International Summer School RESTLAKE

Wągrowiec and Poznań

Macrophytes as an Indicator for the Ecological State during restoration measures on Lake Durowskie

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Introduction

The attraction of Wagrowiec is Lake Durowskie, which is located in the western part of Poland. The local population and tourists use this area for water sport and other recreational activities. Due to the human influence on the lake and the catchment area, the water quality of the lake has been degraded. The ecological state of Lake Durowskie is considered to be eutrophic.

In 2008, a large bloom of cyanobacteria happened during the summer months. Due to this event, the local authorities had to close the lake for recreational activities. They decided to start a research project with a goal of restoring the ecological quality of the lake, so the lake can remain a tourist attraction.

The Water Framework Directive of the European Union (European Union, 2000) prescribes that member states are obliged to assess and report on the ecological state of all lakes exceeding a surface area 0,5 km^2 (Schaumburg et al., 2004). In the year 2009, a restoration program, including students work during a Summer School, started. The goal was to investigate the ecological status of the lake with indicators such as algae, macro-invertebrates, water physio-chemistry, macrophytes, and fishes. Further, all the different indicators are included into a Lake Management program.

As part of the restoration measures, two aerators were built in 2009 to transport oxygen from the water surface to the hypolimnion. This exchange of oxygen should prevent a further cyanobacteria bloom and ensure oxygen in the hypolimnion layer, especially during the summer months. Another restoration measure that took place was a bio-manipulation technique. A large amount of pike, a non-native predator fish, were introduced into the lake. The pike were supposed to prey on smaller fish species. The number of smaller fish species was supposed to decline and with that the amount of zooplankton should have increased, which further should have led to a decrease in phytoplankton biomass. For the restoration process of the lake, macrophytes are a good indicator to determine the ecological status of the lake because of their development at the littoral and sublittoral zone. "Macrophytes provide habitats for fish and smaller animals; they bind sediments, protect banks, absorb nutrients and provide oxygenated. Macrophytes can indicate the impact of increased nutrients in lakes and are also influenced by other pressures, such as water level change or acidification. Different combinations, quantity and numbers of macrophytes are expected to be present, depending on the lakes catchment characteristics".

(http://www.wfduk.org/resources%20/lakes-%E2%80%93-macrophytes-free-index).

Macrophytes serve as an important land – water ecotone. In this ecotone litter and sediment accumulation takes place, and therefore, the nutrient concentrations increase in the littoral zone. Especially, vegetation on the periphery of the lake is a habitat and breeding places for birds and fish species. Furthermore, macrophytes are a natural filter for nutrients, they prevents erosion, and produce oxygen.

In this report, the new data on macrophytes from Lake Durowskie 2013 will be compared with data from the previous years to see whether the ecological status of the lake has improved. Further, it will be discussed whether new and different management strategies need to be implemented.

Materials and Methods

During the first week of July, 2013, field data was collected at Lake Durowskie in Poland. Lake Durowskie is part of a chain of several lakes which are joined together by the river Gołaniecka. It is influenced by the City Wągrowiec, which is located at the southern part of the lake, as well as by other land use activities, such as recreational, agricultural, and forest usage. Furthermore, it has a large catchment area of 236,1 km^2. The investigation topic of this report is macrophytes, their distribution and abundance in Lake Durowskie and at the outflow area of the lake into the river.

The materials needed for this study investigation were boats to navigate on the lake, a GPS device, two different types of anchors to retrieve submerged macropyhtes, and notebook to write down the data. The data collection involved finding and identifying the different macrophyte associations. Further, the GPS coordinates were taken and the area (length and width) of each association was determined to find out the spatial coverage of the macrophyte associations in the lake. Additionally, the maximum depth was measured next to the associations to determine the light availability and the light demand for the different associations. Moreover, for each macrophyte association on the lake the area coverage was determined by using the Braun-Blanquet method (1928). To find submerged associations, an anchor was used, and then the same procedure continued as with the macrophytes that are above the water level. At the outflow area, the macrophyte associations were identified and determined, so that the area coverage in percentage could be converted to values of the MIR index (Macrophyte Index for Rivers).

For the data analysis, which took place during the second week of July, different mapping software to map the spatial distribution according to the GPS coordinates and determine the area coverage of each association patch was used. First, the GPS coordinates were transferred from the GPS device to the software of Quantum GIS. Then, these data points were saved as a shapefile and imported to ArcMap. As a background map, a topographical map (http://geoportal.gov.pl) of the area was used. In ArcMap, all areas of the different macrophyte associations were added as polygons with the correct length and width. After mapping the spatial distribution coverage of the macrophytes of the lake, the shapefiles of the different associations were transferred to MapInfo. MapInfo was used to find out the exact area coverage of each association on the lake.

