Trophic relations in two lakes from the Bulgarian Black Sea coast and possibilities for their restoration

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Abstract Based on quantitative data on nutrients, light penetration, phytoplankton, zooplankton and zoobenthos obtained in the period 1992–1994 the relations between trophic levels were studied by means of statistical analysis. The two lakes are distinguished by relatively high transfer efficiency between phytoplankton and zooplankton, which depends on the size distribution among zooplankton and percentage of blue-green algae. The bottom up influence seems to prevail over the top-down influence, water surface area and phosphorus load are large, and mean depth is more than 1 m. All this let us conclude that biomanipulation measures alone are not sufficient for a substantial lake restoration.
Keywords Lake restoration; nutrients; phytoplankton; trophic relationships; zooplankton

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Introduction

Our previous publications on the trophic state of some Bulgarian coastal lakes showed eutrophication proceeding in most of them during the last four decades. The lakes are important with their fresh water and fish resources; some shelter endemic species or protected migrating birds. From both the economic and conservation point of view the recent eutrophic or even hypereutrophic levels should be lowered to a more acceptable status. One alternative to achieving this goal would be the biological manipulation of lake trophic interactions, which seems to be a more appropriate means for restoration of protected ecosystems than their chemical treatment. Therefore the investigation of the trophic relationships is necessary to motivate and to guarantee the successful application of biomanipulation as a means for eutrophication reduction. Moreover, there are several Bulgarian coastal lakes with similar trophic status, which have a good potential to recover provided by their strong macrophyte standing crops.

Materials and methods

This paper is based mainly on data published in a separate issue containing the results of a complex study of the Shabla and Ezerets lake system. The two lakes are situated on the northeast Bulgarian Black Sea Coast. Their morphometric and hydrologic characteristics were published by Kalchev and Botev (1999) and in a separate issue in 1998. The lake map (Figure 1) with the isobath lines and location of sampling sites is essential for the understanding of the content of the article. All samples except the primary production samples were taken at stations No 1, 2, 3 and 4. Primary production was measured at station No 5. With 2–3 days of tolerance most of the samples were taken simultaneously on the following dates: 28.05.1992, 14.09.1992, 15.05.1993, 01.11.1993, 05.04.1994 and 24.06.1994. The data are scarce and present a semi seasonal dynamics of spring, summer and autumn values from different years. Water chemistry data were taken from Botev (1998); phytoplankton data from Beshkova (1998); primary production and light extiction from Kalchev (1998); zooplankton from Naidenow (1998); zoobenthos from Stoichev (1998). We retrieved biomass, numerical abundance and taxonomic composition data of the trophic levels and used them to calculate the average individual weight (AIW) of phytoplankton, zooplankton and zoobenthos by dividing the biomass through numerical abundance. We also calculated the ratio of zooplankton biomass and phytoplankton biomass ($B_{zp}B_{ph}^{-1}$) and used it as characteristic of the transfer efficiency between them. The production to biomass ratio ($P\ B_{ph}^{-1}$) of the photic zone phytoplankton was calculated by assuming the carbon content to be 10% of B_{ph} and net primary production – 60% of gross primary production. By multiplying the net production by 0.375 we converted it to carbon. For all variables we calculated arithmetic means (AM), geometric means (GM), and standard deviations (σ). Further t-test (for paired or independent samples), Spearman's rank (R_{Sp}) and Parson's (R_P) parametric correlation coefficients and also the linear regression model 1 and non-linear regression (see Weber, 1972) were applied.

