ECOLOGICAL STATUS OF THE LAKE DUROWSKIE 2017
Physical - Chemical Indicators of the water quality

Master Students:
Gulzara Seitmaganbetova (CAU)
Millaray Sierra Olea (CAU)
Madina Alimbayeva

Supervisor: Dr. Naicheng Wu (CAU)

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1. Introduction

Lake Durowskie located in the western part of Poland is the important ecosystem and main source of tourism income for Wagrowiec city. The lake Durowskie is used for tourism, fishing, recreation and agriculture for the local community. Due to these activities the lake was strongly eutrophic with cyanobacterial water blooms. The water quality of the lake suffers through a lot of pressure of agricultural around the lake and nutrients coming from higher lying lakes.
To improve the lake water quality and restore ecosystem services, the local authority decided to start restoration measures in 2009. To restore the lake three methods were used: oxygenation of hypolimnetic waters using wind aerators, phosphorus immobilization using iron treatment, and biomanipulation measures – stocking the lake with pike fingerlings (Goldyn et al., 2013).
To assess the quality of water in the lake, eight points of water samples from inside of the lake and five points of water samples were analyzed from upstream inflows. Due to the reason that main source of nutrients coming from upstream inflows, this year three points of the water samples were taken from upstream inflows (Inflow Golancz, Inflow Bukowieckie, Inflow Kobyleckie). To investigate the quality of water in the lake physico-chemical parameters such as Oxygen concentration (O2), Electrical conductivity (EC), Temperature, pH, Turbidity, ChlorophyII-*a*, Total Phosphorus (TP), Nitrate concentrations, flow velocity, turbidity were measured and analyzed.

The main aims of physico-chemical study were:

I. Determination of nutrients inflows and outflows of the lake
II. Assesment of current ecological state of the lake
III. Evaluation of long-term changes during restoration

1.1. Field area

Durowskie Lake (Fig.1.a) is a postglacial-exorheic lake which is elongated in shape. Its coordinate lies on N 52°49'6'' and E 17°12'1'' situated in the direction northward southward n the Wielkopolska Region (central Poland). The lake is thermally stratified, with an area of 143.7 ha and a maximum depth of 14.6 (Goldyn et al., 2014). On the southern edge of the lake, there is the town of Wągrowiec. This town is the capital of the commune and district with 30,000 citizens.
The river Struga Golaniecka flows from north to south through the lake supplying it with biogenes from other lakes and catchment areas. The catchment area of lake Durowskie is located in mostly agricultural region. The amount of area covered with forest in the Wągrowiec district is only 19%, although the lake itself, apart from most southern and most northern parts, is surrounded by forest (usually more than 1 km from the lake shore).
Wągrowiec community has its own sewage treatment plant that purifies averagely 800,000 m^3 of waste per year (in scale of whole district 87,3% of waste is properly treated).
In former times large loads of nutrients were supplied to this lake, both from towns, when there was no sewage treatment plant and from the agriculture in catchment area.
Lake Kobyleckie, Lake Laskowickie, Lake Grylewskie, and Lake Bukowieckie (Fig.1.b)are situated on the river course above the Durowskie Lake and are strongly eutrophicated (Goldyn et al., 2013).

Figure 1: The location of our study region: a) Lake Durowskie, b) Lakes Kobyleckie, Laskowickie, Grylewskie, and Bukowieckie.

2. Methods

2.1 Sampling locations

Eight points of water samples from inside of the lake and five points of water samples were analyzed from upstream inflows. The sampling points from inside the lake remained the same as previous years (inflow, outflow, beach 1-2, middle 1-2, aerator 1-2), but additional sampling points were added from the upstream lakes; Kobyleckie, Laskownickie, Grylewskie, and Lake Bukowieckie. The sampling dates were from the 26th June till 30th June 2017.

2.2. Flow velocity measurement

In order to calculate the discharge (m^3/s) and furthermore nutrient loads (kg/d) from upper water bodies into Lake Durowskie, the flow velocity at defined cross sections (m^2) were measured by an electromagnetic velocity meter (FlowSens) (SEBA Hydrometrie, Germany)

Therefore the cross sections were divided into different transects, which were defined by its width and its depth. In addition the distance from the river bank and the water level at each vertical was measured. Within each subsection the velocity is measured at water depths along the vertical and at right angel to the flow direction. The total discharge Q (m^3/s) is calculated by multiplication of the area of each subsection (m^2) with the average velocity (m/s) of each section.

2.3. Physical-chemical parameters and water sampling

The basic physical-chemical water parameters temperature (°C), pH, conductivity (µS/cm), oxygen content (mg/l) and saturation (%), were measured on Lake Durowskie in different layers at the patches Aerator 1 and 2, Beach 1 and 2, Middle 1 and 2 and its outflow, using WTW Multi Parameter meters. Within the catchment area these parameters were also measured in the inflows of Lake Durowskie, Laskownikie, Grylewskie, Bukowieckie and Kobyleckie.

Turbidity (Secchi disc depth) and water samples for laboratory analyses of the nutrient concentration ammonium nitrogen (NH_4-N), nitrite nitrogen (NO_2 -N), nitrate nitrogen (NO_3 -N), orthophosphates (PO_4) and total phosphorus (TP) were taken additionally in different depths of some of the 13 sites. For Chlorophyll *a*, analysis the samples were taken at the sampling stations (Fig.2); Aerator 1-2, Beach 1-2 and Middle 1-2 at depths 0 (surface),1, 2 and 3 meters.

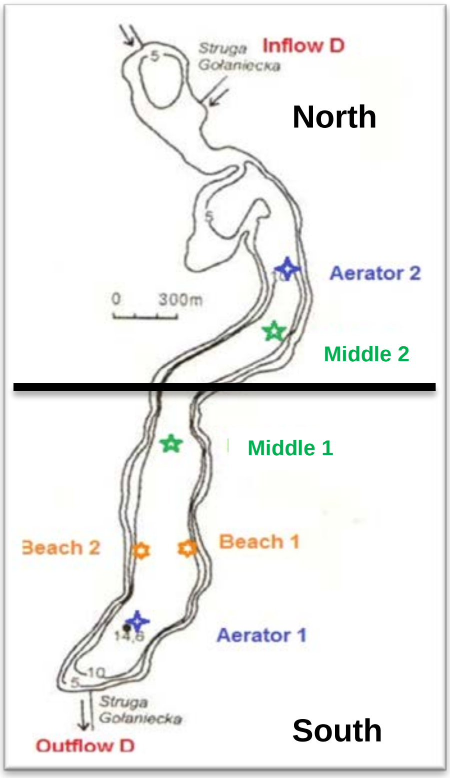

Figure 2: Map showing the in lake sampling sites for water quality assessment tests

2.4. Laboratory analysis

2.4.1. Chlorophyll *a*

The method of determination of concentration of chlorophyll *a* is based on the filtration of a known volume of water sample on a fiberglass filter (Whatman GF/F).
The filter with seston is grinned into a pulp in a mortar, and filled with acetone in a test tube (app. 8 ml). The sample is then extracted from the pulp using a centrifuge and placed in a fridge (4°C) for approximately 24 hours. The chlorophyll measurement is then made on the next day. Each sample is filled into a cuvette and measured in a photometer at 663nm and 750nm. After this measurement, 0,1ml of HCL are added to the samples and measured again after 10 minutes at 665nm and 750 nm.

