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Ecological state of Lake Durowskie during restoration measures:

Macroinvertebrate Analysis 2019

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1. Introduction and aims

1.1 Introduction

There is a global trend of increasing degradation of lake ecosystems caused by a myriad of direct and indirect human-induced pressures (Wetzel, 2001). The overexploitation of lake resources is a major contributor to this degradation - including unsustainable fishing practises, sewerage and pollution, as well as physical modifications from dams and irrigation systems. The intensification of land use in catchment zones through clearing of vegetation, agriculture and urban development also has a large impact (Schallenberg et al., 2013). The current global warming can significantly increase water temperatures, reducing vertical mixing of the water column, which in turn reduces the concentration of oxygen in deeper water resulting in anoxic conditions and reducing overall productivity and water quality (Schallenberg et al., 2013).

A lake is defined as a permanent water body with a relatively slow exchange of water (Messyasz & Pikosz, 2019). It is vital to protect and restore lake ecosystems in order to benefit from the ecosystem services they provide - both for human well-being and intrinsic environmental services (Schallenberg et al., 2013; Dondajewska et al., 2019). Lakes provide habitat for a diversity of species and biodiversity is thought to increase resilience and functioning of ecosystem services (Schallenberg et al., 2013). Lakes are major carbon sinks, sequestering and storing large amounts of carbon and keeping it from the atmosphere, thus significantly helping to mitigate increasing global warming. Lake ecosystems also regulate water flow and quality through sediment and nutrient retention and processing. This is particularly relevant to human-valued ecosystem services, allowing the safe consumption and storage of freshwater sources for the growing human population. Humans also benefit from lakes through economic growth via activities such as commercial and recreational fishing, hydroelectricity and tourism, not to mention the various recreational activities that are possible (Schallenberg et al., 2013).

The importance of these ecosystems is widely recognized within the European Water Framework Directive (WFD), a legislative framework that aims to ensure the restoration of polluted waters within the European Union (European Commission, 2019; Van Hoey et al., 2010). Restoration is defined as the “return of an ecosystem to a close approximation of its condition prior to disturbance” (Kondolf & Micheli, 1995). The WFD defines the ‘ideal state’ of a water body as having clear water, small amounts of phytoplankton, vegetation dominated by submerged macrophytes and rich macroinvertebrate and fish communities (Heerdt et al., 2007). According to the WFD, restoration plans must include thorough monitoring programs to ensure success overtime (European Commission, 2019).

The WFD requires Member States to assess the Ecological Quality Status (EQS) not only assessing the hydromorphological and physical-chemical parameters, but also evaluating the status of the Biological Quality Elements (BQE). The EQS is determined by the deviation that the biological elements exhibit from what is expected at undisturbed or nearly undisturbed situations (Vinagre et al., 2017). One of the indicated BQE are, among others, the macroinvertebrates. The study of benthic macroinvertebrates - composition, abundance, diversity and sensitivity - is a particularly useful method due to the groups high diversity, longevity, sedentary lifestyle, as well as their sensitivity to pollution. Sensitivity to pollution varies across different taxa groups. For this reason, the water quality can be determined according to the presence/absence and abundance of particular taxa (Cairns & Pratt, 1993).

The site of this study is Lake Durowskie - located in the city of Wągrowiec, in the Greater Poland area. The catchment area comprises predominantly rural area, as well as farmland, forest and urban areas (Figure 1). Lake Durowskie is influenced by the inflow of a number of lakes in the wider catchment area. In 2008, Lake Durowskie experienced extreme eutrophication with low oxygen levels, high levels of phosphorus and the presence of hydrogen sulphide resulting in large algae (cyanobacteria) blooms (Goldyn et al., 2014). The poor water quality impacted heavily on local recreational activities as well as the tourism industry in the area. In response to this event, the local government created a restoration plan in 2009 in collaboration with researchers, in accordance with the WFD framework, with the aim of initiating a self-regulating top-down trophic control system. The restoration techniques employed are the oxygenation of deeper water by the use of wind aerators, biomanipulation using predatory fish and phosphorous deactivation. In order to ensure a sustainable ongoing biomonitoring program to assess the continuous state of the lake and ensure success, the universities of Poznan (Poland) and Kiel (Germany) have created a summer school program that incorporates the yearly monitoring of the lake and learning opportunities for students. According to data collected since 2009, there has been an increase in the overall health of Lake Durowskie (Goldyn et al., 2014).

1.2 Aims

The aim of this study is to define the current ecological status of Lake Durowskie as defined by the European Water Framework Directive (WFD), using macroinvertebrates as indicators. In addition, the study will compare the current status with past status within the monitoring period (2009-2018). This study will contribute to the greater monitoring program that encompasses other environmental indicators and will assess the overall success of the restoration project so far.

2. Materials and methods

2.1 Study area

Lake Durowskie 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). It is elongated in shape (oriented north-south) and the Struga Gołaniecka River, which is a tributary of the River Wełna, flows along its longitudinal axis. 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 (Kowalczewska-Madura et al., 2018; Gołdyn et al., 2013). The total catchment surface of Durowskie Lake is 236,1 km^2, covered mainly by fields from which fertilizers penetrated the surface waters. The lake surface area is 1,43 km^2, and the mean and maximum depth are respectively 4,6 and 14,6 m (Table 1). The lake is surrounded by forests in the northern part, and by urban areas in the south, thus recreational pressure (swimming, sailing, and angling) is severe (Dondajewska et al., 2019).

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).

Table 1. Main features of Lake Durowskie (Dondajewska et al., 2019; Kowalczewska-Madura et al., 2018; Gołdyn et al., 2014; Gołdyn et al., 2013).

Parameter	Value
Maximum depth (m)	14,6
Mean depth (m)	4,6
Surface area (km^2)	1,43
Volume (m^3)	11,322,900
Catchment area (km^2)	236,1
Main tributary	River Struga Gołaniecka

2.2 Sampling and laboratory activities

The samples of benthic macroinvertebrates were collected between the 24th and 29th of June 2019. The samples were collected in 14 different sites in the lake and 2 sites in the Struga Gołańska River (inflow and outflow). 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).

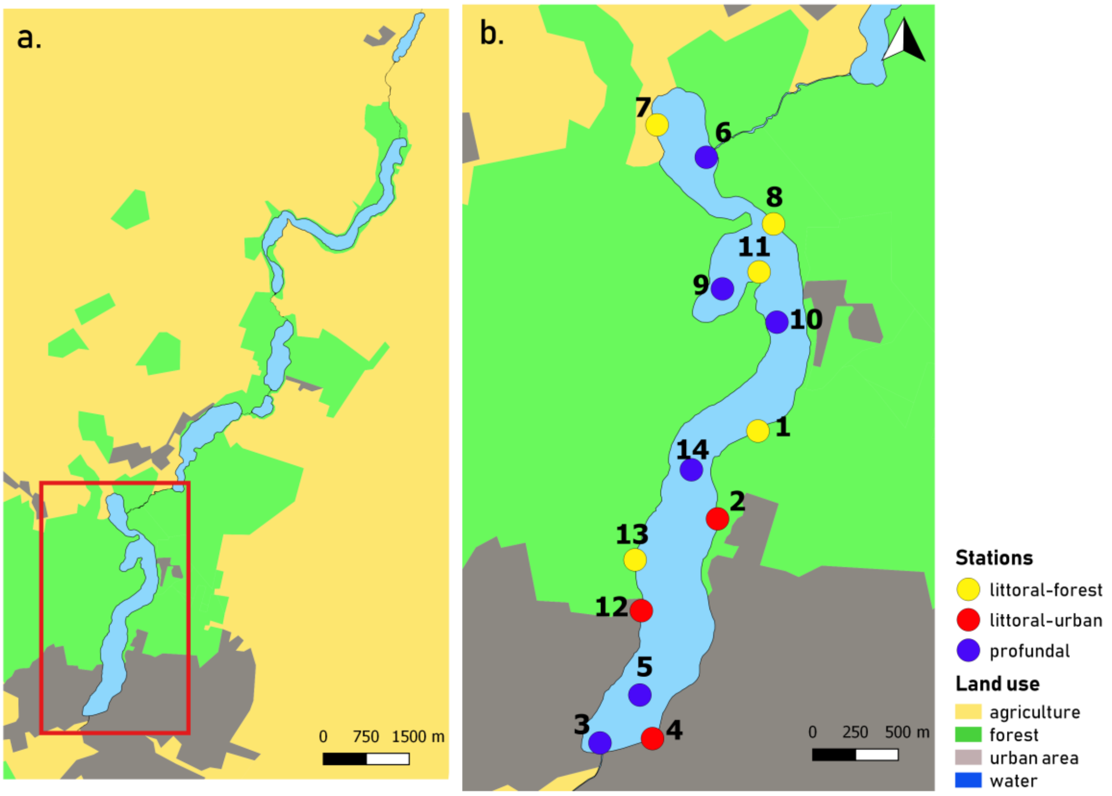


Figure 1. (a) Land use map of the catchment area of Durowskie Lake; (b) Location of the sampling sites represented with different color on the basis of the features of the nearby area: profundal, littoral near forest, and littoral near urban.

