Christian-Albrechts-Universität zu Kiel

Ecological state of Lake Durowskie during restoration measures: Macroinvertebrate Analysis 2018

Supervisor: MSc. Ing Piotr Domek

Authors:	Alam Md Ferdous (CAU)	MSc. Applied Ecology
	Jessica Hodal (CAU)	MSc. Environmental Management
	Oscar Rojas (CAU)	MSc. Applied Ecology
	Agnieszka Szymańska (AMU)	MSc. Environmental Protection

Poznan, .07.07.2018

Content

A. List of Figures

B. List of Tables

1. Introduction

In the renowned book *Walden*, author and naturalist Henry David Thoreau wrote, "A lake is the landscape's most beautiful and expressive feature. It is earth's eye; looking into which the beholder measures the depth of his [or her] own nature" (Thoreau, 1910). In scientific terms, a lake is defined as a natural, permanent existing water body with a relatively slow exchange of water; the function of which is contingent on several factors including the area and shape of its basins, mixing intensity and amount of suspension and chemistry (Messayasz & Pikosz, 2018). Lakes serve a variety of uses and functions including but not limited to: drinking water, irrigation, flood control, fish production and production of other use organisms, mining, urban reservoirs, energy, industry, low energy purifiers, transportation, recreation, conservation and diversity, training and education (Jørgensen, 2005; Singh & Bhatnagar, 2012). Accordingly, proper management of lakes and other water bodies is essential for the continued existence of life.

Sustainable development requires water of acceptable quality and adequate quantity (Bartram & Balance, 1996). However, high-intensity land use activities and increasing population density near lakes and within their watershed can lead to overexploitation of lake resources and the discharge of pollutants into the lake resulting in deterioration of water quality (Fazli et al., 2016). Due to rapid population growth, massive urbanization, and intensified land use alteration, especially from non-point sources, it is challenging to contain pollution that arrives from the upstream catchment areas (Leon-Munoz, J. et al., 2013; Lin, B. et al., 2015). Major factors contributing to the degradation of lakes are diversions and damming of river flows, eutrophication, contamination, global warming, invasion of exotic species, and practices of dredging, filling, and draining (Brinson & Malvárez, 2002). In the last few decades, several European lakes have been drastically affected by human activities (Gruber & Galloway, 2008).

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. In order to achieve restoration objectives, physical, chemical and biological characteristics of the lake water should be known (Ilangovan, 2008).

Although a combination of physical, chemical, and biological measurements provide the basis for most monitoring information (Metcalfe, 1989), biological monitoring—in some respects—is more useful than physico-chemical monitoring when assessing water quality (Muralidharan et al., 2010). Biological monitoring utilizes living organisms as reliable indicators of environmental quality, because they typically tolerate a certain spectrum of physical, chemical, and biological conditions (Holt & Miller, 2010). These organisms comprise a wide composition of groups including macroinvertebrates, fish, algae, diatoms, microorganisms and macrophytes (Ode, Rehn, & May, 2005). Benthic macroinvertebrates are especially well-suited bioindicators for water quality due to their limited movement and sensitivity to pollutants (like nutrients and sediments), which greatly influences the richness and diversity of macroinvertebrate species (Muralidharan et al., 2010). In addition, their ease of sample collection, range of lifespans, and geographic distribution are also reasons for their preferred use as bioindicators (Muralidharan et al., 2010). Ultimately, an integrated approach that involves sampling from all monitoring subsets is necessary to fully understand the status of water body restoration efforts.

Our study is part of a collaborative endeavor to monitor the restoration efforts of Lake Durowskie located in Wągrowiec, Poland. Since 2009, this impaired lake has been the subject of an international summer school to evaluate restoration techniques and assess the ecological response of these measures enacted to fulfill the requirements of the European WFD. The International Summer School is the result of cooperation between Uniwersytet im. Adama Mickiewicza w Poznaniu Faculty of Biology (UAM), Christian-Albrechts-Universität zu Kiel (CAU), and the town authority of Wągrowiec. Under the guidance of experienced and knowledgeable supervisors, students participate in field and laboratory research examining the following target groups: macrophytes, algae, macroinvertebrates, and physico-chemical variables. Our group, hereafter referred to as the "A Team," was responsible for assessment of the composition and biomass of benthic macroinvertebrates as well as the calculation of conversion rates and indices. With this data, the A-Team assessed and evaluated the current ecological state and long-term trends of Lake Durowskie utilizing macroinvertebrates as bioindicators. Our procedure, results, conclusions, and further recommendations are discussed below.

2. Methodology

2.1 Study Site

Lake Durowskie is a postglacial lake with an elongated shape situated in the Wielkopolska Region, in the center of Poland (N 52°49'6" and E 17°12'1"). The lake represents the last element of a complex of five connected lakes. This lake complex drains via the Struga Gołaniecka River which serves as the main tributary of Lake Durowskie (Messyasz & Pikosz, 2017). The catchment area of the river is dominated by agricultural use and contains only twenty percent of forested area concentrated on the north end of the lake (see Fig. 1). The southern end of the lake is surrounded by the town of Wągrowiec populated by 30,000 inhabitants (Messyasz & Pikosz, 2017). With a surface area of 143.7 hectares (ha) and a maximum depth of 14.6 meters (m) (see Tab. 1), Lake Durowskie represents one of the main attractions of Wągrowiec, usually used for recreational purposes such as motor boating, kayaking, bathing, and sport-fishing (Goldyn et al., 2013).

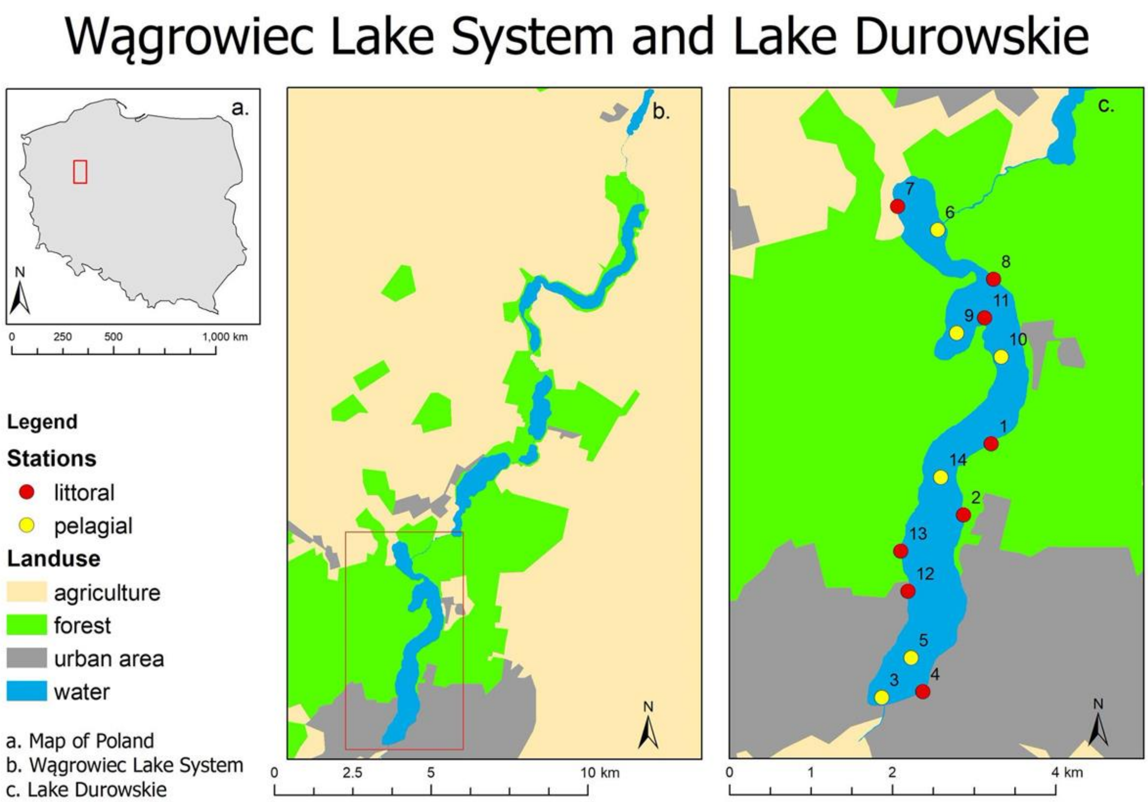

Fig. 1 Maps of the Wągrowiec Lake System and Lake Durowskie including pelagial and littoral sampling stations