The content of chlorophyll *a* is calculated with the following formula:

$$\textbf{Chl } a\ (\mu g/l) = 26{,}73 * [(A663^{b} - A750^{b}) - (A665_{HCl}^{a} - A750_{HCl}^{a})] * V_{acet.}^{E}/V_{H2O}^{W} * 1000$$

A^a = marked absorption of the extract after adding acid
A^b = marked absorption of the extract before adding acid
V_E = volume of the prepared extract
V_W = volume of the filtered water sample
26,73 = conversion factor

2.4.2. Nutrient concentration

All nutrients have been measured in the laboratory at the University of Poznan by a photometer (**see Fig. 3**). The respective concentration of each nutrient has been calculated afterwards with a given Excel-Sheet.

Figure 3. Photometer used for nutrient measurements.

Ammonium Nitrogen (NH_4-N)

Using the Neßler reagent, the ammonium content of the sample could be measured with a photometer by electromagnetic absorption at the wavelength of 410 nm. For this purpose 50 ml of the sampled water was poured into a Neßler glass. 1 ml of sodium-potassium tartrate as well as 1 ml of Neßler reagent were added to the sampled water and mixed. The yellow color of the resulting compound could directly indicate the presence of Ammonium.

Nitrite Nitrogen (NO_2 -N)

To analyze the Nitrate concentration, 100 ml of the sampled water was poured into a Neßler glass. 1 ml of sulfanilic acid and was added and mixed. After 5 minutes, 1 ml of naphthylamine and 1 ml of acetate buffer were also added and stirred. A strong presence nitrite is indicated with a pink color of the solution. After 10 minutes, the solution was measured with a photometer at a wavelength of 520 nm.

Nitrate Nitrogen (NO_3 -N)

In order to calculate the nitrate nitrogen concentration, 5 ml of the sampled water was poured into evaporating dishes. 2-3 drops of 0.5 % NaOH and 1 ml of 0.5% sodium salicylate were added to the sampled water in the evaporating dishes. The evaporating dishes were then placed in water baths and then evaporated. Afterwards, the dried dishes were removed and cooled down to add 1 ml of concentrated sulphuric acid. The acid was stirred in the dish sides and left for 10 minutes. Afterwards, the solution was removed and placed into Neßler glass. 7 ml of alkali sodium-potassium tartrate was added and mixed. The resulting solution was measured with a photometer at a wavelength of 410 nm.

Total Phosphorus (TP)

To measure the total phosphorus concentration of the water samples, 50 ml each of the water sample was poured into a mineralization tube. A few drops of phenolphthalein, 1 ml of sulfuric acid and 10 ml of potassium peroxidsulfate was then added to the water. Dry test-tubes were inserted into a steel stand and placed on a hot pot.
Afterwards, suction pipes were placed on the tubes and the suction pump was started, boiling at a temperature of 220 °C for 40 minutes. The solution from the tube together with distilled water was then transferred into a Neßler glass. a few drops of phenolphthalein and concentrated (6N) NaOH were added to neutralize the solution. Finally, 1 ml of ascorbic acid and 2 ml of molybdenum acid was added and stirred. The observance of a pink color indicates the presence of phosphorous in the solution. After 10 minutes the solution was measured by a photometer at a wavelength of 850 nm.

Phosphate (PO_4)

The measurement of phosphate was made by pouring 50 ml of water sample into a Neßler glass and adding 1 ml ascorbic acid and 2 ml molybdenum acid. After 10 minutes the solution is measured by a photometer at a wavelength of 850 nm.

2.5. Data analysis

In order to calculate the amount of nutrient flowing into and out of lake Durowskie, as well as the inflows of lakes: Laskownikie, Grylewskie, Bukowieckie and Kobyleckie. The discharges as well as the nutrient concentration at these points were used.
The formula below was used to calculate the nutrient presence at different part of the lake per day.

Nutrient per day = [Nutrient concentration (mg/l) x discharge (m^3 /s)] x 86,4

2.6. Trophic State Index

The Trophic State Index (TSI) (CARLSON AND SIMPSON, 1996) was used to define the trophic status of the lake. This classification system is designed to assess individual lakes based on the amount of biological productivity occurring in the water and measured as Chlorophyll *a*, total Phosphorus and transparency (Secchi Depth). Using the index, one can gain a quick idea about how productive a lake is by its assigned TSI number.

The calculation of the Trophic State Index (TSI) was produced with the following formulas, which were established by Carlson's and Simpsons' Trophic State Index (TSI) equations.

TSI (Chl *a*) = 9.81 ln(Chl *a*) + 30.6
TSI (TP) = 14.42 ln(TP) + 4.15
TSI (Sd) = 60 - 14.41 ln(Sd)
TSI = 0.54 TSI (Chl a) + 0.297 TSI (Sd) + 0.163 TSI (TP)

The quantities of nitrogen, phosphorus and other biologically useful nutrients are the primary determinants of a lake's trophic state index (TSI). Nutrients such as nitrogen and phosphorus turns to be limiting resources in standing water bodies. Increasing concentration tend to result in increased plant growth, followed by corollary increases in subsequent trophic levels. Consequently, a lake's trophic index may sometimes be used to make a rough estimate of its biological condition (Table 1.).

Table 1. Classification of trophic state index (TSI) (Carlson and Simpson 1996)

TSI_M	Chl*a* (µg/L)	TP (µg/L)	Sd (m)	Trophic Class
<30—40	0—2.6	0—12	4—>8	Oligotrophic
40—50	2.6—7.3	12—24	2—4	Mesotrophic
50—70	7.3—56	24—96	0.5—2	Eutrophic
70—100+	56—155+	96—384+	<0.25—0.5	Hypereutrophic

3. Results and Discussions

3.1. Dissolved oxygen

Dissolved oxygen refers to the level of free, non-compound oxygen present in water or other liquids. It is an important parameter in assessing water quality because of its influence on the organisms living within a body of water. In limnology, dissolved oxygen is an essential factor second only to water itself (Michaud J.P.,1991). A dissolved oxygen level that is too high or too low can harm aquatic life and affect water quality.

Figure 4. Dissolved oxygen concentrations on selected stations in Durowskie Lake

From the analysis, the highest dissolved oxygen on the lake was recorded at Beach 1 and Middle 2. Also Middle 1 and Beach 2 had much higher dissolved oxygen than Aerator 1 and Aerator 2. Logically, one would expect the sites closer to the aerators supposed to have higher dissolved oxygen than other parts of the lake. But according to our results this was not the case. One reason for the higher dissolved oxygen recorded at the beaches and Middle 1 and Middle 2 could be due to the constant mixing of the water by kayak, speed boat and other water vehicles as well as swimming in these areas.
The lower value of dissolved oxygen near Aerator 2 could be explained by its closer location to inflow. As it was mentioned above turbidity was also lower in north part of the lake. The results of dissolved oxygen were compared with previous years (**see Fig.4**).

