Fish assemblages as indicator of the ecological state of Lake Durowskie

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1 INTRODUCTION

Despite freshwater ecosystems occupy only 0.8% of the earth's surface, nearly 16% of the aquatic species live there and it is crucial for human survival. Nowadays, freshwater species and habitats are among the world's most endangered ecosystems. During the last decades, the pressure on aquatic systems due to human activity has increased remarkably. Especially the discharge of sewage water and an increase in recreational activities have led to an enhanced eutrophication of freshwaters (EFWD, 2000).

According to the Environment Agency a big proportion of all European Freshwater bodies are in a high trophic state and hence feature a low water transparency and a low level of biodiversity (Leaf et al., 2002). In order to announce this problem, the European Water Framework Directive (EWFD) came into force in 2000, with the aim of reaching at least a good ecological state in all European surface and groundwater systems until 2015 (EFWD, 2000). To achieve this, various monitoring and restoration measures are required. Several organisms, such as algae and macro-invertebrates, have been categorized according to their ecological requirements in order to provide indicators, which can be widely applied for the determination of different water qualities (Muxika et al., 2007, Orfanidis et al., 2003). An approach that is less common in monitoring approaches is the investigation of fish assemblages. However, due to fish being at the top of the trophic network and because of its role in changing ecosystems, they can play a major role in the monitoring and restoration process.

In natural ecosystems, fish (ichtiofauna) may cause biotic and abiotic changes of freshwater ecosystems:

Abiotic changes

Fish might – directly or indirectly – cause a decrease of water transparency; directly, due to mixing and re-suspension of sediment during feeding close to the bottom and indirectly by the stimulation of planktonic algae growth due to the enhancement of an accelerated nutrient circulation. Ichtiofauna can also affect sediments structure and nutrients exchange within the lake sediments. Fish communities move nutrient stakes from the deep to the pelagic zone. E.g., during the vegetation period, migrating fish species are responsible for the transport of part of the phosphorus available for plankton (Andersson et al., 1988).

Biotic changes

The role of fish as nutrient carrier may enhance the growth of autotrophs such as cyanobacteria, algae and plants. Nevertheless, fish might also reduce their abundance. For example, roach (*Rutilus rutilus*) and common rudd (*Scardinius erythropthalmus*), the only two native species feeding on hydromacrophytes in Poland, forage to up to 15% of the macrophytes biomass built up during one year.

Both abiotic and biotic changes depend on the number, size, and composition of ichtiofauna and the type of sediment in the lake. Hence, fish can be both used to track changes as well as to provoke changes in the system. Different fish species have been applied in bio-manipulation of eutrophicated lakes. This manipulation can be defined as restructuring the food web in ecosystem by adding or removing species which play a key role in the food web of the system, especially predators. The original idea of biomanipulation relies on the regulation of the phytoplankton community by increased grazing of algae by cladocerans after the reduction of planktivorous fish (Gliwicz, 1990). Biomanipulation has been acknowledged as a useful tool in pushing the lake from a turbid phytoplakton-dominated lake into a clear water state with macrophyte dominance and subsequently a reduction of external nutrient loading (Jeppesen et al., 1997, McQueen et al., 1989).

The trophic state of Lake Durowskie in Western Poland has increased remarkably during the last decades and hence requires monitoring and restoration measures according to the EFWD. Additionally, the importance of the lake for tourism and recreational activities further creates the demand of working towards a decrease in trophy. As a consequence, pike (*Esox lucius*) was stocked in 2012 as a tool for restoration. The growth of this holarctic species is mostly affected by temperature, water transparency, productivity, availability of prey and density of other predators. It plays a crucial role in top down structuring freshwater communities: The pike affects phytoplankton indirectly by foraging on the zooplanktivorous fish. Lower zooplanktivorous fish abundance implies higher growth of genera grazing on phytoplankton which leads to a decrease in total phosphorus and nitrogen concentrations.

Additionally, species composition in lakes can be used as an indicator for the trophy of a lake. Lake Durowskie has been object of several monitoring studies during the last years, including the monitoring of indices for macroinvertebrate and algae assemblages to assess the water quality. However, fish assemblages have never been studied in this lake. Hence, data from the top of the food network are required in order to provide a complete image of the effect of the trophy of the lake on species assemblages and to reliably track changes in the ecosystem. In addition, a study of fish assemblages in Lake Durowskie is of special interest to monitor the success of the bio-manipulation measure in 2012.

