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Trophic Status and Primary Production in Lake Choghakhor, Chaharmahal-Bakhtiyari Province, Islamic Republic of Iran

[1]R. Mousavi Nadushan and [2]S.M. Reza Fatemi
[1]Department of Fishery, Marine Science and Technology Campus,
Islamic Azad University, Darband, Tehran, Iran
[2]Science and Research Campus, Faculty of Marine Science and Technology,
Islamic Azad University, Hesarak, Tehran, Iran

Abstract: In this study, trophic state indicators, total phosphate, algal chlorophyll and Secchi disk transparency and zooplankton community of Lake Choghakhor was studied monthly between May 2003 and April 2004. This lake is a shallow ecologically and economically important water body in eastern part of Iran. Crop farming and recreational activities are examples of the human impact around and within the lake, leading to a loading of DIN (Dissolved Inorganic Nitrogen) and TP (Total Phosphate) into the lake. Now submerged plants especially *Myriophyllum spicatum* has covered almost the entire lake and dense macrophyte beds (*Polygonom amphibium*), located on the East Southern end of the lake appear to act as a sink for these nutrients. Lake Choghakhor appeared to be in a macrophyte dominated clear water state with low TP (annual mean: 24± 15 μg L^{-1}) and chlorophyll a (annual mean: 3±1.28 μg L^{-1}) concentrations and very high Secchi depth. The grazing pressure of dominant pelagic filtering zooplankton *Daphnia longespina* did not seem to be significant in determining the low phytoplankton crop expressed as chlorophyll a. We expect that sequestering of nutrients by submerged plants and associated epiphytes are the dominant stabilizing mechanisms suppressing the phytoplankton crop of Lake Choghakhor.

Key words: Lake Choghakhor, shallow lake, Chl a, total phosphate, submerged macrophytes, filtering zooplankton

INTRODUCTION

The primary productivity of shallow lakes is characterized by mixed populations of phytoplankton and submerged aquatic vegetation in the open water, fringed by various species of emergent vegetation. Research in other parts of the world has indicated that the relative proportion of submerged macrophyte and phytoplankton depends on nutrient loading, water depth, basin slope and size and herbivore (Wetzel, 2001). Some shallow lakes appear to be dominated by submerged aquatic vegetation, whereas other appears to be dominated by dense phytoplankton blooms (and little submerged macrophyte), a finding that has been labeled alternative stable states (Scheffer, 1997). According to this theory at low nutrient levels phytoplankton becomes nutrient limited, which leads to clear water and dominance of macrophytes. At high nutrient levels, phytoplankton dominance will lead to insufficient light for submerged macrophytes and a stable turbid state. At intermediate nutrient levels, however, either macrophytes or phytoplankton can dominate and shifts between the two states are possible. A clearwater state is largely characterized by submerged plants and sufficient piscivorous fish (e.g., Pike and predatory Perch) biomass to extent strong control on planktivorous fish (e.g., Bream, Carp, Roach, Tench) enabling zooplankton (e.g., *Daphnia*) to control phytoplankton and snails to control epiphytes on the plant surfaces (Jeppesen *et al*., 1997; Moss *et al*., 1998; Scheffer, 1997). Nutrient uptake (Wetzel, 2001), reduction of sediment resuspension, improving conditions for micro-macro invertebrate epiphyton filtrates (Cottenie *et al*., 2001), enhancement of denitrification (Perrow *et al*., 1997) may also contribute to the effect of aquatic macrophytes on water clarity. The growth of submerged aquatic macrophytes may be limited by lack of light due to high turbidity (from phytoplankton) (Jeppesen *et al*., 1998), lack of light due to water depth (Moss *et al*., 1994), or low nitrogen (Carpenter *et al*., 1998). Nutrient loading (bottom-up control), predatory fish and invertebrates (top-down control), climatic events (flood/drought), or some combination of external and internal factors may regulate these alternative states

Corresponding Author: R. Mousavi Nadushan, Department of Fishery, Marine Science and Technology Campus, Islamic Azad University, Darband, Tehran, Iran

(Scheffer *et al*., 2001). A change in abundance of fish has been credited with changing the trophic state of shallow lakes (Jeppesen *et al*., 2000; Zimmer *et al*., 2001; Tátrai *et al*., 2003). The role of fish can be particularly large in shallow lakes, because the biomass of fish per cubic meter of water is higher in shallow lakes than in deeper lakes (Jeppesen *et al*., 1997) and because they have access to alternative food resources that may facilitate the top-down control of zooplankton.