In order to find out the ecological state of the water quality of the lake according to the Water Framework Directive of the European Union, the ESMI (Ecological State Macrophyte Index) and the MIR indices were calculated. MIR index is used as a biological indicator value, which gives an indication of water quality of running waters. This classification of natural water courses was designed by the Polish Ministry of the Environment. The values to calculate the MIR index were collected at the outflow area of the lake. The equation for the MIR index is:

$$\text{MIR} = \frac{\sum L_{i*} W_{i}{}_*P_i}{\sum W_{i*} P_i} * 10$$

Where:

L = indicator value for each association

P = coverage for each species

W = weight factor

Table 1: MIR values used to calculate index

Associations	**L**	**W**	**P**	**L*W*P**	**W*P**
Cladophora glomerata	1	2	6	12	12
Butomus umbellatus	5	2	6	60	12
Acorus calamus	2	3	1	6	3
Potamagetum pectinatus	1	1	6	6	6
Phalaris arundinacea	2	1	1	2	1
Rorippa amphibian	3	1	1	3	1
Myriophyllum spicatum	3	2	1	6	2
Scophularia umbrosa	4	1	1	4	1
Sum				**99**	**38**

Table 1 shows the values of the indicator value for each species, the coverage for each species, and the weight factor. The coefficient, which was used to determine the cover of species in % is P, and is displayed and compared in Table 2.

Table 2: Comparison of species cover in % and for P

Cover Coefficient of P	Cover of Species in %
1	<0,1%
2	0,1-1%
3	1-2,5%
4	2,5-5%
5	5-10%
6	10-25%
7	25-50%
8	50-75%
9	75-100%

The second index that was calculated was the ESMI. The ESMI is used as a biological indicator of water quality for inland water bodies (Ciecierska, 2004 and Ciecierska et al. 2010). Therefore, it was used to determine the ecological state of Lake Durowskie. The equation for ESMI is:

$$\mathrm{ESMI} = 1 - \exp(-\frac{H}{H_{max}} \cdot Z \cdot \exp(\frac{N}{P}))$$

Where:

H = Shannon Wiener index

H_{max} = maximal value of Shannon Wiener index

N = total area covered by plant associations

Z = division of total area covered by plant associations (N) and area with a maximal depth of 2,5 m (isob. 2,5m = 20,96 ha)

P = total area of lake (143,7 ha)

Results

The northern part of Lake Durowskie has a larger coverage of macrophyte associations compared to the southern part. Furthermore, the belt of macrophytes in the northern part is fairly continuous with distinctively wider patches. On the other hand, in the southern part there are large gaps between smaller patches.

