Christian-Albrechts-Universität zu Kiel

Ecological state of Lake Durowskie during restoration measures: Macroinvertebrate Analysis 2016

By: Mohamed Ezat (CAU)

Jakub Hływa (AMU)

Mildred Johnson (CAU)

Justyna Józefiak (AMU)

Stenka Vulova (CAU)

Supervisor: MSc. Ing Piotr Domek

Table of contents

List of figures

List of Images

1. Introduction

The European Union (EU) Water Framework Directive (WFD), which was initiated in 2000, established a legal framework aimed at protecting and restoring clean water across Europe and securing its long-term, sustainable use. The essential aim of the WFD is to compare the current ecological state of a water body with an anthropogenically undisturbed state and to intervene in order to bring back water bodies to an ecologically good status whenever necessary (Hoey et al. 2010). In the year 2004 Poland joined the EU. It was therefore necessary to evaluate the status of water bodies in Poland in compliance with the requirements of the WFD, which can be done by biological or physiochemical monitoring.

Biological monitoring, also referred to as biomonitoring, is the systematic use of organisms in order to indicate the quality of the aquatic environment (Barbour and Paul 2010, as cited in Muralidharan et al. 2010). Biological monitoring of water quality is in some respects even more useful than physicochemical monitoring, as it indicates both the past conditions and current conditions of the ecosystem (Muralidharan et al. 2010). The presence or absence of certain species in a water body can provide valuable information about the quality of the water. Bioindicators are species which can be used to assess environmental quality and track how it changes spatially and temporally in biomonitoring initiatives (Holt and Miller 2010). Species generally tolerate a limited range of physical, chemical, and biological conditions, and can therefore be utilized to evaluate environmental quality (Holt and Miller 2010). Benthic macroinvertebrates are especially well-suited as bioindicators for water quality of freshwater water bodies (Klimaszyk and Trawiński 2007). This is because they fulfil the majority of the recommended requirements for an ideal bioindicator organism, which include having a narrow range of environmental requirements, having a sizeable geographic distribution, having a long life cycle, and being relatively easily recognizable for identification purposes (Kownackie 2000, as cited in Klimaszyk and Trawiński 2007). In particular, the abundance and diversity of macroinvertebrates is strongly related to water quality since they have comparatively more limited movement than fish and they respond rapidly to pollutants such as nutrients and sediment (Muralidharan et al. 2010).

Lake Durowskie is adjacent to the urban area of Wągrowiec, although a section of it is surrounded by a forest (Gołdyn et al. 2014). The lake is culturally and economically significant due to the recreation opportunities it provides for the local population and as a tourist attraction (Gołdyn et al. 2014). The lake offers a variety of recreational opportunities for both tourists and local residents ranging from swimming, fishing, kayaking and sailing.

1.2 Research problem

The aim of this study is to assess the current state and the long-term trends of water quality in Lake Durowskie based on macroinvertebrates as indicators.

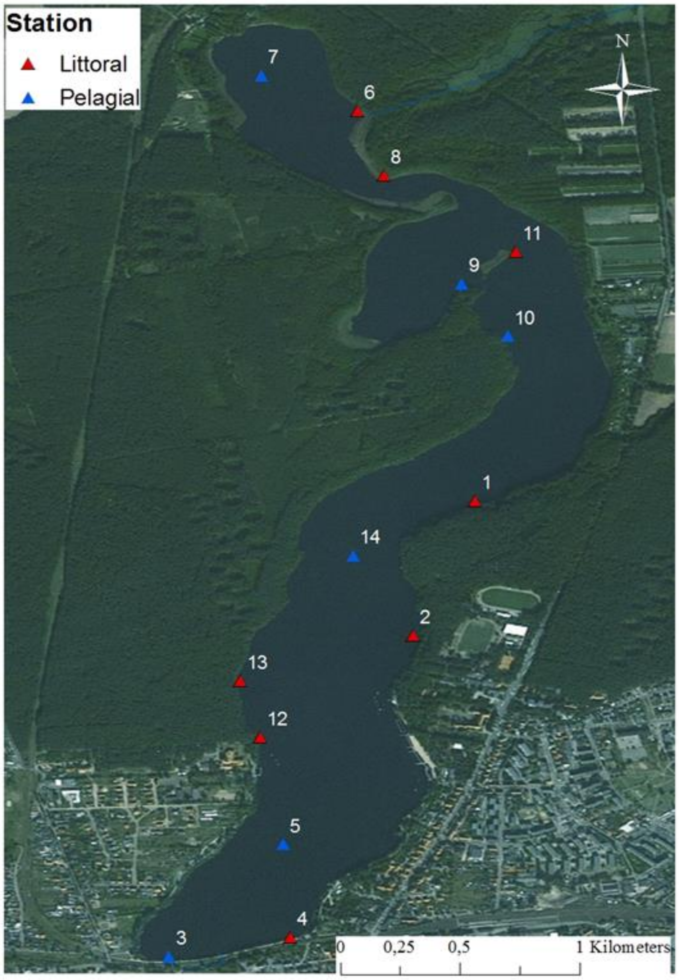
Current management strategies and the restoration measurements

In 2008, Lake Durowskie had an elevated external and internal loading of phosphorus, hydrogen sulphide in the hypolimnion, and large cyanobacterial water blooms (Gołdyn et al. 2014). In 2009, three main restoration measures were implemented in the lake: (i) oxygenation of hypolimnetic waters via two wind aerators, (ii) iron treatment via small doses of coagulant (PIX 112), and (iii) biomanipulation by stocking the lake with pike and pikeperch fry (Gołdyn et al. 2014). One of the aerators is located in the southern part of the lake and was installed at the end of April 2009; the other aerator is located in the northern part of the lake and was installed in July 2009.

2. Research Area

2.1 Study site

Lake Durowskie is located in Wągrowiec, a town situated in the Wielkopolska region of Poland. This lake is a thermally stratified, post-glacial lake with an area of 143.7 ha and a maximum depth of 14.6 m (Gołdyn et al. 2014). Its geographic coordinates are N 52°49'6" and E 17°12'1'. There five other lakes upstream that feed Lake Durowskie and the main tributary is the Struga Gołaniecka River which empties into the Baltic Sea further downstream. The lake is surrounded by forest in the northern part, while the southern part is characterised by urban infrastructure.



Characteristic	Unit/Parameter
Surface area	143,7 ha
Maximum depth	14,6 m
Mean Depth	7,9 m
Catchment area	236,1 km²

Image 1. Characteristics and location of sampling stations in Lake Durowskie.

2.2 Methodology

Sample collection

Samples were collected from a total of 14 predetermined stations from the 27th of June till the 2nd of July 2016. These stations are categorized as the pelagic zone (numbers 3, 5, 7, 9, 11 and 14), the littoral zone near the forest (numbers 1, 6, 8, 10 and 13) and the littoral zone near the urban area (numbers 2, 4 and 12). For samples in the pelagic zone, which is deeper, a Kajak (diameter 7.2 cm) was used to trap the sediment. The shallow littoral zones have a maximum depth of 2 meters, therefore a Czapla (5.7 cm) was used to collect the sediment from these areas.

Image 2. The Kajak and Czapla samplers used to collect sediment.

At each of the sites, 10 samples of sediments were collected. These were washed, sieved and stored in containers containing some lake water for further analysis in the lab. Macroinvertebrates were then counted, identified to the species level using the key, biomass weighed and preserved in 70% ethanol. The areal coverage of each species was determined by converting the number of species found at a site to an area of $1m^2$. This was done by multiplying the number of each species obtained in 10 sampling replicates by a multiplier based on the area of the sampler used. The multiplier used for the Kajak sampler was **26**; the multiplier used for the Czapla was **39.**

Equation 1*:* Number of individuals = (NIS x S)

Equation 2*:* Biomass in mg/m^2 = (BSS x S)

Where:

NIS is the number of species individuals in sample

S is the sampler specific multiplier

BSS is biomass of species in sample

Collected macroinvertebrates were identified to species level using several dichotomous keys.

