REPORT FROM THE INTERNATIONAL SUMMER SCHOOL OF DUROWSKIE LAKE

Macrophytes as an indicator of environmental change in Durowskie Lake

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1. Introduction

The importance of freshwater worldwide cannot be over emphasized. Many agricultural, industrial and day to day human activities rely on water supplies from freshwater. They are habitat for many florae and fauna, serving an especially important role in several ecological processes. Consequently, these freshwaters also receive the waste produced from agriculture, industries, and households, as well as wastes from the biomass which they house.

In recent years, usually as a result of increasing anthropogenic activities, deterioration of the quality of many freshwater bodies (lakes, reservoirs, etc.) has become very common. Discharge of nutrients from point and non-point sources that promote algal growth (leading to eutrophication), toxic chemicals, over-pumping of aquifers, long-range atmospheric transport of pollutants and contamination of water bodies with substances are some of today's major causes of water quality degradation (Matovu et al., 2005). With respect to ecological water quality, eutrophication is currently the prime problem in both inland waters (lakes, reservoirs, etc.) and transition and coastal waters of Europe. And that is the greatest threat to biodiversity (Watt et al., 2007) and to an optimal ecologic state in surface waters (CIS, 2005). Eutrophication occurs when there is an excessive amount of nutrients entering the waterbody, with nitrogen (N) and phosphorus (P) being the primary nutrients of eutrophication. The negative impacts of eutrophication on lakes occur, mainly, when the ecological balance changes to favor higher levels of primary production in the water column (phytoplankton) and lower levels in the benthos (macrophytes) (Carpenter and Lathrop, 1999). The ecological consequences of this can result in ecosystem degradation problems that have societal impact, with the rate of change being dependent upon many complex interactions (Carpenter and Lathrop, 1999). The water quality issues that arise from this problem, such as harmful algal blooms, affect the sustainable use of lakes and provision of the ecosystem services that we depend on (May et al., 2020).

A pressing need has emerged for restoring lakes that have been adversely affected by eutrophication. According to the National Research Council, restoration is the return of an ecosystem to a close approximation of its original condition prior to disturbance, where both the structure and functions of the ecosystem are recreated (National Research Council, 1992). The goal of such restoration is to emulate a natural, functioning, self-regulating system integrated with its surrounding ecological landscape (Perrow and Perry, 2002). In essence, to provide the basis for most monitoring information, a combination of physical, chemical, and biological measurements are required (Metcalfe, 1989).

Since 2008, the ecological state of Durowskie Lake has been monitored annually preceding the implementation of some lake restoration measures. Experts, researchers and students from Adam Mickiewicz University, in Poznań, Christian-Albrecht University in Kiel, Alexandru Ioan Cuza University of Iaşi etc. have been engaged in this annual study with the sole purpose of monitoring the restoration progress of Durowskie Lake using algae, macrophytes, macroinvertebrates, physiochemical parameters and hydrological balances as indicators. The depth, density, diversity, and types of macrophytes present in a lake may indicate the state. Where submerged aquatic macrophytes are abundant, they can have a heavy influence on habitat structure, fishability, recreational use and nutrient dynamics. The absence of macrophytes may indicate water quality problem such as excessive turbidity, herbicides or salinization which interfere with plant growth and development. However, an overabundance of macrophytes can result from high nutrient levels and may affect ecosystem health, recreational activities, and the aesthetic appeal of the system (EPA, 2022).

Therefore, the main objective of our study is to provide the current state of Durowskie Lake using macrophytes as an indicator. To achieve this, we aim to determine the ESMI index of macrophytes in Durowskie Lake, compare the current macrophyte communities to previous data, and also, we aim to deduce the effectiveness of the restoration measures that have been put in place in Durowskie Lake.

2. Study Area and Methodology

2.1 Study Area

Durowskie Lake is located in a town named Wągrowiec which is a part of the Greater Poland District. It is a post glacial lake which is now serving as a recreational spot for different water sports and activities. The main tributary and the flow of the lake is the Struga Gołaniecka which flows through Kobyleckie, Bukowieckie, Grylewskie lakes, and covers a whole catchment area of 236.1 km2. The direct catchment area is 1581.3 ha while the surface area is 143.7 ha. The lake lies along the Kosciuszki Street and its catchment area is dominated by the agriculture of 58.26%, forest area, 33.52%, and 8.25% urban area.

2.2 Field Work

Starting from 27th June to 2nd July 2022, a total of 6 days field works were carried out to assess the biodiversity of macrophytes in the lake. According to the Polish methodlogy water framework directive, the task was to specify all the macrophytes associations in the lake while marking down their location, and distribution area. This was done by several boat trips along the shoreline to visually identify the macrophytes communities, mark the location of the communities with a GPS, estimate the width and length of area distribution of macrophytes, and finally develop a raw map of the territory of each macrophyte associations present in the lake. An anchor was used for assessing underwater species. Then, the collected data were imported on a satellite map of the lake in the ArcGIS software to counter check and calculate the area of the macrophyte associations.

2.3 Data Analysis

At the end of field work, the classification of the macrophytes together with their location and area was obtained. The macrophytes associations were scattered throughout the lake and the total area of each patch was calculated with the help of ArcGIS software. This data was then used to calculate the ESMI index to determine the ecological status of the lake.

2.4 ESMI Index

The ESMI is an index for assessing ecological conditions of lakes on basis of macrophytes compliant with the Water Framework Directive (Ciecierska, Kolada, 2014).