Two core samplers were used to collect sediment samples. The first core sampler is called 'Czapla' (Figure 2b) and was used to collect samples from shallow waters (littoral part of the lake) with a maximum depth of 2 meters. The second sampler, called 'Kajak' (Figure 2a), was employed to collect samples from deeper parts of the lake (including the deepest part at 14,6 meters). The Kajak sampler is a gravity corer. This is lowered to the bottom and the gravity of the device is great enough to cause the corer to free fall rapidly through the last metres in order to strike the bottom with enough force to penetrate the upper sediment layers. The Czapla corer, instead, is manually forced into the sediment.

Figure 2. Pictures of the two core samplers used for the collection of samples of macroinvertebrates: (a) Kajak corer (b) Czapla corer

Samples from each station were washed directly in the field using a sieve (with a mesh 0,4 cm) in order to remove most of the inorganic material. The materials retained by the sieve were washed again with water and were kept in plastic boxes filled with water.

Figure 3. Materials used for collecting macroinvertebrates samples: (a) sieves; (b) PVC box.

The material used in the laboratory are: tweezers, pipette, crepe paper, scale and microscope/stereoscope. In the laboratory in Wągrowiec, the macroinvertebrates were sorted out with tweezers and pipettes and the species were classified and weighed using a scale. Afterwards the organisms were separated from the sediment, dried, weighed, and put in a test tube with a solution of 70% alcohol. After coming back to Poznań, at the University of Adam Mickiewicz, macroinvertebrates were identified to the species level by using the reference keys and microscope/stereoscope. Finally the biomass and number of individuals per square meter was calculated.

3. Data Analysis

3.1 Number of individuals and biomass per square meter

The areal coverage of each species in 1 m² was calculated by multiplying the number of each species by 39 and 35 for the Kajak samples and the Czapla, respectively.

$$Number\ of\ individuals/m^2 = (NIS\ \times S)$$

$$Biomass\ in\ mg/m^2 = (BSS \times S)$$

Where *NIS* is the number of individuals of a taxa in one sample; *S* is the sampler specific multiplier; and *BSS* is biomass of taxa in one sample. Table 2 shows the conversion rate for each zone based on the type of sampler used.

Table 2. Overview of the core samplers used 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*)	39
5	Kajak (*Pelagic*)	35
6	Kajak (*Pelagic*)	35
7	Czapla (*Littoral*)	39
8	Czapla (*Littoral*)	39
9	Kajak (*Pelagic*)	35
10	Kajak (*Pelagic*)	35
11	Kajak (*Pelagic*)	35
12	Czapla (*Littoral*)	39
13	Czapla (*Littoral*)	39

14	Kajak (*Pelagic*)	35

3.2 Biodiversity assessment

Diversity indices measure the diversity of taxa in a community. They provide more information on community composition rather than the species richness (*e.g.* number of species present). They also take the relative abundances of different taxa into account (Beals et al., 2000). We have used Shannon-Wiener Index index and Simpson Index to measure the diversity for macroinvertebrates.

3.2.1 Shannon-Wiener Index

The Shannon-Wiener index is the most common biodiversity index. For an equal distribution, the Shannon-Wiener index has the value of the natural logarithm of Richness $H = \ln(S)$. Shannon index decreases when the proportional abundances became more unequal. Therefore high Shannon entropy means high diversity and low Shannon entropy means low diversity (Donovan and Pawlowski, 2014). The formula to calculate this index is shown below, where p_i represents the number of individuals in the species divided by the total number of individuals.

$$H = -\sum_{i=1}^{S} p_i ln p_i$$

We have used package ‘vegan’ in R to calculate the values (Oksanen et al., 2019).

3.2.2 Simpson Index

The Simpson index (also known as Species Diversity index) is another way of measuring biodiversity. It measures the probability that two individuals, randomly selected from a sample, will belong to the same species (or taxa). It takes into account the number of individuals for each of the species present and the total number of individuals (Barcelona Field Studies Centre 2018).

$$Index = 1 - \sum (n/N)^2$$

Where *n* represents the total number of organisms of a particular species and *N* represents the total number of organisms of all species.

This index ranges from 0 to 1, where 0 represents no diversity and 1 infinite diversity.

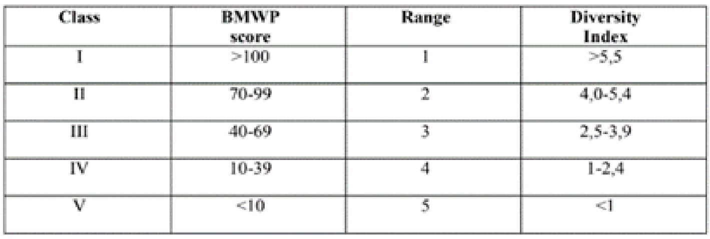
3.3. Other Indices to measure water quality

3.3.1 Biological Monitoring Working Party (BMWP) Score and Average Score per Taxon (AST)

Biological Monitoring Working Party (BMWP) Score and Average Score per Taxon (AST) are procedures for measuring water quality using the presence of species of macroinvertebrates as biological indicators. Different types of macroinvertebrates have different tolerance to pollutants. As the quality of water improves, it is expected that species that are less tolerant to pollution will return to these sites and the diversity will improve (Lopez-Lopez & Sedeno-Diaz, 2015). Each macroinvertebrate taxa is given a score between 1-10 based on pollution tolerance. Higher scores are given to the taxa sensitive to pollution and lower score to taxa tolerant to pollution. The overall BMWP score (sum of value of each taxon) gives an indication of the biological condition of the lake (Lopez-Lopez & Sedeno-Diaz, 2015).

Three limitations are faced by BMWP. Firstly, this index is sensitive not only to pollution but also other environmental factors such as the type of water body or weather conditions. Second, this system was developed for European macroinvertebrate taxa and for this reason cannot be transferred to other regions without knowing the sensitivity of macroinvertebrate taxa in that area. The third limitation is that this index takes into account only the presence of taxa and not their abundance. The five classes of water quality according to BMWP and Diversity Index are presented in the table below.

Table 3. Five classes of quality according to BMWP score and diversity index.



Class	BMWP score	Range	Diversity Index
I	>100	1	>5,5
II	70-99	2	4,0-5,4
III	40-69	3	2,5-3,9
IV	10-39	4	1-2,4
V	<10	5	<1

Average Score per Taxon (ASPT) can be determined by dividing the BMWP score by the number of taxa present (Zeybek et al., 2014). We have calculated BMWP and ASPT for each station and also the differences in results during the years.

3.3.2 Jaccard Index

The Jaccard index compares populations or areas by determining what percent of taxa were present in all populations. This index can range from 0-100%. The higher the percentage represents higher similarity between areas. The formula to calculate the Jaccard index is presented below (Tan et al., 2005):

$$J(X,Y) = \frac{|X \cap Y|}{|X \cup Y|}$$

X and Y represent different sites or populations.

4. Results

4.1 Total number of individuals per m^2

The total number of individuals per m^2 within each station ranges from 616 (station 5) to 4446 (station 13). 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 (4, 12 and 13) have the highest abundances overall.

Figure 4 illustrates the differences in the number of individuals per m^2 (see Appendix # for detailed information). Stations 5 (616 ind/m^2), 8 (741 ind/m^2) and 6 (945 ind/m^2) have considerably lower numbers of individuals per m^2 compared with other stations.

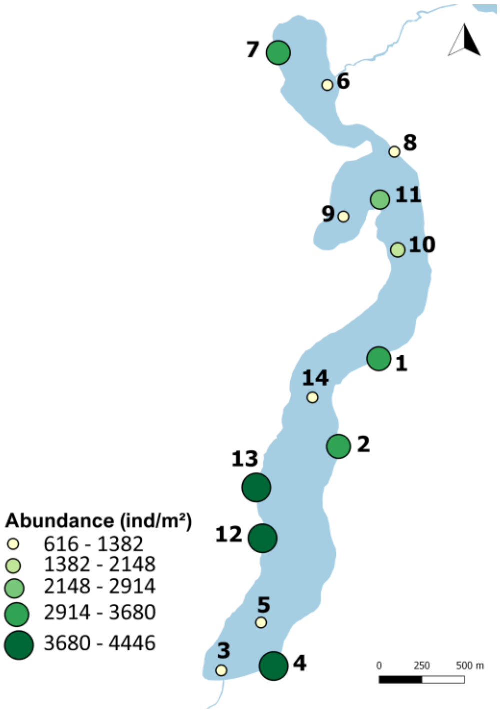


Figure 4. Total abundance recorded in each sampling station in Lake Durowskie in 2019.

The profundal areas are characterized by a huge abundance of larvae of Chaoboridae and Chironomidae. In station numbers 3, 9, 10 and 14, only one to two taxa were identified. 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 7 a high presence of *Dreissena polymorpha* (Bivalvia) was observed (Fig. 5).

