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Seasonal distribution of large phytoplankton in the Keban Dam Reservoir

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Abstract. The Keban Dam Reservoir (KDR), in eastern Anatolia, is one of the largest man-made reservoirs of the world with a storage capacity of >30 billion m^3. In the KDR, long-term water quality surveys have been carried out in order to determine the trophic status of this rather unique reservoir. In this paper, the focus is on the large phytoplankton species that were identified during the field studies conducted between 1991 and 1993. According to the results of the surveys, the overall phytoplankton density is low during the fall and winter months. However, species belonging to various groups started to become abundant in the spring when the water level began to rise. In terms of species diversity, the most dominant group was the Bacillariophyta. Other dominant species belonged to the Cyanophyta, Chloropyta, Pyrrophyta, Chrysophyta and Euglenophyta. The effects of various physicochemical quality parameters on the seasonal distribution and succession of the above taxa, as well as the interrelation with eutrophication, are also discussed.

Introduction

The Keban Dam Reservoir (KDR) is located between latitudes 35°20′ and 38°17′N, and longitudes 38°15′ and 39°52′E, in eastern Turkey (Figure 1). Formed at the confluence of the Munzur, Peri, Murat and Karasu rivers, the KDR is among the most notable reservoirs of the world with a storage volume of ~30.6 billion m^3. The maximum water depth is 163 m at the high supply level. According to long-term records, the average, minimum and maximum flow rates at the dam structure are ~640, 165 and 6600 $m^3\ s^{-1}$, respectively. These flows correspond to theoretical detention times of 18, 71 and 1.8 months, considering the maximum operational volumes.

The Keban Dam was erected mainly for hydroelectric power generation. The construction of the KDR started in the late 1960s and electricity was first produced in Keban in 1972. During the inundation of the KDR, the General Directorate of State Hydraulic Works (DSİ) established an Aquatic Products Department near the town of Keban and initiated a strategic plan for the development of commercial fisheries in the region. Since then, the KDR has evolved into an important fishing area. Today, there are nearly 20 different independent corporations owned by the fishermen living in the villages around the KDR. The waters of the KDR have also been used for seasonal irrigation purposes. Further, there are plans for utilizing the reservoir as a drinking water supply for Elaziğ and other settlement areas in the vicinity.

Considering the above utilization goals, it is clear that the limnological characteristics of the KDR are quite important, not only in terms of public health and environmental aspects, but also for the local economy, which has been altered significantly following the inundation of a relatively large area extending over a

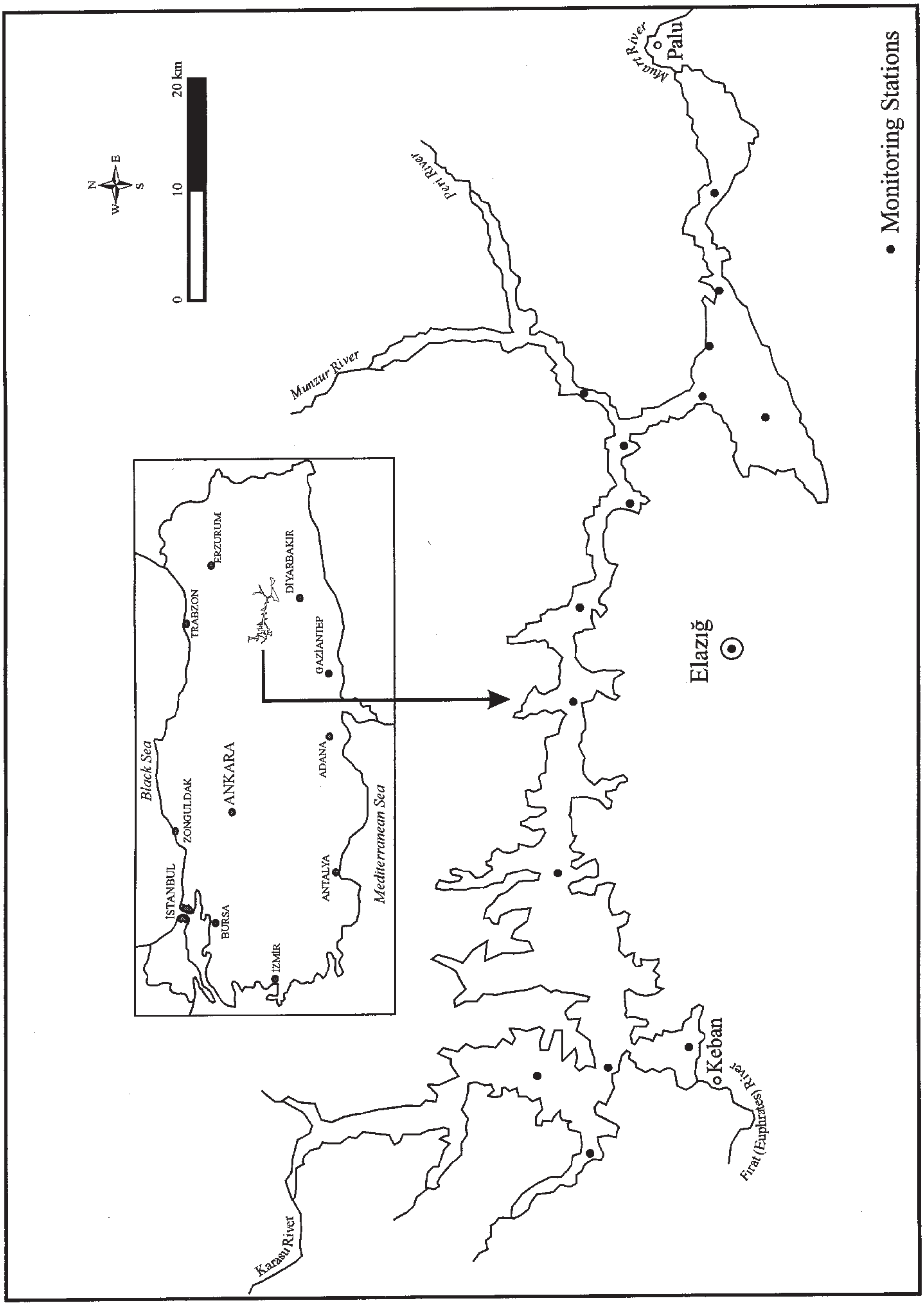

Fig. 1. Location of the KDR.

span of >100 km. Hence, the Turkish Scientific and Technical Research Council (TÜBİTAK) and DSİ have jointly launched an extensive water quality monitoring and research program for the KDR. A total of 15 sampling and measurement stations were established for the water quality surveys in the KDR (Figure 1). Since 1991, the limnological characteristics of the reservoir have been investigated by analyzing the monthly water samples obtained from the monitoring stations.

