Acta Biol. Univ. Daugavp., Suppl. 3, 2012: 141 – 156.
ISSN 1407 – 8953

The Current State and Perspectives of the Coregonid Lakes 2012

COMPARATIVE CHARACTERISTICS OF ZOOPLANKTON FROM TWO TRANSBOUNDARY TOURIST LAKES

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ABSTRACT

Comparative analysis of pelagic zooplankton communities in two trans-boundary (Belarus-Latvia) lakes was carried out on the basis of materials obtained in the July 1988, July 2008, and July 2010. The data concerning the species composition, quantitative indices of development, and analysis of trophic state allowed for the conclusion that in spite of the change of some zooplankton indices both lakes remained mesotrophic with some features of oligotrophy. Considerable restructuring in the ecosystems of lakes can take place if the surface water temperature increases, which was demonstrated during the abnormally hot summer of 2010.

Key words: trans-boundary lakes, zooplankton, trophic status, temperature rise

INTRODUCTION

Lakes Richa and Sita are both located in the trans-boundary area, divided between Latvia and Belarus, in Daugavpils (LV) and Braslav (BY) districts, respectively. Both lakes are favourite destinations of tourists and fishermen. Because of high diversity of rare and protected species such as vendace *Coregonus albula* (L.), European smelt *Osmerus eperlanus* (L.), calanoid *Limnocalanus macrurus* Sars, relict mysid *Mysis relicta* Loven, and amphipod *Pallasiola quadrispinosa* (Sars), Lake Richa is part of protected areas in both countries.

But due to the establishment of the state border between the two countries, the number of visitors decreased, and recreation load is currently quite low. Since the lakes are situated in the border control zone, attendance is not regulated and no research has been carried out for many years. Now that more attention is being paid to trans-boundary transport of pollutants and development of international tourist exchange, ecological conditions of the lakes like the ones under study acquire special importance.

Lake Richa is protected in Belarus because some water animal species inhabiting them, for instance, vendace - *Coregonus albula* (L.), European smelt - *Osmerus eperlanus relicta* L., limnocalanus - *Limnocalanus macrurus* Sars, relict mysid - *Mysis relicta* Loven, and amphipoda - *Pallassiola quadrispinosa* (Sars) are protected in Latvia, too.

As far as protected water animals are concerned, fauna of Lake Sita contains only limnocalanus and vendace. This lake is not listed among specially protected water bodies. Evaluation of the current state of zooplankton in the lakes and populations of valuable and protected species was carried out in connection with growing trans-boundary cooperation in nature protection, need for creating trans-boundary protected nature complexes, and organization of monitoring studies.

For comparative analysis, the lake community of pelagic zooplankton was studied, namely samples of the latter collected in the July 1988, July 2008, and July 2010. The following trophy indices were investigated: change of species composition, total number, proportion of the three major groups, Rotifera, Copepoda, and Cladocera, ratio of the dominant complex, and number of the limnocalanus population. Besides, indices of species diversity and dominance were calculated.

MATERIALS AND METHODS

The lakes under study, Richa (area 12.8 km^2, maximum depth 51.9 m) and Sita (area 1.9 km^2, maximum depth 28.5 m), belong in the meso-trophic type, with features of oligotrophy (Lakes Belarusian, 1983). They are situated not far from each other in the River Daugava (Western Dvina) valley (Figure 1).

Pelagic zooplankton samples from both lakes, collected in July 1988, July 2008, and July 2010, were compared. The samples were collected at the stations with the maximum depth by vertical catches every 5 meters from the surface to the bottom of the lake; a closing plankton net with the diameter of the filtering cone mesh about 100 microns was used. Samples were fixed in 4% formaldehyde. Sample processing and identification of animals were carried out in accordance with the conventional hydro biological methods, i.e. using the stereomicroscope with 4x8