Figure 1: Map of Macrophyte associations in the Northern Part of Lake Durowskie

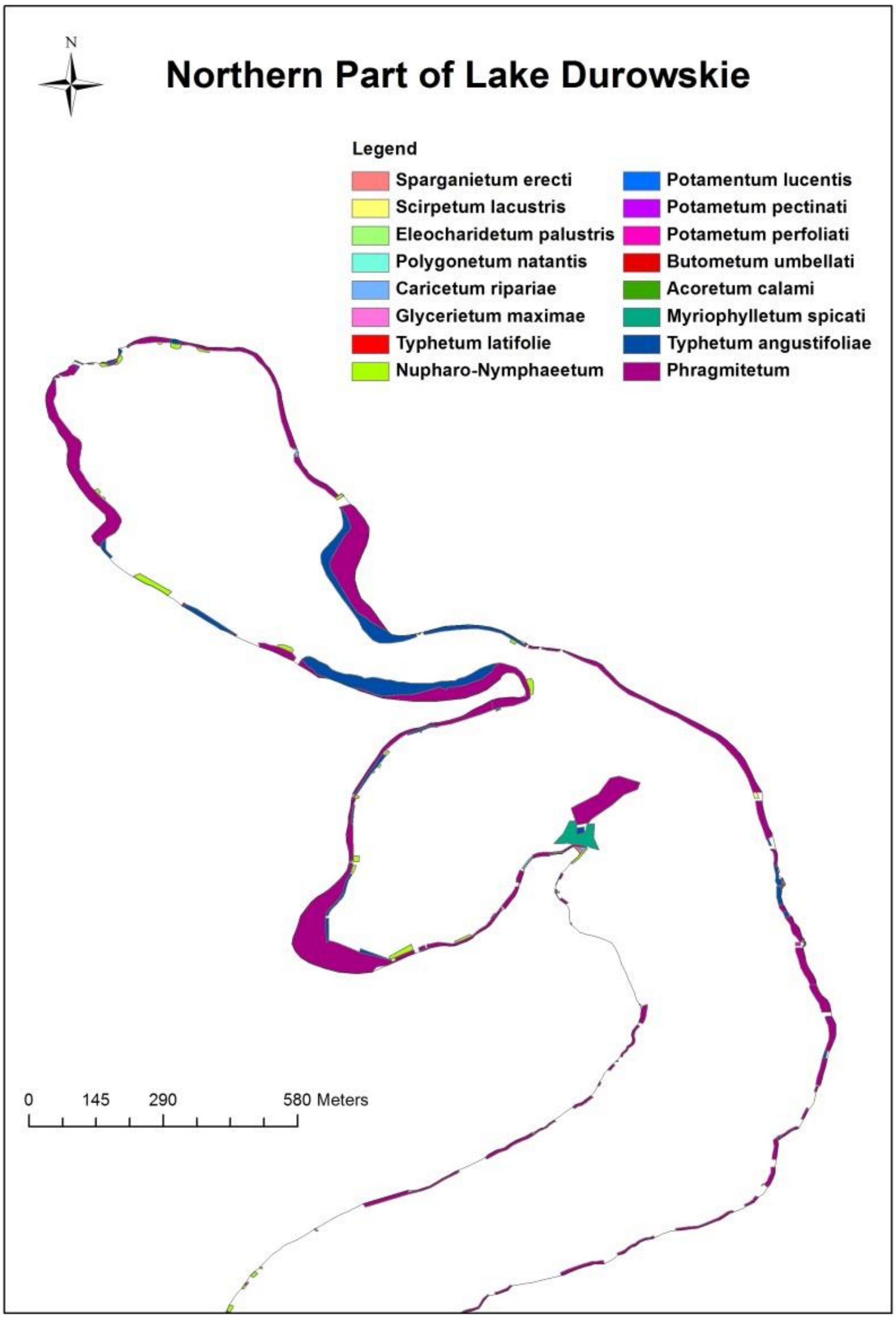
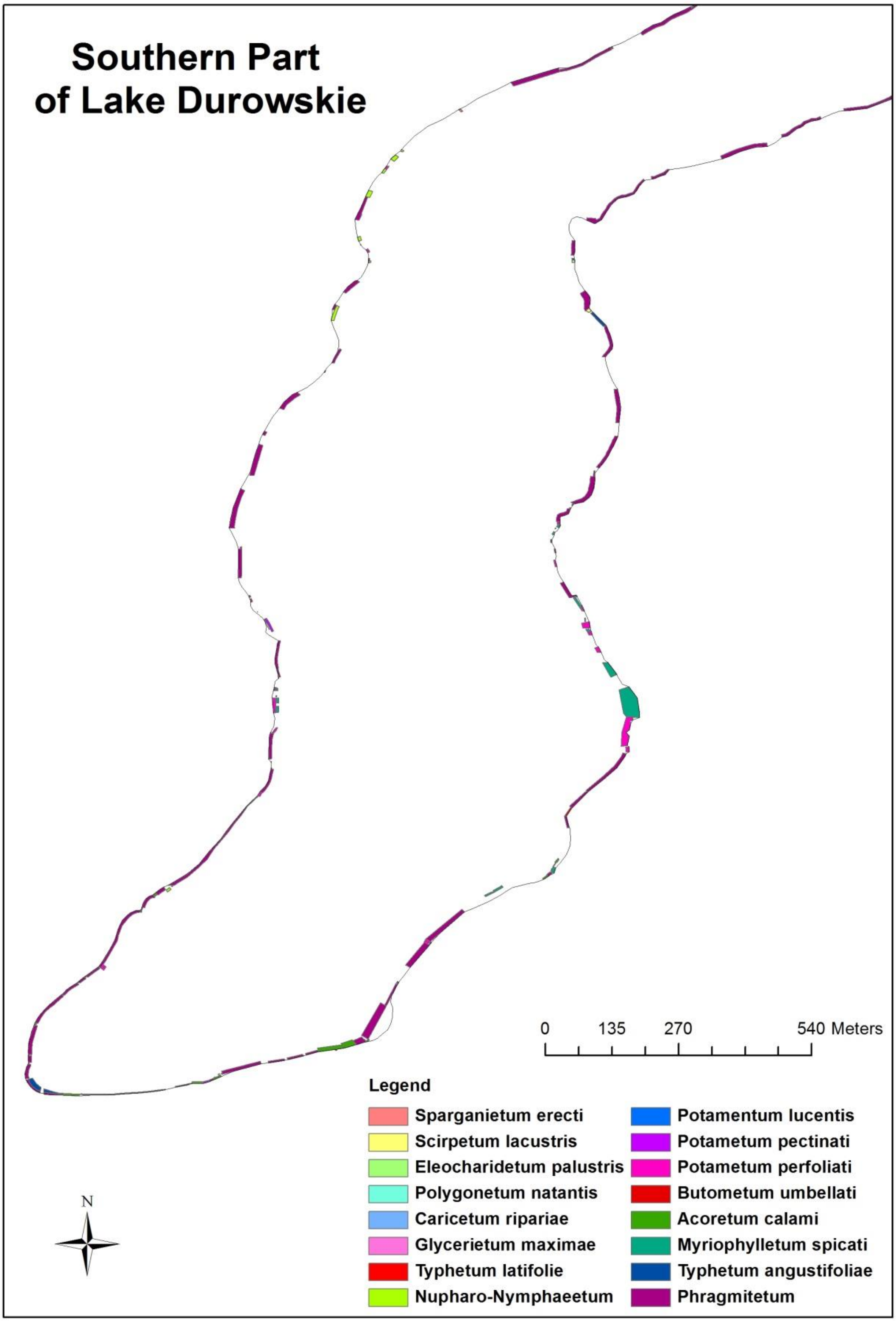