Lake Choghakhor used to be a natural wetland known for its reed mats. In 1991 an earthen dam was constructed at the exit canal of the lake increasing its depth and turning it into a permanent shallow lake. Subsequently, Regional Fisheries Office stocked the lake with Chinese carp species mainly with *Cyprinus carpio*, *Hypophthalmichthys molitrix* and *Ctenopharyngodon idella* for a few years. It is regarded as a wetland by the Department of the Environment because of its natural importance mainly high diversity of aquatics and also a wintering site for waterfowls and migratory birds. Lake Choghakhor is an important ecosystem in the region. It has a great recreational value and also supports waterfowl, local agriculture, tourism and fisheries. In spite of these importance and a few exemptions, there is great deficiency towards the water chemistry and biological aspects. The early studies before construction of the dam indicates that the lake was not entirely covered by macrophytes and their extension was restricted mainly to the littoral belt dominating by *Juncus* (Bagheri, 1997). Today, the lake is completely dominated by submerged aquatic vegetation making great problem for the recreational and fisheries activities. The present study, part of a comprehensive project covering all environmental, biological and socio-economical aspects, aimed to carry out through limnological study in order to draw a clear picture about the prominent environmental conditions, trophic status and primary production of the lake.

MATERIALS AND METHODS

Site description: Lake Choghakhor is located in eastern part of Iran (31°, 54´-31°, 56´N; 50°, 40´-56°, 14´E) Chaharmahal - Bakhtiyari Province and is about 2300 m above sea level. It is a shallow lake (mean depth = 2.5 m) and occupies an area of 14 km^2. The total volume of water varies between 25×10^6 m^3 in summer and 35×10^6 m^3 in winter. This lake surrounded by 8 small villages, agriculture and livestock main activities. The runoff of agricultural lands ends into the lake. There are also about 5 considerable permanent springs' originations from calcareous mountains to the south (Fig. 1). The predominant climate of the area is Mediterranean with very cold winter and mild summers (-20 and 30°C) with an annual precipitation of 800 mm (Annual Statistic of the Country, 2003).

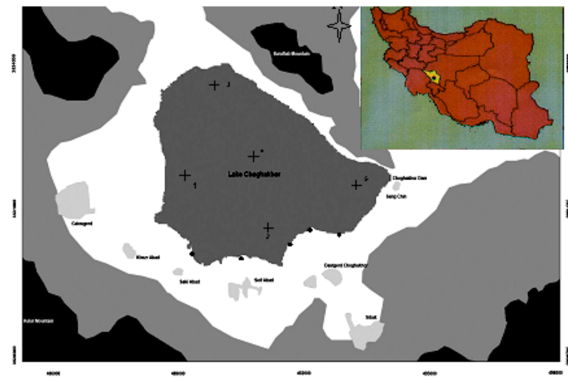

Fig. 1: Schematic map of Lake Choghakhor (not to scale) with the 5 sampling stations(shown as+) and locations of inflows(shown as) and outflow (dam). Station 5 is the deepest part of the lake

Five stations of Lake Choghakhor were sampled monthly from May 2003 to April 2004. Sampling was not done for two months, November and February, because of weather and freezing problem. Water samples were collected by using Ruttner hydrobiological water sampler of 2 L capacity. Water samples for chemical analysis were taken at surface and for physical analysis in two depths (surface and bottom).

Sites were selected to represent different hydrodynamic environment and different diversity and density of submerged macrophytes. Analytical procedures for the chemical analysis were done according to APHA (1992). Water temperature and dissolved oxygen were measured with a YSI 57(Yellow Springs Instruments) digital oxygenmeter. Water transparency was estimated using a Secchi disk. Samples for chlorophyll analysis were filtered onto Whatman GF/F filters within 24 h of collection. Chlorophyll was extracted in 95% acetone and analyzed with a spectrophotometer at 750, 665 and 649 nm. (APHA, 1992).The Chl a concentration was used as a proxy for phytoplankton biomass. The ratio of biologically available nitrogen (NH_4^+, NO_3^-) to biologically available phosphorus (SRP) was calculated to provide an estimate of nutrient limitation (Redfield ratio).

