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Planning and Environment Department

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Assessment and adjustment of the hydrobiomanipulation for an eutrophication mitigation in the Sulejow Reservoir, Central Poland.

LOISEAU Marie

Key words : Hydrobiomanipulation, early-life stages of fish, eutrophication, water quality, Sulejow Reservoir, Central Poland

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Summary

The hydrobiomanipulation is an innovative biomanipulation method based on the concept of Ecohydrology (Zalewski, 1990). This technique has already been implemented in the Sulejow Reservoir since 2006, artificial lake situated in lowlands of Central Poland. First of all, used as drinking source, it currently represents an important touristic area. However, a cyanobacterial bloom harmful for the environment and living organisms is used to occur in summer, inducing socio-economical issues. The previous research namely directed by the European Regional Centre for Ecohydrology (ERCE) showed that the hydrobiomanipulation is a promising method to improve water quality and consequently to conserve the touristic potential of this area, however, it is still under calibration. This technique consists in reducing zooplanktivorous fish abundance by water level fluctuations shortly after their spawning period in order to favour the development of zooplankton, which, by grazing and filtering the phytoplankton, will decrease the risk of algal blooms. The reduction of the water level allows drying up the eggs just laid on the vegetation. The reproductive success of the zooplanktivorous fish is reduced as well as the fish predation pressure. The present project provides more data about the spawning period of *Rutilus rutilus,* one of the most important predators of filtering zooplankton, in order to adjust the hydrobiomanipulation method. The study of the juveniles and the monitoring of the water quality allow determining the current efficiency of the technique. First of all the context of the study will be explained in the report and the protocols will be described. Then, the results obtained will be presented and analysed in a discussion.

Key words : Hydrobiomanipulation, early-life stages of fish, eutrophication, water quality, Sulejow Reservoir, Central Poland

Résumé

L'hydrobiomanipulation est une nouvelle technique de biomanipulation basée sur le concept de l'Ecohydrologie (Zalewski, 1990). Cette technique a été mise en place dans le Sulejow Reservoir, lac artificiel situé dans le centre de la Pologne, depuis 2006. Tout d'abord utilisé comme réserve d'eau potable, il représente actuellement une importante zone touristique. Cependant, un développement algal dangereux pour l'environnement et les organismes vivants se développe en été, engendrant des problèmes sociaux-économiques. Les recherches précédentes, notamment menées par le Centre Régional de l'Ecohydrologie (ERCE) ont montré que l'hydrobiomanipulation était une méthode prometteuse afin d'améliorer la qualité de l'eau et de conserver le potentiel touristique de la zone. Cependant elle est toujours sous calibration. Cette technique consiste à réduire l'abondance de poissons planctonivores par fluctuation du niveau d'eau, rapidement après la période de frai, afin de favoriser le développement de zooplanctons qui, en mangeant et filtrant le phytoplancton, réduisent le risque de développement algal. La réduction du niveau d'eau permet de faire sécher les œufs tout juste pondus sur la végétation. Le succès reproducteur des poissons zooplanctonivores est alors réduit tout comme leur pression de prédation sur le zooplancton. Le présent projet fournit de nouvelles données sur la période de frai de *Rutilus rutilus*, l'un des plus grands prédateurs de zooplanctons, afin d'ajuster la méthode d'hydrobiomanipulation. L'étude des juvéniles et le suivi de la qualité de l'eau permettent de déterminer l'efficacité actuelle de la méthode. Le rapport explique tout d'abord le contexte de l'étude et décrit les protocoles utilisés. Il expose ensuite les résultats obtenus et les analysent au fil d'une discussion.

Mots-clés : Hydrobiomanipulation, premiers stades de vie des poissons, eutrophisation, qualité de l'eau, Sulejow Reservoir, Centre de la Pologne

Preamble

- *Context and goals*

Water is a vital resource for all living organisms, but nowadays, it is increasingly threatened by human activities. The current population growth overuses water resources for domestic purposes, economical, agricultural or industrial plants. The intensive water exploitation negatively impacts the water quality, disrupts the aquatic ecosystem functioning and drastically decreases the drinking water availability.

In lowlands of Central Poland, the Sulejow Reservoir was built in 1974 by a dam (Figure 1) to provide drinking water to the population of Łódź, Tomaszów, Piotrków and Sulejów. Nonetheless, the reservoir was impacted by the surroundings anthropogenic activities leading to the decrease of the water quality and the closing of this drinking water source. The direct catchment of the reservoir is covered mainly by arable land (44,4%), forest areas (38,6%) and grasslands (12,3%) (Corine Land Cover 2006). Since 2004, this man-made reservoir of 220 ha and 3,3 m average depth is used as a touristic and recreational area. Many people come each year to bath or practice several aquatic sports. Despite a serious and long-term monitoring of the water quality, namely by the European Regional Centre for Ecohydrology (ERCE), cyanobacterial blooms occur in summer and threaten the touristic potential of this area ; the bathing is forbidden. Indeed, the cyanobacteria may produce some toxins harmful for the environment and the human health.

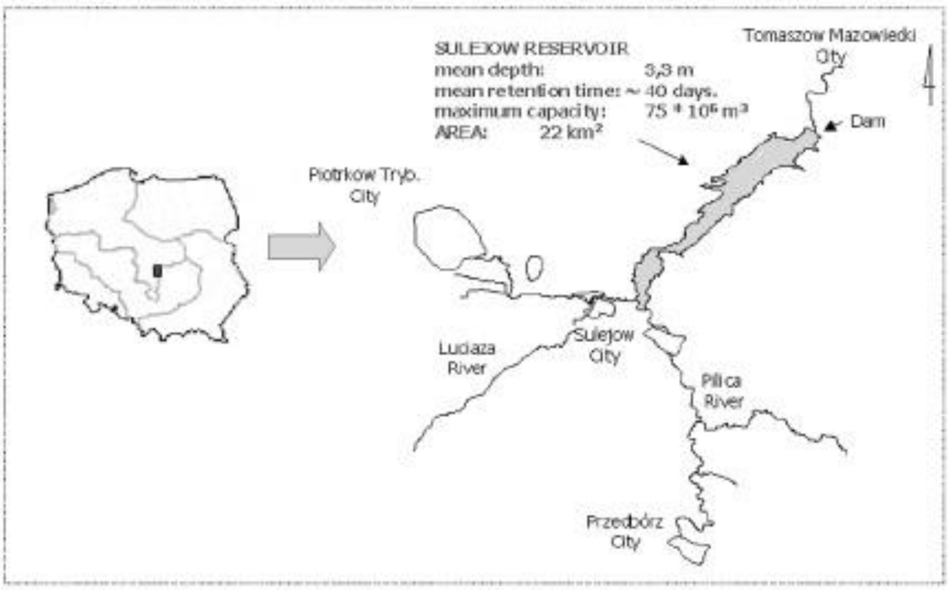

Figure 1 : Location of the Sulejow Reservoir (Wojtal-Frankiewicz *et al.*, 2008)

The management of this reservoir is necessary in order to :

- protect the proper functioning of the aquatic ecosystem and its biodiversity,
- reduce the socio-economical issues by improving the water quality,
- transmit knowledge about the environmental protection to the local population.

Thus, this eutrophic lake has already been studied for 40 years. According to the concept of Ecohydrology (Zalewski, 1990) based on the regulation of the biological dynamics by the hydrological processes and *vice versa*, an alternative biomanipulation method has been implemented in the Sulejow Reservoir. The hydrobiomanipulation directly acts on the trophic cascade by reducing the reproductive success of the most important zooplankton-feeding fish, by a decrease of the water level just after the spawning period, for a few days. Indeed, the decrease of the water level allows drying up one part of the eggs just laid on the vegetation. The water level fluctuation has several impacts on the fish fry recruitment (U. Kahl *et al*., 2008) and lead to an increase of the zooplankton density (Zalewski *et al.* 1990a) which, by grazing and filtering phytoplankton, reduce the risk of algal blooms and improve water quality.

The goal of the present study was to adjust the method and to evaluate its current efficiency on water quality. Thus, on one hand new data was obtained about the number of eggs just laid on the vegetation of four littoral areas in order to determine with precision the first day of the water level decrease. On the other hand an accurate study of the juvenile population in the reservoir as well as the monitoring of the water quality have been done to understand the relationships into the trophic cascade and their effects on the water quality.

- *<u>Material and methods</u>*

The roach (*Rutilus rutilus*), is the most important predator of zooplankton in the Sulejow reservoir. Its biomass is consequent and its favourite prey is zooplankton during its whole life. The large filtering zooplankton like *Daphnia*, allows improving water quality by consuming the phytoplankton. The decrease of the roach recruitment allows both, strongly reducing the predation pressure on the zooplankton and favouring best life conditions for the species (Zalewski *et al.* 1990a).

Barkowice, Bronislawow East, Island and Tresta are the name of the four littoral areas chosen as egg sampling stations (Figure 2). The first samples of littoral vegetation were taken on the 5th of May, at the first day of the spawning period. The bad weather conditions with heavy-rain at the end of April induced a delay in the reproductive period. The number of eggs laid on the vegetation was counted and the substrate was weighed. The results were estimated in number of eggs per gram of dry vegetation. The same experiment was done on the 8th of May, at the end of the spawning period.

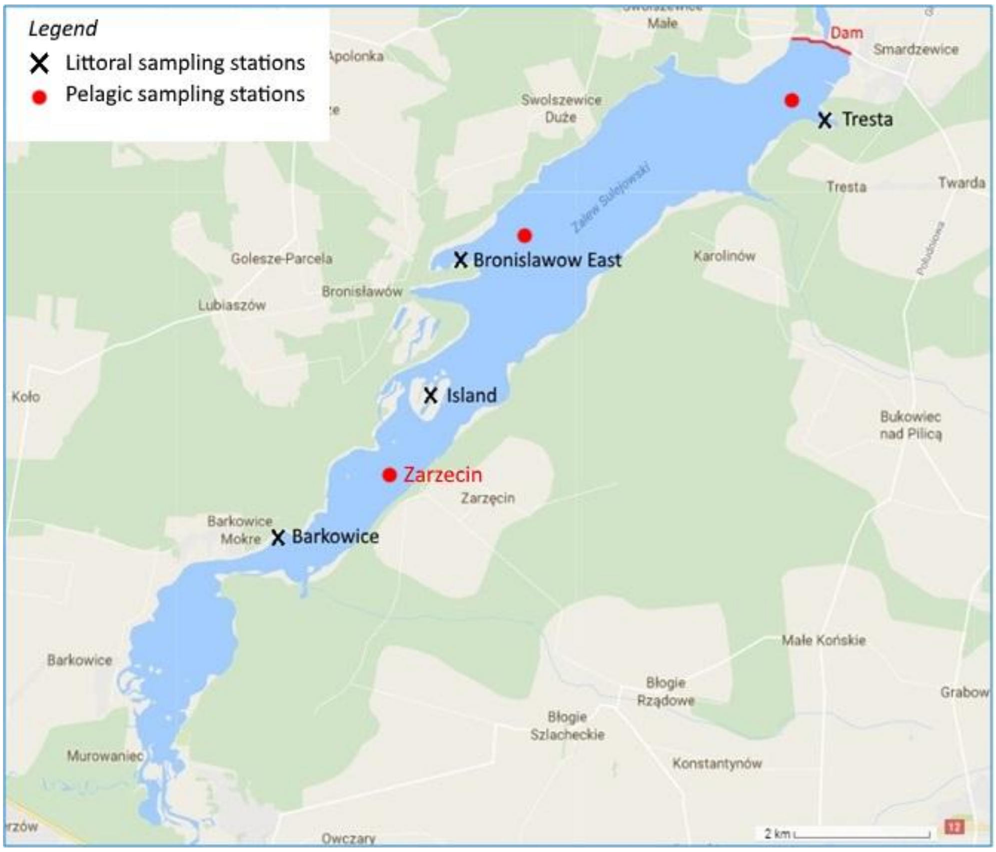

Figure 2 : Map of the sampling stations

After the spawning period, the water level in the reservoir was decreased of about 40 cm during a few days by increasing the outflow. Dried eggs still attached to the macrophytes could be observed. One month later, samples of juvenile fish were taken at the same place than previously, with a 7 m bench-seine net. Three replicates at each site, at the beginning of June and at the beginning of July, were made. The vegetation and the substrate present at each littoral sampling station were also observed. In laboratory, each individual was observed and identified. The number of juvenile by sample was estimated per square meter.

Every two weeks, from the 18th of May to the 29th of June, water samples and physicochemical parameters were measured in three pelagic zones to estimate water quality within the reservoir. In the laboratory, the phytoplankton biomass was analysed by using a fluorimeter Algae Online Analyser (AOA). The concentration of selected ions (phosphates and nitrates) was measured by using a Dionex® ion chromatograph. The zooplankton biomass was also analysed after observation using a 1 mL counting cell and a microscope NikonOptiphot-2.

Statistical tests were performed by using Statistica or Excel. ZWCAD was also used to create some map of vegetation and longitudinal profiles of the sampled zone. Paint.net, Adobe illustrator and Windows Movie Live were used to make photo editing and video.

- *Most important results obtained*

At the end of the spawning period, a gradient increasing of the number of eggs from upstream (Barkowice) to downstream, near the dam (Tresta), was observed. The number of eggs found in Tresta was significantly higher than in the three other sites ($p<0,05$). Indeed, in Tresta the average number of eggs per gram of dry substrate was more than twice higher than in Barkowice, Island and Bronislawow (Figure 3). Nonetheless, the difference of the number of eggs was not significant between the three other sampling points.

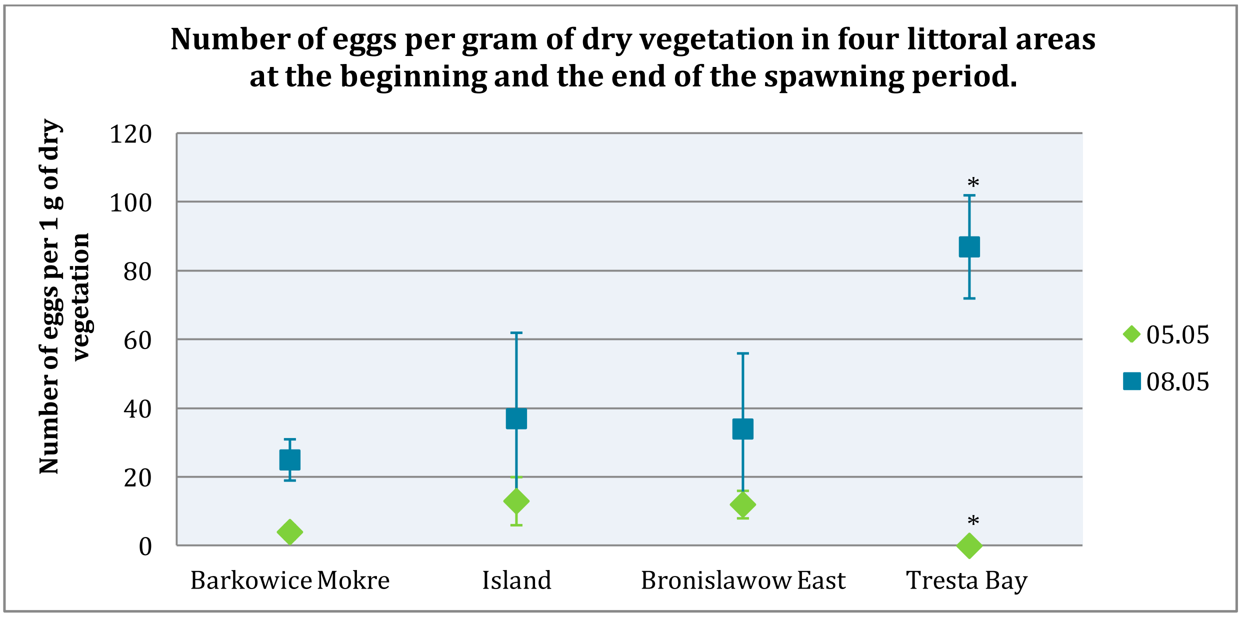

Figure 3 : Graph of the number of eggs per gram of dry vegetation counted in four littoral areas (*: significant difference)

On the 8th of June, the lowest density of juveniles was in Tresta and the highest was in Bronislawow East with a density of 277 ind.m². On the 3rd of July, the density of juveniles was lower in all sites except in Tresta. The average density was estimated of about 8,6 ind.m². The juvenile population was dominated by cyprinids species and namely by roach, silver and common bream. However, some predators like perch and pike perch were observed at the beginning of July.

The zooplankton biomass was dominated by rotifers on the mid-May which were replaced by small and then large zooplankton, like *Daphnia longispina*, from the end of June. The biomass of *Daphnia* at this date was about 17,9 mg.L^{-1} (Figure 4). The increase of the large filtering zooplankton abundance seems to be correlated with the decrease of the number of young fish along the season.