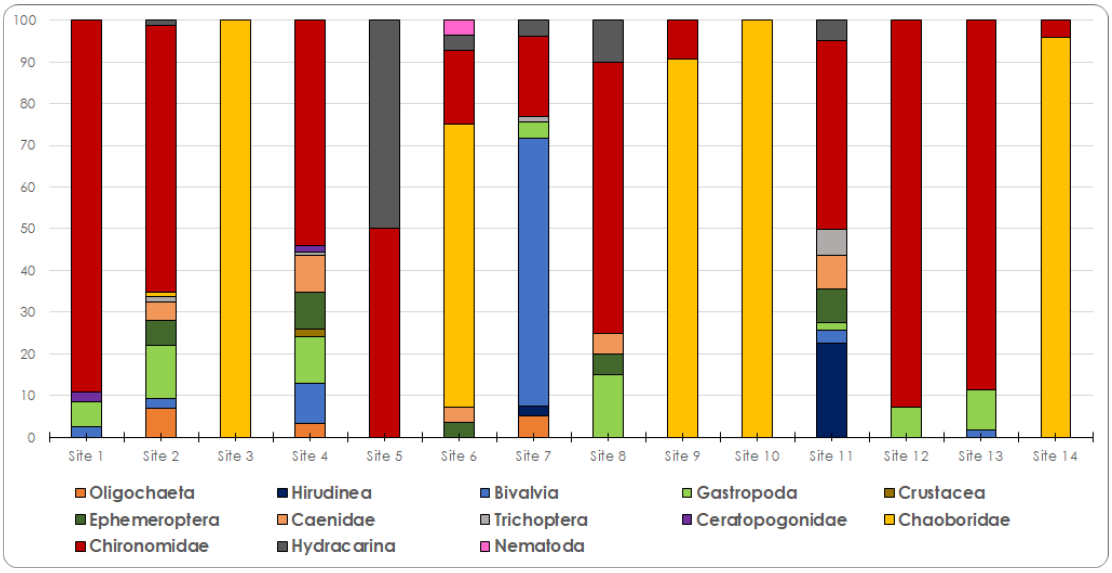


Figure 5. Overall percentage of individuals in all sites in year 2019

The average number of individuals per m^2 spiked in 2017 with 3538 ind/m^2, but then dropped considerably in 2018. In 2019 the average number of individuals per m^2 was 2250,357. This is a slight increase in abundance since the previous year (Fig. 6). The general trend since 2011 has been a small positive increase (Fig. 6).

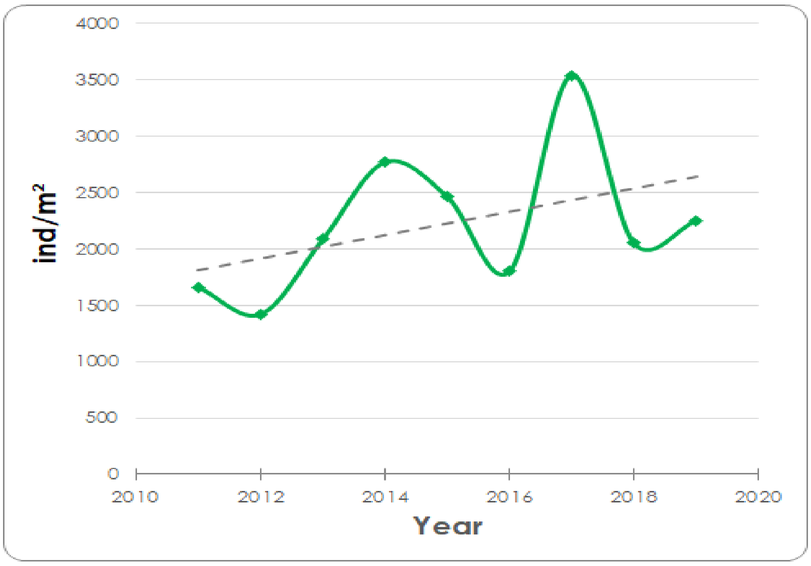


Figure 6. Average number of individuals per m^2 for years 2011 - 2019

4.2 Biomass

Biomass of macroinvertebrates show slightly different results compared to the abundance data (Fig. 7). The maximum value in the biomass was recorded at station number 7 (2138916 mg/m^2). The minimum value of biomass was measured in station number 5 (70 mg/m^2). In general, all the profundal sites showed very low value of biomass - six stations with the smallest amount of biomass belongs to this zone, with a mean value of 4906±4047 mg/m^2, especially compared with the ones recorded in the littoral-forest (842744±806387 mg/m^2) and littoral-urban area (219280±253160 mg/m^2). Bivalvia and Gastropoda are absent in all the profundal stations while their presence is recorded in almost all the littoral stations (Fig. 5). This significantly influences the value of biomass recorded. Indeed, the biomass measurement is highly dependent on which taxa are present in the samples - for instance, Bivalvia and Gastropoda are heavier compared to other taxa like Diptera larvae.

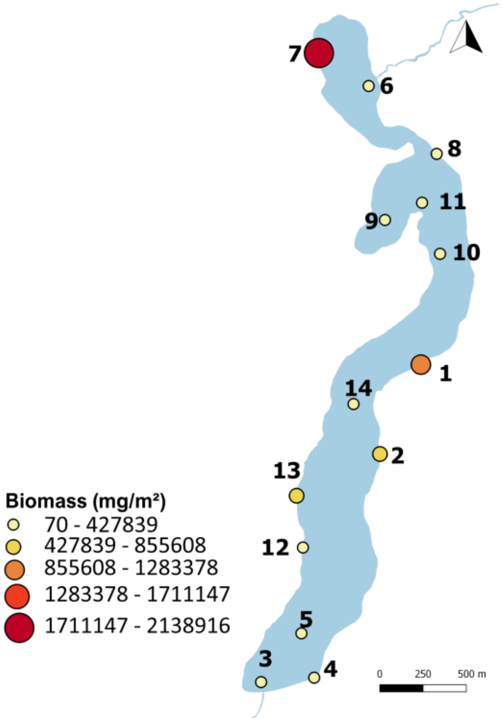


Figure 7. Total biomass recorded in each sampling station in Lake Durowskie in 2019.

The average biomass of macroinvertebrates in Lake Durowskie, compared to the previous years, shows a decrease in 2019, reaching values comparable to the ones recorded in 2017. However, a general increase in macroinvertebrate biomass from 2011 can be highlighted (Fig. 8).

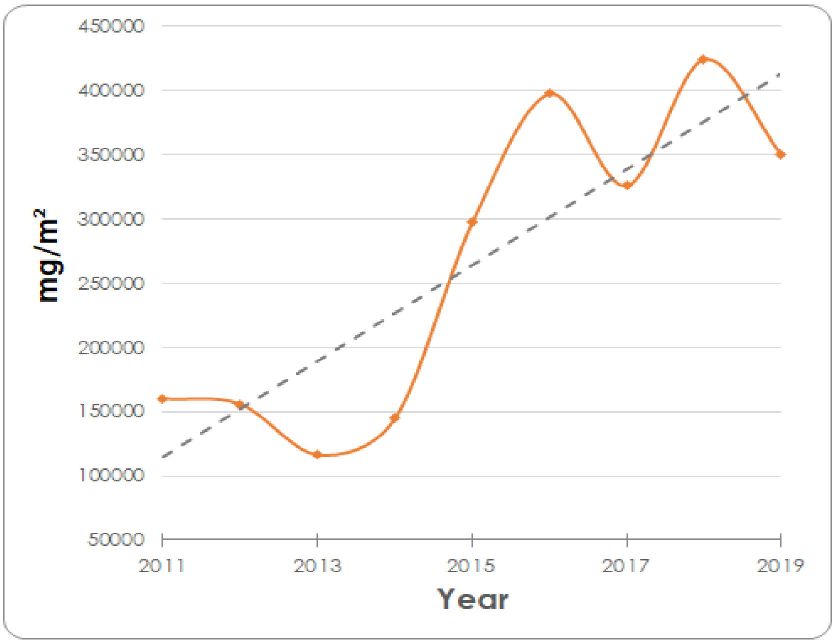


Figure 8. Average biomass of macroinvertebrates (mg/m^2) for years 2011 - 2019 in Lake Durowskie

4.3 Shannon-Wiener Biodiversity Index

The mean values for the Shannon-Wiener biodiversity index shows a significant peak between 2010 and 2011. Between 2011 and 2013 the value decreased, and has been slowly increasing up until 2018. 2019 shows a slight decrease in value.

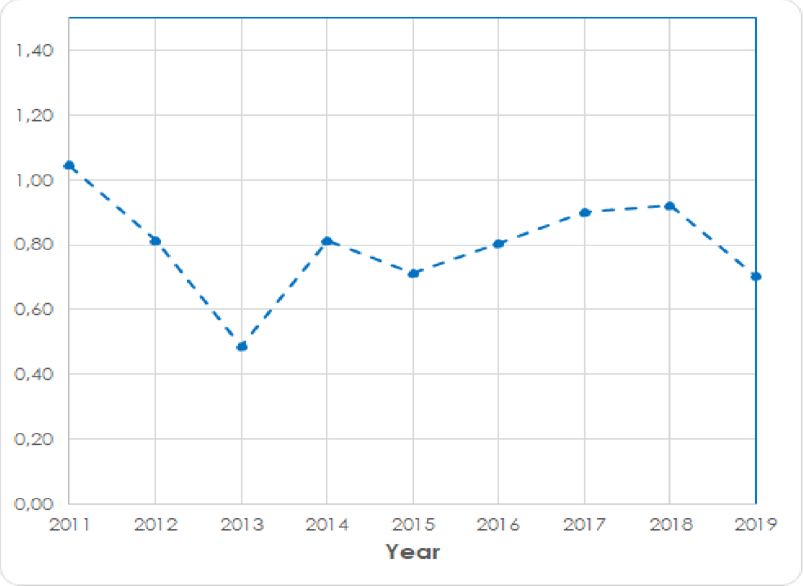


Figure 9. Mean Shannon-Wiener biodiversity index for macroinvertebrates in Lake Durowskie for 2011-2019.