Results and discussion

Comparisons of sampling station means

The first four sampling stations (Figure 1) could be compared in two ways: first, Nos 2, 3 have an open, deep water, more pelagic character, while Nos 1, 4 are more shallow, shore and macrophyte influenced; second – according to the respective lake the stations characterize. This correspondence makes it possible to apply the paired t-test, which is more sensitive. The ecological character of the conclusions justifies the application of a lower significance level ($P < 0.1$) than the standard $P < 0.05$. In many cases the comparisons in

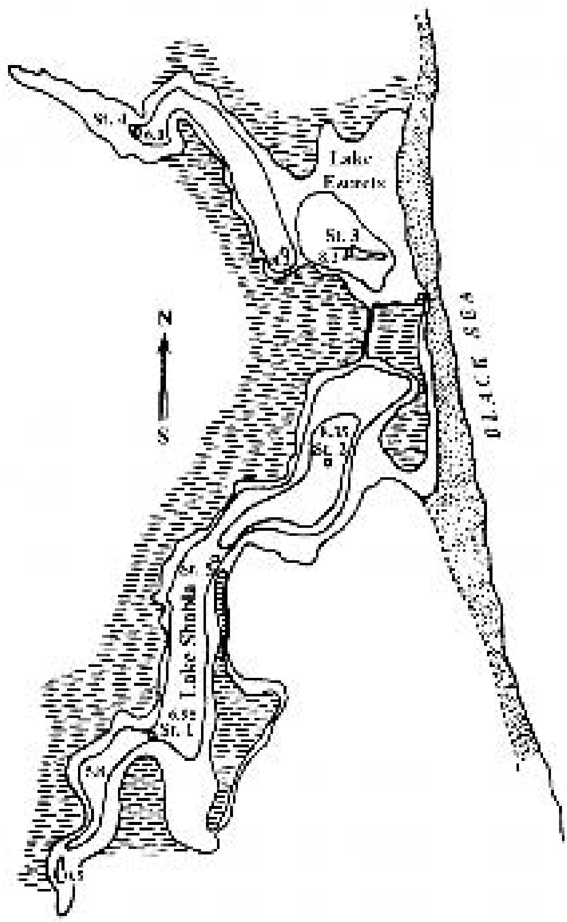

Figure 1 Lake map with depths (m) and sampling site location

Table 1 reveal weak or no significant differences, which allows pooling the data of the two lakes and carrying out correlation and regression analysis on the next stage of investigation. Differences between the lakes prevail on the level of nutrients and light energy. The significantly higher PO_4^{3-} – P of Shabla Lake makes it more nitrogen limited than the Ezerets Lake (Kalchev, 1998). The zoobenthos biomass (B_{zb}) is higher at the shore influenced than at the pelagic stations, while the B_{ph} and B_{zp} do not show any significant differences between these stations. The Ezerets Lake appears to be more productive, with higher values of all three biomasses than the Shabla Lake. The $B_{zp}B_{ph}^{-1}$ ratio is significantly higher at the pelagic stations than at the macrophyte influenced stations and shows no difference between the lakes. The AMs of the ratio are higher than 1. Usually, this ratio ranges between 0 and 1 (Hillbricht-Ilkowska, 1977; Havens, 1998; Lacroix *et al*., 1999). Approximately the same values as the GM are obtained by dividing the means of B_{zp} by the means of B_{ph} (Table 1).

Although in some cases extremely wide ranging absolute values are obtained, the $B_{zp}B_{ph}^{-1}$ ratio appears to be very useful to evaluate the relationships between the transfer efficiency and other variables. The higher ratio registered at the pelagic than that at shore stations is supported by a significantly higher AIW_{zp} at the pelagic stations. This is in accordance with the statistically significant correlation between $B_{zp}B_{ph}^{-1}$ and AIW_{zp} (Figure 3).

Table 1 Comparisons between pelagic and macrophyte influenced sampling sites and between Shabla and Ezerets lakes by t-test for paired and independent samples. The following variables are included: $\sum N$ – sum of inorganic soluble nitrogen compounds; PO_4^{3-} – P phosphate phosphorus; N P^{-1} – nitrogen to phosphorus ratio; r.u. – relative units; Ext – extinction coefficient of photosynthetically active sun radiation; B_{ph}, B_{zp}, B_{zb} – biomasses of phytoplankton, zooplankton and zoobenthos; $B_{zp}B_{ph}^{-1}$ – ratio of zooplankton and phytoplankton biomasses; AIW_{ph}, AIW_{zp}, AIW_{zb} – average individual weight of phytoplankton, zooplankton and zoobenthos; underlined probability level values stress the availability of significant differences. For the other symbols see Material and Methods

