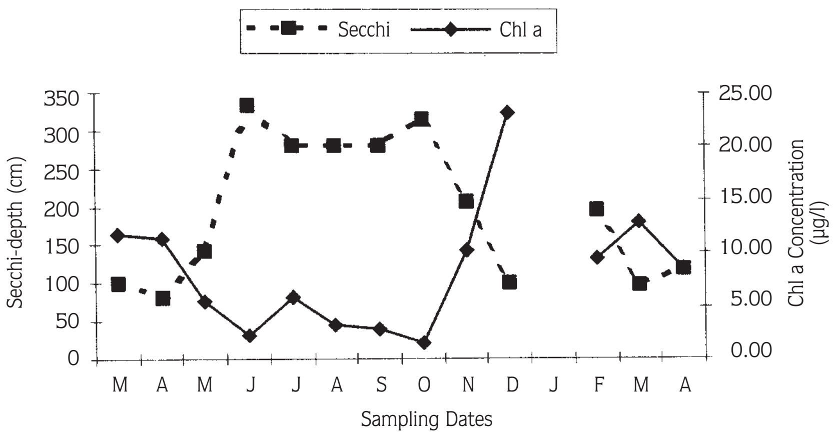


Figure 4. Changes in the Secchi depth and chlorophyll a concentration in Lake Mogan measured between March 97 and April 98.

were absent. There was a significant inverse correlation between the Secchi depth and chlorophyll-*a* concentrations was 8.8±1.8 µg l^{-1}, and the chlorophyll-*a* concentrations were <5 µgl^{-1} throughout the summer (Figure 4).

Large-bodied Zooplankters

In Lake Mogan, the densities of the cladoceran zooplankters were low and the following species were recorded: *Daphnia pulex* (De Geer), *Ceriodaphnia* sp, *Bosmina longirostris* (O. F. Müller), *Diaphanasoma lacustris* (lieven), *Chydorus sphaericus* (O.F. Müller), and *Alona* sp. The densities of *D. pulex* and *Ceriodaphnia* sp. were very low during the study period (Figure 5a), a small increase in their densities was recorded in June 1997 (1.98 ind.l^{-1} and 4.54. ind l^{-1}, respectively). The densities of *B. longirostris, D. lacustris, C. sphaericus* and *Alona* sp. were insignificant throughout the sampling period. The calanoid copepod *Arctodiaptomus* sp. was the dominant copepod in Lake Mogan. However, the density of *Arctodiaptomus* sp. was very low in the summer, with an early spring increase (61.7 ind. l^{-1} in Apr. 1998) (Figure 5b). The density of *Cyclops* sp. was insignificant, being lower that l ind. l^{-1} throughout the sampling period.

Discussion

Although the concentrations of DIN and TP in the inflows (namely Sukesen and Yavucak brooks) of Lake Mogan were extremely high, especially DIN, the annual mean in-lake concentrations were very low (165 µg l^{-1} and 63 mg l^{-1}, respectively). This might have been due to the occurrence of denitrification and direct phosphorus uptake in the very large wetland Çökek or Çölovası Bataklığı (more than twice as big as the total lake area) through which these inflows, excluding Sukesen brook, run into the lake at the southern end. Wetlands are known to act as sinks for N and P via denitrification and direct uptake of phosphorus (26). The denitrification capacity of intact wetlands is severalfold higher than that of the phosphorus uptake capacity, so that reductions of up to 500 kilograms of N and 40 kilograms of P per hectare have been recorded (7). Therefore, the large wetland at the southern end of Lake Mogan might have acted as a sink for these nutrients, though there was no direct measure of the capacity of the wetland for taking up nutrients. Moreover, the luxury nutrient uptake of submerged plants (27) in the lake should not be overlooked in the lowering of the TP and DIN concentrations. The effect of the inflow Sukesen brook on the water chemistry is expected to be low since the inflow runs into the lake very close to the outflow of the lake and the nutrient concentrations may have been flushed out without having made a significant contribution to the lake concentratons.