2.3 Data Analysis

2.3.1 Indices

One of the most common ways to evaluate water quality via biomonitoring is through the use of indices. Biotic indices, such as the Biological Monitoring Working Party (BMWP), are based on the idea that pollution tolerance varies among various organisms (Muralidharan et al. 2010). In addition, various metrics of community structure and function are often utilized when using macroinvertebrates as indicators of water quality, including taxa richness, enumerations (such as number of all macroinvertebrates collected), community diversity indices (such as the Shannon-Wiener index), community similarity indices (such as the Pinkham-Pearson index), and functional feeding group ratios (such as the percentage of the "shredder" functional group) (Muralidharan et al. 2010).

In this study, we selected a biotic index (BMWP), an enumeration (number of macroinvertebrate individuals collected per square meter), biomass per square meter, and a community diversity index (the Shannon-Wiener index) for our analyses in order to provide a comprehensive overview of the water quality of Lake Durowskie as indicated by macroinvertebrates.

2.3.2 ***The Shannon-Wiener Index***

The Shannon-Wiener Index (H') was used to determine the diversity of the lake. The greater the H' value, the greater the biodiversity of the area. The Shannon-Wiener Index takes the number of species as well as evenness into account.

Equation 3: $H' = -\sum pi \ln pi$

Where *pi* is the proportion of individuals found in species i. Here *p*i = ni/N, where ni is the number of individuals in species i and N is the total number of individuals in the community.

2.3.3 ***The Biological Monitoring Working Party (BMWP)***

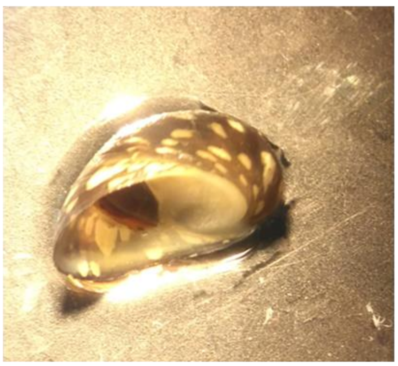
The Biological Monitoring Working Party (BMWP) is a comprehensive index created in order to monitor organic pollution in freshwater systems (Muralidharan et al. 2010). This index assesses water quality using families of macroinvertebrates as bioindicators and is based on the differentiated survival responses of aquatic macroinvertebrates under varying levels of oxygen availability (which is directly related to the levels of organic wastes in a water body). The BMWP consists of approximately 80 different taxa, which are each assigned points ranging from 0 to 10, indicating their sensitivity to contamination (Klimaszyk and Trawiński 2007). Worms (*Oligochaeta*), for instance, are assigned a value of 1 point since they are relatively insensitive to pollution, while stoneflies (*Nemouridae*) are assigned a value of 10 points due to their high sensitivity to pollution (Klimaszyk and Trawiński 2007). The number of different macroinvertebrate taxa also affects the BMWP value, as better-quality water bodies are assumed to exhibit higher diversity. The BMWP score is calculated as the sum of the individual scores (Muralidharan et al. 2010).

3. Results

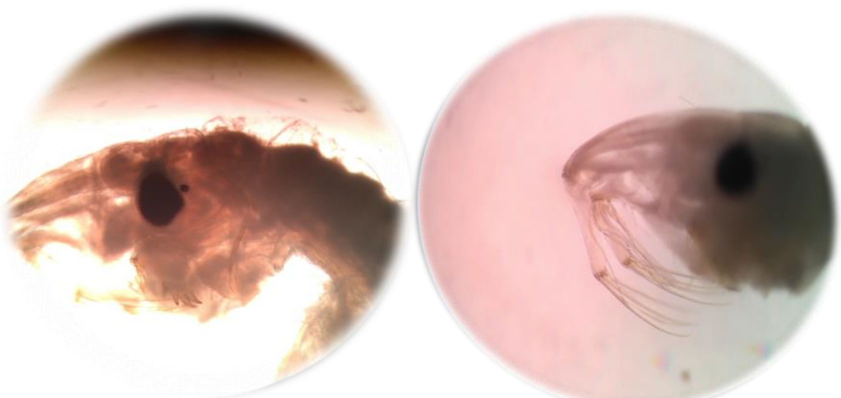
The laboratory and the data analysis investigation provides information about the number of individuals per square meter, biomass of macroinvertebrates (mg/m²). We investigated the long-term trend of biomass per square meter and number of individuals per square meter across the years and compared this year's results with past years. Finally, we evaluated what macroinvertebrates indicated about the water quality of Lake Durowskie according to several indices, including the Shannon-Wiener index and BMWP index.

3.1 Species identification

Overall, 25252 individuals were recorded among 14 different family using different identification keys including: OLIGOCHAETA, HIRUDINEA, BIVALVIA, GASTROPODA, CRUSTACEA, MEGALOPTERA, COLEOPTERA, EPHEMEROPTERA, ODONATA, TRICHOPTERA, CERATOPOGONIDAE, CHAOBORIDAE, CHIRONOMIDAE and ACARI.



Theodoxus fluviatilis (L.)



Chaoborus flavicans

Viviparus viviparus (L.)

Glossiphonia complanata

Anodonta anatina (L.) left and
Unio tumidus Philip, right.

Image 3. Collected macroinvertebrates identified to species level.

3.2 Number of individuals

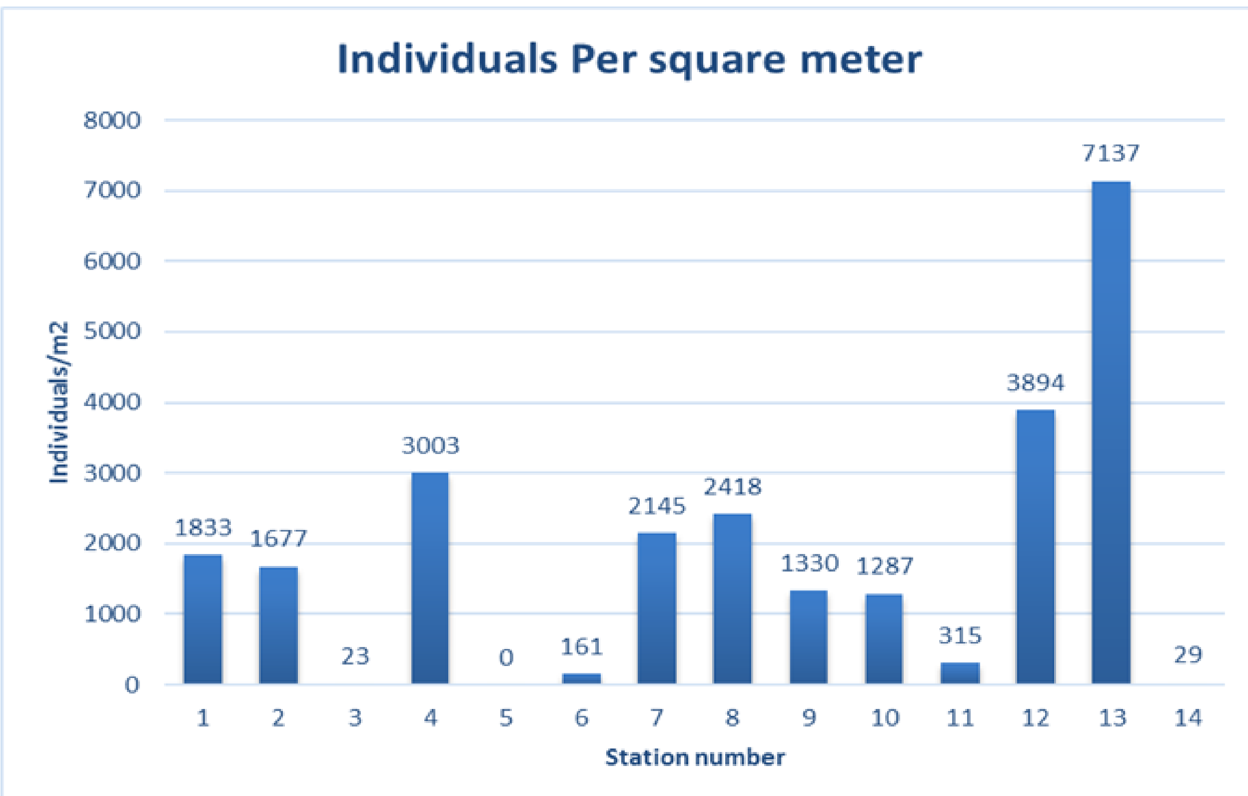


Figure 1. Number of individuals per square meter in 2016.

