ECOLOGICAL STATE OF LAKE DUROWSKIE DURING RESTORATION - BENTHIC MACROINVERTEBRATE ANALYSIS 2022

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1. INTRODUCTION

Throughout the past centuries, the human population has increased at a tremendous rate. In the year 1930, between World War I and World War II, the global population was estimated to be around two billion people. By 1974 that number reached four billion. Fast forward to today in 2022, and the global population is racing towards eight billion people, nearly doubling the amount in less than forty years (worldometer.info). A swelling number of humans requires an increasing amount of water, food, shelter, and work. As a result of this astronomical increase in demand, our human impact on the natural environment has been drastic. Our ecological victims are numerous and far reaching. One of humanity's victims are lakes.

A lake is a natural, permanent body of water that is surrounded by land and possesses a slow water exchange (Messyasz & Pikosz, 2019). Lakes vary in size and depth, and can be found all over the world, at numerous elevations, and in nearly every category of environment. Lakes are composed of different zones including littoral (shallow zone close to the shore), sublittoral (zone below the littoral), profundal (deep zone) and pelagic (open water zone). Each of these zones are characterized by various features, like the amount of light and oxygen, that determine which biodiversity, both flora and fauna, can exist there. In addition to the zones, the area and shape of the basin and watershed in which the lake is located is very important to its functioning. Also important are the lake's mixing intensity, amount of suspension, and water chemistry (Messyasz & Pikosz, 2019).

Lakes have a variety of uses and functions which include human drinking water, agricultural irrigation, flood control, fish production, urban reservoirs, energy creation, industry, transportation, recreation, conservation and diversity, training, and education (Jørgensen, 2005; Singh & Bhatnagar, 2012). Some of these uses and functions benefit human societies by providing economic growth via activities such as commercial and recreational fishing, hydroelectricity, and tourism, as well as various recreational activities (Schallenberg et al., 2013). Aside from the direct anthropogenic benefits, lakes provide habitat for a diversity of species. Rich biodiversity increases the resilience and functioning of ecosystem services (Schallenberg et al., 2013). However, through the overuse of lakes, our activities can be detrimental to their ecological health. Overfishing, for example, can decrease species abundance which can lead to a cascading effect on the overall biodiversity of the water body. Agricultural practices are a major contributor to the ecological status of a lake. Nutrients used in farming fertilizers can make their way into the bodies of water via surface runoff and groundwater runoff, changing the chemical balances of the lakes and leading to algal blooms, for example. Urban pollution can have the same negative impact on lakes that are located close to cities and towns. For those reasons, it is of utmost importance that environmental protectors and scientists find ways to understand the effects of anthropogenic activity on lakes and most importantly, find ways to manage and improve the health of these essential bodies of water.

This study focused specifically on Lake Durowskie located in Wagrowiec, Poland. By utilizing well-known and expertly developed methods, as part of the European Water Framework Directive (WFD), our task was to assess and evaluate the ecological status of Lake Durowskie in July 2022. Status determination was accomplished by using benthic macroinvertebrates as bioindicators and tools. Benthic invertebrates, particularly macroscopic taxa, have been traditionally utilized in the biomonitoring of streams, rivers, and lakes ecosystems. (Klimaszyk, 2022). They are useful environmental quality bioindicators for a variety of reasons including their narrow range of environmental requirements, widespread diversity, long life cycle, easy taxonomical identification, and limited mobility. Benthic macroinvertebrates are taxonomically diverse and consist of four main types: Planarians, Annelids, Anthropoids, and Mollusks (Klimaszyk, 2022). All four of these types were collected in this study.

The European Water Framework Directive (WFD) is a framework for the protection of water bodies within the European Union and gives the legal background for the assessment and improvement of water bodies throughout Europe (Van Hoey et al., 2010). The National Research Council defines restoration as 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 & Perry, 2002). Typical restoration plans have three objectives: 1. to increase or restore the water holding capacity of the lake, 2. to improve the water quality of the lake, and 3. to evolve a sustainable management plan after restoration. To achieve restoration objectives, physical, chemical, and biological characteristics of the lake water should be known (Ilangovan, 2008).

Ecological studies have been completed on Lake Durowskie between the years of 2009 and 2019, with a slight pause in 2020 and 2021 because of the COVID-19 pandemic. The efforts of our own work join a history of consistent and dedicated studies, led by professional and experienced supervisors from Adam Mickiewicz University and Christian Albrecht University, to monitor the restoration efforts of the lake. We stand on the shoulders of giants. Our study compares the present-day status results with those of the past to illustrate how the ecological status of Lake Durowskie has changed. Finally, this study will be an important stroke of the paintbrush that paints a picture of the successes, or failures, of the overall restoration project on Lake Durowskie throughout the years.

2. METHODOLOGY

The field work was executed during the first week of the summer school, from 29th June until the 2nd of July 2022. In the following week, species were determined, and data reviewed. Details on the methods and materials used during the field work are specified in chapter 2.1 and 2.3, whereas more information about the following data analysis can be found in chapter 2.3.

2.1 Study Area

Lake Durowskie is situated approximately 50 km north of Poznan. It is a post-glacial lake situated in an urban area of the Wielkopolska Region (Western Poland) in the city of Wagrowiec (17°12’1” E, 52°49’6” N). This lake has an elongated shape, oriented north-south and the Struga Gołaniecka River, which is a tributary of the River Wełna, flows along its longitudinal axis.

Lake Durowskie has a surface area of 143.7 hectares (ha) and a maximum depth of 14.6 meters (m). The total catchment surface is 236,1 km^2, covered mainly by fields. The lake is part of a system of five connected lakes: a cascade of hypereutrophic lakes is situated in the river course above Lake Durowskie. These are Kobyleckie, Grylewskie, Bukowieckie, and Laskownickie lakes, with cyanobacterial water blooms in summer.

The lake is dimictic - thermally stratified in summer. Typical water mixing in the water column was observed in spring and autumn. The epilimnion usually reached a depth of 3 m, while the metalimnion down to 6–8 m (Dondajewska et al., 2019; Kowalczewska-Madura et al., 2018).

The southern tip of the lake is embraced by the small town of Wagrowiec which has about 30,000 inhabitants (Messyasz & Pikosz 2017). There are different land use types in the surrounding area of Lake Durowskie. It is also the major attraction of Wagrowiec, there are multiple water activities taking place on the lake, like motorboating, kayaking and bathing at the established beach-site (Goldyn et al., 2013).

Table 1 – Hydrological information about Lake Durowskie (Messyasz & Pikosz 2017)

Parameter	Values
surface	143.7 ha
volume	11,322,900 m^3
maximum depth	14.6 m
mean depth	7.9 m
total catchment area	23,610 ha
direct catchment area	1,581.3 ha

Table 2 – Share of different land uses in the direct catchment area of Lake Durowskie (Messyasz & Pikosz 2017)

Land use form	Share of Direct Catchment Area in %
urban	8.25
agriculture	33.52
forest	58.26

