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APPLICABILITY OF ZOOPLANKTON COMMUNITY STUDY FOR ECOLOGICAL QUALITY OF SALMONID WATER LAKES IN LATVIA DURING SUMMER, 2010

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ABSTRACT

According to the Latvian environmental legislation, lakes with high water quality and suitability for such protected salmon fish species as vendace *Coregonus albula* (L.) and whitefish *Coregonus lavaretus* (L.) existence are included in the list of priority fish waters. This status has been assigned to 26 large, mainly deep Latvian lakes. The aim of this study was to clarify changes of the abundance and species' composition of zooplankton in the Latvian salmonid water lakes, and to investigate whether structural changes in zooplankton community provide information about the lakes' ecological quality and trophy. The quantitative and qualitative analyses (comparison of means, analysis of regression, TWINSPAN) of the zooplankton communities between the different lakes' groups show that abundance of zooplankton and taxonomic composition was changing with different degree of the lakes eutrophication. The lakes were divided in three different groups of trophy by zooplankton communities – mesotrophic, mesoeutrophic and eutrophic. Statistically significant difference according to the abundance of zooplankton was observed between the lakes of the first and third group, as the abundance of zooplankton increases if the productivity of lakes increases, as well as the species composition and species occurrence among lakes changes.

Key words: zooplankton, trophy, salmonid water lakes, Latvia

INTRODUCTION

Latvia is a country having diverse lakes in terms of their landscape and morphometry that are both deep and shallow, and rich in water. Significant part of the Latvian lakes has comparatively small area, depth and mainly corresponds to the eutrophic type of lakes. They are subjected to the anthropogenic influence of varied intensity (Kļaviņš et al., 2002).

Yet the number of lakes, which have obtained the status of high water quality, is small. According to the regulations of the Cabinet of Ministers No. 118 (12.03.2002) *Regulations on Surface Waters and Groundwaters Quality*, there are 26 lakes in Latvia that correspond to the high quality water or to priority salmonid water lakes. These regulations determine that priority fish waters are fresh waters, in which water protection or water quality improvement measures should be conducted in order to ensure favourable living conditions for the fish population. Salmonid water lakes are those lakes, in which rare Coregonidae family species vendace *Coregonus albula* and whitefish *Coregonus lavaretus* occur or where it is possible to ensure their existence. According to the Latvian Red Data Book *C. albula* belongs to category 3 (rare species), while *C. lavaretus* belongs to category 2 (endangered species) (Latvijas Sarkanā Grāmata, 2003).

Salmonid water lakes have higher water quality standards comparing to the cyprinid fish water lakes. Therefore, they should be constantly observed to note changes in their ecological quality. By 2009, in the Latvian River Basin Management Plans, 4 % or one of these lakes was evaluated as a lake of high ecological quality, 54 % or 14 lakes – as lakes of good quality, for example, lakes Riču, Sventes, Rāznas and Usmas, and 42 % or 11 lakes – as lakes of average ecological quality (Daugavas baseina apgabala apsaimniekošanas plāns, 2009, Ventas baseina apgabala apsaimniekošanas plāns, 2009). According to the results of surface water quality monitoring conducted by the Latvian Environment, Geology and Meteorology Centre in 2010, the ecological quality of some lakes provisionally was evaluated either higher or lower comparing to investigations before. For example, lakes Riču and Sventes were evaluated as lakes of high ecological quality, while lakes Usmas and Rāznas – only as lakes of average ecological quality (Ziņojums par virszemes un pazemes..., 2011).

The ecological quality of rivers and lakes in the Latvian river basins is evaluated in line with the Cabinet of Ministers Regulations No. 858 (19.10.2004) *Regulations Regarding the Characterisation, Classification, Quality Criteria and Procedures for the Determination of Anthropogenic Loads of the Types of Surface Water Bodies*, in which to the relevant type of lake biological, water physico-chemical, and hydro-morphological criteria have been stated. Biological quality criteria given in these regulations are changes in the taxonomy structure, occurrence, and biomass of phytoplankton communities, as well as the changes in the populations of macrophytes, phytobenthos, benthic invertebrates and fish. Zooplankton as a criterion or indicator has not been named. Nevertheless, zooplankton as a bioindicator is widely used for evaluating ecological quality of water ecosystems and lake trophy. Publications of various authors prove, indicate and discuss the applicability of zooplankton as a bioindicator. For example, a study about the ecological quality assessment of the European shallow lakes regarding the requirements of the EU Water Framework Directive (2000/60/EC of the European Parliament and of the Council (23.10.2000) *establishing a framework for Community action in the field of water policy*) stated that zooplankton is a good indicator of ecological quality. Good indicators appeared to be the proportion of big size Cladocera species and zooplankton (crustaceans) biomass to phytoplankton biomass. Different values of these indicators vary by various types of lakes and may be used as biological quality criteria (Moss et al., 2003). Even in terms of the EU Water Framework Directive, a wide range of researchers note the fact that more attention should be paid to zooplankton as an ecological quality indicator (Jeppensen et al., 2011), the researchers point out that such an important food chain link of water ecosystems should be included in the biological criteria list of the EU Water Framework Directive.

