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Influence of Fish Ponds on the Benthic Invertebrate Composition in Hydrological Networks of Selected Fish Farms in Southern Poland

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Short communication

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Fish production can generate high amounts of wastewater containing compounds such as suspended solids, nitrogen and phosphorus. On the other hand, fish ponds provide a range of ecological functions including biocenotic, physiocenotic, hydrological and microclimatic functions as well as landscape shaping. The aim of this study was to determine the taxonomic composition of the bottom invertebrate fauna in selected watercourses on chosen carp fish farms and to assess the influence of fish farming on the taxonomic composition of the zoobenthos of the watercourses associated with such ponds. The research was conducted in four channels on two semi-intensive aquaculture fish farms located in Zaborze and Kraków (Poland). Sampling of the benthic fauna was carried out once a month between May and September 2018. The results showed that the mean monthly number of zoobenthos families in the inflow canal in Zaborze was higher than those in the outflow canal. Moreover, a decrease of the BMWP-PL index in the aforementioned farm may indicate a deterioration of the water quality resulting from its flow through the ponds. It can therefore be concluded that semi-intensive carp farming may affect the diversity of benthic invertebrate fauna in the watercourses connected to these ponds.

Key words: BMWP index, canals, carp ponds, water quality.

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Pond farms (fish farms) are complexes consisting of ponds employed for fish farming and the accompanying hydrotechnical facilities. The hydrotechnical infrastructure is used to provide, maintain and ensure an adequate water flow and quality in the ponds. Farms may also have their own hatcheries – buildings used for spawning, incubating eggs and rearing fish. Along with the growing demand for freshwater fish, the Polish inland aquaculture sector has been undergoing development. New farms have been built, while many farms have been expanding their business operations. In the period of 2013-2019, the number of ponds increased by almost 800 and the cubic capacity grew by more than 14 thousand dam^3. In 2019, Polish pond farms had 8327 ponds with a total capacity of 328,341 dam^3 (GUS 2020). The hydrological network of the fish farms includes both inflow canals (supplying water to the ponds) and outflow canals (discharging water from the ponds to the receivers). Ponds are supplied with water from watercourses, which in their course below the ponds, often become receivers of water from the ponds.

The main economic function of a fish farm is production. However, fish production can cause pollution in the aquatic environment. Certain aquaculture systems generate high amounts of wastewater containing compounds such as suspended solids, nitrogen and phosphorus. The total pollution load is directly proportional to the production volume (TURCIOS & PAPENBROCK 2014). However, fish ponds, like other small water bodies, provide a range of ecological functions including biocenotic, physiocenotic, hydrological and microclimatic functions, as well as landscape shaping (JAKUBIAK & PANEK 2016; JAKUBIAK & CHMIELOWSKI 2020). The natural value of fish ponds is their additional asset, as the pond farms are a habitat for many species of wild vertebrate animals (MANIKOWSKA-ŚLEPOWROŃSKA *et al.* 2016; BARRETT *et al.* 2019). Fish ponds are also an important habitat for many species of wetland birds. Therefore, research on avifauna is an important part of studies on the biodiversity of fish farm fauna (MOGA *et al.* 2010; KOPIJ 2016, 2019). The pond complexes are also sites where amphibious mammals are found (MYŠIAK *et al.* 2013; MANIKOWSKA-ŚLEPOWROŃSKA *et al.* 2016; BARRETT *et al.* 2019), while the watercourses of a pond farm's hydrological network are a habitat for many species of fish. BOJARSKI *et al.* (2013) showed the presence of 16 fish species in the canals located in the area of a pond farm in Kraków. In subsequent studies, 23 fish species were found in the same canals (BOJARSKI *et al.* 2014). This suggests that the water network ecosystems of pond farms should be subject to regular inventory surveys. Both protected and alien fish species may be present in these ecosystems (MUSIL *et al.* 2007; BOJARSKI *et al.* 2022), and the pond farms are also habitats for many invertebrate species associated with the aquatic environment. BUCZYŃSKA *et al.* (2007) studied selected groups of aquatic invertebrates in the fish pond complex in Zalesie Kańskie (central-eastern Poland) and recorded 45 dragonfly, 25 waterbug, 99 beetle, 35 caddisfly and 55 water mite species. Meanwhile, BOJARSKI *et al.* (2014) identified from 8 to 15 families of benthic fauna in canals located in the area of the pond farm in Kraków. These authors showed that, in a canal lined with concrete slabs, the taxonomic diversity of the zoobenthos was high. The taxonomic composition of benthos in the canals might be very diverse, but this depends mainly on the water current. The zoobenthos of the watercourses included numerous gastropods, leeches, stoneflies, mayflies, caddisflies, flies, other crustaceans and Oligochaeta. The benthos play an important role in the aquatic ecosystem trophic chain and provides food for various fish species (FERRARI & CIIIEREGATO 1981; CZERNIAWSKI *et al.* 2007). The taxonomic diversity of benthic invertebrates is used as one of the biological elements for an assessment of the ecological status of waters, as well as being one of the parameters used in the classification of surface water bodies (REGULATION... 2019). Furthermore, benthos are used for ecotoxicological analyses (ANKLEY & COLLYARD 1995; LI *et al.* 2017; PAGANO *et al.* 2020; STRUNGARU *et al.* 2021).