As a consequence of the agricultural input from the catchment area, Lake Durowskie has presented high levels of eutrophication and numerous cyanobacterial blooms in the past decades. To increase its water quality and restore the ecosystem services provided by the lake, numerous restorations measures have been employed including oxygenation of hypolimnetic waters by wind aerators, phosphorus immobilization through iron treatment, and biomanipulation measures such as stocking the lake with pike fingerlings. To assess the success of these practices, yearly monitoring of the lake has occurred since 2009. The monitoring is conducted by a group of specialists and students from the International Summer School by the UAM and CAU (Goldyn et al., 2013).

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

Tab. 1 Hydrological Information of Lake Durowskie (Messyasz & Pikosz, 2018)

Land Use Form	Share of Direct Catchment Area in %
Urban	8.25
Agriculture	33.52
Forest	58.26

Tab. 2 Landuse in Lake Durowskie Catchment Area (Messyasz & Pikosz, 2018)

2.2 Materials and Procedures

Zoobenthos (macroinvertebrates) samples were collected from 14 stations on the lake: six sampling locations were located in the pelagic zone in deep water (Stations 3, 5, 6, 9, 10 and 14) and eight in the littoral zone in shallow water adjacent to the shoreline banks (Stations 1, 2, 4, 7, 8, 11, 12 and 13). 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 2 m, whereas a "Czapla" core sampler (diameter of 5.6 cm) was used for littoral depths less than 2 m. Fig. 1 depicts the spatial distribution of the 14 sampling stations on Lake Durowskie.

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 (specifically to characterize the species level of mosquito by identification of mandible and knave morphology) and stereoscopes (for larger specimens). Species determination was conducted for each individual as necessary (see references for reference keys). For practical reasons, identification to the genus or species level was not necessary for each type of family. The number of individuals per m² and the total biomass of each taxon was calculated for 1 m^2 and compared to data from previous years.

<u>Calculation (Number of individuals)</u>

$$n = n_{sample} * CR \text{ [individuals/m}^2\text{]}$$

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

n_{sample} = number of individuals from the sample (per taxon)

CR = conversion rate

<u>Calculation (Biomass)</u>

$$g = g_{sample} * CR \text{ [mg/m2]}$$

g = biomass per m^2 (per taxon)

g_{sample} = weight of individuals from the sample (per taxon)

CR = conversion rate

Due to the use of core samplers with varying diameters and different amounts of repeat samples taken, the conversion factors differ between stations. In this case, only 8 samples were taken at Station 4 to account for the difficulty of sample collection because of shoreline stabilization material at this location versus 10 samples taken at the other stations. Table 3 shows the conversion rate used for each station. The acquired data was used to calculate different water quality and biodiversity indices and compared to data from previous years.

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 *(Littoral)*	39
12	Czapla *(Littoral)*	39
13	Czapla *(Littoral)*	39
14	Kajak *(Pelagic)*	35

Tab. 3 Overview of the core samplers used and applied conversion rates for each station

Biodiversity Assessment

The Shannon-Wiener Index (H') was used to assess biodiversity. The index takes both the number of species and the evenness into account. Package "Vegan" was used in R studio 1.0.143 to calculate the values.

$$H' = -\sum_{i=1}^{s} pi \ln pi$$

pi = number of individual in the species / number of individual in total
s = number of species

The value of each station for 2018 was calculated for a comparison among the various stations. In addition, the mean values from 2010 - 2018 were calculated and compared for each year. The Jaccard similarity index was created to cluster the stations based on the similarity in species composition between stations. All data were processed in Microsoft Excel.

Biological Monitoring Working Party (BMWP) Score

The score developed by the BMWP aims at evaluating the state of organic pollution of freshwater bodies by the presence of certain families. It ranks from 1 to 10 with the value of 10 encompassing families known to be very vulnerable to organic pollution (Muralidharan et al., 2010). Although it is an easily applied indicator to assess the water quality by macroinvertebrates, it bears the bias that only the presence of families is taken into account—not their abundance.

Furthermore, the Average Score per Taxon (ASPT) was calculated for each station, giving an idea about the rank of the station within the scoring system. The number was a rounded integer to gain comparability with the general scoring scale. The BMWP has been compared with data from previous years, if available.

3. Results

During the field survey, 14 different taxa were found. Many of the animals were only identified to the family or order taxonomical classification, because keying to the species-level was not practical considering constraints of time and expertise levels. The data show a low number of individuals per m^2, biomass per m^2 and biodiversity in the deep water areas (Stations 3, 5, 10 and 14). Overall, an increase in individuals per m^2, biomass per m^2 and biodiversity compared to the previous years was determined. A closer examination of the acquired data is contained below. Detailed tables with the calculated values are located in the Appendix.

3.1 Number of Individuals

The number of individuals found per m² ranges between 420 (Station 10) and 7,527 (Station 13) across the stations and a total of 28,716 individuals were found (Table 4 in Appendix 8.1).

Fig. 2 illustrates the differences in the number of individuals per m² (see Appendix 8.1 for detailed information). Stations 10 (420 ind/m^2), 9 (490 ind/m^2) and 5 (455 ind/m^2) have considerably lower numbers of individuals per m² than other stations. Stations 14 (505 ind/m^2), 6 (525 ind/m^2), 4 (931 ind/m^2) and 11 (936 ind/m^2) also exhibit low numbers of individuals. Stations 3 and 7 contained 1365 ind/m^2, and Station 8 also had a low number of individuals (1092 ind/m^2). Stations 2, 12, 1 and 13 had a relatively higher abundances of individuals ranging from 3,354 ind/m^2 to 7,527 ind/m^2. Station 13 had the highest number of individuals

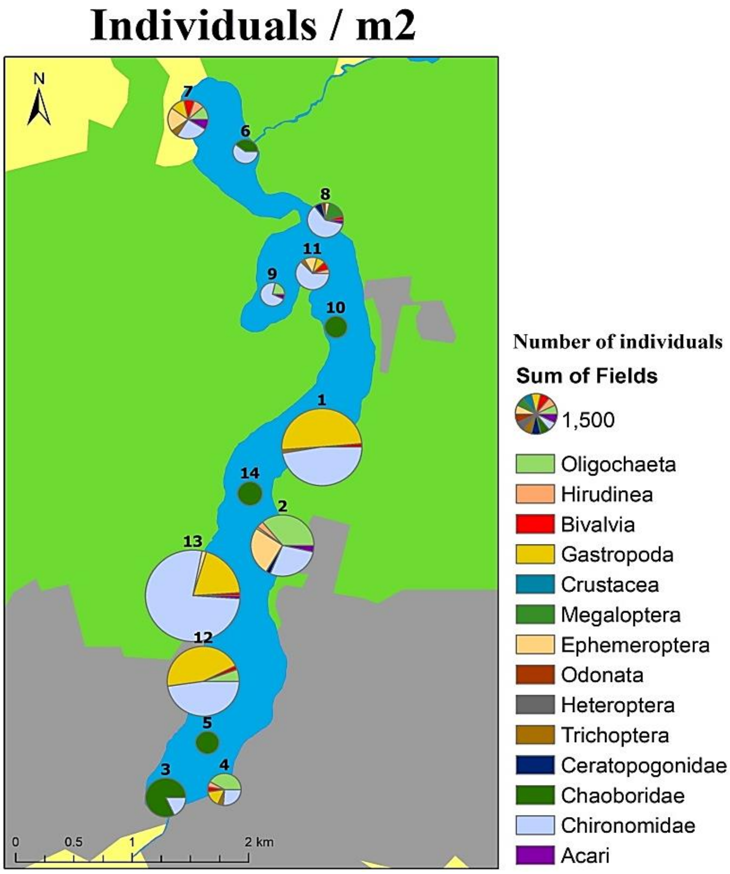

Fig. 2 Number of individuals per m² at sampling stations in Lake Durowskie in 2018