In Figure 6 the highest number of individuals per square meter were recorded in stations 13 and 12, where 7137 and 3894 individuals per square meter were recorded, respectively. On the other hand, the pelagic stations (3, 5, 7, 9, 10 and 14) exhibited a smaller number of individuals per square meter compared with the littoral stations. The number of individuals per square meter were the following in the pelagic stations: 23, 0, 2145, 1330, 1287 and 29 (mg/m²).

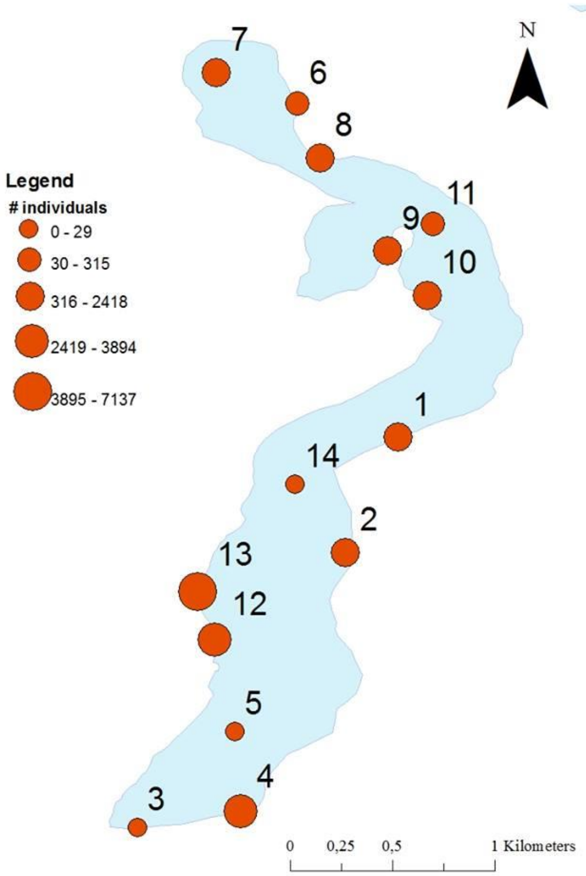


Figure 2. Number of individuals per square meters sampled in Lake Durowskie per station.

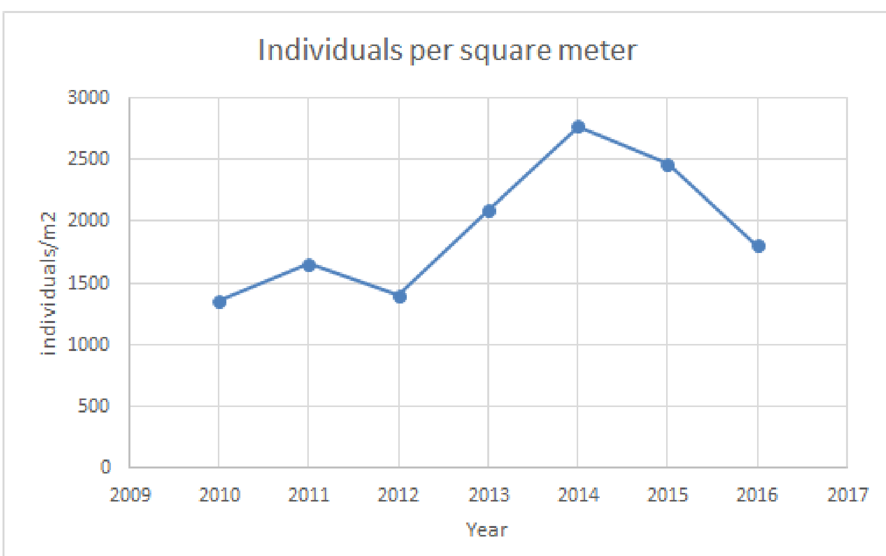


Figure 3. Number of individuals per square meters sampled in Lake Durowskie from 2009 to 2016.

From 2014 to the current year of sampling (2016), the number of individuals per square meter has been consistently decreasing. Prior to that, from 2012 to 2014, there was a clear trend of increase of individuals per square meter. The individuals per square meter for this year (approximately 1804 individuals/m²) are still higher than the individuals per square meter for the first three years of restoration measurement (2010-2012).

3.3 Biomass per square meter

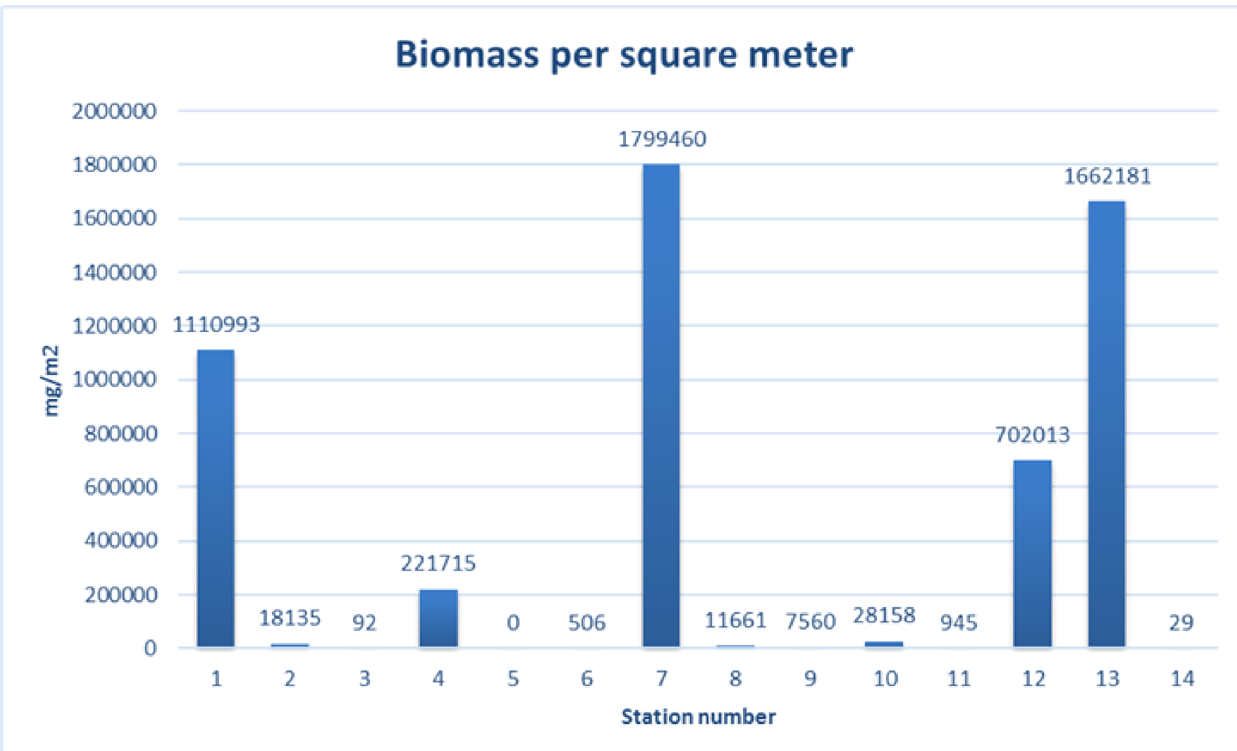


Figure 4. Biomass of sampled species per square meter for all stations in Lake Durowskie in 2016.

