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Benthi-planktivorous Fish-Induced Low Water Quality of Lake Eymir Before Biomanipulation

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Abstract: In this study, Lake Eymir, Eymir inflow 1, Kışlakçı brook and Eymir outflow were sampled monthly betwen March 1997 and April 1998 for physico-chemical and biological parameters. Within the catchment of the lake, there are small-scale industries, sewage effluent of TEK residence and recreational activities causing high concentrations of dissolved inorganic nitrogen (DIN) and total phosphorus (TP) in the eymir inflow 1 and in Kışlakçı brook. In Lake Eymir although diversion of sewage effluent of the Mogan municipality to İmrahor valley appeared to have led to a decrease in TP and DIN concentrations compared with those found in 1994, especially the lake TP concentration was still found to be very high (annual mean: 305 µg l^{-1}) this may be due to the high inflows' concentrations. The lake had a high spring increase in chlorophyll-a concentration which remained relatively low throughout the summer (annual mean: 19 μg^{-1}), perhaps due to very low DIN/TP ratios implying possible N-limitation at the very high TP concentration. Moreover, the Secchi depth was also relatively low throughout summer at the low chlorophyll-a concentration possibly due to feeding of the dominant fish tench (*Tinca tinca*) and carp (*Cyprinus carpio*) of the lake by stirring up the sediment. The densities of large-bodied zooplankters, *Daphnia* and *Arctodiaptomus* remained low in summer following the high spring densities probably due to fish prediation exerted on them by tench and carp. In Lake Eymir, top-down or fish-induced control of the water quality appeared to be the predominant factor,following the reduction of 30% of the tench and carp (biomanipulation), has led to very high Secchi depth and densities of the large grazes.

Key Words: Benthivorus fish, biomanipulation, eutrophication, chlorophyll-a planktivorous fish, Secchi depth, total phosphorus.

Eymirgölü Biyomanipulasyon Öncesi Benti-Planktivor Balık Kaynaklı Düşük Su Kalitesi

Özet: Bu çalışmada Mart 1997 ile Nisan 1998 tarihleri arasında Eymir Gölü'nde, gölün su kaynakları Eymir su girdisi 1, Kışlaçık deresi ve göl çıktısı, fiziksel, kimyasal ve biyolojik parametreleri aylık örneklenmiştir. Göl havzasında bulunan küçük ölçekli endüstri, TEK Lojmanlaarı atık suyu ve çöp dökümü gibi faliyetler, göl su girdilerinden özellikle Eymir su girdisi 1.'in, yüksek toplam fosfat (TP) ve çözünmüş inorganik azot (DIN) yoğunluklarının kaynağıdır. Göl içi TP ve DIN yoğunlukları Gölbaşı kasabasının atıklarımın 1994 İmrahor vadisine bypas ile verilmesi ile azalmakla birlikte özellikle göl TP yoğunluğu (yıllık ortalama: 305 μgl^{-1}) çok yüksektir. Bu durumda özellikle Eymir su girdisi 1'in aşırı TP miktarı ile ilgilidir. Gölde bahar aylarında klorofil-a artar fakat bu artış yaz aylarında düşüktür (yıllık ortalama: 19 μgl^{-1}). Bu da düşük azot yoğunluğu ile ilgili olabilir, düşük DIN/TP oranları yaz aylarında azotun sınırlayıcı besin olduğunu göstermektedir. Yaz aylarında düşük klorofil-a yoğunluğunda Seki yüksekliğide düşük kalmıştır. Düşük ışık geçirgenliğide gölde yoğun olan ve beslenmeleri ile dip çamurunu karıştıran kadife ve sazanla ilgilidir. Ayrıca, büyük vücütlu *Daphnia ve Arctodiaptomus* yoğunlukları bahar aylarında yüksekken yaz aylarında çok düşmüştür, bu da gölde baskın kadife ve sazan beslenmesi sonucu olabilir. Yaz 1998'de göldeki kadife ve sazanın % 30'inin çıkarılması (biyomanipulasyon) sonucu Seki yüksekliği ve *Daphnia* ve *Arctodiaptomus* yoğunlukları çok arttı. Bu artış da göldeki biyomanipulasyon önceki düşük su kalitesinin kadife ve sazan beslenmesi kaynaklı, yukardan-aşağıya kontrol sonucu olduğunu göstermektedir.

Anahtar Sözcükler: Bentivor balık, biyomanipülasyon, klorofil-a, ötrofikasyon, planktivor balık, Seki yüksekliği, toplam fosfat.

Introduction

The introduction of excess nutrients (nitrogen and phosphorus) from industries, domestic household sewage and run off water from the intensive agricultural with heavy application of fertilisers, have lead to worldwide water quality deterioration, namely eutrophication of rivers, lakes, estuaries and coastal waters (1-8). In lakes, increased growth of aquatic plants and algae are the first signals of a moderate level of increase in N and P loading into the lakes (5, 7). However, a further increase in loading of these nutrients has to lead to increased algal biomass, including potentially toxic blue-green algae, and changes in community structure (4, 5, 7).

The consequences of eutrophication can be seen in both deep and shallow lakes, as alterations in the trophic structure and interactions (9). In deep lakes, an increase in nutrient loading results in an increase in the blue-green algae and loss of salmonoid fish, coupled with deoxygenation of the hypoliminion (10). In shallow lakes, an increase in nutrient concentration causes the loss of submerged plants, leading to a decrease in the ratios of piscivorous to planktivorous stock, and the zooplankton to phytoplankton, and domination of the benthi-planktivorous fish (e.g. carp, tench, rudd). This leads to a switch to phytoplankton dominated turbid water (7-9, 11).