Derived from that, the aim of this study is to determine the ecological state of Lake Durowskie based on fish assemblages using data from catches of both active and passive sampling in the inflow and the lake as well as historical information on the catches and stockings in the lake. With this data we aim (I) to classify the actual species composition and abundance, (II) to achieve species-specific morphometric data as a basis for long-term comparisons, and (III) to detect changes in the species abundances throughout the last decades.

2 MATERIALS & METHODS

2.1 Study site

During 1st until the 8th of July 2013 sampling of fish assemblages was carried out in Lake Durowskie located at N 52°49’6’’ and E 17°12’1’’ surrounded by the town of Wągrowiec in Greater Poland. This dimictic lake forms part of Golaniecka River lake chain and extents to a catchment area of 236.1 km^2. Durowskie Lake has a glacial origin, which becomes evident in the steep decrease of its shorelines up to a maximum depth of 14.6 m. The mean depth of the lake is 7.9 m. The recent lake has a length of 4 km (North-South axis) and a maximal width of approximately 600 m. It features a surface area of 143 ha.

2.2 Data acquisition

2.2.1 Survey

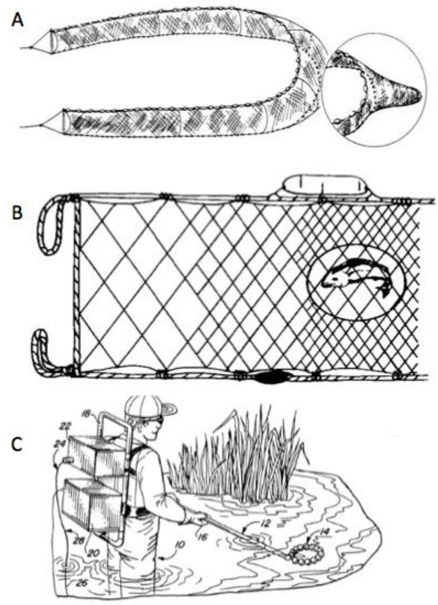

Figure 1. Fishing methods
a) Beach seine net b. gill net mesh sizes
c) electofishing

Sampling was performed throughout the littoral zone of Durowskie Lake and at one sampling point in its inflow - the river that connects Durowskie Lake and Kobylińskie Lake in the North. In order to recover the whole fish assemblage we used active, passive and electrofishing techniques (**Figure 1**). Active net Beach Seine Net (length 40 m, height 2m, mesh-size 6 mm) was used to enclose bay-shaped littoral areas. Furthermore, five passive nets with different lengths and mesh-size (10 m - 1 cm; 10 m - 1.2 cm; 25 m - 4 m; 25 m - 5.5 cm; 40 m - 6 cm) were suspended in the water column for 4 hours to capture fish. Finally, to immobilize and capture fish in the river we used electrofishing, which is an electric-based method efficient in lentic habitats.

All sampled fish were counted, weighted and measured. Total length was measured from the most anterior part of the head to the tip of the longest caudal fin ray when the fin lobes of the tail are pressed together. Total wet weight was measured with four different *Pesola* weight scales (50 g 500g; 1000 g; 40 kg).

2.2.2 Commercial Catch Data

Historical records include data from commercial fishery from 1954 to 2012 at Lake Durowskie. Annual data were recorded on the weight of catches for each species in four different size classes (I: small, II: medium, III: large, IV: biggest).

2.2.3 Stocking Data

Historical records on stocking data were reviewed. These include data from commercial fish stocking from 1954 to 2012 at Lake Durowskie. For each year, data on the amount of fish and the respective species introduced to the Lake were noted.

2.3 Statistical methods

Data were analysed using RStudio 2.15.1.

2.3.1 Survey

For each fish species the average weight and size were calculated separately for river and lake. Weight and size were compared using a two-sided Student t-test for each species which occurred with more than 5 individuals in both lake and river. Jaccard Species Identity (C_j) was applied to determine the similarity in species composition between river and lake. Therefore the number of species which occur both in the lake and the river *j* and the total number of species occurring in the river (*a*) and in the lake (*b*) is needed:

$$C_j = \frac{j}{(a+b)-j}$$

2.3.2 Commercial Fishing data

For all species that are abundant in the historical records a trend analysis was performed. Species were considered as abundant, when their catch size was recorded more than 50 times since 1954. Each size category was counted as separate record. For *Sander lucioperca*, *Tinca tinca*, *Esox Lucius* and *Perca fluviatilis* a linear model was fit to the number of fish catch according to year. Considering the effect of Lake trophy on bream size, for *Abramis brama* a linear model was fit to the catches according to year separately for each size category.