Many studies have been carried out also in Latvia, where the zooplankton as an indicator of the Latvian lake trophy was explored, identified and clarified in terms of species' composition, species' diversity, biomass, interaction with abiotic environment (Urtāne, 1998; Poikane et al., 2001; Latvijas ezeru sinoptiskais monitorings, 2002; Čeirāns, 2007). Great complex studies in the Latvian lakes, including salmonid water lakes, have been conducted in the middle and at the end of 20th century (Līne, 1963; Līne, 1966; Vadzis et al., 1976). Many zooplankton studies have been carried out in such lakes as Rāznas, Usmas, Drīdzis, Puzes and others, mainly evaluating zooplankton community as a basis for fish food (Kumsāre & Selkere, 1955; Sloka & Sloka, 1955; Kumsāre & Gaile, 1960; Laganovska, 1961), as well as in the framework of other limnological studies (Leinerte, 1988). These studies were regularly summarized. During the last 20 and 10 years, such great complex Latvian lake zooplankton studies are carried out considerably less. Also the Latvian National Monitoring Programme for Surface Waters Monitoring does not include zooplankton as an environment quality indicator and research on zooplankton is not done anymore. Thus, in the majority of salmonid water lakes, for the last 20 and 30 years, zooplankton studies have not been conducted or there have been separate studies including only some of these lakes (Brakovska & Škute, 2007; Brakovska et al., 2009; Brakovska & Škute, 2012; Dimante-Deimantovica et al., 2012).

The aim of this study was to clarify changes of the abundance and species' composition of zooplankton in the Latvian salmonid water lakes, and to investigate whether structural changes in zooplankton community provide information about the lakes ecological quality and trophy.

MATERIALS AND METHODS

The salmonid water lakes of Latvia are located mainly in the eastern and south-eastern part of Latvia, in Latgales Highland, and belong to the river basin of Daugava. Only some of the investigated lakes are located in the middle part, and western part of Latvia (Figure 1). Several lakes or parts of the lakes are included also in the list of specially protected natural areas in Latvia and in the network of protected areas in the European Union, Natura 2000. For example, Lake Rāznas is included in the Rāznas National Park, Lake Drīdzis - Nature Park Dridža Lake, Lake Svente - Nature Park Svente. Thereby,

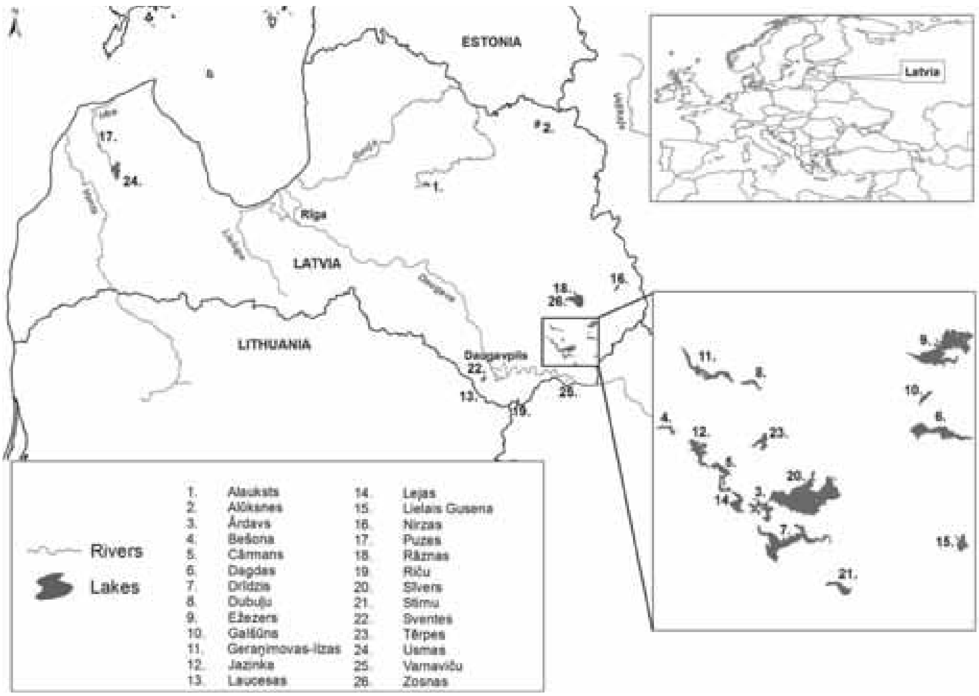

Figure 1. The study site: salmonid water lakes in Latvia.

the lakes ensure the protection of other rare, endangered and protected species and biotopes. Organized and controlled fishing, as well as other economy based activities, its limitation and the lakes protection is arranged in these lakes, which ensure the preservation and good ecological quality of these lakes.

Mainly those are lakes of glacial origin, medium deep or deep lakes (average depth 8.2 m). Drīdzis is a lake with maximum depth 64 m, which is the deepest lake not only in Latvia, but also in the Baltic States. The area of larger lakes is from 40 km^2 to approximately 60 km^2, smaller lakes occupy area of only short square kilometre and correspond to small - medium lake group (Kitaev, 2007) (Table 1). The lakes have varied water volume. Lake Rāznas has the greatest water volume - 402 million m^3, and it is the richest lake in water in Latvia.

The Latvian salmonid water lakes study was carried out in July and August, 2010. The collection of zooplankton samples and measurements of water physico-chemical parameters were performed simultaneously. In order to find the deepest place in a lake, bathometric lake maps were used. Those maps are publicly available and were developed by the Latvian State Institute of Land Amelioration Planning in the 70ties of 20th century. In order to state the deepest place in the lake and mark the geographic points of these places, echo sounder with GPS receiver LOWRANCE LMS-522C was applied.