For ESMI calculations flora associations were measured and processed in the area of lake Durowskie, and upon those, the degree of biodiversity was calculated. The following formula was used for calculations:

H – diversity index of phytocenosis

ni – area of polygons one of association in percent per cover

N – all cover of macrophytes

Hmax - coefficient of variation of the theoretical maximum

S – number of associations

Z – occupancy index

isob2.5m – area of littoral limited by isobath 2.5 m

P – area of the lake

The index can have a value between 0 and 1. Value of zero indicates a complete degradation of the lake, whereas the index with the value of 1 indicates that the given vegetation is the most similar to the vegetation that is supposed to be there. (Ciecierska at.al, 2006).

Table 1: ESMI index for determining ecological conditions of the lake

Ecological status	ESMI Index
Very good	≥ 0,680
Good	≥ 0,410
Moderate	≥ 0,205
Poor	≥ 0,070
Bad	< 0,070

Table 1: ESMI Index

3. Results

3.1 Distribution of Macrophyte Associations

According to saved GPS points and notes, a precise map of macrophyte associations was elaborated. Fig 1-3 shows the designated submerged and emergent vegetation communities in the study area of Durowskie Lake in 2022, divided into three parts: northern, central, and southern.

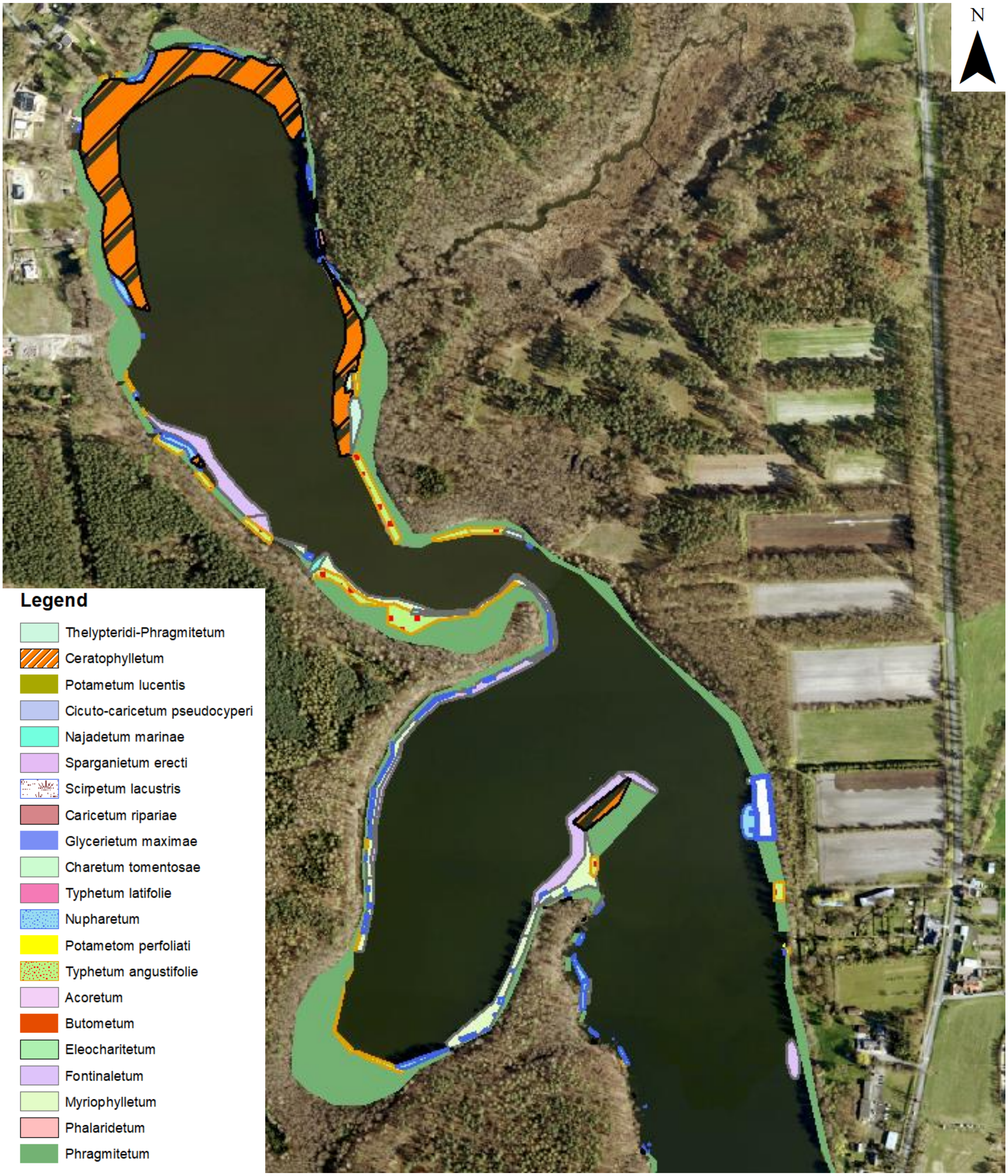

Fig 1: Distribution of macrophyte communities in the northern part of the Lake Durowskie.