The phytoplankton biomass was dominated by diatoms on the mid-May which were replaced by cryptophytes and cyanobacteria since the end of June (Figure 4). The phytoplankton biomass was dominated by cyanobacteria on the 29th of June with a concentration of about 5,1 µg.L^{-1}. A precocious cyanobacterial bloom was visible near the dam from the beginning of July

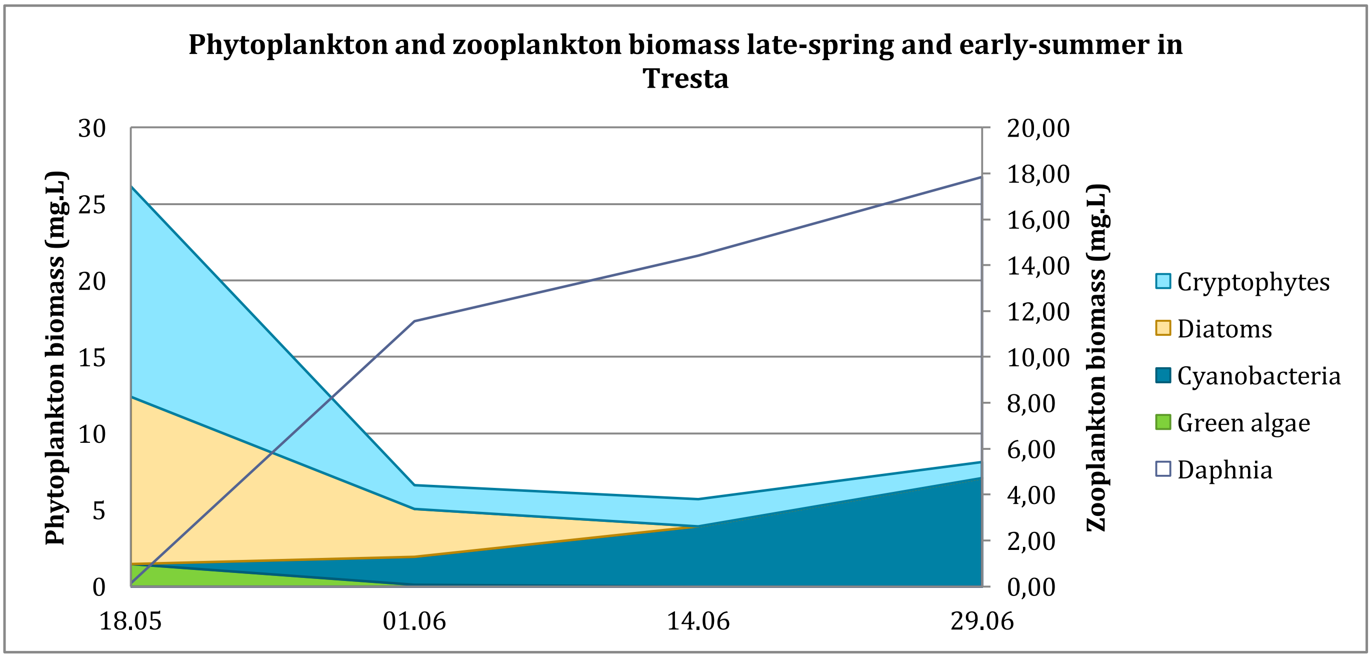

Figure 4 : Graph representing the biomass of phytoplankton and zooplankton throughout the season

The weather conditions were very fluctuant this year with heavy rain in the early-Spring and early-Summer. Moreover, important phosphate concentrations were measured in the water samples at the middle of May and at the end of June.

- *Discussion / conclusion*

○ The number of eggs is an useful data for the next years to determine the best moment to decrease the water level. It cannot be compared with previous data but it is a reference for the next studies.

○ The decrease of the number of juveniles during the season seems to be correlated with a good development of large filtering cladocerans and copepods.

○ The very fluctuant weather conditions of this year with heavy rain could explain the forward development of the bloom. Indeed the total precipitations were connected with elevated phosphate concentration measured in the water. The phosphorus is the most important factor responsible of the eutrophication. The benefits of the hydrobiomanipulation on the water quality could be hidden by the changing abiotic parameters.

○ The hydrobiomanipulation is still a promising method in the Sulejow reservoir which allows improving water quality and obtaining a better balance of the trophic cascade. However, it has to be combined with other solutions to improve its benefits.

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Introduction

"We forget that the water circle and the life circle are one" - Jacques-Yves Cousteau. Indeed, the Anthropocene era is directed by a paradox in which Human and Nature are against each other. While the humans need the nature and its numerous ecosystem services to live, they overexploit and damage it. While the water is the most essential element on the Earth, the water pollution increases and freshwater resources disappear. The current key challenges for science are solving this paradox by creating a greater harmony between the anthropogenic activities and the environment, in order to achieve a sustainable development (Zalewski, 2002, 2010). It is the main objective of the European Regional Centre for Ecohydrology (ERCE) *(Annex 1)*.

ERCE, was established on the 8th March 2006 after the signature of an agreement between the Director General of UNESCO and the Minister of Science and High Education of Poland. This specific research institute ensures a mix of research, education and implementation of measures for restoration of aquatic ecosystem. It is focused on the concept of Ecohydrology, developed in the 1990s by Zalewski *et al.*, for restoring freshwater resources in the framework of UNESCO and for applying the Water Framework Directive (WFD) as part of Poland's national cooperation (Zalewski *et al.*, 2010). It is a transdisciplinary science using the understanding of relationships between hydrological and biological processes in order to implement new environmental biotechnologies, like buffer zones or biomanipulation. Hydrobiomanipulation derived from this last concept, acting on the trophic cascade by hydrological fluctuations, to improve the water quality.

All the human activities, from the agricultural areas to the domestic waste, are responsible for the production and dispersion of several kinds of pollutants in the environment which directly affect the aquatic ecosystem. Some disturbances on the functioning of these sensitive ecosystems can be noticed like the acceleration of the eutrophication phenomenon as we can see in the Sulejow reservoir, artificial lake situated on the middle course of the Pilica River in Central Poland. This man-made reservoir has already been studied intensively for 40 years, namely by scientists from the ERCE, in order to reduce the environmental and socio-economical issues generated by the chronic development of cyanobacterial blooms. Indeed, they are not only dangerous for the proper functioning of the aquatic ecosystem but also for the human health. The reservoir must be closed for bathing when the blooms occur inducing a loss of the touristic potential.

Hydrobiomanipulation has already been implemented in the Sulejow reservoir since 2006. It is a promising method to reduce eutrophication, however it is still under calibration in order to achieve the ecohydrological regulation which allows both, a good balance of the trophic pyramid and a good quality of water (Izydorczyk *et al.*, under publication). Indeed, the previous research showed that the reduction of the most important zooplanktivorous fish species abundance played a key role in the development of large filtering zooplankton which, by grazing and filtering the phytoplankton, reduce the risk of algal bloom. The decrease of the water level after the spawning period allows drying up one part of the eggs just laid on the littoral vegetation and consequently reducing the fish reproductive success. In order to implement an efficient and sustainable management of the reservoir, the centre would like to adjust this innovative method and evaluate its current efficiency. My internship was included in this concept : I've made new experiments providing more data about the spawning period of *Rutilus rutilus*, one of the most important predators of filtering zooplankton in the Sulejow Reservoir allowing to determine when the decrease of the water level should be started. I also determined the current effects of the hydrobiomanipulation on water quality and on the young-of-the-year (YOY) fish population by providing numerous data about the number and specific wealth of juvenile fish.

The present report will be introduced by a presentation of the context of the study with more explanations about Ecohydrology and hydrobiomanipulation concept on one hand and about the expectations of this project on the other hand. The study area will be also described. A second part will explain accurately the material and the methods used. Then the results will be described and explained by several figures and will be followed by the discussion which will analyse them by a critical way. Finally the conclusion will sum up the goals of the project and the most important results of this study. My point of view about the personal and professional interests of this internship will close this report.

1. Study context

1.1 Foreword : concept of Ecohydrology

The urgent need to reverse the degradation of water resources, mainly caused by increasing climate instability and demographic growth, induced the emergence of some programme and science in the last decades. Ecohydrology is a transdisciplinary science, sub-discipline of hydrology, focused on biological aspects of the hydrological cycle (Zalewski *et al.*, 2010). It has been developed in the framework of the International Hydrological Programme of UNESCO (IHP). It is focused on the dual regulation between hydrological and biological processes from molecular to catchment scale in order to improve water quality and enhance biodiversity (Figure 5). In other words, biological processes are controlled by hydrology and reciprocally, biological interactions shape hydrological processes. The Ecohydrology programme aims to improve the understanding of hydrology-biota interplay in order to develop ecohydrological technologies to reduce ecological threat and consequently to solve both, social and environmental issues. Thus, ecological and hydrological research have for goal to generate effective agricultural and environmental policies and practices for integrated water resources management (IWRM) but also to share environmental protection knowledge to the local population. Since 2011, UNESCO-IHP promotes the establishment of demonstration sites around the world like in Ethiopia, China or Australia. In Poland, several sites like that have already been built around the Sulejow Reservoir. For example, some denitrification or biogeochemical barriers were installed to enhance the vegetation buffer zone efficiency by reducing the nitrogen and phosphorus inputs. Each demonstration site applies the Ecohydrology principles which are (1) hydrological principle, by the quantification of the hydrological processes at the basin scale, (2) ecological principle, by the understanding of water-biota interplay and (3) ecological engineering principle based on ecohydrological biotechnologies (Zalewski et al., 2000, 2002, 2006).

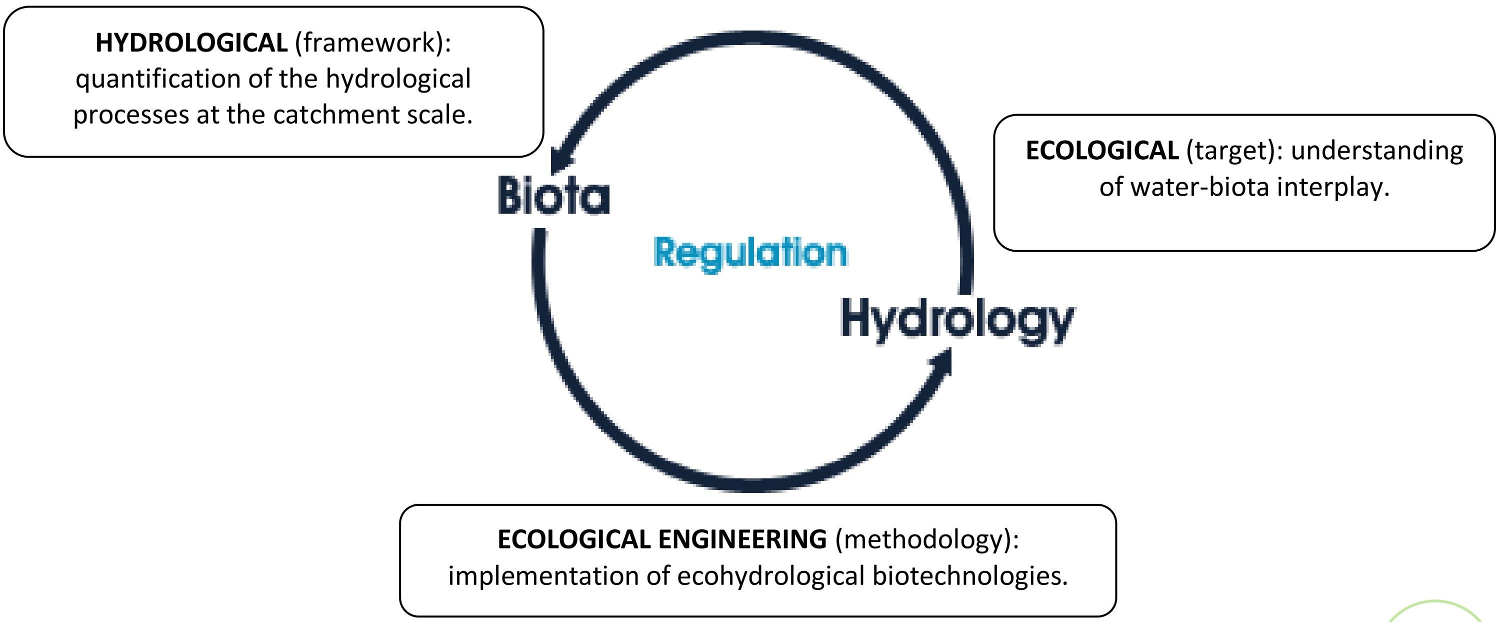

Figure 5 : Schema of the concept of Ecohydrology

1.2 Foreword : biomanipulation and hydrobiomanipulation concept

The biomanipulation is an efficient method to enhance water quality of the aquatic ecosystem by using ecological solutions. It is based on the "trophic cascade theory" (Carpenter & Kitchell, 1992) meaning the manipulation of one trophic level induces modifications in the immediate upper and/or lower level and consequently in the entire trophic pyramid. In the case of the biomanipulation, the control of the trophic pyramid is top-down (Beendorf, 1995). Several techniques can be applied like removing zooplanktivorous fishes by electrical fisheries or by adding some piscivorous fishes in the reservoir. However, the studies directed by Romare *et al*. in Lake Ringsjön, southern Sweden, confirmed some previous observations made in shallow lakes in Denmark and the Netherlands, showing an increase in 0+ fish abundance, 1-3 years after fish reduction by biomanipulation. Indeed, the reduction of adult fish abundance permitted decreasing competition in food resources for the 0+fish (Romare *et al.*, 1999). The young fish abundance increased as well as the predation on the zooplankton community because of the zooplanktivorous diet of the juvenile fish. Nonetheless, the hydrobiomanipulation is an alternative biomanipulation method which directly reduces the young-of-the-year (YOY) zooplanktivorous fish abundance by decreasing the water level in the reservoir just after the spawning period, during a few days, to dry up one part of the eggs attached to the submerged vegetation in the littoral zone.

Indeed the impacts of the water level fluctuation on the proper functioning of the aquatic ecosystem have already been studied. U. Kahl *et al.* (2008) showed that it may influence the recruitment success of roach and the availability of refuges for the juveniles. The roach (*Rutilus rutilus*), is the dominant planktivorous fish species in many European lakes and especially in the lakes suffering from eutrophication. Consequently, the water level reduction shortly after its spawning period can be an interesting solution to reduce its abundance and to promote the development of large filtering zooplankton, like cladocerans. Moreover, the water level fluctuations wouldn't have a negative impact on the predatory fish species (U. Kahl *et al*., 2008).

The cladocerans often play an important role in lacustrine ecosystem because they occupy an intermediate level in the trophic pyramid. They are the principal food for fish fry (Zalewski *et al.*, 1990a) and important grazers of phytoplankton. A predation pressure too intensive from fish will induce both, a drastic decrease of the zooplankton abundance and a reduction of the body size of the individuals (Brooks & Dodson, 1965). Other author showed that to maintain a good quality of water, domination of large forms of filtering zooplankton, like *Daphnia,* should be achieved by reduction of predation pressure from fish (Zalewski *et al.* 1990a, Wagner *et al.,* 2004). Thereby, the water level fluctuation is an interesting way to reduce the predator abundance, indirectly affecting the zooplankton community which can be more numerous and bigger, grazing and filtering more phytoplankton.

In Sulejow Reservoir, the impacts of the water level fluctuations have already been studied on the perch, roach, and filtering zooplankton populations as well as on the cyanobacterial bloom development (Izydorczyk *et al.,* under publication). The number of juvenile fishes would be correlated with the water level reduction : lower is the water level in the reservoir after the spawning period, lower is the juvenile fish abundance (Figure 6). Consequently, a high biomass of filtering zooplankton like *Daphnia* was observed as well as a smaller diatom bloom. In 1990(a), Zalewski *et al.* suggested that up to 8 ind.m^2 is the optimal YOY fish density which does not reduce the zooplankton population and which allows the best environmental conditions of development for the fish population. Izydorczyk *et al.* (under publication) concluded that the hydrobiomanipulation is a promising method of ecohydrological biotechnologies to reduce eutrophication but which is still under calibration to determine and maintain the optimal density of fish. That's why, it is important to continue following the biological dynamics of the reservoir to optimize this innovative method.