In this context, the main objective of this paper is to present selected data and results acquired during the above-mentioned water quality survey program. In particular, the focus is on the large phytoplanktonic organisms identified in the KDR. The effects of various physicochemical water quality parameters and the observed trophic level on the seasonal distribution of the identified organisms are also discussed.

Method

At each monitoring station, temperature, electrical conductivity (EC) and dissolved oxygen (DO) profiles along the water column were measured *in situ* by means of field instruments with sufficiently long probe cables. Both temperature and EC measurements were performed by means of a portable SCT meter (YSI Model Y.10.33), whereas the DO concentrations were measured by using a dedicated DO meter (YSI Model Y10.51B). The incident light and light intensities were also measured *in situ* by using an appropriate probe (Huskey Model 352-K). Profiles of pH and light transparency were determined by means of various field type pH meters and Secchi disks.

All light intensity measurements along the water column were made with small depth increments of 1 or 2 m. Using these light profiles, the level of the euphotic zone was determined at each station (this level was assumed as the water depth where the measured light intensity was 1% of the incident light reaching the surface). For the identification of the planktonic species, composite water samples were collected from the euphotic zone by using a plankton net vertically. As recommended by Round (1973), the mesh size of the plankton net was 55 μm. The samples were preserved in a 5% formaldehyde solution and quantified by examining a prescribed volume under an inverted microscope equipped with a counting chamber (Lund *et al.*, 1958). The chlorophyll (Chl) *a* levels of the samples were determined according to the spectrophotometric method described by Youngman (1978).

The analyses of the conventional quality parameters were carried out on water samples collected at three different depths (i.e. surface, thermocline level and bottom). The surface samples were taken within the first 0.2 m from the water surface. The bottom samples, on the other hand, were collected 1 m above the bottom of the reservoir. During sampling at each station, the *in situ* DO profiles and thus the depth of the thermocline were determined. The mid-depth water samples were collected just at the level of the thermocline.

All water samples, preserved in appropriate containers and conditions, were transferred to the DSİ laboratories in Elaziğ and Keban within 6 h. The total nitrogen (TN) and total phosphorus (TP) concentrations were determined according to the analytical procedures recommended by the United States Environmental Protection Agency (USEPA) (1974). The laboratory determinations of the other conventional water quality parameters were in accordance with the standard methods (Clesceri *et al.*, 1989).

Background information

General characteristics of the KDR

One of the unique characteristics of the KDR is its dynamic nature. In this regard, the reservoir exhibits rather unusual hydrodynamic properties. This complex behavior is mainly due to the water level variations caused by meteorological, hydrological and operational factors (Mukhallalati, 1994).

There are sharp seasonal differences in the climate of eastern Anatolia. The winter months are extremely cold and snowy, whereas summers are hot and dry. Such climatic differences cause significant variations not only in meteorological factors such as precipitation and evaporation, but also in hydrological properties of the incoming rivers and the reservoir itself. The KDR receives such large rivers as the Munzur, Peri, Murat and Karasu. Owing to the climate and topography of the region, these rivers have highly fluctuating flows. As a typical example, the flow rate of the Murat River can be as high as 2000 $m^3\ s^{-1}$ in spring. The same river, however, carries a mere 30–40 $m^3\ s^{-1}$ during the dry season.

The 1330 MW ($4 \times 158 + 4 \times 175$) hydroelectric station at the outlet of the KDR is a vital source for the national power grid. Consequently, the power demand exerted by the interconnected system affects the water level in the KDR substantially. Records of the past 25 years of operation indicate that the annual change in the supply level can be as high as 21 m. Such variations inflict significant changes on both the surface area and the volume of the reservoir, and thus influence its hydrodynamic properties.

In terms of the pollution load, the major point sources are the incoming rivers. In particular, the Murat River has a vast catchment area supporting diverse agricultural activities, and thus carries high amounts of nutrients (especially phosphate). In addition, there are other domestic and industrial points as well as distributed sources around the KDR. The sources carrying pollutants to the reservoir are assessed elsewhere (Soyupak *et al.*, 1993, 1994, 1997).

As confirmed by the results of the long-term limnological surveys, various parts of the KDR have been experiencing different levels of eutrophication under the influence of the pollutant loads referred to above. In earlier studies, three distinct regions with different trophic levels were defined (Soyupak *et al.*, 1993). As can be seen in Figure 1, Region I starts near Palu where the Murat River joins the KDR. This locked portion is connected to the rest of the reservoir through a narrow but rather long channel. The valley-type mid-section of the KDR is called Region II. The remaining part of the reservoir, comprised of rather wider sections extending towards the dam structure, is referred to as Region III.

With respect to water quality, Region I is poorer than the others mainly due to the load carried by the point sources. In this regard, the Murat River brings almost 70% of the total annual flow passing through the KDR. Untreated domestic wastewater discharges of Elaziğ and the effluents of the nearby industries also contribute to the pollution in Region I. Based on commonly used classification criteria involving TP, TN, Chl *a* and light transparency levels, Region I was found to be eutro-hypertrophic. On the other hand, Regions II and III, which are not subjected to any major point load, were meso-eutrophic and oligo-mesotrophic, respectively (Soyupak *et al.*, 1994).

