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Phytoplankton and Periphytic Analysis as Indicators of Water Quality of Durowskie Lake in Wągrowiec

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Table of Contents

1. Introduction

The most important primary producers of freshwater ecosystems are usually summarized under the term algae. They form a very diverse group of polyphyletic species covering organisms of the two domains of Bacteria and Eukarya alike. Therefore it is quite difficult to find a universal definition for algae. Most commonly they are referred to as autotrophic organisms that contain at least chlorophyll a and settle benthic or pelagic biotopes.

Algae adapt fast to changes in their environment which makes them a sensitive indicator for pollution of limnic ecosystems. Their occurrence in all kinds of water bodies, simple sampling methods and easy determination that needs no more equipment than a microscope makes algae a preferential research object. Thus they are a key stone of all freshwater monitoring programs.

In July 2012 the Adam Mickiewicz University of Poznan hosted the international summer school "Ecological state of the lake during restoration measures" concerned with the lake Durowskie. One integral topic studied was the algae composition of the lake. Phytoplankton and Periphyton have been investigated in several sampling sites according to procedures given in the EU Water Framework Directive.

The samples collected during the field work in Wągrowiec have been analyzed and the data gained was evaluated to assess the trophic status of the water body and its development.

Phytoplankton and Periphyton species composition have been determined and their distribution in eight representative sites of the lake has been studied. This was done in order to gain knowledge about the spatial and temporal development of algae distribution in the lake Durowskie.

Based on the periphytic diatom's index an estimation of the water quality was carried out with the aim of evaluating the development of the restoration project which started in 2008. Finally some hints for further management measures could be derived from the analysis results.

2. Materials and Methods

2.1 Investigated Area

Lake Durowskie, which covers an area of 143 ha (table 1), is situated in the vicinity of Wagrowiec, Greater Poland.

Table 1: Main Characteristics of Lake Durowskie

Surface	143.7 ha
Volume	11,322,900 m^3
Maximum depth	14.6 m
Average depth	7.9 m
Main tributary	Struga Golaniecka
Surface of the entire sampling area	236.1 km^2
Surface of the direct catchment area	1.581 ha
Share of agricultural area	58.26 %
Share of forests	33.52 %
Urban area	8.25 %

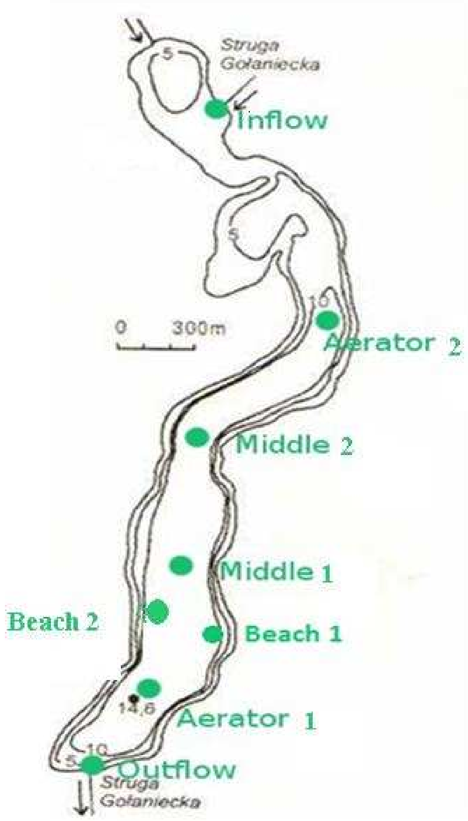


Figure 1: Map of Lake Durowskie and sampling sites

2.2 Methods

In order to analyze the phytoplankton, water samples were collected from seven stations across the Durowskie Lake: Aerator 1, Aerator 2, Middle 1, Middle 2, Inflow, Beach 1 and Beach 2 (figure 1). For periphyton, we had one extra sampling site, the outflow of the lake. The samples were taken during 6 days, starting from 2nd July to 7th July 2012. The depth of sampling was 0 meters, 1 meter and 2 meters. Lugol solution was used to preserve the phytoplankton in special plastic recipients. Suitable small stones with visible growth of periphyton were also collected.

The individual samples consisting of diatoms were analyzed under a light microscope in the laboratory. Species were identified and the biomass was calculated. For a precise quantitative assessment of the diatoms, we counted the cells in 50 randomly selected fields inside the slide. We multiplied the number of cells of each species by the volume of one cell (Edler 1987, Rott 1981); data was expressed in mg x l^{-1}. Standard species were established (Economou-Amilli, 1979). After the analysis the trophic index of the Diatoms was figured to show the trophic state of lake Durowskie. Additionally, the Jaccard and Shannon-Weaver index were determined to compare the variations of phytoplankton and periphyton communities between 2008 and 2012.

3. Results and Discussion

3.1 Number of Species

The laboratory analysis of all the samples that had been collected during the field work resulted in a total algae species number of **54** in the year 2012. As can be seen in figure 2 the number of determined species was rising from 50 in 2008 to 84 in 2011. The decline in species number in comparison with the 2011 can be explained by two independent factors that occurred at the same time.

Firstly the year 2012 had an unusually rainy and cold June. Therefore the water body of the lake was colder and enriched with more particles from the rain inflow. This leads to a very late development of the green algae which are adapted to warm and clear water. As the favorable conditions for green algae have not been met this year, the number in species of that group was lower than in the years before.

A second explanation for the backdrop is the higher grazing pressure by zooplankton in the lake. This can be attributed to the introduction of pike which control the predators of the zooplankton. Thus a higher density of zooplankton, which feed on the algae, was achieved in the lake Durowskie.

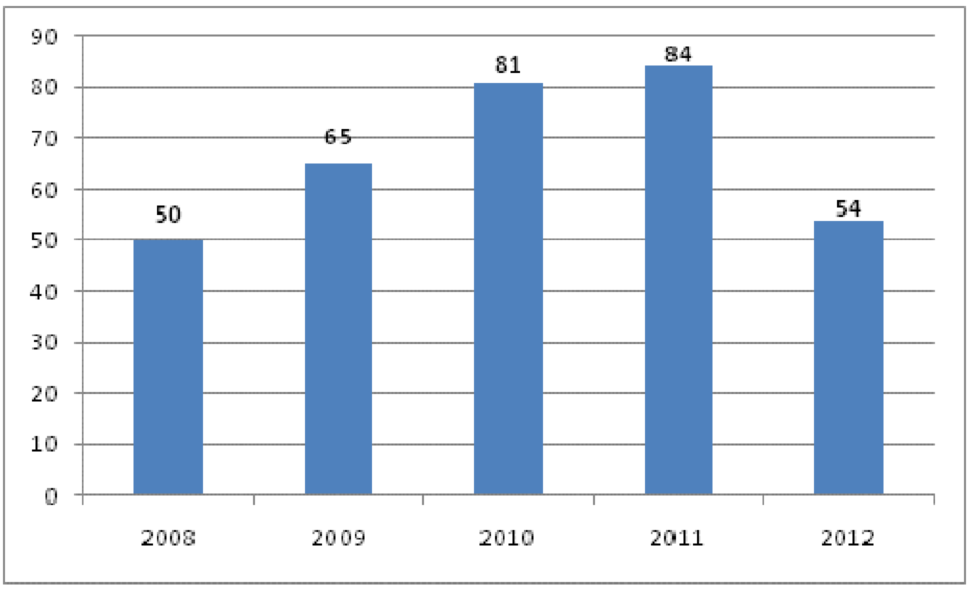


Figure 2: Total Number of Algae Species

3.2 Dominance of Algae Groups

The distribution of algae in the samples showed a significant difference between the inflow and the sampling sites on the lake. As can be seen in figure 2 and 3 Cyanobacteria were the most dominant group in the inflow, whereas they were absent in all other sampling sites. This indicates a higher water quality in the lake compared to the inflow.