3 RESULTS

3.1.1 Survey

In total 9 species were recorded: *Scardinius erythrophtalmus, Perca fluviatilis, Gymnocephalus cernuus, Gobio gobio, Esox lucius, Blicca bjoerkna, Alburnus alburnus, Abramis brama,* and *Rutilus rutilus.* Among them *E. lucius* and *G gobio* were found only to occur in the river, whereas *G cernuus* was only found in the lake (one record only). The most abundant species in the river is *R. rutilus* with 127 records. In the lake, *P. fluviatilis* dominates with 94, followed by *A. alburnus* with 56 individuals (**Figure 2**).

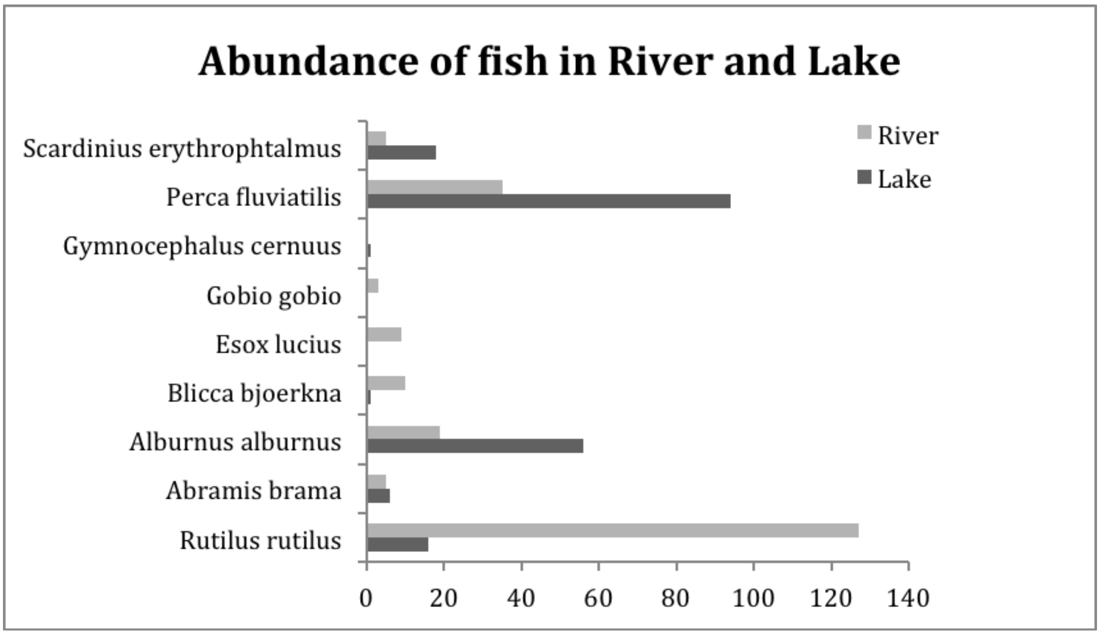

Figure 2: Abundance of the 9 different fish species caught during sampling in Lake Durowskie and the inflow of Lake Durowskie

Taking presence-absence data of species in Lake and River into account, the Jaccard Species Identity is given with 0.66.

In the River, mean sizes of fish varied between 290.4 ± 44.9 mm (mean ± standard error) for *E. lucius* and 108.0 ± 2.3 mm for *S. erythrophtalmus*. Accordingly, the weight was with 256 ± 102.8 g found to be highest for *E. lucius* and lowest for *S. erythrophtalmus* with 15.6 ± 1.9 g. In the Lake, highest sizes were reached with a mean of 162.7 ± 34.1 mm in *A. brama* and minimum sizes with 95.0 ± 0 mm in *G cernuus.* Weight varied between 64.4 ± 33.5 g in *A. brama* and 11.7 ± 1.2 g in *A. alburnus* (**Table 1**).