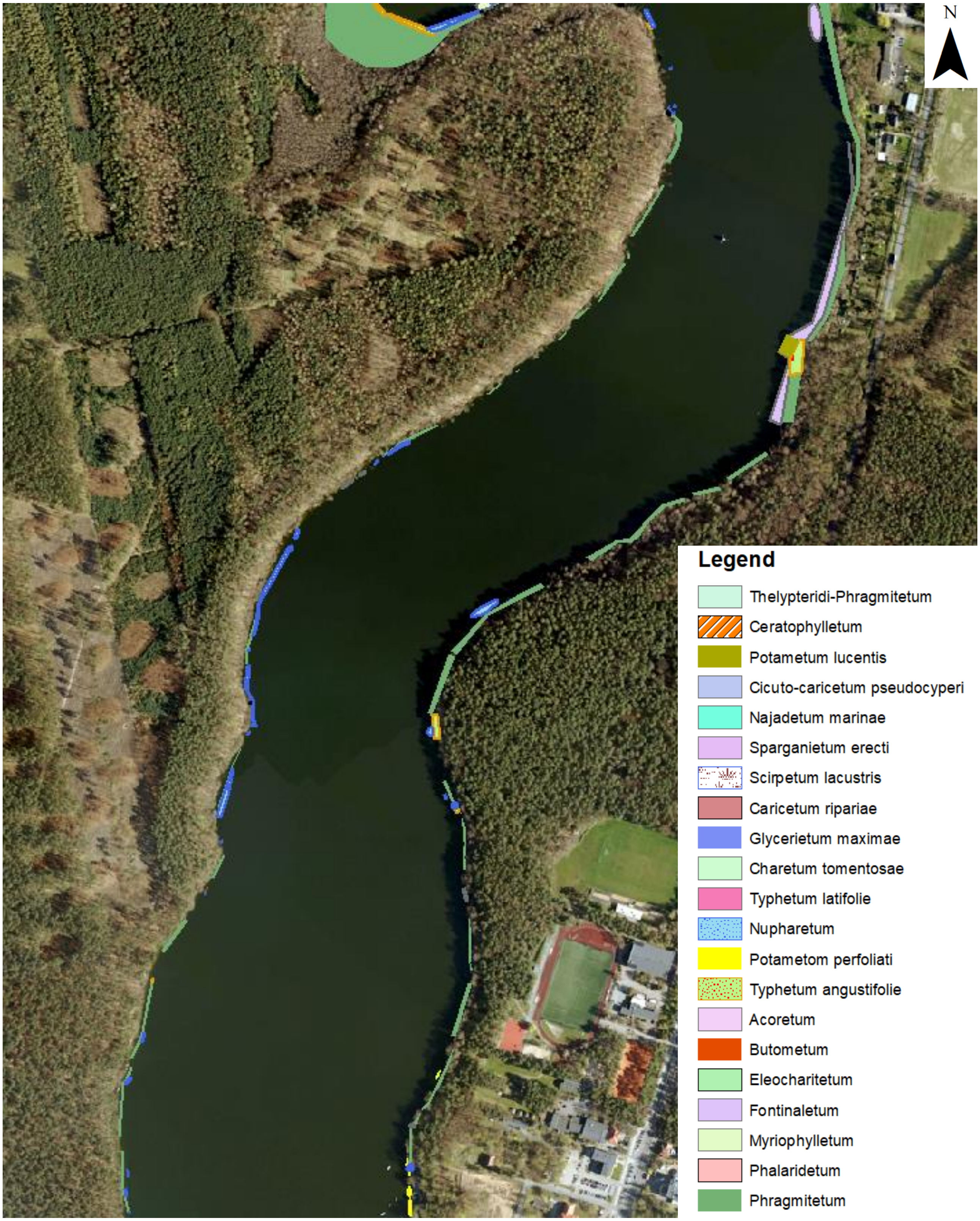

Fig 2: Distribution of macrophyte communities in the middle part of Lake Durowskie.