Regarding the number of cells per liter the Diatoms were the dominating group of algae at all sampling sites on the lake (Figure 2). That was caused by the really high numbers of *Fragilaria ulna* and *Fragilaria crotonensis*. Taking into account the biomass however the Dinophytes are the second group dominating the lake area. Reason for that is most probably the high grazing pressure by zooplankton which fosters the growth of bigger algae, as they are harder to be eaten.

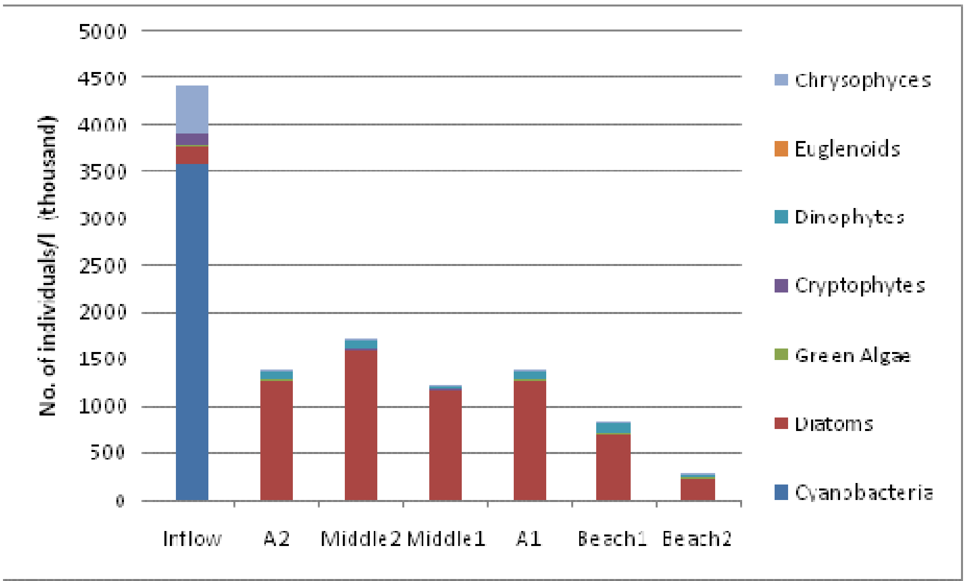


Figure 3: Quantity distribution of algae groups at the sampling sites

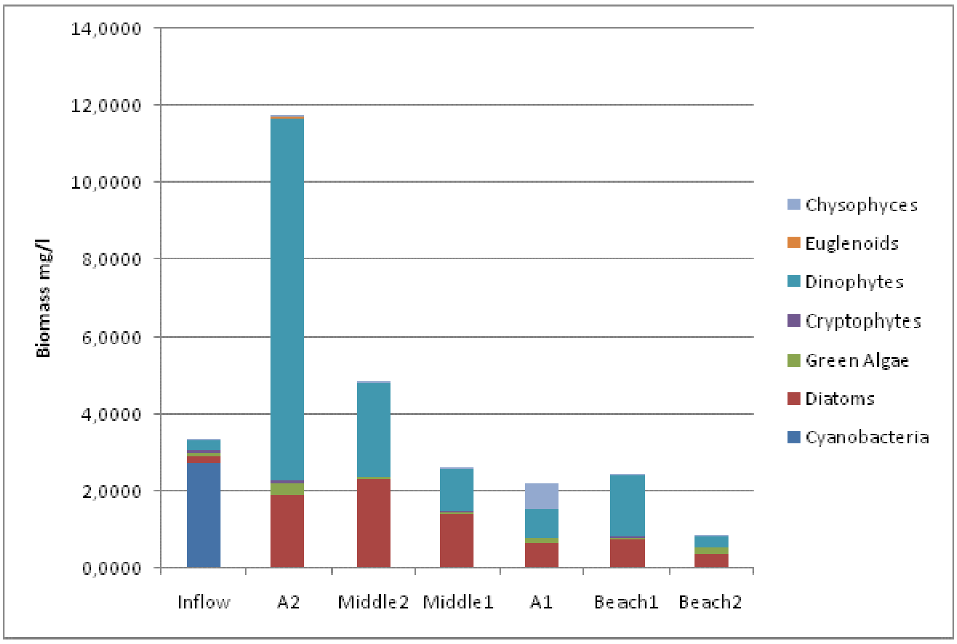


Figure 4: Biomass distribution of algae groups at the sampling sites

3.3 Periphyton

The periphyton community was analyzed by determining the species of 500 individuals. Certain species of periphytic algae are associated with specific levels of oxygen saturation of the water (Table 2). Compared to the results of the two previous years the number of algae indicating very good or good water quality increased. The indicators of moderate and bad quality decreased.

However *Gomphonema parvulum* which indicates poor water quality was the most abundant species growing dramatically from 2011 to this year. There has to be emphasized that this only occurred in site 4. All the other sampling sites showed only one to 34 individuals. The Reason for such a high abundance of *Gomphonema parvulum* at site 4 is most probably the use of the area as wild beaches where people also let their dogs swim. Resulting sediment turbulence causes the lower level of oxygen in the water.

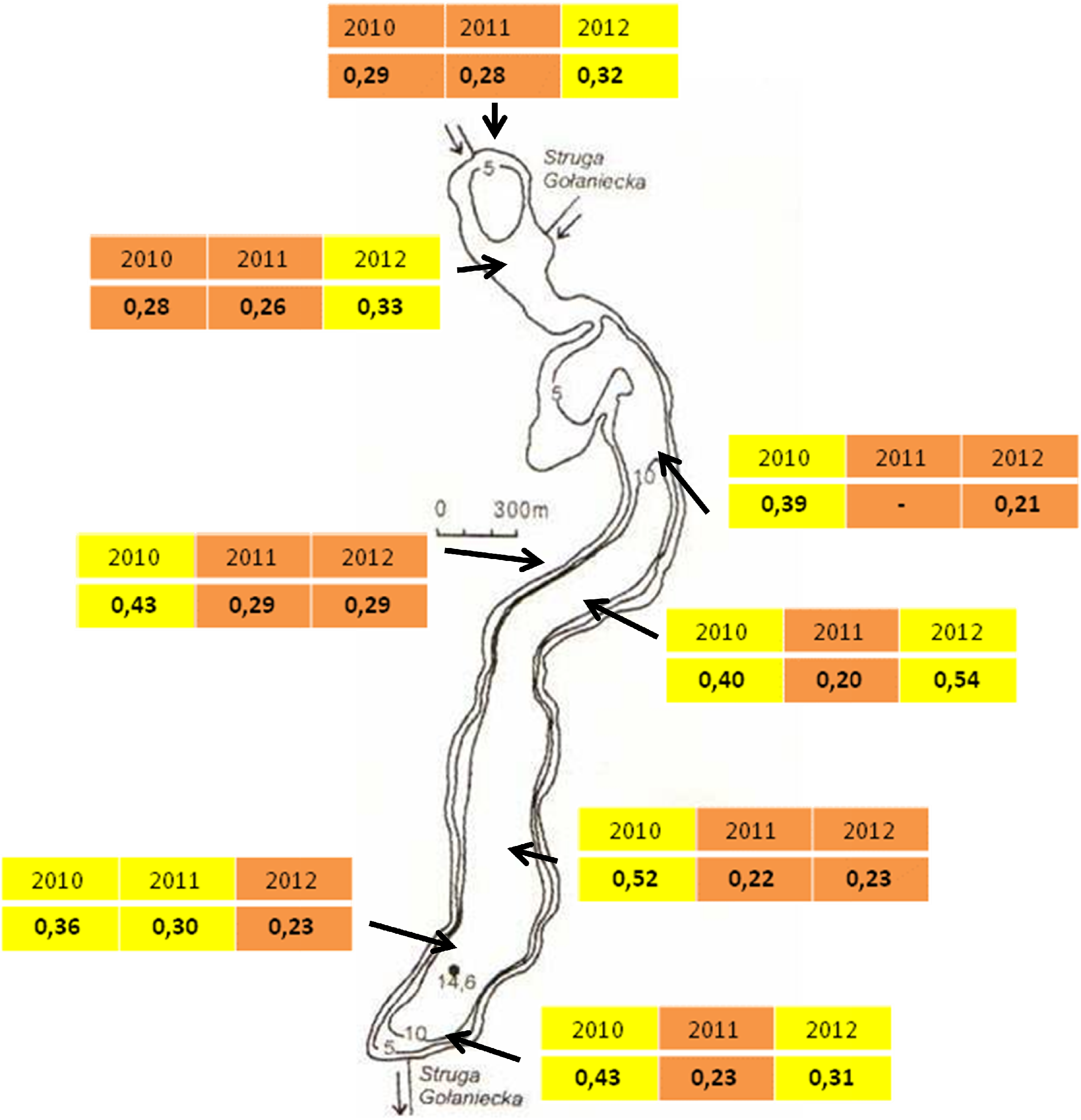
Table 2: Number of individuals per species counted (in brackets) out of a total of 500 and their associated oxygen level preference.