Factors affecting productivity

Such water quality parameters as the DO, TN, TP, Chl *a* and light intensity are among the most important factors affecting phytoplankton productivity, and thus the trophic status of a water body. The levels of these factors observed in the KDR are outlined in the following paragraphs. For the sake of brevity, only a typical set of measurements is given for each parameter and depth-averaged values are presented as a function of downstream traveling distance. The distance axis starts with a zero at the point where the Murat River joins the KDR and extends to a maximum of 110 km at the outlet of the dam structure. Detailed information regarding the limnological characteristics of the KDR can be found elsewhere (Soyupak *et al.*, 1993, 1994, 1997; Yemişen and Soyupak, 1994).

Dissolved oxygen concentrations. In all parts of the KDR, the observed DO concentrations were relatively lower during the summer months, not only due to the higher water temperatures, but also due to the completion of the biochemical oxidation of the organic material fed into the system with the spring flows. Further, the rates of other DO-depleting mechanisms associated with the life cycles of microorganisms (i.e. photosynthetic activities, growth and death) increase during the summer.

As illustrated by a typical summer profile given in Figure 2, the minimum level of DO virtually did not fall below 4 mg l^{-1} even in the most polluted Region I. Thus, the DO levels in the KDR are not deemed critical for the growth of phytoplanktonic organisms. Nevertheless, it is interesting to note the presence of an intermediate layer (at a depth of ~20–30 m below the surface) with relatively lower DO concentrations. This pattern, typical of large and deep reservoirs, is mainly related to the consumption of DO by the settling of the dead microorganisms (Soyupak *et al.*, 1993, 1994).

Total nitrogen and phosphorus concentrations. In natural lakes as well as man-made reservoirs, TN levels of 5–10 mg l^{-1} are accepted as a sign of normal conditions. TN concentrations exceeding 20 mg l^{-1}, on the other hand, indicate a eutrophic character (Wetzel, 1983). Similarly, the phosphorus levels of relatively clean lakes are within the range of 0.1–0.2 mg l^{-1}; however, TP levels between 0.15 and 0.30 mg l^{-1} indicate an increase in algal growth rates and quantities (Nisbet and Verneaux, 1970).

Seasonal variations in the depth-averaged TN and TP concentrations observed at various stations along the KDR are depicted in Figures 3 and 4, respectively.

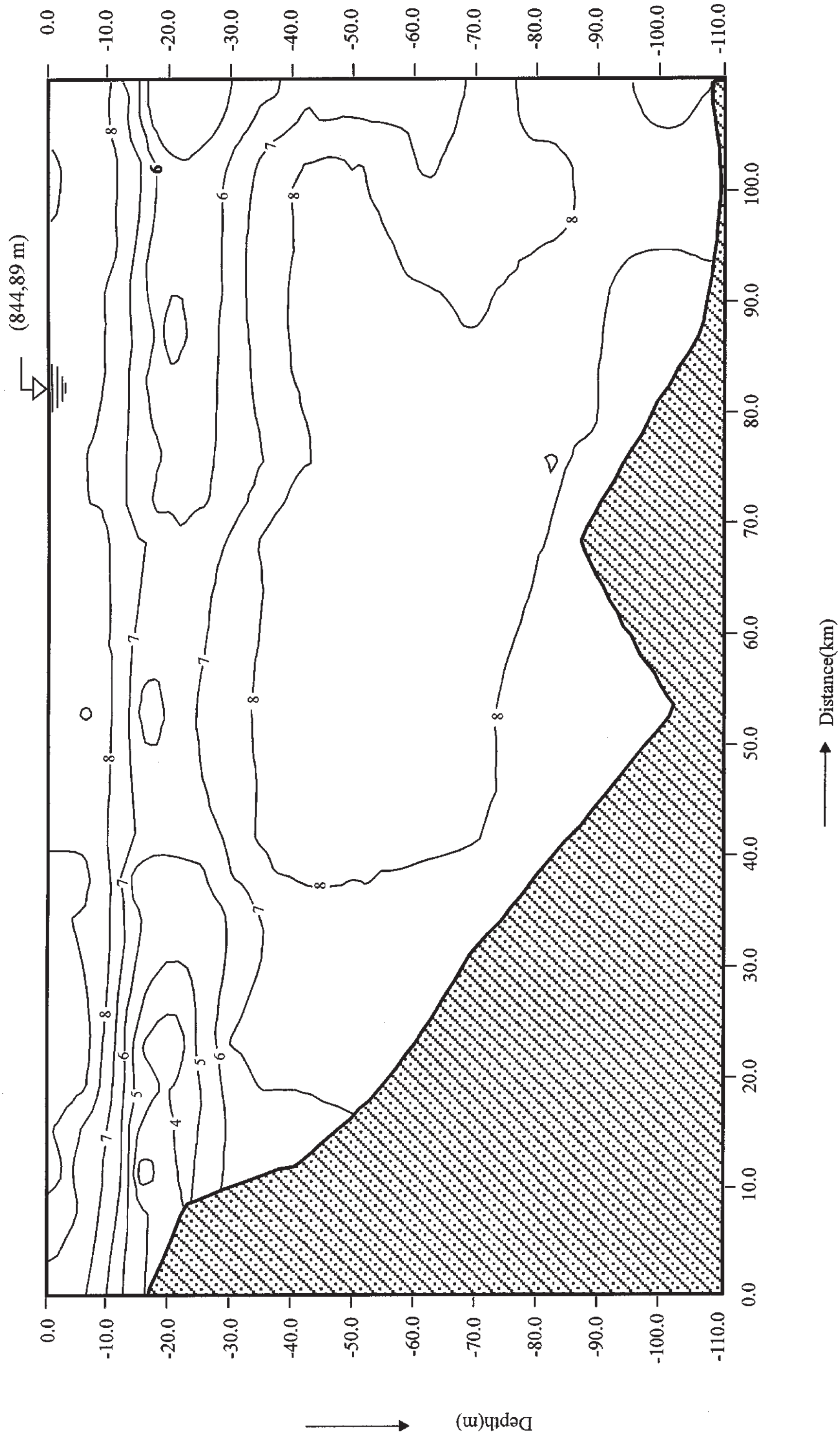

Fig. 2. Typical DO profile along the KDR (July 1993).