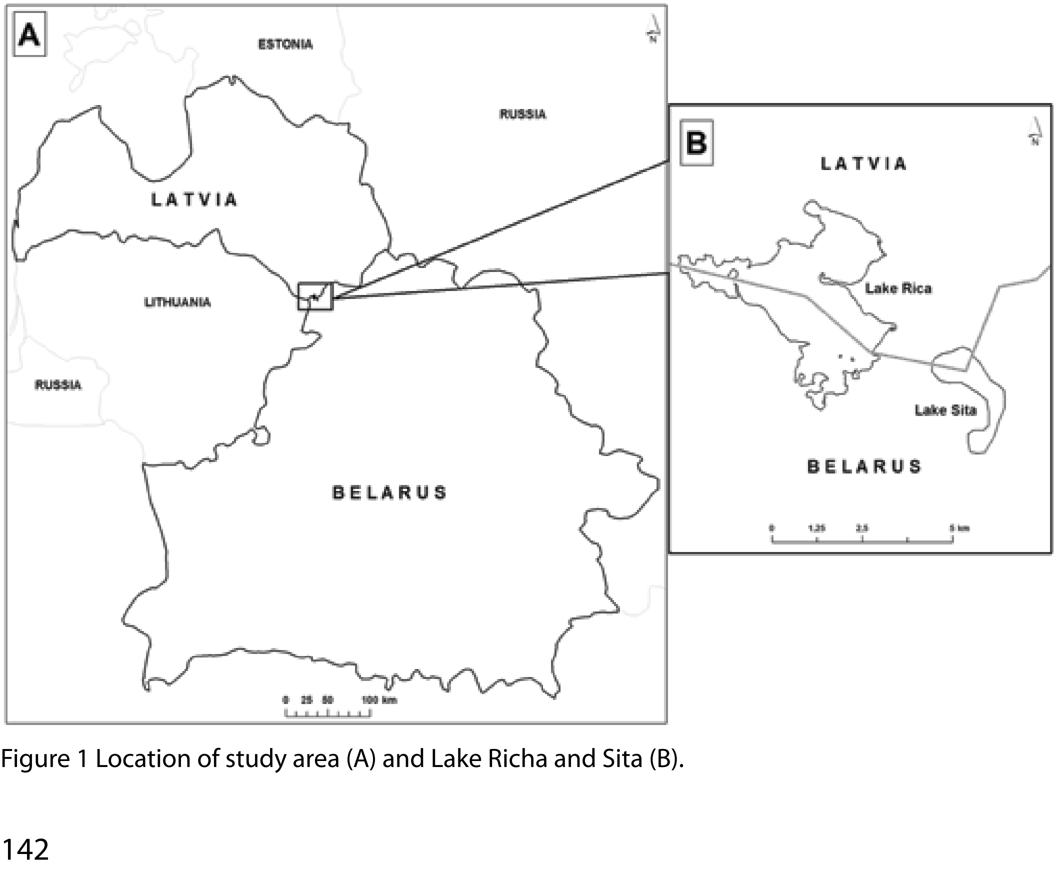

Figure 1 Location of study area (A) and Lake Richa and Sita (B).

magnification. Measurement of temperature and dissolved oxygen was performed by the Hanna HI 9143 portable D.O. meter. Transparency was measured by the white Secchi disk.

For comparative evaluation of the community in different years of examination, some of the most general indices used in hydro biological research were calculated (Shitikov et al., 2003). The Shannon index (Shannon,1948; Shannon & Weaver, 1963) was calculated according to the following formula:

$$H' = -\Sigma p_i \ln p_i$$

where p_i is proportion of individuals (n_i/N) belonging to the i-th species in the dataset, N is the total number, and n_i is the number of each species in community.

Evenness of zooplankton community was calculated according to the Pielou's evenness index (Pielou,1966) by the formula:

$$E = H'/\ln S$$

where H' is the Shannon index and S is the total number of species in the sample.

The index of species diversity was worked out by the Margalef Index of community diversity (Margalef, 1958):

$$D=(S-1)/\ln N$$

where D is the Matgalef index, S is the number of species, and N is the total number of individuals.

The index of similarity was calculated by the Sørensen (Sørensen, 1948) formula:

$$QS = \frac{2C}{A+B}$$

where A and B are the number of species in samples A and B, respectively, and C is the number of species shared by the two samples; QS is the quotient of similarity and ranges from 0 - 1.

An index suggested by Czekanowski (Czekanowski, 1962) was used for the analysis of quantitative data:

$$K(x, y) = \frac{2\sum_{i=1}^{n} \sqrt{x_i y_i}}{\sum_{i=1}^{n} x_i + \sum_{i=1}^{n} y_i}$$

where similarity between communities x and y was assessed by the quantity values of species contained in these communities.

Such trophy reflecting indices as changes in species composition, total number of animals and dominating species complex, ratio of the three main groups – Rotifera, Copepoda and Cladocera, as well as changes of number of *Limnocalanus macrurus* were examined. Numbers of species and their ratio in the lakes have not changed significantly.

RESULTS

Main characteristics of the Lake Sita habitat are presented in Table 1. The lake belongs in the group of dimictic reservoirs with a distinct stratification of water temperature. As demonstrated by the tabulated data, the temperature in the upper strata of water was changing from 21.6^{0}C in 2008 to 26.2^{0}C in 2011. Depending on hydrological conditions in each observed year, the zone of sharp temperature rise is situated in the range of 5-12 meters. In near-bottom strata of water, the temperature does not rise higher than 4.7-6.0^{0}C. The pattern of temperature change has not changed remained the same in the period from 1988 till 2010; the year of 2010, though, faced the maximum warming of the upper strata of epilimnion.