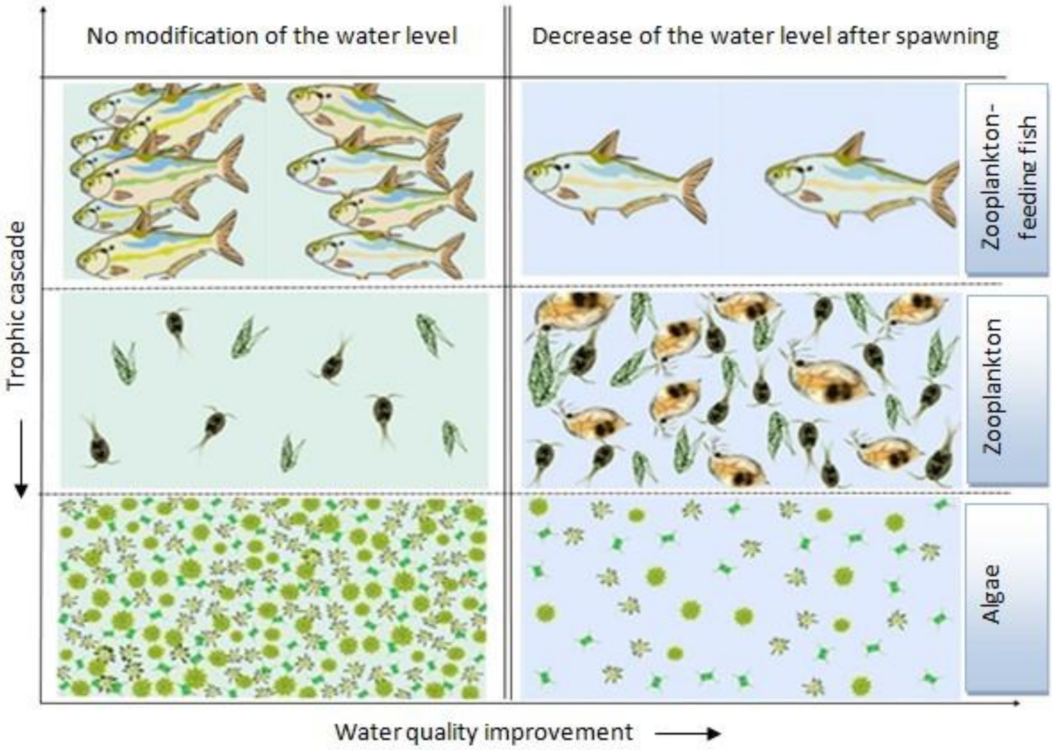

Figure 6 : Schema of the hydrobiomanipulation concept

1.3 Objectives of the study

The present study aims to adjust the hydrobiomanipualtion method implemented in the Sulejow Reservoir for several years and to determine its current efficiency. First of all, the goal is to achieve more data about the spawning period of the most important predator of filtering zooplankton by counting the number of eggs laid on the vegetation. This information is interesting to determine when the decrease of the water level should be started according to concrete data. Indeed, in the last years, the beginning of the hydrobiomanipulation was subjectively determined after visual observations of the eggs attached to the vegetation. This way of analysis has never been studied before and seems to be very interesting as a background for a better implementation of the hydrobiomanipulation in the next years.

Secondly, this project determines the current efficiency of the hydrobiomanipulation on water quality and its effects on juvenile fish populations. A precise monitoring of several water parameters and the study of the zooplankton and the phytoplankton biomass were done. Moreover, the number and the diversity of the juvenile were analysed. Previous research has already studied the juvenile specific wealth in the Sulejow Reservoir, but only in one area. Thereby, the present project will provide more data about the repartition and the behaviour of the young-of-the-year fish. This information allows enriching the long-term database already existing and adjusting the method. The link between the fish, zooplankton, phytoplankton biomass and the water quality also allows knowing if the hydrobiomanipulation is still an interesting method to apply in the Sulejow Reservoir to improve water quality.

1.4 Presentation of the study area

The Sulejow reservoir is an artificial lake created by a dam, built in 1974, in lowlands of Central Poland. The direct reservoir of the catchment (Figure 7) is covered mainly by arable land (44,4%), forest areas (38,6%) and grasslands (12,3%) while urban areas do not exceed 4,7% of the total catchment area (Corine Land Cover 2006). The dominant soil types are loamy sands and sands. The climate of this area is typical for Central Poland, with a mean annual temperature of 7,5°C and a mean annual precipitation of 600 mm. On the average, precipitation in summer is twice higher than in winter (pogodynka.pl).

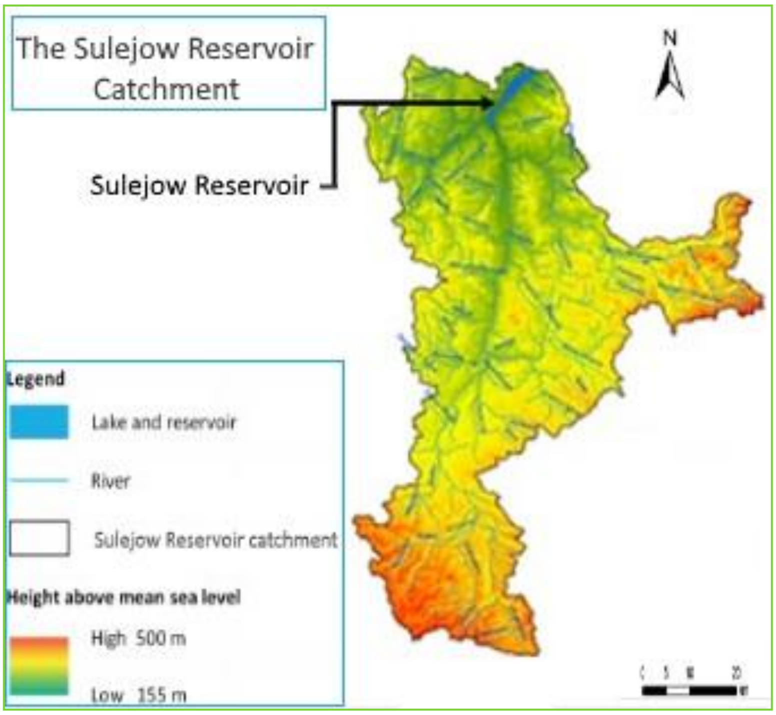

Figure 7 : Map of the reservoir's catchment

This shallow and eutrophic man-made reservoir (Figure 8) is supplied by two main tributaries which are the Pilica and Luciaza Rivers. The reservoir has an average depth of 3,3 m with a maximum depth of 11 m, close to the dam. At its full capacity, this reservoir covers an area of 220 ha and a volume of 75.10^6 m^3 (Zalewski *et al.* 1990). Firstly, it was mainly used as a source of drinking water for the city of Łódź and other cities like Tomaszów, Piotrków and Sulejów until 2004. Currently, it represents an important touristic and recreational area to practice different aquatic sports like windsurfing or kayaking.

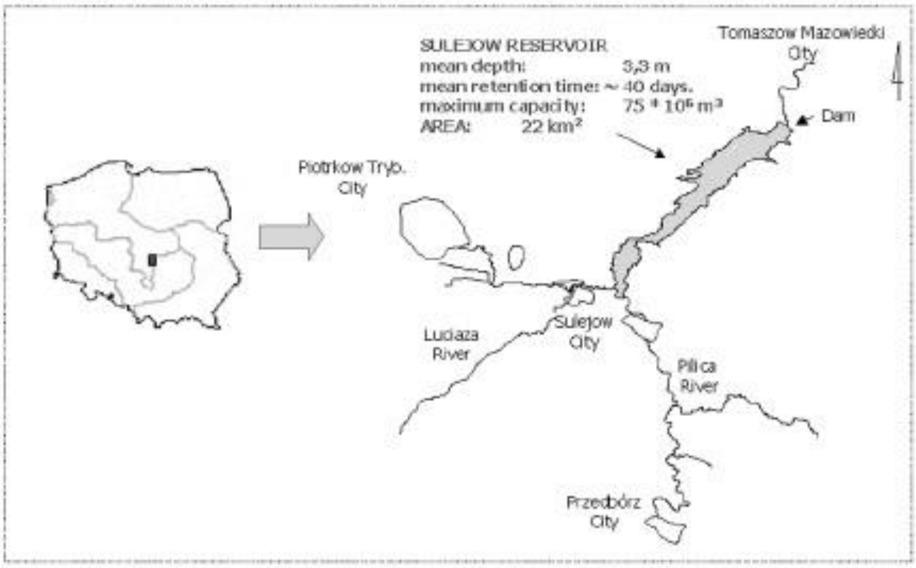

Figure 8 : Schema of the Sulejow Reservoir

The fish population is dominated by roach (*Rutilus rutilus*), silver bream (*Blicca bjoerkna*), common bream (*Abramis brama*), pike perch (*Stizostedion lucioperca*), perch (*Perca fluviatilis*) and bleak (*Alburnus alburnus*) (Frankiewicz & Wojtal-Frankiewicz, 2012). The natural important water level fluctuations in the reservoir induce a poor development of macrophytes in the littoral zone.

Nonetheless *Potamogeton lucens, Potamogeton amphibium, Elodea Canadensis, Gallium palustre, Carex gracilis* can be found, for example.

The Sulejow Reservoir is an eutrophic system for several reasons. First of all, because of its shallow depth, the maturation of the system is quicker than in deep lakes. The sunlight warms the entire water column mixing the water with the bottom sediments which release nutrients all the summer long. The constant exchange of nutrients and the availability of light permit a fast growth of the vegetation which may accelerate the eutrophication of the system. Moreover, the elevated nitrogen and phosphorus loads flowing into the reservoir, caused by multiple point and non-point pollution sources, also accelerate the process. High total phosphorus (150 to 500 $\mu g.dm^{-3}$) and nitrogen concentrations (1500 to 2500 $\mu g.dm^{-3}$) are maintained through the year (Godlewska & Świerzowski, 2003). They are one of the main causes of cyanobacterial bloom which occurred for several years during summer. Hence, it is necessary to ensure a good quality of water in the Sulejow Reservoir in order to reduce the occurrence of toxic blooms and to maintain a favourable socio-economical development of municipalities situated in the catchment of the reservoir.

The Sulejow Water Reservoir is managed by the regional water management authority which headquarters in Warsaw (RZGW Warszawa). This organization manages 29 rivers which are 3 001,36 km long sprinkled in about 1/3 of the territory of Poland. The organization named “Nadzór wodny w Smardzewicach”, situated near the Sulejow Reservoir manages the reservoir more locally. It collects and registers the data about the inflows and the outflows going through the reservoir or the water level of the reservoir above the sea level. Moreover, it supports the closing and the opening of the dam for the hydrobiomanipulation.

2. Material and Methods

2.1 Presentation of the sampling areas

The present study aims to have more knowledge about the proper functioning of the reservoir in order to adjust the hydrobiomanipulation method and consequently, to obtain a better water quality. Thus, several experiments were done. On one hand the water quality was analysed in three pelagic zones : Tresta Bay, Bronislawow Bay, Zarzecin. On the other hand the fish development was studied at two stages, egg and juvenile, in four littoral zones. These areas are described below (Figure 9 and 10) :

- *Barkowice.* Situated at the upstream part of the reservoir, the littoral zone is characterized by a sand substrate and sprinkled plot of macrophytes growing between pontoons and boats used for humans facilities.

- *Island.* Situated on the middle of the reservoir, this zone is shallow and an important density of macrophytes is growing in the shoreline zone, providing shelters for aquatic fauna.

- *Bronislawow East.* The macrophytes on the littoral zone are numerous and spread over a long distance offering refuges and spawning sites for fishes.

- *Tresta*. The nearest bay of the dam was rebuilt in 2016. Consequently, the water depth is very important and a lot of vegetation disappeared on the shoreline zone even if some plots are still present.

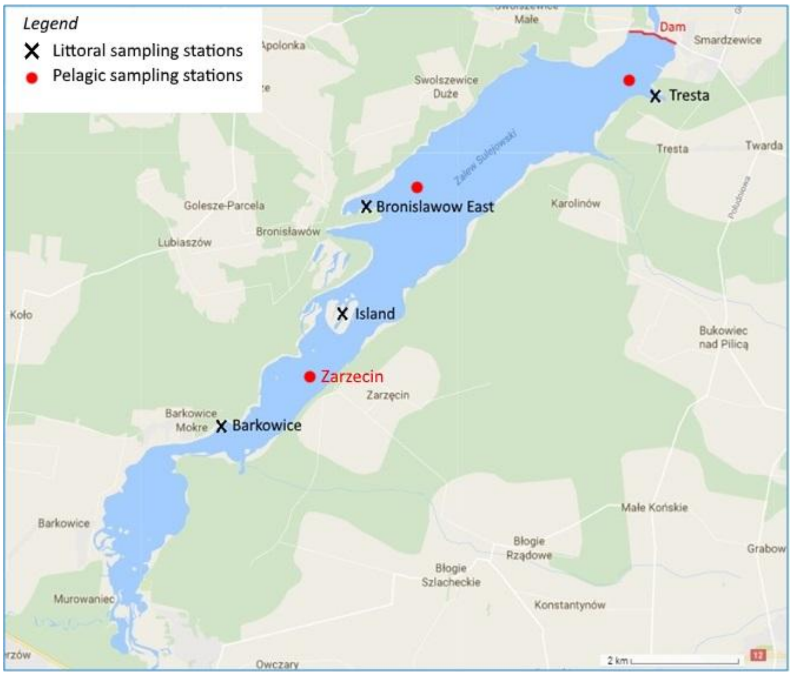

Figure 9 : Map of the sampling stations

Figure 10 : Photos of the littoral sampling areas

2.2 Assessment of the number of eggs and water level fluctuations

2.2.1 Principle

The goal of the hydrobiomanipulation in the present case is to reduce the reproductive success of the zooplanktivorous-feeding fishes which represent an important predation pressure on the filtering zooplankton. The period of the water level decrease is chosen according to the spawning period of the main predators of zooplankton. In the Sulejow Reservoir, *Rutilus rutilus* is one of them because of its high density and its zooplanktivorous diet maintained during its whole life. That's why the number of eggs attached to the littoral vegetation was counted during the spawning period of the roach and the water level was reduced after it. Roach spawning activity occurs when water temperature is higher than 10°C and usually takes place at the turn of April and May. The data concerning this first stage of development will be useful to determine, in the next years, the optimal number of eggs laid before decreasing the water level. Indeed, usually, the water level decrease could be decided after biological assessment. The hydrobiomanipulation will be adjusted by these new data.

2.2.2 Eggs sampling protocol

A monitoring of the water temperature and several visual observations were established in order to determine the beginning of the spawning period. Because of the bad weather conditions at the end of April, the water temperature was low and the spawning activity delayed. Finally, the roach spawning period started on the 5th of May.

Since this date, two experiments were done:

- The first one consists counting the number of eggs laid on the shoreline natural substrates at four different places (Figure 9) in the reservoir at the first and last day of the spawning period.
- The second experiment evaluates the number of eggs laid in natural and artificial substrates in one bay of the reservoir (Bronislawow East and West), at the end of the spawning period.

Indeed, in addition to natural spawning sites in the shoreline zone, a few artificial substrates were installed in the reservoir. They are made of Juniper (*Juniperus communis*) and Spruce (*Picea abies*). A previous study (Frankiewicz P. *et al.*, 2001) showed that roach prefers Juniper as spawning substratum, regardless of the depth. These artificial substrates allow furnishing more knowledge about the fish behaviour and transferring some eggs in other lakes for fishing sport.

During the first sampling *(Annex 2)*, three samples of natural vegetation were taken in the shoreline of Barkowice, Bronislawow East and Island by using a rake. The samples were put in different boxes (Figure 11). A boat was used to move into the reservoir. Only three samples were taken during this day because there were no eggs in the fourth site (Tresta). The day after the sampling, those samples were divided into sub-samples of similar size. Only three of them were counted. After drying, the substrates were weighed allowing determining the number of eggs per gram of dry vegetation. Three days after, on the 8th of May *(Annex 3)*, new samples were taken in the four natural sites for the first experiment. Moreover, samples were taken in two artificial and two natural substrates in Bronislawow Bay for the second experiment. The counting was done by the same way than explained before.

Figure 11 : Sampling and counting egg protocol

2.2.3 Water level fluctuations

Knowing that the spawning activity occurs for a few days, that the water temperature was not favourable anymore and that the number of eggs found was enough, the end of the spawning period was estimated on the 10th of May. Consequently, the water level has been decreased from the 11th of May, of about 40 cm during a few days (Figure 12). Being impossible to control the water inflow coming in the reservoir, the top part of the dam was opened to accelerate the water outflow, reducing the water level. After a few days this part was closed to fill again the reservoir in order to obtain the normal water level. Consequently, the eggs attached to the vegetation, within these 40 cm, dried up. The photos below show the difference of the water level before and after hydrobiomanipulation *(Annex 5)*.

Figure 12 : Photos of the water level fluctuation before and after the hydrobiomanipulation in Bronislawow East station (A : high water level ; B : low water level)

2.3 Assessment of the number of juvenile

2.3.1 Presentation of the juvenile sampling stations

The juvenile samples were taken in the same areas than for the egg samples. However, a more accurate description of the sampling station was done. The vegetation and the substrate were analysed in a quadrat of 10 meters sides. They are represented on the map of vegetation below (Figure 13), made using the ZWCAD software.