A few decades ago, it was strongly argued that food-web structure and interactions in the pelagic of lakes were exclusively determined by "bottom-up" forces through availability of nutrients (namely N and P) i.e. phytoplankton are regulated by nutrients and light zooplankton are regulated by phytoplankton (12). However, it is now evidential that the food-webs may be controlled by "top-down", i.e. zooplankton are regulated by fish, phytoplankton by zooplankton (9). However, the relative significance of resource and predatory controls vary along a nutrient gradient (8). The effect of the top-down control is more significant in shallow eutrophic and hypertrophic lakes (9). Zooplankton grazing was found to be very important in the control of phytoplankton in shallow meres in England (11, 13). The loss of the macrophytes can collapse the buffering mechanisms, which causes the domination of the plantivorous fish, in turn exerting a high predation pressure on zooplankton (13, 14).

The reduction in the external phosphorus level by diverting the nutrient-rich inflow, is the primary issue to restore the eutrophic lakes (15). In deep lakes, the external phosphorus reduction theoretically should restore the lake (10). It has been observed so (16). However, shallow lakes have shown a long resilience or delay in recovery following external phosphorus control (15, 17), due to the internal P loading and also resilience of the biological structure (domination of benthi-planktivorus fish, low zooplankton) (3, 8, 18, 19). Benthivorous fish (carp, grass carp) increase the phosphorus level in the water column by stirring up the sediment while consuming the benthic food items (20, 21). Benthi-planktivorous fish also exert strong predation pressure on the large zooplankton, e. g. *Daphnia,* and lead to high algal biomass and low water clarity (9).

Following the external nutrient control, the next step is biomanipulation, which is the reduction of benthi-planktivorous fish stock to increase water clarity to allow recolonisation of submerged plants in the littoral zone through reduction of chlorophyll-a by enhanced grazing pressure of large-bodied grazers (e.g.*Daphnia*) (6, 8, 10, 22-24). Through removal of benthivorous fish, the suspended matter related turbid condition is also controlled since these fish cause resuspension of sediment while feeding (20, 21). Therefore, the reduction of the benthivorous fish stock is essential for effective biomanipulation.

Study site

Lake Eymir is an alluvial dam lake that was formed by the damming of the İmrahor River valley at the beginning of this century. Lake Eymir is a shallow lake (area: 1.25 km^2, Z_{max}: 6 m, Z_{mean} 3.1 m) located 20 km south of Ankara (39° 57' N-32° 53') (25). The TEK settlement with a population of 2500 people, the Police Academy and small-scale industries are found within the catchment of the lake. The water flows to Gölbaşı Düzlüğü wetland from Lake Mogan, where the TEK Sewage Treatment Works (STW) and industrial zone are located. This water forms the Eymir inflow 1 that enters the lake at the southern end. The other inflow to Lake Eymir is Kışlakçı brook that carries water to the lake at the northern end. The water flows out of the lake to the İmrahor River that is named Eymir outflow.

Studies on Lake Eymir are limited compared with Lake Mogan. Previous studies classified the lake as eutrophic (25, 26, 27). These studies recorded very high concentrations of nitrate (20 mg l^{-1}, 0.5 mg l^{-1} and 3.5 mg l^{-1}, respectively) and phosphate (2.47 mg l^{-1}, 1 mg l^{-1} and 2.12 mg l^{-1}, respectively).

Materials and Methods

Water samples were collected at monthly intervals between March 1997 and Appril 1998. The lake water samples were taken from the deepest point by using a hosepipe with lead weights at the end. The major inflows. Eymir inflow 1 and Kışlakçı brook, and Eymir outflow were sampled. Water temperature and dissolved oxygen were measured using a YSI 57 oxygen-meter, with half metre increments until the bottom of the lake was reached. A litre of water was taken from the inflows and outflow of the lake. Water for chemical analyses was stored in acid-washed l^{-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. (28) to precisions of ±3%, ±8% and ±8%, respectively.

Ammonium-nitrogen (NH_4-N) was determined according to Chaney and Morbach (29) to a precision of ±4%. Silicate-silicon was deteremined according to Golterman et al., (30) to a precision of ± 1-2%. Chlorophyll *a* was extracted in acetone, and concentration was calculated from the absorbance reading at 663 (31) to a precision of ±5%. The caretenoid pigments to chlorophyll-*a ratio* were used to evaluate the state of phytoplankton as nitrogen deficiency, healthy phytoplankton, heavily grazed etc. (32).

Zooplankton samples were collected at the same time and depth as for those for chemical analyses. Zooplanton samples were collected by vertical tows to the water surface using a 45 µm mesh-size, nylon plankton net. The samples were promptly narcotised with chloroform water (33) and preserved in a formaldehyde solution to give a final concentration of 4%. The samples were normally subsampled, using a wide-bore pipette and counted under a stereo microscope. When samples were subsampled, at least 100 of the most common species were counted (34). Animals were identified to species level whenever possible using standard works (35, 36).