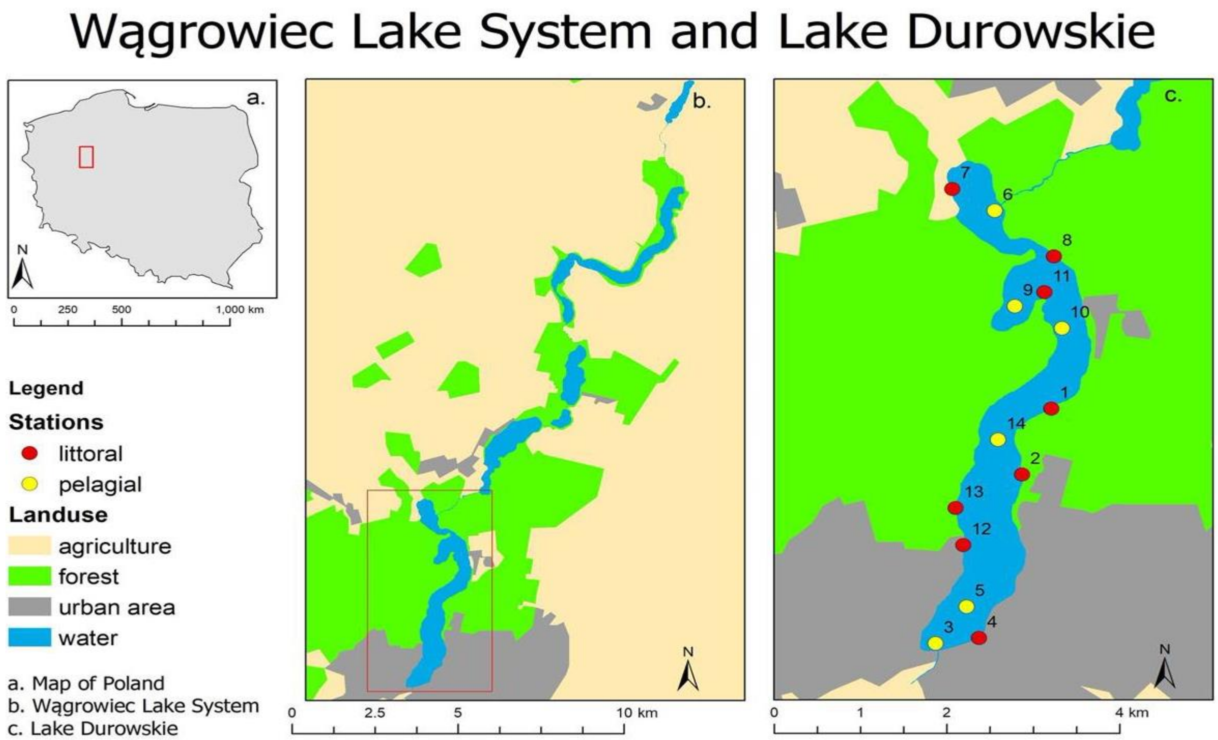

Figure 1 – Maps of the Wągrowiec Lake System and Lake Durowskie including pelagial and littoral sampling stations

2.2 Materials and methods

Zoobenthos (macroinvertebrates) samples were collected between 30th of June and 2nd of July 2022 from 14 stations on the lake. The different sampling points were selected to be representative of the whole lake and therefore are distributed across all areas of the lake.

These points were grouped into different zones: the profundal zone (numbers 3, 5, 6, 9, 10 and 14), the littoral zone near the forest (numbers 1, 7, 8, 11 and 13) and the littoral zone near the urban area (numbers 2, 4 and 12) (Figure 1).

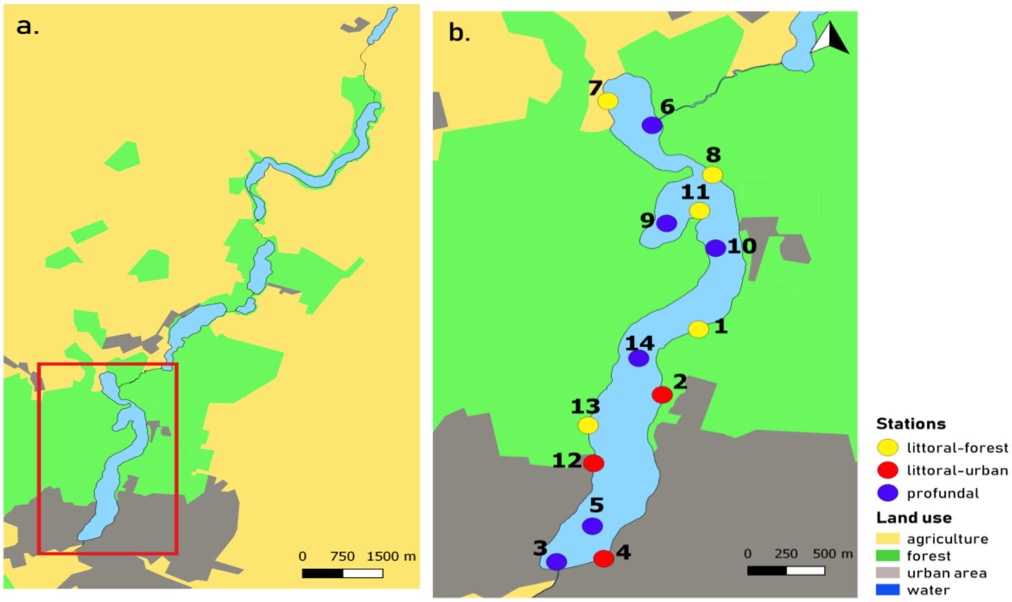

Figure 2 – (a) Land use map of the catchment area of Durowskie Lake; (b) Location of the sampling sites represented with different color based on the features of the nearby area: profundal, littoral near forest, and littoral near urban.

Two different core samplers were used to collect the samples. A — Kajak core sampler (diameter of 6.0 cm) was used for pelagic depths greater than 2m, whereas B — Czapla core sampler (diameter of 5.6 cm) was used for littoral depths less than 2m. Figure 2 depicts the spatial distribution of the 14 sampling stations on Lake Durowskie.

Figure 3 – Pictures of the two core samplers used for the collection of samples of macroinvertebrates: (a) Kajak corer (b) Czapla corer

After sediment samples were obtained from the lake substrate, they were washed in a sieve (mesh 400µm) with lake water to remove sediment and then stored in containers for transport. Then in the lab, samples were put in containers for each individual station and visually inspected under lamps providing light.

Macroinvertebrates were extracted with forceps and sorted by taxonomical families in petri dishes. The organisms were then dried and weighed by family in increments of 5 individuals per weighing. Once weighed, the macroinvertebrates were preserved in tubes with 70 % alcohol for more precise identification in the laboratory.

2.3 Data Analysis

Further examination of individuals was carried out in the laboratory with microscopes and stereoscopes. Species determination was conducted for each individual as necessary. For practical reasons, identification to the genus or species level was not necessary for each type of family. The number of individuals per m^2 and the total biomass of each taxon was calculated for 1 m^2 and compared to data from previous years.

Calculation (Number of individuals)

n = n sample * CR [individuals/m^2]

n = number of individuals per m^2 (per taxon)

N sample = number of individuals from the sample (per taxon)

CR = conversion rate

Calculation (Biomass)

g = g sample * CR [mg/m^2]

g = biomass per m^2 (per taxon)

G sample = weight of individuals from the sample (per taxon)

CR = conversion rate

Indexes

- **Shannon-Wiener and Simpson biodiversity indexes:** used to measure the diversity of species in a community. However, their values have different meanings. For Shannon-Wiener, a higher value means higher biodiversity. For Simpson, a lower value means higher biodiversity.
- **Average Score Per Taxon (ASPT):** Higher value indicates higher biodiversity, while a lower value indicates lower biodiversity.
- **Lake Macroinvertebrate Index (LMI):** Used for the determination of the ecological state of the lake.