Physico-chemical water parameters – water temperature °C, conductivity µS cm^{-1}, dissolved oxygen mg l^{-1}, chlorophyll α µg l^{-1} and oxidation-reduction potential mV – were measured in situ using a HACH Hydrolab DS5 multiprobe. Measurements were done starting from lake bottom up to surface in ± 1 m limits with sampling range of one meter.

Such morphometric parameters of lakes as area of lake, lake catchment basin, location above sea level, and the length of shoreline was obtained vectorizing the orthophoto maps of the scale of 1:10 000 prepared by the Latvian Geospatial Information Agency (LGIA) in 2005, using *ESRI ArcGIS 10* software. Additionally, the shoreline development factor, D (1) was calculated (Kalff, 2002).

$$D = \frac{S}{2\sqrt{A\Pi}} \quad \text{, where (1)}$$

S = length of shoreline
A = area of lake.

Water transparency (measured by a Secchi disk) data were used as basis for dividing the lakes into groups. Water transparency is a good and fast indicator of ecological quality and lake trophy (Edmondson, 1980; Jørgensen et al., 2005). Changes in the transparency may be observed particularly well in deep, oligotrophic lakes with good water quality under the influence of both natural and anthropogenic factors (Tegler et al., 2001; Gunn et al., 2001). To divide lakes into groups by transparency, Carlson's trophic state index (TSI) was used (Carlson, 1977). The first group includes lakes, which transparency is within > 6 to 4 m, the second group – lakes with transparency from 4 to 2 m, and third group – lakes, which transparency is from 2 to < 1 m.

Zooplankton samples were collected in the pelagic zone of lakes, in the deepest place. Zooplankton samples were collected from the upper water layer (epilimnion) at the depth of 0.5 m by filtering 100 l of water through Apstein type plankton net (64 µ). The total volume of the obtained sample was approximately 200-240 ml. The samples were preserved in 4% formalin (Wetzel & Likens, 2000). The analysis of zooplankton samples was conducted at the Hydroecology Laboratory of the Daugavpils University using *ZEISS Primo Star* microscope (100-400 x magnification). The zooplankton 1 ml subsamples were analysed 6x repeatedly using gridded Sedgewick Rafter counting chambers, in total 6 ml sample's subvolume was examined. Regarding the limits of possibilities and competence, specimens

Table 1.

Hydrographical, hydrological and morphological parameters of the salmonid water lakes.

No.	Lakes	River basin	Elevation of lakes above sea level, m	Surface area with island, km^2	Surface area without island, km^2	Max. depth, m*	Mean depth, m*	Catchment basin, km^2	Shore length, km	Shoreline development factor, D**
1.	Alauksts	Daugava	202.9	7.72	7.70	7	3.3	20	16	1.58
2.	Alūksnes	Daugava	183.7	16.16	16.01	15.2	7.1	29	23	1.61
3.	Ārdavs	Daugava	159.1	2.32	2.31	14	4.6	160	22	4.05
4.	Bešona	Daugava	144.1	0.63	0.63	22.7	6.8	30	7	2.43
5.	Cārmans	Daugava	158.5	2.12	2.12	31	9.3	202	18	3.58
6.	Dagdas	Daugava	158.1	4.96	4.88	20	5.2	182	29	3.71
7.	Drīdzis	Daugava	159.8	7.72	7.56	64	12.8	46	42	4.32
8.	Dubuļu	Daugava	152.1	0.71	0.71	30	11.8	14	7	2.44
9.	Ežezers	Daugava	169.2	11.49	10.76	21	6.4	118	63	5.39
10.	Galšūns	Daugava	161.2	0.64	0.64	15	5.6	131	5	1.94
11.	Geraņimovas-Ilzas	Daugava	150.7	3.17	3.17	46	9.8	66	24	3.80
12.	Jazinka	Daugava	155.7	2.61	2.61	33	8.1	11	19	3.30
13.	Laucesas	Daugava	122.7	1.87	1.83	15.5	5.4	320***	11	2.28
14.	Lejas	Daugava	158.6	1.72	1.69	34	8.2	182	11	2.33
15.	Lielais Gusena	Daugava	160.5	1.29	1.29	40	9.3	8	11	2.66
16.	Nirzas	Velikaja	156.3	5.59	5.59	21.2	8.2	25	14	1.69
17.	Puzes	Irbe	11.8	4.97	4.97	33.6	12.4	560	12	1.46
18.	Rāznas	Daugava	163.4	57.13	56.91	17	7	227	56	2.08
19.	Riču	Daugava	145.8	13.12	13.07	39	9.7	123***	34	2.63
20.	Sīvers	Daugava	159.2	17.73	17.22	24.5	6.3	101	51	3.48
21.	Stirnu	Daugava	144.2	1.51	1.50	28	7.7	18	10	2.42
22.	Sventes	Daugava	136.9	7.06	7.03	38	7.8	20	26	2.81
23.	Tērpes	Daugava	163.6	1.35	1.34	14	5.8	6	10	2.47
24.	Usmas	Irbe	21.1	42.87	38.62	27	5.4	437	71	3.23
25.	Varnaviču	Daugava	127.4	0.56	0.56	39	7.6	9***	6	2.16
26.	Zosnas	Daugava	163.5	1.50	1.50	17	6	51	9	1.99

* Data concerning maximum and mean depth of lakes was obtained from the available literature sources (Latvijas Daba, 1994, 1995, 1995a 1997, 1998, 1998a).