Fish Stock

In Lake eymir, the fish stock determination was carried out in May 1998 using multiple mesh-sized (18, 36, 40, 50, 70 mm) gill nets with a length of 100m and width of 3.5m. The multiple mesh-sized gill nets were left overnight and were collected on the following morning, and the study lasted a week. The stock was determined according to Bingel (37), calculations as follows:

$$B = \frac{A \times y}{q \times a}$$

Where A: the total area of the laki in hectares

a: the effective area of the fish net in hectares

q: the efficency coefficient of the net,

y: the daily mean of the caught fish in kilograms.

Aquatic Plants survey

Aquatic plants were surveyed in July 1998. Sampling was carried out from a boat using a grapnel. Aquatic plants were identified using Haslam et al., (38) and Altınayar (39). Percentage cover of submerged plants was estimated from a weighed photocopied image of the vegetation map.

Results

In Lake Eymir, both thermal and oxygen stratification set in May and continued to the end of August. The thermocline was found to set around the depth of 4.5m. Therefore, less than 40% of the total lake water mass went under thermal stratification. In spring, temperature increased from winter values of 1-3°C to summer maximum of 22-24°C. Throughout summer, the hypolimnetic dissolved oxygen concentrations were near anoxic, and much lower (0-2 mg l^{-1}) than the epilimnetic concentrations (6-8 mg l^{-1}).

The TP concentrations of the inflows of Lake Eymir were higher than that of the in-lake concentrations (305 µg l^{-1}) (fig.1a). The outflow of Lake Mogan after passing through Mogan town (annual mean TP: 219 µg l^{-1}) receives the TEK STW effluent (annual mean TP: 5413 µg l^{-1}) and forms eymir inflow 1 which had an annual mean of 474.4 µg l^{-1} TP. The TP concentration of Kışlakçı brook was also high with an annual mean of 255 µg l^{-1}. The DIN concentrations of inflows were also higher than that of the in-lake (91 µg l^{-1}) (Figure 1b). The annual mean of Eymir inflow 1 was 1480 µg l^{-1}. The outflow of Lake Mogan and the TEK STW effluent, which form the Eymir inflow 1, had very high DIN concentrations (1351 µg l^{-1} and 7880 µg l^{-1}, respectively) (Figure 1b). The DIN concentration of Kışlakçı brook was also high with an annual mean of 2559 µg l^{-1}. The eymir outflow had an annual mean of 255 µg l^{-1} that was slightly higher than that of the lake concentration (Figure 1b).

Throughout the study period, TP and SRP concentrations of Lake Eymir showed a similar seasonality in that there was a significant correlation between the SRP and TP concentrations (r: 0.63, p: 0.0183) (Figure 2a). The annual mean ± standard error of TP and SRP concentrations were 305±26 µg l^{-1} and 202±26 µg l^{-1}, respectively. The concentrations were remarkably lower in late winter and early spring in 1998 than that of 1997 (Figure 2a). The SRP concentrations of Lake Eymir and Eymir inflow 1 were significantly correlated (r: 0.86, p: 0.0004). There was also significant correlation between the SRP concentration and Secchi depth (r: 0.57, p: 0.0438). In Lake Eymir the annual mean of DIN, which is the sum of nitrate + nitrite (NO_3+NO_2-N) and ammonium (NH4-N) concentrations, was 91±32 µg l^{-1} (Figure 2b). Of the two forms of inorganic nitrogen analysed, NO_3+NO_2-N was dominant (annual mean: 54±18 µg l^{-1}). The NH_4-N concentrations, however, were low and undetectable several times in the spring of both years (Figure 2b). NO_3+NO_2-N and DIN