Figure 2: Map of Macrophyte associations in the Southern Part of Lake Durowskie



Spatial Coverage of Macrophyte associations

The table shows the areal coverage for each association in square metres and coverage in percent. During this year's studies, on Durowskie lake 16 macrophytes associations were noted. There are certain dominating associations in the lake, and these are: Phragmitetum communis (covers up to 73%), Typhaetum latifoliae (17%), Myriophylletum spicati (4,1%).

The rarest associations are: Polygonetum natantis (0,009%), Potametum lucentis (0,01%), and Typhetum latifoliae (0,004%). The results from the macrophyte survey at Lake Durowskie are presented.

Table 3: List of macrophyte associations in the Durowskie Lake in 2013, their areal extension in m^2 and coverage in %

Association	Area (m^2)	Coverage (%)
Phragmitetum communis (Garms 1927 , Schmale 1931)	62 076,74	72,78
Typhetum angustifoliae (Allorge 1922 , Soo 1927)	14 166,95	16,61
Myriophylletum spicati (Soo 1927)	3 497,87	4,10
Nupharo - Nymphaeetum albae (Tomaszewicz 1977)	2 323,62	2,72
Potametum perfoliati (W. Koch 1926)	1 546,72	1,81
Acoretum calami (Kobendzz 1948)	851,11	1,00
Caricetum ripariae (Soo 1928)	296,32	0,35
Scirpetum lacustris (Allorge 1922 , Chouarge 1924)	130,24	0,15
Potametum pectinati (Carstensen 1955)	105,11	0,12
Sparganietum erecti (Roll 1938)	84,62	0,10
Butometum umbellati (Konczak 1968)	81,61	0,10
Elecharitetum palustrae (Schennikov 1919)	53,99	0,06
Glicerietum maximae (Hueck 1931)	38,78	0,05
Typhetum latifoliae (Soo 1927)	37,93	0,04
Potametum lucentis	5,08	0,01
Polygonetum natantis	0,73	0,0009
Total	**85 297,42**	**100,00**

The following diagram displays two pie charts showing percentage coverage of macrophyte associations. The larger on the left represents 99% of total macrophyte association coverage of the lake and the small pie chart on the right displays macrophytes associations that make up only 1% of the total coverage.

