Course: Hydrobiology Fieldtrip Poland

Lecturers: M.Sc. Piotr Domek, Dr. Wilhelm Windhorst, Prof. Ryszard Goldyn, Prof. Beata Messyasz, Dr. Nai-cheng Wu

Macroinvertebrates in Lake Durowskie

Analysis of the ecological state of Lake Durowskie during restoration measures in 2017

Lena Schenke	Matr. Nr. 1114910, Stu-number: 205888 MSc. Environmental Management
Anne Bartels	Matr. Nr. 1112276, Stu-number: 204577 MSc. Environmental Management
Hsin-Ting Li	Matr. Nr. 1118069, Stu-number: 206704 MSc. Applied Ecology
Sathya Chandra Sagar H S	Matr. Nr. 1118077, Stu-number: 206713 MSc. Applied Ecology

Poznan, 09.07.2017

Content

A. List of Figures

B. List of Tables

1. Introduction

Wetlands around the world are some of the most threatened ecosystems, along with the tropical rain forests (Maltby,1991). Management of wetlands in temperate regions is highly variable across countries. Generally, the major factors responsible for degradation include diversions and damming of river flows, eutrophication, contamination, global warming, invasion of exotics and practices of filling and draining (Brinson & Malvárez, 2002). Loss of wetlands is now a major concern as this increases the price of goods and ecosystem services that were free before in the developed countries (Maltby, 1991).

Lake Durowskie is a post glacial, elongated lake, filled by the catchment water from Struga Gołaniecka River in the Wielkopolska Region. Along the course of the river, Lake Durowskie is connected with five other lakes upstream that are strongly eutrophicated with cyanobacterial water blooms (Gołdyn et al., 2013). In the year 2008, the lake experienced cyanobacterial water blooms that closed the beaches and other recreational activities, affecting the tourism industry of the bordering town Wągrowiec. In order to revive tourism and to meet the requirements of the Water Framework Directive (WFD, 2000) of Europe, local authorities started the restoration measures in 2009 applying three methods: oxygenation of water using wind aerators, immobilizing phosphorous using iron treatment and biomanipulation measures – releasing pike fingerlings into the lake (Gołdyn et al., 2013). The European Water Framework Directive (WFD) is a framework for the protection of water bodies and presents the legal background for the assessment and improvement of water bodies across Europe (Van Hoey et al., 2010).

The desired state for the lake is the presence of a self-regulating “Top-down trophic control” system. Long term monitoring of the restoration is important to assess the success and to adapt the measures to work towards this desired state. Since 2009, restoration measures have been annually monitored during International Summer Schools, organized in July. A combination of physical, chemical and biological measurements form the basis of monitoring as they give a complete spectrum of information (Metcalfe, 1989). However, biological monitoring - the use of organisms in order to indicate the quality of the environment, is more useful than physicochemical monitoring when assessing water (Muralidharan et al., 2010). Aquatic organisms, such as the macrozoobenthos, serve as excellent bio-indicators (Metcalfe, 1989; Resh et al., 1993). With limited movement than other higher trophic species, macro-invertebrates are sensitive to pollutants such as nutrients and sediments. This strongly influences the abundance and diversity of the species, making them reliable biological indicators (Muralidharan et al., 2010).

In the present study, we investigated the development of macroinvertebrate density and richness in response to restoration measures which aimed at determining the potential of the lake to shift towards the desired state.

Research question

Assessment and evaluation of the current ecological state and long-term trend of Lake Durowskie based on macroinvertebrates as indicators was set as the focus of research.

1.1 Study site

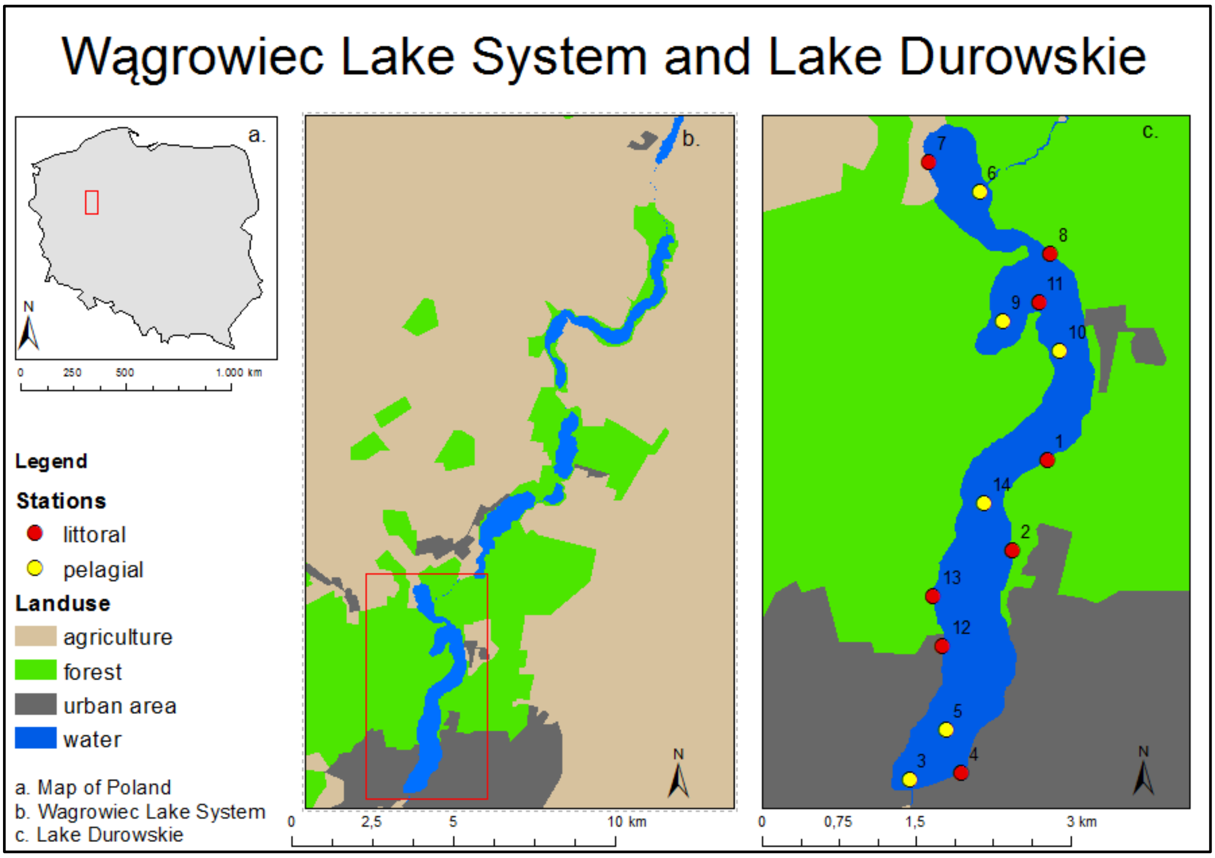

Fig. 1 Maps of the Wagrowiec Lake System and Lake Durowskie including pelagial and littoral sampling stations

Lake Durowskie is situated approximately 50 km north of Poznan. The lake is part of a system of five connected lakes, Durowskie being situated downstream of the rest of them (see Fig. 1). The stream Struga Golaniecka directly connects it to Lake Kobyleckie and flows through Lake Durowskie. It thus serves as the main tributary to Lake Durowskie.