Preferred Oxigen saturation	2012	2011	2010
Very good 100%	Achnanthes minutissima (94)	Achnanthes minutissima (56)	Achnanthes minutissima (10)
Good 75%	Cyclotella radiosa (65)	Cyclotella radiosa (40)	Cyclotella radiosa (28)
Moderate 50%	Navicula capitata (8)	Fragilaria capucina (74)	Gyrosigma attenuatum (25)
Poor 30%	Gomphonema parvulum (327 at site 4; 1-34)	Gomphonema parvulum (10)	Surirella odalis (6)
Bad 10%	Cyclotella meneghiniana (3)	Cyclotella meneghiniana (6)	Cyclotella meneghiniana (1)

3.4 Diatom Index

The diatom index rose from poor to moderate in the two sites in the northern part of the lake Durowskie (Figure 4). An explanation for that is the low human impact in this part of the lake with low sewage input that enables the water quality to recover better than in the other areas.

In the central and southern parts of the lake the diatom index stayed poor or fluctuated between moderate and poor. So no clear development can be seen here. But even though the quality did not increase in that area, it is obvious that there was no decrease in status.



quality and yellow for

3.5 Nygaard`s Mixed Index

One of the indexes used to assess the trophic state at Wągrowiec Lake was proposed by Nygaard (1949), and it is based in several algae groups.

Compound Quotient = (Cyanobacteria + Chlorococcales + Centric Diatoms + Euglenoids) / Desmids

The result of the calculation above points to one of the trophic level states seen at the table 3:

Table 3: Trophic levels according Dokulil (after Nygaard, 1949)

Legend	Result
Dystrophic	0 - 0.3
Oligotrophic	< 1.0
Mesotrophic	1.0 - 2.5
Eutrophic	3 - 5
Hypertrophic	5 - 20
Polytrophic	10 - 43

After the assessment of the sampling sites, the results point to an improvement of the indexes. Though the hypertrophic situation of the lake, it is very important to bounce the enhancement of the general situation. The Middle 1 sampling site, for example, showed a change in the category from hypertrophic to eutrophic. On the other hand the Beach 1 sampling site showed a decrease in the index, probably caused by the high human disturbance in the area. The table 2 presents the results from all the sampling sites for this year, as well as the sampling sites since 2008, as a measure for comparison (some points sampled in the previous years were not measured in this summer).

Table 4: Trophic state of the sampling areas from 2008-2012 at Wągrowiec Lake.

Station	2008	2009	2010	2011	2012	Trophyc State
Aerator 1	9,67	16	8,3	9	7	Hypertrophy
Aerator 2	-	26	11,5	5	8	Hypertrophy
Middle 1	-	9	12,5	13	3	Eutrophy
Middle 2	-	-	8,3	18	9	Hypertrophy
Inflow	-	-	1,8	17	9	Hypertrophy
Outflow	-	-	6,5	5	-	-
North	-	-	11,5	5,3	-	-
Beach 1	-	-	-	3	9	Hypertrophy
Beach 2	-	-	-	-	5	Eutrophy

3.6 Evenness and Shannon-Weaver Index

The Shannon-Weaver index, or just Shannon Index, is being a common indicator in biological diversity and in ecological monitoring to represent species diversity, abundance, on an area (Spellerberg and Fedor, 2003). Eveness is also a diversity index, but it shows how connected (how even) the species are, according to the relation among the number of individuals (Mulder et. al, 2004). The relation between both indexes can defined as:

$$E = \frac{H}{H_{\max}} = \frac{-\sum_{i=1}^{S} p_i \ln\ p_i}{\ln\ S}$$

where *E* is eveness, *H* is Shannon-Weaver index, *S* is the number of species, *pi* is the relative abundance of species and *i* is the community (Gulis and Suberkropp, 2004).

The table 3 and table 4 show the results from the calculation of the indexes with, in most cases, an improvement for the values in comparison with 2011 but still well below the indicators presented in 2010. One possible explanation is that in 2010, after the measurements realized at the lake, was started a biomanipulation regime with the introduction of pikes (*Esox sp.*), aiming the increase of zooplankton in order to graze the cyanobacteria in the area. This regime made a drop in the index for 2011 and the improvement for 2012 shows a natural increasing of the index due the better conditions in the lake.

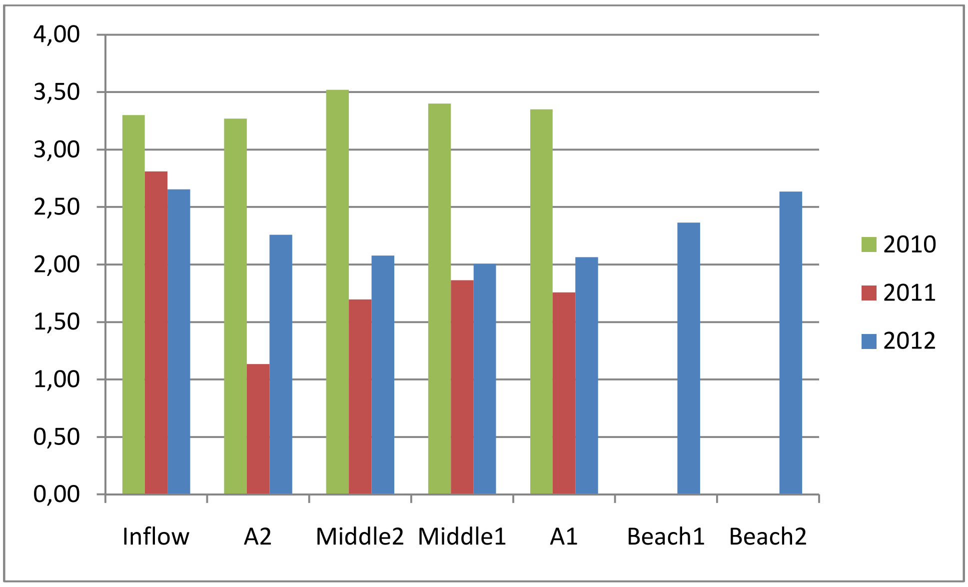


Figure 6: Comparison for the Shannon-Weaver index for the years 2010 to 2012.

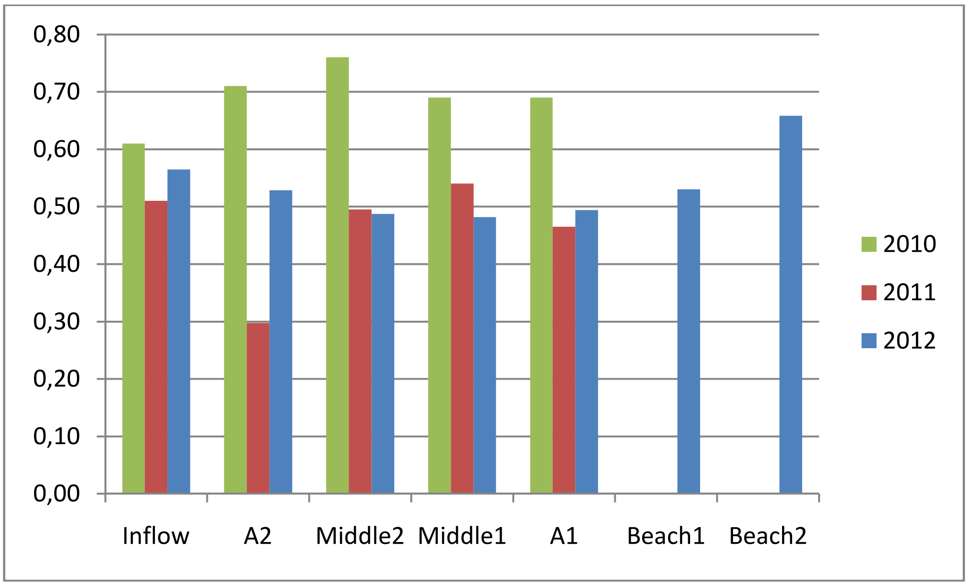


Figure 7: Comparison for the Eveness index for the years 2010 to 2012.