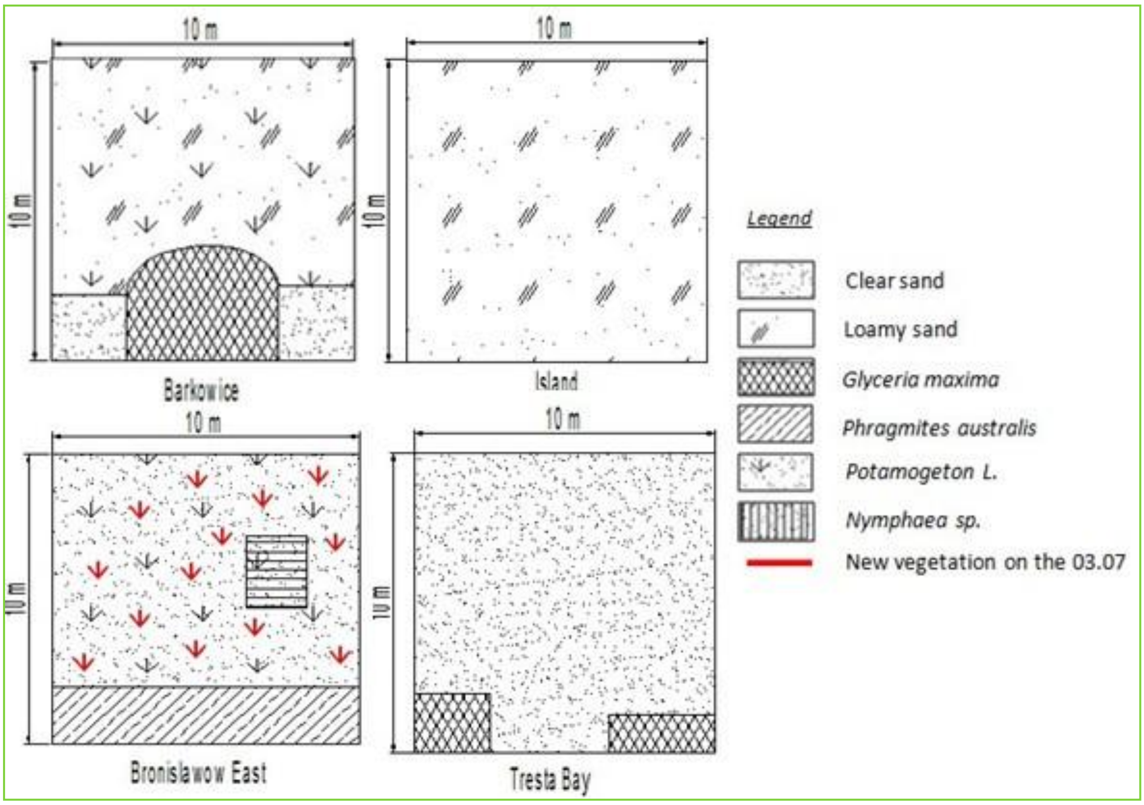

Figure 13 : Maps of vegetation of the juvenile sampling station

In Island, the samples were taken in an area without macrophytes with a mix substrate of sand and organic matter. The water depth did not exceed 80 cm at 10 meters farther from the bank. In Barkowice, a strand of 2 meters wide of clear sand was present along the bank. Farther, the bottom substrate was composed of a mix of sand and loamy sand. *Glyceria maxima* which has one part immerged and one part submerged was near the bank while *Potamogeton L.* was sprinkled and immerged in deeper water. In Bronislawow East, all along the bank, *Phragmites australis* was present on a sand substrate. In deeper water, some *Potamogeton L.* were sprinkled and a plot of *Nymphae sp.* was also present. In Tresta, the bottom was covered by clear sand, and along the bank we could observe some plot of *Glyceria maxima*. In these two last sites, the water depth was up to 1,50 m at 10 meters from the bank. It is important to link this information with the number of juvenile fishes caught in the different sites. Their repartition may be connected to the vegetation cover.

2.3.2 Sampling protocol of the juvenile fish

On the 8th of June *(Annex 6)* and the 3rd of July *(Annex 7)*, the young-of-the-year fishes were sampled in the four stations described just before. Each time, three replicates were made. A 7 m beach seine net with 1 mm mesh was used (Figure 14). The net was towed by hand, forming a semicircle and straight till the shoreline. The sampling surface was included between 20 and 45m². The individuals caught in the net were collected, anaesthetised and preserved in 10% formaline for later analyses in laboratory.

Figure 14 : Photos of the juvenile sampling with the net

2.3.3 Counting and identification of the juvenile fish

The number of YOY collected and the species of each individual were determined after observation with a binocular magnifying glass in laboratory. Fishes belonging at the Percidae or Cyprinidae family were mainly observed (Annex 9):

- The fishes belonging to the Percidae family have two dorsal fins. The front fin is a spiny fin with sharp points as well as the back fin is called a soft ray fin. In this family, two main species were identified: *Perca fluviatilis* and *Sander Luciopera*. To identify them, the perch (*Perca fluviatilis*) has black stripes on the sides of its body and a rounded mouth. The pikeperch (*Sander Luciopera*, has an elongated body shape with a mouth more triangular.

- The fishes belonging at the Cyprinidae family have one dorsal fin. In this family, three species were identified*:* *Rutilus rutilus, Abramis brama, Blicca bjoerkna*. The roach (*Rutilus rutilus*) has a short anal fin with 12 or 13 soft rays (Figure 15) while the two other species have a long anal fin. The common bream (*Abramis brama*) has more than 22 soft rays and the silver bream (*Blicca bjoerkna*) (Figure 15) has less than 22 soft rays. Usually it has 19 or 20 soft rays.

- Pike (*Esox lucius*), Ruffe (*Gymnocephalus cernua*), Aspe (*Aspius aspius*), Dace (*Leuciscus leuciscus*) or Gudgeon (*Gobio gobio*) were also observed.

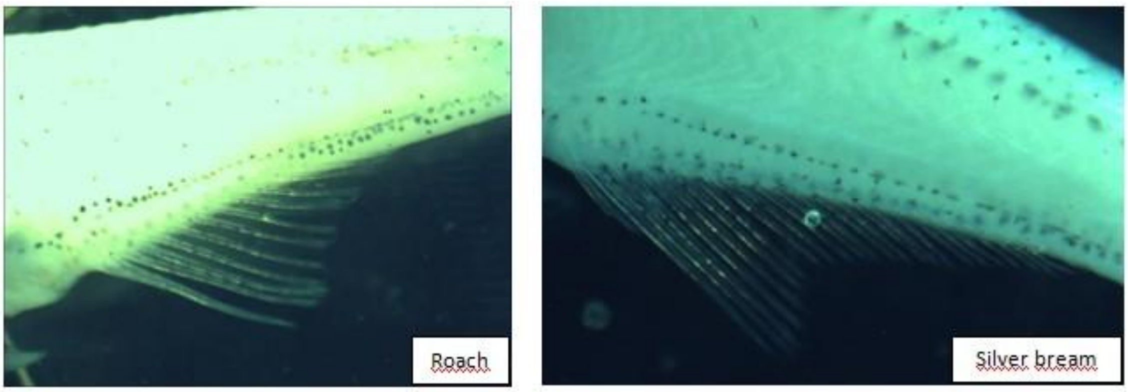

Figure 15 : Identification of the roach and silver bream by observation of the anal fin

2.4 Monitoring of the water quality

To evaluate the water quality, integrated water samples were taken and analysed at three pelagic sampling points in the reservoir (Figure 9) every two weeks since the mid-May. Four samplings were done between the 18th of May and the 29th of June. During the sampling, water temperature and oxygen concentration were measured in a vertical profile. Wind direction and speed as well as high of waves and the clouds cover were noticed. A 5-litre sampler was used to take samples from each meter of the entire water column (Figure 16a). All samples were put in the same bucket and subdivided for several experiments:

- 1 liter was set aside to be analysed by the fluorymeter AOA (Algae Online Analyser) (Figure 16c) in laboratory to measure chlorophyll fluorescence and assess the concentration of several phytoplankton groups like cyanobacteria or green algae (Izydorczyk *et al.* 2009). All the samples, from the three pelagic areas at four dates were analysed by the same way.

- All the water volume collected was filtered through a 50 mm net to concentrate zooplankton (Figure 16b), which was preserved in Lugol's solution. The zooplankton sedimented in the bottom of the bottles was put in a tube with 10mL of water. 1 mL was observed and counted using a 1 mL counting cell and a NikonOptiphot-2 (400x magnification) (Figure 16d). Lake of time, only the samples taken in Tresta were analysed.

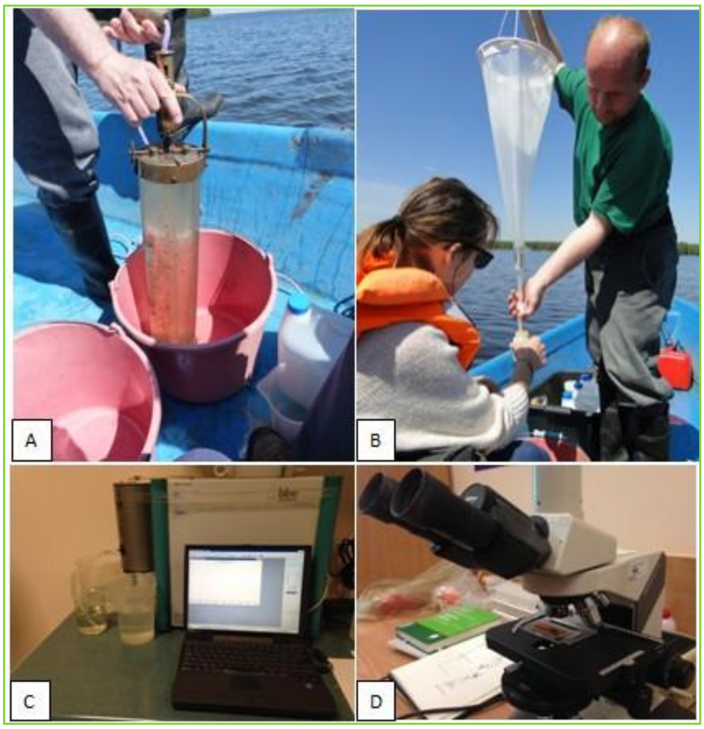

Figure 16 : Photos of the water monitoring (A : water sample with the 5-liter sampler ; B : Collect of the zooplankton after going through the net ; C : AOA fluorimeter ; D : Microspcopic observation of the zooplankton)

Moreover, to determine the phosphorus and nitrogen availability for phytoplankton, the concentration of selected inorganic ions forms (phosphates and nitrates) was analysed using a Dionex® ion chromatograph (Figure 17). It is composed of a cation column (CG18, IonPac CS18, CSRS-ULTRA II) and an anion column (AG22, IonPac AS22, ASRS ULTRA II). After filtration of the water samples, 8 mL of each were put in a tube and put in the chromatograph. The systems were operated in isocratic elution at 30 °C at a flow rate of 1 mL min^{-1}. The information, like graph of concentrations of each ion, was sent to a computer software. For ion identification, combined standards were used (Dionex Corporation). Lack of time, the total phosphorus (TP) and the total nitrogen (TN) have not been measured.

Figure 17 : Dionex® ion chromatograph

2.5 Statistical analysis

Statistical analyses were done using the Statistica software and Excel. One-way ANOVA and Turkey range test were applied to find significant differences between the number of eggs laid in the different substratum. The graphs were made using Excel software.

ZWCAD 2017 was used to make some map of vegetation and longitudinal profiles of the sampling stations.

Photo editing was made using Paint.net and Adobe illustrator while the video was made using Windows Movie Live.

3. Results

3.1 Assessment of the number of eggs

According to the results, in the natural substrates, more eggs were found in the sites closer of the dam *(Annex 4)*. Indeed, even if Tresta was the last place where the fishes spawn, there was like a gradient increasing of the egg abundance from Barkowice (upstream), Bronislawow east and Island (middle) and Tresta (close to the dam) (Figure 18). The number of eggs was maximal at this last site at the end of the spawning period. At this date, the number of eggs per gram of dry vegetation was included between 25 and 87 against an average number of eggs included between 4 and 13 at the beginning of the period. After a Tukey multiple range test a significant difference between the number of eggs found in Tresta and in the three other areas, at the two dates, was observed (in all cases $p<0,05$). Nonetheless, the differences in the number of eggs were not significant between the three other sampling points.

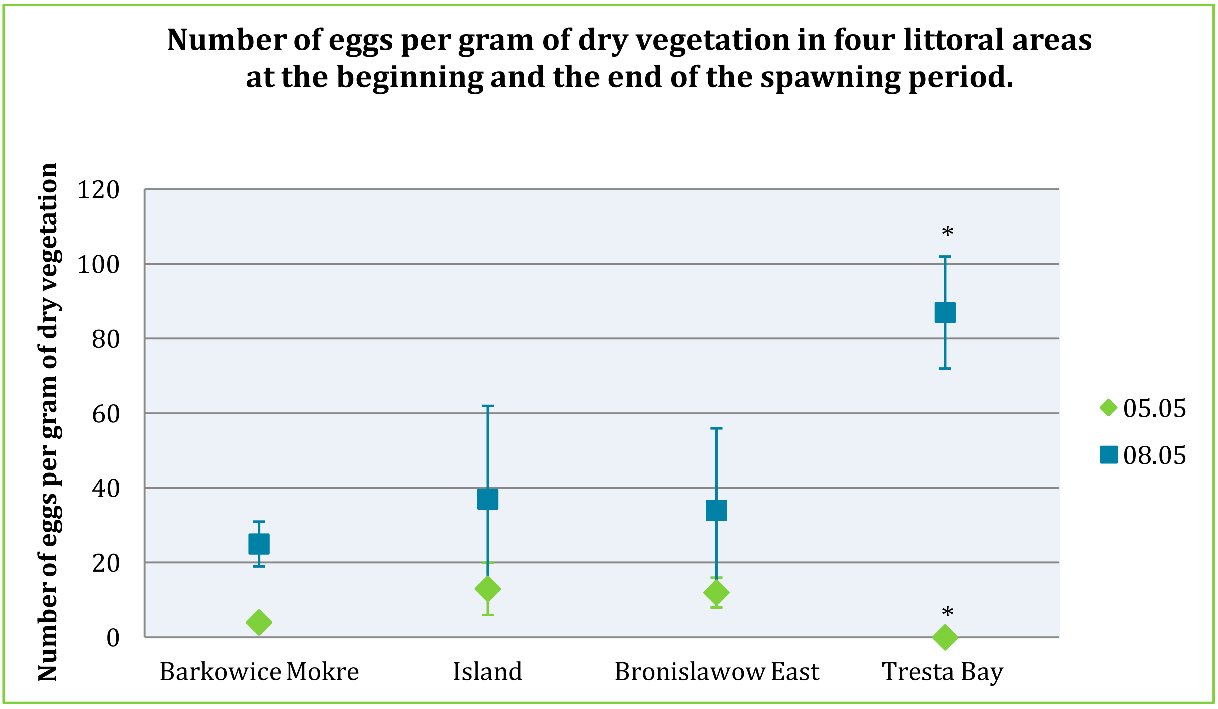

Figure 18 : Graph of the number of eggs per gram of dry vegetation counted in four littoral areas

The results of the second experiment showed that in Bronislawow East and West, the number of eggs in the artificial substrates was lower than in the natural substrates situated in the same area (Figure 19). The fishes may prefer spawning in natural substrates but a not negligible number of fish spawn in the artificial substrates anyway. According to the Tukey multiple range test, the differences in the number of eggs between the natural and the artificial substratum were not significant. However, it can be noticed that the number of eggs found in the natural and the artificial substrate in Bronislawow West was almost significant with p=0,06.