The lake has a total surface area of about 143.7 ha with the direct catchment area extending to 1,581.3 ha. With its maximum depth reaching down to 14.6 m and its mean laying at

7.9 m, a typical thermal stratification of the lake can be observed. Further hydrological information can be found in table 1 below (Messyasz & Pikosz 2017).

The southern tip of the lake is embraced by the small town of Wagrowiec which has roughly 30,000 inhabitants (Messyasz & Pikosz 2017). There are different land use types in the surrounding area of Lake Durowskie (see Tab.1). Seeing that Lake Durowskie is the major attraction of Wagrowiec, there are multiple water activities taking place on the lake, like motor boating, kayaking and bathing at the established beach-site. This leads to an urban character of the lake's southern end. The rest of the lake is mostly surrounded by forested areas. On its central western shores, there is a tree nursery as well as another small community (Durowo) bordering the lake's banks. Table 2 shows the share each land use has in the direct catchment area of Lake Durowskie, as it was given by Messyasz & Pikosz (2017).

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

Tab. 1 Hydrological information on Lake Durowskie (Messyasz & Pikosz 2017)

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

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

2. Methodology

The field work was executed during the first week of the summer school, from 26th June until the 2nd July 2017. In the following week, species were determined and data reviewed. Details on the methods and materials used during the field work are specified in chapter 2.1, whereas more information about the following data analysis can be found in chapter 2.2.

2.1 Methods and Materials

Samples were taken from 14 different points on the lake: seven samples were located in the pelagic zone with deeper waters (stations 3, 5, 6, 9, 10, 11 and 14) and seven in the littoral zone close to the banks (stations 1, 2, 4, 7, 8, 12 and 13). Two different core samplers were used to collect the samples. A core sampler of the type "Kajak" (diameter of 6 cm) was used for the deeper parts of the lake, whereas a "Czapla" core sampler (diameter of 5.7 cm) was used for the littoral zones (2 m water depth or less). Fig. 1 shows the areal distribution of the sampling stations on Lake Durowskie.

After gaining the initial samples from the lake grounds, they were washed in a sieve and stored in plastic boxes filled with lake water. Later on, each sample was sorted and searched for macroinvertebrates. The animals were isolated and their weight was taken as groups of the same families. Separated in groups of the same family, the found macroinvertebrates were preserved in tubes with 70 % alcohol to be determined in the laboratory later on.

2.2 Data Analysis

During the second week, the different samples for every station were examined further. Species were determined for each individual as far as possible (see references for used determination key). The number of individuals per m^2 as well as the total biomass of each taxon was calculated for 1 m^2 and compared to data from previous years.

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

n = number of individuals per m^2 (per taxon)
n_{sample} = number of individuals from the sample (per taxon)
CR = conversion rate

$$\mathbf{g = g_{sample} * CR\ [mg/m^2]}$$

g = biomass per m^2 (per taxon)
g_{sample} = weight of individuals from the sample (per taxon)
CR = conversion rate

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

Tab. 1 Overview over the used core samplers and applied conversion rates for each station

Due to the use of core samplers with different diameters and different amounts of samples replicates that were taken, the conversion factors differ between the different station. Table 3 shows the conversion rate used for each station.

The thus gained data was used to calculate different water quality and biodiversity indices and compared to data from previous years.

Biodiversity assessment

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

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

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

The value of each station for 2017 was calculated to compare the different stations. The mean values from 2010 - 2017 were calculated for each year and then compared.

The Jaccard similarity index was created to cluster the stations based on the similarity in species composition between stations.

Biological Monitoring Working Party (BMWP) Score

The score developed by the Biological Monitoring Working Party 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 10 encompassing families that are known to be very vulnerable to organic pollution (Muralidharan et al. 2010). Although it is an easily applicable indicator to assess the water quality by macroinvertebrates, it bears the bias that only the presence of families is taken into account - but not their abundance.

The Average Score per Taxon (ASPT) was furthermore calculated for each station, giving an idea about the rank of the station within the scoring system. The number was rounded to 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, 27 different taxa were found. Although most of the animals could be determined to the species-level, a few of them could only be determined to the family or order (see Tab.4 in Appendix 8.1). The data shows a low number of individuals per m² biomass per m² and biodiversity in the deep water areas (stations 3, 5, 10 and 14). Overall, an increase in individuals per m², biomass per m² and biodiversity compared to the previous years has been investigated.

In the following, a closer examination of the gained data can be found. Detailed tables with the calculated values are in the Appendix.

3.1 Number of Individuals

The number of individuals found per m² ranges between 35 (station 5 and 14) and 12,389 (station 4) across the stations. Five clusters were defined, going by which stations had similar values (see Fig. 2).

Fig. 2 visualizes the differences in number of individuals per m². Stations 5 and 14 have considerably lower numbers of individuals per m² than the rest, both having only 35 ind./m² in each station. Stations 3, 6, 9 and 10 describe the next cluster, ranging from 245 (station 6) to 840 individuals per m² (station 10). Stations 2, 7 and 8 are in the mid-section (2496 – 3270 ind./m²) and stations 1, 12 and 13 in the cluster with higher values (7410 – 8970 ind./m²). The last cluster peaks higher than the rest, showing 12,389 ind./m² at station 4 and thus leaving a large gap between station 4 (maximum value) and stations 5 and 14 (minimum values). Overall, the

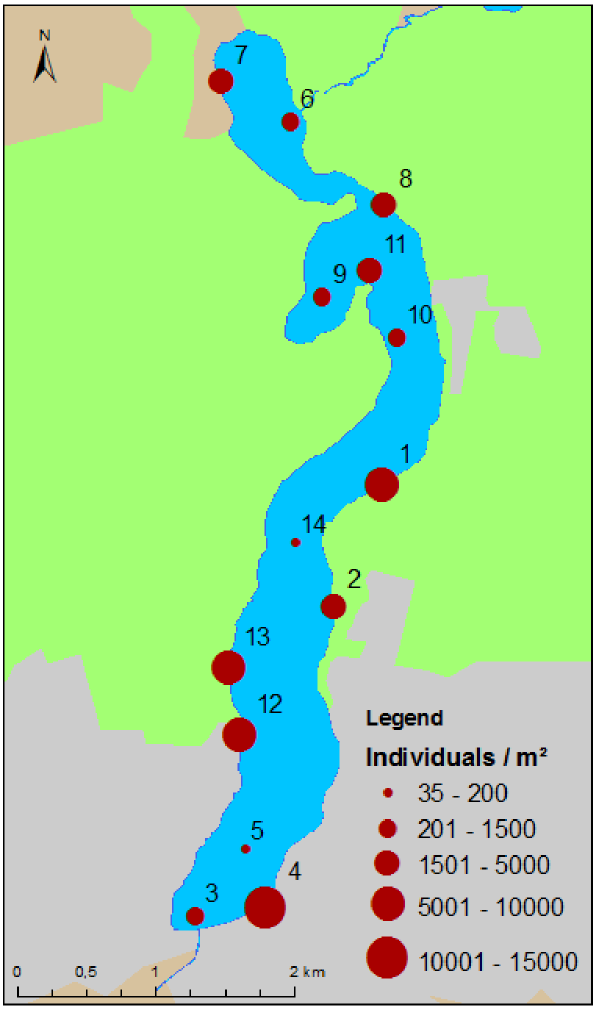

Fig. 2 Number of individuals per m² at different sampling stations in Lake Durowskie in 2017

number of individuals per m² in the littoral was found to be higher than in the pelagial. The highest numbers are observed in the southern half of the lake.