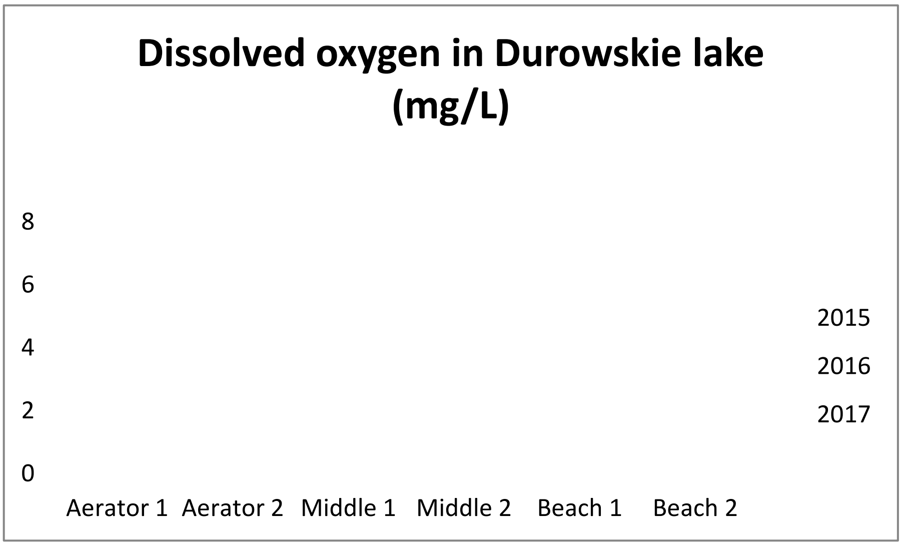

Figure 5. Trend of Dissolved oxygen concentrations on selected stations in Durowskie Lake.

It can be seen that Aerator 1 and Aerator 2 have been showing lower value of dissolved oxygen than other stations. In all years, the value of dissolved oxygen was higher in beaches. It might be explained by human activities near the beaches. Also, this year the value is higher in Middle 1 and Middle 2 (**see Fig.5**). We think that is also might be due to the activities of speed boats.

3.2. Transparency

The transparency of the lake was measured using Secchi disk and the average results were calculated for both the northern and southern part of the lake. The transparency which indicates the degree of turbidity of the water is one of the important parameters used in calculating the Trophic State Index (TSI) of the lake. The results were compared with trophic classes for transparency according to Trophic State Index **(see Table 2)**. According to our results, it can be seen that TSI (SD) result for 2017 is lower than 2016. Thus, ecological state of the lake based on TSI (SD) is in eutrophic level. Although, if we compare long trend data from 2014, the differences are not significant.
Furthermore, from the results 2017 it can be observed that almost all points are quite similar and show mesotrophic state. However, upstream inflow of Durowskie, which is in north part, presents significantly lower value of Secchi disk depth (0.50 cm) (**see Fig 6**). Also, if we look at the long trend results from 2014, it could be seen that north part has been showing lower depth of Secchi disk than south of the lake (**see Fig.7**). Indeed, it should be mentioned that nutrients from upstreams influence the transparency of water in north part (**see Fig.8**).

SD (m)	Trophic Class
4-8	Oligotrophic
2-4	Mesotrophic
0.5-2	Eutrophic
<0.25-0.5	Hypereutrophic

Table 2. Trophic classes for transparency according to Trophic State Index

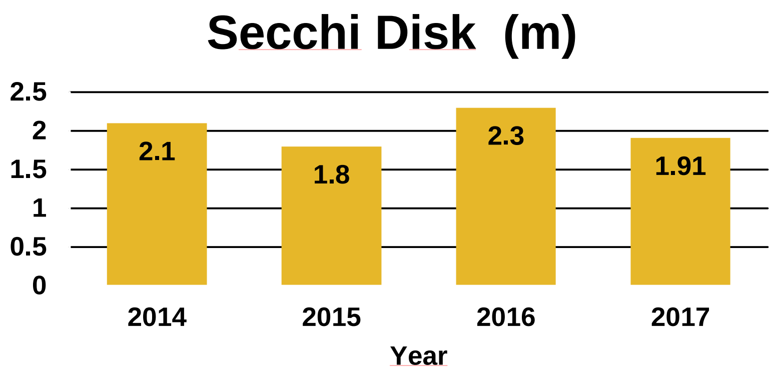

Figure 6. Transparency trend for Durowskie Lake

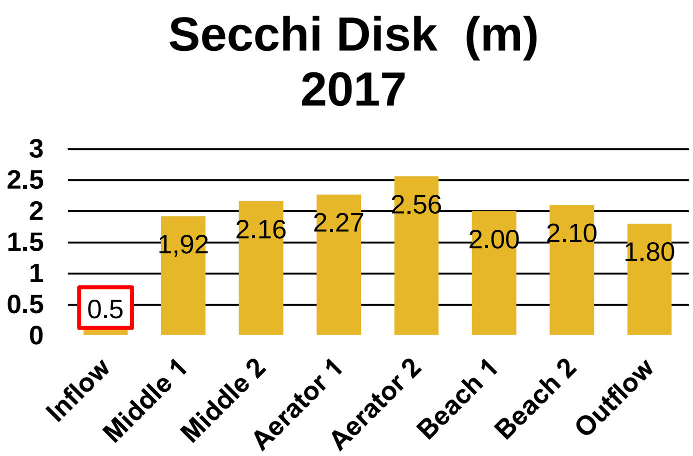

Figure 7. Transparency for Durowskie Lake 2017

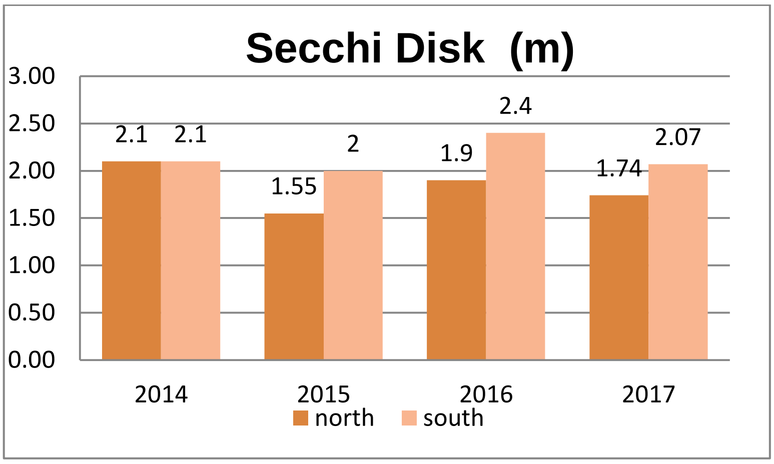

Figure 8. Transparency trend in north and south part of Durowskie Lake

3.3. Nutrients loads per year

The nutrients loads for each sampled station and nutrient was calculated per year. The result was compared with data from previous years to know the temporal trend in nutrient concentration for the stations.

3.3.1. Total Phosphorus (TP)

From the analysis, there has been an increase in the amount of TP from the inflow and outflow of Lake Durowskie as well as the inflow of Kobyleckie (**see Fig.9**). Measurements made in 2017 were higher than previous three years. The increase in 2017 might be explained by heavy rains in April 2017. These heavy rains probably increased the amount of nutrients from surrounding areas arriving to the lake.
Remarkably, the highest result was at the inflow of Lake Kobyleckie, which was higher than the inflow of Lake Durowskie. This means that there is a source of phosphorus pollution at Kobyleckie which might have increased the amount of TP flowing into Durowskie. Furthermore, the difference between inflow and outflow of the lakes (Kobyleckie, Durowskie) indicates that nutrients from upstream are accumulating in Durowskie lake.