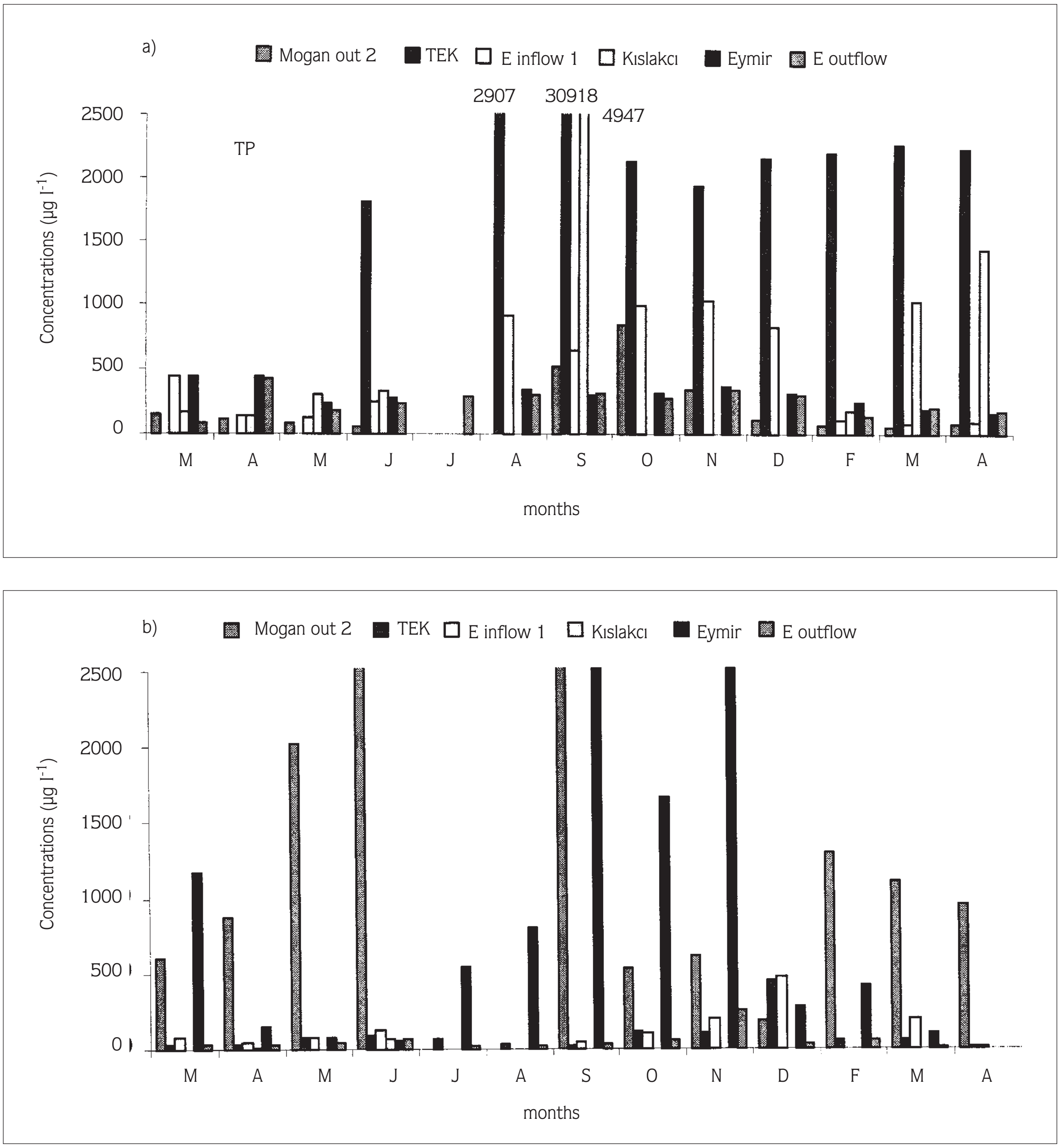

Figure 1. The changes in a) total phopshorus (TP) and b) dissolved inorganic nitrogen (DIN), concentrations of the inflows to Lake Eymir, the lake and the outflow measured March 97 and April 98.

concentrations of Eymir inflow 1 and Lake Eymir were significantly correlated (r: 0.84; p<0.001 and r: 0.89; p<0.001, respectively). The annual mean of reactive silicate-silicon concentration was 3±0.4 µg l^{-1} in Lake Eymir. It was low in autumn and reached a minimum concentration of 0.60 µg l^{-1} in Feb' 98 (Figure 3a). The Secchi-depth was highest in July 1997 (180 cm) and relatively low during late summer, winter and early spring (min: 46 cm in april 1997) (Figure 3b).The maximum chlorophyll-a concentration in Lake Eymir was recorded in February 1998 (36.3 µg l^{-1}), which coincided with the minimum concentration of reactive silicate-