On average, a total of 3,538 ind./m² has been seen in 2017. Compared to the previous years, a positive trend for the total number of individuals per m² can be detected (Fig. 3). After dropping below the 2,000 ind./m² mark, the number of individuals has recovered to a value higher than ever before since the restoration started. The general trend across previous years is positive and shows a major increase in number of individuals per m², given some fluctuations between the years.

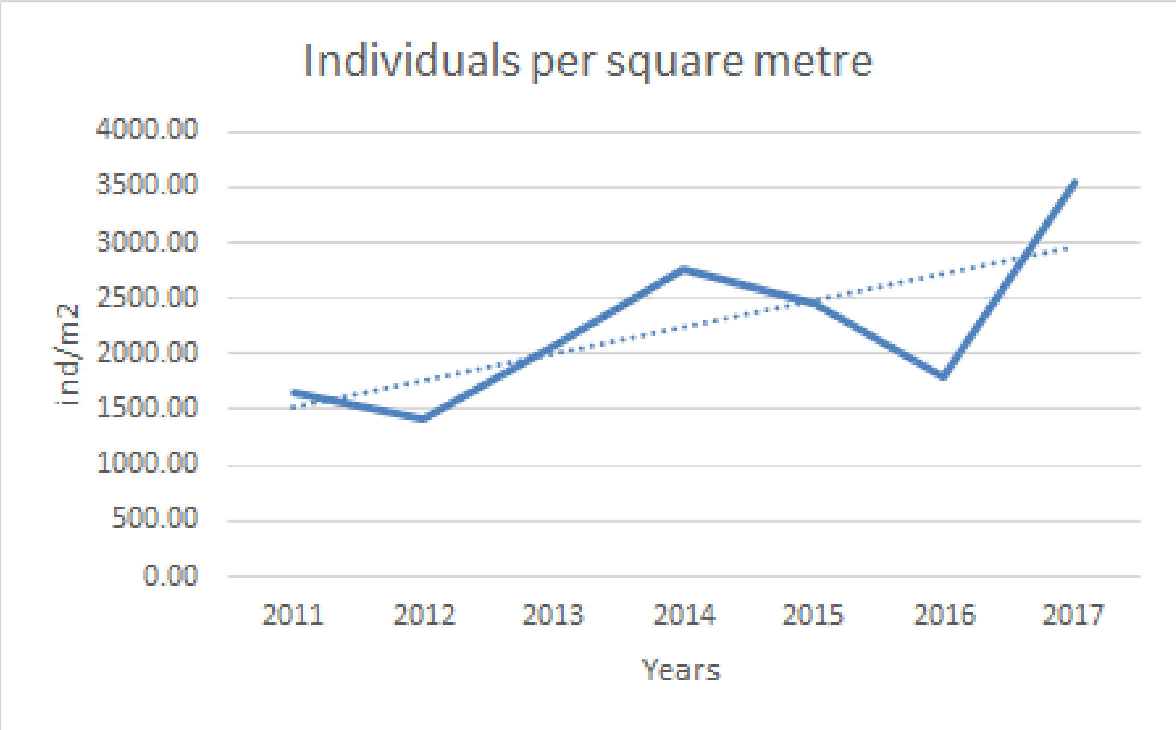

Fig. 3 Average number of individuals per m² for the years between 2011 and 2017

3.2 Biomass

The calculated biomass per m² differs greatly. It ranges from a minimum of 105 mg/m² (station 14) to a maximum of 2,687,132 mg/m² (station 7). Station 7 strikes as very noteworthy since it has a biomass that is more than 1,5 kg/m² higher than station 1 which has the closest value to station 7. The majority of this weight is due to the high abundance Bivalvia. All the other stations settle at values between 105 - 62,766 mg/m² with only stations 1 (1,021,683 mg/m²), 4 (239,561 mg/m²) and 13 (450,684 mg/m²) standing out. Fig. 4 shows the areal distribution of biomass across the different stations. In general, biomass seems to be low in pelagic zones and the area around the inflow and higher in littoral zones and at the outflow.

The total biomass found in 2017 was 326,031 mg/m² and thus decreased in comparison to the previous year (see Fig. 5), even though the number of individuals has increased in the same time span. Regarding the long-term trend from 2011 to 2017, a positive development from 2014 on can still be noticed.

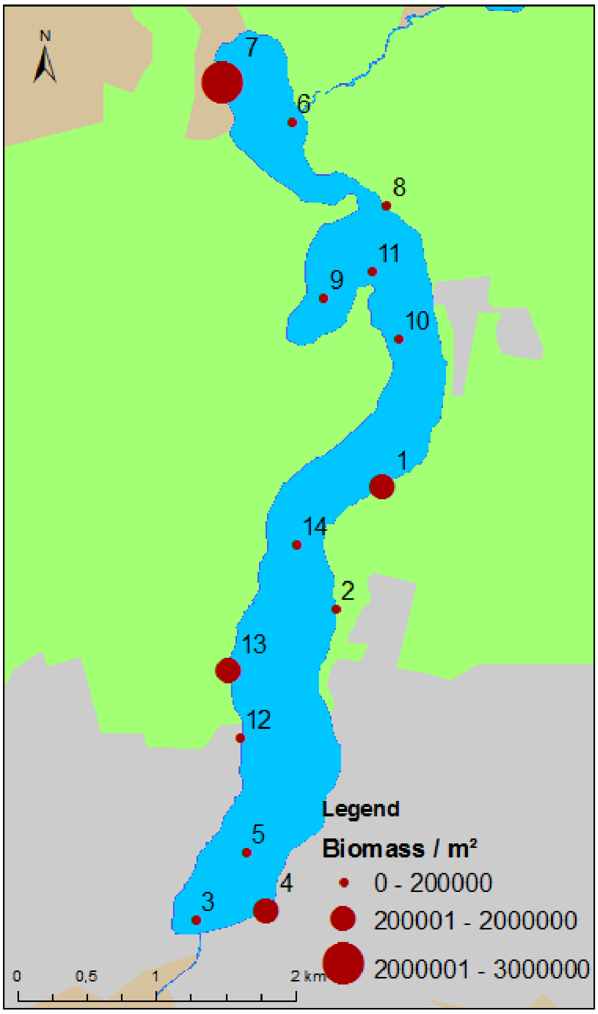

Fig. 4 Biomass of macroinvertebrates per m² at different sampling stations in Lake Durowskie in 2017

