European **M**ountain lake **E**cosystems: **R**egionalisation, dia**G**nostics & socio-economic **E**valuation

Lake District Rila Bulgaria

Ecological Relations in the Pelagial of Nine Glacial Lakes in the Rila Mountains

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Dedicated to the memory of Prof. W.T.Naidenow, an outstanding Bulgarian limnologists and our honoured teacher.

Introduction

The Rila Mountains is the highest mountain on the Balkan Peninsula (Moussala Peak, 2925 m a.s.l.). There are over 140 glacial lakes. The study of morphology, phisico-chemistry and biology of the lakes started in the thirties of the previous century. The first extensive quantitative research in the pelagial of the lakes from the group of the Seven Rila lakes was carried out in the period 1995-1996. Data on water chemistry (including the nutrients), phytoplankton and zooplankton were published by Botev (2000), Beshkova (2000) and Naidenow, Beshkova (2000). These investigations are now continued within the EMERGE project.

The aims of the present study were to identify groups of lakes according to morphometrical, chemical and quantitative plankton variables, to investigate the relations between different ecological variables in the pelagial and to trace the changes in the pelagial in 4 of the lakes in the period 1996-2001.

Description of survey lakes

Three groups of lakes located in different regions (cirques) of the mountain above the conifer tree line were studied. The group of the Seven Rila lakes (Okoto - RI0008, Bubreka - RI0009, Sulzata - RI0010, Bliznaka - RI0011) is located in the north-west part of the mountain, while the groups of Moussalenski lakes (Alekovo - RI0067, Ledeno - RI0070, Karakashevo - RI0071) and Marichini lakes (Dolno Marichino - RI0075, Gorno Marichino - RI0076) - in the central-north part of the mountain.

Lake shores are stony, gravel and sandy, or covered with thin soil layer, overgrown with grass and juniper. Tourist cabins are situated near the lakes and popular tourist routes pass close to the lakes in the three regions. Grazing was observed only in the region of the Seven Rila lakes. The lakes have been stocked regularly for 30 years, more intensively in the past, with brown trout (*Salmo trutta fario* L.) and brook trout (*Salvelinus fontinalis* Mitchill).

Methods

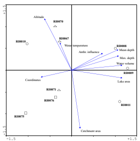
All plankton and chemistry samples were taken at the deepest part of the lakes once a year, during the autumn overturn of years 2000 and 2001. Fishes were caught by gill nets and traps.

All chemical analyses were carried out by application of procedures and suggested methods described by Mosello & Wathne (1997) and Mosello et al. (1997). The bacterioplankton was analyzed by Prof. Straškrabová according to Straškrabová et al.(1999). The chlorophyll-a was extracted in acetone, measured at a spectrophotometer and calculated after Jeffrey & Humphrey (1975). The biovolumes (biomasses) of phytoplankton and zooplankton were obtained as a final result of a preceding profound qualitative sample examination followed by a careful counting and measurements of plankton individuals and cells under microscope according to generally applied routine methodology.

Most of the data were analyzed by CANOCO statistical package for multidimensional analyses. The paired t-test was also applied with Excel package.

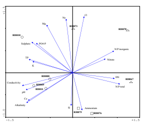
Results

Fig. 1. Correlation and ordination biplot of geographical and morphological variables based on PCA



The first main axis is determined by the variances of the morphological variables. It separates the large and deep lakes (right hand) from the small and shallow lakes (left hand). The second axis orders the lakes along the gradient formed by altitude and catchment area.

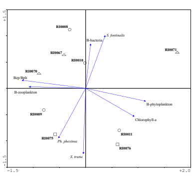
Fig. 2. Correlation and ordination biplot of chemical variables based on PCA



Most vectors of the water chemistry variables are significantly important. The $N.P^{-1}_{total}$ ratio correlates negatively with TP and positively with TN. A positive correlation is observed also between $N.P^{-1}_{inorganic}$ and nitrate nitrogen.

The lake ordination reflects the geographical proximity of the two Marichini lakes (RI0075, RI0076). Three lakes from the group of the Seven Rila lakes (RI0008, RI0009 and RI0011) are also very closely ordinated. Obviously, the highest lake, Sulzata (RI0010), which has a very small catchment area, receives water almost directly from the air and has a different chemistry from the other 3 lakes.

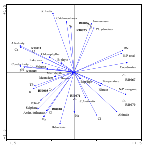
Fig. 3. Correlation and ordination biplot of 8 quantitative biological variables based on PCA



The biovolume of phytoplankton on one hand and the zooplankton biomass and ratio $B_{zp}.B_{ph}^{-1}$ on the other are negatively correlated. This means that the phytoplankton (not bacterioplankton) might be the main food resource of zooplankton, i.e. in these clear, pronounced oligotrophic waters, as expected, the grazing might predominate over the detritus food chain.

A negative correlation between *Phoxinus phoxinus* L. and *S. trutta* on one hand and *S. fontinalis* on the other was observed. Due to the lack of reliable quantitative fish data, the lake ordination seems more reasonable when fish variables are made passive. The first axis separates the lakes into 2 groups: zooplankton rich lakes with a high $B_{zp}.B_{ph}^{-1}$ ratio (RI0008, RI0009, RI0010, RI0067, RI0070) and phytoplankton rich lakes with a high production (RI0071, RI0011). The second axis separates the lakes according to the quantity of bacterial biomass.