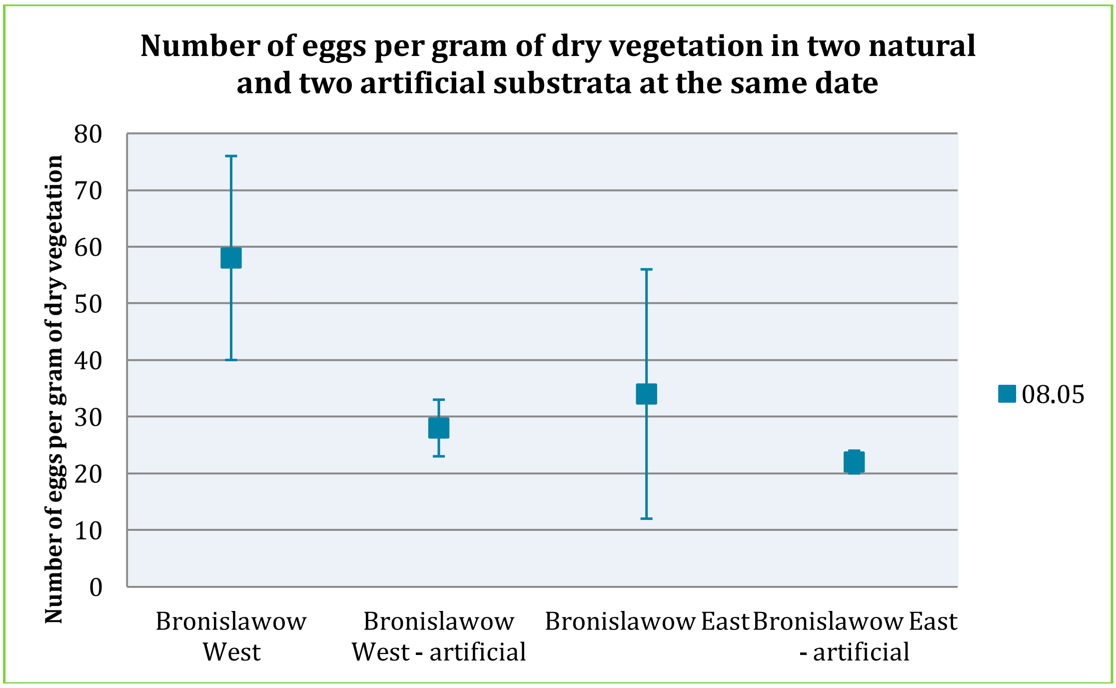

Figure 19 : Graph representing the number of eggs per gram of dry vegetation in Bronislawow bay in natural and artificial substrates

3.2 Decrease of the water level

After evaluation of the number of eggs laid on the littoral vegetation and the estimation of the end of the spawning period, the water level was decreased of about 40 cm from the 11th of May. The water level of the reservoir above the sea level is represented in the next figure (Figure 20). After a few days, the normal outflow was recovered and slowly the reservoir was filled as usual.

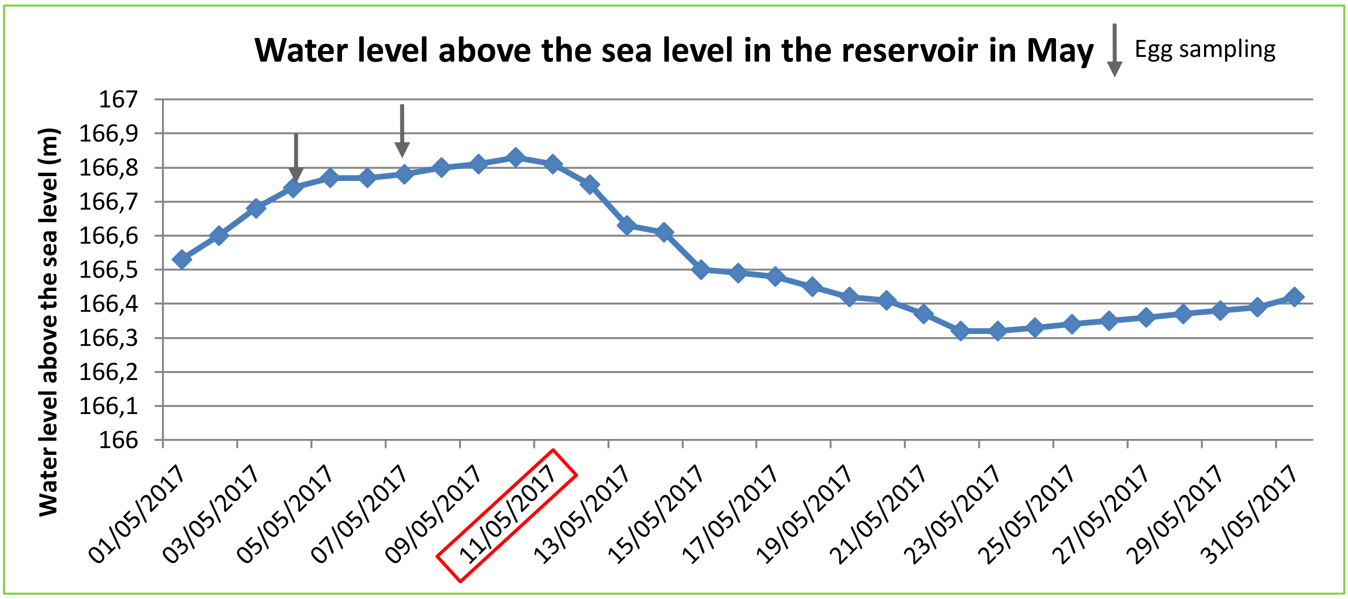

Figure 20 : Graph of the water level above the sea level in May (data from RGZW Warszawa)

3.3 Assessment of the juvenile fish population

On the 8th of June, the lowest density of juveniles was in Tresta (36 ind.m²) and the highest was in Bronislawow East (277 ind.m²) (Figure 21 & *Annex 8*). The number of juveniles was too variable between each sample, even at the same site, and too dependent on several environmental parameters to estimate the total number of juveniles and their rate of elimination. Nonetheless, the water level fluctuation was necessarily responsible for a decrease in the number of juvenile fish. Most of the individuals were cyprinids, namely roach, common bream and silver bream. Only in Island, some predators, pike and pike perch, were found. The mean density of all the samples was 103 ind.m².

On the 3rd of July, the individuals were bigger and less numerous. In Island, Barkowice and Bronislawow East, less than 5 ind.m² were observed with a significant number of predators in comparison with the previous sampling. In Tresta the number of juveniles caught in the net was higher than at the beginning of June with a density of 40 ind.m². The individuals were smaller and belonged just to the Cyprinidae family. The mean density of all samples was 8,6 ind.m².

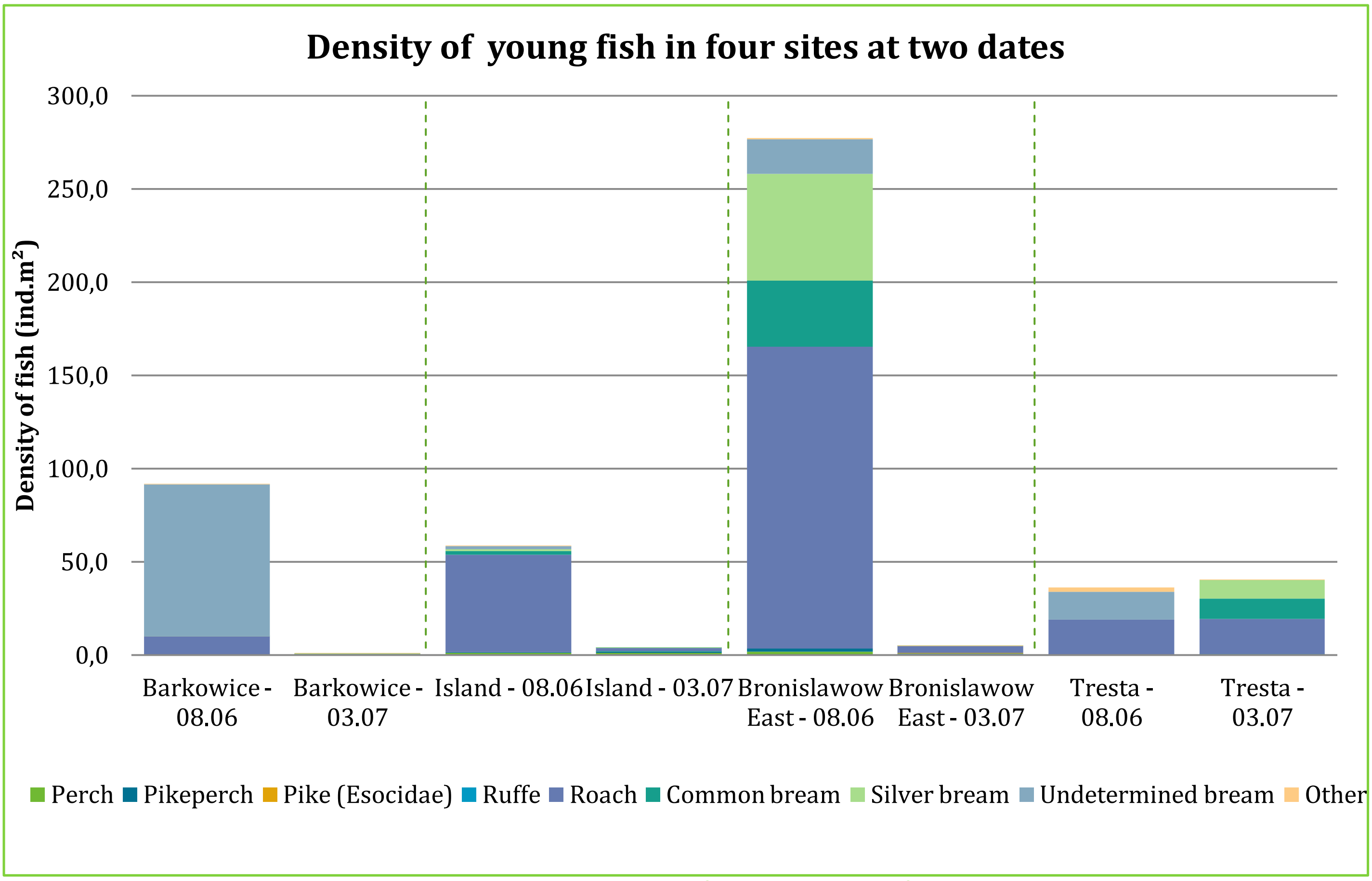

Figure 21 : Graph representing the density and the species of the juveniles in the four natural sampling points at the beginning of June and the beginning of July.

3.4 Assessment of the zooplankton biomass

At the middle of May, the zooplankton community was dominated by rotiferes with a biomass of 15,1 mg.L^{-1} (Figure 22). The mains species of rotifers found were *Kellicottia longispina*, *Keratella quadrata*, *Brachionus calyciflorus* and *Asplanchnra* (Figure 23a). Their concentration decreased along the season to the benefit of small and then large cladocerans and copepods (Figure 23c). *Daphnia longispina* (Figure 23b) and *Diaphanosoma branchyurum* represented the highest biomass at the end of June, 20,71 mg.L^{-1}. This distribution is typical of the functioning of the Sulejow Reservoir if we compare the data with the long-term database. Moreover, the elevation of number of large filtrator like *Daphnia longispina* seems to be correlated with a reduced density of fish.

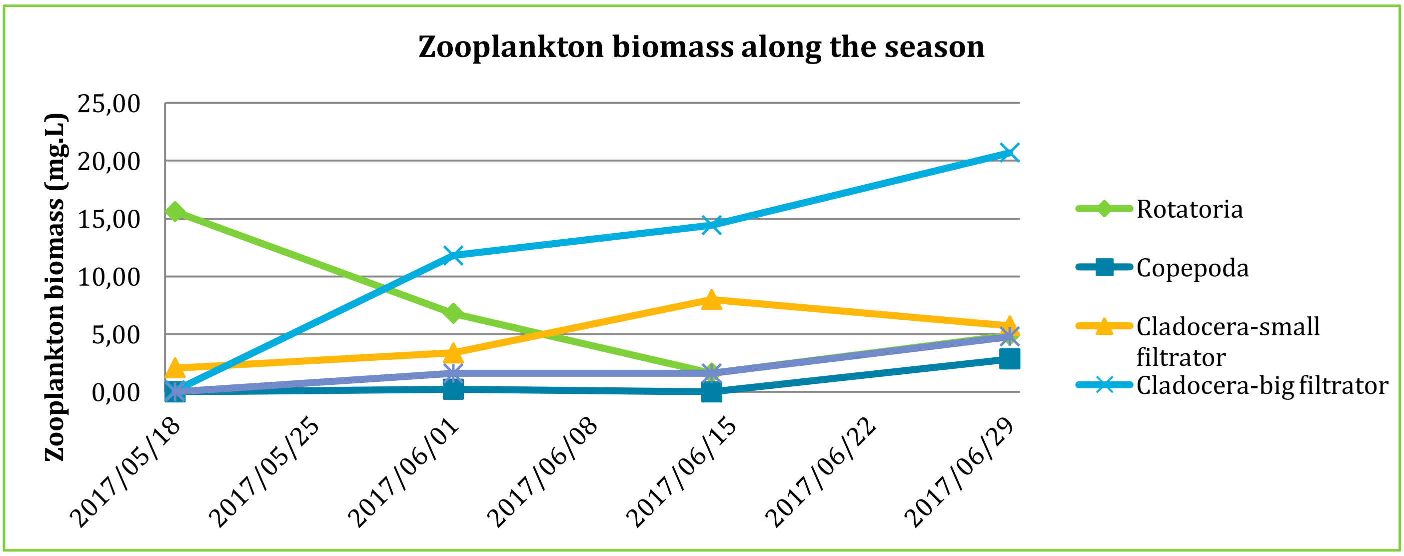

Figure 22 : Graph showing the zooplankton biomass of the main zooplankton groups along the season

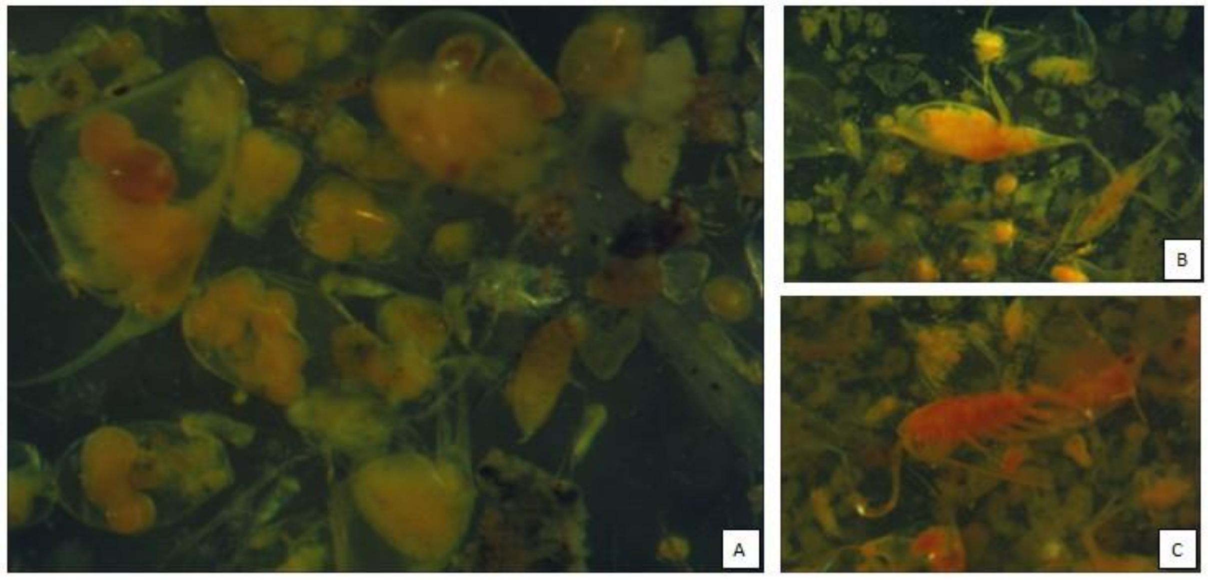

Figure 23 : Photos of the main rotiferes individuals (A), and cladocerans individuals (B : *Daphnia* ; C : copepoda)

3.5 Assessment of the phytoplankton biomass

The results of the phytoplankton biomass obtained after analysis by the fluorimeter AOA showed a total biomass quite high in Mid-May with 31,43 $mg.L^{-1}$ with a dominance of diatoms (Figure 24). This biomass decreased to reach 5,31 $mg.L^{-1}$ at the middle of June. The concentration of cyanobacteria started increasing since this date, mainly in Tresta and Bronislawow, as well as the diatom concentration is non-existent anymore. The concentration of cyanobacteria in these two sampling points was around 7 $mg.L^{-1}$ during the last sampling. Moreover, a cyanobacterial bloom was already developed in early-July near the dam, earlier than usual.