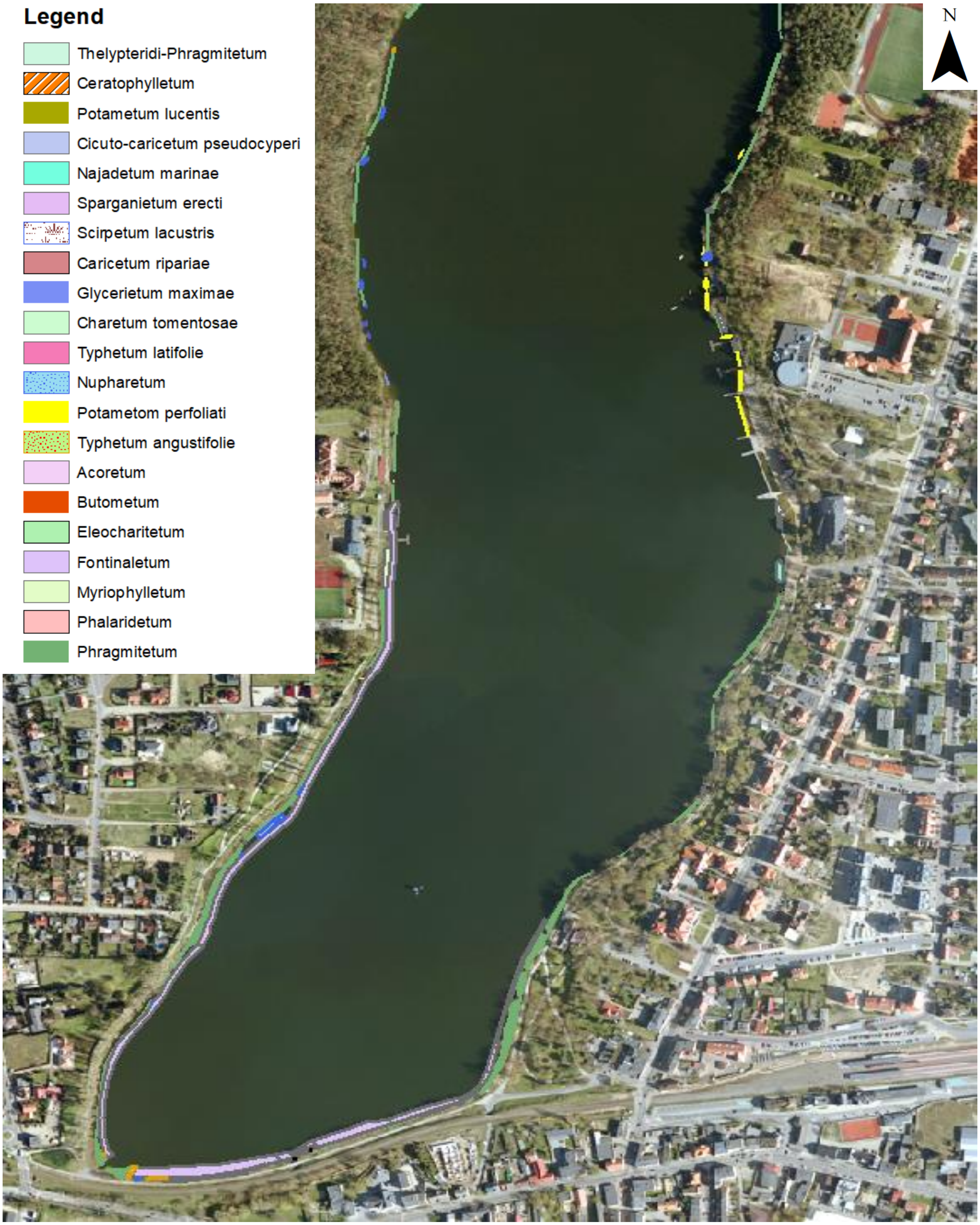

Fig 3: Distribution of macrophyte communities in the southern part of the Lake Durowskie.

Table 2: Macrophyte communities and the area they covered in Durowskie Lake in 2022.

2022		
Association	**Total area [m2]**	**Total area [%]**
Acoretum calami	592,35	0,37%
Butometum umbellati	38,32	0,02%
Caricetum ripariae	310,74	0,19%
Ceratophylletum demersi	**27591,04**	**17,19%**
Charetum tomentosae	49,16	0,03%
Cicuto-Caricetum pseudocyperi	84,07	0,05%
Eleocharitetum palustris	7,53	0,00%
Fontinaletum antipyrethicea	**22626,89**	**14,10%**
Glicerietum maximae	48,84	0,03%
Myriophylletum spicati	9382,49	5,85%
Najadetum marinae	708,07	0,44%
Nupharo-Nymphaeetum albae	6276,86	3,91%
Phalaridetum arundinaceae	0,98	0,00%
Phragmitetum communis	**80679,96**	**50,27%**
Potametum lucentis	496,94	0,31%
Potametum perfoliati	830,30	0,52%
Scirpetum lacustris	1687,05	1,05%
Sparganietum erecti	111,66	0,07%
Thelypteridi-Phragmitetum	850,09	0,53%
Typhetum angustifoliae	8111,81	5,05%
Typhetum latifoliae	3,89	0,00%
SUMA	**160489,06**	**100,00%**

A total of 21 macrophyte associations were identified and assessed in Lake Durowskie in 2022.

3.2 Area comparison of the most occurring submerged and emergent macrophytes in 2022

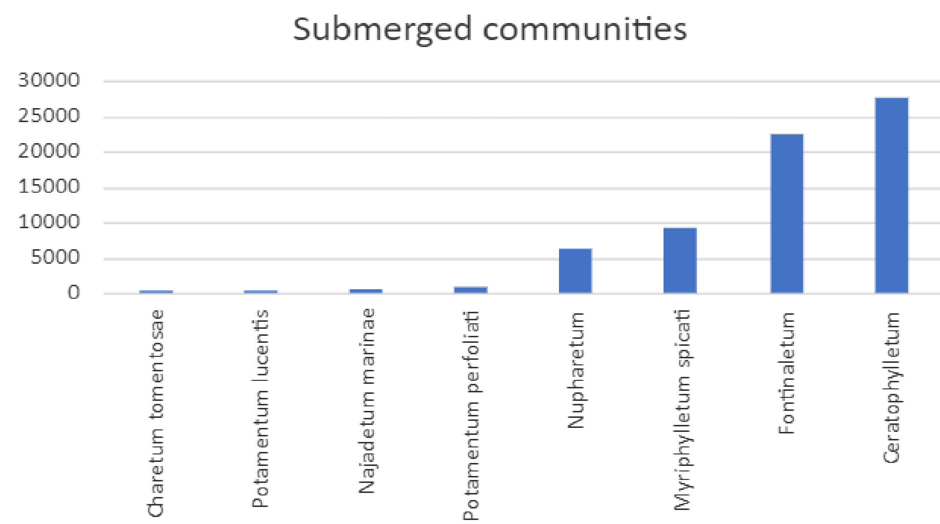

Fig 4: Area covered by nymphaeids and elodeids in Durowskie Lake in 2022

The most abundant association of submerged macrophytes in 2022 was *Ceratophylletum demersi*, with a total area of 27591.04 m^2, followed by *Fontinaletum antipyrethicea*, which covered an area of 22626.89 m^2. The area of these two communities was significantly higher than the area of the other submerged communities. *Myriophylletum spicati* and *Nupharo-Nymphaeetum albae* were also present abundantly, although their area was lower than 10000 $m^{2.}$