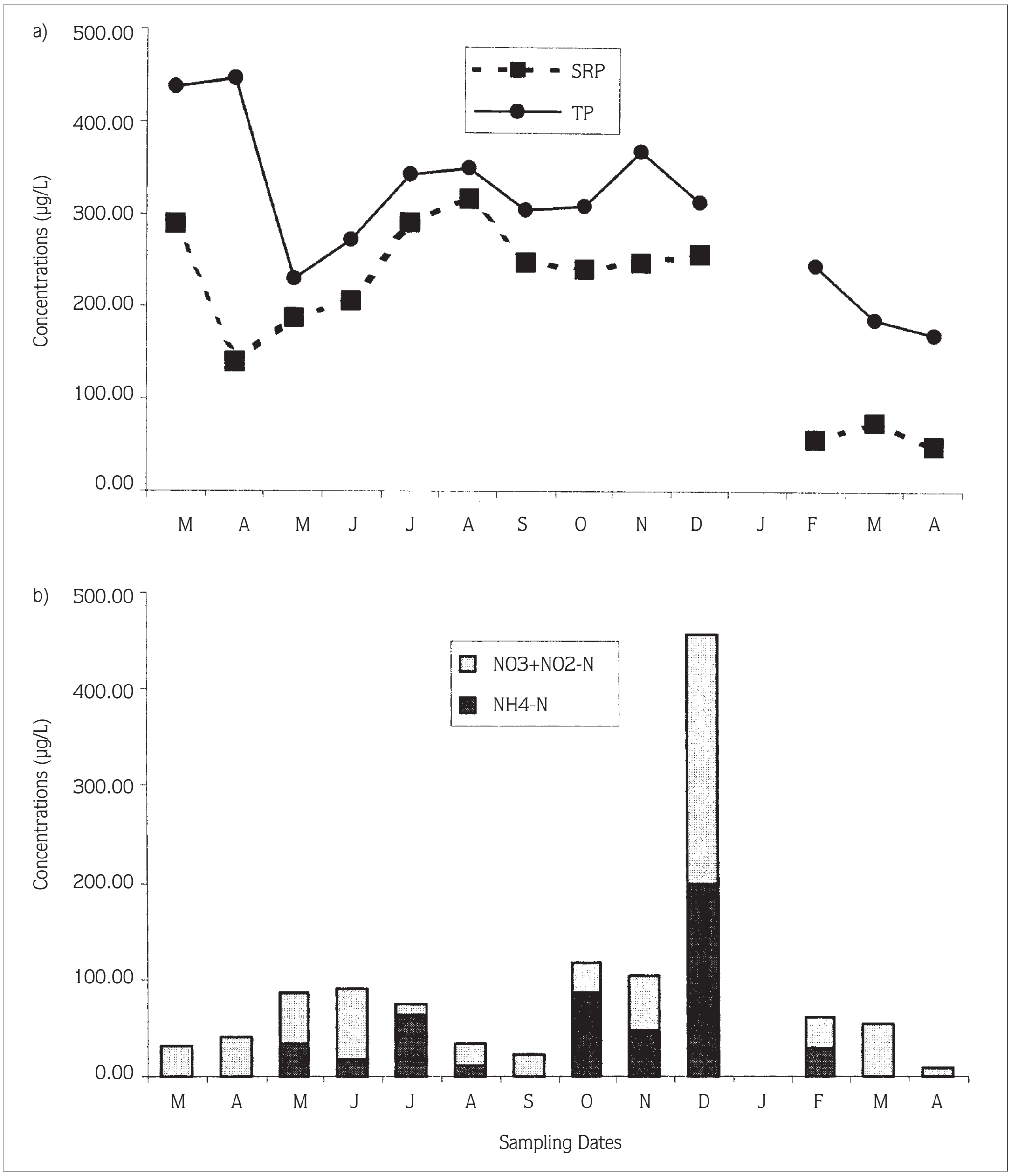

Figure 2. The changes in a) concentrations of soluble reactive phosphorus (SRP) and total phosphorus (TP) and, b) dissolved inorganic nitrogen (DIN) measured in Lake Eymir between March 1997 and April 1998.

silicon (Figure 3a). The annual mean of chlorophyll-a concentrations was 19±3.5 µg l^{-1}. The chlorophyll-a concentrations and Secchi-disc depth (Figure 3b) were inversely correlated but the interaction was not significant (r=-0.36).

The carotenoid pigment to chlorophyll-a ratio is given in Figure 4. The A480/A663 and A430/A410 ratios were either>1.3 and <1.2, respectively or > 1.3 and >1.2, respectively in most of the sampling period indicating that the phytoplankton was either N-deficient or contaminated