Table 3 – Overview for the used core samplers and applied conversion rates for each station

Station Number	Type of Core Sampler *(Zone)*	Conversion Rate
1	Czapla *(Littoral)*	39
2	Czapla *(Littoral)*	39
3	Kajak *(Pelagic)*	35
4	Czapla *(Littoral)*	49
5	Kajak *(Pelagic)*	35
6	Kajak *(Pelagic)*	35
7	Czapla *(Littoral)*	39
8	Czapla *(Littoral)*	35
9	Kajak *(Pelagic)*	35
10	Kajak *(Pelagic)*	35
11	Kajak *(Pelagic)*	39
12	Czapla *(Littoral)*	39
13	Czapla *(Littoral)*	39
14	Kajak *(Pelagic)*	35

3. RESULTS AND DISCUSSION

Table 4 – Number of individuals per m^2 for each sampling station in Lake Durowskie in 2022

Number of individuals of macroinvertebrates at different sampling stations at Lake Durowskie [ind/m^2]														
Taxon	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Nematoda														
Annelida Nematomorpha									70					
Oligochaeta Tubificidae				585								39		
Hirudinea														
Erphobolelidae								39						
Bivalvia														
Dreissenidae - Dreissera polymorpha (Pall.)	117	1326		3666			2379	468			1950	156	39	
Unionidae - Unio tumidus (Philipsson)	78						39					39	78	
Anodonta cygnea (L.)							39							
Gastropoda														
Hydrobidea - Potamorygrus anttipodarum (Smith)	429	39		234								156	39	
Neritidae - Theodosux fluviatilis (L.)	39	351		156								78	39	
Planorbidae				78										
Crustacea														
Asellidae - Asellus aqauaticus (Racov.)		858									39			
Cambaridea											39			
Megaloptera														
Sialidae		78									78			
Ephemeroptera														
Caenidea								39			39			
Trichopetera														
Hyolroptybiolae		39												
Phryganeidae								39						
Polycentropodidae		195						78			39			
Molannidae												117		
Chaoboridea Chaoborus flavicans (Meig.)			1260		1645	420			35	700				2100
Chironomidea	6630	507		429		455	1560	936	735	35	1560		5655	
Acari hydracarina	39										39			
SUM	7332	3393	1260	5148	1645	875	4017	1599	840	735	3783	585	5850	2100
MEAN	2797.29													

Table 5 – Biomass of macroinvertebrates per m^2 for each sampling station in Lake Durowskie in 2022

Biomass of macroinvertebrates at different sampling stations at Lake Durowskie [mg/m^2]														
Taxon	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Nematoda														
Annelida Nematomorpha									805					
Oligochaeta Tubificidae				1560								39		
Hirudinea														
Erphobolelidae								390						
Bivalvia														
Dreissenidae - Dreissera polymorpha (Pall.)	1560	126360		216840			749190	224250			216450	58773	1638	
Unionidae - Unio tumidus (Philipsson)	912990						683280					177840	494754	
Anodonta cygnea (L.)							409500							
Gastropoda														
Hydrobidea - Potamorygrus anttipodarum (Smith)	4329	3666		3198								2067	468	
Neritidae - Theodosux fluviatilis (L.)	3198	42471		16809								3471	2808	
Planorbidae				1638										
Crustacea														
Asellidae - Asellus aqauaticus (Racov.)		1560									195			
Cambaridea											780			
Megaloptera														
Sialidae		3666									936			
Ephemeroptera														
Caenidea								78			39			
Trichopetera												29094		
Hyolroptybiolae		4212												
Phryganeidae								1170						
Polycentropodidae		1482						4290			663			
Molannidae												29094		
N. det (not deteremined)	312													
Chaoboridea Chaoborus flavicans (Meig.)			1260		1645	1260			140	3185				5670
Chironomidea	8229	2340		1482		9800	37284	17238	13020	665	23322		9009	
Acari hydracarina	39										39			
SUM	930657	185757	1260	241527	1645	11060	1879254	247416	13965	3850	242424	300378	508677	5670
MEAN	326681.43													

Table 6 – Shannon-Wiener biodiversity index for each station in Lake Durowskie in 2022

Station	Shannon
1	0.427
2	0.317
3	0
4	1.006
5	0
6	0.692
7	0.768
8	0.951
9	0.324
10	0.119
11	1.032
12	1.124
13	0.157
14	0
MEAN	0.4941

Table 7 – Average Score per Taxon (ASPT) of macroinvertebrates for each sampling station in Lake Durowskie in 2017, 2018, 2019, and 2022

Station	2022	2019	2018	2017
1	4	4	4	5
2	5	4	4	4
3	0	0	2	2
4	5	4	5	4
5	0	2	2	2
6	2	5	3	2
7	4	4	5	4
8	7	5	5	5
9	1	2	3	2
10	2	0	2	4
11	4	5	6	4
12	6	4	4	2
13	6	4	5	4
14	0	2	2	2

Table 8 – Simpson biodiversity index for each station in Lake Durowskie in 2022

Station	Simpson
1	0.822
2	0.079
3	1
4	0.53
5	1
6	0.24
7	0.502
8	0.497
9	0.774
10	0.95
11	0.437
12	0.133
13	0.935
14	1
MEAN	0.6356

Table 9 – Average Score per Taxon (ASPT) for each station on Lake Durowskie in the years 2017, 2018, 2019, and 2022

Station	2022	2019	2018	2017
1	4	4	4	5
2	5	4	4	4
3	0	0	2	2
4	5	4	5	4
5	0	2	2	2
6	2	5	3	2
7	4	4	5	4
8	7	5	5	5
9	1	2	3	2
10	2	0	2	4
11	4	5	6	4
12	6	4	4	2
13	6	4	5	4
14	0	2	2	2