3.7 *Hildenbrandia rivularis*

The red algae Hildenbrandia rivularis is a well-know specie used as bioindicator for good water quality. It is being regularly used to demonstrate improvement or favorable conditions in lake environments. The presence of this specie at Wągrowiec Lake has been reported in the previous researches presenting an increase in the area between 2010 and 2011 but keep stable for 2012, as demonstrated in the picture below.

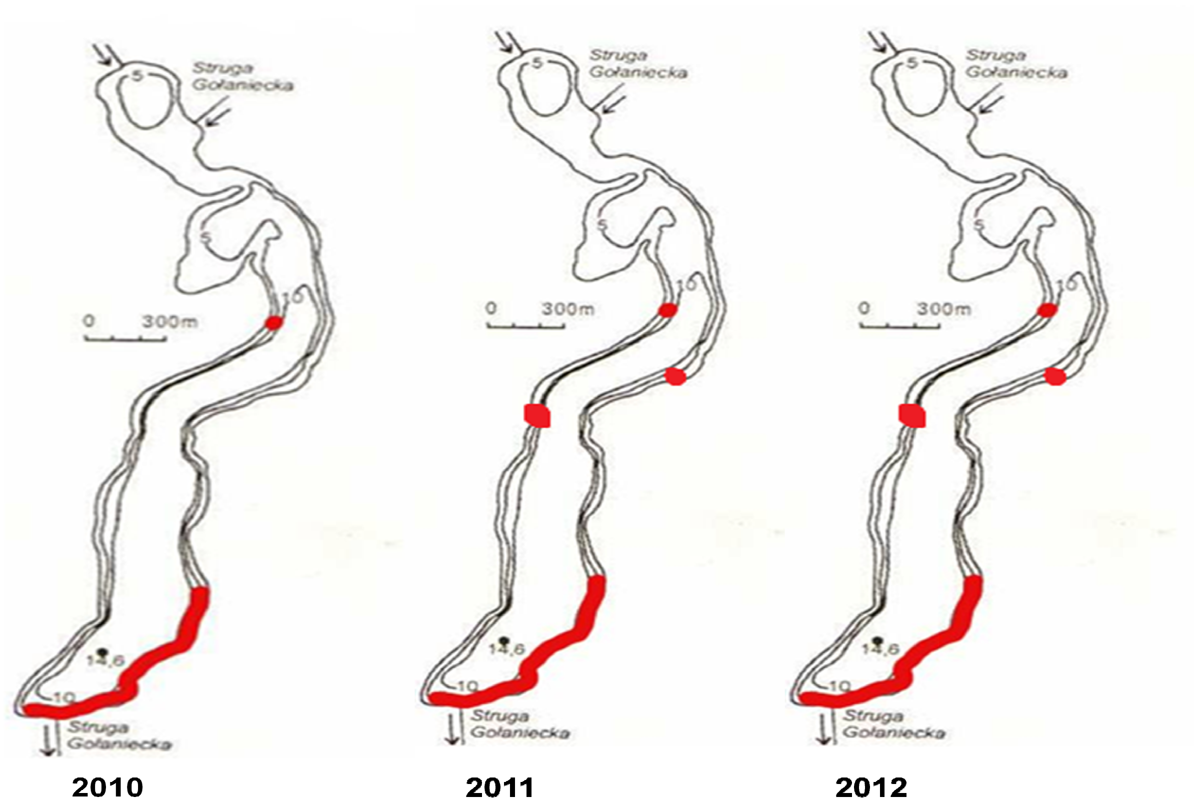


Figure 8: Map showing the presence of *hildenbrandia rivularis* at Wągrowiec Lake

4. Conclusion

The research done on algae distribution and abundance in various sites of the lake Durowskie revealed some major trends in the development of the lake. First of all the Cyanobacteria decreased dramatically in the lake itself and have only been detected in the water sample from the inflow in high quantity. This development is representing the general change of the lake from hypertrophic to eutrophic state. Besides the Nygaard's mixed index showed the same trend.

An increase in the number of periphyton species adapted to high levels of oxygen dissolved in the water further underlines the success of the restoration efforts implemented since 2008.

The Jaccard index also pointed to a further change in the algae community composition away from its original state of the time before the restoration measures have been implemented.

Moreover the effect of the biomanipulation measures proved efficient in two ways. Firstly Diatoms and Dinophytes became the most dominant groups of phytoplankton as they are more resistant to zooplankton grazing than others. Secondly the overall number of taxa determined decreased due to the higher grazing pressure.

All in all the state of the lake is still eutrophic, but a continuous improvement can be seen in some fields of study. Some other data are more ambiguous and show that there is still more to be done on the way to a good ecological state of the lake Dubrowskie.

5. Reference

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Gulis, V. and Suberkropp, K., 2004. Effects of whole-stream nutrient enrichment on the concentration and abundance of aquatic hyphomycete conidia in transport. Mycologia 96, pp. 57-65.

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Spellerberg, I. F. and Fedor, P. J., 2003. A tribute to claude Shannon (1916-2001) and a plea for more rigorous use of species richness, species diversity and the `Shannon-wiener` index. Global Ecology & Biogeography 12, pp. 177-179.

6. Annexes

Taxa	site1	site2	site3	site4	site5	site6	site7	site8
Achnanthes exigua Grun.								9
Achnanthes minutissima Kützing	56	12	15	3	6	8	8	8
Amphora ovalis Kützing							9	
Amphora pediculus (Kütz.) Grunow			8			6		6
Cocconeis placentula Ehr.	5	12	7			17	9	19
Cyclotella radiosa (Grun.) Lemm.					6			7
Cymbella affinis Kützing	5	9	8					
Cymbella minuta Hilse		15		5				
Eunotia praerupta Ehr.							8	
Fragilaria arcus (Ehr.) Cleve								
Fragilaria capucina (Desm.) Rabenhorst						8	7	
Fragilaria crotonensis Kitton	5							
Fragilaria martyi (Heribaud) Lange-Bertalot			7					
Fragilaria ulna (Nitzsch) Lange-Bertalot	5							
Gomphonema intricatum Ehr.				21	9			
Gomphonema olivaceum (Horn.) Breb.				12	29	16		
Gomphonema parvulum (Kütz.) Kütz.				44	6			