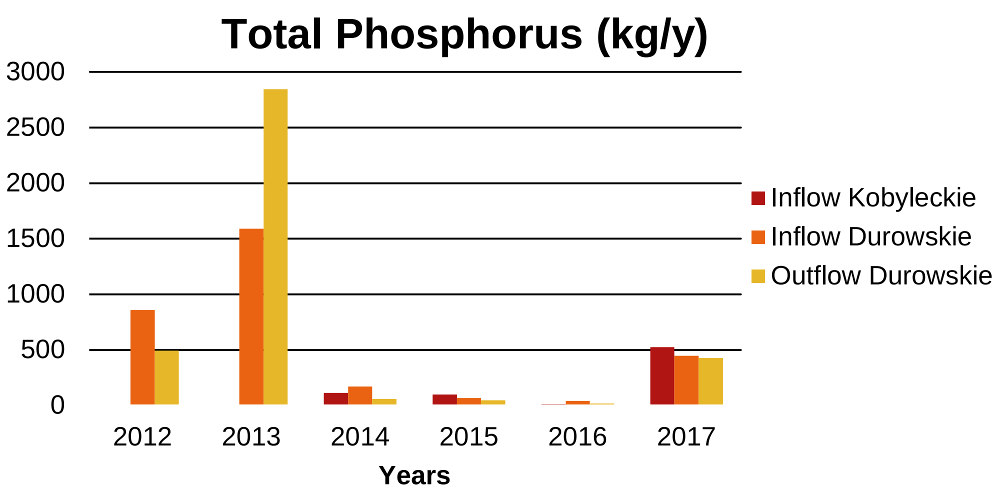

Figure 9. Total phosphorus load on selected stations.

3.3.2. Nitrate (NO_3)

Nitrate did not follow the same trend of steady decrease between 2013 and 2015 years **(see Fig.10**) Furthermore, measurements made in 2017 were much higher than 2016 for both the inflow and outflow of Lake Durowskie. As it was explained above, the reason for this increase might be heavy rains in April 2017. Also, NO_3 loads per year was higher in both inflows (Durowskie and Kobyleckie) than in outflow Durowskie. Again as it was discussed above, this result also pointing that nutrients coming from upstream inflows are accumulating in Durowskie Lake.

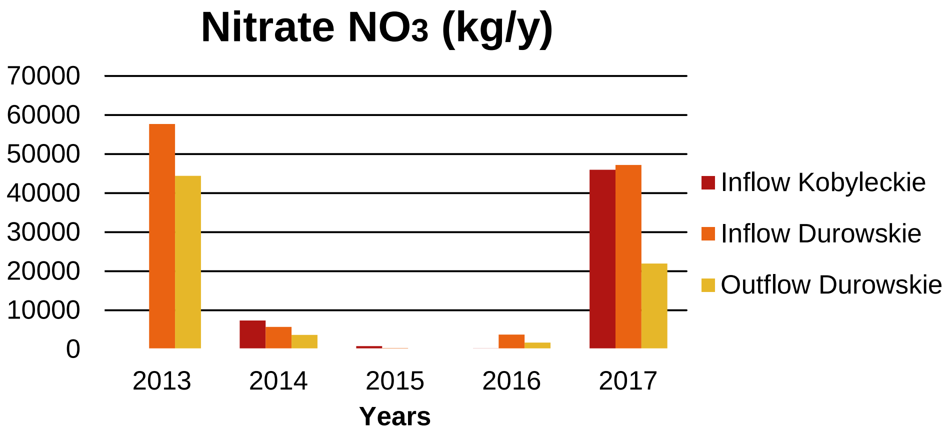

Figure 10. Nitrate load on selected stations

3.3.3. Ammonium (NH_4)

Ammonium load did not follow the steady decrease between 2013 and 2016. Also, NH_4 was recorded in much higher concentration this year as compared to the previous year **(see Fig.11).** From the result 2017 it can be seen that ammonium load is higher in upstream inflow Kobyleckie. Due to high load of nutrients in inflow Kobyleckie, we would like propose additional monitoring and identification of sources of nutrients in upstream lakes.

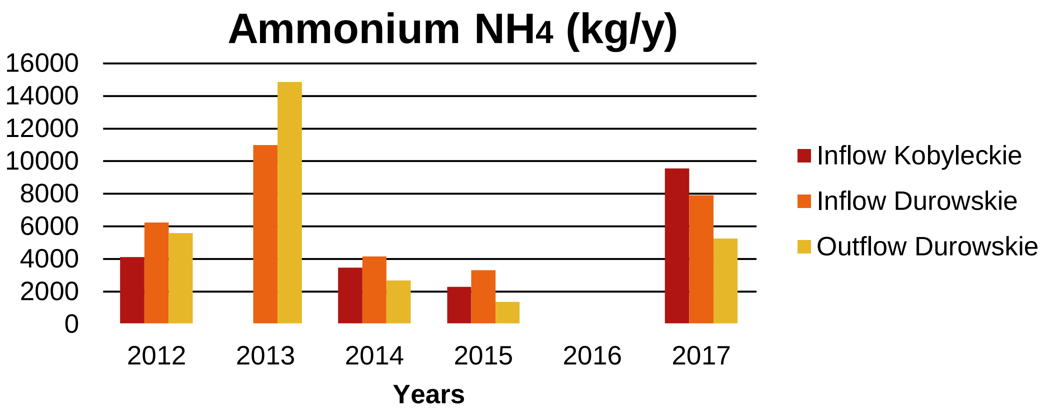

Figure 11. Ammonium load on selected stations

Overall, the loads of nutrients (Phosphate, Ammonium and Nitrate) measured for this year also revealed a higher record in comparison 2016. We believe that the increase of nutrients loads in 2017 was due to heavy rain in April. This brought more nutrients from surrounding areas than previous years.

Also, it is important to point out that the amount of inflow into Lake Durowskie increased in comparison to the previous years. High nutrient loads in the inflows are a negative condition for the improvement of trophic state of the lake. Especially the total phosphorus load is the limiting nutrient for blue green algae growth which eventually leads to eutrophication of the lake. As it was discussed above, it seems that high amount of nutrients are caused by higher lying lakes. Thus, we propose strong monitoring measures in higher lying lakes.

3.2.4. Total Phosphorus (TP)

The Total Phosphorus (TP) trend for the lake was calculated for the eight sample sites on the lake and the results were further categorized into north and south. Two sites were considered as north (Aerator 2 and Middle 2) and four sites were considered as south (Middle 1, Beach 1, Beach 2 and Aerator 1). The results were compared with the previous years, which reveal a visible reduction pathway for total phosphorus between 2014 and 2015 **(see Fig.12)**. However, in comparison with 2016, total phosphorus is much higher. As it was mentioned above, this year total phosphorus load was much higher than in 2016 due to rains.

For the whole lake the trophic state based on total phosphorus shows that the lake is in eutrophic state for 2017. However, according to trophic state index based on total phosphorus, for 2017 TSI (TP) stands almost in the border between mesotrophic and eutrophic **(see Table 3)**.