For the comparison between lake and river, *A.brama, A. alburnus, P. fluviatilis,* and *R. rutilus* were considered. The student t-test revealed significant differences between lake and river in the size for *A. alburnus* ($t = -4.5476$, $df = 59.594$, $p = 2.714*10^{-5}$) and *R. rutilus* ($t = -2.923$, $df = 18.666$, $p = 0.008841$). According to that, both species were found to be significantly bigger in the river (**Figure 3**). No significant difference was detected between the weights of any species. However, the trend is the same, with individuals in the river featuring higher weights.

Table 1. Mean size and weight of all species found in lake and river habitats

River	Size		Weight	
Species	mean	standard error	mean	standard error
Abramis brama	180,60	22,57	92,80	27,96
Alburnus alburnus	135,11	5,28	33,37	12,69
Blicca bjoerkna	124,70	16,51	42,75	8,09
Esox lucius	290,44	44,87	256,11	102,80
Gobio gobio	140,00	30,00	34,00	13,20
Perca fluviatilis	111,54	5,51	22,41	2,44
Rutilus rutilus	149,12	3,67	50,76	2,85
Scardinius erythrophtalmus	108,00	2,30	15,60	1,91
Lake				
Species	mean	standard error	mean	standard error
Abramis brama	162,67	34,14	64,42	33,54
Alburnus alburnus	99,38	5,82	11,70	1,19
Blicca bjoerkna	154,00	0,00	37,00	0,00
Gymnocephalus cernuus	95,00	0,00	13,50	0,00
Perca fluviatilis	104,04	4,44	24,82	7,93
Rutilus rutilus	115,88	10,76	27,35	14,88
Scardinius erythrophtalmus	106,50	3,86	16,39	1,54

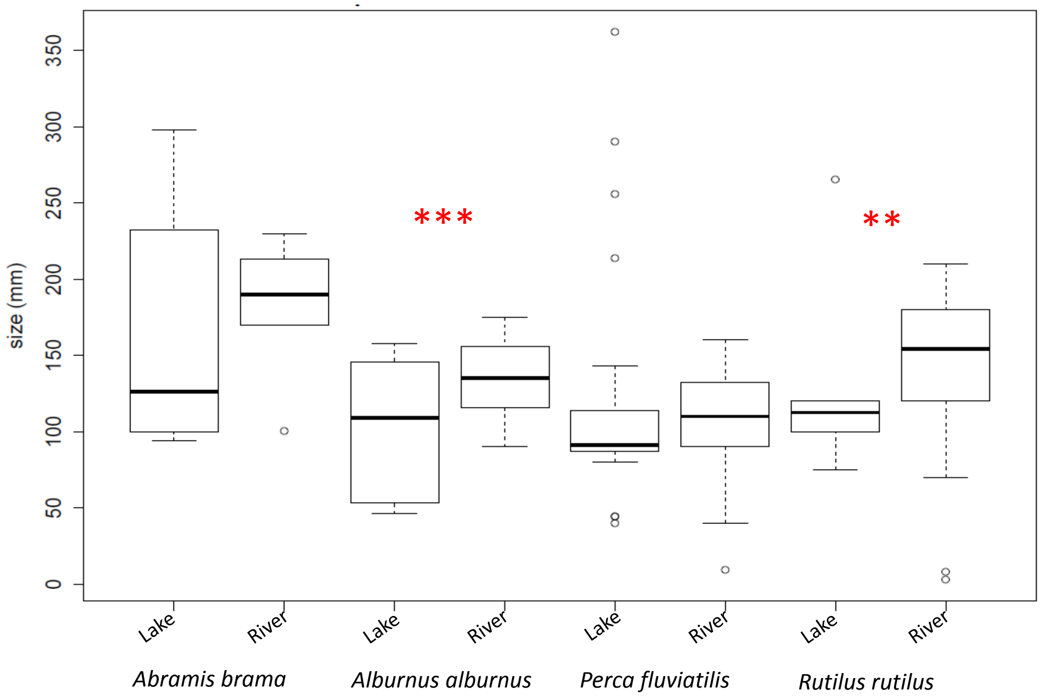

Figure 3. Size comparison between species present at lake and river (***p<0.001, ** p<0.01)

3.1.2 Commercial Catch Data

In total, 18 species were mentioned in the commercial records: *Abramis brama, Alburnus alburnus, Anguilla anguilla, Blicca bjoerkna, Carassius carassius, Coregonus albula, Coregonus laveretus, Ctenopharyngodon idella, Cyprinus carpio, Esox lucius, Hypophthalmichtyhs molitrix, Leuciscus idus, Osmerus eperlanus, Perca fluviatilis, Rutilus rutilus, Sander lucioperca, Silurus glanis,* and *Tinca tinca.*