Tab.1. Periphyton dominants of Lake Durowskie in July 2012

ANNEXES

Phytoplankton

Annex 1. Phytoplankton of Lake Durowskie in July 2012 (A1 - aerator 1; A2 – aerator 2; F – frequency)

	n=1	n=5	n=4	n=4	n=3	n=1	n=1	n=20
	0m	0-1m	0-1m	0-1m	0-2m	0m	0m	
	Inflow	A2	Middle 2	Middle 1	A1	Beach1	Beach2	F [%]
Cyanoprokaryota - cyanobacteria								
Aphanizomenon flos-aquae (L.) Ralfs	+	+	+	+	+		+	50
Limnothrix redekei (Van Goor) Meffert	+	+	+	+	+	+	+	57
Microcystis aeruginosa Kützing			+					4
Phormidium granulatum Gardn. Anagn.		+						4
Planktolyngbya limnetica (Lemm.) Kom. – Legn. Et Cron.	+							4
Planktothrix agardhii (D.C. ex Gom.) Anagn. et Kom.	+	+	+		+	+	+	29
Pseudanabaena limnetica (Lemm.) Kom.	+							4
Spirulina maior Kütz			+					4
Bacillariophyceae - diatoms								
Asterionella formosa Hasall		+	+	+	+	+	+	57
Cocconeis placentula Ehr.				+				4
Cyclotella ocellata Pant.		+	+	+	+			18
Cyclotella radiosa (Grun.) Lemm.	+	+	+	+	+	+	+	71
Cymbella minuta Hilse ex Rabenhorst		+			+			14
Fragilaria crotonensis Kitton	+	+	+	+	+	+	+	71
Fragilaria ulna (Nitzsch) Lange-Bertalot	+	+	+	+	+	+	+	71
Fragilaria ulna var. *angustissima* Sippen	+	+			+			11

Gomphonema acuminatum Ehr.	+			+				7
Navicula radiosa Kützing		+	+					7
Nitzschia palea (Kütz.) W. Smith	+	+	+	+	+			18
***Chlorophyta*- green algae**								
Characium aqngustatum A. Braun					+			4
Coelastrum astroideum De Notaris			+	+		+		11
Cosmarium abbreviatum Raciborski	+							4
Cosmarium regnellii Wille								4
Cosmarium laeve Rabenhorst				+			+	4
Desmodesmus communis (Hegew.) Hegew.		+	+	+	+	+		36
Golenkinia radiata Chodat	+		+	+	+		+	25
Monoraphidium contortum (Thur.) Kom.-Legn.	+	+						7
Mougeotia sp.					+			4
Oocystis lacustris Chodat		+				+		7
Pediastrum boryanum (Turpin) Meneg.		+	+	+	+	+		46
*Phacotus lenticularis (*Ehr.) Stein	+	+	+	+	+	+	+	39
Provasoliella saccata (Skuja) Ettl					+			4
Scenedesmus acuminatus (Lager.) Chodat		+	+					7
Scenedesmus bicaudatus Dedusenko				+				4
Scenedesmus ecornis (Ehr.) Chod.					+			4
Sphaerocystis planctonica (Korsikov) Bourrelly	+	+	+	+	+	+	+	54
Tetraedron minimum (A. Br.) Hansgirg		+	+		+			14
Staurastrum gracile Ralfs				+	+	+		11
Cryptophyta - cryptophytes								
Cryptomonas erosa Ehrenberg	+	+	+	+	+	+	+	64
Cryptomonas marssonii Skuja		+	+					11
Cryptomonas ovata Ehrenberg		+		+	+			11

Cryptomonas rostrata Troitzskaja emend I. Kiselev	+	+	+	+	+		+	39
Rhodomonas minuta Skuja	+	+	+	+	+			32
Dinophyta - dinophytes								
Peridinopsis berolinense (Lemm.) Bourrelly	+	+	+		+	+		21
Ceratium hirundinella (F. B. Müller) Bergh	+	+	+	+	+	+		57
Peridiniopsis cuningtonii Lemm.	+	+	+	+	+	+	+	71
Peridinium cinctum (O.F. Müller) Ehrenberg	+	+	+	+	+	+	+	71
Peridinopsis elpatiewskyi (Ostenf.) Bourrelly		+	+	+	+	+		54
Euglenophyta - euglenoids								
Trachelomonas hispida (Perty) Stein		+			+	+		14
Trachelomonas volocina Ehrenberg	+							4
Euglena caudata Hübner	+		+	+				4
Chrysophyceae - chrysophyces								
Erkenia subaequiciliata Skuja	+	+	+	+	+	+		50
Dinobryon divergens Imhof		+	+	+	+	+	+	50
Dinobryon bavaricum Imhoff		+	+	+	+			25

Annex 2. Comparison of species taxa composition in different investigated years in July in Lake Durowskie

	2008	2009	2010	2011	2012
***Cyanoprokaryota* - cyanobacteria**					
Anabaena flos-aquae Brebisson		+			
Aphanizomenon aphanizomenoides (Forti) Hort. & Kom.	+				+
Aphanizomenon flos-aquae (L.) Ralfs	+	+	+	+	
Aphanizomenon gracile Lemmerman	+				
Aphanizomenon isatschenkoi (Usacc.) Pros. - Lavrenko	+	+	+		
*Aphanocapsa grevillei (*Ber.) Rabenhorst		+			
Aphanocapsa incerta (Lemm.) Cronberg et Komarek	+	+	+		
Arthrospira massartii Kuff.		+			
Chroococcus limneticus Lemm.	+	+		+	
Chroococcus turgidus (Kűtz.) Naeg.		+		+	
Cyanogranis feruginea (Wawrik) Hind.		+	+		
Jaaginema pseudogeminatum (Schmid) Anagn. et Kom.			+	+	
Limnothrix lauterbornii(Schmidle) Anagn.		+			
Limnothrix redekei (Van Goor) Meffert	+		+	+	+
Lyngbya hieronymusii Lemm.		+			
Microcystis aeruginosa Kützing	+			+	+
Microcystis flos-aquae (Wittrock) Kirchner			+		
Jaaginema gracile (Bocher) Anagn. et kom.		+			
Phormidium granulatum Gardn. Anagn.	+	+	+		+
Phormidium tenue (Agards ex Gomont) Anagn. et kom.		+			
Planktolyngbya limnetica (Lemm.) Kom. – Legn. Et Cronenberg		+	+	+	+
Planktothrix agardhii (D.C. ex Gom.) Anagn. et Kom.	+	+	+	+	+
Pseudanabaena limnetica (Lemm.) Kom.	+	+	+		
Spirulina laxissima (W. West)			+		
Spirulina mior Kütz.					+

Bacillariophyceae - diatoms					
Achnanthes exigua Grun.			+		
Achnanthes minutissima Kützing	+		+	+	
Amphora ovalis Kützing	+	+	+	+	
Amphora pediculus (Kütz.) Grun.			+		
Asterionella formosa Hasall		+		+	+
Cocconeis euglypta (Ehr.) Clevei	+				
Cocconeis placentula Ehr.	+		+	+	+
Cyclotella atomus Hustedt		+			
Cyclotella meneghiniana Kütz.	+	+	+		
Cyclotella ocellata Pant.	+		+	+	+
Cyclotella operculata (Ag.) Kützing	+	+	+		
Cyclotella radiosa (Grun.) Lemm.	+	+	+	+	+
Cymbella affinis Kützing				+	
Cymbella microcephala Grun.				+	
Cymbella minuta Hilse ex Rabenhorst	+		+	+	+
Diatoma vulgare Bory				+	
Fragilaria capucina (Desm.) Rabenhorst				+	
Fragilaria crotonensis Kitton	+	+		+	+
Fragilaria pinnata Ehr.	+			+	
Fragilaria ulna (Nitzsch) Lange-Bertalot	+	+	+	+	+
Fragilaria ulna var. *angustissima* Sippen	+	+	+	+	+
Gomphonema acuminatum Ehr.					+
Gomphonema olivaceum (Horn.) Breb.			+	+	
Gomphonema parvulum (Kütz.) Kütz.				+	
Melosira varians Ag.	+				
Navicula cincta (Ehr.) Ralfs	+	+	+		
Navicula mensiculus Schumann	+				