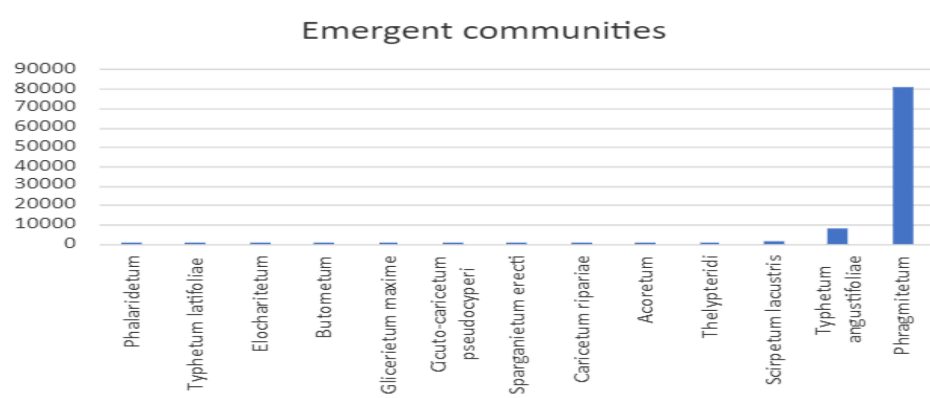

Fig 5: Emergent communities in Durowskie Lake in 2022

In terms of emergent associations, the most dominant community was *Phragmitetum communis* with total area of 80679.96 $m^{2.}$ The areas of all other associations were much lower compared to it.

3.3 Comparison of all the macrophyte associations in 2021 and 2022

Table 3: Comparison of the areas of macrophyte communities in the Durowskie Lake in 2021 and 2022

Association	2021		2022		Difference in occupied area	
	Area [m2]	Area %	Area [m2]	Area %	Area [m2]	Area %
Acoretum calami	544,73	0,41%	592,35	0,37%	47,63	8,74%
Butometum umbellati	31,11	0,02%	38,32	0,02%	7,21	23,17%
Caricetum acutiformis	47,89	0,04%	0,00	0,00%	-47,89	-100,00%
Caricetum ripariae	276,50	0,21%	310,74	0,19%	34,24	12,38%
Ceratophylletum demersi	**1587,13**	**1,20%**	**27591,04**	**17,19%**	**26003,91**	**1638,42%**
Charetum tomentosae	26,44	0,02%	49,16	0,03%	22,72	85,92%
Cicuto-Caricetum pseudocyperi	72,02	0,05%	84,07	0,05%	12,06	16,74%
Eleocharitetum palustris	12,26	0,01%	7,53	0,00%	-4,73	-38,59%
Fontinaletum antipyrethicea	**20951,63**	**15,88%**	**22626,89**	**14,10%**	**1675,26**	**8,00%**
Glicerietum maximae	11,71	0,01%	48,84	0,03%	37,13	316,98%
Myriophylletum spicati	**15506,93**	**11,75%**	**9382,49**	**5,85%**	-6124,44	-39,49%
Najadetum marinae	50,48	0,04%	708,07	0,44%	657,59	1302,65%
Nitellopsidetum optusae	26,39	0,02%	0,00	0,00%	-26,39	-100,00%
Nupharo-Nymphaeetum albae	**3515,55**	**2,66%**	**6276,86**	**3,91%**	**2761,31**	**78,55%**
Phalaridetum arundinaceae	13,30	0,01%	0,98	0,00%	-12,31	-92,60%
Phragmitetum communis	**65044,22**	**49,28%**	**80679,96**	**50,27%**	**15635,74**	**24,04%**
Potametum lucentis	11,88	0,01%	496,94	0,31%	485,06	4084,37%
Potametum perfoliati	9210,06	6,98%	830,30	0,52%	-8379,76	-90,98%
Scirpetum lacustris	61,43	0,05%	1687,05	1,05%	1625,62	2646,29%
Sparganietum erecti	297,19	0,23%	111,66	0,07%	-185,53	-62,43%
Thelypteridi-Phragmitetum	528,25	0,40%	850,09	0,53%	321,85	60,93%
Typhetum angustifoliae	**14143,24**	**10,72%**	**8111,81**	**5,05%**	**-6031,43**	**-42,65%**
Typhetum latifoliae	6,31	0,00%	3,89	0,00%	-2,42	-38,38%
SUM	131976,65	100,00%	160489,06	100,00%		