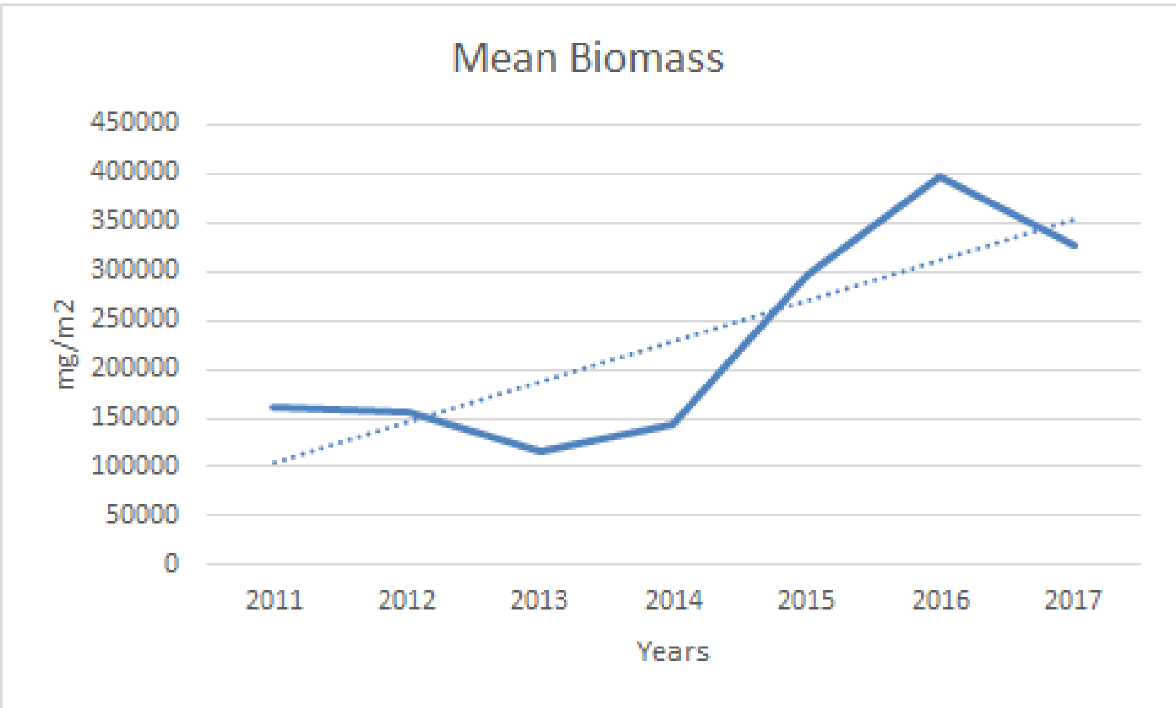

Fig. 5 Mean biomass of macroinvertebrates [mg / m²] from 2011 to 2017 in Lake Durowskie

3.3 Biodiversity: Shannon-Wiener Index

The Shannon-Wiener diversity index varies greatly across the different stations (Fig. 6). It ranges from 0 to 1.99. In station 3, 5, 10 and 14 (all pelagic) the values were all zero. The reason is that only one species, mosquito larvae (*Chaoborus flavicans*), was found in those stations. In station 9 and 13 the values fall in the 0.01 - 0.75 cluster. Stations 1, 6 and 12 belong to the cluster of 0.765 - 1, whereas station 11 is part of the 1.01 - 1.5 cluster. The highest value (1.99) was found in station 2. In station 2, 4, 7 and 8 the values fall in the 1.51 - 2 cluster. In general, the values were higher in the littoral zone than in the pelagic zone (see Appendix 8.3; Tab. 6).

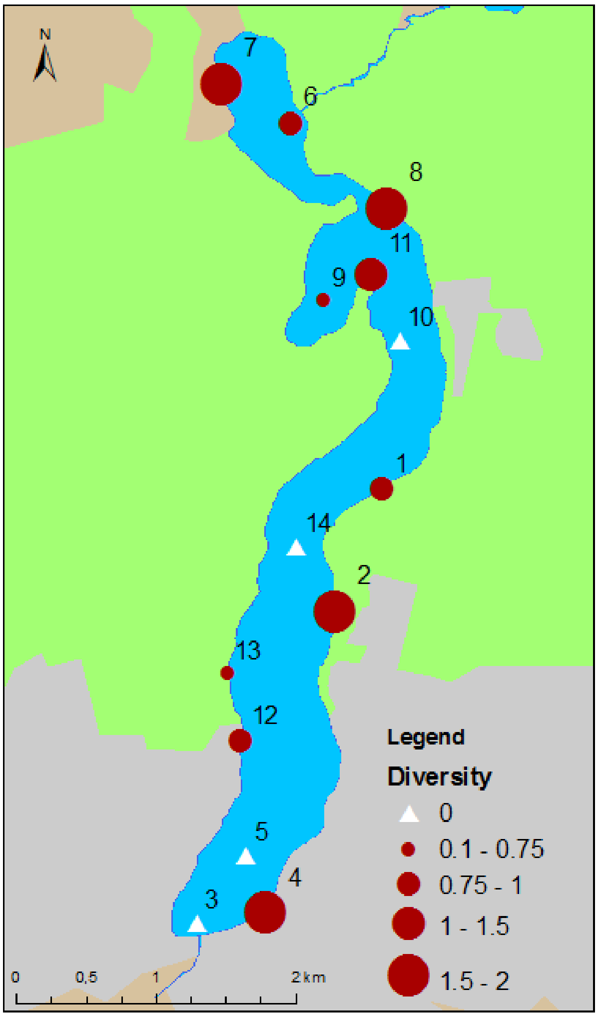

Fig. 6 Shannon-Wiener Index for macroinvertebrates at different sampling stations in Lake Durowskie in 2017

The mean Shannon-Wiener index was calculated for the previous years. After a peak in 2011 the values decreased until 2013 to increase again in the following years. This positive trend continued in 2017 as well (Fig. 7). Overall there is a slightly positive trend observed during the previous seven years.