At least 30 L of water was sampled for zooplankton. Samples were collected by polyethylene tube and 45 µm mesh-size nylon plankton net. The samples for identification were stored in a 4% formaldehyde solution until microscopic - stereoscopic counting (Smith, 2001).

Table 1: Physical-chemical data of Lake Chaghakhor, May 2003-April 2004

		Year										
		2003							2004			
		Month										
Properties		M	J	J	A	S	O	D	J	M	A	Mean± SD
Temp. (°C)	s	15.5	18.60	26.00	21.90	19.00	15.30	4.48	3.00	8.46	11.50	14.370±7.478
	b	15.0	17.50	20.00	19.60	17.60	14.20	4.20	4.00	8.40	11.50	13.200±5.9709
DO (mg L^{-1})	s	8.2	9.50	9.90	10.00	9.25	9.16	9.80	11.20	11.15	10.30	9.842±0.9006
	b	8.0	9.00	9.00	9.10	8.80	8.90	9.50	11.20	11.10	10.30	9.490±1.0461
Secchi depth (m)		1.5	3.40	3.00	3.00	3.00	3.20	2.00	2.00	0.90	1.20	2.320±0.911
pH	s	-	8.72	9.68	9.51	9.28	9.18	8.77	8.42	8.35	8.37	8.028±0.508

s: Surface, b: Bottom

RESULTS

Lake Choghakhor did not undergo stable thermal and oxygen stratifications and lake water was mixed throughout the study. The surface water temperature varied from 3°C (in January) to a maximum of 26°C (in July) and bottom temperature followed the same variation (i.e., from 4°C in January to 19.6 in July) (Table 1). A weak thermal stratification was noticed from June through October while the water mixing began early in autumn. The lake's mixing regime is polymictic.

Dissolved oxygen in surface waters fluctuates between 8.2 and 11.2 mg L^{-1}, appearing the minimum values through the warm period (Table 1). Diurnal stratification was measured throughout the late spring and summer, while the water column was isothermal in winter (Table 1). The maximum concentration, 11.2 mg L^{-1} was recorded in January during the isothermal conditions. Decomposition processing and sediment oxygen demand were sufficient to cause lower dissolved oxygen values, near-bottom, from June to October (Table 1).

Secchi-disk transparency varied between 0.9 and 3.4 m through the year (Fig. 2). The highest value (summer) may be related to low phytoplankton biomass, while there was low seasonal variability throughout the year. The Secchi depth was found to be the minimum in early spring and winter when submerged plants were absent (Fig. 2).

There was a significant inverse correlation between transparency and Chlorophyll *a* concentrations. Annual mean Chlorophyll *a* concentration was 3±1.28 µg L^{-1} and the Chlorophyll *a* concentrations were ≤3 µg L^{-1} throughout the summer (Fig. 2).

In Lake Choghakhor, the annual mean of total phosphorous (TP) and soluble reactive phosphorous (SRP) concentrations were 24±15 and 8±7 µg L^{-1}, respectively that the concentrations were lower throughout the summer than in spring and winter (Fig. 3a). Concentrations of TP had a seasonal range of 0.007 ~ 0.03 mg L^{-1} and exhibited higher values during the spring and winter.

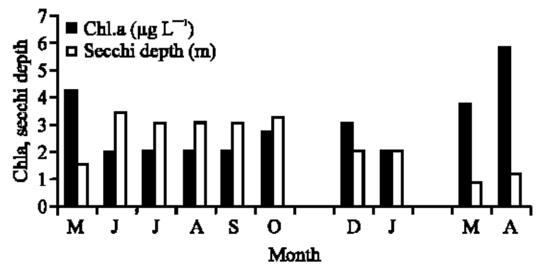

Fig. 2: Fluctuations in Chlorophyll a concentration in Lake Choghakhor, May 2003-April 2004