3.4 Comparison of the most occurring macrophyte associations in 2021 and 2022

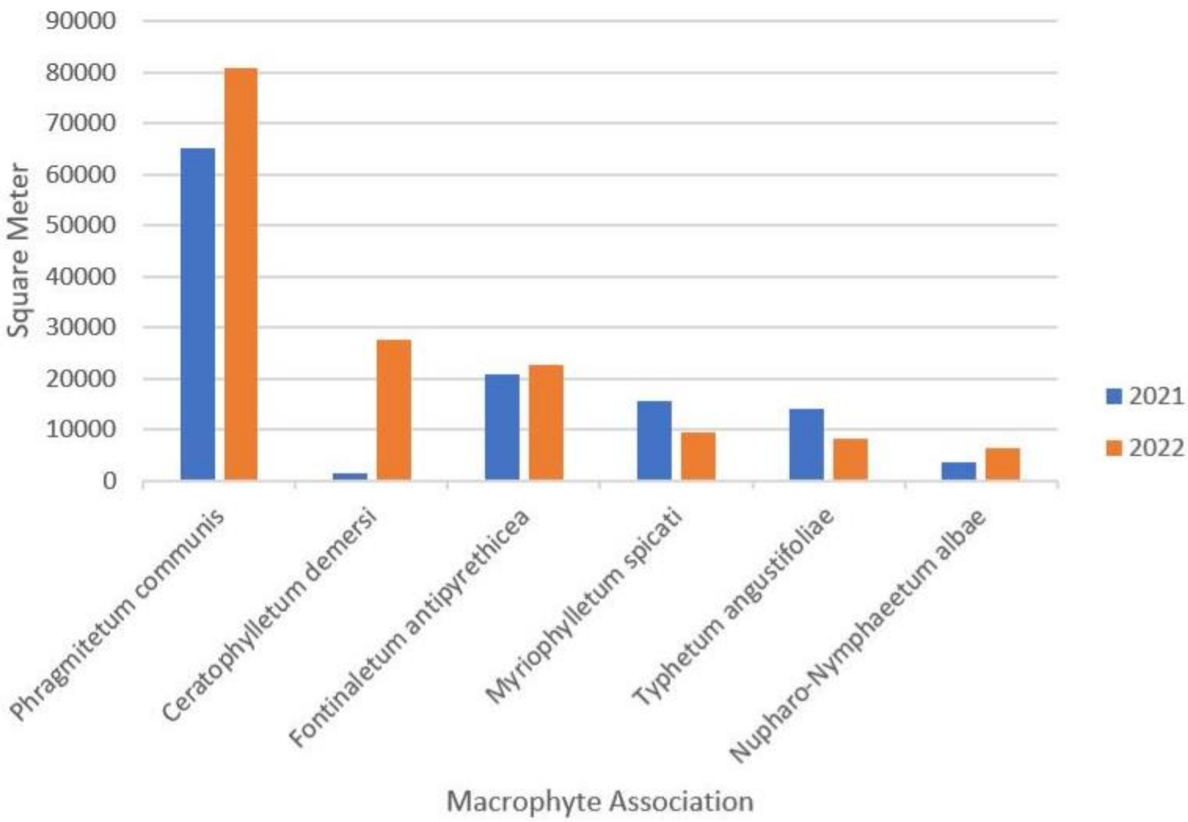

Fig 6: Area comparison of the most occurring plant associations in 2021 and 2022

The most significant difference between the area of each community is noticed for *Ceratophylletum demersi,* which increased by 16 times (1638.42%) compared to the previous year. On the other hand, in terms of emergent species, the most abundant was *Phragmitetum communis*, as in the previous year, which occupied an area of as much as 80679.96 m^2, more than 50% of the area, and increased by 24.04% compared to the previous year. Another community that was quite abundant was *Typhetum angustifoliae*, with an area of 8111.81 m^2, which decreased by 42.65% compared to the previous year. *Myriophylletum spicati*, another submerged species, was lower by 39% compared to the previous year. The last submerged association worth mentioning is *Nupharo-Nymphaeetum albae*. It's area increased by 78.55% compared to the previous year and reached an area of 6276.86 m^2.