Navicula radiosa Kützing			+	+	+
Naviula sp.			+		
Nitzschia palea (Kütz.) W. Smith				+	+
Nitzschia sigmoidea (Ehr.) W. Smith				+	
Nitzschia sinuata (W. Sm.) Grunow				+	
Pinnularia viridis (Nitzsch) Ehr.				+	
Placoneis gastrum(Ehr.) Meresch.		+			
Staurosira construens Ehr.		+			
Chlorophyta- green algae					
*Ankistrodesmus falcatus(*Corda) Ralfs		+			
Characium aqngustatum A. Braun		+		+	+
Chlamydomonas globosa Snow	+	+	+	+	
Chlamydomonas passiva Skuja			+		
Chlamydomonas reinchardtii Dangeard		+			
Closterium acutum var. *variabile* (Lemm.) Krieg.	+		+	+	
Coelasrum astroideum De Notaris			+	+	+
Coelastrum microporum Naegel.			+		
Coelastrum reticulatum (Dang.) Senn	+	+			
Cosmarium abbreviatum Raciborski	+		+	+	+
*Cosmarium exiguum*W. Archer		+			
Cosmarium margaritatum (Turp.) Ralfs				+	
Cosmarium phaseolus Brebisson in Ralfs	+		+	+	
Cosmarium laeve Rabenhorst					+
Cosmarium regnellii Wille	+	+	+		+
Crucigenia tetrapedia (Kirchner) W. et G.S. West			+		
Desmodesmus communis (Hegew.) Hegew.	+	+	+	+	+
Desmodesmus grahneisii (Heynig) Fott				+	
Desmodesmus naegellii (Meyen) Hegew.			+		

Desmodesmus opoliensis (Rchter) Hegew.			+		
Desmodesmus subspicatus (Chod.) Hegew. et Schmidt	+		+		
Dictyosphaerium pulchellum Wood	+	+	+	+	
Didymocystis planctonica Korsikov				+	
Elkatothrix gelatinosa Wille			+	+	
Golenkinia radiata Chodat	+		+	+	+
Kirchneriella contorta var. *elegans* (Schmidle) Bohlin	+				
Koliella longiseta (Vischer) Hindak	+				
Micractinium crassisetum Hortobagyi				+	
Micractinium pusillum Fresenius				+	
Mougeotia sp.				+	+
Monoraphidium arcuatum (Kors.) Hindak	+				
Monoraphidium circinale (Nyg.) Nygaard	+				
Monoraphidium contortum (Thur.) Kom.-Legn.	+	+	+	+	+
Monoraphidium griffithii (Berk.) Kom.-Legn.	+		+		
Monoraphidium irregulare (G.M. Sm.) Kom.-Legn.	+		+		
Monoraphidium komarkovae Nygaard	+	+	+		
Monoraphidium minutum(Nageli) Kom. - Legn.		+			
Monoraphidium obtusum (Kors.)Kom. - Legn.	+				
Nephrocytium limneticum (G. M. Sm.) G. M. Sm.				+	
Oocystis lacustris Chodat	+	+	+	+	+
Palmelochette tenerrima Kors.				+	
Pandorina morum (O.F. Müller) Bory			+		
Pediastrum boryanum (Turpin) Meneg.			+	+	+
Pediastrum tetras (Ehr.) Ralfs			+		
Phacotus lendneri Chodat.				+	
*Phacotus lenticularis (*Ehr.) Stein	+			+	+
Provasoliella saccata (Skuja) Ettl					+
Pteromonas angulosa (Carter) Lemm.		+	+		

Pteromonas angulosa (Carter) Lemm.			+		
Pteromonas cordiformis Lemm.			+		
Scenedesmus acuminatus (Lager.) Chodat			+		+
Scenedesmus bicaudatus Dedusenko			+	+	+
Scenedesmus dimorphus (Turp.) Kütz.		+		+	
Scenedesmus ecornis (Ehr.) Chod.			+	+	+
Scenedesmus obtusus Meyen				+	
Scenedesmus regularis Swirenko		+			
Scenedesmus verucosus Roll				+	
Sphaerocystis planctonica (Korsikov) Bourrelly				+	+
Staurastrum gracile Ralfs			+	+	+
Tetraedron caudatum (Corda) Hansgirg	+		+		
Tetraedron minimum (A. Br.) Hansgirg	+	+	+	+	+
Tetraedron triangulare (Chod.) Kom.	+	+		+	
Tetrastrum glabrum (Roll) Ahlstr. et Tiff			+	+	
Tetrastrum staurogeanieforme (Schroed.) Lemm.			+	+	
Treubaria schmidlei (Schroeder) Fott et Kovacik		+	+	+	
Cryptophyta - cryptophytes					
Chroomonas acuta Uterm.	+				
Cryptomonas erosa Ehrenberg	+	+	+	+	+
Cryptomonas gracilis Skuja		+			
Cryptomonas marssonii Skuja	+	+	+	+	+
Cryptomonas ovata Ehrenberg	+	+	+	+	+
Cryptomonas rostrata Troitzskaja emend I. Kiselev	+		+	+	+
Rhodomonas globosa Skuja		+			
Rhodomonas minuta Skuja	+	+	+	+	+
Dinophyta - dinophytes					

Ceratium hirundinella (F. B. Müller) Bergh	+	+		+	+
Gymnodinium aeruginosum Stein	+				
Gymnodinium albulum Lindemann	+				
Peridiniopsis cuningtonii Lemm.	+	+	+	+	+
Peridinium cinctum (O.F. Müller) Ehrenberg	+	+	+	+	+
Peridinopsis berolinense (Lemm.) Bourrelly	+	+	+	+	+
Peridinopsis elpatiewskyi (Ostenf.) Bourrelly	+		+	+	+
Euglenophyta - euglenoids					
Colacium vesiculosum Ehr.		+		+	
Euglena caudata Hübner					+
Euglena pisciformis Klebs		+		+	
Phacus orbicularis Hubner	+	+			
Trachelomonas hispida (Perty) Stein	+		+	+	+
Trachelomonas planctonica Swirenko	+		+	+	
Trachelomonas volocina Ehrenberg	+		+	+	+
Chrysophyceae - chrysophyces					
Chrysococcus rufescens Klebs				+	
Dinobryon bavaricum Imhoff		+	+	+	+
Dinobryon crenulatum W. et G.S. West		+	+	+	
Dinobryon divergens Imhof		+	+		+
Dinobryon sociale Ehrenberg	+		+	+	
Erkenia subaequiciliata Skuja	+	+	+		+

Annex 3. Phytoplankton biomass (mg l^{-1}) in the epilimnion layer (0-2m) of Lake Durowskie

Species	**Struga**	**A2**	**Middle2**	**Middle1**	**A1**	**Beach1**	**Beach2**
	n=1	n=5	n=4	n=4	n=4	n=1	n=1
Chroomonas acuta Uterm.							
Cosmarium regnellii Wille							0,0010
Mougeotia sp.					0,0075		
Characium aqngustatum A. Braun					0,0002		
Gomphonema acuminata					0,0002		
Provasoliella saccata					0,0000		
Scenedesmus ecornis (Ehr.) Chod.					0,0000		
Cocconeis placentula Ehr.				0,0028			
Cosmarium laeve				0,0003			
Scenedesmus bicaudatus Dedusenko				0,0003			
Staurastrum gracile Ralfs				0,0003	0,0005	0,0020	
Pseudanabaena limnetica (Lemm.) Kom.	0,0790						
Planktolyngbya limnetica (Lemm.) Kom. – Legn. Et Cronenberg	0,0440						
Gomphonema acuminatum	0,0020			0,0003	0,0002		
Cosmarium abbreviatum Raciborski	0,0010						
Trachelomonas volocina Ehrenberg	0,0010						
Cymbella minuta Hilse ex Rabenhorst		0,0091			0,0003		
Oocystis lacustris Chodat		0,0040				0,0020	
Trachelomonas hispida (Perty) Stein		0,0017			0,0007	0,0010	
Euglena pisciformis Klebs		0,0004					
Cryptomonas ovata Ehrenberg		0,0004		0,0003	0,0008		
Fragilaria ulna var. *angustissima* Sippen	0,0370	0,0004			0,0025		
Monoraphidium contortum (Thur.) Kom.-Legn.	0,0004	0,0003					
Fragilaria ulna (Nitzsch) Lange-Bertalot	0,0910	1,5178	2,1528	1,3098	0,5198	0,6420	0,2130
Peridinium cinctum (O.F. Müller) Ehrenberg	0,0640	3,9068	1,1778	0,2045	0,3760	0,9080	0,1260