According to Figure 4 biomass per square meter is greatest for stations 1, 7, 12, and 13. The greatest proportion of biomass for these four stations was contributed by bivalves, which included *Anodonta anatina* (L.), *Unio tumidus Philip.*, *Musculium sp.*, and *Pisidium sp.* All four genera of *Bivalvia* were found in station 12.

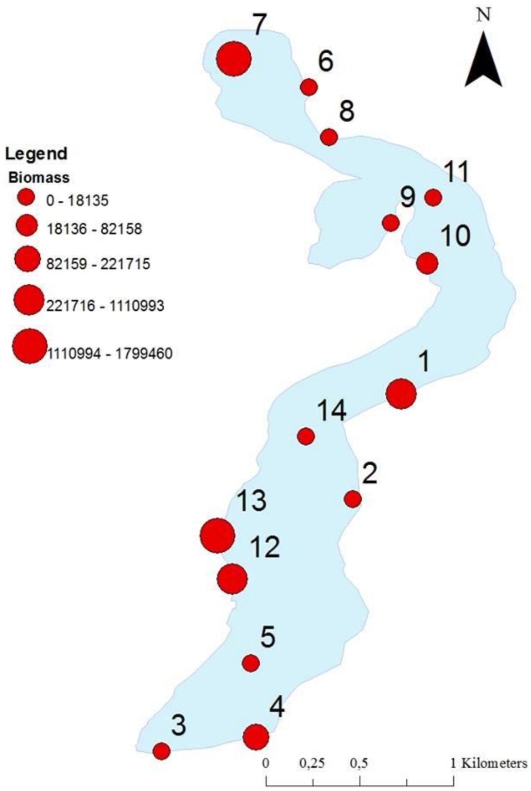


Figure 5. Biomass of sampled species per square meter for all stations in Lake Durowskie in 2016.

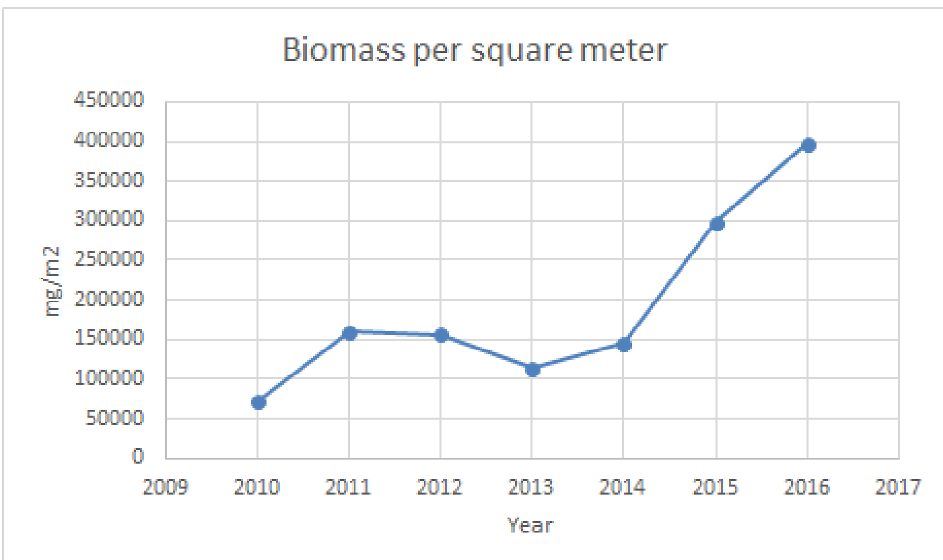


Figure 6. Biomass of sampled species per square meter for all stations in Lake Durowskie from 2010-2016

Since 2013 up to the current year of sampling, biomass per square meter has been consistently increasing. This year's biomass per square meter is in fact more than three times that of three years ago (2013) (397389 mg/m² in 2016 versus 113318 mg/m² in 2013). This year's biomass per square meter is also more than five times the biomass per square meter of the first year of monitoring (2010).

3.4 Diversity: Shannon-Wiener index

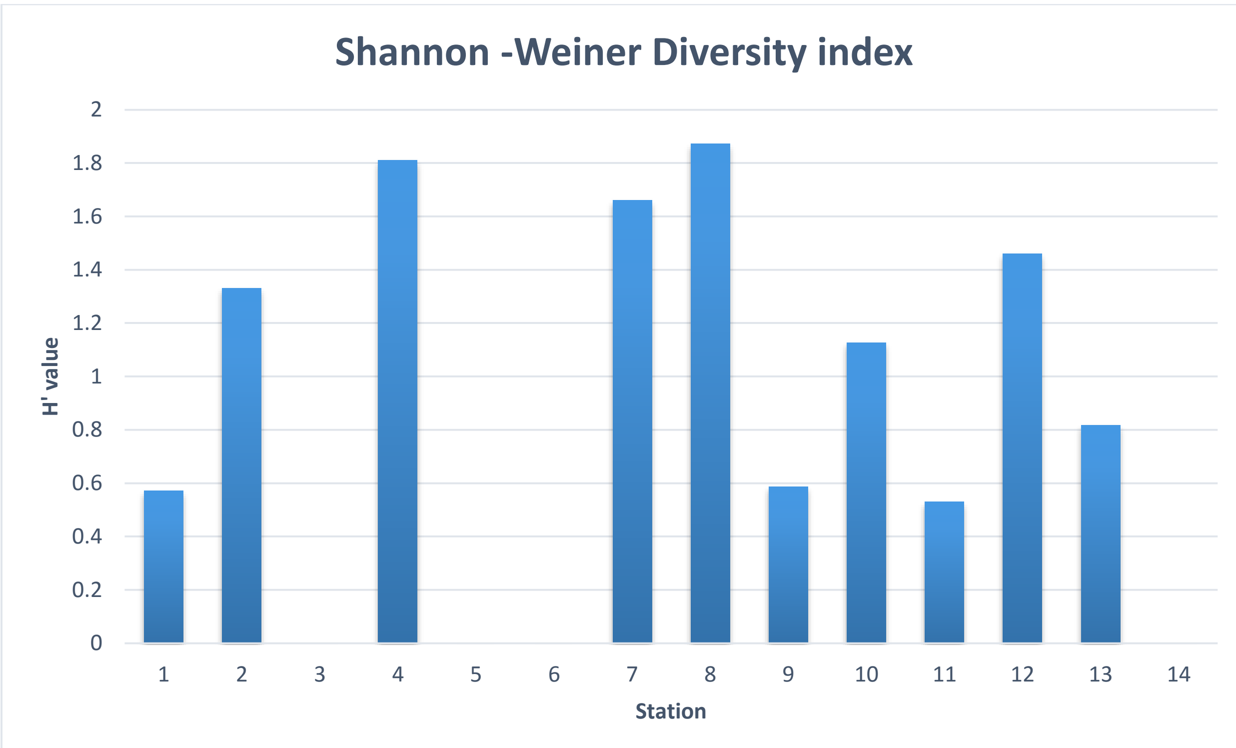


Figure 7. The Shannon-Weiner Diversity Index for each sampling station in Lake Durowskie in 2016.

According to Figure 7, the stations exhibiting the highest diversity based on the Shannon-Wiener index were stations 4, 7, and 8, closely followed by station 12. In stations 3, 6 and 14 only one species was found, therefore there are no values for diversity in these stations while no individuals were found in station 5.