Fig. 4. Correlation and ordination biplot of morphological, geographical, chemical and biological variables based on PCA

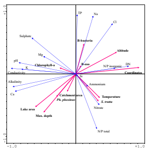


Phytoplankton biomass and chlorophyll-a correlate negatively with the inorganic $N.P^{-1}$, not with total $N.P^{-1}$ ratio. Obviously, the inorganic forms of nutrients are more easily accessible by primary producers. Ammonium and bacterial biomass are negatively correlated, which means that bacterial development might not be involved in the decomposition of nitrogen containing organic materials.

The anthropogenic influence is also negatively correlated with ammonium and probably the ammonium is not released by degradation of allochthonous substances. However, bacteria are to a certain degree a result of anthropogenic influence, which is witnessed by a moderate positive correlation between them.

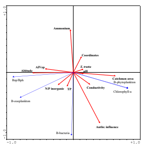
Relations between ecological variables

Fig. 5. Correlation biplot of chemical (dependent) variables with 10 most important morphological, geographical and biological



The altitude, latitude, longitude, surface area and maximum depth have the longest vectors. Although the EV (eigenvalue) of the first axis is not significant (P=0.115 according to Monte Carlo permutation test) the trace is highly significant (P=0.005). Three of the variables have significant t-values: *Ph. phoxinus* (t > 4.0), *S. truta fario* (t ~ 3.5) and altitude (t ~2.9).

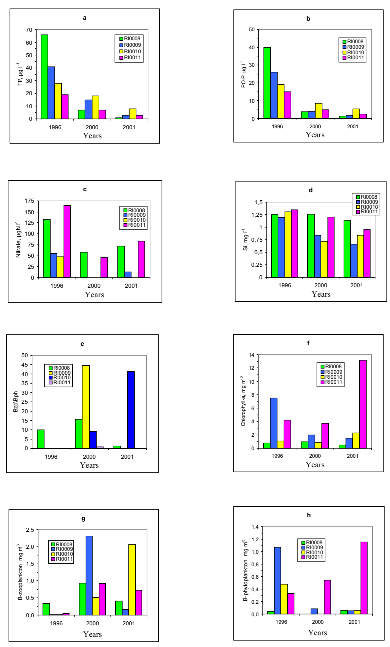
Fig. 6. Correlation biplot of biological (dependent) variables with 10 most important morphological, geographical and chemical (independent) variables based on RDA



Biological variables depend mainly on the anthropogenic influence, altitude and catchment area. From the chemical variables only ammonium has a relatively long vector, followed by one variable of biological nature - average individual volume of zooplankton (AIVzp). None of the variables shows a significant t-value.

However, the percentage of variation explained by the first two axes on Fig.6 is higher than that on Fig.5. The EV of the first axis is close to the significance level (P=0.08) and the trace is highly significant (P=0.005).

Fig. 7. Changes in the pelagial of 4 lakes from the group of the Seven Rila Lakes (RI0008, RI0009, RI0010, RI0011) in the period 1996-2001



A strong decreasing tendency is observed in the amount of phosphorus in the last years. Both PO_4^{3-}-P and TP show a statistically significant decrease even between the years 2000 and 2001 (P=0.0006 and P=0.022). The decrease of PO_4^{3-}-P values is much sharper. We find also significant differences for the periods: 1996-2000 (P=0.05) and 1996-2001 (P=0.035). Values of NO_3^{1-}-N show a significant decrease only for the longer periods: 1996-2000 (P=0.019) and 1996-2001 (P=0.0071). The silica concentration was significantly higher in 1996 only compared to the year 2001 (P=0.027). The dramatic phosphorus decrease led probably to a stronger consumption of silica caused by a possible shift to diatom and chrysophyte development in the phytoplankton.

The alkalinity, chlorophyll-a, phytoplankton biovolume and ratio between zooplankton and phytoplankton biomasses show no significant changes in the considered period. From biological variables only the biomass of zooplankton after log-transformation shows a significant or close to a significant increase for both periods: 1996-2000 (P=0.037) and 1996-2001 (P=0.077).

Conclusions

The morphological and geographical characteristics of the Rila Mountain lakes, such as altitude, geographical position, catchment area, maximum depth, water surface area and human impact from local origin have a decisive influence on the chemical and biological variables in the pelagial. The results of regional analyses show no indications for a significant atmospheric deposition. In the last 5-6 years the lakes underwent a substantional nutrient decrease. At the same time an increase of zooplankton biomass was observed. Thus both effects (directed bottom-up and top-down along the foodchain) have acted in one and the same direction - the improvement of lake ecological status. The preservation and even further improvement of the recent ecological situation in the lakes and its harmonisation with the expected future growth in tourist industry and pasture will require a regular, modern environmental monitoring. This is one of mandatory conditions for achieving a reasonable compromise between measures for environment conservation and business interests.

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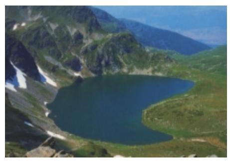
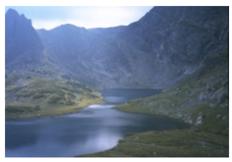
RI0008



RI0009

RI0010

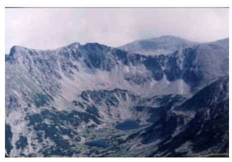


RI0011

RI0067

RI0070

RI0071



RI0075 and RI76