3.5 Distribution of macrophyte associations from 2009 to 2022

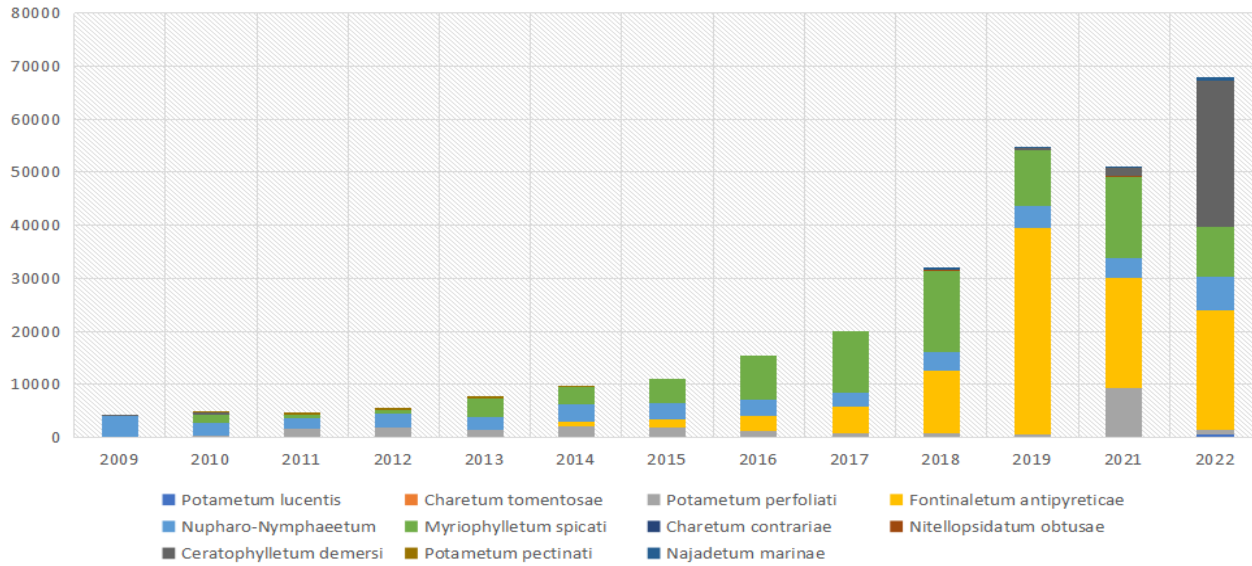

Fig 7: Distribution of macrophyte associations from 2009 to 2022

From the following charts, it can be observed that macrophytes association has been continuously varying not only in diversity but also in numbers throughout the years. From 2015 there has been a bloom in total macrophyte area and it has been continuous until 2022. *Frontinaletum antipyreticae* has been the most dominant association in the lake for the last 3 years. But the dominance of *Myriophylletum spicati* is overwhelmed by *Ceratophylletum demersi* in 2022 as there was a bloom of this species which is about 17 times of the last year. And for the area, the existence of macrophytes in the lake is noticeably increasing until 2022. Which in turn supporting as a barrier to the lake from direct pollution.

3.6 Trend of macrophyte abundance from 2009 to 2022

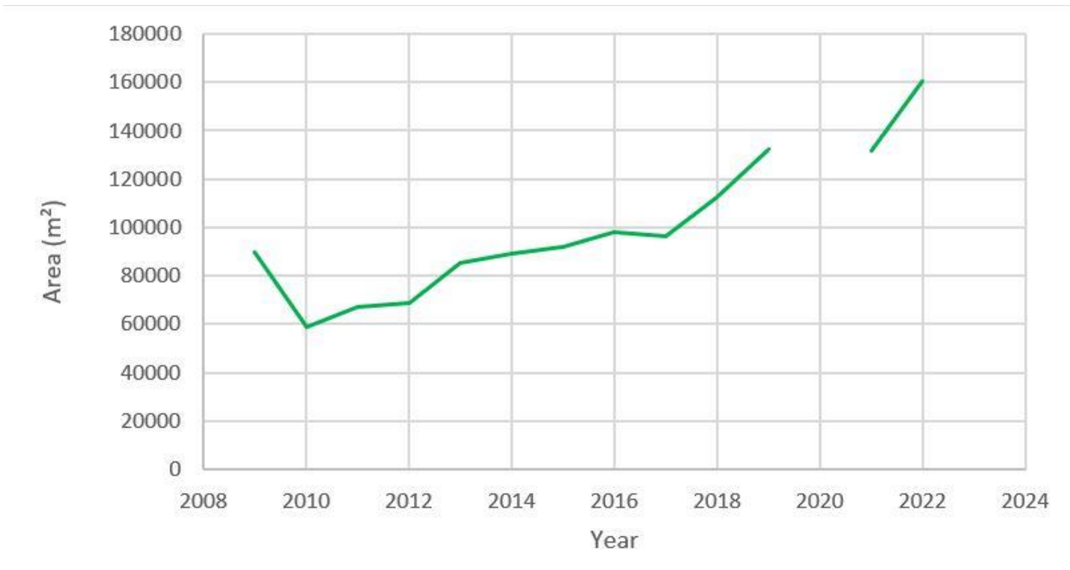

Fig 8: Trend of macrophyte abundance from 2009 to 2022

3.7 Interpretation of ESMI index

The ESMI index was used to measure the quality of Lake Durowskie. The obtained value was 0,356. According to the ranges of the indices, the ecological condition of Lake Durowskie is moderate, however the value 0,356 is the highest compared to the previous years. Moreover, since 2016 rapid growth of the values of the index is noticeable.

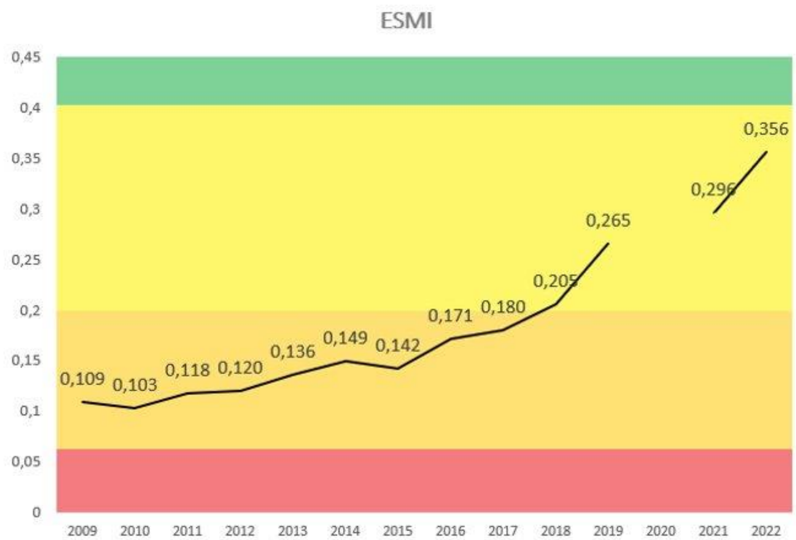

Fig 9: Graphical representation of ESMI index of macrophytes in Durowskie Lake (2009-2022)

Ecological status	ESMI Index
Very good	≥ 0,680
Good	≥ 0,410
Moderate	≥ 0,205
Poor	≥ 0,070
Bad	< 0,070