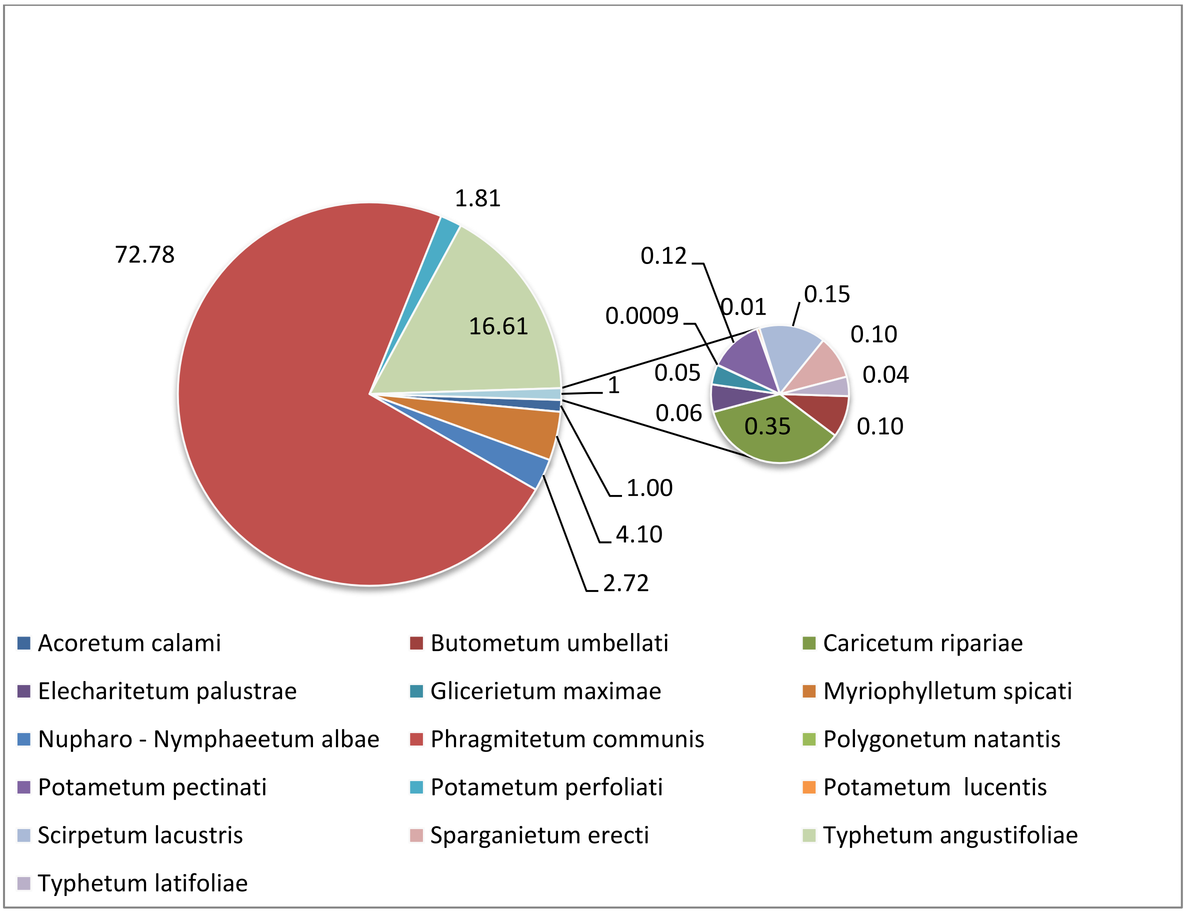


Figure 3: Spatial coverage of macrophyte associations expressed in %

Trends in Macrophyte Coverage

There has been an increase in overall macrophyte coverage since 2010 from 5.8ha to 8.5ha. Phragmitetum communis has had a large increase in only one year from 2012 to 2013 by 1.5 ha. Additionally, Myriophylletum spicati, a submerged macrophyte association, increased 4 fold to 0.35 ha in the last year.

The figure below presents the 6 most abundant species by surface area that make up greater than 99% of lake macrophytes cover from 2009 to 2013.

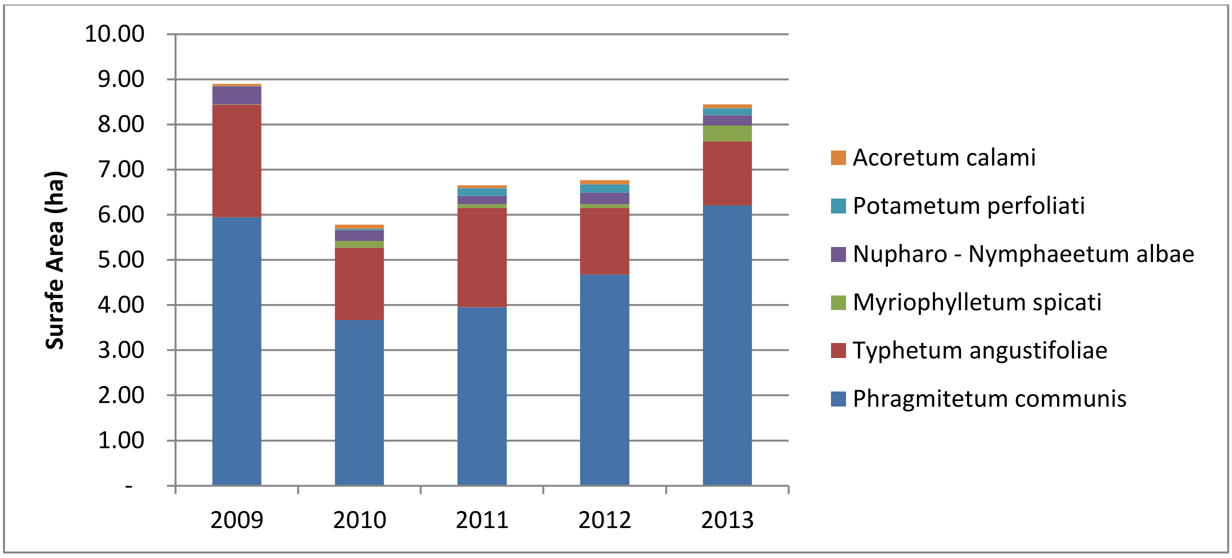


Figure 4: Figure: Dominant macrophyte associations (2009 - 2013)

Though not as numerous (<1% of macrophyte coverage), the remaining associations identified are useful for biodiversity and help represent ecological status.