Content of the dissolved oxygen is unevenly distributed in the water column and is not

Table 1.

Change in temperature (t0C) and DO (O2, mg l-1) in the water column in Lake Sita. Strata of thermo- and oxycline are shown in bold type.

Lake Sita	1988. Transparency 3.8 m		2008. Transparency 5.0 m		2010. Transparency 3.6 m	
Depth, m	t^0C	O_2, mg l^{-1}	t^0C	O_2, mg l^{-1}	t^0C	O_2, mg l^{-1}
0	23.7	9.9	21.6	10.5	26.2	9.5
1	23.7	9.7	21.4	9.96	26.2	9.5
2	23.7	9.7	21.2	9.9	26.1	9.3
3	23.7	9.6	21.2	9.9	25.5	***9.1***
4	23.5	***9.3***	20.4	9.8	***22.6***	***6.4***
5	***18.9***	***7.9***	19.9	***9.79***	***19.1***	***0.8***
6	***14.4***	***6.7***	19.0	***8.8***	***15.3***	0.3
7	***12.4***	5.9	***17.8***	***7.2***	***12.9***	1.0
8	***9.9***	5.4	***14.9***	7.1	***9.8***	2.1
9	***8.8***	5.2	***11.3***	6.95	***11.1***	2.7
10	***7.9***	5.6	***9.4***	6.4	***9.0***	2.6
11	7.2	5.4	***8.0***	6.3	***7.9***	2.2
12	6.6	5.3	***7.0***	5.9	7.0	1.4
13	6.0	5.3	6.6	5.7	6.7	1.4
14	5.4	5.4	6.4	5.5	6.4	1.0
15	5.2	5.4	6.4	5.4	6.3	0.8
16	5.2	5.3	6.6	5.3	6.2	0.7
17	5.1	5.2	6.5	5.2	6.1	0.7
18	5.0	5.1	6.4	5.1	6.0	0.7
19	5.0	5.1	6.4	5.0	5.9	0.6
20	4.9	5.1	6.2	4.6	5.8	0.2
25	4.7	3.9	6.0	3.4	5.8	0.1
27.5	4.7	2.7	6.0	2.4	5.8	0.0

Table 2.

Change in temperature (t^0C) and DO (O_2, mg l^{-1}) in the water column in Lake Richa. Strata of thermo- and oxycline are shown in bold type.

Lake Richa	1988 Transparency 4.75 m		2008 Transparency 5.5 m		2010 Transparency 5.3 m	
Depth, m	t^0C	O_2, mg l^{-1}	t^0C	O_2, mg l^{-1}	t^0C	O_2, mg l^{-1}
0	22.8	9.9	21.5	10.3	25.8	10.1
1	22.8	9.9	21.5	9.7	25.8	9.8
2	22.8	9.9	21.4	9.5	25.8	9.7
3	22.8	9.9	21.3	9.6	25.6	9.6
4	22.3	9.8	21.3	10.3	25.4	10.1
5	***17.2***	***10.1***	21.2	***10.8***	22.2	***10.3***
6	***15***	***8.6***	21.1	***9.3***	*19.2*	***9.4***
7	***11.8***	***7.6***	***20.3***	***9.1***	***18.2***	***9.1***
8	***9.7***	8.3	***18.4***	8.8	***15.1***	8.8
9	***8.8***	8.1	***17.6***	8.7	***13.8***	8.7
10	8.2	8.0	***17.2***	8.6	***11.4***	8.2
11	7.8	8.0	***16.8***	8.2	***10***	8
12	7.5	8.0	***16.0***	7.8	9.4	7.6
13	7.3	8.0	***13.2***	7.4	8.8	7.2
14	7.2	7.9	***9.6***	7	8.4	6.8
15	7	7.9	***8.6***	6.8	8.0	6.4
16	6.9	7.9	7.6	6.7	7.7	6.2
17	6.8	7.9	7.4	6.7	7.4	6.2
18	6.7	7.9	7.2	6.4	7.2	5.8
19	6.6	7.9	7	6.3	7	5.7
20	6.5	7.9	6.8	6.2	6.8	5.5
25	6.3	7.7	6.6	5.8	6.4	5.1
30	6	7.7	6.4	5.5	6.3	5.1
35	5.6	7.6	6.2	5.4	6.3	4.9
47	5.6	7.0	6.0	5.3	6.3	4.9

generally different/essentially the same in 1988 and 2008, but a sharp deficit of oxygen was observed in the abnormally hot summer of 2010 both in the beginning of epilimnion and in near-bottom strata of water, which could cause unfavourable living conditions for water animals, particularly for those species that inhabit deep water strata.