The trend of the diversity across the years from 2009 to 2016 according to Shannon-Wiener Index

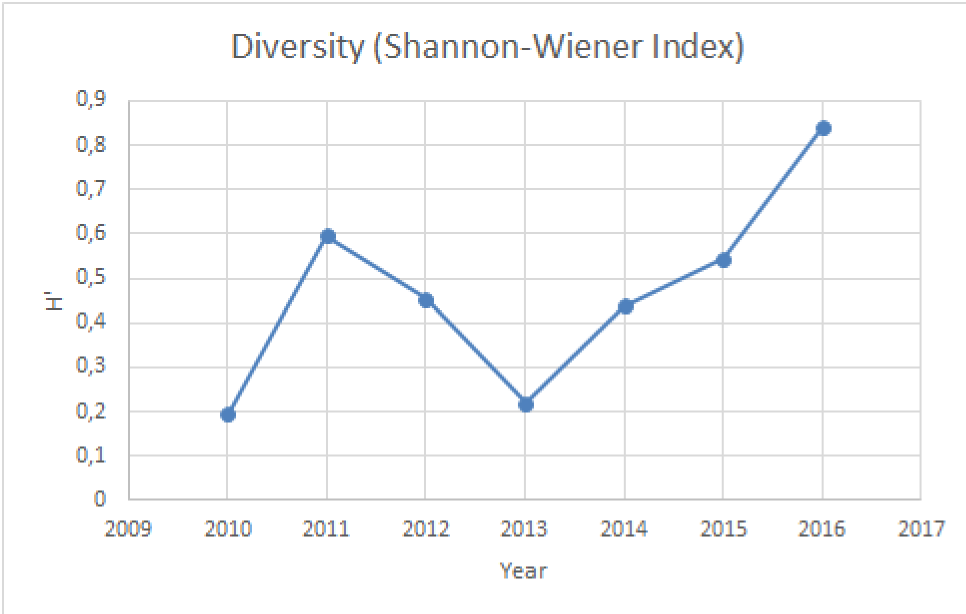


Figure 8. The Shannon-Weiner Diversity Index for all stations in Lake Durowskie from 2010 to 2016

Based on the Shannon diversity index, macroinvertebrate species diversity has been consistently increasing from 2013 up to the current year of sampling (2016). The macroinvertebrate species diversity for 2016 is also notably higher than that of the first year of monitoring (2010). From 2011 up to 2013, there was a two-year trend of decrease of diversity.

3.5 Biological Monitoring Working Party (BMWP) Scores

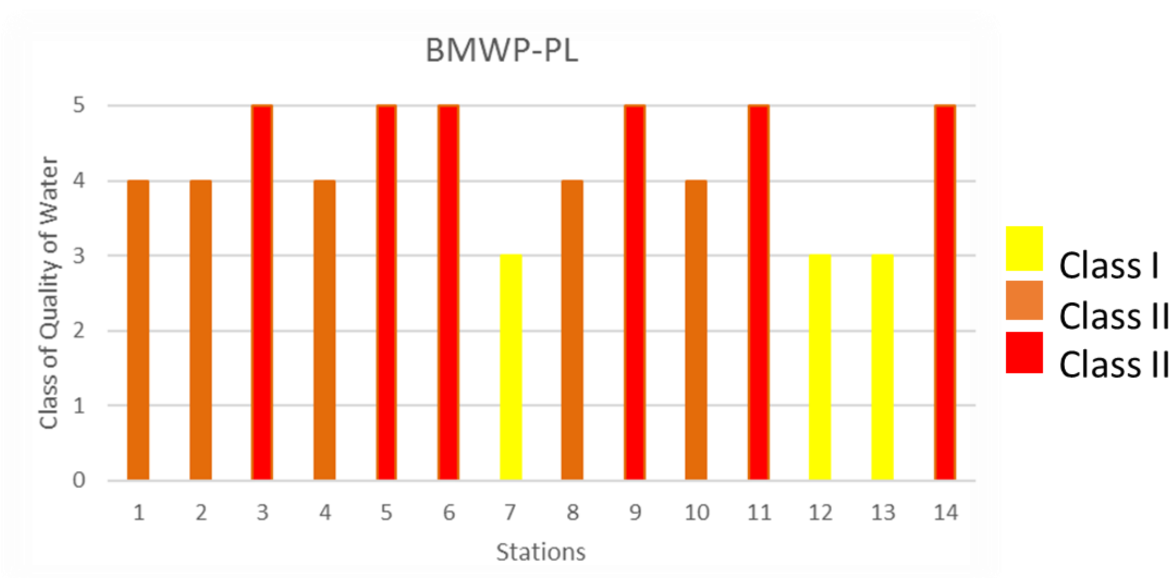


Figure 9. Water quality at Lake Durowskie based on the Biological Monitoring Working Party (BMWP) for each station, 2016.

This figure shows the water quality classes according to the BMWP index at each station in the lake. Based on this assessment, the water quality can be classified in the moderate class (Class 3) at Station 7 in the north side of the lake, with an index score of 50. The rest of the sites within the pelagial zone were all ranked in class 5, the lowest BMWP class.

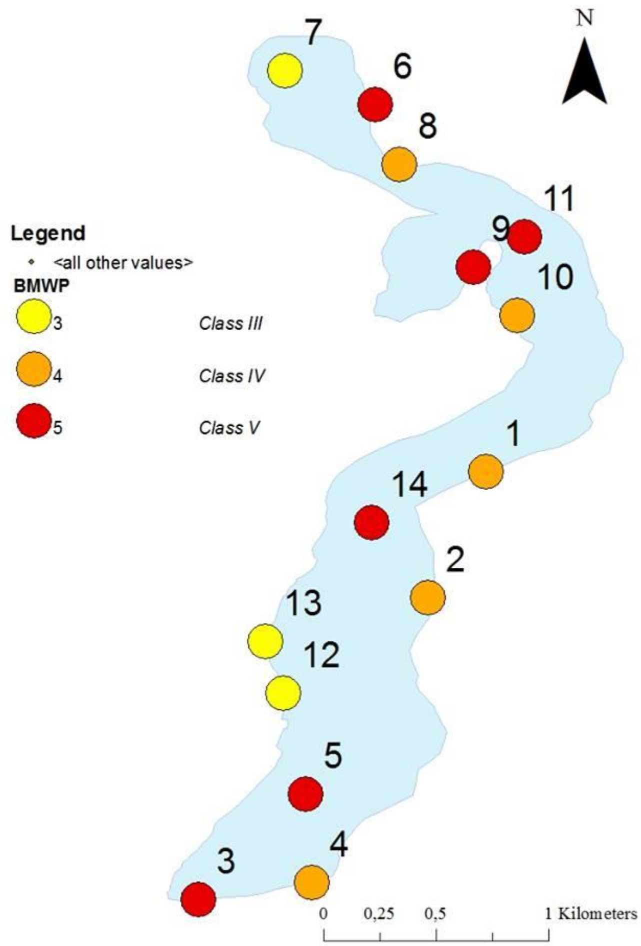


Figure 10. Water quality classifications of sampling stations in Lake Durowskie based on the Biological Monitoring Working Party (BMWP) for each station, 2016.

An improvement in the water quality can be noted for stations 12 and 13 based on the BMWP index when comparing the current year (2016) with the previous year (2015). These two stations are close to the bank on the southwestern side of the lake. Their scores were 44 and 40 respectively, which is fairly close to the cut-off point separating Class 3 from Class 4.

The remaining locations were ranked in Class 4, indicating a poor water quality. The stations in Class 4 included Station 6 (inflow) and Station 3 (outflow).