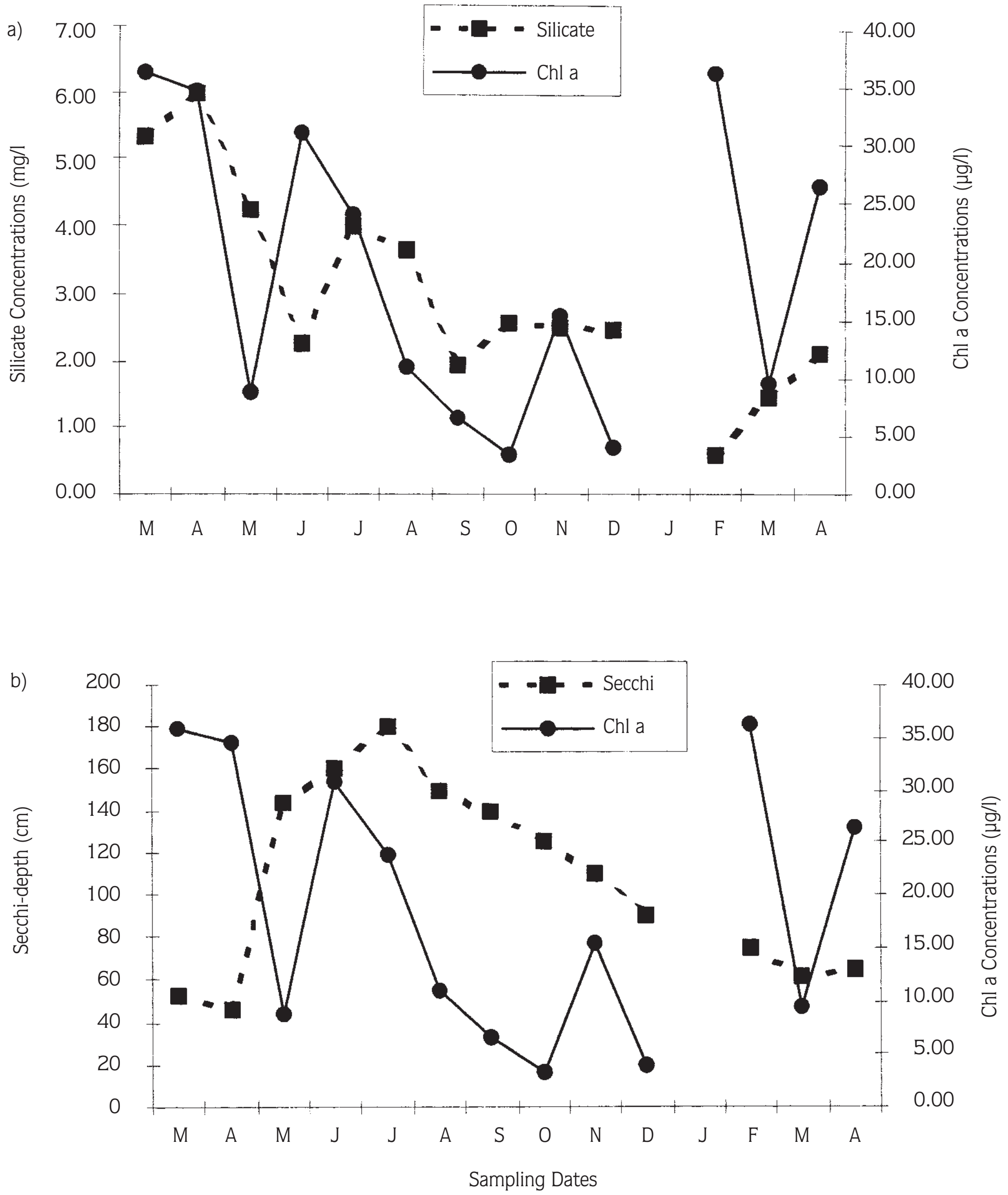

Figure 3. The changes in the concenntrations of a) reactive silicate-silicon and chlorophyll-*a* and b) Secchi depth and chlorophyll-*a* measured in Lake Eymir between March 1997 and April 1998.

with degradation products via sediment resuspension (32).

Zooplankton

In Lake Eymir, the densities of the cladoceran grazers were low and the following species were recorded: *Daphnia pulex* De Geer, *Ceriodaphnia* sp., *Bosmina longirostiris* O. F. Müller, *Diaphanosoma* sp. *Chydorus sphaericus* O. F. Müller and *Alona* sp. The density of large-sized *D. pulex* and small-sized *Ceriodaphnia* sp. were lower than 10 ind.l^{-1} throughout the study period, especially in summer (Figure 5a). *B. longirostiris, Diaphanosoma* sp. *C. sphaericus* and *Alona* sp. were recorded, however their densities were less than 1 ind. l^{-1}. The densities of *Arctodiaptomus* p. and *Cyclops* sp. were abundant in the spring (max: 24 ind. l^{-1} and 10 ind. l^{-1}, respectively in April 1998), and the densities remained very low in summer (Figure 5b).

Fish Stock

The results of the fish stock of Lake Eymir are given in Table 1. Pike (*Esox lucius* L.), tench (*Tinca tinca* L.), carp (*Cyprinus carpio* L.) and *Alburnus escherrichi* Steinoachner were recorded. The total of 6870 kg fish with a daily average of 980 kg was caught using 500m long and 3.5m wide gill nets covering a total effective area of 1.125 ha for seven days. The total fish stock was estimated as 200 000 kg (1600 kg ha^{-1}). The fish stock of Lake Eymir consists of 89% (1420 kg ha^{-1}) tench, 10% (160 kg ha^{-1}) carp and 1 % pike. The tench population was dominated by 3^+ and 4^+ age classes.

Aquatic Plants

In Eymir Lake the recorded submerged plants were *Myrophilum spicatum* L., *Ceratophyllum demersum* L., *Potomageton pectinatus* L., *Najas marina* L. and *Najas* sp. The distribution of submerged plants was very limited covering around 5% of the Lake's total surface area. The submerged plants were only confined to the southern and northern end of the lake despite the long littoral shoreline (5866 m long and 10-15 m width). The dominant emergent plant is common reed (*Phragmites austrialis* L.) covering the whole shoreline of the lake like a belt with a width of 5-10m.

Table 1. The size and the total fish catch in Lake Eymir in May 1998.

	Weight (kg)	Length (cm)	Age Class
Tench	6142	20-33	3^+ and 4^+
Carp	698	30-84	
Pike	33	25-35	
TOTAL	6873		

Discussion

Until 1994, Lake Eymir received the untreated raw sewage effluent of the Mogan Municipality that was diverted to the outflow (İmrahor Valley) of Lake Eymir by a by-pass channel. Before the effluent diversion, the effluent running into Lake Eymir was very rich in DIN and TP (min: 690 µg l^{-1} and max: 49 mg l^{-1}, and min: 110 µg l^{-1} and max:725 mg l^{-1}, respectively) (25). The annual

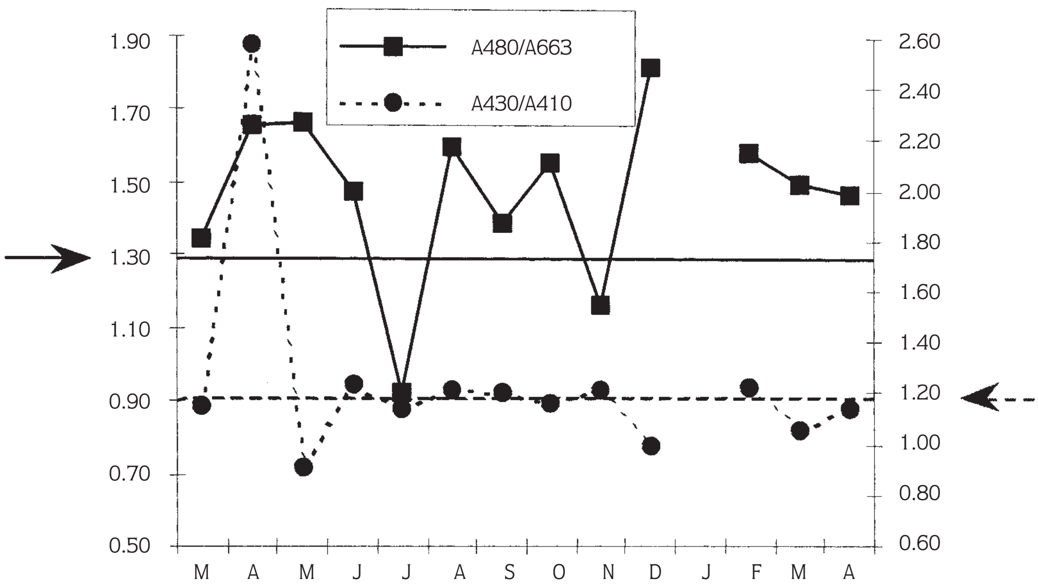

Figure 4. The changes in carotenoid pigment to chlorophyll-*a* ratios measured in Lake Eymir between March 1997 and April 1998.