Although previous studies (16-18, 28, 29) have classified the lake as eutrophic or hypertrophic, the results of this study, with low TP (annual mean: 63 µg l^{-1}) and chlorophyll-a concentrations (annual mean: 8.5 µg l^{-1}), very high Secchi depth (found to be the bottom), and submerged plants covering the entire lake (17, 18), revealed that the lake was in a macrophyte-dominated clearwater state. Shallow lakes have been found to be in an exclusively macrophyte-dominated clearwater state when TP concentrations are <50 µg l^{-1} (1-5, 30, 31). The TP concentration of Lake Mogan appeared to be close to the suggested TP range in which shallow lakes are found exclusively in a macrophyte-dominated clearwater state.

The densities of the large-bodied grazers *Daphnia* sp. (2 ind. l^{-1}) and *Arcthodiaptomus* sp. were also low throughout summer. Open-water grazers such as *Daphnia* seem to be disfavoured by very structured

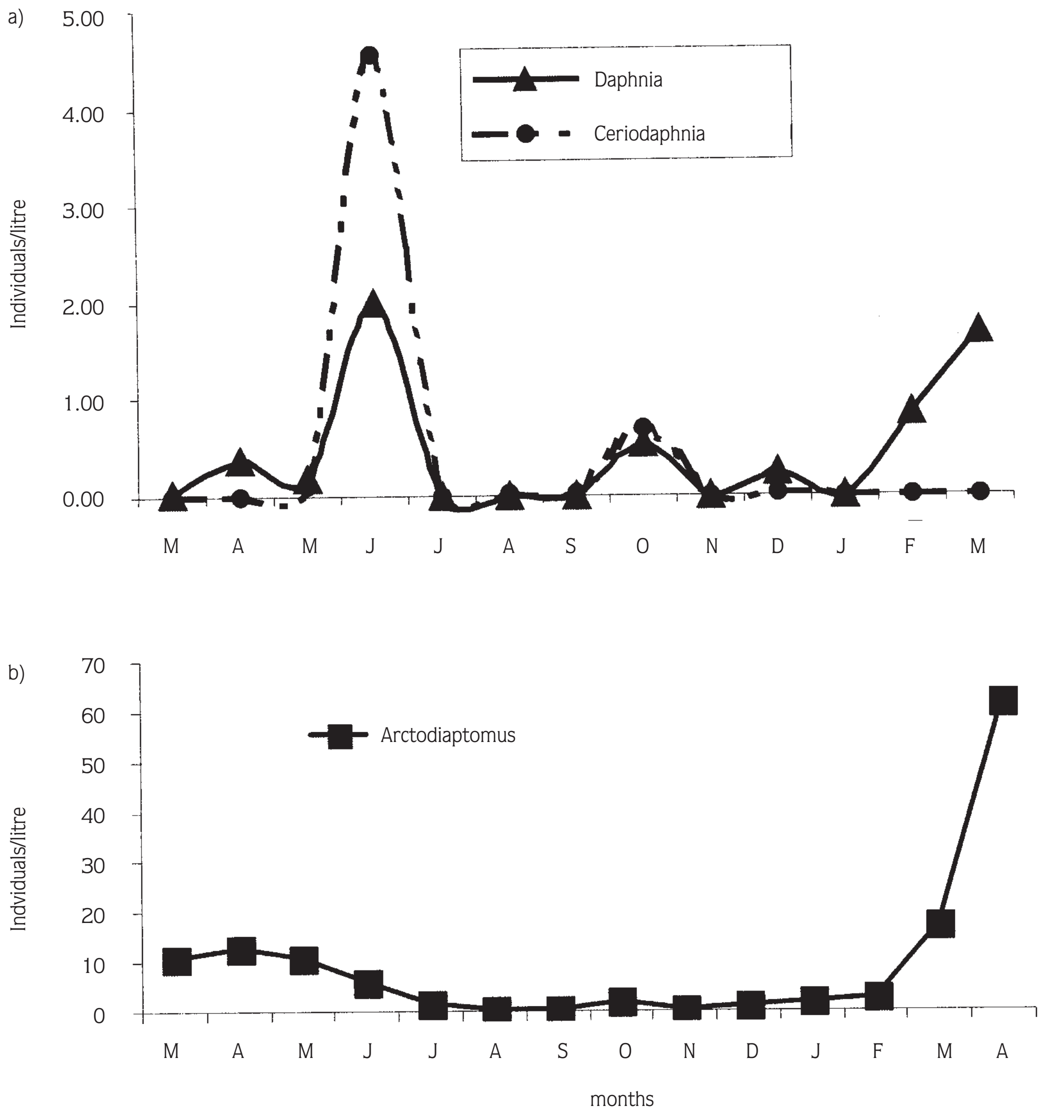


Figure 5. Changes in the densities of a) *D. pulex* and *Ceriodaphnia* sp., b) *Arcthodiaptamus* sp. and *Cyclops* sp. in Lake Mogan between March 97 and April 98.

vegetated habitats, increased predation pressure exerted by macroinvertebrates and aggregation of juvenile fish in the plant beds (10). The entire coverage of submerged plants and high densities of juvenile fish schooling in the lake throughout the summer (personal observation) might have led to the very low densities of the large grazers. In the lake, carp and tench were found to spawn from May to August, and their diet largely involved Cladocera, especially *Daphnia* (32) . However, one might expect to find very high densities of plant-associated grazers in the lake, since sampling of plant-associated grazers (intact plants + surrounding water) was not carried out. This needs further study for elaboration.

In submerged plants dominated shallow lakes, phytoplankton biomass can be suppressed through the release of organic compounds from submerged plants, especially Characeae, with allelopathic effects on phytoplanton (e.g., the release of copper compounds from *Chara* sp.) (15). *Chara* sp. has had a wide distribution confined to the sandy basins in Lake Mogan (16-18). The luxury nutrient uptake by submerged plants as well as associated