Biological Monitoring Working Party (BMWP) across the years

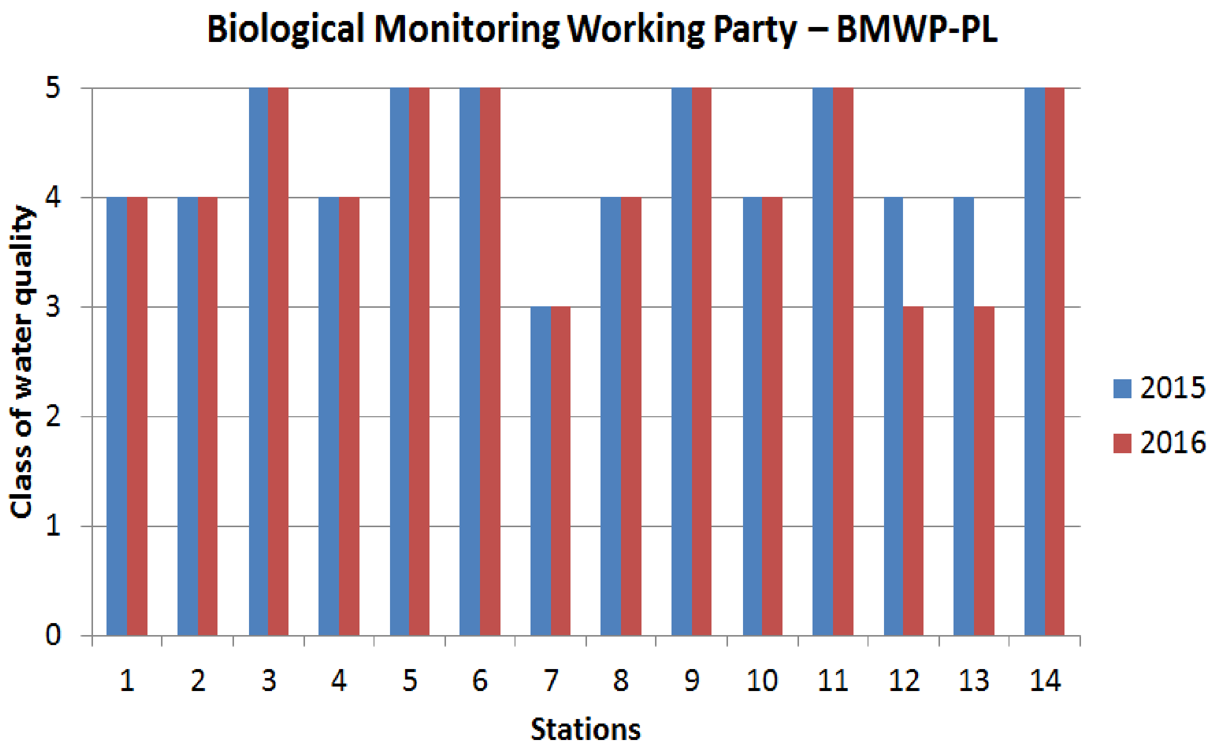


Figure 11. Comparison of 2015 and 2016 water quality classifications of sampling stations in Lake Durowskie, based on the Biological Monitoring Working Party (BMWP).

According to BMWP, Stations 12 and 13 improved in water quality compared with the previous year (2015). These stations are in the vicinity of the first aerator and close the bank on the southwestern side of the lake. The highest biomass of mussels was also recorded in Station 12 (including all four different genera of *Bivalvia*).

4. Discussion

Compared to previous years, we can observe a decline in the numbers of individuals from the year 2014, the lowest observed in 2016 (Figure 3). For the past two years, the ice cover of the lake in winter has been comparatively low and therefore during the spring the water has heated up faster. Pupae of some macroinvertebrates, such as *Ephemeroptera* and *Trichoptera*, develop faster in warmer conditions, and thus move to the surface of water sooner (MSc. Ing Piotr Domek, personal communication, July 8 2016). An experimental study testing the effect of a 3°C temperature increase on macroinvertebrate communities found that numbers of certain taxa (including *Ephemeroptera* and *Odonata*) decreased when subjected to warmer conditions (Feuchtmayr et al. 2007).

For the past three years, biomass per square meter has also been consistently increasing. This year's biomass per square meter is in fact more than three times that of three years ago (2013). This year's biomass per square meter is also more than five times the biomass per square meter of the first year of monitoring (2010). The relatively high biomass noted this year can largely be attributed to the contribution of biomass of *Bivalvia* species, which contributed a disproportionately large proportion of several stations' biomass. In all of the stations where biomass per square meter was highest (7, 13, 1 and 12), *Bivalvia* species contributed to a sizeable portion of the biomass. The considerable biomass of *Bivalvia* specimens collected explains how biomass per square meter increased despite a decrease in the number of individuals per square meter as compared to the previous annual sampling. Bivalves are filter-feeders, which are considered to be good indicators of water quality (Ostroumov 2005). Filter-feeders such as bivalves are notable for their key roles in aquatic ecosystems, including enhancing water quality, contributing to the stability of the functioning of the ecosystem, and creating habitat heterogeneity (Ostroumov 2005). The notable presence of *Bivalvia* species may be a sign of a continued positive development of the state of Lake Durowskie.

This trend of annual biomass increase may also indicate that the collected macroinvertebrate individuals are growing larger in size because more food is available or because more adult individuals have been collected. Further studies should sample for other organisms (such as algae and macrophytes) in the same locations where macroinvertebrate sampling is conducted in order to further clarify the influence of other organisms on the biomass and abundance of macroinvertebrates.

Generally, greater diversity of macroinvertebrates is assumed to be related to better water quality (Muralidharan et al. 2010). As explained in an EU guiding document on using benthic macroinvertebrates when implementing the Water Framework Directive, low values of diversity are generally associated with more eutrophic lakes (Solimini et al. 2006). Thus, the trend of increase of diversity (Shannon-Wiener index) could indicate water quality in Lake Durowskie is steadily improving.

The BMWP scores of stations 7, 12 and 13 scores are the best among the fourteen stations (Class III), indicating a moderate water quality (Figure 9). According to the BMWP index, Station 7 had the best water quality. This station is located in an area with a substantial surrounding macrophyte cover, dominated by *Phragmitetum communis* associations (personal communication, Brzozowski et al. group, July 8 2016). Thus, this area had a high number of associations which could provide shelter and food for macroinvertebrates. Macrophyte cover generally supports greater diversity and abundance of macroinvertebrates than open silty areas or those dominated by gravel or stones (Watkins et al. 1983). Macroinvertebrates utilize macrophytes, especially submerged macrophytes, as habitat (Cheruvelil et al. 2000). Macroinvertebrate communities can respond to a combination of factors such as nutrients, availability of oxygen, food quality and quantity, habitat structure and shelter (Liston et al. 2008). Thus, the biotic recovery of the lake could involve co-recovery of macroinvertebrates and macrophytes in overlapping areas. As the current data is insufficient to answer this question, further studies could investigate the importance of macrophyte cover to macroinvertebrates by sampling for both organisms at the same sites. In addition, the area in the vicinity of Station 7 is a private area, which could contribute to its comparatively high water quality. Private areas of the lake are likely subjected to less anthropogenic pressure which could detrimentally affect macroinvertebrates.

Based on the BMWP index, the water quality improved in stations 12 and 13 compared to that of 2015. The water quality of all other stations remained at the same level. Stations 12 and 13, though also in Class III, they had BMWP scores which were relatively close to the classification cut-off point between Class III and Class IV. Eleven of the fourteen stations sampled are still classified as Class IV or V, indicating that water quality of the lake as indicated by macroinvertebrates is still not optimal. However, macroinvertebrate recovery following restoration can be expected to be slower than recovery of physio-chemical parameters of the lake. Macroinvertebrates' proximity to sediment is one factor explaining their relatively slow recovery compared to that of other lake physico-chemical or biotic elements. Since nutrients sink into the sediments and due to macroinvertebrates' complex relationship with other biota in the lake, macroinvertebrates may take longer to respond to restoration measures. A meta-study of lake restoration case studies estimated that the time required to reach full recovery for macroinvertebrates after restoration measures ranged from ten to twenty years (Verdonschot et al. 2012). Macrophyte recovery in lakes after restoration measures can range from 2 to more than 40 years according to the same meta-study, indicating that there is a high degree of uncertainty in the current scientific literature on the recovery time necessary for different organisms in lake environments (Verdonschot et al. 2012).

Several external factors likely affected the accuracy of the results. Intermittent rain during the sampling period and the movement of motorboats throughout the lake may have affected the quantity and variety of macroinvertebrates collected during sampling.