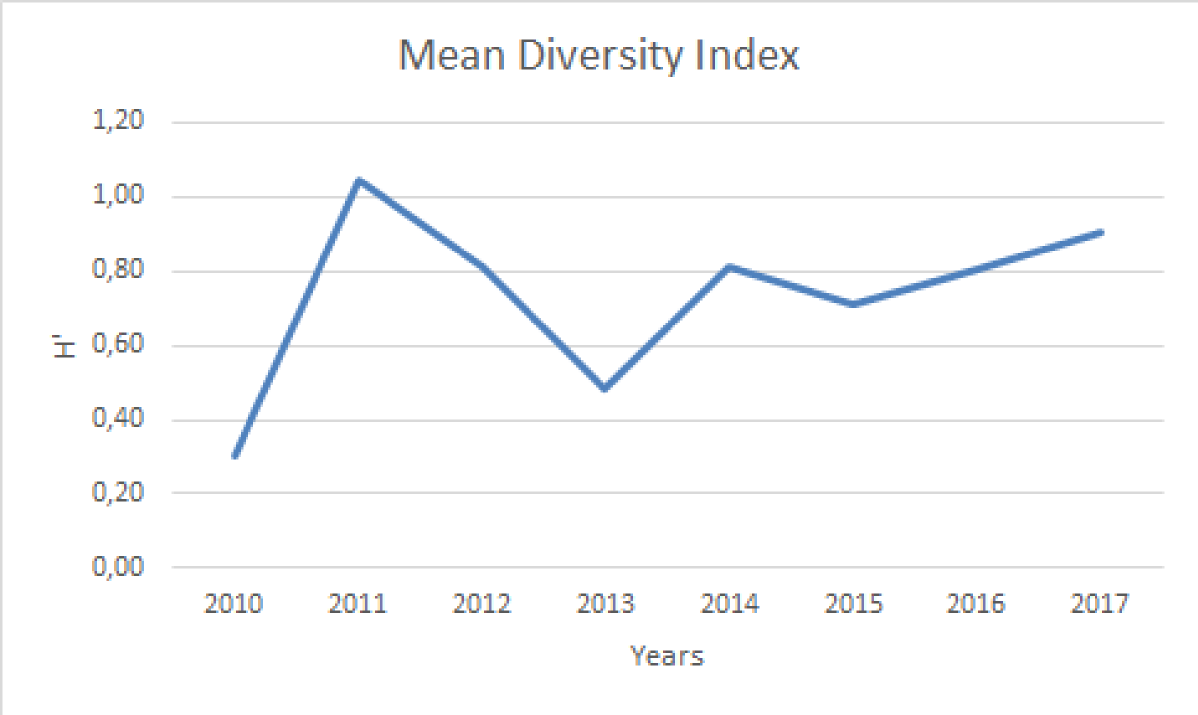

Fig. 7 Mean Shannon-Wiener diversity index for macroinvertebrates in Lake Durowskie from 2010-2017

Jaccard Similarity Index

The Jaccard similarity index shows a clear distribution of pelagic and littoral stations into clusters based on the species composition (Fig. 8). 6 out of 7 pelagic stations are arranged in the same cluster.

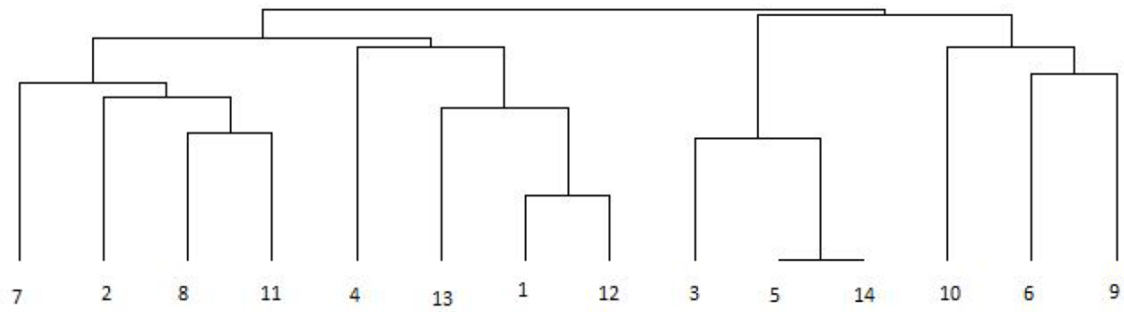

Fig. 8 Jaccard Similarity Index for the species compositions of all 14 stations in Lake Durowskie in 2017

3.4 Biological Monitoring Working Party (BMWP) Scores

The BMWP scores reached in 2017 are ranging from 2 to 5, indicating poor to medium water quality across the stations. The highest value scored was in stations 1, 8 and 10 (see Fig. 9). The lowest score was in station 9. At four stations there was no indicator species for the BMWP score present so that no value for stations 3, 5, 12 and 14 could be determined. Not all macroinvertebrates that were collected during the field work could be determined to the species or families. A few, like Plathelminthes and Trichoptera, were only determined to the order and thus could not be used for the BMWP score although they might have contributed to it (see chapter 3).

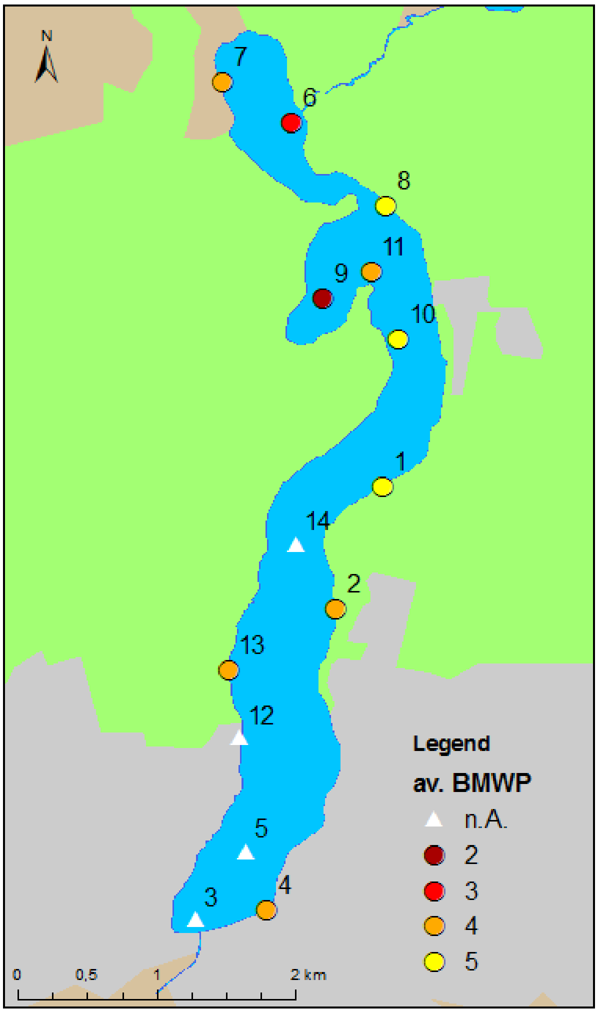

Fig. 9 Biological Monitoring Working Party (BMWP) [average] at different sampling stations in Lake Durowskie in 2017

Comparing the ASPT values from 2016 and 2017, it can be said that almost all stations have decreased in their scores compared to the previous year. The maximum value scored decreased by 1 from 2016 to 2017. Only stations 8 and 11 have increased by one point. There were three stations in 2016 and one station in 2017 with BMWP values that were only based on one family. Four stations had no taxon contributing to the BMWP score as indicators in 2016 (see Fig. 10, lighter colors).

Fig. 9 shows the areal distribution of ASPT scores across lake Durowskie. The two lowest values were found in the northern half of the lake whereas the higher values could be observed in the forested, central parts of the lake.