4.3.1. Comparison between Simpson and Shannon-Wiener Biodiversity Indexes

The Simpson and Shannon-Wiener diversity indices indicate similar trends. The results of various biodiversity indices (Figure 10) confirm the trend of highest concentration located in forest site 11 and 7 and in urban sites 2 and 4. The reason may be due to a number of pollution tolerant species that survive in this habitat, and which may even benefit from human activities such as bait left by fishermen inside the lake.

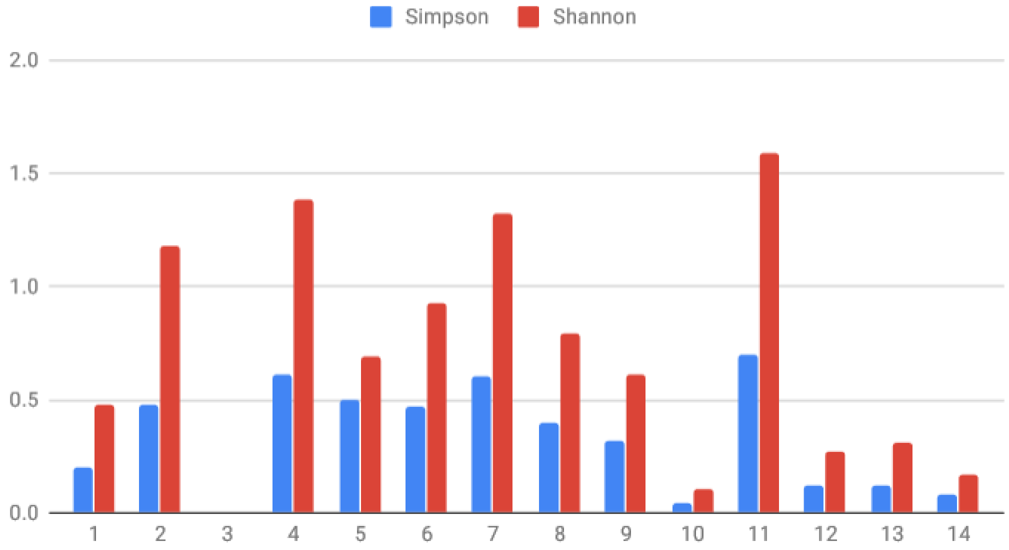


Figure 10. Comparison between Simpson and Shannon-Wiener biodiversity index for macroinvertebrates in Lake Durowskie

By comparing the data of 2011 with those of 2019 using the Shannon-Wiener and Simpson indices, we cannot see a clear pattern (Fig. 11 and Fig. 12). However, we can observe that with both methods, site 11 (forest area) increases in biodiversity, while biodiversity decreases at sites 1, 12 and 13. It is important to keep in mind that these indices show also evenness in number of taxa.

The most biodiverse site is station 11 which has a strong dominance of Chironomidae (share 49%). This environment includes also two species of Hirudinea (25%) and Ephemeroptera (9%). To compare with the top three sites in biodiversity, site 7 has as dominant group Bivalvia with share 64% and site 4 has the dominant group Chironomidae with a share of 54%.

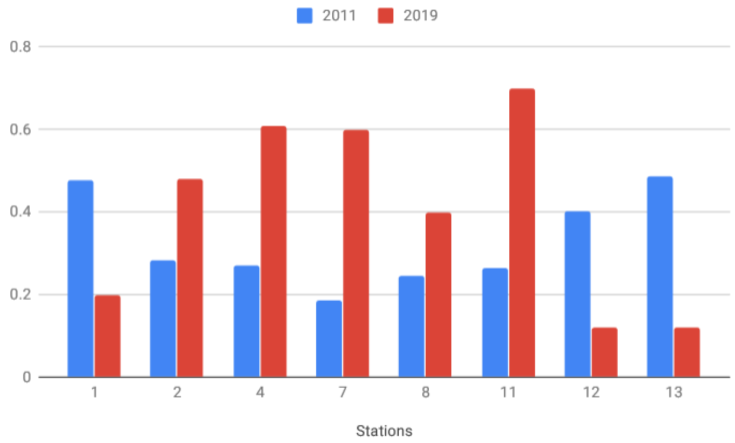


Figure 11. The change of Simpson index for macroinvertebrates in Lake Durowskie for the years 2011 and 2019.

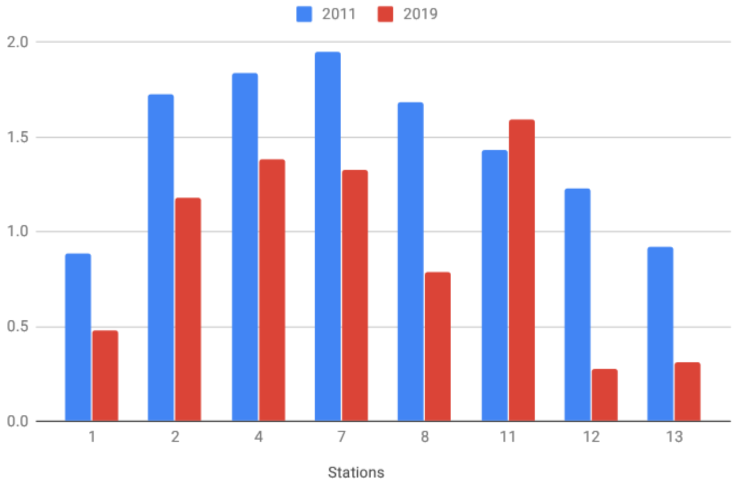


Figure 12. The change of Shannon-Wiener biodiversity index for macroinvertebrates in Lake Durowskie for the years 2011 and 2019.

4.4 Jaccard Similarity Index

We can see a clear division of stations by profundal versus littoral zones (Fig. 13). Profundal zones have, on average, more similar taxonomic composition of macroinvertebrates. Five (3, 6, 9, 10, 14) of six profundal stations are clustered and all (1, 2, 4, 7, 8, 11, 12, 13) littoral stations are roughly clustered. There is also a general clustering based on urban and forest stations, with the exception of the forest stations 1 and 13, which are clustered with the urban sites. Station 5 does not appear to conform to either cluster.

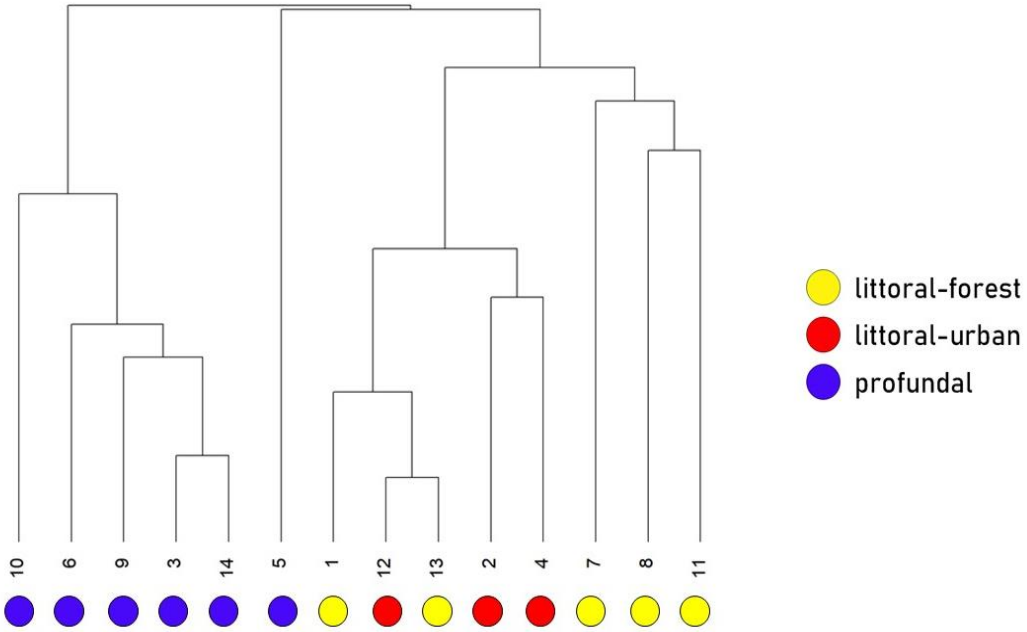


Figure 13. Jaccard Similarity Index for the species composition of all 14 stations in Lake Durowskie in 2019.

4.5 Biological Monitoring Working Party (BMWP) Scores and Average Score Per Taxon (ASPT)

The overall BMWP class for the lake is 4 (ecological status ‘poor’). The classes in all stations range between 4 and 5 (ecological status ‘bad’). The profundal stations scored particularly badly with a score of 5, while the littoral stations all scored 4. According to the ASPT value, there is no site above 5 (usually the values range between 1 and 10). Sites 3 and 10 both have a value of 0 - but this is because of a lack of data provided by the BMWP scores and can not be interpreted. Stations 5, 9 and 14 have a value of 1-2. Stations 1, 2, 4, 7, 12 and 13 have a value of 3-4. Stations 6, 8 and 11 have a value of 4-5.