Fig 10: Ecological state of Durowskie Lake accordinfg to ESMI index of macrophytes

4. Discussion

The more macrophytes in a lake, the more significant is the protective barrier against pollutants that can flow into the lake from the direct catchment and disturb its physical and chemical properties. Also, greater the amount of macrophytes results to greater the amount of shelter for zooplankton, invertebrates and fish. Furthermore, macrophytes have developed defense mechanisms against humic substances and other environmental stresses (Resitema et al., 2018), proving another important reason to encourage the vegetation around the lakes. Moreover, not all macrophytes are good for water quality (Thomaz i da Cunha, 2010). Contrary to the prediction of a decline in vegetation by other students after doing the same studies in 2021, there was an increase in the area covered by macrophytes in 2022 than in 2021. Although Two (2) macrophyte associations, *Caricetum acutiformis* and *Nitellopsidetum optusae* were absent in 2022. But generally, more area was covered by macrophytes 2022, up by 28512.41 m^2.

Previous studies showed that *Ceratophyllum demersum* did not appeared since 2010. In this year's study, the presence of *Ceratophyllum demersum* was confirmed, and it has spread significantly in the northern part of the lake. In 2021, it covered only 1587.13 m^2, whereas it covered an area of 27591.04 m^2 in 2022 according to this year's study, representing a 1638.42% increase. Our research shows that the major factor responsible for the increase in the abundance of *Ceratophyllum demersum* is anthropopressure resulting from the construction of houses around the lake, in too close proximity. *C. demersum* is a species of highly eutrophic and highly turbid habitats. It is considered to grow rapidly, and moreover it is resistant to disturbance and stress. Only elodeids are able to survive in high trophic levels and turbid water conditions (Sugier et al., 2010).

Last year's results indicated a tendency which showed decreasing *Fontinaletum antipyrethicea*, with overall area of 20951.63 m^2 and with 15.88% of the whole surface. On the other hand, this year's community of *Fontinaletum antipyrethicea* covered 22626.89 m^2, indicating a significant proliferation of this plant. Despite this, it accounted for only 14.10% of the total macrophyte area. This year, by contrast, there was no indication that *F. antipyrethicea* had receded in favor of *Myriophylletum spicati* and *Typhetum angustifoliae,* whose areas decreased by 6124.44 m^2 and 6031.43 m^2 respectively, compared to the previous year. A decrease in these communities may indicate an improvement in water status, as *T. angustifoliae* is a characteristic indicator for intensive farming around the study area (Pawlat-Zawrzykraj, 2005). This may mean that fertilizers were used more appropriately in the last year, but it could also be the result of the most recent restoration measure (PIX) that was implemented in Durowskie Lake.

This year's survey showed 57.65% emergent plant communities, compared to 42.35% for submerged plant communities. This is a satisfactory result, because the entire area of macrophytes covered by the submerged communities increased from only 38.58% in the previous year to 42.35% in 2022. Especially since the area of the total macrophyte area was 17.82% higher in 2022. As predicted last year, high water transparency may have been a factor in the gradual increase in the extent of submerged vegetation. In some lakes, abundance, coverage, plant volume inhabited or depth distribution of submerged macrophytes increase during reduced nutrient loading (Hilt et al., 2022). For this reason, they are very good indicators of water quality, and an increase in its abundance, may be a signal of improved conditions of the lake.

The most common community of emergent macrophytes in lake Durowskie, was *Phragmitetum communis*, which generally is considered good for a lake, because they acts as a filter for the Lake and they create a “belt” around the lake. They slow down inflow of water from the catchment area. This year, they covered more than 50% of the whole macrophyte area, which made them the most dominant species.

Fig 11: Coastal region of Durowskie Lake in 2016 with few Estates.

Fig 12: Coastal region of Durowskie Lake in 2021 with more Estates.

The above satellite images from Google Earth, fig 11 from 2016 and fig 12 from 2021 show the emergence of coastal estates around Durowskie Lake in recent years. The impact of this is shown by the occurrence of *C. demersum*. Although the presence of submerged macrophytes often represent a positive state of a water body, but it different in the case of *C. demersum* because it is characterizes a eutrophic environment. This is as a result of houses that are now located very close to the shores of lake, which leads to direct contact of the pollutants with the lake shore. Therefore, the occurrence of *C. demersum* is justified here.

5. Conclusions

In 2022, only 21 macrophytes communties were identified with *Phragmitetum communis* being the most abundant macrophyte association in Durowskie Lake. *Caricetum acutiformis* and *Nitellopsidetum optusae* associations were the only associations of macrophytes that were observed in 2021 but not in 2022. With an ESMI score of 0,356, we conclude that the ecological state of Durowskie Lake is in a moderate condition, in accordance with the European Water Framework Directive.

Furthermore, judging from the higher ESMI index score and the evident increase of the area covered by macrophytes in Durowkie Lake as at the time of this study compared to previous years; we also conclude that the recent implementation of PIX (using Iron compounds) as a lake restoration measure in Durowskie Lake has been fruitful.

We recommend that the government should poise more energy in the control of anthropogenic activities around the Lake, especially in the aspect of building residential homes close to the Lake. This will help to compliment the efforts of the lake restoration measures in Durowskie Lake.

Finally, we encourage more studies like this in the future. We applaud all the teachers, staff and students who have participated in this wonderful effort to keep Durowskie Lake healthy.

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