In the deeper Lake Richa (Table 2), thermal stratification in the water column is also observed in summer. The temperature in the upper strata was changing from 21.5 to 25.8^{0}C, and in the near-bottom ones from 5.3 to 6.3^{0}C. The thermocline zone is formed at the depth of 5-15 meters. The differences between the years of observation are in the depth of termocline beginning and the length of this zone. In 1988, the beginning of thermocline (the upper border of metaliminion) was observed at the depth between 4 and 5 meters, actually corresponding to the depth of transparency. During the last years of observation, with an insignificant increase of transparency, the upper border of metaliminion has shifted to the deeper water strata of 6-7 meters.

Unlike Lake Sita, the distribution pattern of dissolved oxygen in water column of Lake Richa has remained unchanged during the years of observation. Moreover, the beginning of the oxycline zone has always been linked to the depth of transparency. And, finally, a distinctive feature of this lake is a poorly expressed rise of concentration before the beginning of oxycline, known as metalimnial maximum (Kitaev, 2007). A gradual decrease of O_2 concentration from 7 to 4.9 mg l^{-1} is seen in the near-bottom stratum of water.

Totaly 63 species and forms of animals were encountered in both lakes, among them 30 species of Rotifera, 13 species of copepods, and 20 species of cladoceran crustacea. They have a similar species composition, although the bigger Lake Richa has a wider fauna (Table 3).

During the observation period in Lake Sita, the total number of species in pelagic zone of both lakes did not change: 33-34 species were encountered in Sita and 38-41 in Richa. On the whole, the ratio of species remains the same, i.e. nearly 50% of species composition is rotifera and crustacea (Table 3); the ratio of numbers of copepod and cladocera species was irregularly changing in the years of observation. The number of Rotifera species in both lakes is growing.

Species that had not been encountered previously were registered in the pelagic zone of both lakes. Some of them are typical inhabitants of the littoral zone and are occasionally encountered in pelagic plankton. But some new species are euplanktonic organisms; thus the pelagic plankton of Lake Sita comprises new big Rotifera species from the genus *Polyarthra* - *Polyarthra euryptera* and *Polyarthra major.* A range of plankton organisms, characteristic of more trophic waters, such as *Brachionus urceus, Keratella cochlearis tecta, Pompholyx sulcata, Bosmina coregoni, Synchaeta oblonga,* and *Synchaeta pectinata* have recently been recorded in pelagic plankton of Lake Richa.

The total number of organisms has considerably increased in Lake Sita from 55700 to 114600 ind. m^{-3}, while in Richa the increase has been slight, from 44400 to 55800 ind. m^{-3}. As for the ratio of three main groups of zooplankton in Lake Richa, Rotifera showed a trend of increasing from 21.6% in 1988 to 49.1% in 2008 and 33.8% in 2010 (Table 4).

The dominating complex in both lakes comprises 4-6 species (Table 5). Copepods at different age stages and *Conochilus unicornis* of the Rotifera have permanently been dominating. Changes in the dominating complex consist in dropping out/ disappearance of some Rotifera and Copepod species such as *Kellicottia longispina* and *Daphnia cristata*, respectively, from dominant and sub-dominant species in Lake Sita in 2010. Such forms as *Polyarthra major* and

Diaphanosoma brachiurum, their amounts making over 10% of the total, are becoming dominant in the pelagic zone of the lake.

In the lake Richa, a cladoceran crustacean *Diaphanosoma brachiurum* and nauplii and copepodite development stages of Copepods have been in the dominating complex with a permanent relative density. The relict *Limnocalanus macrurus,* that used to be among dominant species in 1988 and 2008, made only 3.9% of the total amount of zooplankton in 2010.

Table 6 shows change in density of limnocalanus in both lakes. In Lake Sita, stable indices of mean population density have been registered during all observations. At the same time, maximal density in the water column, indicating aggregation or unevenness of the vertical distribution, is decreasing. Decrease of relative density is also observed. In Lake Richa, nearly all indices of this species, except maximum density, demonstrate a distinct tendency to lower.

DISCUSSION

As stated above, the studied lakes demonstrated changes in vertical distribution of dissolved oxygen, which is a major index of living conditions for water animals, under the abnormal rise of temperature in 2010. These changes were not similar; in the bigger lake, Richa, decrease of concentration is observed only in the near-bottom stratum where the concentration of oxygen had lowered by 2 mg l^{-1} during more than 20 years. The recent period of observation showed that the concentration of oxygen in hypolimnion is 5 mg l^{-1}, which is favourable for the development of deep water fauna.