Variables and statistics		Sampling stations		Probability level, t-test		Lakes		Probability level, t-test	
		Pelagic	Macrophyte influenced	Paired samples	Independent samples	Shabla	Ezerets	Paired samples	Independent samples
$\sum N$,	AM	0.698	0.698	0.71	> 0.1	0.555	0.802	0.13	> 0.1
[mg m^{-3}],	σ^2	0.343	0.161			0.09	0.38		
PO_4^{3-} P,	AM	0.525	0.479	0.61	> 0.1	0.509	0.415	0.09	> 0.1
[mg m^{-3}],	σ^2	0.070	0.024			0.024	0.025		
NP^{-1},	AM	3.900	3.4	0.45	> 0.1	2.62	4.67	0.0222	0.08
[r.u.],	σ^2	12.200	5.02			2.86	12.25		
Ext,	AM	1.781	1.96	0.17	> 0.1	1.750	1.990	0.069	> 0.1
[r.u.m^{-1}]	σ^2	0.297	0.199			0.245	0.237		
B_{ph},	AM	3.160	4.04	0.22	> 0.1	2.620	4.400	0.180	> 0.1
[g m^{-3}],	σ^2	4.190	12.06			9.02	7.33		
B_{zp},	AM	3.070	2.72	0.579	> 0.1	2.100	3.640	0.004	0.036
[g m^{-3}],	σ^2	7.620	8.67			5.060	10.150		
B_{zb},	AM	8.230	11.7	0.076	> 0.1	8.460	11.470	0.099	> 0.1
[g m^{-2}],	σ^2	38.130	50.73			51.400	39.000		
$B_{zp}B_{ph}^{-1}$	AM	2.287	1.781	0.054	> 0.1	2.070	2.000	1.900	> 0.1
[r,u],	σ^2	7.060	4.88			5.070	7.000		
	G M	0.750	0.89			0.830	0.810		
AIW_{ph},	AM	1.010	1.02	0.91	> 0.1	0.9	1.14	0.32	> 0.1
[mg ind^{-1}]	σ^2	0.155	0.219			0.2	0.18		
AIW_{zp},	AM	7.290	5.51	0.00552	> 0.1	5.31	7.49	0.048	> 0.1
[mg ind^{-1}]	σ^2	25.000	10.75			9.3	25.6		
AIW_{zb},	AM	6.350	11.93	0.096	0.088	9.9	8.37	0.64	> 0.1
[mg ind^{-1}]	σ^2	14.550	102.4			112.2	20.56		

The size of individuals of different trophic levels is especially important as an element of the so-called size spectra. They are very useful especially when the quantitative data are rare (Sprules *et al.*, 1991). Unfortunately in our case only the average values of individual size, not the full size spectra are available.

The zoobenthic organisms are significantly larger at the macrophyte-influenced than at the pelagic stations. Probably the zoobenthos finds more food and better opportunities to escape the fishes near to the macrophytes than far, from them. The zooplankton of the pelagic stations is significantly larger than that on the macrophyte shore stations probably due to the stronger fish press on the shallower stations (Lacroix *et al.*, 1999). Another explanation might be that usually the phytophilous zooplankton is smaller than the pelagic. The size of Ezerets zooplankton is significantly larger than that of Shabla zooplankton and it is of approximately the same value as the zooplankton size at the pelagic stations.