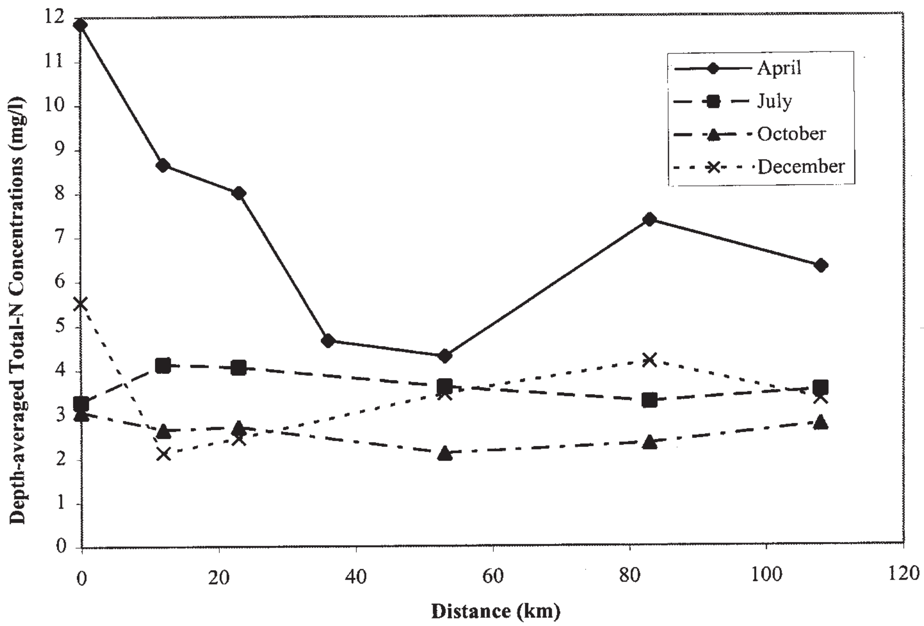

Fig. 3. Variation of the depth-averaged total nitrogen concentrations with downstream travel distance (1993).

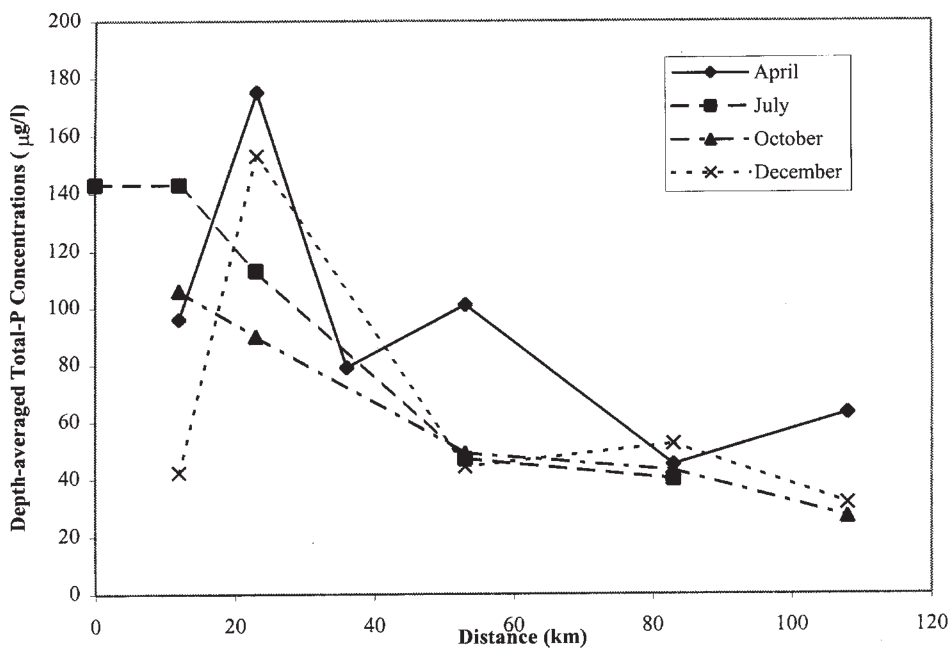

Fig. 4. Variation of the depth-averaged total phosphorus concentrations with downstream travel distance (1993).

As can be seen in the figures, the observed TN levels are within acceptable limits and thus cannot be held solely responsible for the eutrophic conditions within the reservoir. Conversely, at all times and stations, the observed TP values were above the range deemed normal in relatively clean water bodies. Hence, as presented in the subsequent sections, the trophic status governed mainly by the phosphorus levels plays an important role in terms of the distribution of the planktonic organisms.

Chlorophyll a concentrations. Numerous researchers (e.g. Vörös and Padisak, 1991) accept Chl *a* as an indicator of algal biomass levels (and thus eutrophication) in water bodies. Typical Chl *a* concentrations observed in the KDR are given in Figure 5. As shown in this figure, Chl *a* levels measured in the summer months were significantly higher than those observed throughout the fall and winter. The Chl *a* levels during the summer months might have been enhanced by higher water temperatures as well as higher nutrient and organic matter concentrations that are boosted during the spring flows.

As can be seen in Figure 5, the measured Chl *a* concentrations exhibit a decreasing trend with the downstream distance away from the point sources in Region I. In this regard, the KDR exhibited different trophic levels with respect to the average and maximum Chl *a* concentrations. Based on the average Chl *a* values, Regions I, II and III were hypertrophic, meso-eutrophic and mesotrophic, respectively. On the other hand, all three regions were found to be eutrophic, when trophic status is assessed only on the basis of the maximum Chl *a* levels (Soyupak *et al.*, 1994).