Stations 5, 10 and 14 are solely dominated by Chaoboridae, while Stations 3 and 6 are dominated by both Chaoboridae and Chironomidae. In Station 7, the highest amount of diversity was observed with 8 taxa. High levels of biodiversity (7 taxa) were also observed in Stations 1, 2, 8 and 12, while 6 taxa were identified in Stations 4, 11 and 13. The taxon Chironomidae was found as a dominating group in all stations except 5, 10, 14 and 3. Overall, the number of individuals per m² in the littoral zones was found to be higher than in the pelagial zones. The highest numbers of individuals were observed towards the southern end of the lake, but excluded the 3 southernmost stations.

On average, a total of 2,051 ind./m² was found in 2018, which exhibits a decline in comparison with the previous year's finding (Fig. 3). After reaching the highest overall value in 2017 (3538 ind/m^2), the mean number of individuals dropped. However, the general trend across previous years is positive and shows an increase in number of individuals per m² with some fluctuations throughout the years.

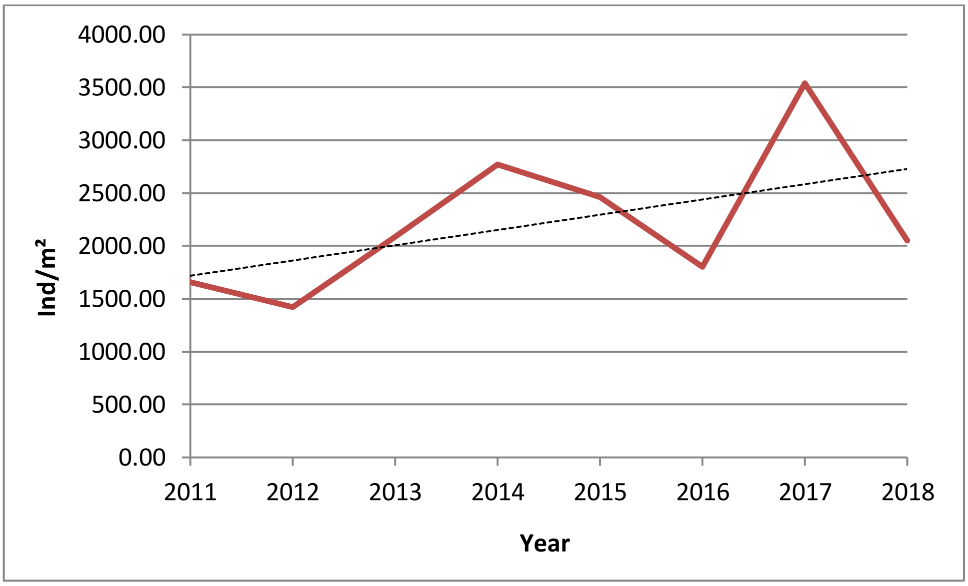

Fig. 2 Average number of individuals per m² for years 2011 - 2018

3.2 Biomass

The calculated biomass per m² differs greatly among stations. The values range from a minimum of 1155 mg/m² (Station 9) to a maximum of 2,519,361 mg/m² (Station 7). Stations 5 and 10 have the same biomass of 1505 mg/m². Stations 14 (1925 mg/m²), 3 (4445 mg/m²), 8 (5187 mg/m²) and 2 (5226 mg/m²) also have low biomass. However, a relatively higher biomass was observed in Stations 6, 4, 12, 1, 11 13 and 7 ranging from 12075 mg/m² to 2,519,361 (see Table 5 in Appendix 8.2).

Fig. 4 shows the spatial distribution of biomass across the various stations. In

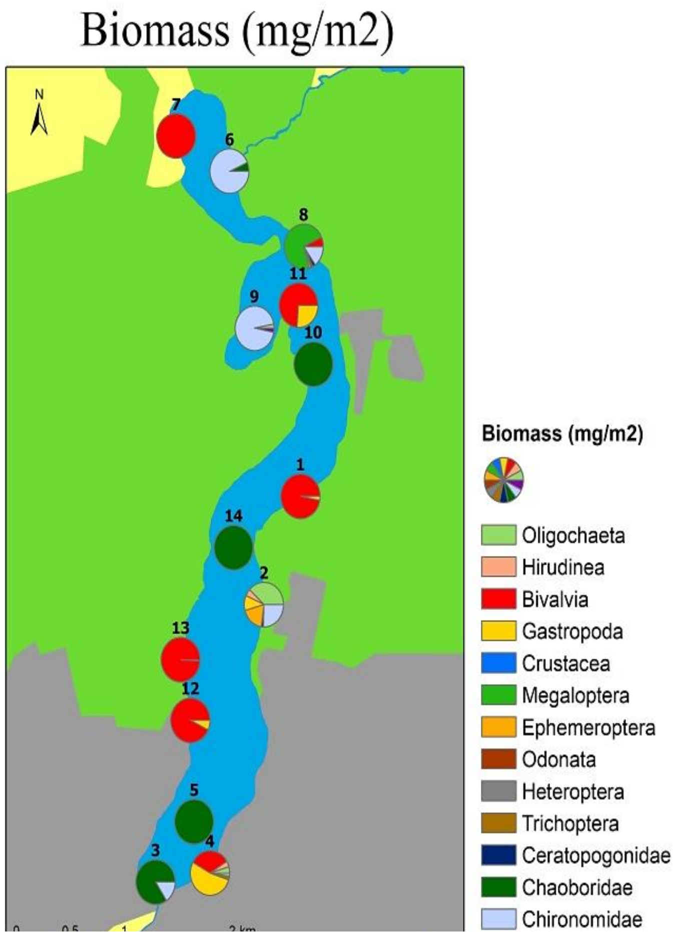

Fig. 3 Biomass of macroinvertebrates per m² at sampling stations in Lake Durowskie in 2018

terms of biomass, Stations 5, 10 and 14 were dominated by the taxon Chaoboridae, whereas Bivalvia prevailed at Stations 1, 7, 11, 12 and 13. Chironomidae was the dominant taxon at Stations 6 and 9. Oligochaeta leads in biomass at Station 2, Gastropoda leads at Station 4, and Megaloptera leads at Station 8. The majority of biomass is attributed to the high weights of Bivalvia and Gastropoda. In general, biomass is lower in pelagic zones and around the inflow, while biomass is higher in littoral zones and at the outflow. The total biomass found in 2017 was 5,942,189 mg/m² and thus increased in comparison to the previous year (see Fig. 5)—despite a decrease in the number of individuals in the same time period. Regarding the long-term trend from 2011 to 2018, a positive trend is observed.