Relationships at the food chain's bottom

Figure 2A demonstrates a statistically significant, positive relationship between nitrogen concentration as a limiting factor in Shabla Lake and B_{ph}. The phosphorus neither correlated with B_{ph} nor in Shabla or in Ezerets. The light penetration in the water column presented by the Ext correlates with the B_{ph} being stronger than the nitrogen (Figure 2B). No doubt in this relationship the dependent and independent variables can change their places because they exert a mutual influence. In Shabla Lake the phytoplankton P B_{ph}^{-1}depends inversely on the extinction (Figure 2D). This means that the phytoplankton is light limited by self-shading. The same is very probable for the Ezerets Lake, where the extinction is significantly higher and the B_{ph} has the same value as in Shabla Lake. The Ext also correlates with the $B_{zp}B_{ph}^{-1}$ ratio. This relationship is highly statistically significant in both lakes and for both pelagic and macrophyte influenced stations. The B_{zp} and AIW_{zp} do not correlate significantly with the light extinction. The $B_{zp}B_{ph}^{-1}$ ratio correlates significantly but moderately with AIW_{zp} (Figure 3A). This relationship remains statistically significant for P =

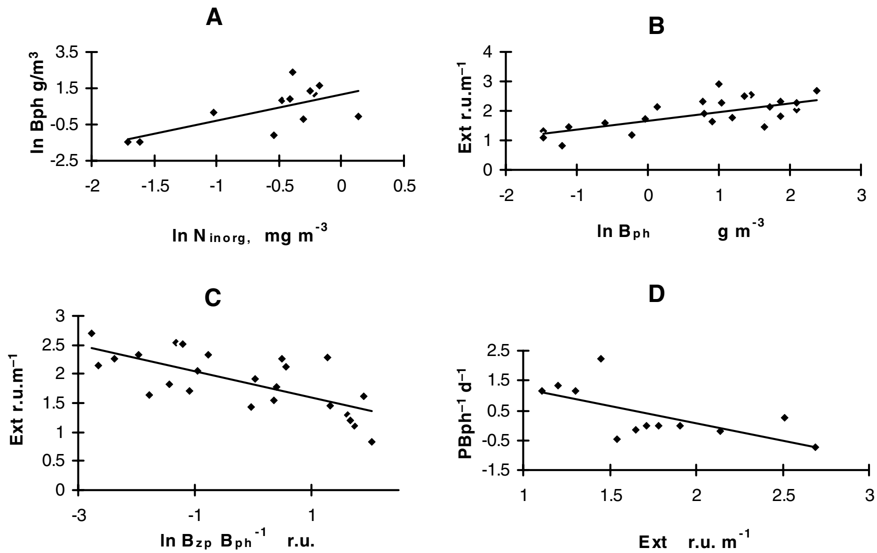

Figure 2 Relationships between: A – sum of inorganic soluble nitrogen and phytoplankton biomass (B_{ph}) in Shabla Lake ($R_{Sp} = 0.606$, $R_P = 0.664$, $P = 0.018$); B – B_{ph} and extinctions coefficient (Ext) in both lakes ($R_{Sp} = 0.599$, $R_P = 0.678$, $P = 0.00027$); C – transfer efficiency $B_{zp}B_{ph}^{-1}$ and Ext in both lakes ($R_{Sp} = -0.669$, $R_P = -0.691$, $P = 0.00018$); D – Ext and production to biomass ratio (P B_{ph}^{-1}) in Shabla Lake ($R_{Sp} = -0.636$, $R_P = -0.651$, $P = 0.022$) ; critical values of $R_{Sp\,(0.05\ 12)} = 0.506$ and $R_{Sp(0.05\ 24)} = 0.343$