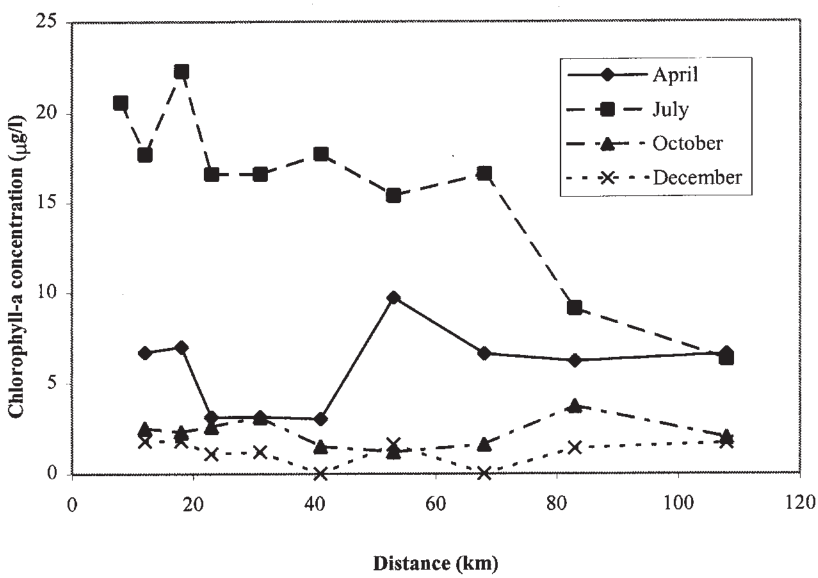

Fig. 5. Variation of the Chl *a* concentrations with downstream travel distance (1993).

Light transparency. As an important factor affecting phytoplankton productivity, the amount of light reaching a given cell depends on the vertical positioning of the cell along the water column. Other factors important in this respect include the incident solar radiation at any time, surface solar radiation density and the light transparency of the water (Sommer, 1985). Since dissolved and suspended substances limit the penetration of light, light transparencies were measured as Secchi depths in this study. Typical Secchi depths measured at various stations along the KDR are presented in Figure 6.

Owing to the higher organic and inorganic contents resulting from the material transport via the point sources, light transparency was considerably lower in Region I as compared to the other parts of the KDR. Further, the Secchi depths increase proportionally with the distance from the entrance point of the Murat River, and the light transparency throughout the entire reservoir was lower during the summer months. By the same token, the EC values were also higher in Region I, particularly during the spring and summer months.

Results and discussion

Between 1991 and 1993, a total of 17 expeditions were conducted in the KDR during which both phytoplankton and zooplankton samples were collected at the monitoring stations. As a result of the laboratory investigations carried out on these samples, a myriad of large phytoplankton (>55 μm) species from the Bacillariophyta, Chlorophyta, Cyanophyta, Pyrrophyta, Chrysophyta and Euglenophyta groups were identified in the KDR. The most dominant group was the Bacillariophyta, followed by Cyanophyta and Chlorophyta (see Table I).

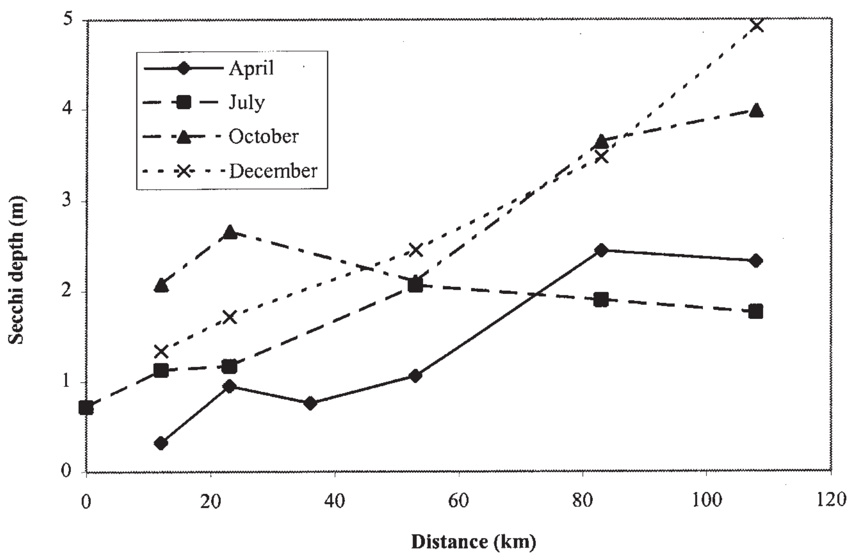

Fig. 6. Variation of Secchi depth measurements with downstream travel distance (1993).

Table I. List of large phytoplanktonic organisms in the KDR

BACILLARIOPHYTA	EUGLENOPHYTA	CHRYSOPHYTA
Navicula spp.	*Euglena* sp.	*Dinobryon* sp.
Cyclotella sp.	*Trachelomona* sp.	*Chrysococcus* sp.
Cocconies sp.		
Melosira granulata	CHLOROPHYTA	CYANOPHYTA
Fragilaria sp.	*Ankistrodesmus* sp.	*Oscillatoria prolifera*
Fragilaria contruens	*Oocystis* sp.	*Oscillatoria limosa*
Nitzschia spectabilis	*Pediastrum duplex*	*Microcystis viridis*
Nitzschia sigmoidea	*Pediastrum simplex*	*Microcystis aeruginosa*
Nitzschia linearis	*Pediastrum boryanum*	*Aphanocapsa* sp.
Nitzschia dissipata	*Spirogyra* sp.	*Aphanizomenon flos-aquae*
Synedra ulna	*Closterium costatum*	*Aphanotheca* sp.
Synedra capitata	*Closterium probiscideum*	*Gomphosphaeria aponina*
Gyrosigma sp.	*Closterium aciculare*	*Gomphosphaeria lacustris*
Gyrosigma kützingii	*Chlorella* sp.	*Anabaena circinalis*
Gyrosigma acuminatum	*Micractinium pusillum*	*Anabaena flos-aquae*
Stephanodiscus sp.	*Tetraedron minimum*	*Gleocapsa dispersa*
Surirella sp.	*Staurastrum longiradiatum*	*Chroococcus* sp.
Cymatopleura solea	*Planctonema lauterbornii*	*Tetrapedia* sp.
Ceratoneis argus	*Coelastrum* sp.	*Merismopedia glauca*
Caloneis amphisbaena	*Scenedesmus* sp.	*Merismopedia minima*
Asterionella gracillima	*Scenedesmus quadricauda*	*Lyngbya* sp.
Pinnularia spp.		
Tabellaria sp.	PYRROPHYTA	
Asterionella formosa	*Ceratium hirundinella*	
Gomphonema acuminata	*Peridinium* sp.	
Cymbella spp.	*Tetradinium* sp.	
Diatoma sp.		
Amphora ovalis		

During the first 10 expeditions between August 1991 and June 1992, plankton samples were collected only in the most polluted Region I. As shown in Figure 7, even though more individuals were identified in warmer months, the total quantities of the large phytoplanktonic organisms fluctuated considerably. Plankton samples were collected at all stations during the course of the following seven surveys. In Figure 8, the total quantities of organisms observed in all three regions of the KDR are plotted separately as a function of the sampling time. As depicted in Figure 8, the total number of organisms found in Regions I and II is generally higher than that observed in Region III. This phenomenon indicates a positive relationship between the phytoplankton productivity and pollution load.