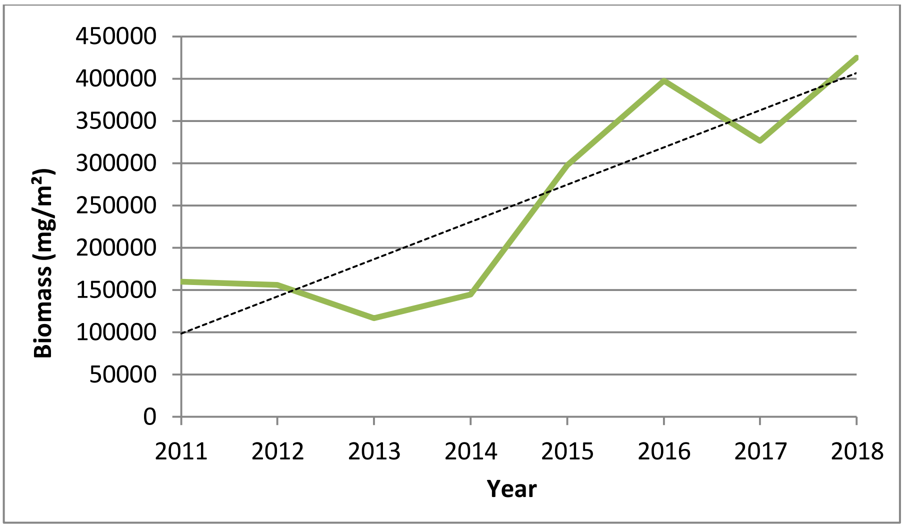

Fig. 4 Mean biomass of macroinvertebrates [mg / m²] for years 2011 - 2018 in Lake Durowskie

3.3 Shannon-Wiener Biodiversity Index

The Shannon-Wiener diversity index varies greatly across the stations (Fig. 6). The index ranges from 0 to 2.21. In Stations 5, 10 and 14 (pelagic) all values were zero. The reason is because only one species, mosquito larvae (*Chaoborus flavicans*), was found at those stations. In Stations 3 and 6,

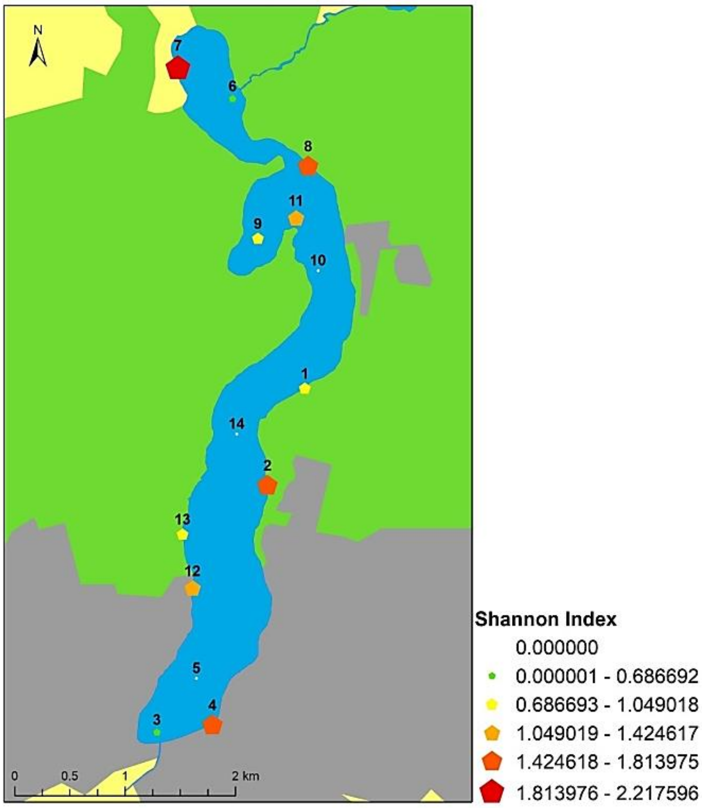

Fig. 5 Shannon-Wiener Index for macroinvertebrates at sampling stations in Lake Durowskie in 2018

the values fall in the 0.000001 - 0.69 cluster. Stations 1, 9 and 13 belong to the cluster 0.69 – 1.05, whereas Stations 11 and 12 are part of the 1.05 – 1.42 cluster. Stations 2, 4 and 8 fall in the 1.42 – 1.81 cluster, and only Station 7 is found in the 1.81 – 2.22 cluster with the highest value (2.22). In general, the values were higher in the littoral zone than in the pelagic zone (see Table 6 in Appendix 8.3).

The mean Shannon-Wiener index was calculated for the previous years. After a peak in 2011, the values decreased until 2013, and then increased again in the following years. This positive trend continued in 2018 as well (Fig. 7). Ultimately, there is a slight positive trend seen throughout the previous seven years.

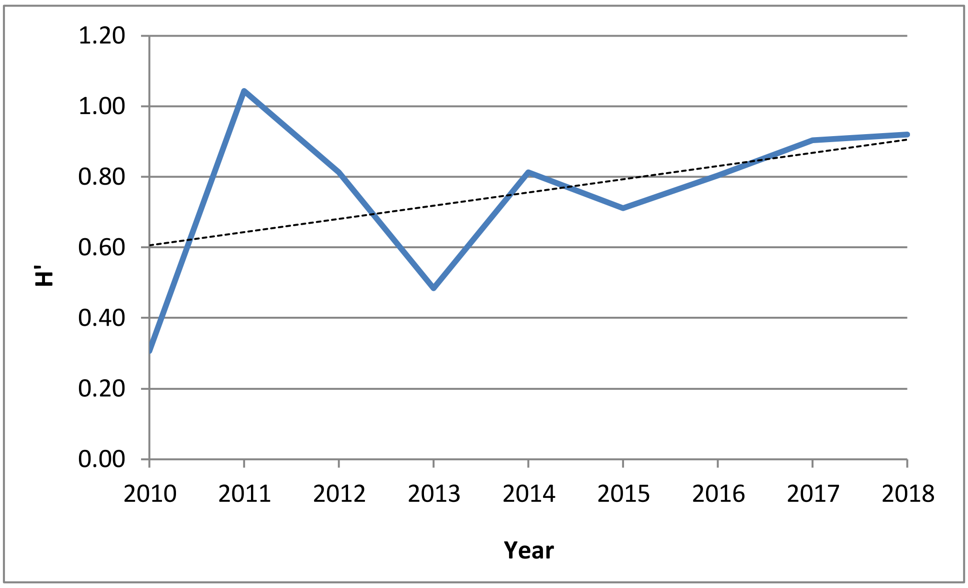

Fig. 6 Mean Shannon-Wiener diversity index for macroinvertebrates in Lake Durowskie for years 2010-2018

3.4 Jaccard Similarity Index

The Jaccard similarity index distributes pelagic and littoral stations into clusters based on species composition (Fig. 8). Four (3, 5, 10 & 14) of 6 pelagic stations are arranged in the same cluster and 6 (1, 12, 13; 2, 4 7) of 8 littoral stations fall in two separate clusters.

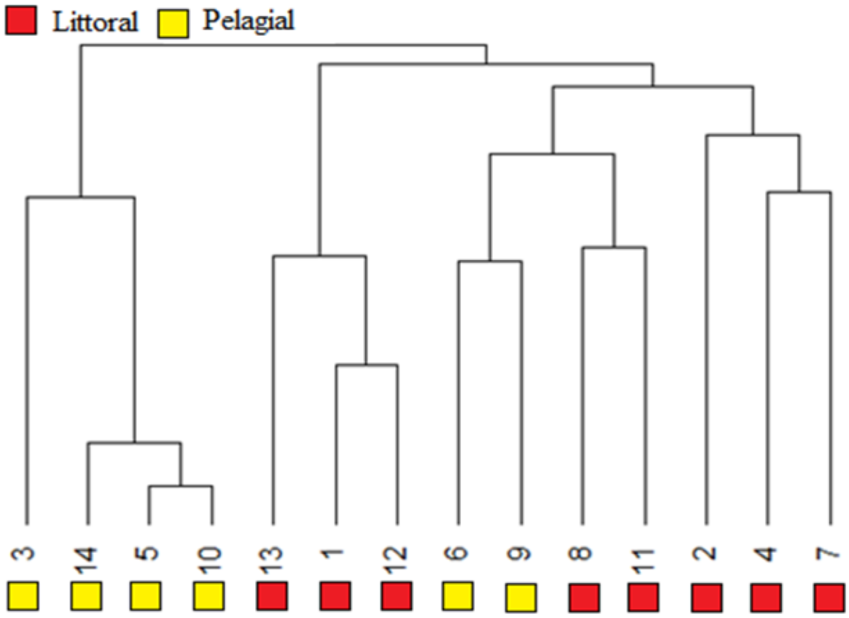

Fig. 7 Jaccard Similarity Index for the species compositions of all 14 stations in Lake Durowskie in 2018

3.4 Biological Monitoring Working Party (BMWP) Scores

The 2018 BMWP scores range from 2 to 6, indicating poor to medium water quality across the stations (see Fig. 9; see also Tables 7 & 8 in Appendix 8.4). The highest value (6) was scored at Station 11, followed by scores of 5 at Stations 4, 7 and 8, and scores of 4 at Stations 1, 2 and 11. Stations 6 and 9 received a score of 3. The lowest score (2) was determined for Stations 3, 5, 10 and 14. Not all macroinvertebrates collected were identified to the species or family level. Acari was determined only to the order level, and could not be used for the BMWP score (although this taxa might have been able to contribute to the score).