5. Conclusion

Compared to results of previous years we observe a decline in the numbers of individuals from the year 2014, the lowest observed in 2016 (Figure 1)

Since 2013 up to the current year of sampling 2016, biomass per square meter has been consistently increasing. This year's biomass per square meter is in the fact more than three times that of three years ago (2013) (397389 mg/m2 in 2016 versus 113318 mg/m2 in 2013). This year's biomass per square meter is also more than five times the biomass per square meter of the first year of monitoring (2010).

Biomass per square meter was high in stations 7, 13, 1 and 12 with 1799460, 166218, 11110993 and 702013 respectively (Figure 4). This high biomass can be attributed to the high proportion of *Bivalvia* species that were found in these stations (Figure 4 & 5). *Anodonta anatina (L.)* and *Unio tumidus Philip*. were the two main Bivalvia species in the four stations. According to the trend observed over time, the biomass per square meter has been steadily increasing since 2014 (Figure 6).

On the other hand, The Shannon Weiner index indicates that there is higher diversity in stations 8, 4 and 7. Generally, greater diversity of macroinvertebrates is assumed to be related to better water quality (Muralidharan et al. 2010). Thus, the trend of increase of diversity (Shannon-Wiener index) could indicate water quality in Lake Durowskie is steadily improving (Figure 8)

Moreover, according to the BMWP index stations 7, 12 and 13 scores are the best among the fourteen stations (Class III), indicating a moderate water quality (Figure 9 & 10). According to the BMWP index, Station 7 had the best water quality. This station is located in an area with a substantial surrounding macrophyte cover, dominated by *Phragmitetum communis*. Macroinvertebrates utilize macrophytes, especially submerged macrophytes, as habitat (Cheruvelil et al. 2000). Thus, the biotic recovery of the lake could involve co-recovery of macroinvertebrates and macrophytes in overlapping areas. Macroinvertebrate communities can respond to a combination of factors such as nutrients, availability of oxygen, food quality and quantity, habitat structure and shelter (Liston et al. 2008). As the current data is insufficient to answer this question, further studies could investigate the importance of macrophyte cover to macroinvertebrates by sampling for both organisms at the same sites.

Stations 12 and 13, though also in Class III, they had a BMWP score of 44 and 40 respectively. This is just past the classification cut-off point of Class IV which ranges from. All other stations remained at the same level as the previous years (Figure 10 & 11).

Generally, greater diversity of macroinvertebrates is assumed to be related to better water quality (Muralidharan et al. 2010). Thus, the trend of increase of diversity (Shannon-Wiener index) could indicate water quality in Lake Durowskie is steadily improving.

6. Recommendations

Biomanipulation of *Dreissena* (Zebra Mussel) as an additional management strategy

Algal and cyanobacterial blooms in reservoirs are driven by nutrient enrichment and may present economic and conservation challenges for water managers. Current approaches such as suppression of algal growth with barley straw, ferric dosing or manipulation of fish stocks have not yielded long term successes. A possibility that has sparked growing interest is the encouragement and cultivation of natural filter feeders, such as mussels, which remove suspended matter from the water and reduce nutrient levels through bio deposition and assimilation (McLaughlan et al., 2013)

Mussel species such as Dreissena are filter feeders with a high filtration potential, with filtration rates of 3000-4000 1m-2d-1. They feed on algae and more importantly harmful cyanobacteria and it has found that they work well deep/ pelagic waters. These are some of the reasons why using this species is appropriate for improving the water quality of eutrophic lakes. The possibility of this species to be cultivated, thus providing an additional source of income. Moreover, it is necessary that cautionary measures be taken when introducing a new species into an ecosystem. This is because the species can easily outcompeted native species and become a pest. First and foremost, the ecosystem dynamics and food web/trophic levels should be determined. On the other hand, it is most likely to use the endemic mussel species but they should have a sufficient biomass to be effective. Therefore, native mussel species with high filtration potentials should be considered in Lake Durowskie.

Biomanipulation -- stocking of fish as a lake restoration method

Mitigation of eutrophication-related issues can be achieved via biomanipulation. Biomanipulation with fish is a method to shift the system from one state in another, most commonly comprising a shift from algae domination to macrophyte domination (FAO 2001). In particular, stocks of zooplanktivorous fish can be reduced via stocking of carnivorous fish, which can lead to increased populations of phytoplankton-feeding zooplankton. The end result of a successful biomanipulation program can replace the dominance of bream and/or roach in most European waters with species associated with macrophytes (such as tench and rudd) (FAO 2001).

In northern Europe, cyprinids such as the bream (*Abramis brama*) and roach (*Rutilus rutilus*) are some of the most common planktivores in eutrophic lakes (Bernes et al. 2013). Reducing the stocks of such planktivores increases the survival of zooplankton that these fish feed on, which subsequently reduces the abundance of planktonic algae that zooplankton feed on (Bernes et al. 2013).

Removing planktivorous fish also assists in improving water quality since many adult planktivorous fish, such as bream, are also benthivores (Bernes et al. 2013). Benthivorous fish search for food in the sediments, which can serve to disturb nutrient-rich silt and contribute to a higher turbidity and phosphorus content in the water of eutrophic lakes. This feeding behaviour can also lead to a lack of benthic vegetation in lakes (Bernes et al. 2013).

Removal of planktivorous and benthivorous fish can be achieving by stocking lakes with predatory fish (piscivores) such as pike (*Esox lucius*), pikeperch, or walleye (Bernes et al. 2013). Biomanipulation can also consist of removing planktivores and benthivores from lakes, usually through intensive fishing. (Bernes et al. 2013)

Restoration of Lake Durowskie, which began in 2009, includes biomanipulation (stocking of the lake with the fry of pike and pikeperch) as one of three restoration measures (Gołdyn et al. 2014). Generally, fish stocking was conducted on an annual basis, although stocking was not done in 2014. The use of fish stocking for biomanipulation requires a continual, sustained effort and may only be effective when combined with other nutrient control and reduction mechanisms (FAO 2001).

Generally, stocking can only be successful as a biomanipulation measure when piscivore catch restrictions are introduced (including catch limit per day; high minimum size; careful handling of piscivores by utilizing barbless hooks) (FAO 2001). When stocking fish, it is preferable to stock juvenile fish rather than adults. Stocking juvenile fish can create food pressure for various planktivorous and benthivorous emerging larvae and small fish, since juvenile fish are also planktivorous and benthivorous.

It is necessary to re-stock with fish for the first few years of lake restoration, at least until macrophytes re-grow. In order to achieve the best results, it is recommended to use a large number of hatchery pike fries. The recommended number of fries to add is at least 1,000 individuals per hectare. Fish used for stocking are recommended to have a length exceeding 10 cm, because at this stage of development pike is piscivorous. Stocking with fish that are smaller than this size can be counter-productive, as smaller fish could consume zooplankton and actually have a negative effect on the lake restoration initiative.

7. References

Bernes, C., S.R. Carpenter, A. Gårdmark, P. Larsson, L. Persson, C. Skov, and E.V. Donk. 2013. What is the influence on water quality in temperate eutrophic lakes of a reduction of planktivorous and benthivorous fish? A systematic review protocol. Environmental Science 2:9.

Cheruvelil, K.S., P.A. Soranno, and R.D. Serbin. 2000. Macroinvertebrates associated with submerged macrophytes: sample size and power to detect effects. Hydrobiological 1: 133-139.

Gołdyn, R., S. Podsiadłowski, R. Dondajewska, and A. Kozak. 2014. The sustainable restoration of lakes – towards the challenges of the Water Framework Directive. Ecohydrology & Biology 14: 68-74.

Hoey, G.V., A. Borja, S. Birchenough, L. Buhl-Mortensen, S. Degrauer, D. Fleischer, F. Kerckhof, P. Magni, I. Muxika, H. Reiss, A. Schröder, and M.L. Zettler. 2010. The use of benthic indicators in Europe: From the Water Framework Directive to the Marine Strategy Framework Directive. Marine Pollution Bulletin 60: 2187-2196.

Holt, E.A. and S.W. Miller. 2010. Bioindicators: Using Organisms to Measure Environmental Impacts. Nature Education Knowledge 3(10).