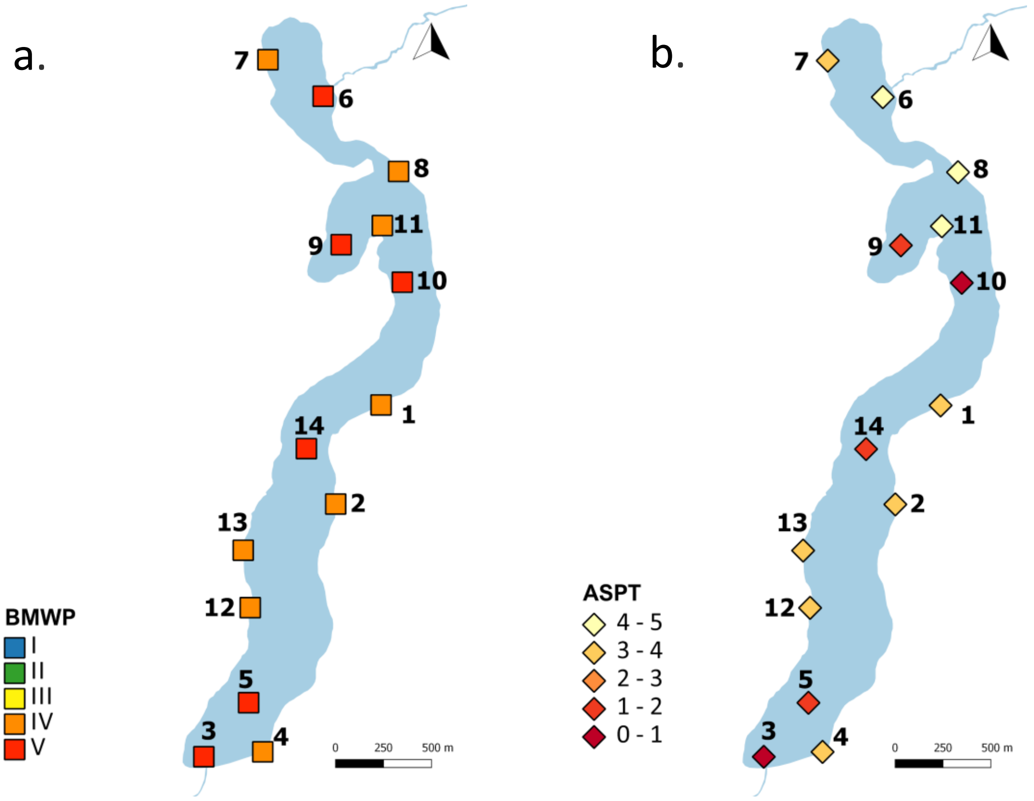


Figure 14. a) Biological Monitoring Working Party (BMWP) and b) Scores and Average Score Per Taxon (ASPT).

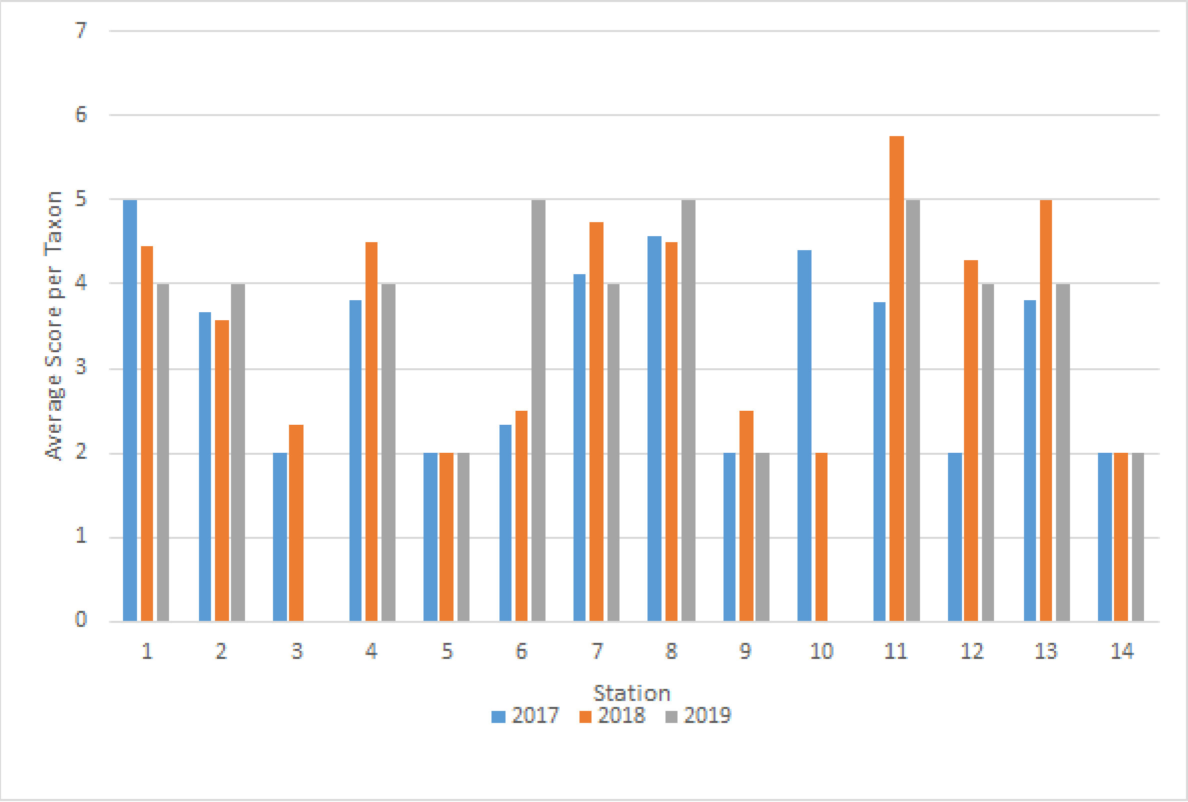


Figure 15. Average Score per Taxon for every station in years 2017-2019.

5. Discussion

Macroinvertebrates can provide useful information about the current ecological status and the effect of restoration measurements for lake Durowskie. Our results show that the number of individuals per square meter has increased slightly since the previous year in 2018. Overall, there has been a positive trend, with some fluctuations (Fig. 6). Biomass also shows a general positive trend since 2011. However, there has been a decrease in biomass between 2018 and 2019 (Fig. 8). Peaks and falls can be caused by a number of environmental factors - fluctuations in nutrients, temperature, pH, water turbidity, oxygen levels and changes in the food web, in particular predator populations (Klimaszyk & Heymann, 2010; Feuchtmayr et al., 2007). Further information is needed to clearly understand the processes affecting macroinvertebrates in Lake Durowskie and further studies should be performed to assess the overall quality. However, some general considerations can be made. The general positive trend recorded for both biomass and abundance is likely to be a result of the restoration measurements put in place in Lake Durowskie since 2009. Indeed, during the last 10 years, oxygen conditions in the lake hypolimnion gradually improved, leading to positive cascading effects - *e.g.* nitrification process and phytoplankton biomass reduction (Dondajewska et al., 2019). However, the global pattern of increasing water temperature linked to climate change can undermine the positive results obtained, as increased temperatures are reported to intensify the symptoms of eutrophication with negative effects on both physical-chemical parameters and biological communities (Woolway et al., 2019; Moss et al., 2011). Thus, the heat-wave and the high temperature recorded during the sampling period in 2019 could explain the deterioration of the water quality of Lake Durowskie in this time. However, many other factors can play a role. For example, the small number and low biomass of all taxonomic groups, compared to the historical data, could be the result of strong feeding pressure exerted by fish, mainly due to the domination of Cyprinidae (Leppä et al., 2003). Further studies can help clarify the processes undergoing.

Our data show a greater number of individuals per m^2 in littoral versus profundal sites. Littoral zones are characterised by shallow waters and typically the presence of macrophytes, which provide important habitat for many invertebrate taxa (Watkins, et al 1983, Klimaszyk & Heymann, 2010). In contrast, profundal zones are more hostile environments for many macroinvertebrates because they have low levels of oxygen and light (Bartram & Ballance, 1996; James et al., 1998). In general, it is reported that in lakes with a stable level regime and a wide littoral zone, the highest species diversity and quantitative parameters of macrozoobenthos are recorded in the littoral and the lowest parameters are recorded in the profundal ares (Shcherbina, 2013). Similarly to individuals per m^2, biomass is also greater in littoral zones in comparison to profundal zones. In this case, the difference can be related to the different taxa composition in these different ecotones. Indeed, the littoral stations have a high percentage of Bivalvia and Gastropoda taxa (Figure 5), which are larger specimens, and therefore significantly increase the total biomass of sites where they are present. In contrast, profundal zones are dominated by Chironomidae and Chaoboridae, which have a high number of individuals but are much smaller specimens with small biomass overall.

Diversity index can provide useful information to synthesize the data collected. Shannon-Wiener diversity index for macroinvertebrate taxa across years shows a decrease of biodiversity (Figure 12). For example, Odonata and Megaloptera taxa were absent in our samples, which were previously observed. Indeed, the overall mean of the Shannon-Wiener index value is the smallest since 2013 (Fig. 9). Our comparison of the Shannon-Wiener index with the Simpson index shows different values but the trend is similar.