Remarkably, it should be pointed that this year, the southern part of the lake shows much better results comparing to north part (**see Fig.13**). Thus, the south part of the lake remains in mesotrophic state, while the north part dropped from mesotrophic class to eutrophic class **(see Fig.14).** This drop from mesotrophic class to eutrophic class in north probably was caused by upstream inflows. Moreover, if we look at TSI (TP) for 2017, it can be seen that almost all points were in similar level, except Aerator 2**.** Again it should be mentioned that Aerator 2 is located in north of the lake, where TSI (TP) was in eutrophic class. Logically, all inflows are located in north of the lake and nutrients reach the northern part before the southern part. This could explain the differences in TSI (TP) between north and south area of the lake.

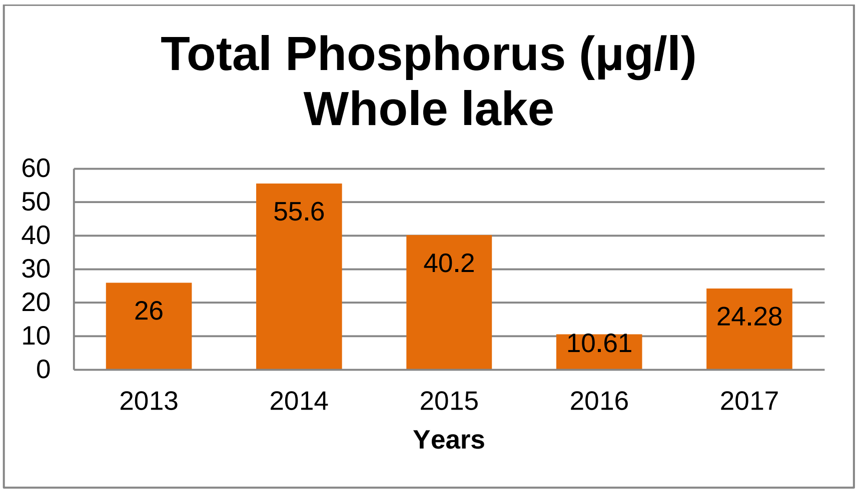

Figure 12. Total phosphorus trend for Durowskie Lake

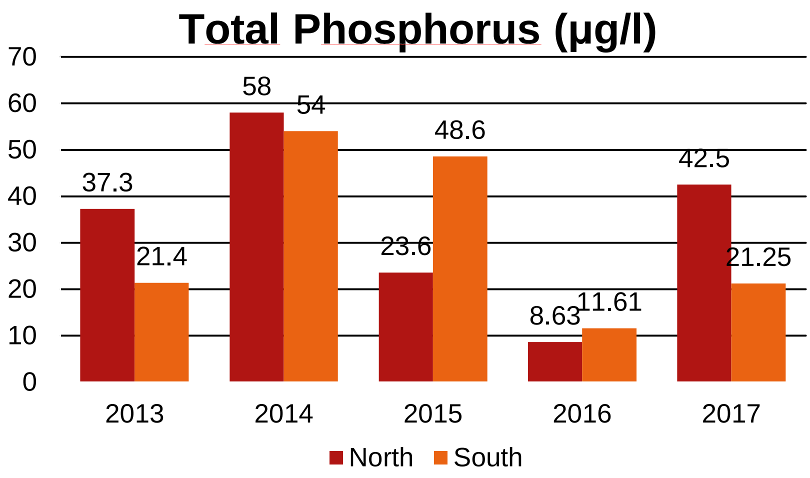

Figure 13. Total phosphorus trend in North and South parts of Durowskie Lake

TP (µg/l	Trophic Class
0-12	Oligotrophic
12-24	Mesotrophic
24-96	Eutrophic
96-384+	Hypereutrophic

Table 3. Classification of trophic state index based on total phosphorus.

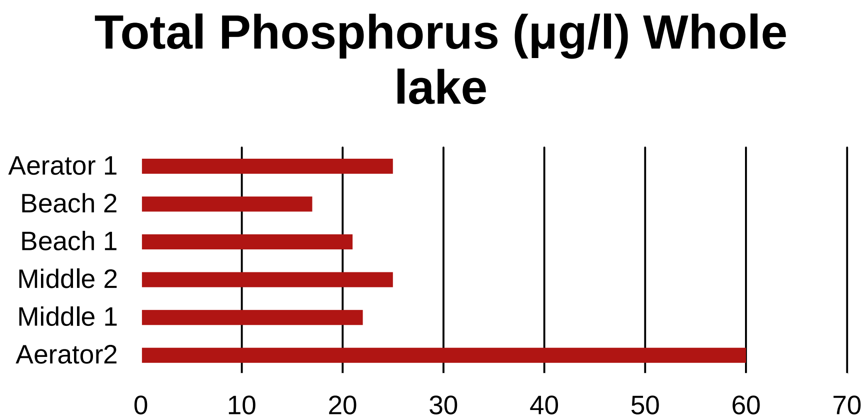

Figure 14. Total phosphorus in lake sampling sites in 2017.

3.4. Nutrients Concentration 2017

3.4.1. Nitrate (NO_3)

The nitrate concentration of the catchment area in general shows a variation that can be explained by weather conditions for the sampling dates. Although the nitrate concentration in the inflow from Golancz is less than 1 mg/l, this increases by almost five times in the inflow to lake Durowskie (**see Fig. 15**), which suggest that the source from this nitrate could be run off from surrounding areas.

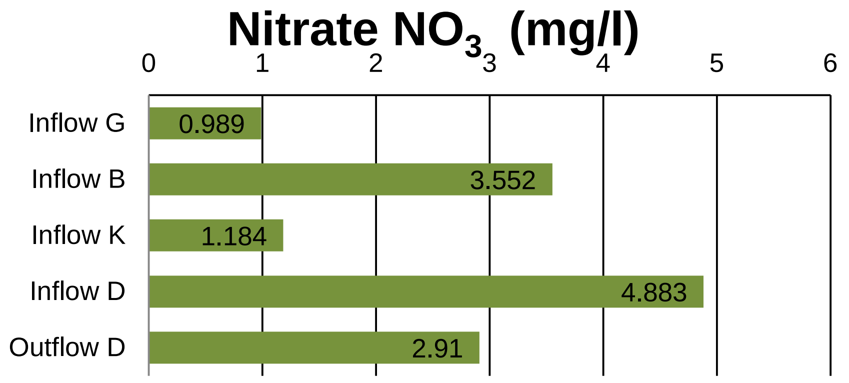

Figure 15. Nitrate concentration in catchment area.

3.4.2. Ammonium (NH_4)

The ammonium concentration decreases progressively through the catchment area (**see Fig. 16**). This is mainly due to the fact that different amounts of ammonium were immobilized within each lake. As an indication of point sources, the higher ammonium concentration in upstream demonstrated the greater human disturbance or activities, which warrant further attention and investment in the future restoration.