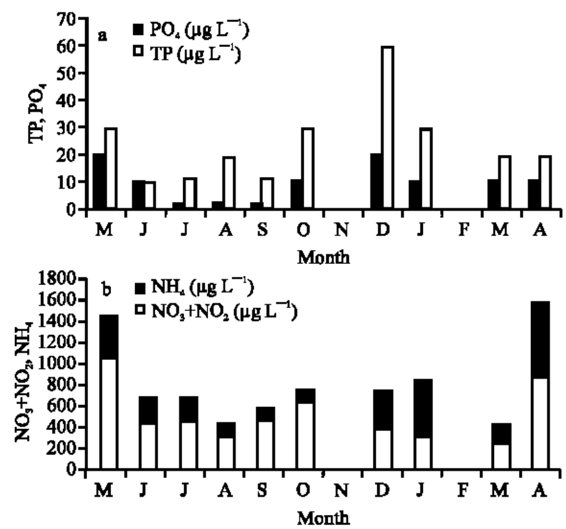

Fig. 3: Changes in (a) soluble reactive phosphorous (SRP) and total phosphorus (TP) and (b) dissolved inorganic nitrogen (DIN) concentrations of Lake Choghakhor, May 2003-April 2004

The annual mean DIN concentration, which is the sum of the nitrite, nitrate and ammonium concentrations, was 670 µg L^{-1} (Fig. 3b). Of the two forms of inorganic nitrogen analyzed, NO_3+NO_2-N was dominant, with an annual mean of 508 µg L^{-1} and the concentrations peaked in spring (Fig. 3b). The NH_4-N concentrations were low (annual mean: 160 µg L^{-1}) during (throughout) the

Table 2: Density of large bodied zooplankton (ind L^{-1}) in Lake Choghakhor, May 2003-April 2004

	Year										
	2003							2004			
	Month										
Species	M	J	J	A	S	O	D	J	M	A	Mean±SD
Cladocera											
Daphnia longespina	2.7	3.2	1.1	-	-	-	-	-	3.2	7.0	1.7
Chydorus sphæricus	1.6	1.4	1.9	1.0	2.2	6.2	6.6	0.5	1.0	3.0	2.5
Bosmina longirostris	0.7	0.7	0.9	-	0.4	-	-	-	0.6	-	0.4
Copepoda											
Cyclops sp.	1.0	1.0	2.5	1.3	2.6	7.1	6.8	1.1	1.7	2.1	2.7

sampling period except December and January 2003 (maximum: 560 μg L^{-1}), which coincided with rotting of the submerged plants (Fig. 3b).

Large-bodied filtering zooplankton: In Lake Choghakhor, the densities of Cladoceran zooplankters were low and the following genera were recorded: *Daphnia longespina*, *Bosmina longirostris* and *Chydorus sphaericus*. The density of *D. longespina* were very low during the study period and a small increase was recorded in spring 2003 (7 ind L^{-1}) (Table 2). The density of *Chydorus* was also low, but it was observed throughout the sampling period, with an increase in summer and autumn (6.6 ind L^{-1} in December 2003). The density of *Bosmina* was insignificant being lower than 1 ind L^{-1} during the sampling period. The Calanoid Copepod *Cyclops* sp. was the dominant copepod in Lake Choghakhor. However, the density of *Cyclops* was also low (2.7 ind L^{-1}) throughout the sampling period, with an increase in autumn (7.1 ind L^{-1} in October, 2003).

DISCUSSION

Nutrient availability, particularly of phosphorous (Schindler, 1978) determines potential phytoplankton biomass, while the grazing rate of zooplankton determines how much of this potential realized (Schriver *et al*., 1995). At low nutrient levels (<50 μg TP L^{-1}) phytoplankton becomes nutrient limited, which leads to clear water and dominance of macrophytes. In this situation if P/N>>10, a decline in macrophyte species diversity and dominance of nutrient tolerant species occurs and subsequently the most abundant species will be tolerant and canopy forming species like *Myriophyllum spicatum* and *Potamogeton pectinatus* (Korner, 2002). At high nutrient levels, (>100 μg TP L^{-1}) phytoplankton dominance will lead to insufficient light for submerged macrophytes and a stable turbid state. At intermediate nutrient levels (50-100 μg TP L^{-1}), however, either macrophytes or phytoplankton can dominate and shifts between the two states are possible (Scheffer *et al*., 1993; Korner, 2002; Bachman *et al*., 2002).