** Shoreline development factor (D) = 1 (circular), 1.4 - < 3 (subcircular, to elliptical), > 4 (the most irregular) (Kalff, 2002).

*** Catchment basin in the territory of Latvia.

of zooplankton were determined by species, genus or family applying relevant identification guides - Manuilova, 1964; Kutikova, 1970; Ruttner-Kolisko, 1974; Pontin, 1978; Scourfield & Harding, 1994; Segers, 1995; Dussart, & Defay, 2001; Nogrady & Segers, 2002; Radwan et al., 2004; Benzie, 2005; Segers, 2007; Data base: The World of Protozoa, Rotifera, Nematoda and Oligochaeta. Identification. Rotifera and others. Nauplii and copepodites of copepods were enumerated separately, as well.

In order to clarify the interactions of lake limnological (morphometric, catchment basin, water physico-chemical and biological) parameters, multiple regression analysis, analysis of variance *ANOVA*, as well as *Pearson's* correlation analysis was used. Means' comparison method (*Independent Samples T-Test* with *ANOVA*) was applied in order to state differences between the groups of lakes by the biological parameters of zooplankton. Statistical data analysis was conducted using *IBM SPSS Statistics 20*. In order to compare lakes and identify indicator species, two way indicator species analysis TWINSPAN (*TWINSPAN for Windovs version 2.3*) was applied.

RESULTS AND DISCUSSION

The first trophic state group of Latvian salmonid water lakes consists mainly of small lakes, whose average area is 10 km^2 (max – 17.2 km^2, min – 2.6 km^2), but with a high average depth of 9 m (max – 12.8 m, min – 6.3 m) (Kitaev, 2007). In comparison with other lake groups, these lakes are with a rather small catchment basin (average – 60 km^2, max – 123 km^2, min – 11 km^2). The shoreline is rather long in comparison with other lake groups (average – 34 km, max – 51 km, min – 19 km). The Shoreline development factor indicates that lakes are an irregular form (average Shoreline development factor = 3.3).

The second group consists mainly of very small lakes (average area – 3 km^2, max – 16 km^2, min – 0.6 km^2), with an average depth of 7.5 m (max – 11.8 m, min – 4.6 m) (Kitaev, 2007). In comparison with other groups this group is represented by a rather big catchment basin (average – 78.2 km^2, max – 202 km^2, min – 6 km^2), but with a smaller length of shoreline (average – 14 km, max – 29 km, min – 5 km). The Shoreline development factor indicates that lakes are more of rounded to irregular form (average Shoreline development factor = 2.6).

The third group consists of lakes of different sizes, including also the largest salmonid water lakes Rāznas and Usmas (average area – 17.5 km^2, max – 57 km^2, min – 1.5 km^2), with an average depth of 6.8 m (max – 12.4 m, min – 3.3 m) (Kitaev, 2007). In comparison with other groups this lake group is mainly represented by lakes with big catchment basins (average – 243 km^2, max – 560 km^2, min – 18 km^2) and with a long shoreline (average – 34 km, max – 71 km, min – 10 km). The Shoreline development factor indicates that lakes are more of rounded to irregular form (average Shoreline development factor = 2.6).

During the research water stratification was noticed in the lakes of first and second group and in the most part of the third group lakes. The metalimnion layer mainly formed in the depth of 9–3 m with an extremely high increase of temperature from 6–10˚C to 24–25˚C. The average water temperature in the lakes of first and second groups were somewhat lower (the average temperature of second group lakes was 12˚C, the average minimal temperature – 7°C, the average maximal temperature – 23˚C) than in the lakes of the third group (the average temperature was 17˚C, the average minimal temperature – 10˚C, the average maximal temperature – 24˚C). In the lakes with a high average depth the lake area is rather small, with a little littoral part. As for example in the lakes Varnaviču and Lielā Gusena, water stratification was expressive as the water temperature was low (6˚C) until the metalimnion layer. Also the lowest water temperature was observed in these lakes (3.14˚C in the Lake Lielā Gusena in 39 m depth and 3.83 ˚C in the Lake Varnaviču in 38 m depth). However, the division of temperature in such lakes of the third group as Rāznas, Alauksts, Usmas and of the second group as Alūksnes indicates that these lakes were mixed in the whole water layer. If stratification was observed, it was only in the deepest water layers. The mixing of water layers in the depth of these lakes is explained by the fact that these are comparatively shallow lakes with large area and explicit littoral part, exposed to a greater wind impact. This is also indicated by the result of multiple regression analyses, that showed a significant impact of lake depth and area towards the division of temperature and its changes in lakes (R^2= 0.85, *ANOVA* $P < 0.0001$, $\hat{y}$ =17.5 – 0.263x maximal depth, $\hat{y}$ =17.5 + 5.578x lake area).