Temperature in the shallower lake, Sita, had lead to complete disappearance of oxygen in the near-bottom strata and its sharp deficit in the entire water column, starting from the transparency depth. The cline reflecting vertical distribution of oxygen had a complex nature; the minimal distribution reaching 0.3 mg l^{-1} (metalimnial) was observed at the depth of 6 meters, then at the depth of 8-11 meters the concentration of oxygen had the value of over 2 meters and gradually decreased until complete disappearance near the bottom (Table 1). It is well known that the concentration of oxygen below 2 mg l^{-1} is unfavourable for the majority of water animals. Low concentration of oxygen particularly tells on relict Crustacea. It had been shown earlier that the lower limit of comfortable living in a reservoir for limnocalanus is the concentration of oxygen not below 3 mg l^{-1} in near-water stratum (Vezhnovets, 1984; Vezhnovets, 1988), whereas the concentration of oxygen below 2 mg l^{-1} caused death of animals in experiment conditions. Decrease to 1 mg l^{-1} leads to 100% death of animals at the temperature 0-4^{0}C.

The changed living conditions were to lead to changes in zooplankton community. Taking into account the fact that both lakes are hardly influenced by an anthropological factor and pollution, widely used conventional methods of assessment mainly based on the change of throphic status were used for clarifying this question. There exist various methods of evaluating ecological quality of water by pelagic zooplankton; they are based on the total amount and biomass, and a number of ratios, i.e. between the main groups of zooplankton, between Cladocera and Copepods in crustacean plankton, calanoid and cyclopoid planktons, propotion of some indicator species, etc.

An intermediary summary and compatibility of the employed methods are also discussed in a great number of works (Karabin, 1985; Lebedeva et al., 1999; Kitaev, 2007; Semenchenko & Razlutsky, 2010, etc.); it does not appear possible to refer to them in the given paper. It is known that the mesotrophic lakes, which have been analysed here according to O. F. Yakushko (1971), have had stable zooplankton development indices for many

Table 3.
Species composition of the studied lakes. (*species recorded in the last years of observation; ** occasional species not typical for pelagic plankton).

Lakes		Sita			Richa		
Study Year		1988	2008	2010	1988	2008	2010
1	*Ascomorpha ecaudis* Perty,1850*		x	x		x	x
2	*Asplanchna priodonta priodonta* Gosse,1850	x	x	x	x	x	x
3	Bdelloida sp.**				x		
4	*Bipalpus hudsoni* (Imhof,1891)	x	x		x	x	x
5	*Brachionus urceus* (Linnaeus,1758)*						x
6	*Chromogaster ovalis* (Bergendal,1892)	x		x	x	x	x
7	*Collotheca pelagica* (Rousselet,1893)	x	x	x	x	x	x
8	*Conochilus hippocrepis* (Schrank,1803)		x	x		x	x
9	*Conochilus unicornis* Rousselet,1892	x	x	x	x	x	x
10	*Euchlanis dilatata lucksiana* Hauer, 1930**		x		x		
11	*Filinia major* (Colditz,1914)	x		x	x	x	x
12	*Gastropus stylifer* Imhof,1891	x	x	x		x	x
13	*Kellicottia longispina* (Kellicott,1879)	x	x	x	x	x	x
14	*Keratella cochlearis cochlearis* (Gosse,1851)	x	x	x	x	x	x
15	*Keratella cochlearis hispida* (Lauterborn, 1898)				x		
16	*Keratella cochlearis tecta* (Gosse,1851)*						x
17	*Keratella quadrata* (Muller,1786)	x	x	x	x	x	x
18	*Polyarthra euryptera* Wierzejski, 1891*			x			
19	*Polyarthra major* Burckhardt,1900*		x	x		x	x
20	*Polyarthra remata* Skorikov,1896					x	
21	*Polyarthra vulgaris* Carlin,1943	x	x	x	x	x	x
22	*Pompholyx sulcata* Hudson, 1885*					x	x
23	*Postclausa hyptopus* (Ehrenberg,1838)**			x			
24	*Synchaeta oblonga* Ehrenberg, 1831*					x	
25	*Synchaeta pectinata* (Ehrenberg,1832)*					x	x
26	*Synchaeta tremula* (Müller, 1786)	x					
27	*Trichocerca (D) similis* (Wierzejski,1893)	x		x	x	x	x
28	*Trichocerca (D.) rousseleti* (Voigt, 1902)**			x	x		
29	*Trichocerca capucina* (Wierzejski et Zacharias,1893)	x		x	x	x	x
30	*Trichotria pocillum* (Muller,1776)**						x
Rotifera		**14**	**13**	**18**	**16**	**20**	**21**
1	*Acanthocyclops* sp.**					x	
2	*Cyclops lacustris* Sars,1863			x	x	x	x
3	*Cyclops* sp.				x		
4	*Ergasilis* sp.**			x	x		
5	*Eucyclops serrulatus* (Fischer, 1851)				x		
6	*Eudiaptomus gracilis* (Sars,1863)						x
7	*Eudiaptomus graciloides* (Lilljeborg,1888)	x	x	x	x	x	x