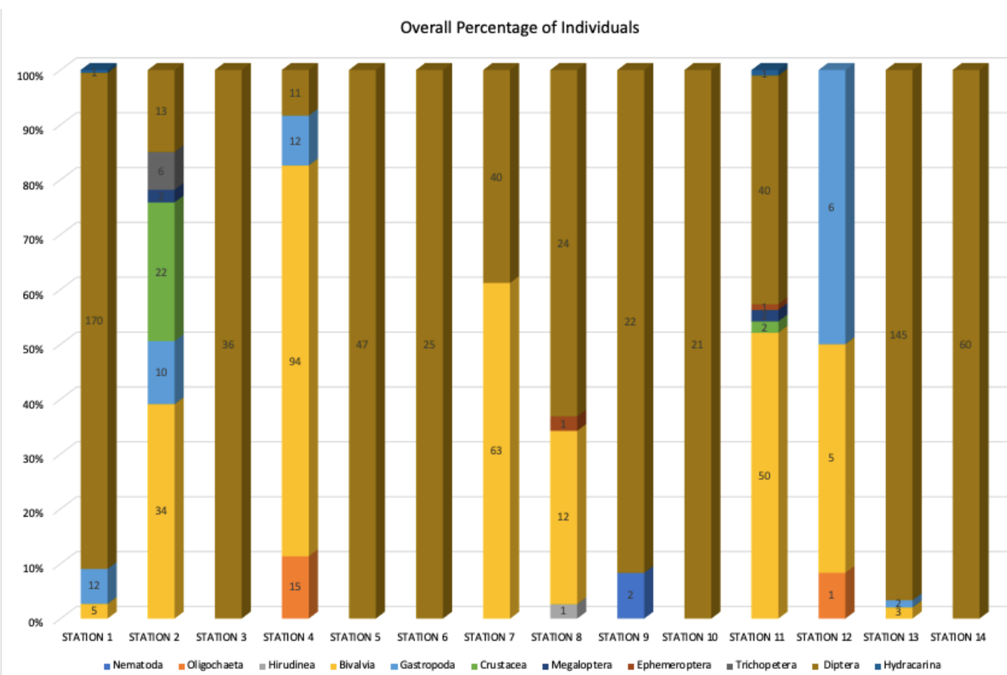

Figure 4 – Overall percentage of individuals per m^2 at each station in 2022

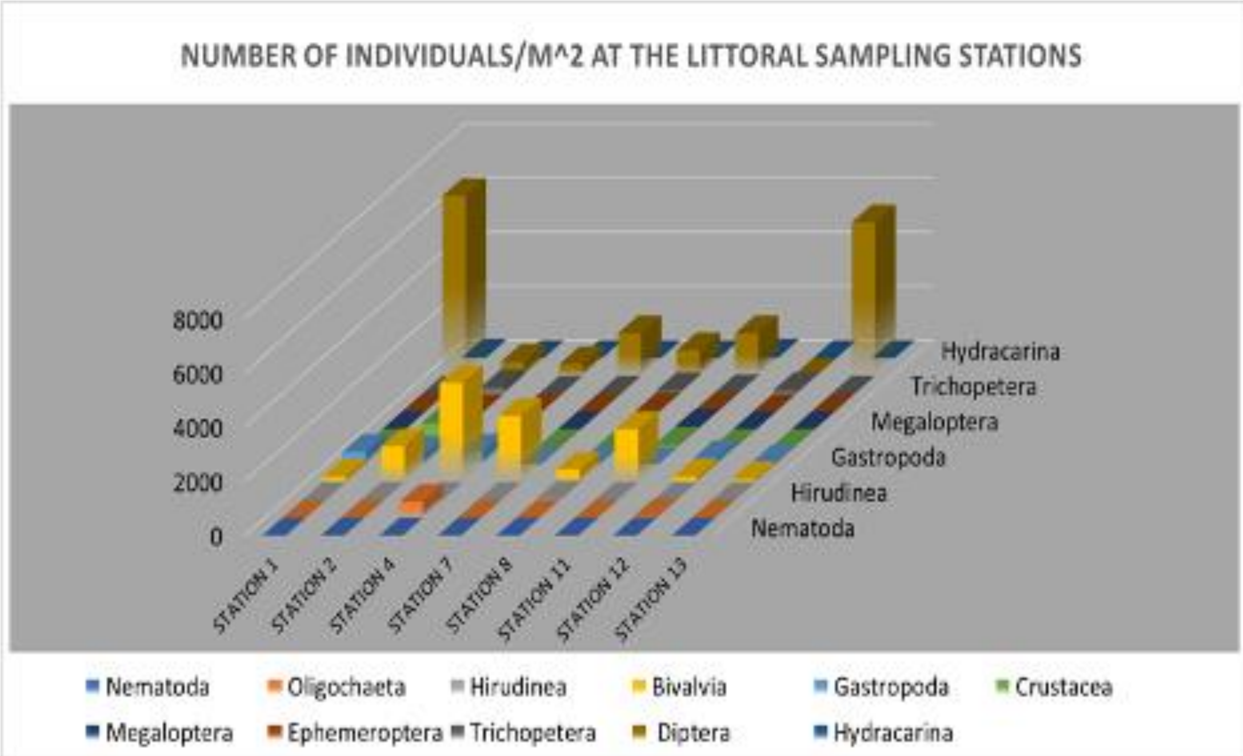

Figure 5 – Number of individuals per m^2 at the littoral zones

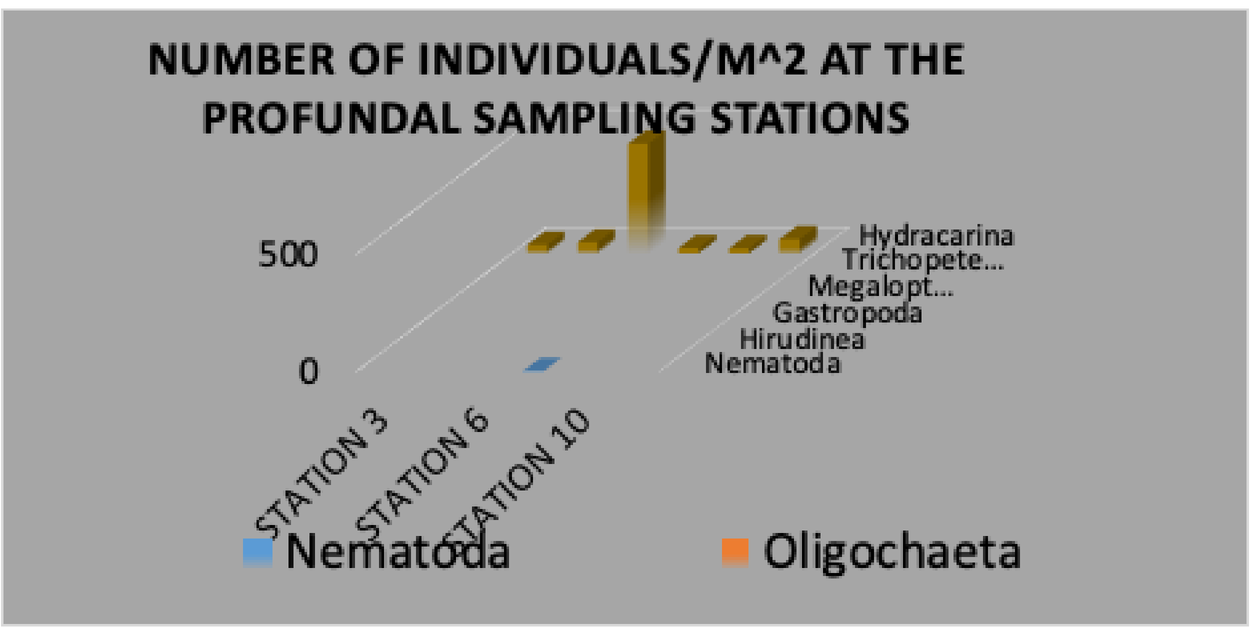

Figure 6 – Number of individuals per m^2 at the profundal zones

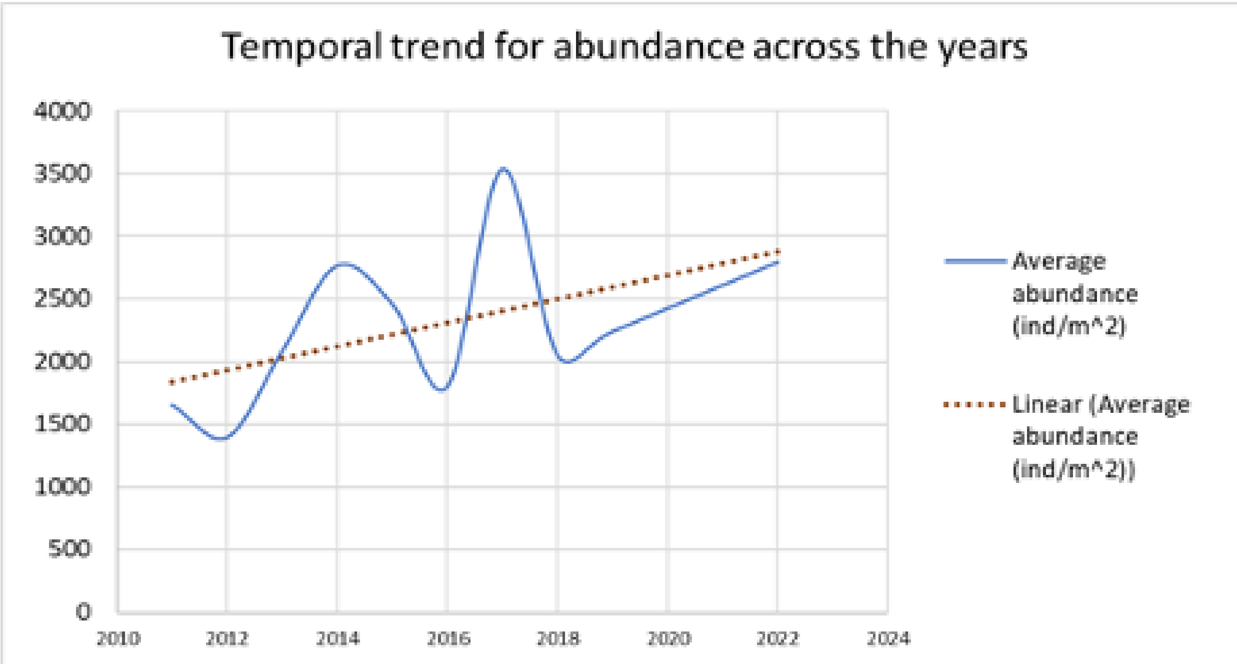

Figure 7 – Average number of individuals per m^2 for 2012-2022 (excluding 2020 and 2021)