mean DIN and TP in-lake concentrations 91 μg l^{-1} and 305 μg l^{-1}, respectively) Decreased several-fold compared with before effluent diversion concentrations (183 μg l^{-1} and 860 μg l^{-1}, respectively) (25). The isolation of lakes from external phosphorus loading is thus often considered to be the first step in reversing the undersirable effects of eutrophication (15, 22), and has proved to be effective in deep lakes (3,16). Lake Eymir does not seem to be an exception to this generalisation with a three-fold decrease in TP concentration. However, the present lake TP concentrations were very high especially in summer months, which may be attributed to internal phosphorus loading which is found to be very significant in eutrophic lakes after effluent diversion (11, 17). The independent measurements of hypolimnetic TP concentrations were slightly higher in Lake Eymir, however, since the lake is thermaly stratified throughout the summer, the released concentrations might not have been available to the epilimnion.

Following the effluent diversion, there was a decrease in nutrients from Mogan town to the inflow of the lake, yet the DIN and TP concentrations of the Eymir inflow, Which receives the point sources of the TEK STW, were still very high (Figure 3a). However, the in-lake concentrations of these nutrients were much lower than those of the inflow, probably due to the large reed-bed (0.2 km^2: 1/6 of the total lake area) at southern end of the lake through which the Eymir inflow runs into the lake. Emergent plants of wetlands are known to act as sinks for N and P via denitrification and direct uptake of phosphorus (40, 41). Denitrification capacity of intact wetlands is several-fold 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 (40, 41). Therefore, the reed-bed at the southern end of Lake eymir 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.

Lake Eymir had a sharp spring increase in the chlorophyll-a in both years (35 μg l^{-1}) that was followed by a sharp decrease in the concentration which coincided with the increase in the density of the large-bodied grazers, *Daphnia* and *Arctodiaptomus.* A sharp early spring increase in chlorophyll-a is very common in temperate lakes (7, 42) often followed by a short ' spring clear' water phase that is attributed to increased density of large-bodied grazers (e.g. *Daphnia, Diaptomus*) (43, 44) as found in Lake Eymir. However, the increase in the density of the large bodied grazers in the lake was not as pronounced as found elsewhere (43), probably because our zooplankton data only covered the epilimnetic density and neglected that of the hypolimnetic, thus the density of the grazers might have been underestimated. Several studies have shown the significance of the diel vertical migration of the large bodied grazers to the hypolimnion with a day-time descent and night-time ascent to the surface water to avoid predation (45).

The lake had a second peak of chlorophyll-a concentration in June then the concentrations remained low in summer 1997, which was not attributable to the grazing pressure exerted by the large grazers whose densities remained low as well. In Lake Eymir, the relatively low summer chlorophyll-a concentrations might have been due to nitrogen limitations. Smith (46) suggested that if the N:P<9-13:1, the phytoplankton yield was severely nitrogen-limited. The DIN:TP ratios recorded throughout summer were 0.6-1.7, which indicates a strong nitrogen limitation of the algal crop in the lake. The caretenoid/chlorophyll-a; A480/A663:>1.3 and A430/410:<1.2 ratios also provided further evidence for significance of the possible nitrogen limitation (Figure 4).

The very low summer densities of the large-bodied grazers, *Daphnia* sp. and *Arctodiaptomus* sp. in the lake appeared to be due to predation pressure exerted by tench (*Tinca tinca*), whose contribution to the total fish stock of the lake was 89%, and by carp (*Cyprinus carpio*) to a lower extent. In Lake Eymir, further evidence of the significance of fish predation on large-bodied grazers comes from the tremendous increase in the density of large-bodied *Daphhnia* in the lake following the removal of 30 % of the tench and carp (biomanipulation) undertaken in summer 1998 (İnce and Beklioğlu, unpublished data). There is also a growing body of evidence which shows the significance of zooplanktivorous fish predation on large-bodied grazers in summer (2, 4, 47). In Lake Eymir piscivorous pike (*Esox lucius*) made up a very small portion (1%) of the fish stock, which appeared to be the main reason for the domination by tench due to less predatory control as well as eutrophic conditions which favour planktivorous fish. In Lake Eymir, the summer fish-kill experienced in 1993 (the Lake's Warden: Personal commun.) due to anoxic conditions (25), selective high angling pressure on pike, (though pike fishing has been banned since May 1998), and a very limited littoral zone with submerged plants might have been the reasons for low recruitment of pike, leading in turn to the low biomass. However, the dissolved oxygen concentrations have increased and the prohibition of pike angling may lead to an increase in the fish biomass.