Lakes		Sita			Richa		
Study Year		1988	2008	2010	1988	2008	2010
8	Harpacticoida sp.**		x		x		
9	*Heterocope appendiculata* Sars, 1863	x	x	x			
10	*Limnocalanus macrurus* Sars,1863	x	x	x	x	x	x
11	*Megacyclops viridis* (Jurine, 1820)				x	x	x
12	*Mesocyclops leuckarti* (Claus,1857)	x	x	x	x	x	x
13	*Thermocyclops oithonoides* (Sars,1863)	x	x	x	x	x	x
Copepoda		**5**	**6**	**7**	**10**	**7**	**7**
1	*Alona affinis* Leydig,1860**					x	
2	*Alonella excisa* (Fisher, 1854)**				x		
3	*Alonella nana* (Baird, 1850)**	x					
4	*Bosmina coregoni gibbera* (Schoedler,1866)*					x	x
5	*Bosmina crassicornis* (P.E.Muller,1867)	x	x	x	x	x	x
6	*Bosmina* sp. (juv.)				x		
7	*Bosmina longirostris* (O.F.Muller,1785)	x		x	x	x	x
8	*Bosmina longispina* Leydig, 1860	x	x	x	x	x	x
9	*Bythotrephes longimanus* Leydig, 1860	x	x		x	x	x
10	*Ceriodaphnia pulchella* Sars,1862		x				
11	*Ceriodaphnia quadrangula* (O.F.Muller,1785)				x	x	x
12	*Chydorus sphaericus* Sars,1863	x	x	x	x		x
13	*Daphnia cristata* Sars,1862	x	x	x	x	x	x
14	*Daphnia cucullata* Sars,1862	x	x	x	x	x	x
15	*Daphnia longispina* (O.F.Muller,1785)	x	x	x		x	x
16	*Diaphanosoma brachiurum* (Lievin,1848)	x	x	x	x	x	x
17	*Leptodora kindtii* (Focke,1844)	x	x	x	x	x	x
18	*Leydigia leydigii* (Schodler, 1863)**		x				
19	*Polyphemus pediculus* (Linne,1778)**					x	
20	*Sida cristallina* (O.F.Muller,1776)**	x	x		x		x
Cladocera		**12**	**12**	**9**	**13**	**13**	**13**
Total		**31**	**31**	**34**	**38**	**40**	**41**

Table 4.
Species number (n); absolute (N, thousands of ind. m^{-3}) and relative (%) amounts of main zooplankton groups.

Zooplankton group	**n**	**%**	**N**	**%**
Lake Sita				
1988.				
Rotifera	14	45.2	21.5	38.5
Copepoda	5	16.1	26.4	47.3
Cladocera	12	38.7	7.9	14.2
Totaly:	**31**	100.0	**55.8**	100.0
2008.				
Rotifera	13	41.9	44.1	55.9
Copepoda	6	19.4	24.7	31.3
Cladocera	12	38.7	10.1	12.8
Totaly:	**31**	100.0	**78.8**	100.0
2010.				
Rotifera	18	52.9	40.3	35.2
Copepoda	7	20.6	44.9	39.2
Cladocera	9	26.5	29.4	25.7
Totaly:	**34**	**100.0**	**114.7**	100.0
Lake Richa				
1988.				
Rotifera	16	43.2	9.6	21.6
Copepoda	9	24.3	21.4	48.2
Cladocera	12	32.4	13.4	30.3
Totaly:	**37**	100.0	**44.4**	100.0
2008.				
Rotifera	20	50.0	25.8	49.1
Copepoda	7	17.5	18.1	34.4
Cladocera	13	32.5	8.6	16.4
Totaly:	**40**	100.0	**52.5**	100.0
2010.				
Rotifera	21	51.2	18.9	33.8
Copepoda	7	17.1	25.8	46.2
Cladocera	13	31.7	11.2	20.0
Totaly:	**41**	100.0	**55.8**	100.0

Table 5.
Complex of dominating species (% of the total number) in various years of observation (% of the total number of species is given in brackets when a species in question does not make part of the dominating complex).