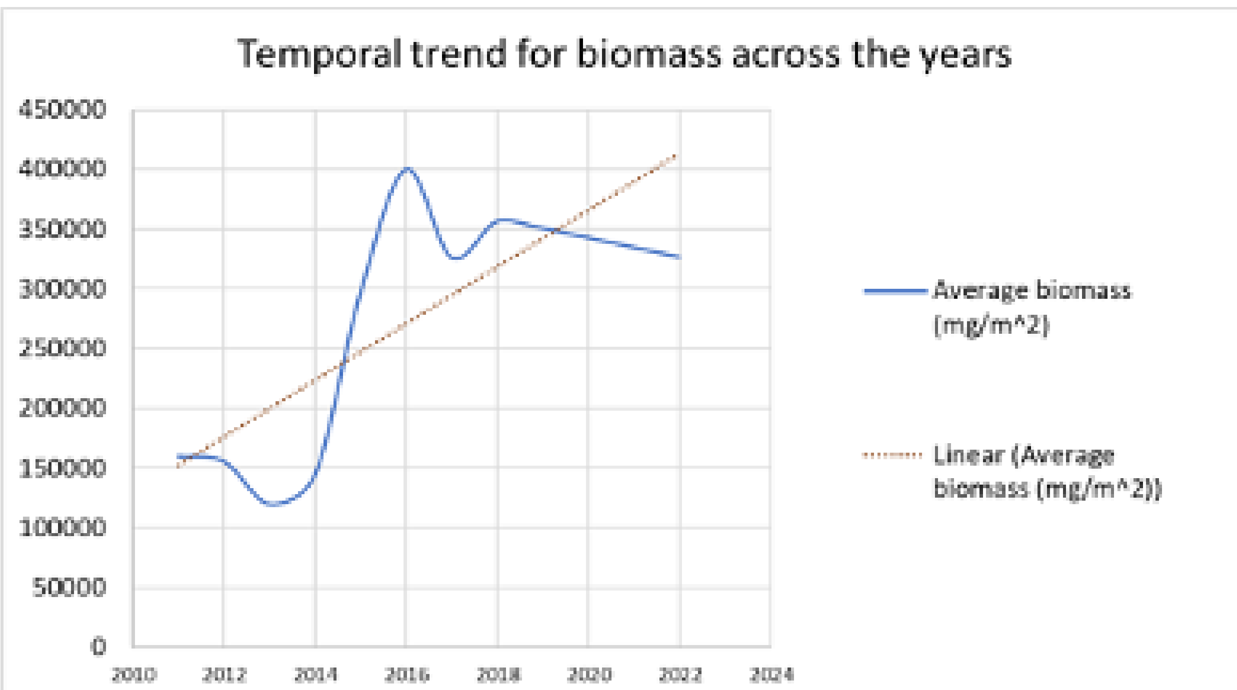

Figure 8 – Average biomass of macroinvertebrates (mg/m^2) for 2012-2022 (excluding 2020 and 2021)

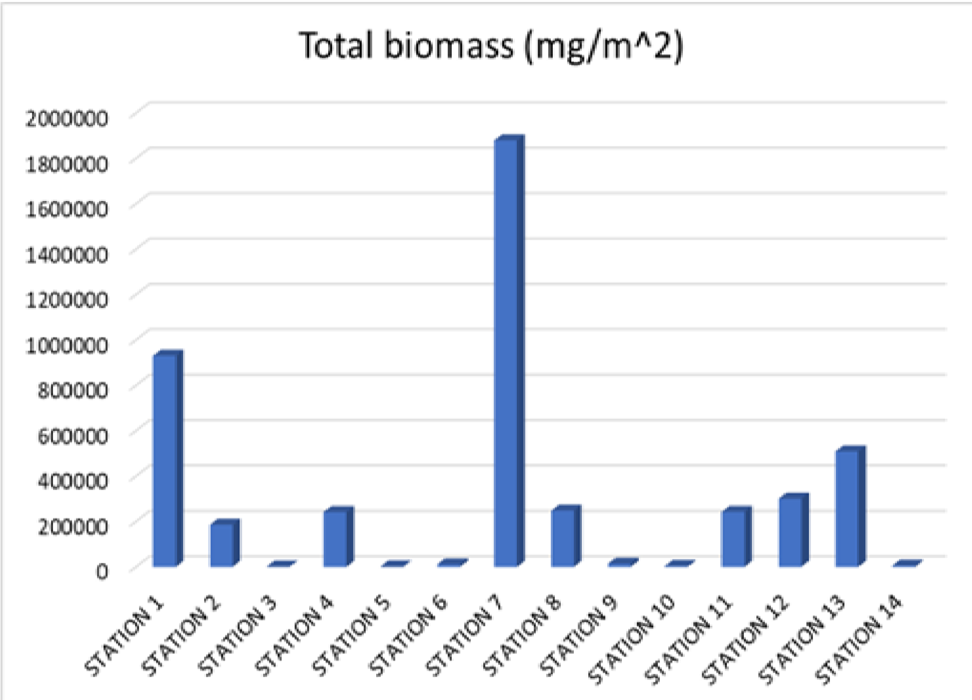

Figure 9 – Total biomass of macroinvertebrates at each station in Lake Durowskie in 2022

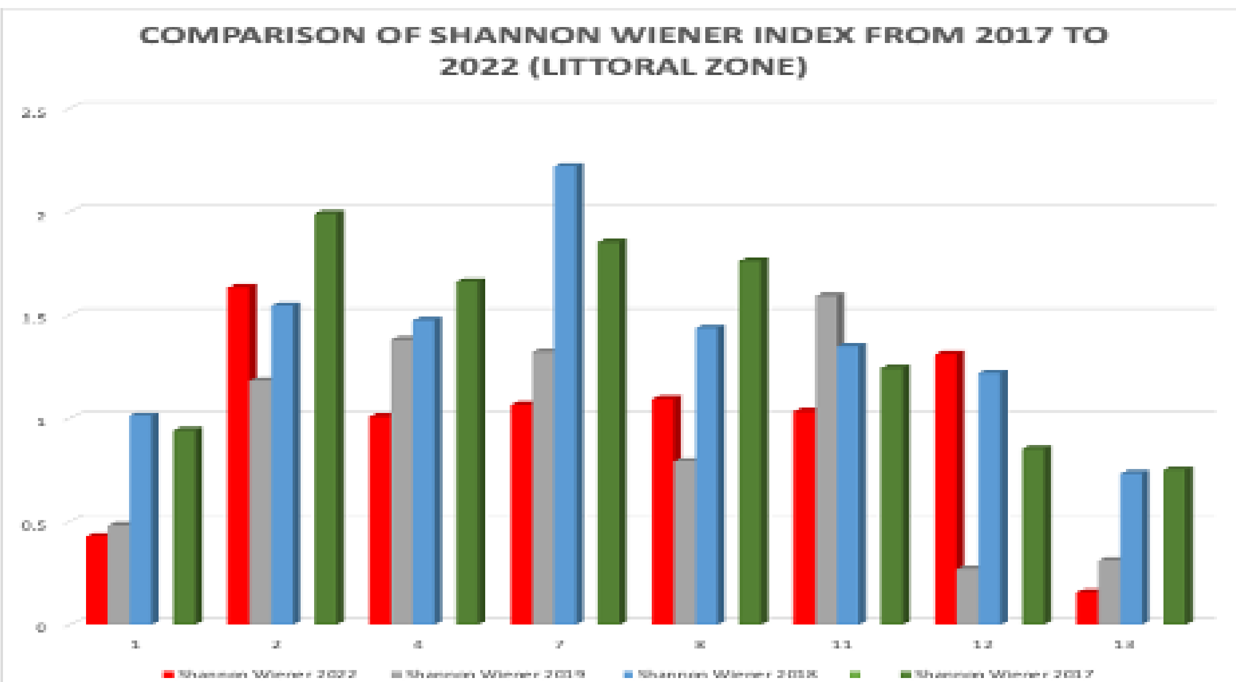

Figure 10 – Comparison of Shannon-Wiener biodiversity index stations in the littoral zone in Lake Durowskie for years 2017, 2018, 2019, and 2022