For *S. lucioperca, A. anguilla, E. lucius and P. fluviatilis* no trend in the weight of catches was found (*S. lucioperca*: df = 61, F(1,61) = 1.99, adj. R^2 = 0.01572, p = 0.01634; *A. anguilla*: df = 141, F(1,141)=3.547, adj. R^2 = 0.01762, p = 0.0673; *E. lucius*: df = 130, F(1,130)=0.985, adj. R^2 = -0.0001147, p = 0.3228; *P. fluviatilis*: df = 75, F(1,75) = 0.5014, adj. R^2 = -0.006604, p = 0.4811). However, for the tench *T. tinca* a significant increase in catches was found (df = 95, F(1,95)=12.46, adj. R^2 = 0.1066, p = 0.0006429) (**Figure 4**).

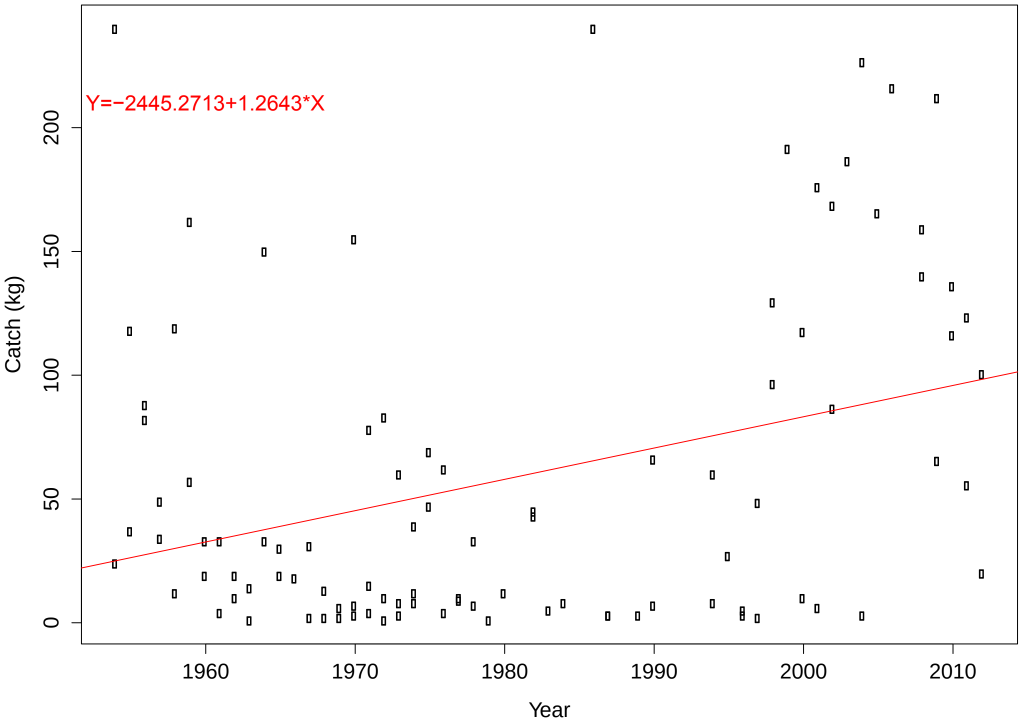

Figure 4. Development of tench (*Tinca tinca)* catches since 1954

The analysis of the development of the catches for *A. brama* revealed a significant decrease in catches for small-sized individuals was found (df = 45, F(1,45) = 15.92, adj. R^2 = 0.2449, p = 0.0002407). Catches of medium-sized and big individuals were not found to have undergone a change over time (*medium*: df = 53, F(1,53) = 0.2259, adj. R^2 = -0.01454, p = 0.6366; *big*: df = 31, F(1,31) = 0.3911, adj. R^2 = -0.0194, p = 0.5363) (**Figure 5**).