Importantly, Ceratophylletum demersi, an indicator of bad water quality, which was present in 2010 has disappeared and still absent this year.

Furthermore, the surface area of the rare associations has decreased from 2010 till 2012 and has increased in the last year.

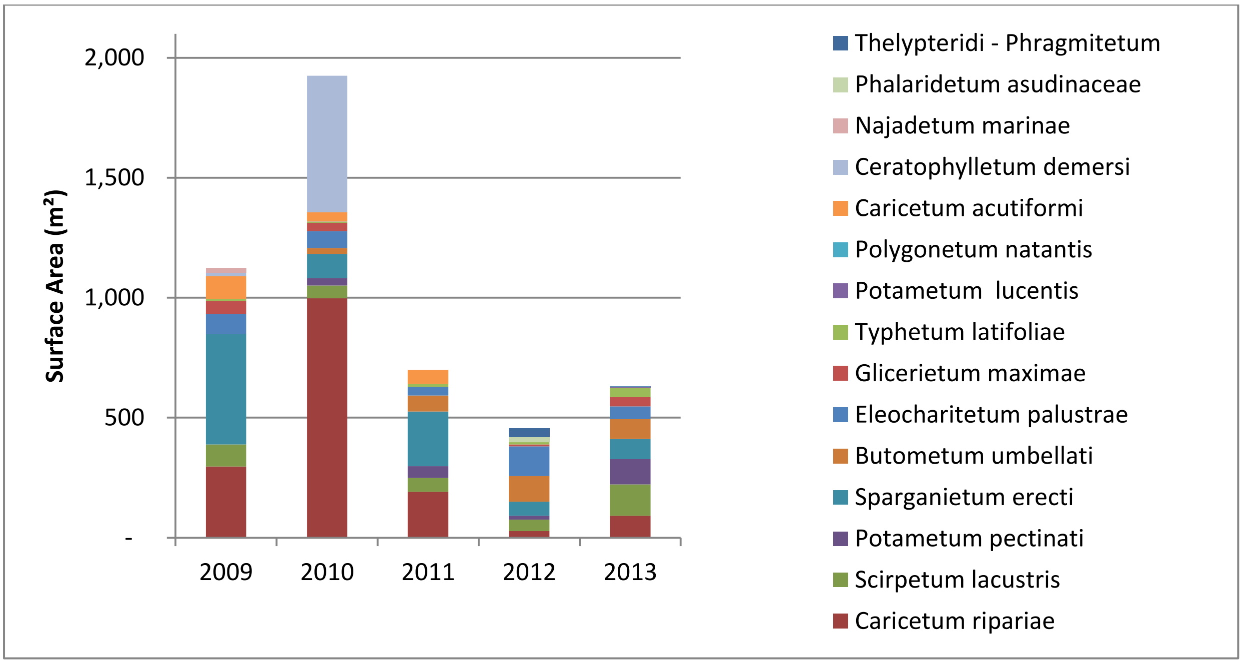


Figure 5: Minor macrophyte associations by area (2009 - 2013)

Total macrophyte coverage considerably decreased after 2009, however from 2010 to 2013, there has been a steady increase. The total coverage of 2013 almost reaches the same value of 2009 (9ha).