Seasonal distribution

In general, different planktonic species can tolerate different ranges of temperature as well as light and nutrient limitation. These tolerance levels determine the dominance of different species within different seasons (Fogg, 1975). Hence, the seasonal changes in the dominant classes of phytoplankton can be explained in terms of not only the variations in water temperature, but also in relation to the competition for nutrients and light.

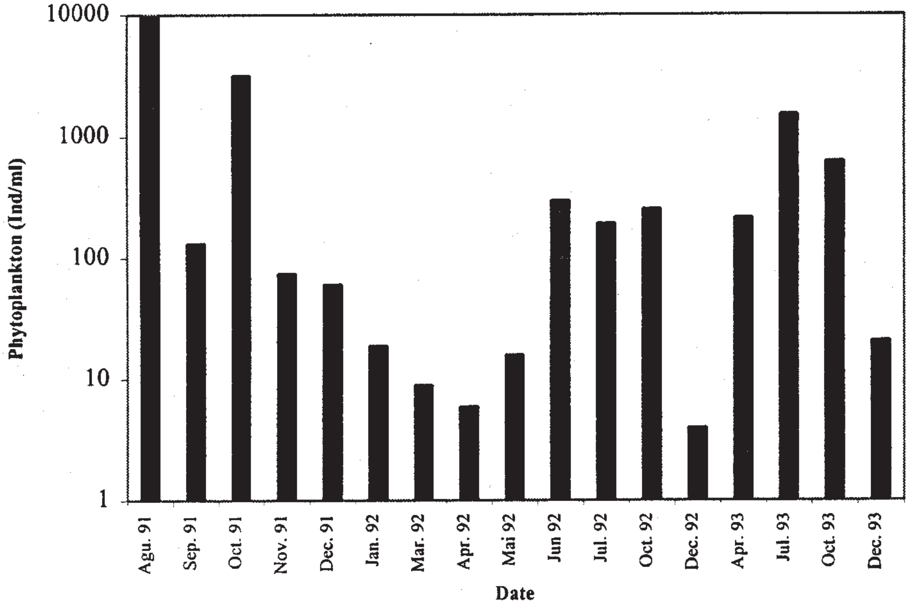

Fig. 7. Seasonal distribution of large phytoplanktonic organisms in Region I (1991–1993).

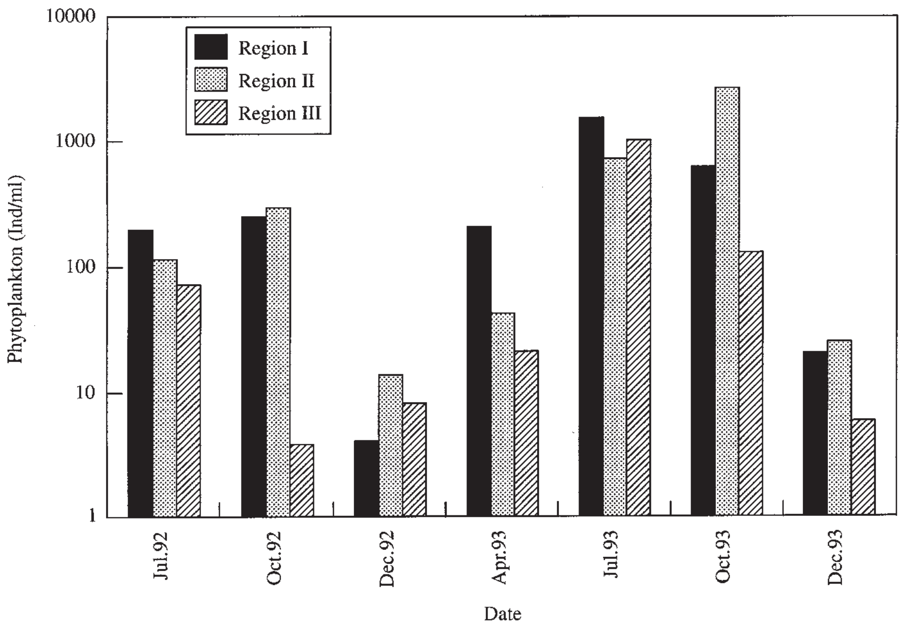

Fig. 8. Seasonal distribution of large phytoplanktonic organisms in Regions I, II and III (1992–1993).

In the case of the KDR, the species belonging to the Bacillariophyta, Cyanophyta and Chlorophyta started to become more dominant following the spring thaw in April. (The same groups were also dominant during the winter months, but with considerably fewer individuals.) As an example, in August 1991, the total quantity of phytoplanktonic species exhibited a maximum level establishing a fairly even representation of both blue-green algae and diatom species, with *Oscillatoria prolifica* of the Cyanophyta being the most distinctive species.

The increase in Bacillariophyta and blue-green algae during the warmer months can be attributed to the increases in temperature, food and nutrient levels. In general, elevated water temperatures provide a suitable environment for the above divisions, while both food and nutrients become more soluble with rising temperatures (Sommer, 1985). However, species belonging to such groups as the Chrysophyta can usually start to grow towards the end of fall due to their high dependency on temperature (Munawar *et al.*, 1991).