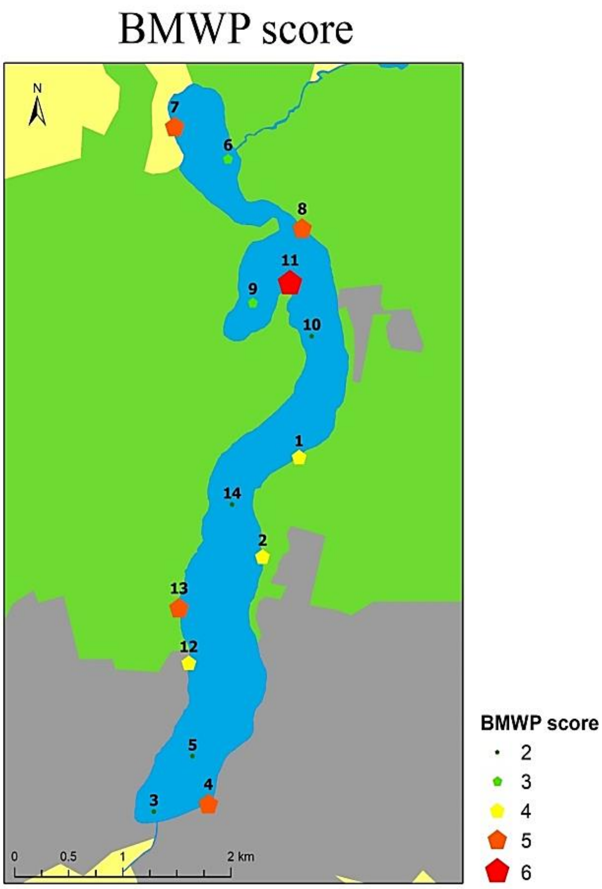

Fig. 8 BMWP [average] at sampling stations in Lake Durowskie in 2018

A comparison of the ASPT values from 2017 and 2018 reveals that scores for 5 of the 14 stations have decreased from the previous year. In Stations 3, 5 and 14 the score increased; however, only one taxon was found in Stations 5 and 14 (see Fig. 10, lighter colors). Fig. 9 shows the spatial distribution of ASPT scores across Lake Durowskie. The lowest values appear concentrated along the central portion of the lake.

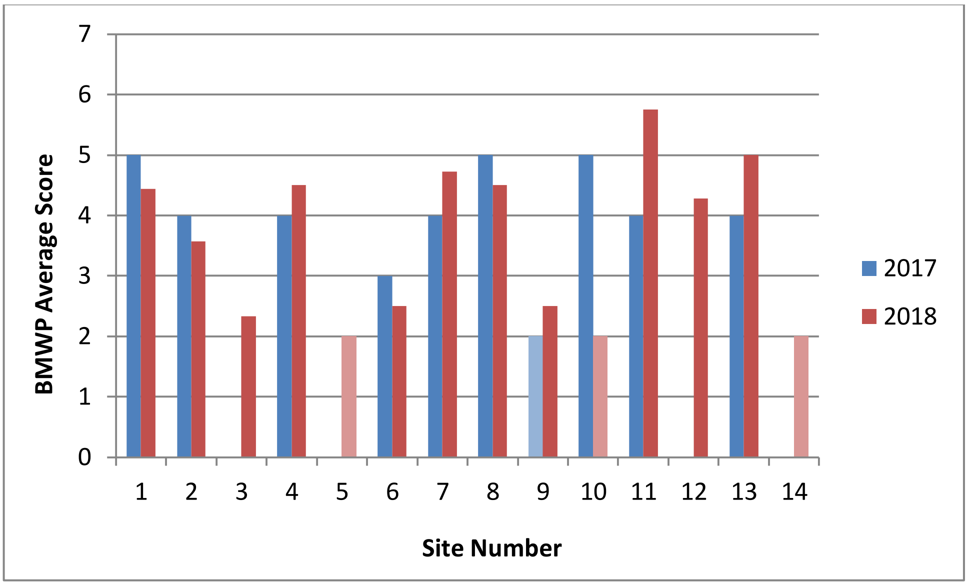

Fig. 9 Average BMWP for each station (lighter colors indicate that only one species served as an indicator species)

4. Discussion

The A Team observed that the stations with a higher number of individuals per m² are found mainly in littoral regions with water depths less than 2-3 m. These shallow areas are dominated by the presence of emergent and submerged vegetation (Macrophyte Team, 2018). Studies have shown that macrophytes support a higher abundance of macroinvertebrates by acting as a shelter to various species (Watkins et al., 1983; Cheruvelil et al., 2000; Liston et al., 2008). Overall, the number of individuals per m² is higher in the southern parts of the lake than in the northern part, but the species diversity does not exhibit this same tendency. This discrepancy might be due to in part to the presence of different emergent and submerged vegetation associations (Macrophyte Team, 2018), which could also be supported by physico-chemical and algae data (Physico-Chemical Team, 2018; Algae Team, 2018). When compared with previous years, there are periodic fluctuations in individual abundance, but an overall increasing trend. These fluctuations might be a result of changes in environmental factors, nutrient concentrations, and interspecific interactions with higher trophic levels—such as predatory fish possibly reducing macroinvertebrate abundance (Feuchtmayr et al., 2007).

With regard to biomass, the same trend was noticed for littoral areas. Higher biomasses were found in the northern part of the lake with Stations 1, 7, and 11, which occupy 13%, 11% and 43% of total biomass, respectively. The stations with high biomass (1, 7, 11, 12 and 13) were mainly attributed to the weights of bivalves and gastropods. The presence of these mussels and snails contributes to the high water filtration capacity characteristic of littoral areas, which is supported by both the physico-chemical and algae data (Physico-Chemical Team, 2018; Algae Team, 2018). In Stations 3 and 7, the same number of individuals was found; however, they greatly differed in terms of both diversity and biomass, which might be due to better habitat conditions provided by the macrophytes, as the northern part of the lake contained higher aerial coverage of macrophytes (Macrophyte Team, 2018).

Despite Station 4's proximity to an urban area with high anthropogenic disturbance and little to no presence of macrophytes (Macrophyte Team, 2018), the biomass and species diversity at this site is considerably high. However, the abundance of *Dreissena polymorpha*, an exotic species from the Caspian Sea, decreased five-fold compared to the previous year. In addition, *Anadonta anatine* decreased three-fold, whereas the abundance of *Unio tumidu* increased slightly. Here, biomass doubled (Annex 8.2), which likely contributes to improved water quality by filter feeders and may support the decreasing trend of Chlorophyll-A concentration—observed by both the physico-chemical and algae teams (Physico-Chemical Team, 2018; Algae Team, 2018). Specific biomass and abundance data fluctuate throughout the years, but demonstrate an overall increasing trend. This suggests an enhanced ability of Lake Durowskie to capture and store nutrients, signifying an overall increase in the water quality of the lake.