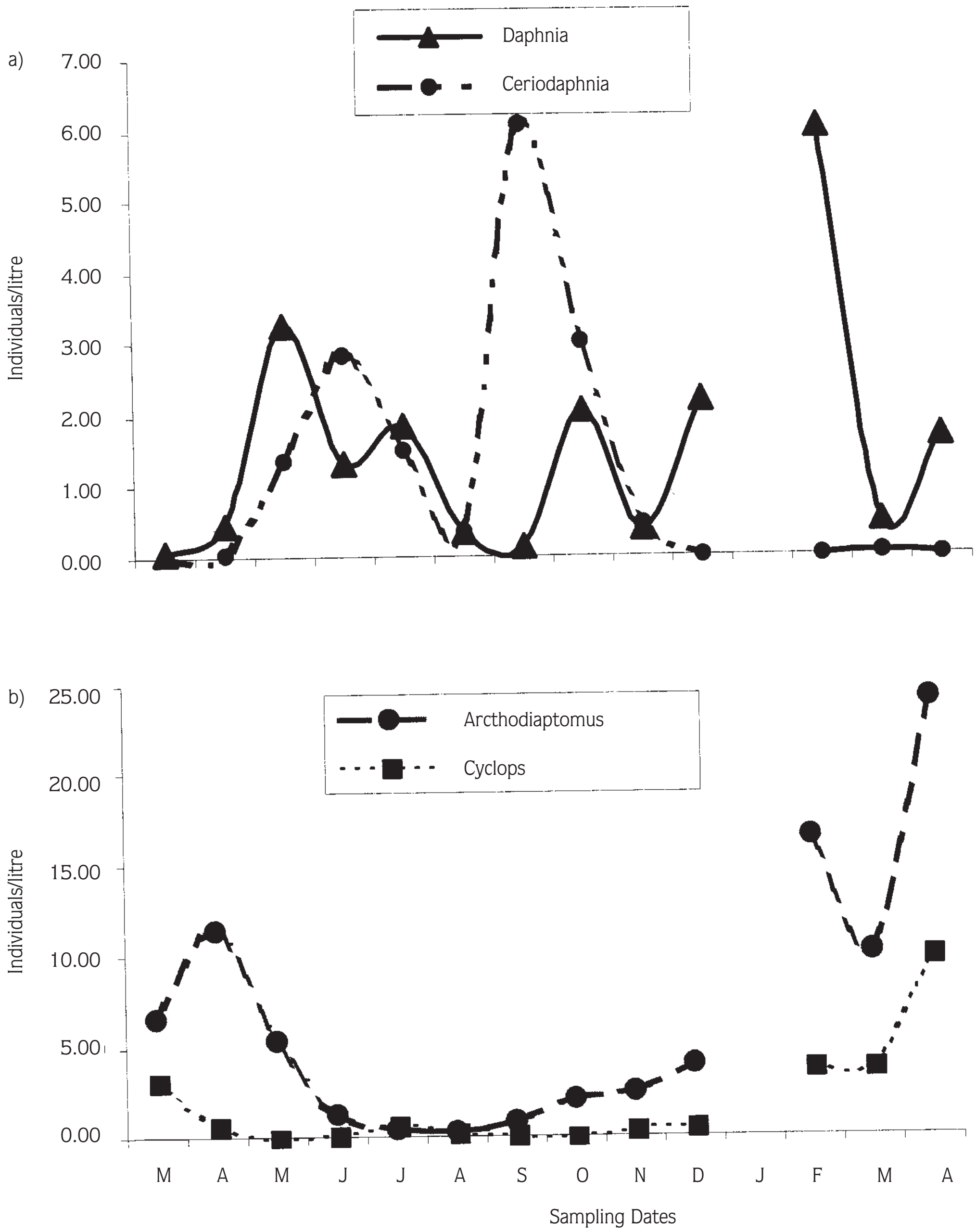

Figure 5. The changes in densities of a) *D. pulex* and *Ceriodaphnia* sp., b) *Arcthodiaptomus* sp. and *Cyclops* sp. in Lake Eymir between March 1997 and April 1998.

The poor water clarity of eutrophic lakes is strongly correlated with phytoplankton biomass (1,2,4,7-9). In Lake Eymir, the water clarity, measured as Secchi depth, was inversely correlated with the chlorophyll-a concentration, though the interaction was not significant. Throughout summer, the water clarity was low at relatively low chlorophyll-a concentrations. Therefore, the clarity of the water did not appear to be largely determined by phytoplankton biomass. Rather turbid water of the lake might be due to the high biomass of benthivorous fish, tench and carp. Especially feeding of carp stirs up the sediment and results in resuspension that is strongly correlated with fish total length (20, 21). The mean total length of carp was 50 cm in Lake Eymir. The feeding of mainly carp, and tench to a lesser extent might have been very important in determining the water clarity through sediment resuspension. Following the removal of 30% of tench and carp (biomanipulation), undertaken in summer 1998 (İnce and Beklioğlu, unpublished data), the Secchi depth increased to >5m implying that the decrease in suspended matter was caused by fish feeding.

In Lake Eymir, following the removal of 30% fish (biomanipulation) in summer 1998, the water clarity, measured as Secchi depth in early summer 1999, increased to >5m owing to very low phytoplankton crop (1-3 $\mu g\ l^{-1}$) due to very high density of large-bodied grazers (*Daphnia*) and perhaps reduced suspended matter in the water column (İnce and Beklioğlu, unpublished data). It appears that top-down control played a significant role in determining the water clarity in Lake Eymir before biomanipulation and that post-biomanipulation the clear water condition has supported this hypothesis.

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