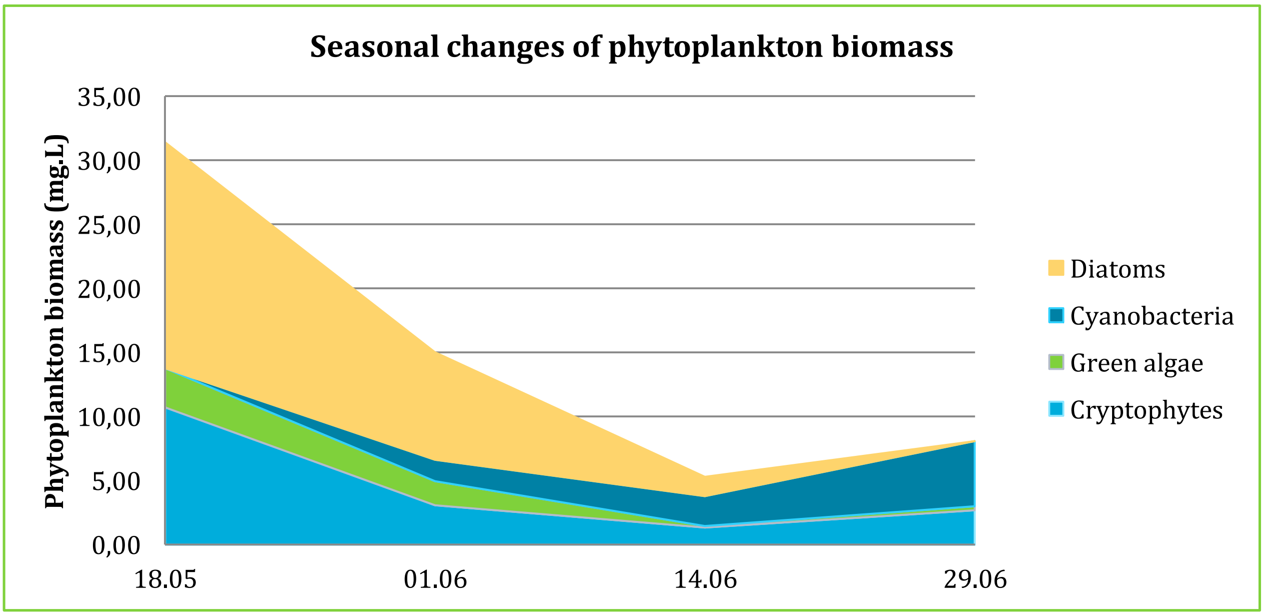

Figure 24 : Graph showing the phytoplankton biomass of the main phytoplankton groups throughout the season

3.5 Physical and chemical water measurements

The mean water temperature for the 3-months study was about 20,2 °C with the maximum temperature at the end of June (22,4 °C). The nitrate nitrogen (N-NO_3) and nitrite nitrogen (N-NO_2) concentrations were low during all the period and at each sampling station (<0,007 µg.L^{-1}). The phosphate concentration was high in the middle of May (0,46 µg.L^{-1}), as well as at the end of June (0,58 µg.L^{-1}) and in the middle of July (0,47 µg.L^{-1}) (Figure 25).

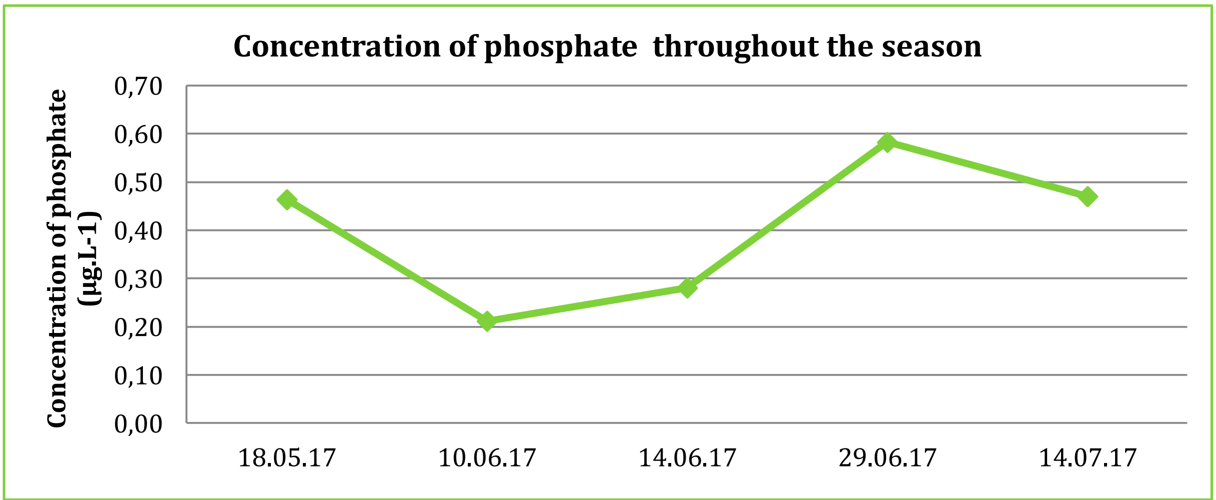

Figure 25 : Graph representing the mean concentration of phosphate throughout the season

3.6 Weather conditions

The period of study was marked by peculiar weather conditions, namely about high precipitations. Indeed, the total precipitations in April were almost three times more important than during the 40 previous years (pogodynka.pl). It was about 85 mm against average total precipitations of about 31 mm for the previous years. The total precipitations occurred in May and June were lower than usual even if a new episode of heavy rain occurred at the end of June and beginning of July. The data about the total precipitations for this last month are still not available. The heavy rain at the early-Spring and early-Summer seems to be correlated with an elevation of the phosphate phosphorous present in the Sulejow Reservoir. Indeed, the high volume of precipitation occurred in April may induce an important concentration of phosphate in the middle of May. By contrast the low precipitations of May are correlated with a decrease of the phosphate concentration in the first part of June. Finally, the high precipitations from the 20th of June may induce an increase of the phosphate concentration at the end of June and at the beginning of July.

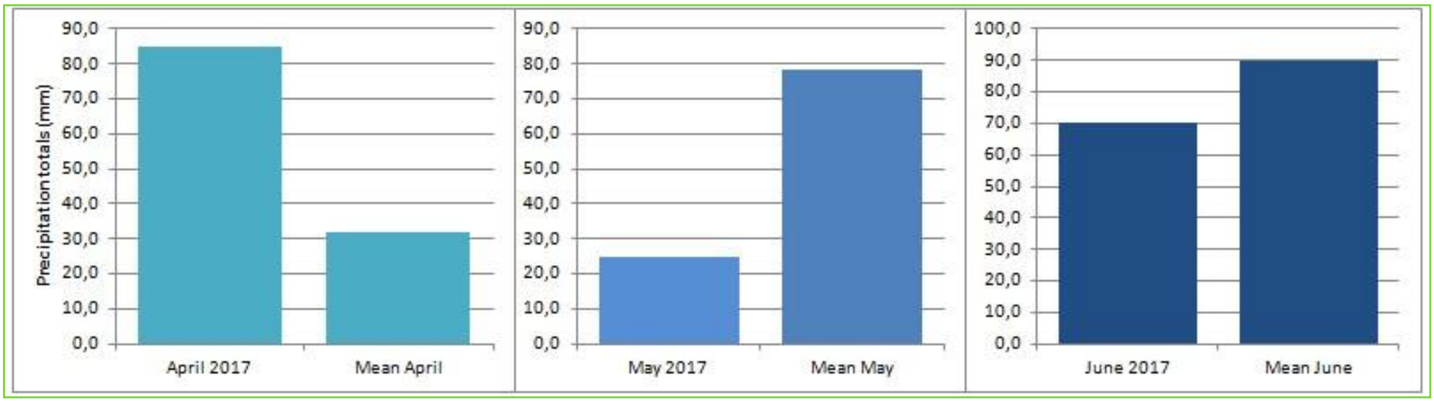

Figure 26 : Total precipitations (mm) in April, May, June 2017 and mean total precipitation in April, May, June from 1971 to 2016 (pogodynka.pl)

4. Discussion

The water quality in the Sulejow reservoir is threatened by the anthropogenic activities and mainly by important nitrogen and phosphorus inputs coming from the catchment ; cyanobacterial blooms occur during summer. The cyanobactoria can produce harmful toxins for the ecosystem and the living organisms. Consequently, sanitary problems induce socio-economical issues with a loss of the touristic potential of this area. Thus, it is very important to solve these problems by the implementation of ecotechnical solutions. Previous research showed that the hydrobiomanipulation is an interesting way to improve the water quality in the reservoir. Therefore, the goal of the present study is to continue improving the knowledge about the functioning of this reservoir in order to adjust and evaluate the efficiency of this innovative method, to make it, as efficient as possible.

For several years, many studies have focused on trophic relationships between fish, zooplankton and phytoplankton, in freshwater ecosystems, in order to improve water quality and protect these sensitive ecosystems which are endlessly menaced by the anthropogenic activities. Assuming the fish as the principal consumer of zooplankton and large cladocerans such as *Daphnia* in temperate reservoirs, Zalewski *et al.* showed in 1990 that the fry density is the most important component responsible for the interaction between algae and zooplankton and consequently, determining largely the water quality. If the fish predation pressure on the zooplankton is too important, their biomass collapse dramatically as well as the water quality. Indeed, without a sufficient zooplankton pressure on the phytoplankton, this one and especially the cyanobacteria will drastically develop. To avoid this phenomenon, and to obtain a good balance in the entire trophic pyramid, the fish population must be controlled. Removal of zooplanktivorous fish and/or stocking of predatory fish can be applied as a biomanipulation method but an analogous effect can be obtained by water level manipulation in the Sulejow Reservoir (Zalewski *et al.* 1990a). It is the concept of hydrobiomanipulation.

Water level fluctuations have an impact on the recruitment success of fish species using the littoral zone as habitat for reproduction (U.Kahl *et al.*, 2008). Izydorczyk *et al*. (under publication) have also showed that YOY fish recruitment depends on the shallow littoral areas and can be regulated by manipulation of the water level. Indeed, this last parameter is positively correlated with the diversity of littoral habitats, enabling larger densities of juvenile fish to occur. The roach is a very successful and abundant species in many European lakes. It is a single-spawning fish with a short spawning period which is used to spawn in the shallow littoral, very close to the surface. The reduction of the water level shortly after its spawning period has a strong impact on its recruitment success and the availability for juvenile refuges (U.Kahl *et al.*, 2008). The roach represents one of the most important predation pressure on zooplankton in the Sulejow Reservoir, that's why, it seems interesting to start the hydrobiomanipulation protocol just after its spawning period, for a few days. Nonetheless, it is also important to have more biological knowledge about this period, to choose the best moment to reduce the water level in order to do not disturb their spawning behaviour and reduce their reproductive success properly.

Therefore, the first and innovative step of the project was to determine the number of eggs laid on the littoral vegetation in four natural sites in the reservoir. Firstly, the results showed that this number is connected with the water temperature. As previous studies have already shown, the spawning period did not start when the water temperature is below 10°C (Zalewski *et al.*, 1990a). For instance, even if some fish started spawning in some sites of the reservoir on the 5th of May, the low water temperature in Tresta may induce a delay in the spawning period in this area. Moreover, the bad weather conditions of this year, with low temperature and heavy rain, at the end of April induced a delay in the roach spawning period. Usually, the roach spawn earlier in the season and before the common or silver bream. This year, the two species have probably spawned at the same period and consequently, the hydrobiomanipulation did not only reduce only the roach reproductive success.

These first experimentations have also shown that, at the end of the spawning period, a significant difference between the number of eggs laid in Tresta and the three other sites was observed. In this area the number of eggs per gram of dry vegetation was almost twice numerous than in the other areas. However, it is important to notice that the results cannot be exhaustive and have to be analysed carefully. The reservoir is a complex ecosystem which has to be studied as a whole. Even if the number of eggs was significantly higher in Tresta, it is not enough to admit that the fishes prefer spawning there. The number of eggs laid on the littoral vegetations is connected with the density of vegetation present. Because of the reconstruction of the banks of Tresta Bay, the littoral vegetation is poorer in this area than in other sites like Bronislawow East for example. Consequently the fishes have less spawning choices. While in Tresta the eggs may be more concentrated on some favorable macrophytes, in Bronislawow East they must be sprinkled on all vegetation. We can think that the fishes are changing their behavior according to their environment. Even if they prefer avoiding to spawning at the same place than another partner, they will do it if their environment does not provide more choices. Moreover, we noticed a better efficiency of the hydrobiomanipulation on young and dressed littoral vegetation. When the macrophytes are old or do not have a port erected, they float and the eggs do not dry up.

Nonetheless, this data is useful to determine the beginning of the water level decrease more accurately. Indeed, previously, the first day of the hydrobiomanipulation protocol was estimated after several visual observations of the eggs laid on the shoreline zone, to determine the beginning and the end of the spawning period. The present study provides, for the first time, accurate data about the number of eggs laid at four areas of the reservoir at the beginning and at the end of the spawning period. It allows estimating when the number of offspring is enough and corresponds to the end of the spawning period. Being the first experiment suchlike, the results cannot be compared with previous ones. However they represent the first reference and could be compared with the next similar studies. The reservoir is studied according to numerous ways with a long-term monitoring, that's why this new data is interesting to acquire more knowledge about the biological functioning of the ecosystem and to see if this parameter is stable or not during the time. However, the reservoir is such a huge ecosystem, dependant on so many environmental parameters than we cannot estimate the number of eggs laid in the entire reservoir.

The number of juvenile fish and the specific wealth have been studied in the same four natural sites at the beginning of June and at the beginning of July. Similar experiments have already been made in the Sulejow Reservoir but just at one site. These samplings are more representative of the entire juvenile fish population living in the reservoir. Being impossible to determine with rightness the number of eggs laid and the number of juvenile present in the entire reservoir, it is, unfortunately not possible to determine the rate of elimination of the zooplanktivorous fish caused by the hydrobiomanipulation. However, the water level fluctuation was necessarily responsible for a decrease of the fish reproductive success, that's why it is interesting to evaluate the effects of this lower abundance on the other communities as we can read farther.

Moreover, the results provide interesting data about the composition and the density of the juvenile fish community. The cyprinids species, namely roach, silver bream and common bream, dominated the samples in terms of density. Some predator species have also been observed and mainly perch and pike perch belonging to the Percidae family. Once again, the results showed a high rate of error probably due to the behavioural traits of the juvenile fish. Indeed, the YOY are not really sprinkled in the shoreline zone, they form some groups, that's why a very important number of individuals can be caught in one time. The density of juvenile fish was important during the first sampling, about 103 ind.m², as well as the density was more than ten times lower at the beginning of July (8,6 ind.m²). By comparison with previous data, we can observe than this decrease in the season is a typical phenomenon (Izydorczyk *et al*., under publication). Several biotic and abiotic parameters, like predation, food availability, weather conditions may explain this reduction in the number of fish in one month.

The goal of the reduction of the fish recruitment is not only to improve the water quality but also to generate better life conditions for the fish. Indeed, Zalewski *et al*. showed in 1990, that the growth and sizes of fry were connected with the fry density. In other words, a high fry density induces a reduction and homogenization of the fry size whereas a lower fry density induces a bigger fry size. This phenomenon is probably due to sharp declines in the density of cladocerans when the fry density is too high. This study showed that the optimal density of perch was up to 8 ind.m², regarding water quality and the maximal growth of the individuals. In the present project, the juvenile density results at the beginning of July were about this threshold. Hence, we can highlight the good management of the hydrobiomanipulation's method in the reservoir.

Lake of time, the zooplankton community was studied only in Tresta. The zooplankton density in this area was high in the mid-May with 263 ind.L^{-1} dominated by rotifers. They were replaced by small and then large cladocerans and copepods. *Daphnia longispin*a, large filtering species, had the highest biomass at the end of June (17,86 mg.L^{-1}). The biomass of cladocerans, mainly *Daphnia*, was almost similar than the biomass observed in 2006 at the same period with a water level decrease of about 40 cm (Izydorczyk *et al*., under publication). However it is higher than in 2007 when the water level was just decreased of about 20 cm. The biomass of *Daphnia* was included between 0,14 and 17,86mg.L^{-1} in 2017 as well as it was included between 5 and 12 mg.L^{-1} at the same period, in 2007. Therefore, the reduction of the water level may have a good influence on the development of large filtering zooplankton like *Daphnia*, probably due to a reduction of the zooplanktivorous fishes. Indeed, a correlation can be observed between the reduction of the zooplanktivorous fish abundance throughoutthe season and the development of large filtering zooplankton. Thus, the hydrobiomanipulation seems to be efficient on these two first trophic level and steady in the time.

However, according to the graph below (Figure 27) showing the biomass of different group of phytoplankton during the season in Tresta, a high development of diatoms can be noticed in the middle of May. It was replaced by green algae, cryptophytes and cyanobacteria along the season. Since the end of June, the phytoplankton community was dominated by cyanobacteria. They represented 63% of the total phytoplankton biomass at this date. Consequently, an algal bloom was visible near the dam, where the water was the more stagnant. Thus even if the biomass of filtering zooplankton increased with the reduction of zooplanktivorous fish abundance, a cyanobacterial bloom occurred earlier than usual. However, we can think that this development is still limited but the high density of *Daphnia*.