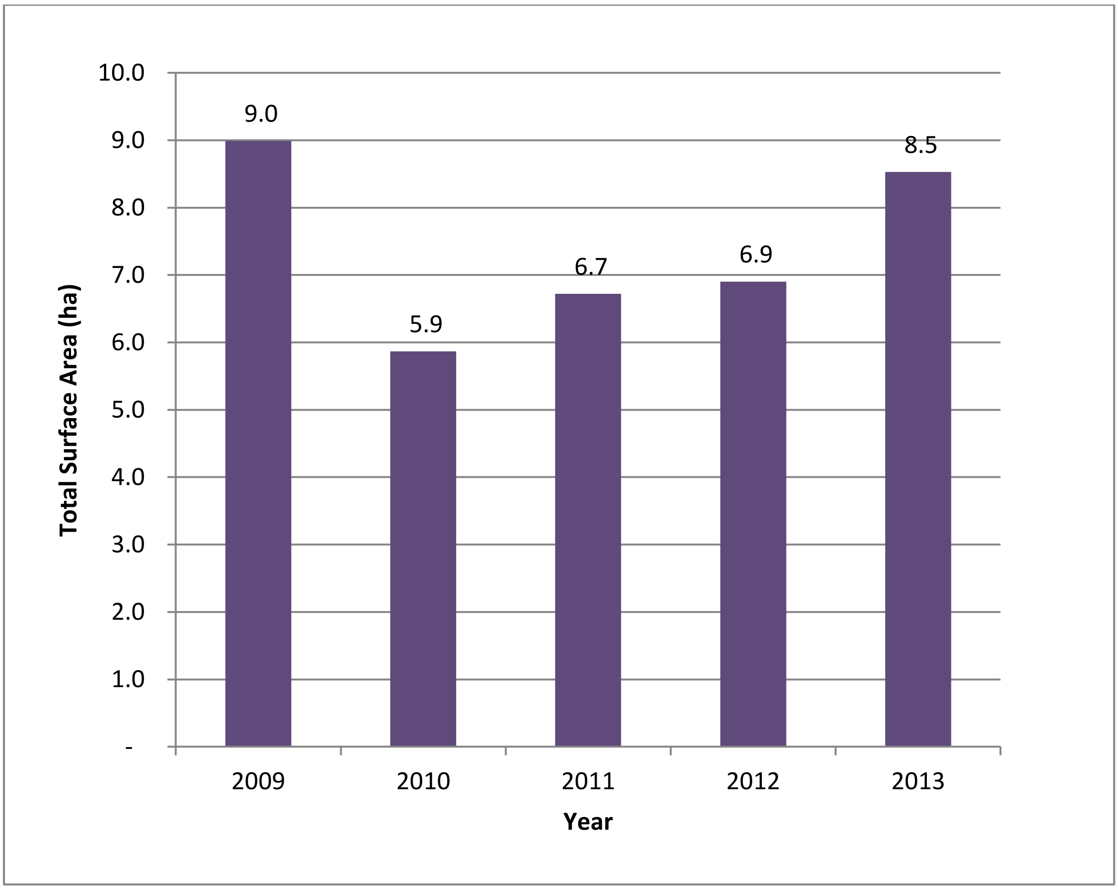


Figure 6: Change in total macrophyte coverage from 2009 – 2013 in hectares

Species Composition at Outflow

Species composition differs in comparison to the previous year in the outflow area. There is a noted loss of 2 species in 2013: *Lysimachia thyrsiflora* and *Potamogetum perfoliatus*. On the other hand, 3 new species appeared: *Rorippa amphibian*, *Cladophora glomerata* and *Phalaris arundinacea*.

Table 4: Change in species composition at the outflow

Species Composition	2012	2013
Butomus umbellatus	6	6
Acorus calamus	4	1
Potamagetum pectinatus	6	6
Myriophyllum spicatum	4	1
Scophularia umbrosa	1	1
Potamogetum perfoliatus	1	
Lysimachia thyrsiflora	1	
Rorippa amphibia		1
Cladophora glomerata		6
Phalaris arundinacea		1

Ecological State Macrophyte Index (ESMI) and Macrophyte Index for Rivers (MIR)

Based on the ESMI and MIR ecological status of lakes and rivers may be classified from bad to very good.

Table 5: Classification of ESMI (for deep stratified lakes) and MIR values used for assessment of ecological state

Ecological state	ESMI	MIR
very good	0,680 - 1,000	≥44,5
good	0,340 - 0,679	44,5 - 35,0
moderate	0,170 - 0,339	35,0 - 25,4
poor	0,090 - 0,169	25,4 - 15,8
bad	< 0,090	< 15,8

In comparison to the previous years when investigations took place, the results of the MIR values from the outflow area in 2013 have changed significantly. The values from 2012 to 2013 show a decrease from 33,41 to 26,05 which indicate the water quality went from a medium moderate (close to good) state to a moderate (almost poor) state. On the other hand, the ESMI values show a small and continued improvement since 2010 reaching a highest value of 0,136 in 2013; however, still reflect a poor water quality state of the lake.

The results from 2009 to 2013 this year are presented in the table below.

Table 6: Values of ESMI index changing over 2009 – 2013.

	2009	2010	2011	2012	2013
ESMI	0,109	0,103	0,118	0,120	0,136
MIR	30,6	31,7	29,8	33,41	26,05

Discussion

The results show that Durowskie Lake has a fairly stable eutrophic state. The values for the ESMI and MIR values have changed but they are still in the same general conditions, in regards to the ESMI and MIR classification table, as they were in the previous years. It is significant to mention, however, that the macrophyte associations have increased. Especially, Phragmitetum communis, which is the most dominant association increased its cover by 32% in comparison to last year. Further, this association is spreading to deeper water. With this result, we can assume that the light availability has increased, which shows a positive trend for the ecological status of the lake.