Considering the class obtained from the Biological Monitoring Working Party (BMWP) score, all stations are within the 4 and 5 class. These classes indicate 'poor' and 'bad' water quality, respectively. The profundal stations scored particularly badly with a score of 5, while the littoral stations all scored 4. According to the ASPT value, there is no site above 5 (usually the values range between 1 and 10). Again, there is a difference between littoral and profundal stations.

The Jaccard index clearly captures the dissimilarity between littoral and profundal stations. Indeed, they have very different conditions and therefore different composition of taxa (Figure 13). Littoral zones in lakes can be regions of high biodiversity and productivity, whereas the profundal zone is a harsher environment with lower oxygen and light penetration (James et al., 1998). On Figure 13 stations 1 and 13, both forest sites are clustered with the urban sites. This could be due to their proximity to urban areas compared to other forest sites in the north of the lake, where the distance to urban areas is greater. The results suggest that the habitat diversity should be taken into account when comparing macroinvertebrates in the profundal and in the littoral zone. Indeed, it is already reported in previous studies as habitat and microhabitat diversity are one of the most important factors influencing group composition of benthic macroinvertebrates and that different benthic zones represent different subsystems that should be treated separately (Bazzanti et al., 2017; Callisto et al., 2004).

6. Conclusion

6.1 Summary

The macroinvertebrate taxa richness and diversity indicate the water quality. In our study, there was a general decrease in the Shannon-Wiener diversity index compared to previous years. According to the BMWP score, the water quality in this monitoring period is poor-bad quality. The abundance of less-sensitive organisms such as Chironomidae, and the low number of sensitive taxa such as Plecoptera, Ephemeroptera and Trichoptera could be an indication of increasing pollution. However, there is an overall positive trend in the number of individuals per m^2 and biomass.

Furthermore, there are many fluctuations across the entire monitoring period. These fluctuations could be a result of external environmental factors such as temperature. There was a heat wave during this sampling period in 2019. According to Fenoglio et al. (2004), higher current velocity has a positive effect richness and abundance of macroinvertebrate assemblages. A possible reason may be the increase of water oxygenation with the increase in velocity, which is beneficial to some macroinvertebrates. Higher temperatures have a negative effect on water velocity and as a consequence also macroinvertebrate assemblages (Silva et al., 2009). Furthermore, macroinvertebrates are sensitive to changes in water temperature and will move to find their optimal temperature. If temperatures are too high for long periods of time, they can die (Flores and Zafaralla, 2012).

6.2 Recommendations

In addition to current restoration techniques, there are a number of additional actions that can be taken to further improve the water quality of Lake Durowskie. Firstly, revegetation or management of macrophytes along the lake edges will create new habitats for macroinvertebrates, absorb nutrients directly from the lake and also filter pollutants from run-off from agriculture and urban sources (Wetzel, 2001). It is important to also work in collaboration with farmers and other municipalities to reduce run-off and non-point sources of pollution in the catchment area, by incentivising the use of sustainable agricultural methods and directly manage lakes in the northern section of the catchment area (Goldyn et al., 2013). Also is important to continue to regularly monitor the ecological status of the lake to be able to assess the effectiveness of restoration techniques and to implement mitigating measures, if necessary. Finally, biomanipulation with filter feeders could be an effective restoration strategy. Biomanipulation of predatory fish is already in place but we suggest also using filter feeders - they eat phytoplankton and reduce particles from the water column as well as significantly contributing to biogeochemical processes in the lake (Jeppensen et al., 2009).

6.3 Future research

We put forward several suggestions to improve future research into the assessment of Lake Durowskie. Firstly, all parameters - physical and chemical, algae, macrophytes and macroinvertebrates - should be integrated and discussed together to get a more complete image of the current state of the lake. Secondly, samples could be collected from the inflow and outflow rivers to get an indication of water quality coming into the lake in contrast to exiting the lake. Finally, we suggest that littoral and profundal zones could be analysed separately to remove any bias that come from the innate differences between these zones.

7. References

Barcelona Field Studies Centre (2018). Simpson’s Diversity Index. Retrieved from https://geographyfieldwork.com/Simpson'sDiversityIndex.html

Bartram, J. and Ballance, R. (1996). *Water Quality Monitoring - A Practical Guide to the Design and Implementation of Freshwater Quality Studies and Monitoring Programmes.* United Nations Environment Programme and World Health Organisation.

Bazzanti, M., Mastrantuono, L., Pilotto, F. (2017). Depth-related response of macroinvertebrates to the reversal of eutrophication in a Mediterranean lake: Implications for ecological assessment. *Science of the Total Environment, 1(579):* 456-465.

Beals, M., Gross, L., and Harrell, S. (2000). Diversity Indices: Shannon’s H and E. Retrieved from http://www.tiem.utk.edu/~gross/bioed/bealsmodules/shannonDI.html

Cairns, J. Jr. and Pratt J., (1993). A History of Biological Monitoring Using Benthic Macroinvertebrates. *A History of Biological Monitoring, 1(11),* 10-24.

Callisto, M., Goulart, M., Medeiros, A. O., Moreno, P., Rosa, C. A. (2004). Diversity assessment of benthic macroinvertebrates, yeasts, and microbiological indicators along a longitudinal gradient in Serra do Cipó, Brazil. *Brazilian Journal of Biology, 64(4):* 743-755.

Dondajewska, R., Kowalczewska-Madura, K., Goldyn, R., Kozak, A., Messyasz, B. and Cerbin, S. (2019). Long-term water quality changes as a result of a sustainable restoration - a case study of Dimictic Lake Durowskie. *Water, 11(3),* 616.

European Commission (2000). Establishing a framework for community action in the field of water policy. Retrieved from https://eur-lex.europa.eu/resource.html?uri=cellar:5c835afb-2ec6-4577-bdf8-756d3d694eeb.0004.02/DOC_1&format=PDF

European Commission (2019). Introduction to the EU Water Framework Directive. Retrieved from http://ec.europa.eu/environment/water/water-framework/info/intro_en.htm

Gołdyn, R., Messyasz, B., Domek, P., Windhorst, W., Hugenschmidt, C., Nicoara, M., Plavan, G. (2013). The response of Lake Durowskie ecosystem to restoration measures. *Carpathian journal of earth and environmental sciences, 8(3),* 43-48.

Gołdyn, R., Podsiadłowski, S., Dondajewska, R., Kozak, A. (2014). The sustainable restoration of lakes—towards the challenges of the Water Framework Directive. *Ecohydrology & Hydrobiology, 14*, 68-64.

Heerdt ter, G.N.J., Schep, S.A., Janse, J.H. and Ouboter, M. (2007). Climate change and the EU Water Framework Directive: how to deal with indirect effects of changes in hydrology on water quality and ecology? *Water Science & Technology, 56(4)*, 19-26.

Hoey, G., Borja, A., Bierchenough, A., Buhl-Mortensen, L., Degraer, S., Fleischer, D., Kerckhof, F., Magni, P., Muxika, I., Reiss, H., Schroeder, A. and Zettler, M. (2010). The use of benthic indicators in Europe: from the Water Framework Directive to the Marine Strategy Framework Directive. *Marine Pollution Bulletin, 60(2010)*, 2187-2196.

Jeppensen, E., Sondergaard, M., Jensen, H.S. and Ventala, M. (2009). Lake and reservoir management. Encyclopedia of inland waters. 295-309.

Klimaszyk P. and Heymann D. (2010). Vertical distribution of benthic macroinvertebrates in a meromictic lake (Lake Czarne, Drawieński National Park). *Oceanological and Hydrobiological Studies, 39(4)*, 99–106.

Kondolf. G.M. and Micheli, E.R. (1995). Evaluating stream restoration projects. *Environmental Management. 19(1),* 1-15.

Kowalczewska-Madura, K., Dondajewska, R., Goldyn, R., Kozak, A. and Messyasz, B. (2018). Internal phosphorus loading from the bottom sediments of a dimictic lake during its sustainable restoration. *Water Air and Soil Pollution, 229(8).*

Lopez-Lopez, E. and Sedeno-Diaz, J.E. (2015). Biological indicators of water quality - the role of fish and macroinvertebrates as indicators of water quality. Coral Bleaching. 643-661.

Flores M. J. L. and Zafaralla M. T. (2012). Macroinvertebrate composition, diversity and richness in relation to the water quality status of Mananga River, Cebu, Philippines. *Sciences Cluster.* 108-111.

Messyasz, B. & Pikosz, M. (2019). Materials for participants of summer school. International summer school of Durowskie Lake.

Moss, B., Kosten, S., Meerhoff, M., W. Battarbee, R. W., Jeppesen, E., Mazzeo, N., Havens, K., Lacerot, G., Liu, Z., De Meester L., Paerl, H., and Scheffer, M. (2011). Allied attack: climate change and eutrophication. *Inland Waters. 1(2), 101-105*.

Tan, P., Steinbach, M., Kumar, V. (2006). Introduction to Data Mining. Pearson Addison-Wesley.

Schallenberg, M., de Winton, M.D., Verburg, P., Kelly, D.J., Hamill, K.D. and Hamilton, D.P. (2013). Ecosystem services of lakes. In Dymond JR ed. Ecosystem services in New Zealand – conditions and trends. New Zealand: Manaaki Whenua Press.