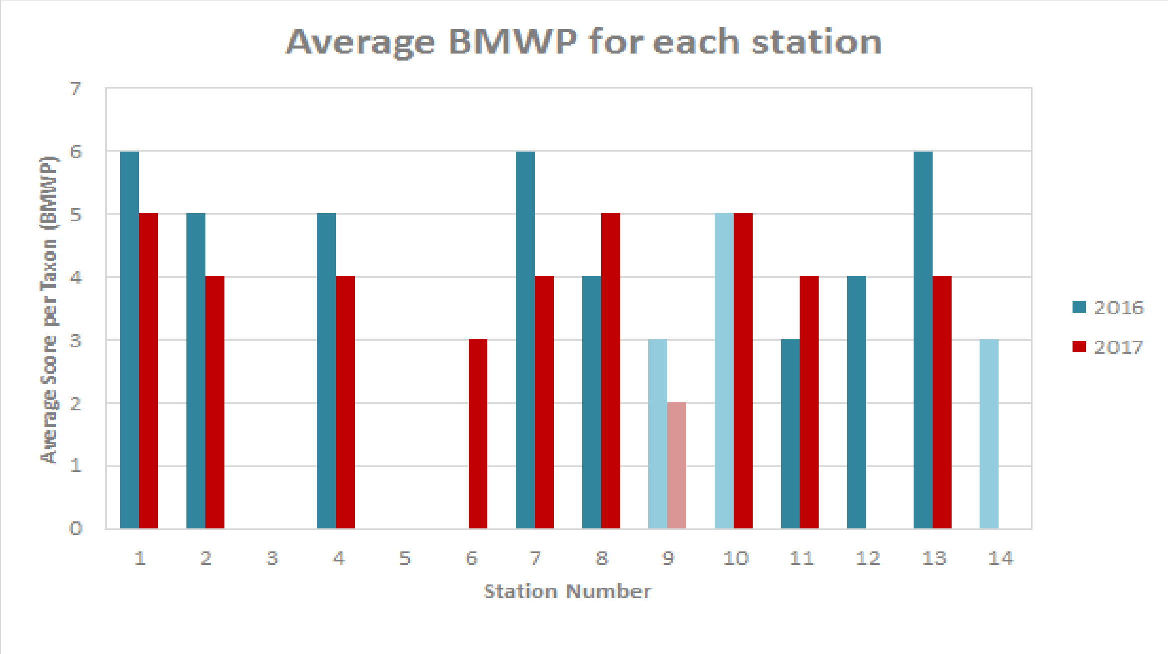

Fig. 10 Average BMWP for each station. Lighter colors indicate that just one species served as an indicator species.

4. Discussion

We observe that the stations with individuals >5,000 per m² are found only in the littoral regions with the water depth less than 2 m. This is also a region dominated by the presence of emerged and submerged macrophyte groups (Macrophyte Group, 2017). Studies have shown that macrophytes support higher abundance of macro-invertebrates 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. This is also supported by the physical-chemical analysis data, where the area below the station 10, is oligotrophic – with better quality of water than the northern part (Physical-Chemical Team, 2017). When compared with the previous years, there is a general positive trend with periodic fluctuations. The fluctuations might be due to the periodic environmental changes, nutrient changes, and interspecific interactions with the higher trophic levels – predatory fish noticeably reducing the micro-invertebrate abundance (Feuchtmayr et al., 2007).

When the biomass of the lake is compared between stations, the general trend is that it is considerably high in littoral areas with stations 7 in the north being the highest with 2.5 times the biomass compared to the following stations – station no. 1. The biomass is extremely low in the pelagic and the inflow area. The high biomass in station 7, 13, 1 and 4 is greatly influenced by the presence of high abundance of bivalves and gastropods. The presence of these mussels shows that there is a very high water infiltration capacity in the littoral area. Being situated north of the inflow, away from the flow direction may be the reason for an extremely rich littoral region with high biomass. A possible inflow of water with lesser eutrophication from the irregular catchment area from the north might also have an influence. Despite being located next to the town with the presence of relatively low macrophyte cover (Macrophyte Team, 2017), the biomass at station 4 is considerably large. This may be due to the presence of highly oxygenated water in the southern littoral zone of the lake (Algae Team, 2017). However, 33.4% of the biomass is contributed by *Dreissena polymorpha*, an exotic species from the Caspian Sea. With its large filtration capacity and mass occurrences, *D. polymorpha* reduces the chlorophyll *a* content, increases the water transparency and helps to reduce eutrophication (Millane et al., 2008). However, being an alien species to Europe they pose serious ecological and economical threats. *D. polymorpha* are known to outcompete species of *Unio* and *Anodonta,* both found in lake Durowskie (see Appendix 8.1, Tab. 4) and change the food web structure of the lake (Boehmer et al., 2001; Leppäkoski et al., 2013). Increasing *D. polymorpha* populations make the littoral and beach zone inaccessible, making it impossible to walk and threatening the recreational value of the lake (Leppäkoski et al., 2013). A recent study has documented an increased population of *D. polymorpha* due to habitat availability with the increase in water transparency. Therefore, there is a high chance that the population of *D. polymorpha* may increase in Lake Durowskie with the increase in restoration measures, threatening its ecosystem services and biodiversity. Millane et al. (2008) also saw no decrease in the total phosphorous concentration in the lake despite after a seven year period of colonization of *D. polymorpha,* which questions the common concept that zebra mussel introduction leads to overall improvements in water quality. When compared with the previous years, there has been a steady increase of biomass of macro-invertebrates since 2014. This shows that the capacity of the lake to capture and store the nutrient has increased, signifying an overall increase in water quality of the lake.

The Shannon-Wiener diversity index for the macro-invertebrate species across different stations shows a clear distinction between the diversity of species between the pelagic and littoral region (Fig 8). Like individuals per m² and biomass per m², diversity can also be observed highest in the littoral region. However, with a mean of 1.5 species in the pelagic stations, we observe a diversity index zero in four out of six stations due to the presence of single species. The mean number of species in the littoral stations is 9.8. As the diversity index takes evenness into account, the results do not correlate with individuals per m² found in each station, as some stations might have less species with high number of individuals.

This high difference between the numbers of macrozoobenthos species found in the littoral and pelagic is complemented by the results from the Algae Team of 2017. The Algae Team (2017) observed thriving phyto- and zooplankton until a depth of 3 m from the surface of the lake. Later, they saw a sharp decrease in the population of phyto- and zooplankton due to a decrease in the dissolved oxygen concentrations. We believe that deeper areas of the lake are deprived of the dissolved oxygen, unable to support a rich planktonic and macro-invertebrate community. Comparing the diversity index results across years, we notice that there is a steady increase in the diversity of the species since 2013, after sharp fluctuations between 2011 and 2013. This shows that the restoration measures have been effective. However, it is important to note that the diversity is not evenly distributed across different depths and locations of the lake.

The overall score of the BMWP was located in the lower to medium range and thus indicated poor to medium water quality. To some stations however, no value could be assigned because of the lack of appropriate indicator families. One has to bear in mind that the BMWP score is easily biased due to the fact that it does not take the abundance into account. Especially those stations where only one family was found that could be used for the score are not representative and have to be seen very critically (see chapter 3.4, Fig. 10). The overall range of scores of the lake however, can be seen as more reliable indication rather than the scores from single stations.