The oxidation reduction potential (ORP) changed differently between lake groups. Smaller ORP values were observed among the lakes of the third group (average ORP was 356 mV, average max – 470 mV, average min – 56 mV). Higher ORP values were observed among the lakes of the first group (average ORP – 473 mV, average max – 525 mV, average min – 433 mV). In the lakes of the second and third group there were lakes with negative ORP values, for example, in the Lake Laucesas ORP was -48 mV in the metalimnion and hypolimnion, and in the Lake Varnaviču in the deepest water layers it was -29 mV. ORP value close to zero or lower than 200 mV was observed also in other lakes (Alūksnes, Tērpes, Dagdas, Nirzas, Galšūns, Stirnu, Zosnas) in the hypolimnion's deepest water layers. The low ORP indicates the presence of organic matters and other reducents, and oxidation reduction processes that decrease the volume of oxygen, especially in the deepest water layers (Kalff, 2002). During the summer period oxygen concentration in the deepest water layers in the most part of lakes was small, from 0.2 to 4 mg l^{-1}, thus indicating that the dissolved oxygen of summer stagnation periods is significantly used in the processes of organic matter degradation. Concentration of the oxygen dissolved in the upper water layers was sufficiently high up to 9 mg l^{-1}. ORP changes depend on the productivity of lakes, especially in eutrophic waters, and on the concentration of the dissolved oxygen (Horne & Goldman, 1994).

According to the division of lakes into groups, it is visible that in lakes with high transparency the concentration of chlorophyll α is comparatively lower than in lakes with low transparency (Figure 2). The significant negative correlation between transparency and chlorophyll α ($r = -0.631$, $P<0.001$) indicates that primary productivity of lakes affects their ecological quality. Dispersion analyses show that lake transparency is significantly affected by the concentration of chlorophyll α (*ANOVA*, $P<0.005$). Higher average chlorophyll α concentration was observed among the lakes of the third group (2.3 μg l^{-1}). For example, the highest concentration of chlorophyll α from 9 to 11 μg l^{-1} in the metalimnion was observed in the Lake Laucesas. It must be noted that maximal concentration of chlorophyll α was observed exactly in metalimnion for the most part of stratified lakes. Average concentration of chlorophyll α in the lakes of the first group was very low (1.2 μg l^{-1}) and correspond to high water quality (Poikāne, 2009).

According to the multiple regression analyses it was established that transparency in lakes depends on the totality of many factors, i.e., not only from the concentration of chlorophyll α, but also from the lake morphometry. The larger lakes' area, the higher their transparency (R^2= 0.501, *ANOVA* $P < 0.0001$, $\hat{y}$ =3.6 – 0.77x chlorophyll α, $\hat{y}$ =3.6 + 0.038x max depth). According to regression analyses it was established that the concentration of chlorophyll α depends also from the size of lake catchment basin, the larger the catchment basin, the higher the chlorophyll α values (r = 0.634, $P<0.001$, R^2= 0.402, *ANOVA* $P<0.001$, $\hat{y}$ =1.512 + 0.005x the size of the catchment

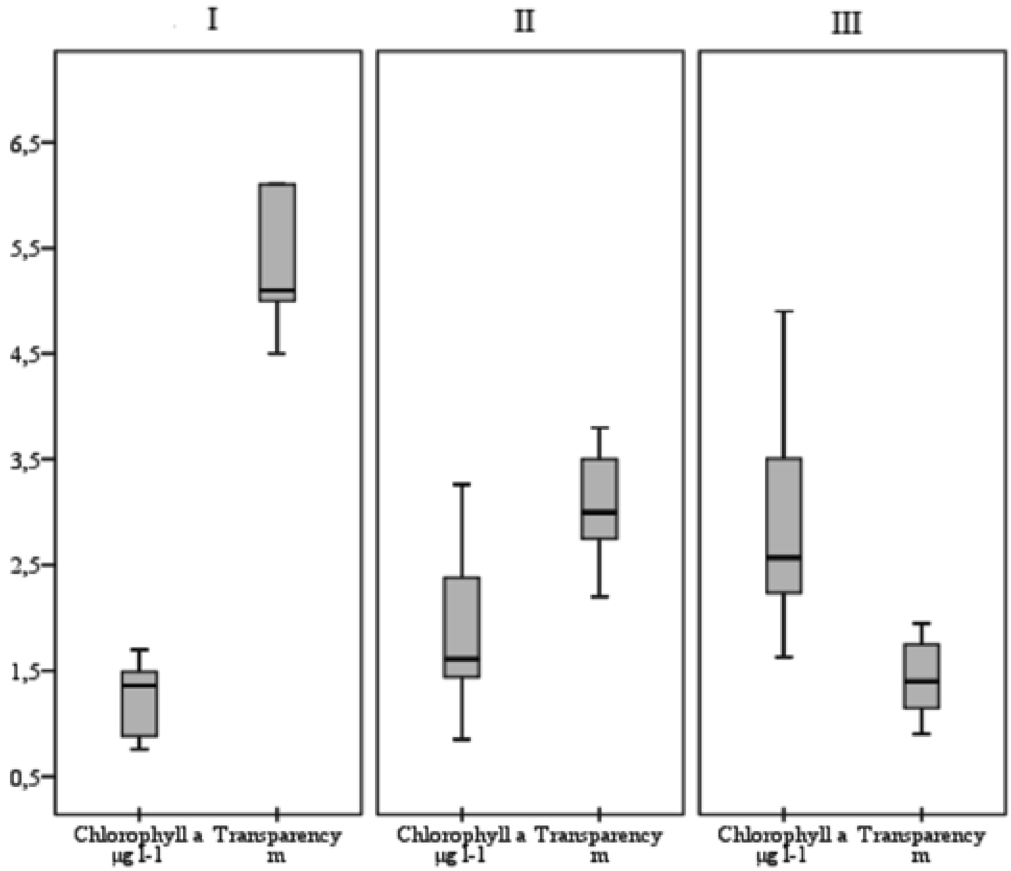

Figure 2. Chlorophyll α and transparency in salmonid water lakes' groups.