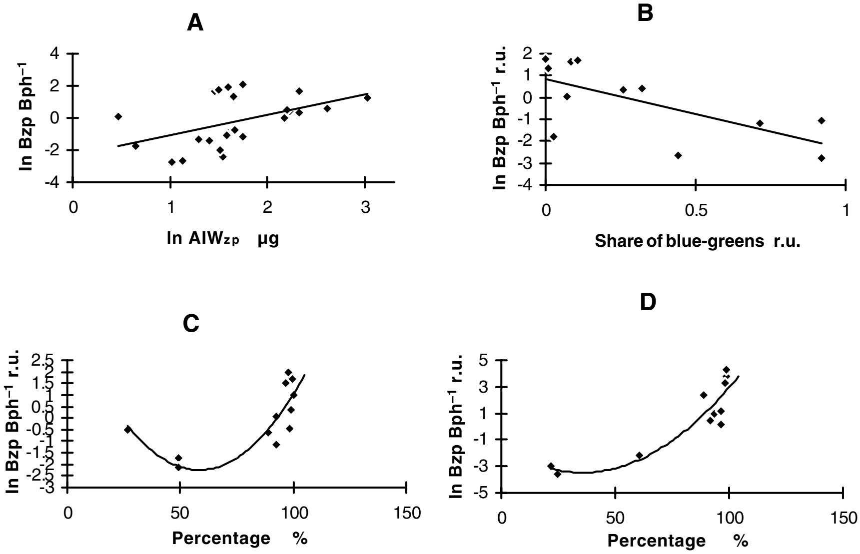

Figure 3 Relationships between: A – zooplankton average individual weight (AIW_{zp}) and zooplankton to phytoplankton biomass ratio ($B_{zp}B_{ph}^{-1}$) in Shabla and Ezerets lakes ($R_{Sp} = 0.514$, $R_P = 0.478$, $P = 0.018$); B – Cyanoprokaryota biomass share and $B_{zp}B_{ph}^{-1}$ in Shabla Lake ($R_{Sp} = -0.601$, $R_P = -0.675$, $P = 0.016$); C – biomass percentage of the zooplankton with largest AIW and $B_{zp}B_{ph}^{-1}$ in both lakes ($R_{Sp} = 0.748$, $R = 0.822$, $P < 0.01$); D – biomass percentage of the sum of Cladocera and Copepoda and $B_{zp}B_{ph}^{-1}$ ratio in Dourankoulak Lake ($R_{Sp} = 0.864$, $R = 0.902$, $P < 0.01$); critical values of $R_{Sp\ (0.05\ 12)} = 0.506$ and $R_{Sp(0.05\ 24)} = 0.343$

0.05 at the pelagic stations and in Ezerets Lake where the zooplankton size is also statistically higher (Table 1) than at the macrophyte influenced stations and in Lake Shabla. In the latter cases the AIW_{zp} does not correlate with $B_{zp}B_{ph}^{-1}$. The Cyanoprokaryota predominates the phytoplankton (only in Shabla) and this is coupled with the lack of a significant relationship between $B_{zp}B_{ph}^{-1}$ and AIW_{zp}. All this suggests that the bottom-up influence in both lakes (especially in Shabla) might be stronger than the top-down influence.

Variables influencing the $B_{zp}B_{ph}^{-1}$ ratio

This ratio correlates significantly with AIW_{zp} (Figure 3A) and does not correlate with the phytoplankter size (AIW_{ph}) in Shabla and Ezerets lakes. However, in Dourankoulak Lake the correlation between AIW_{ph} and $BM_{zp}BM_{ph}^{-1}$ is statistically significant and positive ($R_{Sp} = 0.594$, n = 12). Maybe this is due to the fact that the AIW_{ph} values in Shabla and Ezerets are considerably smaller and they vary within a narrower range than those in Dourankoulak (Table 2). One of the reasons for the small AIW_{ph} might be the supposed quick disintegration of bundles into filaments (e.g. Aphanizomenon sp.) after the formalin fixation. Another variable, which correlates with the transfer efficiency, is the share of Cyanoprokaryota from the total BM_{ph}. Figure 3B demonstrates a significantly negative relationship between both variables in Shabla Lake where Cyanobacteria frequently and strongly predominated (about 44%, see Kalchev and Botev (1999)). However, in Ezerets Lake where the blue-green percentage was considerably lower (6–7%) it correlated positively with $B_{zp}B_{ph}^{-1}$ ($R_{Sp} = 0.524$, n = 12). Unfortunately, the data of Saiz (1981) on the blue-greens of Dourankoulak Lake are not suitable for such a comparison. The $B_{zp}B_{ph}^{-1}$ ratio of both lakes neither correlates with the biomass percentage of Cladocera, nor with that of Copepoda or with the sum of both: the transfer efficiency between zooplankton and phytoplankton correlates with biomass percentage of a taxonomic group or sum of groups, which have distinctly larger individuals (Figure 3C). Thus, in September 1992, we summed up Rotatoria and Copepoda, which had AIW of 10.22 μg.ind^{-1} and 7.11 respectively, while the AIW of Cladocera amounted only to 3.4 μg.ind^{-1}. In May 1993 we used only the percentage of Copepoda because its AIW was 5.63 while those of Rotatoria and Cladocera amounted to 1.33 and 1.31 μg.ind^{-1} respectively. The literature information on taxonomic structure of zooplankton and data used for calculating $B_{zp}B_{ph}^{-1}$ in Dourankoulak Lake are available only as means of single visits, different seasons and years (Naidenow (1981), Figure 3D), i.e. they are only conditionally comparable with Figure 3C. Figure 3C shows that, relatively high and highest transfer efficiencies are observed when correspondingly small and large individuals dominate. When the small and large individuals abundance is close or equal the $B_{zp}B_{ph}^{-1}$ ratio is lowest probably due to significant influence of predation among zooplankton (Hansson *et al*., 1998). Figure 3D partly confirms Figure 3C.