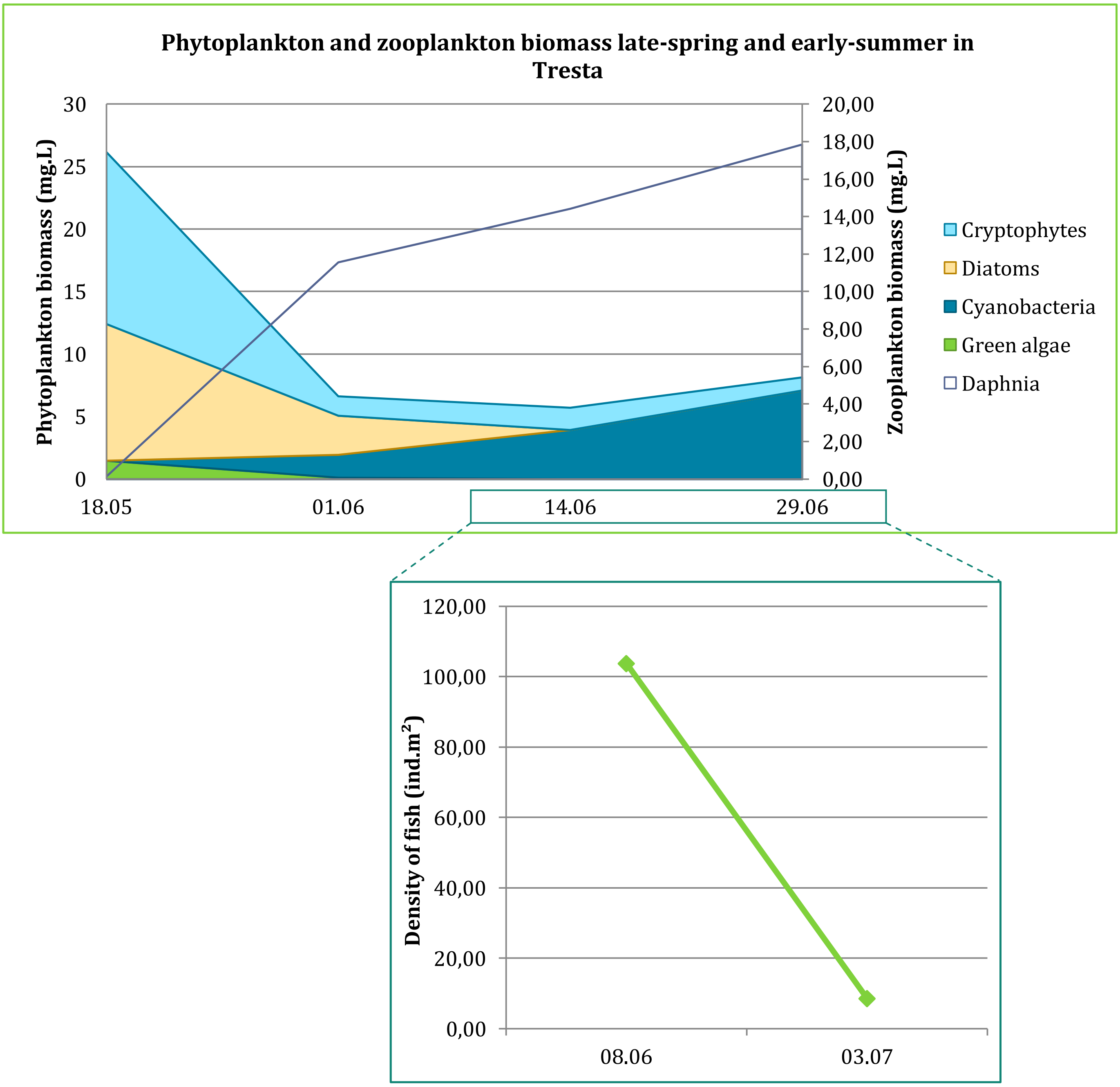

Figure 27 : Graphs showing the phytoplankton and zooplankton biomass and the density of fish

It is important to notice that this algal development is not only connected with biotic parameters like the fish predation pressure but also with abiotic parameters. It is positively correlated with a high water temperature, long water time retention or a high concentration of phosphorus. Indeed, an increase of water retention time from 10 up to 100 days results in a six-time increase of cyanobacterial biomass (Tarczyńska *et al.*, 2001). Moreover, the major environmental factor which determines the intensity of cyanobacterial bloom is the phosphorous availability according to Izydorczyk *et al.* (2008). However, even if the hydrobiomanipulation can provide a better balance in the trophic cascade and consequently reduce the risk of algal blooms, Zalewski *et al.* (1990) showed that the abiotic parameters influence the biotic dynamics. The weather conditions of this year were especially fluctuant with heavy rain and strong wind in early-spring and early-summer. A correlation between the phosphate concentration measured in the water samples and the total precipitations could be observed. Indeed, the rainfall may transport a high concentration of phosphorus from the catchment to the reservoir. The phosphorus is the main factor of eutrophication. Thus, the specific weather conditions of this year are the most likely reason of the previous cyanobacterial bloom development, hiding the benefits of the hydrobiomanipulation.

Unfortunately, the 3-months period of the study was not enough to have comparable results with the previous years data about the cyanobacterial biomass in function of the total phosphorus concentration. This data could be interesting to determine if the cyanobacterial biomass was lower or not that expected according to the total concentration of phosphorus. In this case, the benefits of the hydrobiomanipulation could explain this reduction. Nevertheless, this correlation is based on the average data of a 6-month period. Therefore, the present project should be implemented on a longer period to obtain exhaustive and more representative data.

Finally, with the long-term monitoring of about more than 40 years, the Sulejow Reservoir is a model in which one ecological solutions are implemented. It seems important to continue studying it in order to understand its functioning as good as possible and to develop new innovative solutions like the hydrobiomanipulation. The knowledge sharing is essential to improve the water quality and to protect the freshwater ecosystem.

Conclusion

The Sulejow Reservoir is an artificial lake built in 1974 in the lowlands of Central Poland, usually used as touristic area. An usual development of cyanobacterial bloom develops in summer threatening the proper functioning of the reservoir as well as the human health. To solve the socio-economical issues generated an innovative biomanipulation method has been implemented in the reservoir for several years. Based on the water level fluctuations, this method follows the concept of Ecohydrology (Zalewski, 1990) which is focused on the control of the biological processes by the hydrological dynamics and reciprocally. The present study had for main goal to adjust and evaluate the current efficiency of this technique named hydrobiomanipulation. It is based on the reduction of the water level in the reservoir shortly after the spawning period of the most important zooplanktivorous fish, main predator of zooplankton. The decrease of the water level allows drying up the eggs just laid on the vegetation and consequently reducing the fish reproductive success. The decrease of their abundance should allow a better development of the filtering zooplankton community, which by grazing and filtering the phytoplankton would reduce the risk of algal bloom.

The present project provides more data about the spawning period of *Rutilus rutilus*, one of the most important predator of filtering zooplankton in the Sulejow Reservoir. The number of eggs laid on the littoral vegetation in four littoral areas of the reservoir was counted at the beginning and at the end of the spawning period. The number is very variable according to the site and is dependent on the density of vegetation. This data is important, as a background for the next years, to determine when the decrease of the water level should be started. Consequently the water level decrease was about 40 cm from the 11th of May and during a few days, inducing a loss of the fish reproductive success. The monitoring of the number of juveniles in the same four areas showed a decrease of the fish density between the beginning of June and the beginning of July with an average density of about 8,6 ind.m^2. According to previous research, this density is around the optimal number of the young-of-the-year (YOY) density which does not reduce the zooplankton population and which allows the best environmental conditions of development for the fish population. Moreover, the decrease of the number of juvenile throughout the season seems to be correlated with a good development of large filtering zooplankton like *Daphnia*. However, a previous cyanobacterial bloom developed at the beginning of July. The fluctuant and specific weather conditions of this year with heavy-rain in early-spring and early-summer may be correlated with high phosphorus concentration inputs into the reservoir from the catchment. The phosphorus is the main factor of eutrophication that’s why, the weather conditions is the most likely reason of the previous cyanobacterial development.

To conclude, the hydrobiomanipulation is still an efficient method which can be applied in a shallow lake like in the Sulejow reservoir, to improve water quality. Nonetheless this kind of ecosystem is dependent on numerous biotic and abiotic factors. Its efficiency could be hidden by the changing abiotic parameters. Moreover, the hydrobiomanipulation is not the only method which can allow obtaining a better water quality in the reservoir. It has to be combined with other solutions like buffer zones for example, to obtain the best water quality as possible. Therefore, it is important to continue studying the functioning of the reservoir every year to develop and share ecological solutions all around the world.

This internship was very interesting and knowledge-rich for me. I learnt the concept of Ecohydrology and the implementation of an innovative method. I also learnt a lot of things about the management of a reservoir and the procurement of new data in order to acquire more knowledge about the functioning of the proper ecosystem. From the technical point of view, I acquired several knowledge about the ecology, biology and life development of different fish species. I also learnt in laboratory how identifying several species of zooplankton and how analysing water samples. I achieved the main objectives of the project : I provided new data useful for the next years and I filled up the database about the juvenile fish in order to estimate the current efficiency of the method. The data about the number of eggs as well as the number of juveniles should be used in later research to still improve the technique or to develop new ones. It is useful for the scientists of the centre. Moreover, my work will be presented on a poster during the international conference of Warsaw in September 2017.

My mentor was really busy, that’s why I had to work alone on my project. It was difficult to have some answers or working track about it. However, it was also rewarding, because I learnt how to work by myself, reading a lot of publication or taking the initiative to ask the point of view of other scientists of the centre. All of them were very helpful. Finally, it was also a good experience to be completely autonomous on the project and to manage it as I wanted. This experience abroad taught me new methods and work mode. Even if the work conditions are different, I adapted myself to work in their way and to become more open-minded. After this internship I’m convinced I really like the scientist research, however, I would like also to learn more about working in engineering consultancy that’s why I will orientate the research for my next internship towards this kind of plant.

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Table of figures

Annex

Annex 1 : Presentation of the host organization

The European Regional Centre for Ecohydrology is an international institute of the Polish Academy of Sciences. The agreement about the establishment of the Centre under the auspices of UNESCO was signed on the 8th of March 2006 in the UNESCO headquarters in Paris by the Director General of UNESCO, Koichiro Matsuura, and the Minister of Science and High Education of Poland, Michal Sewerynski (erce.unesco.lodz.pl). It emerged from the International Centre for Ecology (ICE) based on Ecological Bioenergetics developed in the 1970s through the International Biological Programme (IBP). This last programme favoured the dialogue between ecologists and hydrologists in the 1990s and consequently the emergence of Ecohydrology concept. Then, it was formulated and developed in the phases V ("Ecohydrology, engineering harmony for a sustainable world") and VI ("Water education, key for water security") of the framework of UNESCO-International Hydrological Programme (IHP). This intergovernmental programme, founded in 1975, is devoted to water research and water resources management. It is implemented in six-year programmatic time intervals or phases (en.unesco.org).

The aims of the Centre are diverse:

- Develop international and national research focused on interactions between hydrological, biogeochemical and biological processes at the catchment scale in order to protect and restore freshwater resources in the framework of the UNESCO International Hydrological Programme.
- Deliver tools for implementing the European Water Framework Directive as part of Poland's national cooperation.
- Co-operate with various Polish and international institutions in order to link science with policy and management. It is for example involved in three LIFE+ projects including "EKOROB: Ecotones for reducing diffusion pollution" (Figure 28) or "EH-REK : Ecohydrologic rehabilitation of Arturowek recreational reservoirs (in Lodz) as a model approach to rehabilitation of urban reservoirs. It is also involved in a European project (EXPEER : Distributed Infrastructure for EXPErimentation in Ecosystem Research) and a series of national projects.
- Share environmental protection knowledge with international scientists, policies but also with the local population and the students. Indeed, the agreement signed between the President of the Academy of Science and the Rector of the University of Lodz allows the implementation of new dimensions of education at international and national levels.

Scientists from several disciplines (hydrobiology, river ecology, environmental chemistry...) work in collaboration at the Centre but also at the Faculty of Biology and Environmental Protection (University of Lodz). The research is included in different projects as explained before, and results in the publication of scientific paper. The Centre is involved in the publication of the international "Ecohydrology & Hydrobiology journal" that aims at advance Ecohydrology. Moreover, it is involved in a lot of regional, national and international cooperation. It is the organizer of the international Symposium "Ecohydrology for circular economy and nature-based solutions towards mitigation/adaptation to climate change" which will take place in Warsaw at the end of September 2017.

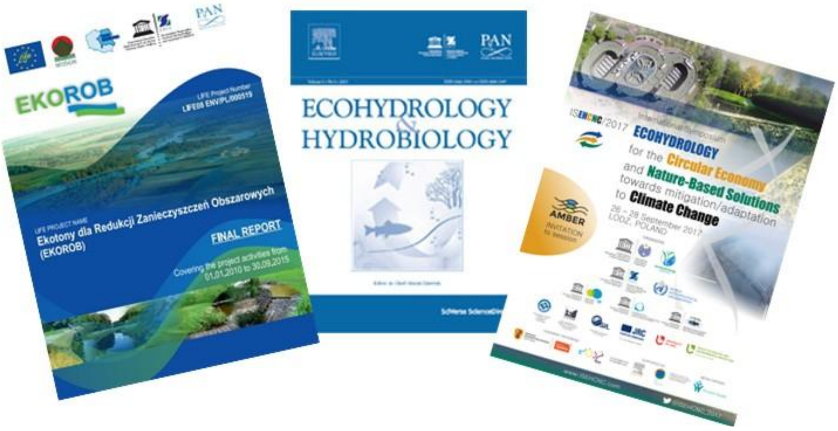

Figure 28 : Illustration of the ERCE projects involvement

Annex 2 : Field record of the 5^{th} of May

Field trip n°2 : Sulejow Reservoir	**5th May 2017 11:25am to 3.40pm Cloudy Water level above the sea level : 166,77 m**		
Tresta Bay Point n° 55 (GPS) 11:25	Elevation : 975 ft Distance : 0,26 mi N 51°27,173 E 019°59,648	11,1°C 10,91 mg/L (O2)	No eggs neither in natural nor artificial substrate. Always the last place where the fishes spawn. + Adding 2 news artificial substrate
Island Point n°56 12 :40 pm (1^{st} Sampling)	Elevation : 225 ft Distance : 3,57 mi N 51°25,950 E 019°55,333	12,3 °C 10,34 mg/L (O2) 12,5 °C 13,46 mg/L (O2)	1^{er} day of the spawning period at this place. Vegetation : Turzyce (Carex). Eggs only in the old vegetation.
Barkowice mokre Point n°58 2pm (2^{e} sampling)	Elevation : 579 ft Distance : 6,03 mi N 51°24,367 E 019°52,778	13,1 °C 8,26 mg/L (O2)	Vegetation : Manna mielec (Poacea : Glyceria maxima) Eggs only in the old vegetation.
Bronislawow West Point n°59 3 pm (3e sampling)	Elevation : 325 ft Distance : 3,26 mi N 51°26,801 E 019°55,446	Problem with the electrod.	Végétaux : 2 différents : Turzyca (carex) et trzcina (phragmites) We added a new artificial substrate
Bronislawow East Point n°60 3 : 35pm (4e sampling + 5e in a close artificial substrate)	Elevation : 513 ft Distance : 3,14 mi N 51°26,678 E 019°55,640	Problem with the electrod.	Vegetation : Turzyca (carex) et trzcina (phragmites) A lot of eggs in the close artificial substrate.
Further information : The water temperature is hotter allowing the beginning of the spawning period in some areas in the reservoir : it's the first day of the spawning period. The samplings were done in Barkowice, Island, Bronislawow East and West but not in Tresta because of the low water temperature in this last zone.			

Annex 3 : Field record of the 8th of May

Field trip n°3: Sulejow Reservoir	**8th May 2017 11:40am to 16:20pm Cloudy and Windy Water level above the sea level : 166,80 m**		
Bronislawow West 12:22 (Sampling in the natural and artificial zone)	11, 3°C 8,87 mg/L (O2) Water level : 70 cm	Photo : in the line of the trees eaten by the beavers.	Eggs were attached only in the recent artificial substrates, not in the old ones. It is important to put the artificial substrate only the first day of the spawning period, else, they are not used by the fishes.
Bronislawow East 13 :00 pm (Sampling in the natural and artificial zone)	11, 9°C 8,68 mg/L (O2) Water level : 70 cm	Photo : 3 rakes and half from the tree eaten by the beaver.	
Island 13 :42pm (Sampling in the natural zone)	13, 7°C 10,72 mg/L (O2) Water level : 80 cm	Photo : in the hole of the vegetation in front of the pile of wood debris.	
Barkowice 14 :15 pm (Sampling in the natural zone)	13, 8°C 7,32 mg/L (O2) Water level : 60 cm	Photo : 50 cm of the gray pole near the green boat.	
Tresta Bay 15 :38 pm (Sampling in the natural zone)	13,1°C 8,61 mg/L (O2) Water level : 80 cm	Photo : in front of the 2 birchs	
Further information : The water temperature was lower, we didn't see the fishes spawning. It's the end of the spawning period. The water-level will be decreased in 2 or 3 days.			