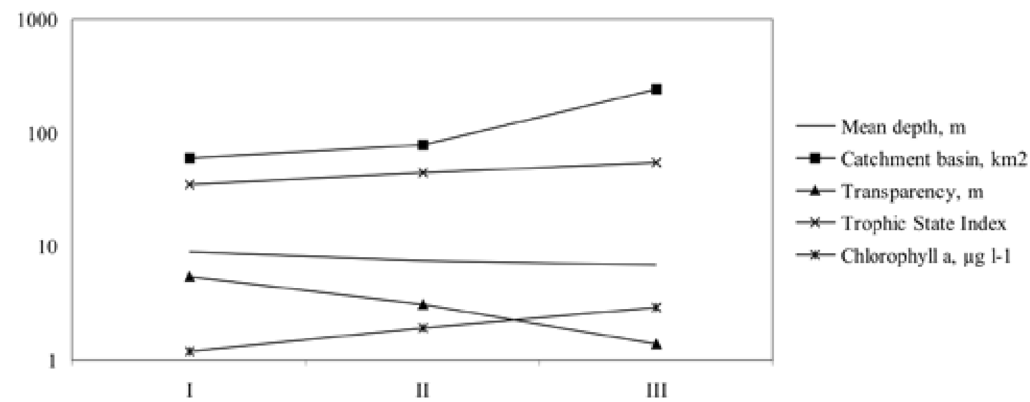

Figure 3. Comparison of the lake groups according to lakes' limnological parameters (logarithmic scale).

basin). Results confirm the impact of nutrients runoff on the lakes' productivity (Horne & Goldman, 1994).

After comparing these lakes according to their morphometry, size of catchment basin and physico-chemical parameters of water, the greatest difference was between the first group (deepest salmonid water lakes with a high average depth, high transparency, low concentration of chlorophyll α) and the third group (average deep lakes with large area, big catchment basin, but low transparency) (Figure 3).

The existence of significant correlations between such lakes limnological parameters as transparency, temperature, chlorophyll α and lakes morphometry (depth, area), as well as catchment basin, shows the impact of catchment basin on the lakes biological and water physico-chemical processes. These processes are depending from the lakes morphometry, as noticeable also in other research (Armengol & Miracle, 1999; Tegler et al., 2001; Karatayev et al., 2005).

Different division of zooplankton abundance between the lake groups was observed. The highest average zooplankton abundance was observed among the lakes of the third group (580903 m^{-3}) and the lowest – among the lakes of the first group (187651 m^{-3}). Such differences are also observed for separate groups of zooplankton – Rotifera, Cladocera, Copepoda (Figure 4). Statistically significant difference between the groups both according to the average abundance of zooplankton (*T-Test*,