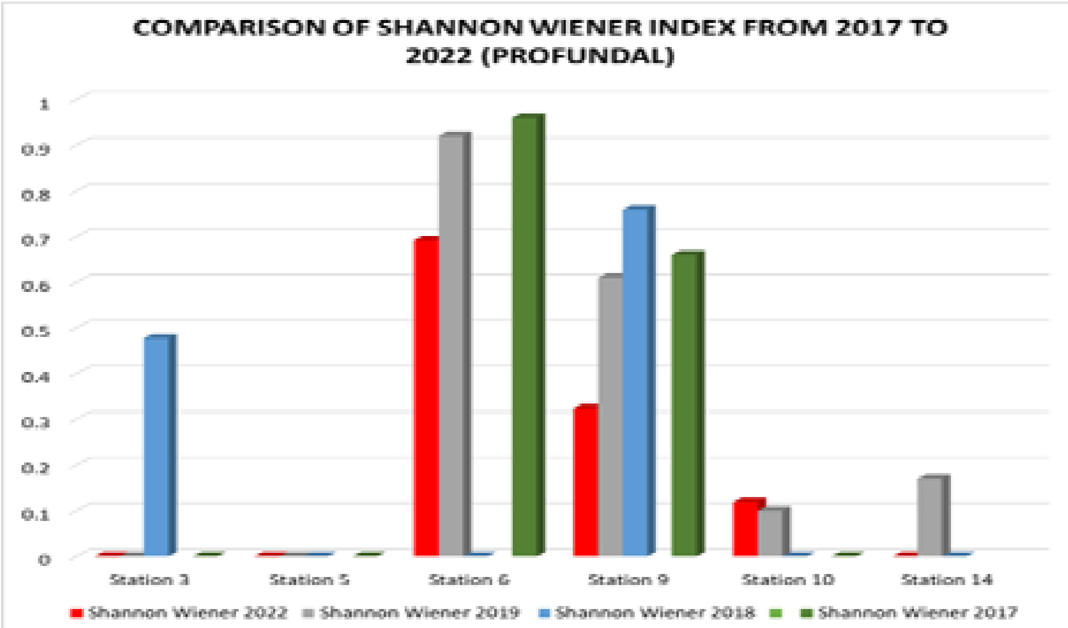

Figure 11 – Comparison of Shannon-Wiener biodiversity index stations in the profundal zone in Lake Durowskie for years 2017, 2018, 2019, and 2022

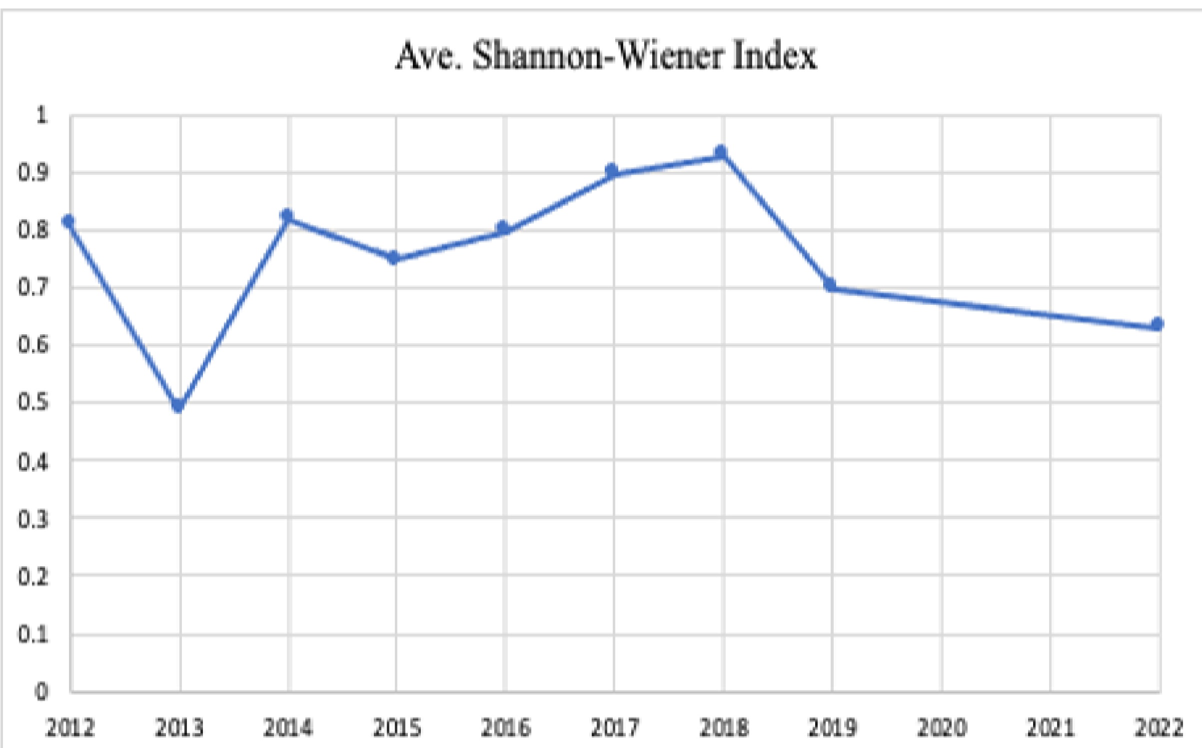

Figure 12 – Average Shannon-Wiener biodiversity index for macroinvertebrates in Lake Durowskie for 2012-2022 (excluding 2020 and 2021)

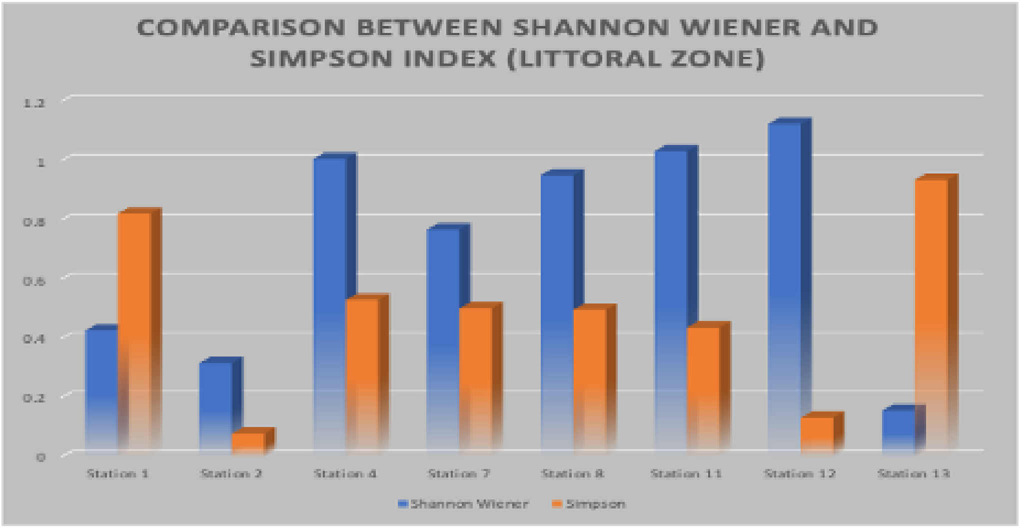

Figure 13 – Comparison between Shannon-Wiener and Simpson Biodiversity Indexes for benthic macroinvertebrates in the littoral zones of Lake Durowskie in 2022