The Shannon-Wiener diversity index is a measurement of biodiversity for a specific site, which includes not only the number of species at the site, but also their evenness (the proportion of each species' abundance in relation to the abundance of the other species) (Nolan & Callahan, 2006). The Shannon-Wiener diversity index for macroinvertebrate species across the stations showed a clear distinction between the biodiversity of pelagic and littoral regions (Figure 6). The index was very low in pelagic sites (0 in the deepest sites and 0.47, 0.67 and 0.76 in Sites 3, 6 and 9, respectively), as there are only a few species that can survive at a depth of more than 5 meters due to anoxic conditions, such as mosquito larvae. Biodiversity was higher in littoral regions. Site 7 presented the highest index score, as it contained an even distribution of various species. This site is adjacent to croplands and forest, which might provide for a composition of species representative of both land-uses and large coverage of diverse macrophyte communities. This great difference between the numbers of macrozoobenthic species present in the littoral and pelagic zones was complemented by the results from the Algae Group of 2018. High densities of phytoplankton and zooplankton were observed by the Algae Group until a depth of 1 m from the surface, while deeper waters (greater than 1 m) denoted a sharp decrease in these communities. The reason for this decrease in macroinvertebrates and microplankton densities might be associated with reduced oxygen and light availability at these sites (low dissolved oxygen and turbid waters), which can negatively impact macroinvertebrates and phytoplankton.

A comparison of the general Shannon-Wiener diversity index (the average index for all sampling stations) throughout the years indicated an index only slightly higher than the previous year. When compared with annual data spanning back to 2010, the Shannon-Wiener diversity index for 2018 presented the second highest value after 2011, indicating that the restoration measures have been effective for increasing biodiversity. However, it is important to note that the diversity from site to site is not homogeneously distributed and some species are not as well-suited for water quality assessment. For this purpose, the BMWP score appears to provide more insight for determining the extent of water quality improvement.

The sites with depths above 11 m (Stations 5, 10, 14 and 3) presented similar assemblages of species according to the Jaccard index (Figure 8). The first three stations contained only mosquito larvae (Chaoboridae) and Site 3 contained predominately mosquito larvae with some individuals of Chironomidae (perhaps due to the proximity of the station to the lake outflow (Figure 1). The other pelagic sites (Stations 6 and 9) presented similar assemblages between each other with water depths of approximately 5 m, but not with the first group of pelagic sites with water depths greater than 11 m (Figure 8)—which may explain the difference in species assemblages. Stations 13, 1, and 12 (littoral sites) presented similar assemblages likely due to their location near urban and forested areas. Some stations, such as 8 and 11, exhibited similar assemblages possibly due to their close proximity to one another and forested areas. Sites 4 and 7 (littoral sites) presented some level of similarity (Figure 8) potentially explained by their location near the riverine inflow and outflow at opposite ends of the lake (Figure 1). Station 2 on the other hand presented a totally different assemblage of species according to Jaccard's index (Figure 8).

The overall BMWP score for all the stations was 4 (Table 7 in Annex 8.4), which indicates medium quality of water. However, the individual BMWP scores varied greatly from station to station. At six stations (3, 5, 6, 9, 10 and 14), the score was 2 (Fig. 2 & 9; Table 7 in Annex 8.4). A value of 2 indicates low water quality, and the observed species composition justifies this score. These stations are mainly inhabited by *Chaoborus flavicans* and Chironomidae, which are indicator species for poor water quality. In the stations where medium to high BMWP values were scored (3 – 6), a relatively high species diversity of low pollution tolerant species (e.g. Bivalvia, Gastropoda, Ephemeroptera and Trichoptera) was present at those stations (Fig. 2 & 9; Table 8 in Annex 8.4). Nevertheless, one must keep in mind that the overall score of the lake is a better indicator of water quality, as opposed to scores from single sampling stations.

5. Conclusion

Lake Durowskie was severely eutrophied and impaired with algal blooms in the past, specifically with cyanobacteria. However, the implementation of restoration measures since 2009 has led to incremental improvements of the water quality in the lake. Macroinvertebrates (along with algae, macrophytes, and physico-chemical properties) have been sampled annually over the past 10 years to monitor the progress of restoration efforts.

The 14 sites exhibited high variation of macroinvertebrate scores throughout the lake. Generally, the pelagic stations contained less individuals, lower biodiversity (Shannon-Wiener index), less biomass and lower BMWP scores than the littoral stations. These lower values are likely the result of lower levels of dissolved oxygen and light in the pelagic zones than in the littoral zones. The littoral sites with the highest abundance of individuals were 13, 12, 1 and 2—all of which were located near urban and forested areas. The sites with the highest biodiversity (Shannon-Wiener index) in the lake were Station 7 (northwestern section) and Stations 8, 2 and 4 (eastern section). The highest macroinvertebrate biomasses were observed in Stations 7, 13, 11 and 1 in the north and middle of the lake. Bivalves predominantly comprised these stations also with an instance of Gastropods at Station 11. Finally, the highest BMWP was observed at Station 11 as it contained pollution-sensitive species of Bivalvia, Gastropodae, Ephemenoptera and Tricoptera; Stations 13, 7, 8, and 4 also presented high BWMP values in comparison with the rest of the stations, mainly due to the presence of Bivalvia, Gastropodae, and Ephemenoptera.

Although the overall number of individuals decreased from the previous year's value, biodiversity (Shannon-Wiener index) increased slightly and biomass (mg/m2) increased considerably, mainly the result of a greater presence of Bivalvia and Gastropodae. Overall the BMWP score experienced a marginal increase from 2017. These multiple positive trends demonstrate incremental enhancement of the lake's water quality throughout the last decade. These results are promising, but continuous research and management efforts are necessary to ensure complete restoration of Lake Durowskie.

6. Recommendations

Since macroinvertebrates serve as excellent bio-indicators for the water quality of the lake, the outcome of this study can be used to create recommendations on how to further improve restoration measures. In the following, recommendations for further research as well as lake management are given.

6.1 Further research recommendations

Annual scientific monitoring of the restoration progress of Lake Durowskie should continue. In addition to the overall water quality trends of lake restoration, additional research should be conducted to obtain a better understanding of the factors that lead to variations between the sampling stations as well as differences in data from year to year. Moreover, possible reasons for the high biodiversity values at Station 4, despite the large amount of anthropogenic disturbance, could be investigated. To improve the result accuracy, taxa abundance should be taken into account when scoring with the BMWP index. The significant derivation between weights of certain taxa can skew values of the indices and result in less accurate interpretations.

6.2 Management recommendations

Restoration measures in Lake Durowskie have resulted in a positive trend of water quality improvement. The goal of the restoration is to return the lake to a self-regulated "top-down trophic control" system. Accordingly, the number of individuals per m^2, biomass and diversity of macroinvertebrates has been increasing over the last decade. However, these results are not evenly distributed across stations, especially considering low values in the deeper areas of the lake.

Therefore, a possible management strategy to improve the situation in pelagic zones of the lake involves the construction of additional aerators to increase oxygenation at these depths. Another management option includes the planting and protection of diverse macrophyte communities. Additionally, boosting local mussel populations would increase the filtration rate of pollutants from the water body and provide economic opportunity for local residents, but impacts of such a measure on the local ecosystem should be fully vetted prior to implementation. Non-native zebra mussels (*Dreissena polymorpha*) already inhabit the lake, and monitoring should be conducted to ensure this species is not becoming invasive and displacing native species.