Shcherbina, G. K. (2013). Species Composition and Structure of Macrozoobenthos in Lake Sevan during the Period of its Increased Water Level. *Inland Water Biology, 6(2):* 44-50.

Silva FL, Moreira DC, Ruiz SS, Bochini GL. (2009). Diversity and abundance of aquatic macroinvertebrates in a lotic environment in Midwestern São Paolo State, Brazil. *Ambiente & Água*, 4(1):37-44.

Vinagre P. A., Pais-Costa, A.J., Hawkins, S.J., Borja, A., Marques, J.C. and Neto, M. (2017). Addressing a gap in the Water Framework Directive implementation: Rocky shores assessment based on benthic macroinvertebrates. *Ecological Indicators, 78,* 489-501.

Wetzel, R.G.(2001). Limnology: Lake and river ecosystems. United States: Elsevier Academic Press.

Woolway I. R., Weyhenmeyer, G.A., Schmid, M., Dokulil, M.T., Eyto, E., Maberly, S.C., May, L., Merchant, C.J.(2019). Substantial increase in minimum lake surface temperatures under climate change. Climate Change, 155, 81-94.

Zeybek, M., Kalyoncu, H., Karakas, B. and Özgul, S. (2014). The use of BMWP and ASPT indices for evaluation of water quality according to macroinvertebrates in Değirmendere Stream (Isparta, Turkey). *Turkish Journal of Zoology, 38*, 603-613.

Literature of Identification Keys and Indices

Ciecierska, H. and Dynowska, M. (2013). Biologiczne metody oceny stanu środowiska Tom. Uniwersytet Warmińsko-Mazurski W Olsztynie.

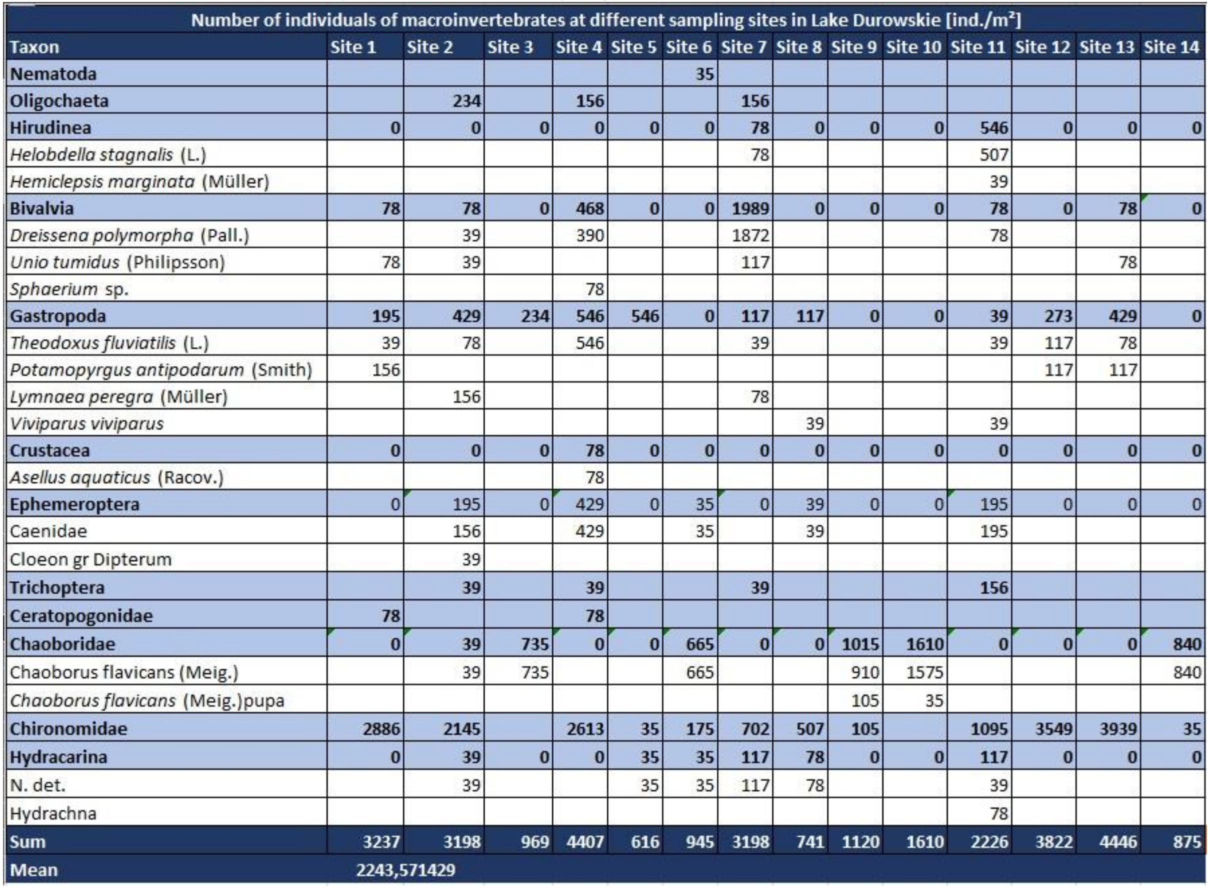
Kolodziejczak, A., Koperski P. (2000). Bezkręgowce słodkowodne Polski. Wydawnictwa Uniwersytetu Warszawskiego. Warszawa.

Pawley, S., Dobson, M. and Fletcher, M. (2012). “Guide to British Freshwater Macroinvertebrates for Biotic Assessment” Freshwater Biological Association. Ambleside.

8. Appendix

8.1 Number of Individuals per m^2

Table 4. Number of individuals per m^2 for each sampling station in Lake Durowskie in 2019.

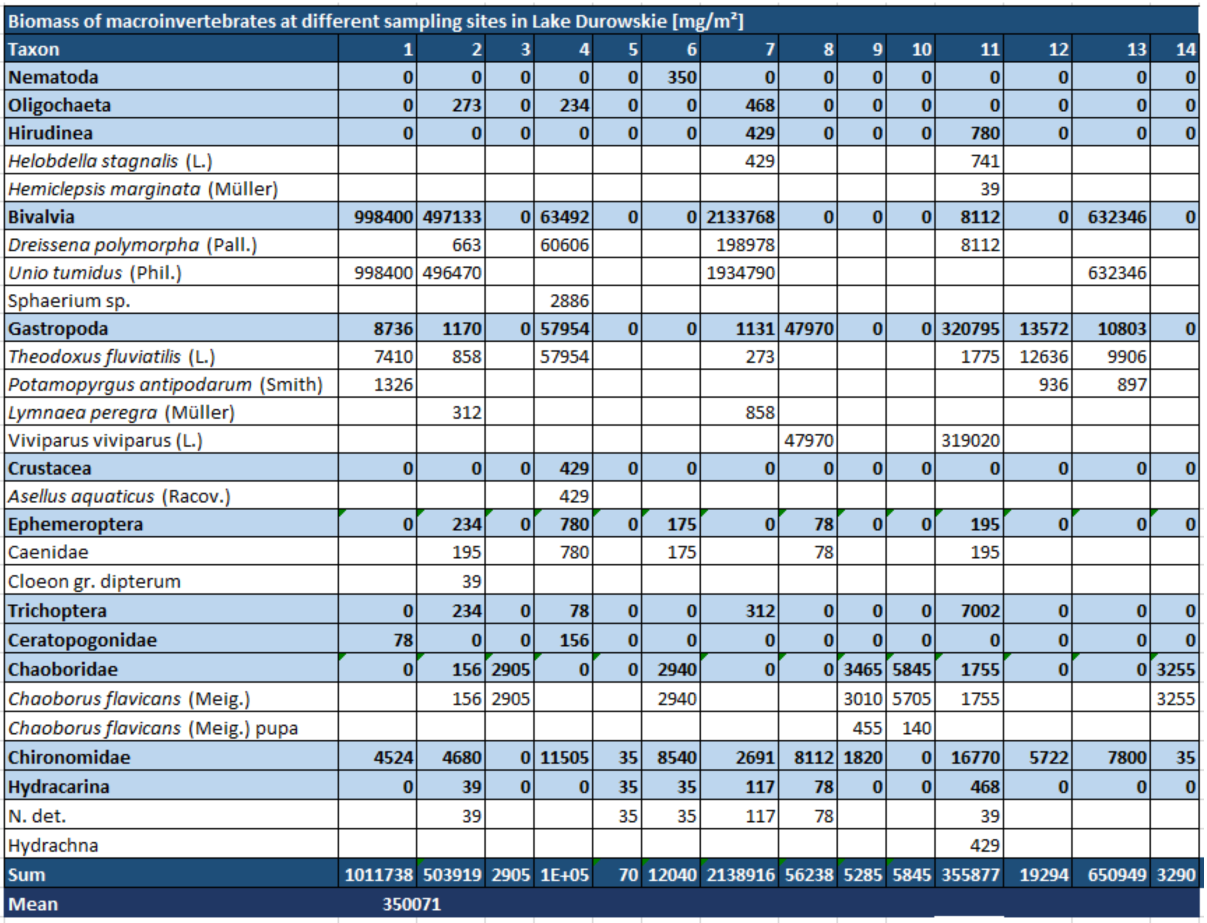


Number of individuals of macroinvertebrates at different sampling sites in Lake Durowskie [ind./m^2]