Figure 3D shows that the sum of percentages of Cladocera and Copepoda involves in most cases the largest zooplankton individuals. Thus the three relationships on Figure 3 show clearly the influence of zooplankton on the transfer efficiency between zooplankton and phytoplankton. Therefore, we can conclude that a top-down influence (a weak or moderate) exists despite the fact that the available B_{ph} and B_{zp} data did not correlate at all.

The last two positive relationships on Figure 4 seem to be a result of the food excess existing at least on the levels of phytoplankton, zooplankton and zoobenthos. The AIW_{ph} does not show any sign of a negative relation with AIW_{zp} – contrary to what is often described in the scientific literature.

Table 2 summarizes some important trophic parameters of the three lakes. Because of the big scattering of primary data we prefer the geometric means (GM). Most of the Dourankoulak literature data are available already averaged and are not statistically comparable with Shabla and Ezerets. BM_{ph} is an exception, which however, shows no

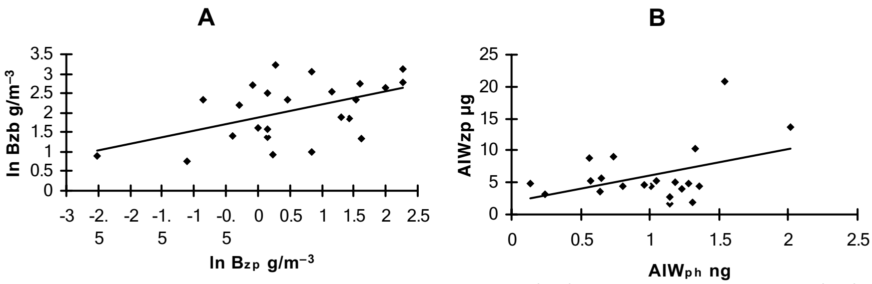

Figure 4 Relationships between: A – biomass of zooplankton (B_{zp}) and biomass of zoobenthos (B_{zb}) ($R_{Sp} = 0.493$, $R_P = 0.505$, $P = 0.012$); B – average individual weight of phytoplankton (AIW_{ph}) and of zooplankton (AIW_{zp}) ($R_{Sp} = 0.315$, $R_P = 0.445$, $P = 0.03$); critical value of $R_{Sp\,(0.05\,24)} = 0.343$

Table 2 Selected data of Shabla, Ezerets and Dourankoulak lakes presented by their geometric means(GM); n – number of samples; for the other symbols see Table 1