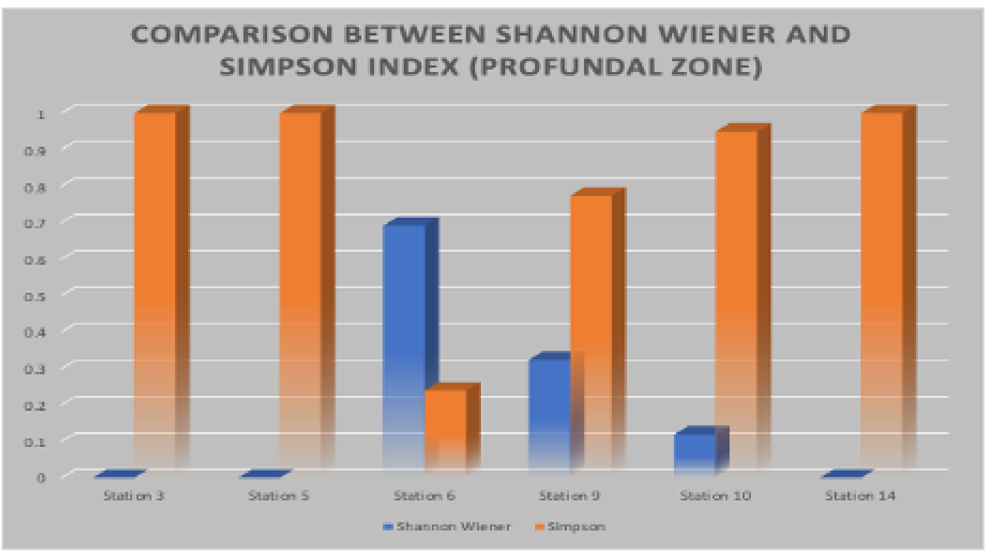

Figure 14 – Comparison between Shannon-Wiener and Simpson Biodiversity Indexes for benthic macroinvertebrates in the profundal zones of Lake Durowskie in 2022

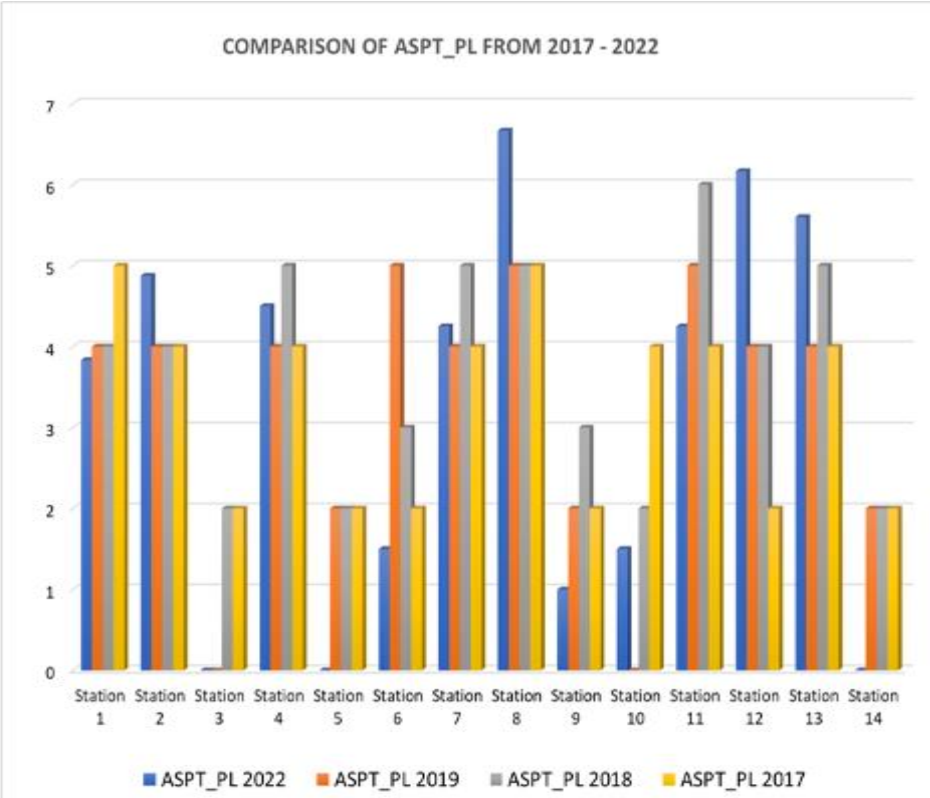

Figure 15 – Average Score per Taxon (ASPT) on Lake Durowksie for years 2017, 2018, 2019, and 2022

Table 10 – Lake Macroinvertebrates Index of Lake Durowskie 2022

Stations	LMI
Station 1	0.13
Station 2	1.05
Station 4	1.71
Station 7	1.15
Station 8	2.16
Station 11	1.01
Station 12	
Station 13	0.53
Average LMI=	0.552857
	Moderate

Benthic macroinvertebrates are a widely used and applied tool for the bioassessment of the ecological status of a lake both on small and large scales. Hence, this valuable tool was employed for the determination of the ecological status of Lake Durowskie. During the field trip, 11 different taxa were found. The number of individuals per m^2 within each station ranges from 35 (Stations 9 and 10) to 7,332 (Station 1). The total number of individuals found was 39,162. The data show many individuals per m^2 in the littoral water areas (Stations 1, 2, 4, 11 and 13). Overall, an increase in individuals per m^2 compared to the previous years was determined. Stations 12 (585 ind/m^2), 10 (735 ind/m^2) and 9 (840 ind/m^2) have considerably lower numbers of individuals per m^2 compared with other stations.

The total number of individuals per m^2 within each station ranges from 585 (station 12) to 7332 (station 1). The lowest abundances of individuals are mostly found in the profundal stations (stations 3, 5, 6, 9, 10 and 14). Station 8, a littoral station, is also very low. Generally, stations in the littoral zone have higher abundances – both forest and urban. Littoral stations in the southern part of the lake (1, 4 and 13) have the highest abundances overall. The number of individuals in 2022 is 2,797 ind/m^2. That is a decrease since the last recorded year, 2019 with 3,538 ind/m^2. The average number of individuals per m^2 spiked in 2014 with 4,671. It dropped in 2015 and again in 2016. In 2017, the number increased before it dropped once more in 2018.

Based on the result obtained, it is apparent that there is a decrease in the abundance of macroinvertebrates per square meter in comparison with that obtained in 2017. This might be due to the fact that the sampling was done in June which is in contrast with the standard practice. According to Hill et. al. (2016), the best time to sample aquatic macroinvertebrates in ponds and lakes is during the spring and autumn months before the macroinvertebrates becomes adult and leaves the aquatic ecosystem to the terrestrial ecosystem. There is a slight decrease in the total biomass of the macroinvertebrate observed when compared with the result obtained in 2019. This could be expected given the reason that the abundance followed a downward trend in comparison to previous years. Other factors such as fluctuations in nutrients, temperature, pH, water turbidity, oxygen levels and changes in the food web, in particular predator populations (Klimaszyk and Heymann, 2010; Feuchtmayr et al., 2007). Strong feeding pressure by fish could also be considered a possible reason for the low abundance and biomass (Leppä et al., 2003).

It was observed that the abundance of macroinvertebrates at the littoral zone was significantly higher than that of the profundal zone. This is expected as the littoral zone consists of different habitat types which support characteristic faunas (Shcherbina, 2013; Klimaszyk and Heymann, 2010). However, the profundal zone is normally characterized with reduced oxygen concentration, thus creating a much hostile environment for macroinvertebrates (Bartram & Ballance, 1996). Furthermore, the biomass of macroinvertebrates was higher in the littoral zone than in the profundal zone owing to the different taxa composition in the different habitat types and ecotones. Taxas such as bivalves and gastropods with large biomass are enormous at the littoral zone, thus increasing the biomass of macroinvertebrates in the littoral zone. On the other hand, profundal zones are dominated by chironomidae and chaoboridae, with small biomass. It should be noted that chironomidae which was found in all the sampled stations is an indication of low dissolved oxygen concentration in water thus, implying high nutrient load. The calculated biomass per m^2 differs greatly among stations. The values range from a minimum of 1,260 mg/m^2 (Station 3) to a maximum of 930,657 mg/m^2 (Station 1). Station 3 has the lowest biomass (1,260 mg/m^2). Stations 10 (3,850 mg/m^2), 14 (5,670 mg/m^2) and 5 (1,645 mg/m^2) also have low biomass. However, a relatively higher biomass was observed in Stations 1, 2, 4, 7, 8 and 12 ranging from 241,527 mg/m^2 to 930,657 mg/m^2. In terms of biomass, Stations 1, 2, 6, 7, and 11 were dominated by the taxon Chironomidae, whereas Bivalvia prevailed at Stations 4, 7, and 12. In general, biomass is lower in pelagic zones and around the inflow, while biomass is higher in littoral zones and at the outflow. Regarding the long-term trend from 2012 to 2022, an increase is observed.