The stations that reached a score of 5, indicating a medium water quality, are concentrated in the central part of the lake, in the area surrounded by forests. This seems to be the region of the lake, according to the BMWP score, with the best water quality compared to the rest. Station 9, scored with a value of 2, is the station with the lowest water quality out of all stations. A possible reason for this might be the location and hydrological conditions in its surroundings. It is located in a sort of pocket with the water flow passing by in some distance. So the water exchange there might not be as good, compared to the rest of the lake which could lead to organic pollution accumulating in this area and negatively influencing the macroinvertebrates. Station 6 is located right at the inflow from the upper lake system. Since the upper lakes haven't been restored yet and are constantly feeding pollutants into Lake Durowskie, this explains the low value of 3 for that station. The concentration of pollutants close to the inflow will naturally be higher than further away from it.

Since there is little data from the previous years, it is very hard to draw a reliable conclusion on the development of the BMWP score. Previous groups have used the BMWP score to classify the stations into a water quality classification system. Unfortunately, they didn't give any reference as to which classification system they used so that the ranking could not be replicated in this report. Only a classification system for the revised BMWP score was found - which is not compatible with the original BMWP score used in this (and previous) reports. A reason for the decrease in 2017 might be fluctuations within the species composition and biomass like the ones that are also present in the development of number of individuals per m² or biomass per m² (Feuchtmayr et al., 2007). It is necessary to do a steady observation of the BMWP score over the following years in order to gain a long term trend.

5. Conclusion

Lake Durowskie had serious problems in the past with cyanobacterial water blooms but the implementation of restoration measures since 2009 improved the water quality. In order to monitor the progress of restauration efforts, macroinvertebrates were used as indicators, amongst other groups.

The 14 sampling stations showed a high variability of results in each year. Deeper, pelagic areas of lake Durowskie have shown numbers that were strikingly lower in individuals and biomass per m² as well as in biodiversity compared to littoral zones. The BMWP scores indicate poor to medium water quality all across the lake, areas near the inflow have proven to have the lowest water quality. Furthermore, according to the BMWP score, the water quality has slightly decreased since 2016. Generally speaking, the number of individuals per m², the biomass per m² as well as the biodiversity has shown positive trends over the years including annual fluctuations. In this year a considerable amount of *D. polymorpha* – an invasive species, was observed in one of the stations, which should further monitored regularly.

The nine-year restoration efforts at lake Durowskie have proven to be rather successful but continuous research and management efforts are necessary to keep the lake at its current state and to further improve its water and ecological quality.

6. Recommendation

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

6.1 Further research recommendations

Scientific monitoring of the restoration progress on an annual basis should be continued. Further research should be conducted to get a wider understanding of the processes occurring in Lake Durowskie.

In order to improve the accuracy of the results, additional baseline information about the stations and the lake should be collected and stored in a common database (including the exact GPS positions of the sampling stations and shapefiles of the shoreline). The abundances of each species should be taken into account when working with indices like the BMWP score.

The large derivations of weights between certain species can lead to inaccurate indices and interpretations. Furthermore, the methods of data analysis should be standardized for future examinations to assure a better comparability of data when analyzing long term trends.

6.2 Management recommendations

Restoration measures in Lake Durowskie have been conducted for 9 years now and they have already helped achieving improvements in the overall water quality towards the desired state of a self-regulating “Top-down trophic control” system.

The number of individuals per m^2, biomass and diversity of macroinvertebrates has increased during the last years. However, the individuals and biomass per m^2 and the diversity are not evenly distributed and show very low values in the deeper areas of the lake.

Therefore, a suitable management strategy to improve the situation in deeper areas of the lake would be to construct more aerators to oxygenate these parts. The introduction and protection of higher trophic species, also by protecting macrophytes as a nursery for fish, could support the process of shifting towards a “Top-down trophic control” system.

Additionally, the installation of cages with local mussel species could help to increase the filter capacity especially in areas with low water quality. However, further investigation on possible influences of such measure on the local ecosystem is essential and should be conducted before the installation.

Generally, an increase in restoration effort is needed. The restoration measures taken in the past years already have a positive influence on the macroinvertebrates population but have to be continued and probably also increased. It is not enough to just focus on this single lake when implementing restoration measures, as this lake is connected to five other lakes on the upstream side which directly influence it. Restoration measures should also be applied to all of these lakes. If this will not happen, then even the greatest effort taken in lake Durowskie will be in vain.

7. References

BOEHMER, H.J., HEGER, T. & TREPL, L. (2001) Fallstudien zu gebietsfremden Arten in Deutschland-Case studies on Aliens Species in Germany: Robinia pseudoacacia, Reynoutria japonica, Senecio inaequidens, Dreissena polymorpha, Ondatra zibethicus, Mustela vison. Texte des Umweltbundesamtes.

BRINSON, M.M. & MALVÁREZ, A.I. (2002) Temperate freshwater wetlands: types, status, and threats. *Environmental conservation*, 29, 115–133. Cambridge University Press.

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. Springer.

FEUCHTMAYR, H., MCKEE, D., HARVEY, I.F., ATKINSON, D. & MOSS, B. (2007) Response of macroinvertebrates to warming, nutrient addition and predation in large-scale mesocosm tanks. *Hydrobiologia*, 584, 425–432. Springer.

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, 43–48.

VAN HOEY, G., BORJA, A., BIRCHENOUGH, S., BUHL-MORTENSEN, L., DEGRAER, S., FLEISCHER, D., ET AL. (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. Elsevier.

LEPPÄKOSKI, E., GOLLASCH, S. & OLENIN, S. (2013) Invasive aquatic species of Europe. Distribution, impacts and management. Springer Science & Business Media.

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. BioOne.

MALTBY, E. (1991) The World's Wetlands under Threat. In *Environmental Concerns* pp. 109–136. Springer.

MESSYASZ, B., PIKOSZ, M. (2017) International Summer School of Durowskie Lake Wagrowiec – Poznan 2017.

METCALFE, J.L. (1989) Biological water quality assessment of running waters based on macroinvertebrate communities: history and present status in Europe. *Environmental pollution*, 60, 101–139. Elsevier.

MILLANE, M., KELLY-QUINN, M. & CHAMP, T. (2008) Impact of the zebra mussel invasion on the ecological integrity of Lough Sheelin, Ireland: distribution, population characteristics and water quality changes in the lake. *Aquatic Invasions*, 3, 271–281. European Research Network on Invasive Species.

MURALIDHARAN, M., SELVAKUMAR, C., SUNDAR, S. & RAJA, M. (2010) Macroinvertebrates as potential indicators of environmental quality. *International Journal of Biological Technology*, 1, 23–28.

RESH, V.H.R., DAVID, M. & VH, R. (1993) Freshwater biomonitoring and benthic macroinvertebrates.

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

CELIFFORD, 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.