Variables and statistics		Lakes		
		Shabla	Ezerets	Dourankoulak
B_{ph}, [g m^{-3}]	GM	1.40	3.15	1.04
	n	12	12	12
AIW_{ph}, [mg ind.$^{-1}$]	GM	0.76	1.06	13.40
	n	12	12	5
AIW_{zp}, [mg ind.$^{-1}$]	GM	4.51	6.44	15.20
	n	12	12	5
$B_{zp}B_{ph}^{-1}$, [r.u.]	GM	0.83	0.81	0.58
	n	12	12	12

significant differences between the lakes. The AIW_{ph} of Dourankoulak is one order of magnitude higher than that of Shabla and Ezerets, however, the $B_{zp}B_{ph}^{-1}$ ratio is the lowest. We did not consider the AM values of $B_{zp}B_{ph}^{-1}$ because of their plausible character due to the extremes as discussed above. The very small size of phytoplankton individuals in Shabla and Ezerets would be an explanation for higher transfer efficiency than in Dourankoulak. Despite some doubts concerning size we have to indicate the good reproducibility of AIW_{ph} during all six samplings (the relatively small values of standard deviation compared to the mean value, Table 1). We suggest that either the algal colonies from all samples decompose quickly and to the same degree despite their very different composition or the AIW_{ph} is really small.

Conclusions

The bottom-up influence seems to prevail over the top-down one in the short stretch of the food chain, consisting of nutrients, light energy – phytoplankton – zooplankton. The average transfer efficiency between phytoplankton and zooplankton is relatively high. This is probably mainly due to the small size of phytoplankton. Despite the permanent small size of phytoplankton the prevalence of blue-greens in Shabla Lake significantly influenced the transfer efficiency. The zooplankton influence seems to be sustained by two factors: availability of only one obligate planktivorous fish species, *Clupeonella cultriventris* (Pehlivanov, 1998) and by the abundant, mainly macrophyte crops which present an appropriate refuge for the zooplankton. Based on a rough estimate by observation (Vassilev, 1998) it could be supposed that the non-piscivorous fishes seem to predominate which is not suitable for development of large zooplankton. Despite that, the predator impact does not seem to be exclusively and regularly directed to zooplankton due to the excess of other food resources, such as large attractive zoobenthic dwellers.

There are arguments "for" and "against" biomanipulation as a tool for lake restoration.

1. "For" biomanipulation: the small size or easily decomposable colonies of phytoplankton individuals, which makes them accessible (edible) by zooplankton; selective fishing of non-piscivorous fishes and introduction of piscivorous fishes (20 kg ha^{-1} recommended as optimum by Wissel *et al.* (2000)) which improves their relative proportions; abundant macrophytes crops and their stimulation to provide more zooplankton refuges, Moss (1990); harvesting of macrophyte in order to reduce the rottenness of the biomass and to remove the nutrients (Galanti *et al.*, 1990); restricted development of blue-greens in Ezerets makes it more suitable for biomanipulation, Reynolds (1994); Daphnia species are available in spring (Naidenow, 1998) and could be enhanced by appropriate measures (Reynolds, 1994).
2. "Against" biomanipulation: high phosphate phosphorus concentrations available (about 1.5–2 $g.m^{-2}$) which are above the level of 0.5–1 $g.m^{-2}$ a^{-1} for a successful biomanipulation (Goutel'makher *et al.*, 1988); the trophic status is estimated as eutrophic or higher while the perspectives for success are good at mesotrophic to eutrophic conditions (Straškraba, 1996); the lakes are too large and too deep: for successful biomanipulation, their area should be < 4 ha and mean depth < 1 m (Reynolds, 1994); the retention time is much higher than 30 days or less (Reynolds, 1994); the blue-green predominance in Shabla Lake makes it inappropriate for biomanipulation (Reynolds, 1994).

The comparison of "for" and "against" shows that the application only of biomanipulation will hardly be successful for the lake restoration. Other additional measures such as restriction of phosphorus fertilizer, excessive use in farming land belonging to the catchment area and an obligatory accompaniment of biomanipulation by phosphorus removal from lakes by non-biological means will be necessary. The recent situation in Shabla and Ezerets is also a result of a growing consumption of lake water for municipal needs. Some measures such as reasonable water prices and prevention of water losses through leakage will lower the water consumption and probably will allow returning to the spring high waters observed frequently in the past.

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