Seasonal distributions of the dominant large phytoplankton species of the KDR are illustrated in Figure 9. As can be seen in this matrix, *Cyclotella* sp. and *Melosira granulata* of the Bacillariophyta, *Oscillatoria* sp. (especially *O.prolifica*) of the Cyanophyta, and *Pediastrum simplex* and *P.dublex* of the Chlorophyta dominated the KDR throughout all seasons.

In particular, *Cyclotella* was observed to be the paramount taxon of the KDR, especially in Region I. It should be noted that Thompson and Phee (1994) reported *Cyclotella* to be more widespread in oligotrophic lakes. However, as confirmed by the results of this study, *Cyclotella* was reported among the governing organisms of the eutrophic lakes and reservoirs of Turkey (Aykulu *et al.*, 1983; Obalı, 1984; Gönülol and Șomak, 1992; Sen *et al.*, 1994).

At this point of the discussion, it should also be reminded that certain species of *Oscillatoria* are also able to survive in lower temperatures. *Oscillatoria rubescens*, for instance, grows in vast quantities during the summer, but can also enjoy cold waters and create surface blooms over the hypolimnion during the winter months (Makulla and Sommer, 1993). Hence, in water bodies like the KDR, *O.prolifica* is expected to be a dominant group not only in winter, but also during any season (Hutchinson, 1957). In Region I, *O.prolifica* was the dominant organism both in December 1991 and January 1992. This observation supports the previous findings of Hutchinson (1957) regarding winter blooms of *Oscillatoria*.

In addition to the species which showed high relative abundance in all seasons and regions, *Ceratium hirundinella* of the Pyrrophyta existed in large quantities only during the summer months. Similarly, *Asterionella* (mainly *A.formosa*), *Synedra*, *Navicula* and *Fragilaria* species of the Bacillariophyta, *Aphanocapsa* and *Gomphosphaeria* (especially *G.aponina*) species of the Cyanophyta, and *Peridinium* sp. of the Pyrrophyta, exhibited significant growth rates and relative abundances only in the warmer months of the spring, summer and fall seasons.

On the other hand, *Microcystis* (specifically *M.viridis*) species of Cyanophyta were observed in relatively higher numbers only during the colder months of fall and winter. As mentioned in the earlier paragraphs, a reduction was observed in the phytoplankton density during the winter months.

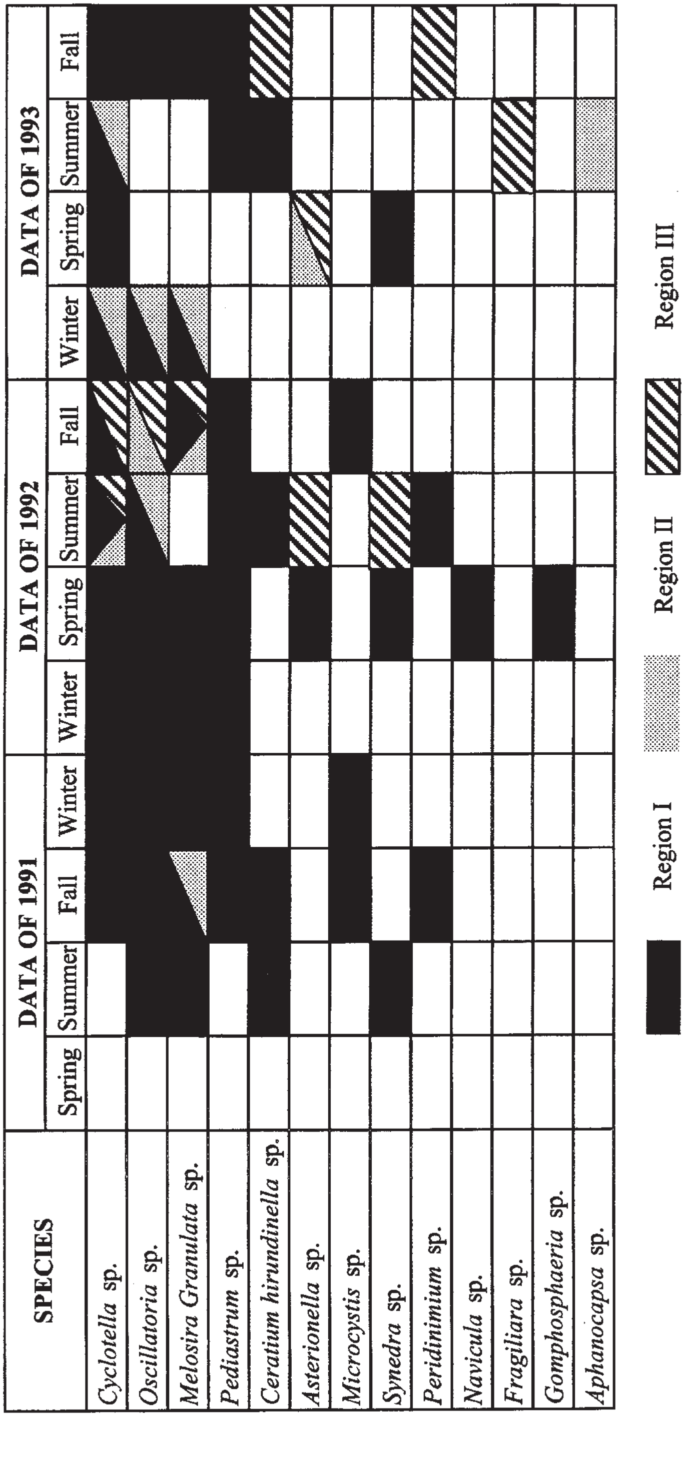

Fig. 9. Seasonal distribution of the dominant large phytoplanktonic organisms in the KDR (1991–1993).

Diversity

The prevailing eutrophic conditions can be examined through algal biomass and species diversity data. With this intention, certain blue-green algae species, including *Microcystis* spp., *Anabaena* spp. and *Aphanizomenon flos-aquae*, as well as some species of diatoms (*Asterionella* spp., *Fragilaria crotonensis*, *Synedra* spp. and *Melosira granulata*), are commonly used as indicator organisms for eutrophication. All these species were found to exist in the KDR.