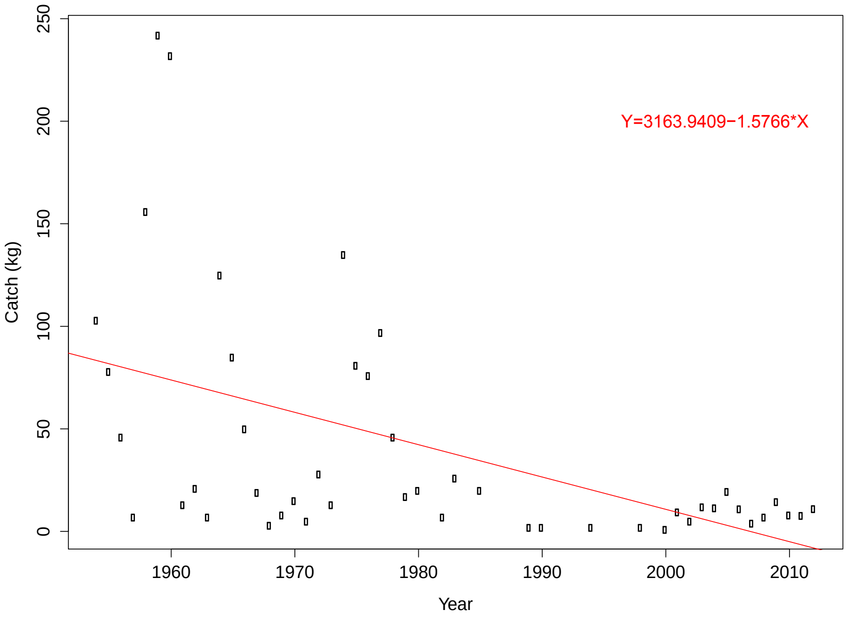

Figure 5. Development of bream (*Abramis brama)* catches since 1954

3.1.3 Stocking Data

In total, 10 species were stocked since 1954: *Abramis brama, Anguilla anguilla, Carassius carassius, Coregonus albula, Coregonus lavaretus, Cyprinus carpio, Esox lucius, Rutilus rutilus, Sander lucioperca,* and *Tinca tinca.* Vendace (*Coregonus albula)* was stocked eight times between 1955 and 2008. Its biggest introduction is dated for 1961 with number 2,900,000. The comparison of the stocking with the actual catches reveals that stocking of Coregonids did not lead to the establishment of Coregonids in the fish assemblage. Since the early 1970's no Coregonid species were caught, with the exception of 2008 (**Figure 6**).

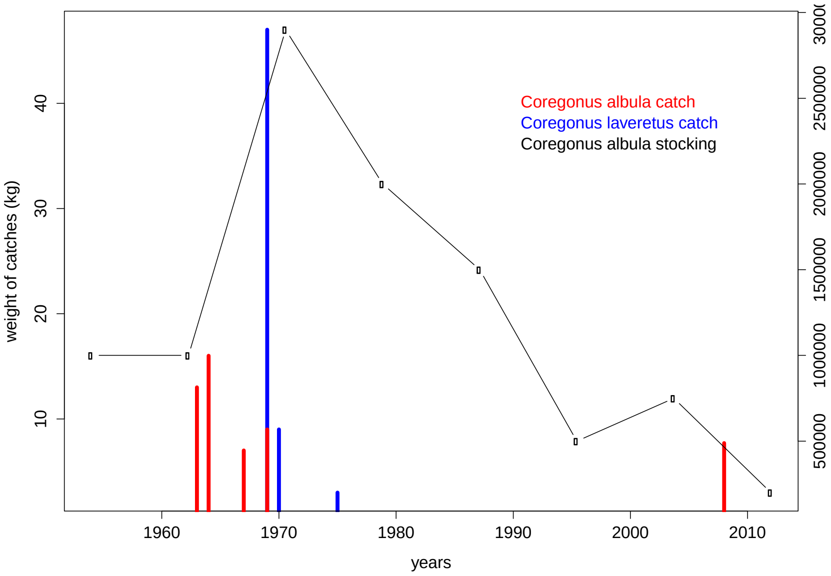

Figure 6. Occurrence of coregonids in Lake Durowskie

(Bars are the catches in kg for both species of coregonids; line shows the stocking in individuals)

Pike (*Esox lucius*) was stocked 19 times until 2012, firstly in 1962 in number of 800. Its biggest introduction is dated for 1999 with a number 520,000. Despite the decrease in stocking effort, catches remained stable during the last decade (**Figure 7**).