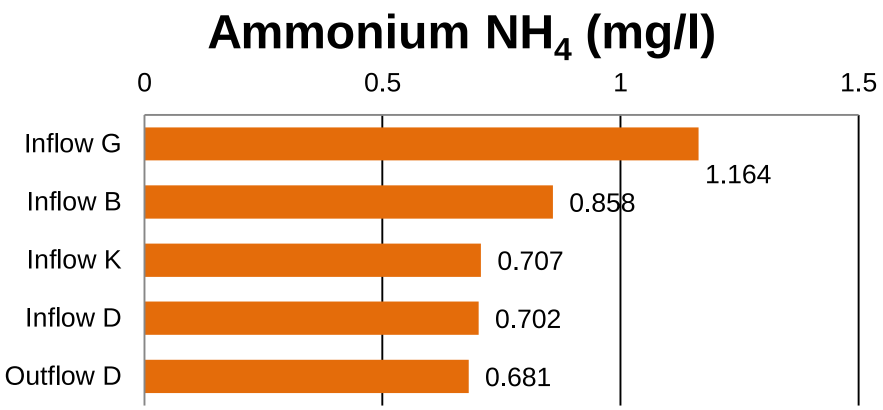

Figure 16. Ammonium concentration in catchment area.

3.4.3. Total Phosphorus (TP)

Even though there is a decreasing trend in the total phosphorus concentration from the beginning of the catchment area, there is an increase of total phosphorus concentration in the outflow of lake Durowskie (**see Fig. 17**), this could be associated to different reasons, mainly; resuspension of phosphorus by human activities, run off and or alteration of hydraulic characteristics caused by weather conditions, and quite possibly diffuse pollution sources. From the figure it can be seen that main source of TP coming from upstream inflows. It should be pointed out that this year we measured new upstream station (Inflow Golancz), and this station shows the highest amount of TP.

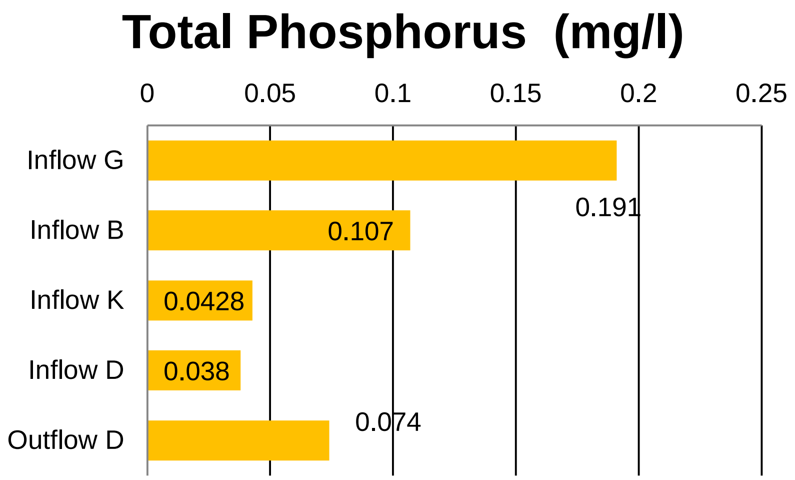

Figure 17. Total phosphorus concentration in catchment area.

3.5. Nutrient Loads 2017

3.5.1. Nitrate (NO_3)

Nitrate loads in the catchment area indicate that there is a major source of pollution in Lake Kobyleckie and Bukowieckie (see Fig.18). There is little to no retention of nitrate in Lake Kobyleckie which is visible in the load observed in inflow to Lake Durowskie.

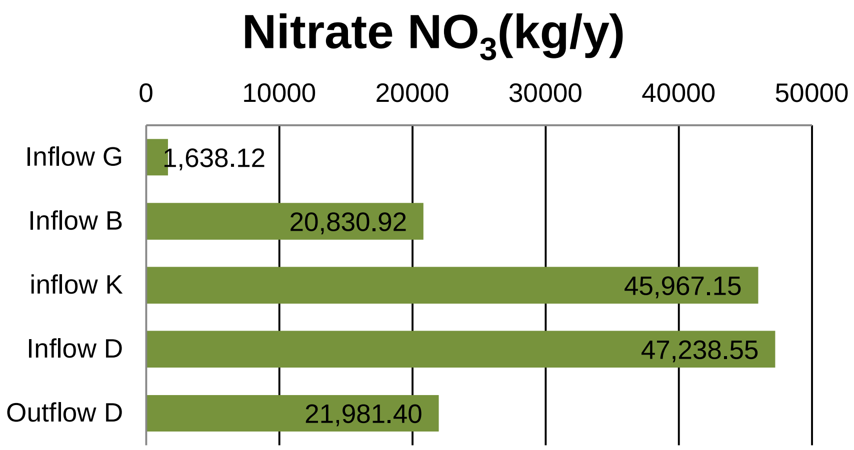

Figure 18. Nitrate loads in lake sampling sites.

3.5.2. Ammonium (NH_4)

Ammonium loads in the catchment area indicate that there is a major source of pollution in Lake Kobyleckie **(see Fig.19)**. This higher concentration indicates contamination of water body by anthropogenic activities. We suggest a close monitoring of Lake Kobyleckie in order to identify the source of ammonium pollution and also to develop a plan of action for the community. It is of the utmost importance to work with Kobyleckie municipality in order to control the inputs of pollutants in their water bodies, not only because of the negative effects these loads have on Lake Durowskie but also because it is necessary to consider the water safety of the community.

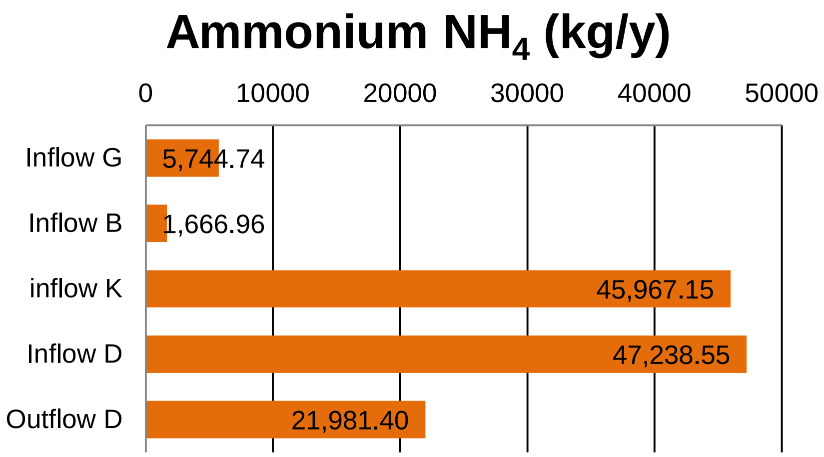

Figure 19. Ammonium loads in lake sampling sites.

3.5.3. Total phosphorus (TP)

As observed in Fig. 20 there is a high input of phosphorus in Lake Bukowieckie. This high nutrient load is consequently distributed in the subsequent lakes. Each lake is retention ability, but this nutrient which is the limiting factor in biogenesis, is easily available for different organism. In this particular case, a closer monitoring of sources of total phosphorus should be implemented in Lake Bukowieckie

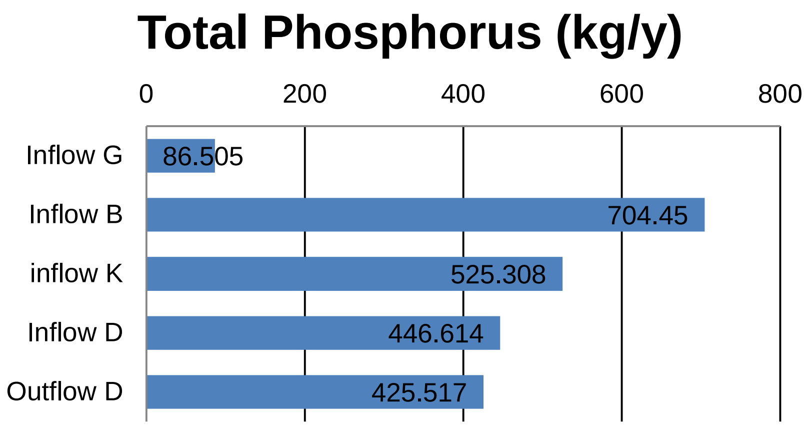

Figure 20. Total phosphorus loads in lake sampling sites.