An increase in restoration efforts throughout the entire catchment is needed to eliminate or at least reduce pollution sources from upstream. Past restoration measures within Lake Durowskie have resulted in a localized positive influence on the macroinvertebrate population. However, these efforts should encompass the entire 5-lake system. Establishing baseline studies for other lakes within the system can set the stage for future restoration activities. There is no one-size-fits-all approach, and restoration plans should be tailored to the individual characteristics and problems specific to each lake. Without a collaborative effort between the authorities of each municipality, the effectiveness of any downstream restoration efforts—like that of Lake Durowskie—is significantly hindered.

7. References

Bartram, J. & Balance, R. (1996). Water quality monitoring : A practical guide to the design and implementation of freshwater quality studies and monitoring programmes. World Health Organization & United Nations Environment Programme. London : E & FN Spon..

Brinson, M. M., & Malvárez, A. I. (2002). Temperate freshwater wetlands: Types, status, and threats. Environmental Conservation, 29(02). doi:10.1017/s0376892902000085

Cheruvelil, K.S., Soranno, P.A. & Serbin, R.D. (2000). Macroinvertebrates associated with submerged macrophytes: Sample size and power to detect effects. Hydrobiologia, 441, 133–139.

Fazli, B., Shafie, A., Yahaya, N. K., Awang, S., Jusoh, A. M., Noordin, N., & Ghani, P. H. (2016). Lake and Watershed Management: Issues and Challenges in Managing Lake Water Quality. Proceedings of the 2nd World Congress on New Technologies. doi:10.11159/icepr16.169

Feuchtmayr, H., McKee, D., Harvey, I.F., Aykinson, D. & Moss, B. (2007). Response of macroinvertebrates to warming, nutrient addition and predation mesocosm tanks. Hydrobiologia, 584, 425–432.

Goldyn, 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, 43–48.

Gruber, N., & Galloway, J. N. (2008). An Earth-system perspective of the global nitrogen cycle. *Nature, 451*(7176), 293-296. doi:10.1038/nature06592

Hoey, G. V., Borja, A., Birchenough, S., Buhl-Mortensen, L., Degraer, S., Fleischer, D., . . . Zettler, M. L. (2010). The use of benthic indicators in Europe: From the Water Framework Directive to the Marine Strategy Framework Directive. *Marine Pollution Bulletin, 60*(12), 2187-2196. doi:10.1016/j.marpolbul.2010.09.015

Holt, E. A. & Miller, S. W. (2010). Bioindicators: Using organisms to measure Environmental impacts. Nature Education Knowledge, 3(10): 8.

Ilangovan, R. (2008). Restoration of polluted lakes – A new approach. In Sengupta, M., and Dalwani, R. Proceedings of Taal2007. Paper presented at the 12th World Lake Conference, 1321-1328.

Jørgensen, S. E. (2005). *Lake and reservoir management*. Amsterdam: Elsevier.

León-Muñoz, J., Echeverría, C., Marcé, R., Riss, W., Sherman, B., & Iriarte, J. L. (2013). The combined impact of land use change and aquaculture on sediment and water quality in oligotrophic Lake Rupanco (North Patagonia, Chile, 40.8°S). *Journal of Environmental Management, 128*, 283-291. doi:10.1016/j.jenvman.2013.05.008

Lin, B., Chen, X., Yao, H., Chen, Y., Liu, M., Gao, L., & James, A. (2015). Analyses of landuse change impacts on catchment runoff using different time indicators based on SWAT model. Ecological Indicators, 58, 55-63. doi:10.1016/j.ecolind.2015.05.031

Liston, S.E., Newman, S. & Trexler, J.C. (2008). Macroinvertebrate community response to eutrophication in an oligotrophic wetland: An in situ mesocosm experiment. Wetlands, 28, 686–694.

Messayasz, B. & Pikosz, M. (2018). Materials for participants of International Summer School of Durowskie Lake.

Metcalfe, J. L. (1989). Biological water quality assessment of running waters based on macroinvertebrate communities: History and present status in Europe. *Environmental Pollution, 60*(1-2), 101-139. doi:10.1016/0269-7491(89)90223-6

Muralidharan, M., Selvakumar, C., Sundar, S., & Raja, M. (2010). Macroinvertebrates as potential indicators of environmental quality. International Journal of Biological Technology, 1, 23–28.

National Research Council. (1992). Restoration of Aquatic Ecosystems: Science, Technology and Public Policy. Washington, DC: National Academy Press.

Nolan, K. A., & Callahan, J. E. (2006). Beachcomber biology: The Shannon-Wiener species diversity index. *Proc. Workshop ABLE*. 27: 334-338.

Ode, P. R., Rehn, A. C., & May, J. T. (2005). A Quantitative Tool for Assessing the Integrity of Southern Coastal California Streams. *Environmental Management, 35*(4), 493-504. doi:10.1007/s00267-004-0035-8

Perrow, M., & Perry, A. (Eds.). (2002). *Handbook of Ecological Restoration: Principles of Restoration* (Vol. 1). Cambridge: Cambridge University Press.

Pikosz, M., Messyasz, B., & Gąbka, M. (2017). Functional structure of algal mat (Cladophora glomerata) in a freshwater in western Poland. *Ecological indicators*, 74, 1-9.

Thoreau, H. D. (1910). Walden, or, life in the woods. Ticknor and Fields.

Watkins, C. E., Shireman, J. V. & Haller, W.T. (1983). The influence of aquatic vegetation upon zooplankton and benthic macroinvertebrates in Orange Lake, Florida. Journal of Aquatic Plant Management, 21, 78–83.

Literature of Identification Keys and Indices

Celifford, H. F. (1991). Aquatic Invertebrates of Alberta. The University of Alberta Press. Canada

Ciecierska, H. and Dynowska, M. (2013). Biologiczne metody oceny stanu środowiska Tom. 2 Ekosystemy wodne. Uniwesytet Warminsko-Mazurski W Olsztynie.

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

Oscoz, J., Galiicia, D., Miranda, R. (Eds.). (2011). Identification Guide of Freshwater Macroinvertebrates of Spain. Springer. New York.

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

Skierska, B. (Ed.). (1971). Klucze Do Oznaczania Owadów Polski. Państwowe Wydawnictwo Naukowe. Warszawa

Tachet, H., Richoux., P., Bournaud, M. & Usseglio-Polatera, P. (2002). Invertébrés D'eau Douce: Systématique, Biologie, Écologie. CNRS Éditions. Paris.

8. Appendix

8.1 Number of Individuals per m²

Number of individuals per m² for each sampling station in Lake Durowskie in 2018 [ind./m²]														
Taxon	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Oligochaeta		1209		392			156		105			234	39	
Hirudinea	0	117	0	49	0	0	117	0	0	0	39	0	0	0
Helobdella stagnalis (L.)		78		49			78				39			
Hemiclepsis marginata (Müller)		39					39							
Bivalvia	78	0	0	49	0	0	117	39	0	0	78	78	78	0
Dreissena polymorpha (Pall.)				49										
Anadonta anatina (L.)											39			
Unio tumidus (Philipsson)	78						117				39	78	78	
Pisidium sp.								39						
Gastropoda	2613	39	0	147	0	0	156	0	0	0	78	1912	1443	0
Theodoxus fluviatilis (L.)	39			147			39				39	196	39	
Potamopyrgus antipodarum (Smith)	2535						78					1716	1404	
Lymnaea peregra (Müller)	39	39					39							
Viviparus viviparus											39			
Crustacea	39	0	0	0	0	0	0	0	0	0	0	0	0	0
Asellus aquaticus (Racov.)	39													
Megaloptera	0	0	0	0	0	0	0	195	0	0	0	0	0	0
Sialis fuliginosa (Pictet.)								195						
Ephemeroptera	39	858	0	0	0	0	273	39	0	0	117	0	117	0
Caenidae	39	858					234	39			117		117	
Leptophlebiidae							39							
Odonata	0	0	0	0	0	0	0	39	0	0	0	0	0	0
Zygoptera														
Corduliidae								39						
Heteroptera	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**39**	**0**	**0**
Corixidae							0					39		
Trichoptera	78		0	49			78				39			
Ceratopogonidae	**0**	**78**	**0**	**0**	**0**	**0**	**0**	**78**	**0**	**0**	**0**	**0**	**0**	**0**
Bezia sp.		78						78						
Chaoboridae	0	0	1120	0	455	210	0	0	0	420	0	39	0	505
Chaoborus flavicans (Meig.)			1085		455	210				420		39		505
Chaoborus flavicans (Meig.)pupa			35											
Chironomidae	2496	936	245	245		315	351	663	350		585	2028	5772	
Acari	**39**	**117**	**0**	**0**	**0**	**0**	**117**	**39**	**35**	**0**	**0**	**39**	**78**	**0**
Hydracarina	39	117					117	39	35			39	78	
Total	**5382**	**3354**	**1365**	**931**	**455**	**525**	**1365**	**1092**	**490**	**420**	**936**	**4369**	**7527**	**505**