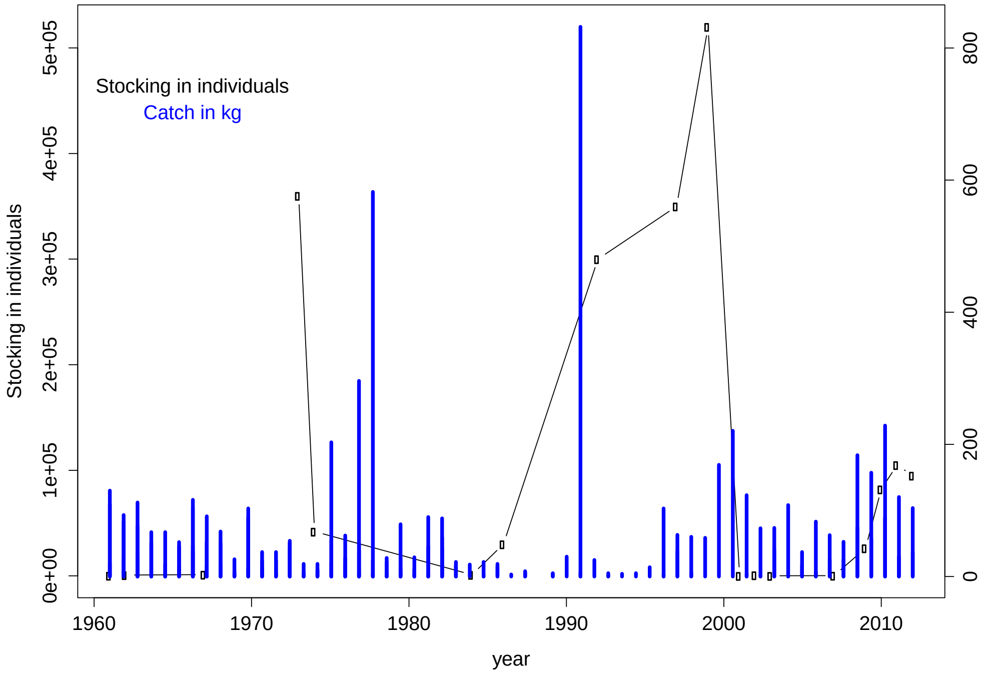

Figure 7. Occurrence of pike (*Exos Lucius)* in Lake Durowskie

(Bars are the catches in kg of pike; line shows the stocking in individuals)

Lavaret (*Coregonus lavaretus*) was stocked only once in 1962 with 21,000 individuals. Common bream (*Abramis brama*) stocked 7 times between 1965 and 1994. The maximum stocking was 15 600 individuals in 1965. Zander (*Sander lucioperca)* was stocked 4 times, firstly in 1993 with 243 individuals. Its biggest introduction is dated for 2010 with 114,000 individuals. Roach (*Rutilus rutilus*) was stocked 4 times between 1962 and 1966. Its biggest introduction is dated for 1962 with 220,000 individuals. European eel (*Anguila anguila*) was firstly introduced in 1954 in a number 5000. Its biggest introduction is dates back to 1980, when 62,500 individuals were released into the lake. European eel was stocked 42 times until 2012. Crucian carp (*Carassius carassius*) was stocked five times. Its biggest and last introduction is dated for 2005 with 500,000 individuals. Tench (*Tinca tinca*) was stocked four times between 1965 and 2012. The highest number was introduced in 1965 with a number of 4,000.

4 DISCUSSION

The most abundant fish species in lake are bleak (*Alburnus alburnus*) and perch (*Perca fluviatilis*). These species are characteristic for high trophic states of freshwater ecosystem. Bleak is a species, which can survive in turbid and poorly oxygenated waters, but is then seen mostly at the surface of the water. It feeds on zooplankton, mainly on small crustaceans (Horppila and Kairesalo, 1992). The loss of zooplanktonic populations may enhance rapid growth of cyanobacteria, which can cause water blooms (Wheeler and Newman, 1992). Perch is omnivorous species, which can be found in waters of different quality. Perch feeds on small crustaceans and insect larvae, but also on smaller perch (intraspecific cannibalism). Foraging activity of perch can enhance growth of phytoplankton. The dominance of perch can be explained by the existence of optimal breeding conditions: perch lay eggs around macrophytes and tree roots (Wheeler and Newman, 1992). The shoreline of Lake Durowskie is surrounded by many tree roots, and hence provides good habitat for breeding.