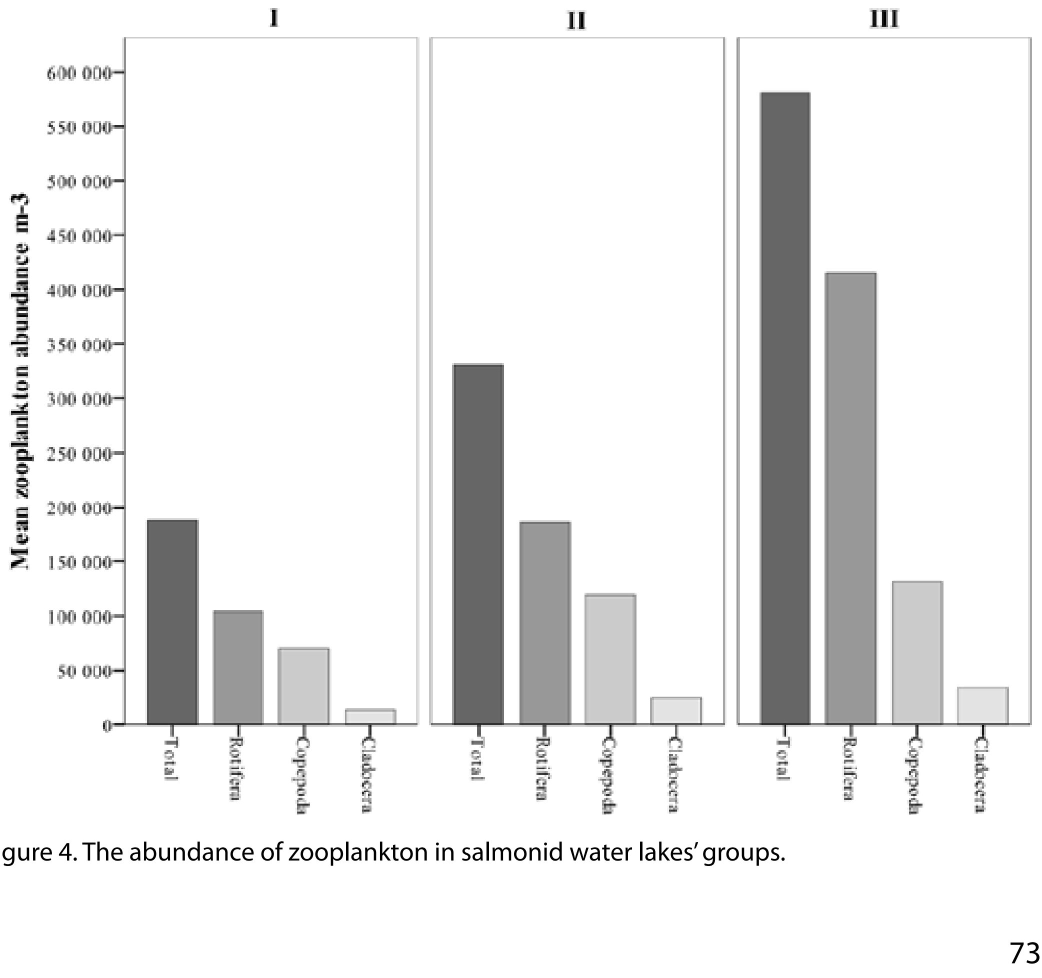

Figure 4. The abundance of zooplankton in salmonid water lakes' groups.

P<0.011) and to the average abundance of Rotifera (*T-Test*, P<0.024), Cladocera (*T-Test*, P<0.042) and Copepoda (*T-Test*, P<0.006) was observed between the first and third group.

Multiple regression analyses were applied in order to evaluate impact of environmental factors on the changes of zooplankton abundance. Results showed that chlorophyll α has a statistically significant impact on the changes of Rotifera and Cladocera abundance and on the total zooplankton abundance ($r = 0.691$, $R^2 = 0.447$, *ANOVA* $P<0.0001$, $\hat{y} = 4.621 + 0.28x$ chlorophyll α; $r = 0.553$, $R^2 = 0.306$, *ANOVA* $P<0.003$, $\hat{y} = 3.9 + 0.175x$ chlorophyll α; $r = 0.725$, $R^2 = 0.526$, *ANOVA* $P<0.0001$, $\hat{y} = 4.993 + 0.229x$ chlorophyll α respectively). The average abundance of Copepoda is influenced by both the concentration of chlorophyll α and the average depth of the lake ($r = 0.671$, $R^2 = 0.45$, *ANOVA* $P<0.001$, $\hat{y} = 11.6 + 0.273x$ chlorophyll α, $\hat{y} = 11.6 - 0.09x$ average depth). As indicated by other research, the abundance of zooplankton, species' composition, the size of organisms, as well as species' diversity is influenced by the way of catchment basin usage and the depth of the lake (Dodson et al., 2000; Dodson, 2005; Hoffmann & Karatayev et al., 2005; Dodson et al., 2009).

In total 59 zooplankton taxons were found in the lakes, 34 - Rotifera, 17 -Cladocera, 8 - Copepoda. The taxonomic composition mainly consists of planktonic forms. Many zooplankton taxons found are widespread and tolerant to different ecological conditions regarding concentration of oxygen, temperature, lake trophy and other limnological parameters (Maemets, 1983; Pejler, 1983; Bērziņš & Bertilsson, 1989; Bērziņš & Pejler, 1989; Bērziņš & Pejler, 1989a; Bērziņš & Pejler, 1989b; Pejler & Bērziņš, 1993; Andronikova, 1996; Bertilsson et al., 1995). However, specific consistencies were observed also here. According to *TWINSPAN* analyses it was found that such species as *Keratella cochlearis*, *Trichocerca similis*, *Daphnia cucullata*, *Diaphanosoma brachyurum*, *Daphnia cristata*, *Mesocyclops leuckarti* and *Thermocyclops oithonoides* have the lowest significance as indicator species. Nevertheless, the occurrence of these species and the changes in abundance vary according to the lake group. The abundance of organisms and the occurrence of these species were higher mainly among the lakes of the third group, except *D. cristata*, as this species is mainly found in the lakes of the first group.

Such taxons according to the *TWINSPAN* analyses were pointed out as the most important indicator species of the lakes trophy: Rotifera - *Ascomorpha ovalis*, *A. ecaudis*, *Trichocerca pusilla*, *T. rousseleti*; Cladocera - *Bosmina (Eubosmina) coregoni*, *B. (Eubosmina) longispina*, *Chydorus sphaericus*, *D. longispina*. Also such significant in addition preferential taxons were obtained for the lake comparison: Rotifera - *Anuraeopsis fissa*, *Conochilus (Conochiloides)* sp., *Filinia longiseta*, *Pompholyx sulcata*, *T. capucina*, *T. cylindrica*, *Synchaeta kitina*; Cladocera – *B. (Eubosmina) crassicornis*; Copepoda - *Eudiaptomus graciloides*.

The first group lakes are combined with such species as *B. (Eubosmina) longispina* and *B. (Eubosmina) crassicornis*. In accordance to these taxons lakes of this group are the most similar ones. The lakes of the second group are combined with such taxons as *A. ovalis, A. ecaudis*, *F. longiseta, T. capucina* and *B. (Eubosmina) coregoni*. The third group lakes are combined with such taxons as *A. fissa, C. (Conochiloides)* sp., *S. kitina*, *T. cylindrica, T. pusilla, T. rousseleti*, *C. sphaericus* and *D. longispina*.