Tab. 4 Number of individuals per m² for each sampling station in Lake Durowskie in 2018

8.2 Biomass [mg/m2]

Biomass of macroinvertebrates per m² for each sampling station in Lake Durowskie in 2018 [mg/m²]														
Taxon	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Oligochaeta		**1989**		**1029**			**351**		**35**			**546**	**39**	
Hirudinea	**0**	**273**	**0**	**980**	**0**	**0**	**429**	**0**	**0**	**0**	**117**	**0**	**0**	**0**
Helobdella stagnalis (L.)		156		980			195				117			
Hemiclepsis marginata (Müller)		117					234							
Bivalvia	**769080**	**0**	**0**	**7938**	**0**	**0**	**2517060**	**351**	**0**	**0**	**697710**	**477711**	**1083420**	**0**
Dreissena polymorpha (Pall.)				7938										
Anadonta anatina (L.)											386880			
Unio tumidus (Phil.)	769080						2517060				310830	477711	1083420	
Pisidium sp.								351						
Gastropoda	**23790**	**546**	**0**	**12397**	**0**	**0**	**1053**	**0**	**0**	**0**	**248352**	**36933**	**11076**	**0**
Theodoxus fluviatilis (L.)	6474			12397			741				2652	24726	3666	
Potamopyrgus antipodarum (Smith)	17043						273					12207	7410	
Lymnaea peregra (Müller)	273	546					39							
Viviparus viviparus (L.)											245700			
Crustacea	**117**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Asellus aquaticus (Racov.)	117													
Megaloptera	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**3744**	**0**	**0**	**0**	**0**	**0**	**0**
Sialis fuliginosa (Pictet.)								3744						
Ephemeroptera	**39**	**975**	**0**	**0**	**0**	**0**	**195**	**78**	**0**	**0**	**39**	**0**	**195**	**0**
Caenidae	39	975					156	78			39		195	
Leptophlebiidae							39							
Odonata	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**78**	**0**	**0**	**0**	**0**	**0**	**0**
Corduliidae								78						
Heteroptera	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**39**	**0**	**0**
Corixidae												39		
Trichoptera	**78**			**637**			**117**				**117**			
Ceratopogonidae	**0**	**78**	**0**	**0**	**0**	**0**	**0**	**117**	**0**	**0**	**0**	**0**	**0**	**0**
Bezia sp.		78						117						
Chaoboridae	**0**	**0**	**3745**	**0**	**1505**	**805**	**0**	**0**	**0**	**1505**	**0**	**156**	**0**	**1925**
Chaoborus flavicans (Meig.)			3675		1505	805				1505		156		1925
Chaoborus flavicans (Meig.) pupa			70											
Chironomidae	**2067**	**1326**	**700**	**539**		**11270**	**117**	**780**	**1085**		**8190**	**2613**	**3744**	
Acari	**39**	**39**	**0**	**0**	**0**	**0**	**39**	**39**	**35**	**0**	**0**	**39**	**39**	**0**
Hydracarina	39	39					39	39	35			39	39	
Sum	795210	5226	4445	23520	1505	12075	2519361	5187	1155	1505	954525	518037	1098513	1925

Tab. 5 Biomass of macroinvertebrates per m² for each sampling station in Lake Durowskie in 2018

8.3 Biodiversity: Shannon-Wiener Index

Site	H' in R
1	1,0122082
2	1,5434215
3	0,4777184
4	1,4718833
5	0
6	0,6730117
7	2,2175963
8	1,4350505
9	0,7589368
10	0
11	1,3481959
12	1,2175648
13	0,73076
14	0

Tab. 6 Shannon-Wiener Index of macroinvertebrates per sampling station in Lake Durowskie in 2018 (H` has been calculated in R and E is the normalized index.)

8.4 Biological Monitoring Working Party Scores

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

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

Biological Monitoring Working Party (BMWP) score														
Taxon	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Oligochaeta	**0**	**2**	**0**	**2**	**0**	**0**	**2**	**0**	**2**	**0**	**0**	**2**	**2**	**0**
Hirudinea														
Helobdella stagnalis (L.)	0	3	0	3	0	0	3	0	0	0	3	0	0	0
Hemiclepsis marginata (Müller)	0	3	0	0	0	0	3	0	0	0	0	0	0	0
Bivalvia														
Dreissena polymorpha (Pall.)	0	0	0	7	0	0	0	0	0	0	0	0	0	0
Anadonta anatina (L.)	0	0	0	0	0	0	0	0	0	0	7	0	0	0
Unio tumidus (Phil.)	7	0	0	0	0	0	7	0	0	0	7	7	7	0
Pisidium sp.	0	0	0	0	0	0	0	4	0	0	0	0	0	0
Gastropoda														
Theodoxus fluviatilis (L.)	6	0	0	6	0	0	6	0	0	0	6	6	6	0
Potamopyrgus antipodarum (Smith)	5	0	0	0	0	0	5	0	0	0	0	5	5	0
Lymnaea peregra (Müller)	3	3	0	0	0	0	3	0	0	0	0	0	0	0
Viviparus viviparus (L.)	0	0	0	0	0	0	0	0	0	0	7	0	0	0
Crustacea														
Asellus aquaticus (Racov.)	3	0	0	0	0	0	0	0	0	0	0	0	0	0
Megaloptera														
Sialis fuliginosa (Pictet.)	0	0	0	0	0	0	0	3	0	0	0	0	0	0
Ephemeroptera														
Caenidae	7	7	0	0	0	0	7	7	0	0	7	0	7	0
Leptophlebiidae	0	0	0	0	0	0	7	0	0	0	0	0	0	0
Odonata														
Corduliidae	0	0	0	0	0	0	0	6	0	0	0	0	0	0
Heteroptera														
Corixidae	0	0	0	0	0	0	0	0	0	0	0	5	0	0
Trichoptera	**6**	**0**	**0**	**6**	**0**	**0**	**6**	**0**	**0**	**0**	**6**	**0**	**0**	**0**
Ceratopogonidae														
Bezia sp.	0	4	0	0	0	0	0	4	0	0	0	0	0	0
Chaoboridae														
Chaoborus flavicans (Meig.)	0	0	2	0	2	2	0	0	0	2	0	2	0	2
Chaoborus flavicans (Meig.) pupa	0	0	2	0	0	0	0	0	0	0	0	0	0	0
Chironomidae	**3**	**3**	**3**	**3**	**0**	**3**	**3**	**3**	**3**	**0**	**3**	**3**	**3**	**0**
Acari														
Hydracarina	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sum	**40**	**25**	**7**	**27**	**2**	**5**	**52**	**27**	**5**	**2**	**46**	**30**	**30**	**2**
Average Score	**4**	**4**	**2**	**5**	**2**	**3**	**5**	**5**	**3**	**2**	**6**	**4**	**5**	**2**

Tab. 8 BMWP score per taxon for each sampling station in Lake Durowskie in 2018