Not only Phragmitetum communis, but also Myriophilletum spicati has increased its overall coverage in the lake to a great extent (4 times) in comparison to last year. With the increase of the coverage, Myriophilletum spicati is know the third most abundant species in Lake Durowskie. Myriophilletum spicati is a submerged macrophytes species, which means it is an even better indicator of better light availability than emergent macrophyte associations in the lake. With the large increase of Myriophilletum spicati, we expect that the oxygen production in the water column in localities of the association will increase improving the water quality. The better state of water quality and the higher abundance of oxygen in the water column will have a positive effect on other organisms, such as macro-invertebrates, fish, and others. The increase of Myriophilletum spicati can have a positive effect on predator fish species, such as *Esox lucius*, because these species need submerged macrophyte plant associations for breeding habitats.

Other changes that are important to mention are that Ceratophyllum demersii has continuously not been found since 2011. Ceratophyllum demersii is an indicator for bad water quality. Therefore, it is important to know that the water quality has not decreased.

A positive change that took place was that Potametum lucentis has appeared with a new small patch ($5m^2$). This species is a submerged macrophyte plant and has similar positive effects like Myriophylletum spicati. Moreover, it is known that Potametum lucentis is usually present in water of moderate water quality.

Conclusions: Recommendations for Management

In order to stabilize and further increase the spatial coverage of macrophytes, different management strategies could be implemented. One strategy could be to introduce other native macropyhte species, with a special focus on submerged macrophyte species since they bring the greatest benefit to the lake ecosystem. One example that could be introduced at Lake Durowksie that could improve nutrient cycling is the macrophyte Chara (stonewort). This association was found at Lake Durowskie until the early 1990's (Goldyn, 2013) and it is presumed that seeds from this species are still present in the lake sediments. However, after many years of a high trophic state and sedimentation, none of the spores are able to grow. The introduction of a former native species could help to improve the water quality. Propagation of a combination of this and other species currently present in the lake may help improve macrophyte coverage and ecological functions of the lake (Kufel and Kufel, 2002).

A different management strategy could be to designate ecological sensitive areas at the lakes shoreline. These ecological sensitive areas could include macrophyte associations that are trying to become established or that have been heavily disturbed by fishermen or motor boats. In accordance with the sensitive protected areas, the education of local fishermen and other recreational users should be a priority. Only if users of Lake Durowskie become aware of the damage that they do to the belt of macrophytes and how important the health of the macrophyte associations are for the complete ecosystem of the lake, then the restoration measures, such as introduction of Charales, would have a chance. Therefore, the education and the increase of public awareness for a good ecological state of Lake Durowskie should become a priority.

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Appendix

Appendix I: Macrophyte Coverage in Square Metres (2009-2013)

Association	2009	2010	2011	2012	2013
Acoretum calami (Kobendzz 1948)	528	871	651	862	851
Butometum umbellati (Konczak 1968)	-	24	68	107	82
Caricetum acutiformi	94	38	58	-	-
Caricetum ripariae (Soo 1928)	92	27	192	997	296
Ceratophylletum demersi	15	570	-	-	-
Eleocharitetum palustrae (Schennikov 1919)	84	70	34	124	54
Glicerietum maximae (Hueck 1931)	55	35,5	2	7	39
Myriophylletum spicati (Soo 1927)	124	1 520	833	850	3 498
Najadetum marinae	20	-	-	-	-
Nupharo - Nymphaeetum albae (Tomaszewicz 1977)	3 969	2 300	1 872	2 540	2 324
Phragmitetum communis (Garms 1927 , Schmale 1931)	59 448	36 691	39 504	46 745	62 077
Polygonetum natantis	-	1	-	-	1
Potametum lucentis	-	-	-	-	5
Potametum pectinati (Carstensen 1955)	-	30	49	17	105
Potametum perfoliati (W. Koch 1926)	26	387	1 668	1 882	1 547
Scirpetum lacustris (Allorge 1922 , Chouarge 1924)	92	54	57	48	130
Phalaridetum asudinaceae (Libb. 1931) 0,03	-	-	-	23	-
Sparganietum erecti (Roll 1938)	460	102	228	58	85
Typhetum angustifoliae (Allorge 1922 , Soo 1927)	24 910	16 001	21 987	14 743	14 167
Typhetum latifoliae (Soo 1927)	8	4	12	10	38
Thelypteridi - Phragmitetum (Kuiper 1957) 0,05	-	-	-	35	-
Total	**89 925,00**	**58 725,50**	**67 213,50**	**69 048,00**	**85 297,42**