The trophic status of lakes can also be characterized by assemblage and seasonal succession of phytoplankton. In this respect, the growth and periodicity of the phytoplanktonic organisms exhibit variations that are related to certain physicochemical factors such as water temperature, light, nutrients and existence of zooplankton which feed on phytoplankton (Reynolds, 1984). As mentioned earlier, phytoplankton densities in the KDR increased when water temperatures and nutrient levels were both high. Under these circumstances, the members of the Cyanophyta grew in large quantities.

The diversity indices for the years 1992 and 1993 are shown in Figure 10. In terms of the general trend, the diversities were lower during the summer months as compared to the winter months. The increase in diversities during the winter season was more notable in the relatively cleaner regions (i.e. II and III). The possible reasons for this phenomenon include the relative decreases observed in pollutant concentrations, water temperatures and thus predation effects. (Particularly in Regions I and II, pollutant concentrations in winter decrease mainly due to the increase in water volumes. It should be noted that many organisms exhibit

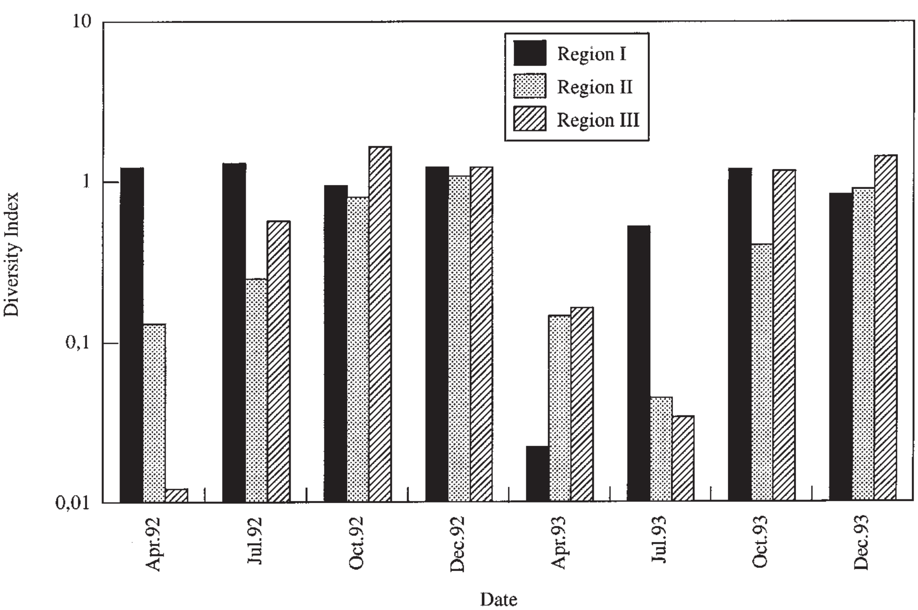

Fig. 10. Seasonal distribution of the observed diversity indices for Regions I, II and III (1992–1993).

avoidance reactions when pollutant concentrations exceed certain levels and start to cause limitation effects within the water body. Certain species and organisms can disappear under such extreme conditions of the medium.)

However, as a result of a comparative evaluation of the diversity indices observed in different seasons, one can see that, in the months of April and July 1992, the index values of the most polluted Region I were considerably higher than those of the other regions. Conversely, in April 1993, the diversities observed in Regions II and III were significantly higher than that of Region I, which decreased rather dramatically. Such fluctuations in the diversity of plankton can be attributed to the seasonal variations in the water level of the reservoir rather than pollution. Further, as discussed by Barone and Flores (1994), water level variations affect predation patterns which, in turn, affect species diversity.

Large phytoplanktonic organisms such as the colonial diatoms, large dinoflagellates and some gelatinous green algae are the preferred foods of many herbivores. As an example, Cladocera and Copepoda graze colonial diatoms such as *Melosira granulata*, *Asterionella formosa* and such large dinoflagellates as *Ceratium hirundinella* and *Peridinium*. These species mentioned above are among the relatively abundant species of the KDR. Being the preferred foods of the zooplanktonic species, they also determine the zooplanktonic structure of the reservoir. Indeed, a critical evaluation of the zooplanktonic organisms in the KDR has indicated that their population density was dependent on the growth of the phytoplanktonic organisms (Yemişen and Soyupak, 1994). By the same token, zooplanktonic grazing affects the distribution of the phytoplanktonic organisms in the reservoir.

Similarity

Similarity index analyses, used for the comparison of the three regions which are ecologically different, revealed that Regions II and III showed resemblance throughout the fall and winter months. However, parallel to the increase in water temperatures, the eutrophic characteristics of Region II started to become more noticeable in the summer months. Consequently, Regions I and II became more similar during the summer months. In fall, due to the gradually decreasing water temperatures and eutrophication reaction rates, the eutrophic characters of all three regions tended to become similar. This similarity was more apparent between Regions II and III, since Region I received a considerable amount of pollution even during the winter months.

Summary and concluding remarks

The seasonal distributions of the large phytoplanktonic organisms inhabiting the KDR were determined together with their successions. The trophic status of the reservoir was also assessed in reference to both water quality and the indicator organisms. Bacillariophyta were the most dominant group with respect to species diversity. Other species and genera of phytoplanktonic organisms observed to be dominant included Cyanophyta and Chlorophyta.

During the summer and early fall months, parallel to the increase in water temperatures, blooms of blue-green algae were observed along with other species of Bacillariophyta. Starting from the fall, a reduction was observed in the phytoplankton density and the reduction in population density has continued during the winter months.

In general, *Cyclotella*, *Melosira*, *Asterionella* and *Synedra* of the Bacillariophyta, *Oscillatoria* and *Microcystis* of the Cyanophyta, *Pediastrum* and *Oocystis* of the Chlorophyta, and *Ceratium hirudinella* and *Peridinium* of the Pyrrophyta were the most characteristic organisms. As reported by many authors, starting from Hutchinson (1957), these species are usually found in eutrophic environments and thus commonly used as indicators of eutrophication. Details pertinent to the assessment of the effectiveness of various eutrophication control alternatives in the KDR are given elsewhere (Soyupak *et al.*, 1997).

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