3.6. Long term changes of the lake state during restoration.

3.6.1. Chlorophyll α 2011-2017

The trend for the Chlorophyll a concentration shows a steady decrease from the year 2013, according to the TSI this lake remained as a Mesotrophic lake during the past four years. This results show that the efforts made in the restoration program have slowly but surely improved the overall state of the lake (**see Fig.21**).
This results show that phytoplankton was mostly grazed by zooplankton, and that the present cyanobacteria community is residing in the metalimnion.

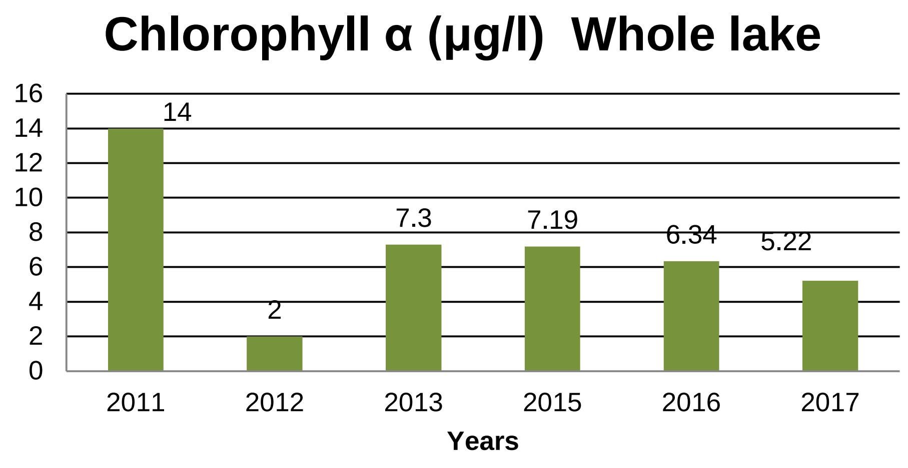

Figure 21. Chlorophyll *a* concentration in whole lake.

3.6.2. Chlorophyll α 2011-2017: Comparison of North and South of lake Durowskie.

Although it should be expected to observe a decreased concentration of Chlorophyll in the southern region of the lake (outflow) this is not observed this present year (**see Fig. 22**). During sampling times there were strong winds and also sometimes the movement of motor boats at high speed, which could have caused alterations in the hydraulic properties of the lake water layers.

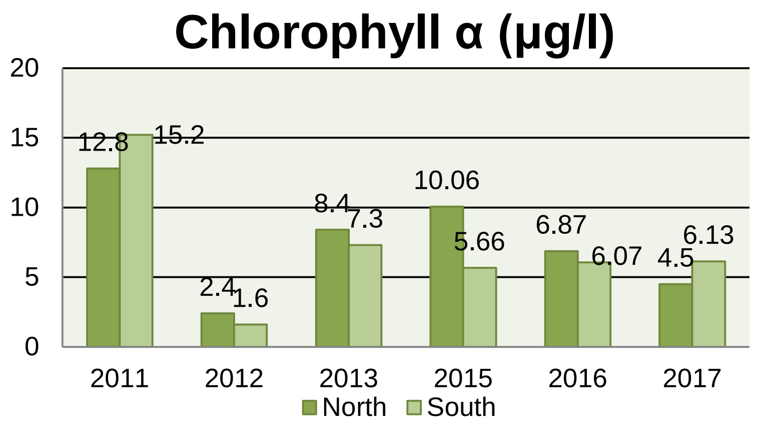

Figure 22. Chlorophyll a concentration in North and South region of Lake Durowskie

3.7. Current ecological state of the lake.

3.7.1. Chlorophyll α 2017

The variability in the concentration of Chlorophyll a is mainly observed in two particular sampling points; middle 1 and aerator 1(**see Fig. 23**), here the concentrations is the highest of the overall lake . We propose that this is due to microclimate conditions, for example the rainfall, and the steep slopes of the lake. In this particular area there is and easy input from run off into the lake, also winds affect the movements of nutrients in the water currents, the synergy of these conditions allow different species of algae to thrive.

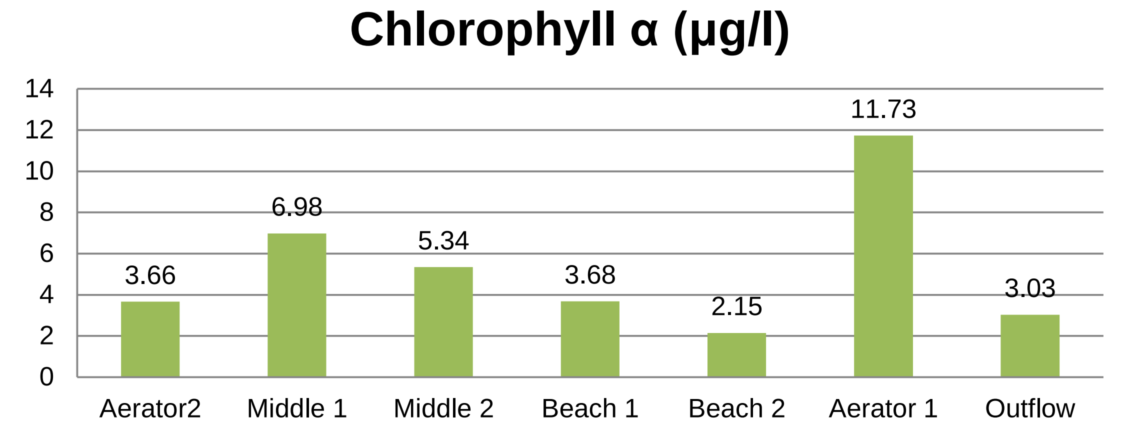

Figure 23. Chlorophyll a concentration inlake sampling points.

3.7.2. Trophic State Index (TSI) 2010-2017

The north and south regions (**see Fig. 24**) of the lake display similar values in regards to the TSI_M placing these sites in general in the mesotrophic interval of the evaluation table. Although in Fig.25-a. We can observe a value under 40, we must take into consideration that we do not have the Chlorophyll a and nutrient values for the „inflow" sampling point. Consequently we suspect that the TSI_M value would be even higher had this sampling point been considered.