epiphytes may impose nutrient-limitation on phytoplankton (6, 27). An increased share of plant-associated zooplankters, some of which are filter-feeders of phytoplankton (e.g., *Sida, Eurycercus*), may play an important role in controlling algal crop (12, 33). Some of these direct buffering mechanisms of submerged plants may have been important in the very low phytoplankton crop expressed as the chlorophyll-a concentration of Lake Mogan. In the absence of the submerged plants, except the overwintering part, in winter, the collapse of these mechanisms offered by the submerged plants might have been the reason for the sharp increase in the chlorophyll-a concentration (23.10 $\mu g\ l^{-1}$) in December 1997. Moreover, in the early seventies, Lake Mogan had a low Secchi depth, measured at undetectable phosphorus and nitrate concentrations and very low chlorophyll-a concentrations (16). This might have been due also to very limited submerged plant coverage in the lake and the lack of their stabilising buffer mechanisms. Lake Mogan is a large shallow lake with open wind-induced resuspension. Therefore, the presence of submerged plants with a wide coverage might have been important in stabilising the sediment aganist turbidity originating from wind-induced suspended matter (8).

A few decades ago, Lake Mogan was not entirely covered by macrophytes (16). The decrease in water level was experienced after the implementation of the regulater in 1974 to control possible flooding (17), which might have caused the recolonisation of submerged macrophytes. Another factor that might have been significant in the expansion of the submerged plants is the loss of crayfish (*Astacus leptodactylus* ESCH.) owing to the plague (34), since the abundance of crayfish was high in the lake (max yield was 45 000 kg in 1983) before the disease (35). The crayfish in an omnivore that feeds on snails and macrophytes (36) and has both direct and indirect effects on macrophytes. The indirect effect of crayfish on macrophytes is to exert predation pressure on snails, having a positive effect on epiphytes, which leads to the shading out of macrophytes. Obviously, the direct effect is consumption of macrophytes by crayfish, which is more significant.

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