Lake Sita			
Dominating species	**1988.**	**2008.**	**2010.**
Rotifera			
Conochilus unicornis	20.6	13.6	(1.0)
Conochilus hippocrepis	(0.0)	(0.1)	17.2
Polyarthra major	(3.5)	(0.2)	10.2
Kellicottia longispina	6.0	37.0	(1.2)
Copepoda			
Cyclopoida (copepodit + nauplii)	16.8	21.8	16.8
Diaptomus (copepodit + nauplii)	13.5	(3.1)	6.9
Thermocyclops oithonoides	(4.7)	(1.8)	6.6
Eudiaptomus graciloides	6.7	(1.0)	8.1
Cladocera			
Daphnia cucullata	(4.2)	(2.4)	5.5
Daphnia cristata	(3.5)	5.9	(4.7)
Diaphanosoma brachiurum	(1.5)	(1.9)	10.5
Number of dominating species	**4**	**4**	**6**
Degree of dominance	**63.6**	**78.3**	**74.9**
Lake Richa			
Rotifera			
Kellicottia longispina	10.6	(4.0)	12.7
Conochilus unicornis	(0.5)	38.5	(2.3)
Conochilus hippocrepis	(0.0)	(0.3)	7.1
Copepoda			
Cyclopoida (copepodit + nauplii)	24.5	16.9	34.0
Limnocalanus macrurus	12.5	7.5	(3.9)
Cladocera			
Bosmina longispina	6.8	(1.7)	(2.7)
Daphnia cucullata	5.4	(4.5)	(3.5)
Diaphanosoma brachiurum	6.1	6.0	6.4
Number of dominating species	**6**	**4**	**4**
Degree of dominance	**66.0**	**68.8**	**60.1**

Table 6.
Maximal (N_{max}, ind. m^{-3}), mean (N_{mean}, ind. m^{-3}, in water column) and relative (% of the total number) density of *Limnocalanus macrurus* population.

Years	**Lake Sita**			**Lake Richa**		
	N_{max}	**N_{mean}**	**%**	**N_{max}**	**N_{mean}**	**%**
1988.	16 551	2 683	4.8	10 090	5558	12.5
2008.	15 785	2 500	3.2	6 772	3926	7.5
2010.	8 319	2 483	2.2	9 898	2199	3.9

Table 7.
Comparative description of lakes according to species diversity indices.

Index	**Lake Sita**			**Lake Richa**		
	1988.	**2008.**	**2010.**	**1988.**	**2008.**	**2010.**
Shannon (*H'*)	2.75	2.19	2.71	2.87	2.35	2.66
Pielou (*E*)	0.77	0.62	0.75	0.76	0.62	0.70
Margalef (*D*)	3.11	3.02	3.18	4.11	4.51	4.39

Table 8.
Similarity index of Sørensen and Czekanowski in observation years.

Lake Sita			**Lake Richa**		
On quantitative data (Czekanowski)					
	2008	2010		2008	2010
1988	0.58	0.48	1988	0.53	0.57
2008		0.40	2008		0.55
On qualitative data (Sørensen)					
	2008 г	2010 г		2008	2010
1988	0.80	0.79	1988	0.74	0.74
2008		0.77	2008		0.86

years, if not decades. Besides, widely used indicators of trophy change are applicable to a relatively wide range of environmental changes. That is why while comparing the lakes under study, both between them and across the observation time, we looked into only some aspects of zooplankton community reaction to various degrees of change in some factors of living conditions (temperature and, particularly, oxygen). As was stated above, an abnormally low concentration of dissolved oxygen and its distribution in the water column was for the first time recorded in Lake Sita, which we link to the temperature rise in epilimnion and activisation of the organic matter oxidation. A similar rise in the neighbouring lake did not lead to a sharp decrease of oxygen concentration.

Use of formalised methods of determining change did not give the expected results (Table 7). The Shannon index for pelagic zooplankton has quite high values for both lakes, is quite similar in value in both cases, and has been irregularly changing across the years of ovservation. The Pielou's evenness index, which is widely used by ecologists and applied to the study of any community, was also varying in a narrow range of its values. These indices might be not sensitive enough for such a narrow scope of change in conditions, which was also highlighted by other researchers (Tereshchenko et al., 1994). The index of species diversity, calculated according to Margalef, demonstrated a clear difference between the lakes although no regular temporary trends were discovered.

Use of Czekanowski-Sørensen similarity index yielded contradictory data, both quantitative and related to species composition (Table 8). Overall, the obtained similarity indices for species composition (qualitative data) and quantitative data are close in their values.

In other words, on the basis of this analysis of faunistic changes in both lakes, it is possible to conclude that a relatively stable species composition is observed against the background of its annual variations.

In spite of the obtained formal data, the species composition has actually undergone some changes; species characteristic for more trophic waters were found in the lakes. Special attention need to be paid to the appearance of the following Rotifera species recorded in Lake Richa: *Brachionus urceus, Keratella cochlearis tecta,* and *Pompholyx sulcata,* which are not specific for reservoirs of this type (Karabin, 1985). Registration of the cladoceran crustacea *Bosmina coregoni* also testifies to the increased trophy of this lake. Rotifera *Bosmina coregoni*, previously recorded only in coastal plankton of mesotrophic lakes in Belarus and in river ecosystems (Galkovskaya et al., 2001), was found in epy- and metalimnion of Lake Sita in numbers exceeding one thousand ind. m^{-3}.