Annex 4 : Raw data of the number of eggs

Experiment 1	05.05					08.05				
Bronislawow East		Sum	Nbr of eggs/sample	Grams	Nbr of eggs/g		Sum	Nbr of eggs/sample	Grams	Nbr of eggs/g
	Lot 1	305	512	42,99	12	Lot 1	2181	2387	39,69	60
	Lot 2	203	410	44,21	9	Lot 2	824	1030	56,7	18
	Lot 3	410	617	37,9	16	Lot 3	1253	1459	58,01	25
	Bottom	828	207			Bottom	1032	206		
	Nbr total of lot : 4	Mean nbr egg/sample	513	Mean nbr egg/g	12	Nbr total of lot : 5	Mean nbr egg/sample	1626	Mean nbr egg/g	34
Island		Sum	Nbr of eggs/sample	Grams	Nbr of eggs/g		Sum	Nbr of eggs/sample	Grams	Nbr of eggs/g
	Lot 1	356	368	61,8	6	Lot 1	569	1140	67,23	17
	Lot 2	614	626	45,99	14	Lot 2	2657	3228	49,39	65
	Lot 3	1118	1130	53,99	21	Lot 3	1175	1746	59,29	29
	Bottom	81	12			Bottom	4000	571		
	Nbr total of lot : 7	Mean nbr egg/sample	708	Mean nbr egg/g	13	Nbr total of lot : 7	Mean nbr egg/sample	2038	Mean nbr egg/g	37
Barkowice Mokre		Sum	Nbr of eggs/sample	Grams	Nbr of eggs/g		Sum	Nbr of eggs/sample	Grams	Nbr of eggs/g
	Lot 1	486	527	135,6	4	Lot 1	821	1192	43,4	27
	Lot 2	654	695	116,6	6	Lot 2	904	1275	70,07	18
	Lot 3	328	369	142,5	3	Lot 3	963	1334	45,86	29
	Bottom	246	41			Bottom	2228	371		
	Nbr total of lot : 6	Mean nbr egg/sample	530	Mean nbr egg/g	4	Nbr total of lot : 6	Mean nbr egg/sample	1267	Mean nbr egg/g	25
Tresta		Sum	Nbr of eggs/sample	Grams	Nbr of eggs/g		Sum	Nbr of eggs/sample	Grams	Nbr of eggs/g
	Lot 1					Lot 1	2372	3648,2	48,15	76
	Lot 2					Lot 2	2314	3590,2	34,76	103
	Lot 3					Lot 3	2552	3828,2	46,94	82
	Bottom					Bottom	12762	1276,2		
	Nbr total of lot					Nbr total of lot : 10	Mean nbr egg/sample	3689	Mean nbr egg/g	87

Experiment 2	08.05				
Bronislawow East (Natural)		Sum	Nbr of eggs/sample	Grams	Nbr of eggs/g
	Lot 1	2181	2387	39,69	60
	Lot 2	824	1030	56,7	18
	Lot 3	1253	1459	58,01	25
	Bottom	1032	206		
	Nbr total of lot : 5	Mean nbr egg/sample	1626	Moyenne nbr œufs/g	34

Bronislawow East (Artificial)		Sum	Nbr of eggs/sample	Grams	Nbr of eggs/g
	Lot 1	1171	1233	56,67	22
	Lot 2	856	918	46,16	20
	Lot 3	847	909	38,1	24
	Bottom	310	62		
	Nbr total of lot : 5	Mean nbr egg/sample	1020	Mean nbr egg/g	22

Bronislawow West (Natural)		Sum	Nbr of eggs/sample	Grams	Nbr of eggs/g
	Lot 1	1223	1566	39	40
	Lot 2	1630	1973	26,18	75
	Lot 3	1805	2148	36,58	59
	Bottom	1717	343		
	Nbr total of lot : 5	Mean nbr egg/sample	1896	Mean nbr egg/g	58

Bronislawow West (Artificial)		Sum	Nbr of eggs/sample	Grams	Nbr of eggs/g
	Lot 1	2027	2190	68,12	32
	Lot 2	1448	1611	70,1	23
	Lot 3	1492	1655	59,12	28
	Bottom	1300	163		
	Nbr total of lot: 8	Mean nbr egg/sample	1818	Mean nbr egg/g	28

Annex 5 : Photos of the water level fluctuations

	High water level (08.05)	Low water level (18.05)
Barkowice	 60 cm	 20 cm
Bronislawow East	 70 cm	 30 cm
Bronislawow West		

	70 cm	30 cm
Island	 80 cm	 40 cm
Tresta Bay	 80cm	 40 cm

Annex 6 : Field record of the 8th of June

Sampling nbr 1 **Date : 08/06/2017** **Time : 12:45 – 19:40**	Weather : Sunny/Cloudy Wind : SW – 2-3°B	*Substrate*
Site 1 : **Island** 13 : 30 GPS : pt 61 N 51° 27,068 E 019° 59,962 Secchi : 70 cm	Average water depht : Bord : 35cm – A 10 m : 80 cm Water temperature : 22,7°C O2 concentration : 8,87 mg/L – 103 % Bank characteristics (slope, natural/artificial, vegetation) : No macrophytes in the sample area. Always more juveniles in the opposite bank.	% vegetation : x % gravel : x % sand : 100 (gray) % silt : x other :
	Sample 1 : bank where we took the egg samples 35 m2	Juvenile : 1 pike Adult : 6 roach + 2 tench + 1 spined loach (Cobitis taenia) + 1 perch
	Sample 2 : bank where we took the egg samples 45 m2	Juvenile : 1 cyprinidae Adult : 69 roach + 3 perch
	Sample 3 : Opposite bank 35 m²	Juveniles : a lot -> to count and to identify -> 5% were taken in the bottle -> a lot of cyprinids Adult : 20-30 roach + 5-10 perch + 2-5 bleak
	Sample 4 : Opposite bank 40 m²	Juveniles : we took 100% -> to count and to identify -> a lot of predators Adult : 2 roach + 1 Cobiti
Site 2 : **Barkowice** 15 : 20 GPS : 62 N 51° 24,360 E 019° 52,771 Elevation : 650 Ft Secchi : 50 cm	Average water depht : Bord : 5cm – A 10 m : 110 cm Water temperature : 21,2 °C O2 concentration : 18,35 mg/L – 206 % Bank characteristics (slope, natural/artificial, vegetation) : Gentle slope, clear sand near the bank. Macrophytes near the bank (to identify) + another species submerged, sprinkled	% vegetation : 2 % gravel : x % sand : 2 first meters, sand clear and then grey % silt : other :
	Sample 1 : 40 m²	Juvénile : to count Adult : 22 roach + 1 perch
	Sample 2 : 45 m²	Juveniles : to count (very small) Adult : 11 roach + 1 wzodvega + 1 Jazgarz + 1 common bream + 1 perch Observations : a lot of juvenile are present at 20m farther than the bank. We cannot catch them.
	Sample 3 : 40 m²	Juveniles : a lot, to count, they are in 2 bottles (2,5% of the sample in each) Adult : Environ 10 roach
Site 3 : **Bronislawow East** 17 : 15	Average water depht : Bord : 20cm – A 7 m : 130 cm Water temperature : 22,3°C O2 concentration : 9,06 mg/L – 104,3 %	% vegetation : macrophytes near the bank (Trzinne) + rolestnica sprinkled + nenuphea % gravel : % sand : 100% clear sand

GPS : 63 N 51° 26, 686 E 019° 55,657 Elevation : 521 Ft Secchi : 1,55m	Bank characteristics (slope, natural/artificial, vegetation) :	% silt : other :
	Sample 1: 30 m²	Juvniles : to count and identify -> 2 bottles, 5% of the sample in each Adult : 15 roach + 2-3 bleak
	Sample 2 : 30 m²	Juveniles : to count and identify -> 2 bottles, 5% of the sample in each Adult : >20 roach + 10 perch + 1 bream
	Sample 3 : 30 m²	Juveniles : less but they were less macrophytes at the bottom Adult : 5-6 roach + 5-6 perch
Site 4 : **Tresta** 18:40 GPS : 64 N 51° 27,198 E 019° 59,443 Elevation : 571 Ft Secchi : 2,35m	Average water depht : Au bord : 30 cm – à 7 m : 130 cm et à 10m : 150cm Water temperature : 22,1°C O2 concentration : 10,87 mg/L – 124,6 % Bank characteristics (slope, natural/artificial, vegetation) : The banks were rebuilted the last year. Just a few favourable place for spawning. Very deep because of the works. Water very clear. Hydrobiomanipulation efficient in this area.	% vegetation : 3 the same macrophyte than in Barkowice (to identify) % gravel : x % sand : 100 % clear sand % silt : x other :
	Sample 1 : 35 m²	Juvniles : to count and identify -> 20 % of the sample Adult : 1 tench + >20 roach + >10 perch
	Sample 2 : 35 m²	Juveniles : just a few Adult : >50 roach + >20 perch
	Sample 3 : 35 m²	Juveniles : 0 Adult : >50 roach + >20 perch
+ : <1 - 1 : 1-5% - 2 : 5-25 % - 3 : 25-50 % - 4 : 50-75% - 5 : 75 – 100 %		

Annex 7 : Field record of the 3rd of July

Sampling nbr 2 **Date : 03.07.17** **Time : 10:50 - 12:10**	Weather : Cloudy / Windy Wind : SW	*Substrate*
Site 1 : Bronislawow East	Water depth (at 10 m from the bank) : 2,20 m Water temperature : 21,4°C O2 concentration : 8,06 mg.L / 91,3% Secchi : 1,5m	% vegetation : % sand : % sand +organic matter : other : Same substrate More potamots (indice 3-4)
Sampling 1 :	Adult : 1 roach + Juveniles to count (+ 1 pikeperch)	35 m²
Sampling 2 :	Adult : 1 tench + juveniles to count (too many individuals, 2 bottles for the same sample)	40 m²
Sampling 3 :	Adult : 2 roach + juveniles to count	45 m²
+ : <1 - 1 : 1-5% - 2 : 5-25 % - 3 : 25-50 % - 4 : 50-75% - 5 : 75 – 100 %		
Site 2 : Island	Water depth (at 10 m from the bank) : 1,20 m (et après très profond) Water temperature : 21,5°C O2 concentration : 11,05 mg.L / 125% Secchi : 75 cm	% vegetation : % sand : % sand +organic matter : other : 2 or 3 species to identify + add on the map (< 25%)
Sampling 1 :	Adult : 2 roach + 2 perch + juvenile to count	45 m²
Sampling 2 :	Adult : 0 + juvenile to count	35m²
Sampling 3 : fait de l'autre côté	Adult : 7 roach + 1 bream (on the bottle) + 2 perch + 1 koza + 1 rozanka	Just predators 35 m²
Other	No potamot	
Site 3 : Barkowice	Water depth (at 10 m from the bank) : 1,75 m Water temperature : 20,5°C O2 concentration : 10,12 mg.L / 111,6% Secchi : 50 cm	% vegetation : % sand : % sand +organic matter : other :
Sampling 1 :	Adult : 2 tench (big) 4 roach 1 Alburnus (on the bottle) + juveniles to count (+ 1 pikeperch)	40 m²
Sampling 2 :	Adult : 2 perch 1 roach 1 zdrega + Juveniles to count (new species	40 m²

	Gobio gobio)	
Sampling 3 :	Adult : 7 roach + 2 perch + Juveniles to count	35 m²
Site 4 : Tresta	Water depth (at 10 m from the bank) : 1,55 m Water temperature : 21,2°C O2 concentration : 13,33 mg.L / 150,4% Secchi : 70 cm	% vegetation : % sand : % sand +organic matter : other : The same
Sampling 1 :	Adult : 7 roach + juveniles to count	20 m²
Sampling 2 :	Adult : 0 + juveniles to count (new species : *Aspius aspius + Leuciscus leuciscus*)	20 m²
Sampling 3 :	Adult : 0 + juveniles to count (in 2 bottles)	20 m²
Other	A lot of individuals in Tresta while the last time we found just a few individuals. This year is very special about the weather conditions with heavy rain in the early Spring and early Summer, which can explain the earlier development of the cyanobacterial bloom. Abiotic parameters influence the biotic parameters.	

Annex 8 : Raw data of the number of juveniles

Raw data : 08.06	Number of the sample	Sampled area (m²)	Nbr of individual in each sample	Projection	Nbr of individual/m²	Perch	Pikeperch	Roach	Common bream	Silver bream	Undetermined bream	Undetermined cyprinidae	Pike (Esocidae)
Island	1	35	1	x	0,03		1						
	2	45	1	x	0,02			1					
	3			8740,00		20	0	8000	320	160	240		
	4	40	327	x	8,18	140	36	112	19	7	12	1	
			9069			160	37	8113	339	167	252	1	0
	Total	155	9069,00		58,51								
Barkowice	1	40	6	x	0,15	1		1					4
	2	45	15	x	0,33	1		2		6	5		1
	3	40	286	11440,00	286,00			31			254	1	
								1240	0	0	10160	40	
			11461,00			2	0	1243	0	6	10165	40	5
		125	11461,00		91,69								
Bronislawow East	1			12140,00		120	60	7100	1260	3440	80	80	
	2			12540,00		40	80	7440	1940	1720	1320	0	
	3	30	286	x	9,53			31			254	1	
			24966		277,40	160	140	14571	3200	5160	1654	81	
		90	24966,00		277,40								
Tresta	1	35	754	3770,00	107,71			2000	0	0	1535	235	
	2	35	17	x	0,49			3			4	10	
	3	35	0	x	0,00								
			3787		53,98	0	0	2003	0	0	1539	245	0
		140	3787,00		27,05								
Total		510	49283,00		96,63								

Raw data : 03.07	Number of the sample	Sampled area (m²)	Nbr of individual in each sample	Nbr of individual/m²	Perch	Pikeperch	Pike	Roach	Common bream	Silver bream	Ruffe	*Gobio gobio*	Grass carp	Asp	Leuciscus leuciscus	Catfish
Island	1	45	242	5,38	76		2	122	8	5	29					
	2	35	102	2,91	20	2		64	3	2	11					
	3	35	108	3,09	45	45	1	12	5							
	Total	115	452,00	3,93	141	47	3	198	16	7	40					
Barkowice	1	40	22	0,55			2	18	2							
	2	40	46	1,15				20	7	13		6				
	3	35	14	0,40	1			13								
	Total	115	82,00	0,71	1	0	2	51	9	13	0	6				
Bronislawow East	1	35	150	4,29	17	4	2	118	7	1			1			
	2	40	382	9,55	23	38	1	307	12	1						
	3	45	39	0,87	29		1	9								
	Total	120	571,00	4,76	69	42	4	434	19	2	0	0	1	0	0	0
Tresta	1	20	258	12,90	3	6		148	50	20	23			7		1
	2	20	554	27,70				220	156	172	2	0	0	2	2	0
	3	20	1605	80,25				756	448	400	1					
	Total	60	2417	40,28	3	6	0	1124	654	592	26	0	0	9	2	1
Total		410	3522,00	8,59												

Annex 9 : Identification of the juvenile fishes

Esox lucius (Pike)

Sander lucioperca (Pike perch)

Perca fluviatilis (Perch)

Gymnocephalus cernua (Ruffe)

Rutilus rutilus (Roach)

1.Leuciscus leuciscus (Dace)- 2. Aspius aspius

Annex 10 : Other missions

- *Monitoring of the fish population*

A monitoring of the fish population is done every year in the Sulejow Reservoir from the middle of June to September, of about 6 times. Two nets of 35 m long each (Figure 29), with different size of mesh are installed before the sunset in the pelagic zone near Tresta bay and near Bronislawow bay. According to the species, the fishes do not have the same behaviour. Some of them prefer going in the littoral zone during the night and in the pelagic zone during the day while other fishes have the opposite behaviour. The migration between pelagic and littoral zone is very important during the night. That’s why it is interesting to install the net just before the sunset and to put it off just after the sunrise to have a representative sample of the fish composition.

I participated to the first sampling of adult fish of the season. We installed two big nets around 8 pm in the Sulejow Reservoir on the 12^{th} of June. After a few hours of waiting, we put them off around 3 am, with all the fishes caught. At the field station, we separated the fishes from the net, identified, measured and weighed all individuals (Figure 30). We mainly found roach, common bream, silver bream, perch, pike perch and ruffe.

This monitoring allows knowing the fish diversity present in the reservoir and adapting the environmental protection. It allows to have a long-term monitoring data about the fish species living in the reservoir and to observe the potential changing of composition linked to a better or a worst water quality for example. It was interesting for me to participate to this sampling in order to learn more about this kind of monitoring.

Figure 29 : photo of the laying net

Figure 30 : Photo of the fishes classified according to the size of the mesh

- *Presentation of my project in the international Symposium of Warsaw*

The European Regional Centre for Ecohydrology is involved in the organization of the international Symposium which will take place in the next 26-28 September. Hundreds scientists from all around the world will come to this international conference in Warsaw. I am very glad to have written an abstract with the help of Pawel Jarosiewicz and made a poster to present my project. The Centre gives me also the opportunity to come to the Symposium in order to meet and learn a lot about international projects for the protection of freshwater resources.

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