Ceratium hirundinella (F. B. Müller) Bergh	0,1190	2,4650	0,8123	0,6718	0,2328	0,0070	
Peridiniopsis cuningtonii Lemm.	0,0280	2,5788	0,2553	0,1755	0,1340	0,4060	0,1380
Peridinopsis elpatiewskyi (Ostenf.) Bourrelly		0,4390	0,1873	0,0475	0,0098	0,0570	
Fragilaria crotonensis Kitton	0,0460	0,2452	0,0993	0,0648	0,0736	0,0870	0,1200
Pediastrum boryanum (Turpin) Meneg.		0,2348	0,0590	0,0295	0,1175	0,0120	
Cyclotella ocellata Pant.		0,0016	0,0195	0,0003	0,0002		
Cyclotella radiosa (Grun.) Lemm.	0,0030	0,0676	0,0120	0,0225	0,0168	0,0060	0,0040
Sphaerocystis planctonica (Korsikov) Bourrelly	0,0710	0,0222	0,0118	0,0038	0,0100	0,0170	0,1540
Cryptomonas erosa Ehrenberg	0,0040	0,0462	0,0053	0,0053	0,0026	0,0120	0,0020
Peridinopsis berolinense (Lemm.) Bourrelly	0,0440	0,0190	0,0035		0,0018	0,2000	
Dinobryon bavaricum Imhoff		0,0006	0,0035	0,0003	0,6506		
Limnothrix redekei (Van Goor) Meffert	0,6540	0,0008	0,0028	0,0010	0,0015	0,0010	0,0010
Cryptomonas rostrata Troitzskaja emend I. Kiselev	0,0100	0,0134	0,0028	0,0030	0,0008		0,0330
Asterionella formosa Hasall		0,0131	0,0020	0,0008	0,0029	0,0020	0,0010
Dinobryon divergens Imhof		0,0138	0,0020	0,0030	0,0007	0,0020	0,0020
Planktothrix agardhii (D.C. ex Gom.) Anagn. et Kom.	0,3830	0,0100	0,0018		0,0003	0,0010	0,0010
Euglena caudata Hübner	0,0060		0,0010	0,0010			
Erkenia subaequiciliata Skuja	0,0280	0,0073	0,0009	0,0010	0,0009	0,0010	
Aphanizomenon flos-aquae (L.) Ralfs	1,5490	0,0153	0,0008	0,0038	0,0064		
Desmodesmus communis (Hegew.) Hegew.		0,0018	0,0008	0,0005	0,0002	0,0020	
Coelastrum astroideum De Notaris			0,0005	0,0053		0,0130	
Cryptomonas marssonii Skuja		0,0101	0,0005				
Navicula radiosa Kützing		0,0038	0,0005				
Golenkinia radiata Chodat	0,0003		0,0003	0,0004	0,0006		0,0040
*Phacotus lenticularis (*Ehr.) Stein	0,0040	0,0286	0,0003	0,0030	0,0004	0,0020	0,0010
Rhodomonas minuta Skuja	0,0730	0,0098	0,0003	0,0005	0,0003		
Nitzschia palea (Kütz.) W. Smith	0,0020	0,0001	0,0003	0,0005	0,0001		
Scenedesmus acuminatus (Lager.) Chodat		0,0012	0,0001				
Microcystis aeruginosa Kützing			0,0001				

Spirulina maior			0,0001				
Tetraedron minimum (A. Br.) Hansgirg		0,0000	0,0000		0,0000		

Annex 4. Phytoplankton dominants quantity of Lake Durowskie in July 2012

Species	**Struga**	**A2**	**Middle2**	**Middle1**	**A1**	**Beach1**	**Beach2**
	n=1	n=5	n=4	n=4	n=4	n=1	n=1
Cosmarium regnellii Wille							800
Cocconeis placentula Ehr.				400			
Cosmarium laeve Rabenh.				200			
Scenedesmus bicaudatus Dedusenko				200			
Staurastrum gracile Ralfs				200		800	
Coelastrum astroideum De Notaris			400	1600		4000	
Microcystis aeruginosa Kützing			200				
Spirulina major Kützing			200				
Peridinopsis elpatiewskyi (Ostenf.) Bourrelly		8000	23400	5600	8000	8000	
Asterionella formosa Hasall		4480	12600	5800	4480	10400	5600
Dinobryon divergens Imhoff		3520	3800	6800	3520	3200	4000
Pediastrum boryanum (Turpin) Meneg.		2240	2000	1000	2240	4000	
Dinobryon bavaricum Imhoff		1120	7400	400	1120		
Cryptomonas marssonii Skuja		800	400		800		
Cymbella minuta Hilse ex Rabenhorst		640			640		
Desmodesmus communis (Hegew.) Hegew.		640	1000	400	640	2400	
Phormidium granulatum Gardn. Anagn.		320			320		

Euglena pisciformis Klebs		320			320		
Oocystis lacustris Chodat		160			160	800	
Trachelomonas hispida (Perty) Stein		160			160	800	
Cryptomonas ovata Ehrenberg		160		200	160		
Cyclotella ocellata Pant.		160	2000	200	160		
Navicula radiosa Kützing		160	200		160		
Scenedesmus acuminatus (Lager.) Chodat		160	200		160		
Tetraedron minimum (A. Br.) Hansgirg		160	200		160		
Limnothrix redekei (Van Goor) Meffert	2083200	2240	9000	3800	2240	3200	1600
Aphanizomenon flos-aquae (L.) Ralfs	789600	1760	400	2000	1760		2400
Erkenia subaequiciliata Skuja	504000	8160	17400	14200	8160	9600	
Planktothrix agardhii (D.C. ex Gom.) Anagn. et Kom.	304800	1200	1400		1200	800	800
Pseudanabaena limnetica (Lemm.) Kom.	254400						
Planktolyngbya limnetica (Lemm.) Kom. – Legn. Et Cron.	139200						
Rhodomonas minuta Skuja	103200	2560	400	400	2560		
Fragilaria crotonensis Kitton	100800	135520	197000	145000	135520	202400	51200
Fragilaria ulna (Nitzsch) Lange-Bertalot	67200	1120800	1365073	979800	1120800	472000	157600
Fragilaria ulna var. angustissima Sippen	21600	160			160		
*Phacotus lenticularis (*Ehr.) Stein	4800	1440	200	3600	1440	3200	1600
Cryptomonas rostrata Troitz. emend I. Kiselev	4800	640	1200	1400	640		1600
Peridinopsis berolinense (Lemm.) Bourrelly	4800	640	400		640	1600	
Trachelomonas volocina Ehrenberg	2400						
Gomphonema acuminatum Ehr.	2400			200			
Golenkinia radiata Chodat	2400		600	800			800
Euglena caudata Hübner	2400		600	600			
Peridiniopsis cuningtonii Lemm.	2400	31200	22600	16800	31200	35200	12000
Peridinium cinctum (O.F. Müller) Ehrenberg	2400	24640	21000	8000	24640	34400	4800
Ceratium hirundinella (F. B. Müller) Bergh	2400	9600	8400	7200	9600	800	
Cyclotella radiosa (Grun.) Lemm.	2400	9440	9600	17600	9440	4800	3200

Cryptomonas erosa Ehrenberg	2400	6400	3200	3400	6400	8000	1600
Sphaerocystis planctonica (Korsikov) Bourrelly	2400	1920	5200	1600	1920	8000	10400
Monoraphidium contortum (Thur.) Kom.-Legn.	2400	160			160		
Nitzschia palea (Kütz.) W. Smith	2400	160	200	400	160		
Cosmarium abbreviatum Raciborski	800						