Increase of the total number of zooplankton in both lakes, which is more expressed in Lake Sita where this indicator has doubled (from 56 to 114 thousand ind. m^{-3}) during the recent 20 years, can be explained by reaction to temperature rise and as a consequence of an increased rate of eutrophication. Lake Richa demonstrates a gradual growth of zooplankton density, namely 44.4 thousand ind. m^{-3} in 1988 and 55.8 thousand ind. m^{-3} in 2010. Judging by the development indices of zooplankton community, both lakes remain mesotrophic.

High surface water temperature had led to the change of dominating complex. In 1988 it included relatively cold-loving representatives of zooplankton, Rotifera *Conochilus unicornis* and *Kellicottia longispina* and Cladoceran Crustacea *Daphnia cristata*. It is worth mentioning that these species are widely spread mainly in the lakes in northerly latitudes.

A different situation was observed in 2010. The dominant role in plankton was played by typical warmth-loving forms such as

Conochilus hippocrepis and *Polyarthra major* from Rotifera and *Diaphanosoma brachyurum, Eudiaptomus graciloides,* and *Thermocyclops oithonoides* from Crustacean, all of which mainly inhabit the epilimnion of lakes.

The change in density of limnocalanus was considered specially. According to own data (Sushchenya et al., 1984) and those presented in related literature, this relic belongs to cold-loving stenothermic and oxyphilic organisms and concentrates in hypolimnion and in near-bottom strata during the day time, with a high enough concentration of oxygen of not less than 4 mg l^{-1}. This species can be used as an indicator of clean waters, and the state of population allows for judging about trophy change and water quality (Vezhnovets, 1988). The maximum density of this species in Lake Sita before 2010 was recorded at the depth of 20-25 meters. In 2010, because of oxygen deficit, this species shifted to the lower border of metalimnion, into the stratum at the depth of 10-15 meters with the maximum temperature of living for this species, namely 9^0C.

Moreover, according to the data obtained during many years of observation in Lake Sita, absolute density of the species had not changed, whereas relative one lowered from 4.8% to 2.2% of the total numbers. In spite of the relatively stable population density, unfavourable conditions in 2010 are likely to tell on the generations to come. With peculiarities of reproduction biology, i.e. monocyclicity, laying eggs in winter straight in water, and their development on the bottom (Vezhnovets, 1984), oxygen deficit will lead to a delay in the population development and unbalanced reproduction cycle. That is why it seems that the maximally low content of oxygen and unfavourable temperature conditions for the existence of this species may cause a sharp decrease in its numbers and complete disappearance of this valuable nutrition object for the cisco fishes in the fauna of this lake.

The vertical position of this species in Richa had not changed. Nevertheless, it is important to note a gradual decrease of its density from 5.5 thousand ind. m^{-3} in 1988 to 2.2 thousand ind. m^{-3} in 2010 in the situation of the observed lowering of oxygen concentration in the near-bottom strata of water. The relative density had also sharply lessened; this species had previously been in the dominating complex with its 12.5% of the total density of zooplankton; in 2010 its share in zooplankton fell to 3.9%. As it is considered a main nutrition object in the diet of the plankton-eating cisco fishes, vendace and European smelt inhabiting this lake; consequently, nutrition conditions for these fish species had worsened.

CONCLUSIONS

In spite of the minimal anthropogenic load on the studied lakes, processes of natural eutrophication do take place in them. Use of various methods for assessing this process in relation to zooplankton showed that only some of the conventional indicators can be employed in the narrow range of change of trophy status or for the comparison of trophy statuses of similar lakes. These indicators may include a detailed analysis of species composition, structure of the dominating comples, total number, number of indicator species, and change of the vertical structure; these indicators give result only when applied as a complex. Formalised evaluation according to diversity and similarity indices did not reveal noticeable changes over time; some of them, though, drew a distinct borderline between the lakes.

An abnormally high water temperature in 2010 considerably boosted the process of eutrophication of Lake Sita, but on the whole did not tell on the plankton community in Lake Richa which had to a great degree preserved its features of an oligotrophic water body. The temperature rise distorted the vertical structures of zooplankton and changed the dominating complex. Changes most drastically influenced the populations of the cold-loving types of zooplankton, particularly *Limnocalanus macrurus* and some Rotifera species. It may lead to a breakdown of the established functional links in the lake exosystem and be an illustration of how global warming influences ecosystem of lakes.

Thus, in general, the studied lakes retain their status of a mesotrophic type of water bodies with some oligotrophic features.

ACKNOWLEDGEMENTS

This research was supported by ESF project "Formation of interdisciplinary research group for securing the sustainability of salmonid lakes in Latvia" No.2009/0214/1DP/1.1.1.2.0/09/APIA/VIAA/089.

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