The maximal and, thus, the average *P. sulcata* abundance was greater among the lakes of the third group, however, *P. sulcata* and also *E. graciloides* ensured the greater similarities for the lakes of the second group. The average abundance of *E. graciloides* was greater among the lakes of the second group.

The occurrence and abundance of the two species *T. capucina* and *T. cylindrica* between the lake groups was completely opposite. If the abundance and the occurrence of *T. cylindrica* increased from the second to the third group of lakes, then the abundance and the occurrence of *T. capucina* increased from the first to the second group of lakes, and species was not at all observed in the third group of lakes. *F. longiseta* was observed only among the lakes of the second and the third groups, with the greatest abundance of organisms among the lakes of the second group. The greatest number and occurrence of such taxons as *C. (Conochiloides)* sp. and *S. kitina* was among the lakes of the third group, especially lakes Usmas, Puzes and Rāznas. *A. fissa* was rarely observed, but the greatest abundance was among the lakes of the third group, especially in the Lake Laucesas.

The biology of zooplankton organisms and their ecological demands determine their taxonomic composition, the division of abundance and occurrence between the lake groups. The increase in the abundance of Rotifera organisms from the first groups to the third indicates the intensity of eutrophication processes (Andronikova, 1996; Gliwicz, 2004). These processes are influenced by the availability of nutrients, as well as temperature. These are conditions characteristic of the third group of lakes, as these lakes are not deep, the temperature is comparatively higher than that of the first and second group lakes, some of these lakes are not stratified. Large catchment basin is characteristic for these lakes, bringing additional nutrition and increasing primary productivity. The taxons that characterise third lakes' group are Rotifera – *A. fissa, T. pusilla, T. rousseleti*. Also such species as *P. sulcata* and *T. cylindrica* are present in great abundance among the lakes of this group.

These species are pointed out as eutrophic environmental indicators, as they can live in conditions with a small concentration of oxygen, they are warm stenotherms, tolerate high concentrations of phosphorus, and feed on bacteria, detritus or algae characteristic for such eutrophic waters (Maemets, 1983; Pejler & Bērziņš, 1993; Pejler, 1983; Bērziņš & Pejler, 1989; Bērziņš & Pejler, 1989a; Bērziņš & Pejler, 1989b; Andronikova, 1996).

Rotifera contributes greatly to abundance also in the lakes of the first group, but in this lakes' group Cladocera *B. (Eubosmina) longispina* and *B. (Eubosmina) crassicornis* are pointed out as indicators. The occurrence and the abundance of these species among the lakes of this group are higher than in the other lakes' groups. Low temperatures as well as higher concentrations of oxygen are some of the survival factors for these species (Bērziņš & Bertilsson, 1989; Bertilsson et al., 1995). Since the lakes of this group are deep, they are stratified, with low concentration of chlorophyll α and high transparency. Such conditions indicate the existence of these filtrates in the waters with low concentration of nutrients and low productivity (Andronikova, 1996).

Individually each lake is different, for example, Lake Riču, who belongs to the lakes of the first group according to the physico-chemical water parameters corresponds to the oligotrophic type of lakes, with a high ecological quality. However, the analyses of zooplankton indicate that this lake is with a higher trophy than other lakes of this group, and, thus, it is less similar to other lakes. It has comparatively more zooplankton species indicating eutrophic environment. *Limnocalanus macrurus* is observed in the Lake Riču, as well as in the Lake Sventes, that indicates towards a good ecological condition of environment in order to this glacial relict to exist.

The second group combines zooplankton species that are both oligotrophic (*A. ovalis, A. ecaudis, T. capucina*) and eutrophic (*F. longiseta P. sulcata, B. (Eubosmina) coregoni*) environment indicators (Maemets, 1983; Pejler & Bērziņš, 1993; Pejler, 1983; Bērziņš & Bertilsson, 1989; Bērziņš & Pejler, 1989; Bērziņš & Pejler, 1989a; Bērziņš & Pejler, 1989b; Bertilsson et al., 1995). According to the abundance of zooplankton and the presence of indicators, these lakes differ among themselves with a lower or higher trophy. For example, lakes Alūksnes, Dagdas and Ārdavs are with a higher trophy according to the presence of indicators, while lakes Bešona, Zosnas, Cārmans, Lejas, Nirzas, Dubuļu and Geraņimovas-Ilzas are with a lower trophy. Glacial relict copepod *Eurytemora lacustris* has been found in the lakes of this group (Lejas, Geraņimovas-Ilzas, Bešona) and indicates good ecological conditions of the environment.

CONCLUSIONS

In general, the quantitative and qualitative analyses of the zooplankton communities among the lakes of different groups show that the abundance of zooplankton and the taxonomic composition changes in lakes with a different level of eutrophication. Statistically significant difference according to the abundance of zooplankton was observed between the lakes of the first and third group, as the abundance of zooplankton increases if the productivity of lakes increases, as well as the species composition and species occurrence among lakes changes. The lakes of the first group mainly correspond to mesotrophic, of the third group – to eutrophic, but of the second group – to mesoeutrophic lake type. It depends both on the lake morphometry and on the influence of lakes catchments basin that generally determines physico-chemical water processes in lakes and their productivity. The result of the research corresponds to the opinion of Jeppensen and other authors (Jeppensen et al., 2011) that "zooplanktons are important indicators of the structure and function of freshwater lake ecosystems and their ecological status" and therefore should be used as bioindicators in the lakes.

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