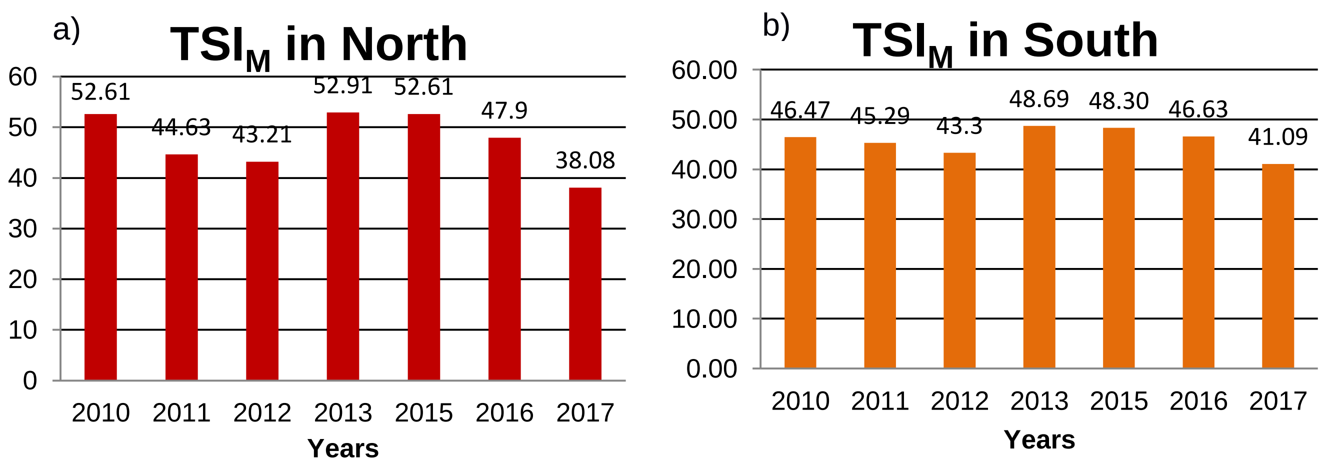

Figure 24. a) Trophic state index for north area of the lake.b) Trophic state index for south are of the lake.

As stated previously in general the TSI_M state for the whole lake has improved during these last years of restoration efforts (**see Fig. 25**). In comparison with the three previous year we can observe that this year this year score in the TSI scale for the whole lake is of 40.16 which is an overall very positive score, even considering weather conditions (precipitations) on sampling dates.

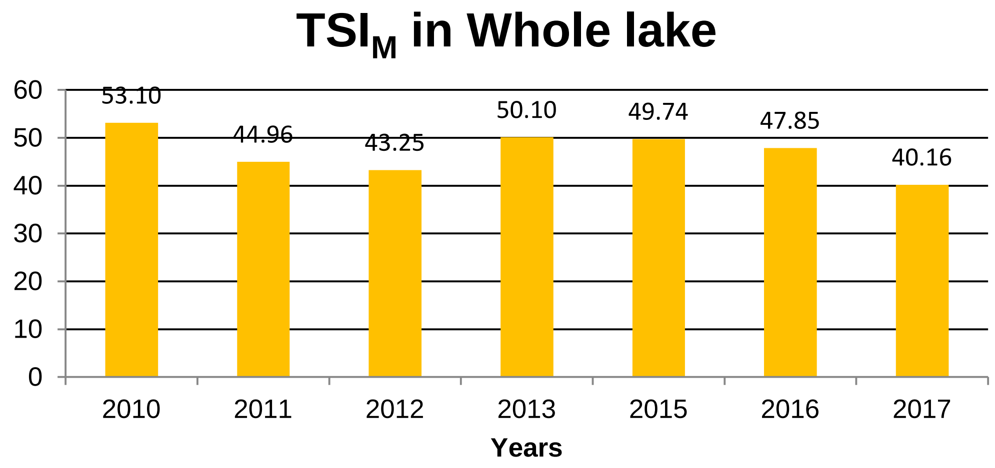

Figure 25. TSI_M in whole lake.

3.7.3. Trophic State Index (TSI_M) 2017

The general state of the lake is mesotrophic with three sampling points qualifying as oligotrophic. Two of the three points that are considered oligotrophic are the aerators1-2 (**see Fig. 26**), this can be due to better oxygenation conditions in the particular area. The value obtained for the outflow is significantly lower than other sampling sites so we can deduce that most nutrients and chlorophyll *a* are being retained in the lake.

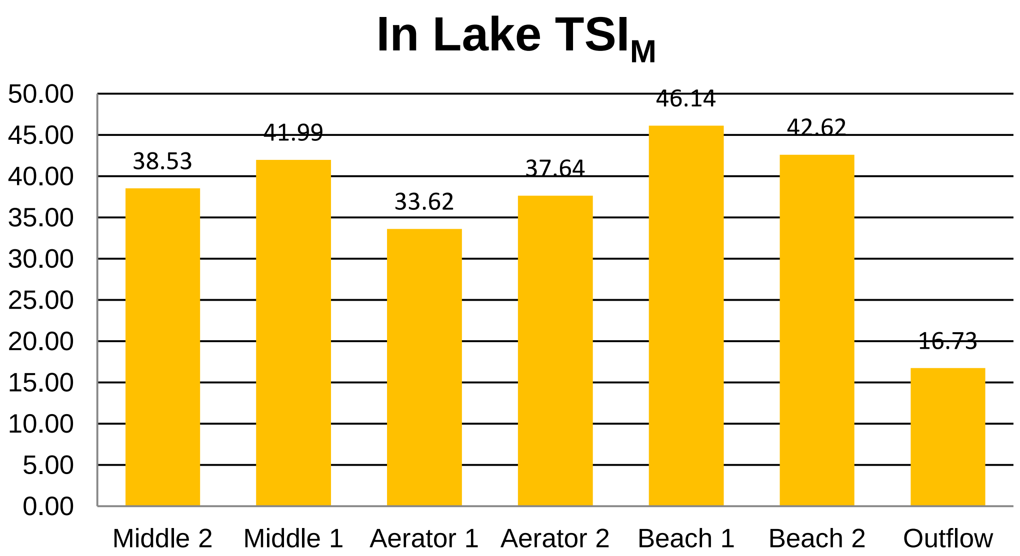

Figure 26. In lake TSI_M.

Furthermore, it is necessary to point out that this particular year the lake could not be restocked with pike, which allows us to pose the following questions: *“how would the timely restocking of pike fish affected the physico-chemical parameters?”.*
As indicated by our results human activities are having a negative impact on the concentration of chlorophyll *a* in the south part of the lake. We suspect that the use of motor boats with high potency engines are altering the water levels causing upwelling of nutrients which become available for the creation of biomass and raise the turbidity of the water.

4. Conclusion

The current state of Lake Durowskie according to the results of the physic-chemical analysis and the application of the Trophic State Index (TSI) is Mesotrophic. This means that the efforts to manage and improve the ecosystem health of this catchment area are reaching the goals set out by the municipality.
It is also necessary to indicate that, although the current efforts are having the expected effect by diminishing the negative effects of anthropogenic activities in the catchment area, the overall lake health would improve with the application of close monitoring and development of specific cost effective alternatives to help improve the removal of nutrients in upstream lakes.

References

Gołdyn, Ryszard, et al. "The response of Lake Durowskie ecosystem to restoration measures." *Carpathian Journal of Earth and Environmental Sciences* 8.3 (2013): 43-48.

Gołdyn, Ryszard, et al. "The sustainable restoration of lakes—towards the challenges of the Water Framework Directive." *Ecohydrology & Hydrobiology* 14.1 (2014): 68-74.

Michaud, J.P. 1991. A citizen's guide to understanding and monitoring lakes and streams. Publ. #94-149. Washington State Dept. of Ecology, Publications Office, Olympia, WA, USA (360) 407-7472. Moore, M.L. 1989.