According to nutrients and Chlorophyll a concentrations measured during this study, Lake Choghakhor is classified as oligo-mesotrophic lake (Vollenweider and Kereks, 1982; OECD, 1982). The ratio of DIN/SRP (where DIN = NO_3^- + NH_4^+, NO_2^- was found negligible) reflects the limiting factor, controlling the primary production (Reynolds, 1984). In our case, this ratio was greater than Redfield ratio of 16, suggesting a phosphorous limitation (the ratio ranged between 50-500 with a mean value of 227).

Although there was not sufficient information about the trophic status of the lake Choghakhor, the results of this study revealed that this lake with low TP (annual mean: 24 μg L^{-1}) and Chlorophyll a concentrations (annual mean: 3 μg L^{-1}), very high Secchi depth (found to be the bottom) and submerged plants (*Myriophyllum spicatum)* covering almost the entire lake is in a pristine condition, macrophyte dominated clear water state.

Myriophyllum spicatum is a highly competitive freshwater macrophyte that produces and releases algicidal and cyanobactericidal polyphenols but existence of allelopathy has been a subject of ongoing debate, since its significance under field conditions is still too poorly evidenced (Gross, 2003). Therefore in Lake Choghakhor luxury nutrient uptake by submerged plants as well as associated epiphytes may impose nutrient limitation on phytoplankton (Wetzel, 2001).

The increased grazing by pelagic zooplankton hiding in macrophytes during daytime (Søndergaard and Moss, 1998), as well as the grazing by macrophyte-associated zooplankton species (Lauridsen and Buenk, 1996), has been often considered among the most important factors controlling phytoplankton biomass in macrophyte dominated lakes (Schriver *et al*., 1995; Jeppesen *et al*., 1998). In Lake Choghakhor density of large bodied grazer *Daphnia longespina* (2 ind L^{-1}) was low throughout summer. In this lake, carp and tench were found to spawn from May to August and their diet largely involved Cladocera, especially *Daphnia* (Søndergaard *et al*., 1990). The entire coverage of observed submerged plants and high densities of juvenile fish schooling in the lake (personal observation) throughout the summer might have led to the very low densities of the large grazers. Plant-associated cladocerans, less vulnerable to fish predation than pelagic species, can have high grazing impact on phytoplankton (Jeppesen *et al.*, 1998; Balaya and Moss, 2004). Chydorids scrape on epiphytic algae and are considered less effective (Lövgren and Persson, 2002). In Lake Choghakhor *Chydorus sphaericus* as a plant associated grazer was observed in all samples, especially when the density of *Daphnia* was minimum. The biomasses of *Chydorus sphaericus* increased with macrophytes and were likely even higher than observed, since water sampling underestimated the numbers of plant associated species (Vakkailainen and Kairesalo, 2005).

Submerged plants are thought to negatively affect phytoplankton crops in the temperate zone by a number of mechanisms, including nutrient and light limitation. Macrophytes may reduce turbidity by both sequestering algal growth-limiting nutrients and by restricting turbulent resuspension of bottom deposits (Hamilton and Mitchel, 1996). Lake Choghakhor is a large shallow lake with open wind induced resuspension and strong winds in late autumn, winter and spring. In the absence of submerged plants, powerful upward flux of nutrients in the lake, caused mainly by resuspension, could enhance phytoplankton growth in March and April 2003-2004 ($5.8\ \mu$ Chl. a L^{-1}).

In Lake Choghakhor the growth and dominancy of macrophytes has been increasing for the last 10 years, so resulting more or less into the coverage of the whole lake nowadays. Recent climate trends with periodic (droughts and) lowering of water tables (especially in summer) may foster shallow water favoring submerged plants. Studies have suggested that macrophytes will become established within a few months, even for short time, if propagules are readily available (Perrow *et al.*, 1997). Another factor that might have been significant in the expansion of the submerged macrophytes is the lack of grass carp (0.3%), which is the case with this lake after the release of this species, was stopped.

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