Taxon	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11	Site 12	Site 13	Site 14
Nematoda						**35**								
Oligochaeta		**234**		**156**			**156**							
Hirudinea	**0**	**0**	**0**	**0**	**0**	**0**	**78**	**0**	**0**	**0**	**546**	**0**	**0**	**0**
Helobdella stagnalis (L.)							78				507			
Hemiclepsis marginata (Müller)											39			
Bivalvia	**78**	**78**	**0**	**468**	**0**	**0**	**1989**	**0**	**0**	**0**	**78**	**0**	**78**	**0**
Dreissena polymorpha (Pall.)		39		390			1872				78			
Unio tumidus (Philipsson)	78	39					117						78	
Sphaerium sp.				78										
Gastropoda	**195**	**429**	**234**	**546**	**546**	**0**	**117**	**117**	**0**	**0**	**39**	**273**	**429**	**0**
Theodoxus fluviatilis (L.)	39	78		546			39				39	117	78	
Potamopyrgus antipodarum (Smith)	156											117	117	
Lymnaea peregra (Müller)		156					78							
Viviparus viviparus								39			39			
Crustacea	**0**	**0**	**0**	**78**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Asellus aquaticus (Racov.)				78										
Ephemeroptera	0	195	0	429	0	35	0	39	0	0	195	0	0	0
Caenidae		156		429		35		39			195			
Cloeon gr Dipterum		39												
Trichoptera		**39**		**39**			**39**				**156**			
Ceratopogonidae	**78**			**78**										
Chaoboridae	**0**	**39**	**735**	**0**	**0**	**665**	**0**	**0**	**1015**	**1610**	**0**	**0**	**0**	**840**
Chaoborus flavicans (Meig.)		39	735			665			910	1575				840
Chaoborus flavicans (Meig.)pupa									105	35				
Chironomidae	**2886**	**2145**		**2613**	**35**	**175**	**702**	**507**	**105**		**1095**	**3549**	**3939**	**35**
Hydracarina	**0**	**39**	**0**	**0**	**35**	**35**	**117**	**78**	**0**	**0**	**117**	**0**	**0**	**0**
N. det.		39			35	35	117	78			39			
Hydrachna											78			
Sum	**3237**	**3198**	**969**	**4407**	**616**	**945**	**3198**	**741**	**1120**	**1610**	**2226**	**3822**	**4446**	**875**
Mean	**2243,571429**													

8.2 Biomass

Table 5. Biomass of macroinvertebrates per m2 for each sampling station in Lake Durowskie in 2019.



Biomass of macroinvertebrates at different sampling sites in Lake Durowskie [mg/m²]														
Taxon	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Nematoda	**0**	**0**	**0**	**0**	**0**	**350**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Oligochaeta	**0**	**273**	**0**	**234**	**0**	**0**	**468**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Hirudinea	**0**	**0**	**0**	**0**	**0**	**0**	**429**	**0**	**0**	**0**	**780**	**0**	**0**	**0**
Helobdella stagnalis (L.)							429				741			
Hemiclepsis marginata (Müller)											39			
Bivalvia	**998400**	**497133**	**0**	**63492**	**0**	**0**	**2133768**	**0**	**0**	**0**	**8112**	**0**	**632346**	**0**
Dreissena polymorpha (Pall.)		663		60606			198978				8112			
Unio tumidus (Phil.)	998400	496470					1934790						632346	
Sphaerium sp.				2886										
Gastropoda	**8736**	**1170**	**0**	**57954**	**0**	**0**	**1131**	**47970**	**0**	**0**	**320795**	**13572**	**10803**	**0**
Theodoxus fluviatilis (L.)	7410	858		57954			273				1775	12636	9906	
Potamopyrgus antipodarum (Smith)	1326											936	897	
Lymnaea peregra (Müller)		312					858							
Viviparus viviparus (L.)								47970			319020			
Crustacea	**0**	**0**	**0**	**429**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Asellus aquaticus (Racov.)				429										
Ephemeroptera	**0**	**234**	**0**	**780**	**0**	**175**	**0**	**78**	**0**	**0**	**195**	**0**	**0**	**0**
Caenidae		195		780		175		78			195			
Cloeon gr. dipterum		39												
Trichoptera	**0**	**234**	**0**	**78**	**0**	**0**	**312**	**0**	**0**	**0**	**7002**	**0**	**0**	**0**
Ceratopogonidae	**78**	**0**	**0**	**156**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Chaoboridae	**0**	**156**	**2905**	**0**	**0**	**2940**	**0**	**0**	**3465**	**5845**	**1755**	**0**	**0**	**3255**
Chaoborus flavicans (Meig.)		156	2905			2940			3010	5705	1755			3255
Chaoborus flavicans (Meig.) pupa									455	140				
Chironomidae	**4524**	**4680**	**0**	**11505**	**35**	**8540**	**2691**	**8112**	**1820**	**0**	**16770**	**5722**	**7800**	**35**
Hydracarina	**0**	**39**	**0**	**0**	**35**	**35**	**117**	**78**	**0**	**0**	**468**	**0**	**0**	**0**
N. det.		39			35	35	117	78			39			
Hydrachna											429			
Sum	**1011738**	**503919**	**2905**	**1E+05**	**70**	**12040**	**2138916**	**56238**	**5285**	**5845**	**355877**	**19294**	**650949**	**3290**
Mean	350071													

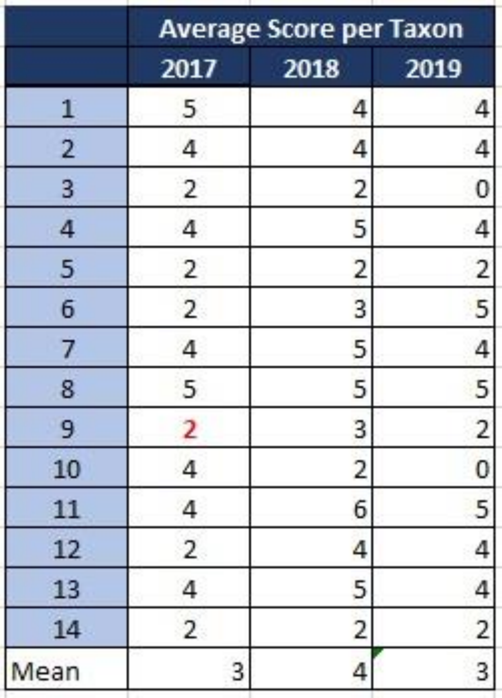
8.3 Biodiversity: Shannon-Wiener Index

Table 6. Shannon-Wiener Index of macroinvertebrates per sampling station in Lake Durowskie in 2019.

Site	Shannon
Site 1	0,481267
Site 2	1,179773
Site 3	0,000000
Site 4	1,384308
Site 5	0,693147
Site 6	0,925780
Site 7	1,324356
Site 8	0,790235
Site 9	0,612543
Site 10	0,104732
Site 11	1,593587
Site 12	0,274918
Site 13	0,309950
Site 14	0,167944
MEAN	**0,703039**

8.4 Biological Monitoring Working Party Scores

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



	Average Score per Taxon		
	2017	2018	2019
1	5	4	4
2	4	4	4
3	2	2	0
4	4	5	4
5	2	2	2
6	2	3	5
7	4	5	4
8	5	5	5
9	2	3	2
10	4	2	0
11	4	6	5
12	2	4	4
13	4	5	4
14	2	2	2
Mean	3	4	3

Table 8. BMWP score per taxon for each sampling station in Lake Durowskie in 2019.

Number of individuals of macroinvertebrates at different sampling sites in Lake Durowskie [ind./m^2]														
Taxon	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Oligochaeta		**1**		**1**			**1**							
Hirudinea														
Helobdella stagnalis (L.)							3				3			
Hemiclepsis marginata (Müller)											3			
Bivalvia														
Dreissena polymorpha (Pall.)		/		/			/				/			
Unio tumidus (Philipsson)	6	6					6						6	
Sphaerium sp.				3										
Gastropoda														
Theodoxus fluviatilis (L.)	6	6		6			6				6	6	6	
Potamopyrgus antipodarum (Smith)	3											3	3	
Lymnaea peregra (Müller)		3					3							
Viviparus viviparus								6			6			
Crustacea														
Asellus aquaticus (Racov.)				3										
Ephemeroptera														
Caenidae		7		7		7		7			7			
Cloeon gr Dipterum		4												
Trichoptera		**/**		**/**			**/**				**/**			
Ceratopogonidae	**/**			**/**										
Chaoboridae														
Chaoborus flavicans (Meig.)		/	/			/			/	/				/
Chaoborus flavicans (Meig.)pupa									/	/				
Chironomidae	**2**	**2**		**2**	**2**	**2**	**2**	**2**	**2**		**2**	**2**	**2**	**2**
Hydracarina														
Small acari		/			/	/	/	/			/			
Hydrachna											/			
Nematode						**/**								
Sum	**17**	**29**	**0**	**22**	**2**	**9**	**21**	**15**	**2**	**0**	**27**	**11**	**17**	**2**
Average Score per Taxon	**4,25**	**4,1429**	**0**	**3,667**	**2**	**4,5**	**3,5**	**5**	**2**	**0**	**4,5**	**3,6667**	**4,25**	**2**