PERIPHYTON

Annex 5. Comparing diatoms taxa represented by the large cell numbers in periphyton communities of individual research stations in the littoral of Lake Durowskie in July 2012 (trophic state and % of oxygen according Van Dam et al 1994 ecological scale for diatoms); (Ox- oxygen, T - trophic state, O – oligotrophy, M – mesotrophy, E – eutrophy, H – hypertrophy, C – cosmopolitic)

			site1	site2	site3	site4	site5	site6	site7	site8
Ox [%]	Trophy									
		Bacillariophyceae								
75	C	*Achnanthes conspicua* Mayer		+	+			+		+
100	C	*Achnanthes exigua* Grun.		+	+	+		+		+
30	H	*Achnanthes hungarica*(Grun.) Grun.				+				+
50	E	*Achnathes lanceolata* (Breb.) Grunow				+		+	+	+
50	E	*Achnanthes lanceolata v. elliptica* Cleve sensu Straub		+						
50	E	*Achnanthes lanceolta var. rostrata* (Oestrup) Hustedt		+	+					
100	C	*Achnanthes minutissima* Kützing	+	+	+	+	+	+	+	+
-	-	*Achnanthes minutissima var. affinis* (Grun.) Lange-Bertalot								+
-	O	*Achnanthes minutissima var. garcillina* (Meister) Lange-Bertalot				+		+		+
-	-	*Achnanthidium microcephalum* (Kütz) Cleve		+						
75	E	*Amphora ovalis* Kützing	+	+	+	+	+	+	+	+
75	E	*Amphora pediculus* (Kütz.) Grunow	+	+	+	+	+	+	+	+
75	M	*Asterionella formosa* Hass				+	+	+		+
50	E	*Cocconeis euglypta* (Ehr.) Clevei	+	+						+
75	E	*Cocconeis pediculus* Ehr.		+	+	+	+	+		
50	E	*Cocconeis placentula* Ehr.	+	+	+	+	+	+		+
50	E	*Cocconeis placentula var. lineata* (Ehr.) van Henreck				+		+	+	+
-	-	*Cocconeis placentula var. pseudolineata* Geitler		+						
10	E	*Cyclotella meneghiniana* Kütz.	+	+		+	+	+		+
100	M	*Cyclotella ocellata* Pant.					+			+
100	-	*Cyclotella operculata* (Ag.) Kützing					+			+
75	E	*Cyclotella radiosa* (Grun.) Lemm.	+	+	+	+	+	+	+	+

-	-	*Cyclotella steligera* Cl. et Grun.								+
50	E	*Cymatopleura solea* (Breb.) W. Smith					+			
100	E	*Cymbella affinis* Kützing	+	+	+	+	+	+	+	+
-	-	*Cymbella aequalis* W. Sm.					+			
75	E	*Cymbella cistula* (Ehr.) Kirch.			+		+			
100	C	*Cymbella lanceolata* (Ehr.) Kirchner			+		+			
100	M	*Cymbella microcephala* Grun.	+			+			+	+
-	-	*Cymbella minuta* Hilse	+	+	+	+	+	+	+	+
-	-	*Cymbella parva* W.Sm.	+	+	+					
100	E	*Cymbella prostrata* (Berk.) Cleve					+			
50	E	*Diatoma tenuis* Agardh					+			
75	M	*Diatoma vulgaris* Bory	+		+		+	+	+	
75	M	*Diatoma vulgaris* Bory Morphotyp *ovalis*					+		+	
-	-	*Didymosphenia geminata* (L.) Schm.		+			+			
100	M	*Diploneis elliptica* (Kütz.) Cleve					+			
75	E	*Epithemia sorex* Kütz.				+				
75	M	*Epithemia turgida* (Ehr.) Kütz				+				
-	-	*Epithemia praeurpta* Ehr				+				
-	-	*Epithemia zebra* (Ehr.) Kütz.						+		
-	-	*Eunotia bidentula* W. Sm.							+	
75	C	*Eunotia bilunaris* (Ehr.) Mills var. *bilunaris*			+					
75	C	*Eunotia exigua* (Breb.) Rabenh.					+			
100	O	*Eunotia faba* (Ehr.) Grun.					+			
100	O	*Eunotia praerupta* Ehr.	+				+	+	+	+
100	O	*Fragilaria arcus* (Ehr.) Cleve		+	+					
-	M	*Fragilaria capucina* (Desm.) Rabenhorst	+		+	+	+	+	+	
100	M	*Fragilaria construens* (Ehr.) Grun.			+				+	
75	M	*Fragilaria crotonensis* Kitton	+	+		+	+	+	+	+
100	O	*Fragilaria exigua* Grun.								+
-	-	*Fragilaria heidenii* Oestrup				+				
-	-	*Fragilaria martyi* (Heribaud) Lange-Bertalot			+		+			

100	O	*Fragilaria pinnata* Ehr.	+	+	+	+	+	+	+	+
50	C	*Fragilaria ulna* (Nitzsch) Lange-Bertalot	+	+	+		+	+	+	+
100	C	*Fragilaria ulna* var. *angustissima* Sippen		+		+		+		+
100	E	*Fragilaria dilatata* (Bréb.) Lange - Bertalot					+			
50	E	*Fragilaria capucina var. vaucheriae* (Kütz.) Lange - Bertalot	+				+			
75	E	*Gomphonema acuminatum* Ehr.	+	+		+	+	+		+
100	M	*Gomphonema gracile* Ehr.					+			
75	M	*Gomphonema intricatum* Ehr.			+					
100	O	*Gomphonema angustum* Ehr.	+	+	+	+	+			
75	E	*Gomphonema micropus* Kütz.			+		+			
100	O	*Gomphonema olivaceum var. minutissimum* Hust.					+			
75	E	*Gomphonema olivaceum* (Horn.) Breb.	+	+	+	+	+	+	+	+
30	E	*Gomphonema parvulum* (Kütz.) Kütz.	+	+	+	+	+	+	+	+
-	-	*Gomphonema subtile* Ehr.	+	+			+			
50	E	*Gyrosigma acuminatum* (Kütz.) Rabenhorst						+		
75	C	*Hantzschia amphioxys* (Ehr.) Grunow					+		+	
75	C	*Meridion circulare* Ag.	+						+	
-	-	*Navicula agrestis* Hustedt								+
50	M	*Navicula capitata* Patrick in Patrick & Reimer	+	+	+	+	+		+	+
50	E	*Navicula cincta* (Ehr.) Ralfs	+		+	+	+		+	+
50	C	*Navicula cryptocephala* Kütz.				+	+			
30	E	*Navicula gregaria* Donkin				+				+
100	M	*Navicula pseudoanglica* Lange-Bertalot					+			
75	M	*Navicula radiosa* Kützing	+	+	+	+	+	+	+	+
30	C	*Navicula rhynchocephala* Kütz.			+					
75	E	*Navicula tripunctata* (O. F. Müller) Bory	+	+	+	+	+	+	+	+
75	E	*Navicula viridula (*Kütz.) Ehr.			+		+			
-	-	*Neidium productum* (W. Sm.) Cleve						+		
50	E	*Nitzschia amphibia* Grun.			+	+	+		+	
100	M	*Nitzschia angustata*		+						
-	-	*Nitzschia denticula* Grun.	+	+				+		

75	M	*Nitzschia dissipata* (Kütz) Grun.		+	+					
-	E	*Nitzschia intermedia* Hantzsch					+			
30	H	*Nitzschia palea* (Kütz.) *W. Sm.*		+		+		+	+	+
50	E	*Nitzschia paleacea* Grun.		+				+		
75	C	*Nitzschia recta* Hantzsch		+	+			+	+	+
50	E	*Nitzschia sigmoidea* (Ehr.) W. Sm.		+		+				
75	M	*Pinnularia maior* (Kütz.) Cleve			+			+		+
75	E	*Navicula eleginensis* (Greg.) Ral. In Prit.		+	+		+	+	+	+
75	E	*Rhoicosphaenia abbreviata* (Ag.) Lange-Bertalot					+			
50	E	*Rhopalodia gibba* (Ehr.) O. Müller	+						+	
50	M	*Stauroneis phoenicentron* Ehr.		+						+
-	-	*Stephanodiscus astraea* (Ehr.) Grun.				+	+		+	
30	H	*Stephanodiscus hantzschii* Grun.		+				+		+
30	E	*Surirella ovalis* Breb.					+			
100	O	*Tabellaria fenestrata* (Lyngb.) Kützing								+