Feuchtmayr, H., D. McKee, I.F. Harvey, D. Atkinson, and B. Moss. Response of macroinvertebrates to warming, nutrient addition and predation in large-scale mesocosm tanks. Hydrobiologia 584(1): 425-432.

Klimaszyk, P. and A. Trawiński. 2007. Ocena stanu rzek na podstawie makrobezkręgowców bentosowych. INDEKS BMWP-PL. Poznań.

Lammens, E.R. Consequences of Biomanipulation for Fish and Fisheries. FAO Fisheries Circular No. 952. Food and Agriculture Organization of the United Nations. Rome, 2001.

Liston, S. E., Newman, S. and Trexler, J.C. (2008). Macroinvertebrate Community Response to Eutrophication in an Oligotrophic Wetland: An in situ Mesocom Experiment. *Wetlands,* 28 (3) 686-694

Muralidharan, M., C. Selvakumar, S. Sundar, and M. Raja. 2010. Macroinvertebrates as Potential Indicators of Environmental Quality. IJBT 1: 23-28.

McLaughlan, C., D.C. Aldridge, 2013, Cultivation of zebra mussels (Dreissena polymorpha) within their invaded range to improve water quality in reservoirs.

Solimini, A.G., G. Free, I. Donohue, K. Irvine, M. Pusch, B. Rossaro, L. Sandin, and A.C. Cardoso. 2006. Using Benthic Macroinvertebrates to Assess Ecological Status of Lakes: Current Knowledge and Way Forward to Support WFD Implementation. Institute for Environment and Sustainability.

Verdonschot, P.F.M., B.M. Spears, C.K. Feld, S. Brucet, H. Heizer-Vlek, A. Borja, M. Elliott, M. Kernan, and R.K. Johnson. 2012. A comparative review of recovery processes in rivers, lakes, estuarine and coastal waters. Hydrobiologia 692.

Watkins, C.E., J.V. Shireman, and W.T. Haller. 1983. The Influence of Aquatic Vegetation upon Zooplankton and Benthic Macroinvertebrates in Orange Lake, Florida. Journal of Aquatic Plant Management 21: 78-83.

Identification Keys

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

Kołodziejczyk 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 & 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.

Photo Credits

1. Mildred Johnson
2. Stenka Vulova

8. Appendix

Number of macroinvertebrates collected from the sampling stations in Lake Durowskie (1m2)														
Taxon	1	2	3	4	5	6	7	8	9	10	11	12	13	14
OLIGOCHAETA				78								507		
HIRUDINEA														
Erpobdella octoculata (L.)							39	39				39		
Glossiphoria complanata (L.)				39				39						
Helobdella stagnalis (L.)							117	39		117				
BIVALVIA														
Anodonta anatina (L.)	39											39	39	
Unio tumidus Philip.	117						78					72	39	
Musculium sp.												39		
Pisidium sp.												39		
GASTROPODA														
Bithynia tentaculata (L.)							39	117						
Lymnaea peregra (O. F. Müller)										39		39		
Potamopyrgus antipodarum (A.E. Smith)	117	78					117			78		858	1755	
Theodoxus fluviatilis (L.)		117		117			117			78		39		
Valvata piscinalis (O. F. Müller)		39											39	
Viviparus viviparus (L).				39										
CRUSTACEA														
Asselus aquaticus Racov		39		858										
MEGALOPTERA														
Sialis lutaria (L.)				39				39						
COLEOPTERA														
Hydrophilidae		78												
EPHEMEROPTERA														
Baetidae							39							
Caenidae		195		234			117	507		39			39	
Ephemeridae							39							
Ephemeroptera sp.													39	
ODONATA														
Coenagrionidae				78										
TRICHOPTERA		78		429			195	117		39				
DIPTERA														
CERATOPOGONIDAE								117						
CHAOBORIDAE														
Chaoborus flavicans (Meig.)			23			161		78	1085		245			
Pupae									175					
CHIRONOMIDAE	1560	1053		975			1209	897	70	897	70	1989	5031	29
ACARI														
Hydracarina sp.				117			39	390				234	156	
Hydrachna								39						
Sum	1833	1677	23	3003	0	161	2145	2418	1330	1287	315	3894	7137	29

Number of macroinvertebrates collected from the sampling stations in Lake Durowskie (1m2)

Taxon	1	2	3	4	5	6	7	8	9	10	11	12	13	14
OLIGOCHAETA				78								507		
HIRUDINEA														
Erpobdella octoculata (L.)							39	39				39		
Glossiphoria complanata (L.)				39				39						
Helobdella stagnalis (L.)							117	39		117				
BIVALVIA														
Anodonta anatina (L.)	39											39	39	
Unio tumidus Philip.	117						78					72	39	
Musculium sp.												39		
Pisidium sp.												39		
GASTROPODA														
Bithynia tentaculata (L.)							39	117						
Lymnaea peregra (O. F. Müller)										39		39		
Potamopyrgus antipodarum (A.E. Smith)	117	78					117			78		858	1755	
Theodoxus fluviatilis (L.)		117		117			117			78		39		
Valvata piscinalis (O. F. Müller)		39											39	
Viviparus viviparus (L).				39										
CRUSTACEA														
Asselus aquaticus Racov		39		858										
MEGALOPTERA														
Sialis lutaria (L.)				39				39						
COLEOPTERA														
Hydrophilidae		78												
EPHEMEROPTERA														
Baetidae							39							
Caenidae		195		234			117	507		39			39	
Ephemeridae							39							
Ephemeroptera sp.													39	
ODONATA														
Coenagrionidae				78										
TRICHOPTERA		78		429			195	117		39				
DIPTERA														
CERATOPOGONIDAE								117						
CHAOBORIDAE														
Chaoborus flavicans (Meig.)			23			161		78	1085		245			
Pupae									175					
CHIRONOMIDAE	1560	1053		975			1209	897	70	897	70	1989	5031	29
ACARI														
Hydracarina sp.				117			39	390				234	156	
Hydrachna								39						
Sum	1833	1677	23	3003	0	161	2145	2418	1330	1287	315	3894	7137	29

BMWP Classification for each of species

Taxon	Punctation	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8	Station 9	Station 10	Station 11	Station 12	Station 13	Station 14
OLIGOCHAETA	2				2								2		
HIRUDINEA	-							3	3						
Erpobdella octoculata (L.)	3												3		
Glossiphoria complanata (L.)	-														
Helobdella stagnalis (L.)	-														
BIVALVIA	-														
Anodonta anatina (L.)	7	7											7	7	
Unio tumidus Philip.	7	7						7					7	7	
Musculium sp.	4												4		
Pisidium sp.	4												4		
GASTROPODA	-														
Bithynia tentaculata (L.)	6							6	6						
Lymnaea peregra (O. F. Müller)	3										3		3		
Potamopyrgus antipodarum (A.E. Smith)	5	5	5					5			5		5	5	
Theodoxus fluviatilis (L.)	6		6		6			6			6		6		
Valvata piscinalis (O. F. Müller)	4		4											4	
Viviparus viviparus (L).	7				7										
CRUSTACEA	-														
Asselus aquaticus Racov	3		3		3										
MEGALOPTERA	-														
Sialis lutaria (L.)	3				3				3						
COLEOPTERA	-														
Hydrophilidae	5		5												
EPHEMEROPTERA	-														
Baetidae	6							6							
Caenidae	7		7		7			7	7		7			7	
Ephemeridae	7							7							
Ephemeroptera sp.	7													7	
ODONATA	-														
Coenagrionidae	6				6										
TRICHOPTERA	-														
CERATOPOGONIDAE	4								4						
CHAOBORIDAE	-														
Chaoborus flavicans (Meig.)	-														
Pupae	-														
CHIRONOMIDAE	3	3	3		3			3	3	3	3	3	3	3	3
ACARI	-														
Hydracarina sp.	-														
Hydrachna	-														
SUM		22	33	0	37	0	0	50	26	3	24	3	44	40	3