The sizes and weight of fish were found to be bigger in the river for all observed species. Since the sampling in the inflow was complete, the achieved average sizes and weights can be considered as representative for the individuals in the river. In the lake, many small individuals were caught. Due to the high similarity in species composition between the lake and the river (expressed in the Jaccard-Species Identity of 0.66), the two habitats cannot be considered as different. It can thus be concluded, that the difference in size is due to the age of the individuals rather than due to differences in food quality. Indeed, adults use rivers and streams for migration, whereas younger individuals stay in lakes, where stream velocity is lower. However, our result could be an artefact of an incomplete sampling in the lake. Therefore, we recommend increasing the sampling area including evenly distributed sampling points at different depths of the lake oxygenated layers.

While analysing the species-specific historical trends it is relevant to recognize it's biased towards commercial species. It is possible that non-commercial species present positive or negative trends. Hence, more studies should be done in order to compare our results.

For the abundant species recorded in the catches since 1954 (*Tinca tinca, Abramis brama, Sander lucioperca, Anguilla anguilla, Esox lucius* and *Perca fluviatilis*) significant trend were found for *Tinca tinca* and *Abramis brama.* Tench (*Tinca tinca*) shows a significant increase in the catch size since 1954. It can survive in habitats, where only few other species can survive. Tench tolerates high temperatures, low water velocities, soft substrate, low oxygen levels, and low water transparency. Tench can also change the ecosystem through bottom-up effects on food webs: It reduces macrophyte coverage by stimulating periphyton growth on macrophyte surface (Rowe, 2004). Hence, the increase of tench indicates the gradual increase of the trophy of Lake Durowskie. Additionally, it can further contribute to a worsening of the water quality. A control of the number of tench in the lake by active removal of individuals can thus be recommended. A negative trend was detected in the catch of small-sized bream, whereas catches of medium-sized and big-sized bream remained the same. This observation cannot be correlated to changes in water quality. A possible explanation for this development can be a change of preferences in the fishing industry: The catch of small-sized individuals can e.g. actively be avoided by choosing bigger mesh-sizes.

Pike (*Esox lucius*) abundance in Lake Durowskie is low, because it does not provide good conditions for foraging and breeding probably due to the lack of submerged water plants. Because of the absence of *Esox lucius* catches in the lake, the biomanipulation of the Lake by pike stocking can be considered as unsuccessful. Despite on going stocking activities throughout the last decades, no stable pike population established in the lake. This can be due to the size of the introduced fish: Lake Durowskie was stocked with small-sized pike (so called „fingerling"), which may be eaten by other predators. Furthermore, pike are likely to suffer from competition in the littoral zone with the perch. Due to the big discrepancy between current conditions in the lake and the optimal conditions for pike, further biomanipulation with pike cannot be recommended at this stage. Better water quality is required to assure the establishment of a pike population and guarantee a positive impact of pike on the system.

The comparison between stocking and catches of Coregonid species *Coregonus albula* and *Coregonus laveretus* reveals that, despite ongoing stocking no Coregonid community is established in the lake. Coregonid species occur mainly in deep-water bodies, which display a low trophy. Due to the high level of adaptation of Coregonids to such conditions, lakes with these characteristics are classified as Coregonid Lake. A high proportion of lakes with glacial origin are thus classified as such. Derived from that, Lake Durowskie is expected to be a Coregonid Lake. However, data obtained in this study suggest Lake Durowskie to be in the state of a Bream Lake, which further underlines the effect of eutrophication on the fish assemblage in the lake.

5 CONCLUSION

Fish assemblages in Durowskie indicate a high trophy of the lake. This condition is demonstrated by the community structure, species abundances, historical catchment trends and stocking information. Nowadays, Lake Durowskie presents domination of *Perca fluviatilis* as predator species and of *Alburnus alburnus*. Furthermore, a significant increase of *Tinca tinca* can be noted. This species occurs in waters with high trophy and can lead to a further worsening of the trophic state. Hence, the active control of the population size of *Tinca tinca* can be recommended as tool for restoration. Comparisons between historical catches and stocking demonstrate the shift of Lake Durowskie from a Coregonid Lake to a Bream Lake, which as well indicates the shift to higher trophic conditions. Additionally, our investigation demonstrates ineffective bio-manipulation of the lake reflected in unsuccessful reintroductions of *Esox lucius*.

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