A general higher biodiversity can be highlighted in the samples collected in the littoral areas compared to the profundal zone. The predominant species in the littoral area are Chironomidae, Gastropoda and Bivalvia. In site 1 a high presence of Chironomidae was observed. According to the Shannon-Wiener Diversity Index across four (4) different sampling years (2017, 2018, 2019 and 2022), a decrease in biodiversity was observed. This was the lowest observed within those years and in fact, some taxa such as Odonata and Plecoptera were totally missing. The stations with highest values, thus the highest diversity, are 4, 11, and 12 – all littoral zones. The stations with the lowest values, thus the lowest diversity, are 3, 5, and 14 – all profundal zones. To corroborate the observed trend, the overall mean of the Shannon-Wiener Index value is the smallest since 2013 which implies very low biodiversity. Based on the Simpson index, the stations with the highest value, thus the lowest diversity, are 3, 5, and 14 – all profundal zones. The stations with the lowest value, thus the highest diversity, are 2 (littoral), 6 (profundal), and 12 (littoral). The comparison of the Shannon-Wiener index with the Simpson index shows that the littoral stations with the highest biodiversity, according to the Shannon-Wiener Index, are 4, 11, and 12. The littoral stations with the highest biodiversity, according to the Simpson Index, are 2 and 12. The littoral stations with the lowest biodiversity, according to the Shannon-Wiener Index, are 1, 2 and 13. The littoral stations with the lowest biodiversity, according to the Simpson Index, are 1 and 13. The profundal stations with the highest biodiversity, according to the Shannon-Wiener Index, is 6. The profundal stations with the highest biodiversity, according to the Simpson Index, is 6. The results are consistent between the two indices. The profundal stations with the lowest biodiversity, according to the Shannon-Wiener Index, are 3, 5, 10, and 14. The profundal stations with the lowest biodiversity, according to the Simpson Index, are 3, 5, 10, and 14. The results are consistent between the two indices. Like the littoral zones, the values of the profundal zones show that both indices resulted in very similar results.

As expected, the littoral zone has the highest Average Score per Taxon (ASPT) value in comparison with the profundal zone. The highest ASPT value was recorded for station 8 and 12 respectively. However, the ASPT mean value follows the trend observed since 2017 with a slight fluctuation in 2018. For the 2022 study, stations 8, 12, and 13 have values of 6 or greater which means they have the highest biodiversity. Station 8 had the highest biodiversity. Stations 2 and 4 have values of 4 which means they have an average amount of biodiversity. Stations 3, 5, 9, and 14 all have values of 1 or less which means they have lowest biodiversity.

Compared to past years, stations 1, 2, 4, 8, 12, and 13 have maintained an average or higher level of biodiversity. Stations 3, 5, and 14 have consistently been locations with low biodiversity.
The Lake Macroinvertebrate Index was used as a conclusive assessment index for the ecological state of Lake Durowskie based on benthic macroinvertebrates. According to the result obtained from the LMI index (0.553), it could be said that the ecological state of Lake Durowskie is "Moderate".

4. CONCLUSION

Past algal blooms, particularly those involving cyanobacteria, severely eutrophied and damaged Lake Durowskie. The water quality of the lake has, however, gradually improved since 2009, thanks to the adoption of restorative procedures. Over the past ten years, macroinvertebrates have been sampled annually to track the success of restoration efforts, along with macrophytes, algae, and physico-chemical elements.

The littoral stations of Lake Durowskie outperformed the profundal stations in terms of macroinvertebrate diversity and abundance out of all 14 stations. This is so because benthic invertebrates are often located in shallow lake waters, and as a lake gets deeper, their diversity and density decrease. Low levels of dissolved oxygen and light in the pelagic zones compared to the littoral zones may have contributed to the reduced variety and abundance of macroinvertebrates in the profundal stations. The littoral sites with the highest abundance of individuals were 1, 13 (both stations located near forested areas) and 4 (located near urban center) respectively while the sites with the highest biodiversity (Shannon-Wiener index) in the lake were Stations 12, 11 and 4 (all littoral stations).

Station 7 has the highest macroinvertebrate biomass (littoral - forested zone). This station was primarily composed of bivalves, then dipterans. The stations with the lowest biomass were 3,5,6,9,10, and 14 (all profundal zones).

Finally, Station 8 had the highest lake macroinvertebrate index (LMI), which was due to the presence of species of bivalves, dipterans, hindinea, Ephemeroptera, and tricoptera that are vulnerable to pollution. Dipterans are significant in the release of nutrients and the decomposition of decaying organic waste (Jan Frouz, 1999). High abundance of Chironomids indicate low quality of lake (Henn and Marina, 2019). Invasive bivalves can reduce nutrients load in lakes (Balogh et al. 2022).

Overall, the sample time, lake quality, and climate factors all likely contributed to the population decline. Bivalves are quite abundant, which increases biomass. The lake's macroinvertebrate condition is moderate, according to the temporal trends for abundance and biomass, which are slowly rising. The lake is being maintained by the restoration plan, although stronger measures are required. These findings are encouraging, but more research and management work must be done to guarantee Lake Durowskie's full restoration.

5. RECOMMENDATIONS

Macroinvertebrates are good bioindicators of the lake's water quality, therefore the findings of this study can be used to develop suggestions on how to enhance restoration efforts even further. The recommendations for future study as well as lake management are listed below.

5.1 Further research recommendations

Lake Durowskie’s rehabilitation should continue to be observed scientifically on an annual basis. Additional research should be done to better understand the causes that cause variations between sampling stations and variations in data from year to year in addition to the overall trends in water quality of lake restoration. Further, it would be reasonable to look into reasons why Station 4's high biodiversity values persist despite the significant anthropogenic disturbance (this was also pointed out in 2018).

5.2 Management recommendations

To minimize the nutrients that flow into Durowskie, restoration attention should be given to the entire chain of lakes and the river. This chain effect could minimize the care and money that is used to maintain the quality of Lake Durowskie. By planting forested buffer zones between the agricultural fields and the lake shores, more nutrients could be absorbed by the root systems of the trees and other vegetation. The water quality at Lake Durowskie has been improving because of restoration efforts. The restoration intends to bring the lake's self-contained, top-down trophic control system back to life. As a result, over the past ten years, macroinvertebrate diversity, biomass, and individuals per square meter have all increased. However, given the low readings in the deeper parts of the lake, these results are not spread equally between stations.

In order to promote oxygenation at these depths, more aerators may be built as part of a management strategy to improve the condition in the lake's pelagic zones.

Planting and preserving various macrophyte 22 communities is another management strategy. Increasing local mussel populations would also speed up the removal of contaminants from the water body and create job opportunities for the community, but the effects of such a move on the ecosystem in the area should be thoroughly examined before being put into action.

There are already non-native zebra mussels (*Dreissena polymorpha*) in the lake, therefore it's important to monitor them to make sure they do not supplant native species by becoming invasive.

To eliminate or at least lessen upstream and downstream pollution, increased restoration activities are required throughout the entire catchment. The macroinvertebrate community in Lake Durowskie has benefited locally from previous restoration efforts.

However, the entire 5-lake system should be included in these efforts. The foundation for upcoming restoration efforts can be laid by creating baseline studies for other lakes in the system. There is no one solution that works for all situations, thus restoration strategies should be customized to each lake's unique qualities and issues. The success of any downstream restoration efforts, including those for Lake Durowskie, is severely hampered in the absence of cooperation between the authorities of each municipality.

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