8. Appendix

8.1 Number of Individuals per m²

Number of individuals of macroinvertebrates at different sampling sites in Lake Durowskie [ind./m²]														
Taxon	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Plathehelminthes				1										
Oligochaeta		507		49			78					78	39	
Hirudinea														
Helobdella stagnalis (L.)				392			195	39			117			
Hemiclepsis marginata (Müller)		39		98										
Erpobdella octooculata (L.)		39												
Bivalvia														
Dreissena polymorpha (Pall.)				245										
Anadonta anatina (L.)				49			78							
Unio tumidus (Philipsson)	78						195						39	
Sphaeriidae	195	39					195							
Gastropoda														
Theodoxus fluviatilis (L.)		273		343			72				39	195		
Bythynia tentaculata (L.)		39		49										
Planorbarius corneus (L.)				49										
Valvata piscinalis (Müller)						35	39							
Potamopyrgus antipodarum (Smith)	5811						39					4407	2106	
Lymnaea peregra (Müller)								39						
Physa fontinalis (L.)		351												
Crustacea														
Asellus aquaticus (Racov.)		117		3234			39	39						
Megaloptera														
Sialis fuliginosa (Pictet.)				147				156						
Coleoptera														
Elminthidae	117	78												
Ephemeroptera														
Caenidae	78	117		147			507	234			117			
Ephemerellidae								39						
Odonata														
Zygoptera								39						
Trichoptera	117			481			234	78			195	39	78	
Ceratopogonidae	39	39		735			78	234			156			
Chaoboridae														
Chaoborus flavicans (Meig.)			630		35	140			280	840				35
Chironomidae	2535	1092		5782		70	1521	975	490		1014	2691	5460	
Acari														
Hydracarina		279		588				624					78	
Sum	**8970**	**3009**	**630**	**12389**	**35**	**245**	**3270**	**2496**	**770**	**840**	**1638**	**7410**	**7800**	**35**

Tab. 2 Number of individuals of macroinvertebrates per m² for each sampling station in Lake Durowski in 2017

8.2 Biomass [mg/m2]

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**
Plathehelminthes				49										
Oligochaeta		624		98			351					78	78	
Hirudinea														
Helobdella stagnalis (L.)				637			312	78			312			
Hemiclepsis marginata (Muller)		78		490										
Erpobdella octooculata (L.)		234												
Bivalvia														
Dreissena polymorpha (Pall.)				80115										
Anadonta anatina (L.)				90160			1495260							
Unio tumidus (Philipsson)	973830						1133535						424320	
Sphaeriidae	4134	13338					32916							
Gastropoda														
Theodoxus fluviatilis (L.)		38961		31164			2184				7644	21762		
Bythynia tentaculata (L.)		3900		2940										
Planorbarius corneus (L.)				343										
Valvata piscinalis (Müller)						1085	11810							
Potamopyrgus antipodarum (Smith)	38064						390					31317	17940	
Lymnaea peregra (Müller)								3081						
Physa fontinalis (L.)		2184												
Crustacea														
Asellus aquaticus (Racov.)		351		9310			156	78						
Megaloptera														
Sialis fuliginosa (Pictet.)				490				1560						
Coleoptera														
Elminthidae	78	78												
Ephemeroptera														
Caenidae	39	249		245			1794	351			312			
Ephemerellidae								78						
Odonata														
Zygoptera								39						
Trichoptera	624			4067			3783	1482			1404	663	1989	
Ceratopogonidae	39	39		147			195	117			117			
Chaoboridae														
Chaoborus flavicans (Meig.)			2660		210	630			875	3010				105
Chironomidae	4875	2613		19159		245	4446	4602	8365		5187	4737	6318	
Acari														
Hydracarina		117		147				429					39	
Sum	**1021683**	**62766**	**2660**	**239561**	**210**	**1960**	**2687132**	**11895**	**9240**	**3010**	**14976**	**58557**	**450684**	**105**

Tab. 3 Number of individuals of macroinvertebrates per m² for each sampling station in Lake Durowski in 2017

8.3 Biodiversity: Shannon-Wiener Index

Shannon-Wiener Index		
Site	H' in R	E
1	0,94	0,45
2	1,99	0,77
3	0	n.A.
4	1,66	0,60
5	0	n.A.
6	0,96	0,87
7	1,85	0,72
8	1,76	0,74
9	0,66	0,94
10	0	n.A.
11	1,24	0,69
12	0,85	0,53
13	0,75	0,42
14	0	n.A.

Tab. 4 Shannon-Wiener Index of macroinvertebrates per sampling station in Lake Durowskie in 2017. (H` has been calculated in R and E is the normalized index.)

8.4 Biological Monitoring Working Party Scores

Site	Average Score per Taxon (ASPT)	
	2016	2017
1	6	5
2	5	4
3	n. A.	n.A.
4	5	4
5	n. A.	n. A.
6	n. A.	3
7	6	4
8	4	5
9	3	2
10	5	5
11	3	4
12	4	n. A.
13	6	4
14	3	n. A.

Tab. 5 Average Score per Taxon (ASPT) of macroinvertebrates per sampling station in Lake Durowskie in 2016 and 2017

Biological Monitoring Working Party (BMWP) score														
Taxon	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Plathelminthes				?									?	
Oligochaeta		1		1			1				1		1	
Hirudinea														
Helobdella stagnalis (L.)				3			3	3					3	
Hemiclepsis marginata (Müller)		3		3							3		3	
Erpobdella octooculata (L.)		3									4			
Bivalvia														
Dreissena polymorpha (Pall.)				/									/	
Anodonta anatina (L.)				6			6						6	
Unio tumidus (Philipsson)	6						6			6				
Sphaeriidae	/	/					/			/	/			
Gastropoda														
Theodoxus fluviatilis (L.)		6		6			6				6		6	
Bythynia tentaculata (L.)		/		/							/		/	
Planorbarius corneus (L.)				3									3	
Valvata piscinalis (Müller)						3	3							
Potamopyrgus antipodarum (Smith)	/						/			/				
Lymnaea peregra (Müller)								3						
Physa fontinalis (L.)		3									3			
Crustacea														
Asellus aquaticus (Racov.)		3		3			3	3			3		3	
Megaloptera														
Sialis fuliginosa (Pictet.)				4				4					4	
Coleoptera														
Elminthidae	5	5								5	5			
Ephemeroptera														
Caenidae	7	7		7			7	7		7	7		7	
Ephemerellidae								10						
Odonata														
Zygoptera								/						
Trichoptera	?			?			?	?		?			?	
Ceratopogonidae	/	/		/			/	/		/	/		/	
Chaoboridae														
Chaoborus flavicans (Meig.)			/		/	/			/			/		/
Chironomidae	2	2		2		2	2	2	2	2	2		2	
Acari														
Hydracarina		/		/				/			/		/	
Sum	**20**	**33**	**0**	**38**	**0**	**5**	**37**	**32**	**2**	**20**	**34**	**0**	**38**	**0**
Average Score per Taxon (ASPT)	**5**	**4**	**n.A.**	**4**	**n. A.**	**3**	**4**	**5**	**2**	**5**	**4**	**n. A.**	**4**	**n. A.**

Tab. 6 Number of individuals of macroinvertebrates per m² for each sampling station in Lake Durowski in 2017