The aim of this study was: 1) to determine the bottom invertebrate fauna taxonomic composition and its temporal variations in selected watercourses of the hydrotechnical network of carp pond farm, 2) an attempt to determine the influence of fish farms on the taxonomic composition of the zoobenthos of watercourses associated with them; and 3) to make a preliminary assessment of the water quality in selected watercourses located on the fish farms, on the basis of the Biological Monitoring Working Party (BMWP-PL) index and the taxonomic diversity of the zoobenthos.

Materials and Methods

Study 1 – Zaborze fish farm

The research was conducted on two inflow canals and two outflow canals located on two fish farms. The first farm is located in Southern Poland (49°52′10′′N, 18°47′50′′E), mainly in Zaborze. It is owned by the Institute of Ichthyobiology and Aquaculture of the Polish Academy of Sciences in Gołysz. The farm has carp-type ponds, for both breeding and experimental purposes. The total area of the water surface is about 900 hectares (BOJARSKI *et al.* 2022). The primary activity of the farm is the rearing and breeding of common carp (*Cyprinus carpio* L.), but other species (e.g. wels catfish *Silurus glanis* L., tench *Tinca tinca* (L.), northern pike *Esox lucius* L., pike-perch *Sander lucioperca* (L.), crucian carp *Carassius carassius* (L.), Prussian carp *Carassius gibelio* (B.) and common roach *Rutilus* (L.)) are also cultured on the farm. The measuring points were located on the main canal supplying water to the farm (inflow canal sampling point) and on the canal draining the water from all ponds (outflow canal sampling point). The main inflow canal feeds the fish farms with water from the Vistula River. The water flow in the main inflow canal is regulated by a vertical lift gate that allows the water to be diverted into a dense network of smaller inflow canals, which supply all the fish ponds with fresh water. Samples of benthic invertebrates were collected from the section of the canal preceding the gate. Further downstream, the main canal flows through the farm site and receives water from the fish ponds (outflow canal). In this case, the samples of benthic invertebrates were collected from the section of the canal located below the last pond.

Study 2 – Kraków fish farm

The second fish farm is also located in Southern Poland (50°05′06′′N, 19°50′25′′E), mainly in Kraków. It belongs to the Experimental Fisheries Station of the University of Agriculture in Kraków. The total area of the water surface is 26.5 hectares (comprised of rearing and experimental carp ponds) (BOJARSKI *et al.* 2013). Common carp is the main fish species reared on the farm. Additionally, as on the Zaborze fish farm, other species are cultured. Water to the ponds is supplied by an inflow canal from the Rudawa River. On this farm, the measuring points were located on the inflow canal and on the last part of the outflow canal, directly before its discharge into the Rudawa River.

Sampling and indices

Sampling was carried out in accordance with the guidance on procedures for the pro rata Multi-Habitat-Sampling (MHS) of benthic macro invertebrates in wadeable rivers and streams (according to the EN 16150:2012 standard). A rectangular style kick-net was used for the sampling. Samples were taken from the bottom sediment layer with a thickness of 5-10 cm, while the sub-samples were taken from 20 m long sections of the watercourses. In order to capture the full spectrum of diversity of benthic fauna in the watercourse, the sub-sampling sites were equally distributed to represent both the near-shore and mid-bottom zones of the canal bed. Each time, the total area sampled was 1.25 m^2 (20 sub-samples), while the sampling started in the lower part of the surveyed section. The sampling was carried out once a month between May and September 2018. At both watercourses on single fish farm, the samples were collected on the same day, in the morning. The collected material was then identified in the laboratory. After an identification of the taxonomic composition, the Biological Monitoring Working Party (BMWP-PL) index was calculated according to BIS & MIKULEC (2013). BMWP-PL is a version of the British BMWP index that has been adapted to Polish conditions. Sørensen's similarity coefficient was calculated for both of the studied watercourses in each fish farm. For a single watercourse, the average monthly number of zoobenthic families and the BMWP-PL index were calculated.

Statistical analysis

For every fish farm and every parameter studied, the difference between the results obtained for the inflow canal and for the outflow canal was considered. The hypothesis that the difference would equal zero was tested using the Welch two sample t-test, and the assumption of the Welch two sample t-test was verified. The compliance of the results with the normal distribution was tested by the Shapiro-Wilk test, where none of them disproved the hypothesis that the data were normally distributed. The homogeneity of variances was tested by the F test to compare two variances, where none of them disproved the hypothesis that the variances were equal. The statistical analysis was performed using R free software (The R Foundation for Statistical Computing, version 4.1.2). The significance level of each test was equal to 0.05, and the data is expressed as the mean ± SD.

Results

Study 1 – Zaborze fish farm

Among the benthic invertebrates collected from the studied watercourses, the presence of oligochaetes (Oligochaeta) – 1 family, bivalves (Bivalvia) – 2 families, gastropods (Gastropoda) – 1 family, insects (Insecta) – 17 families and crustaceans (Crustacea) – 2 families was recorded (Tables 1 and 2). A total of 18 families of zoobenthos were recorded in the inflow canal, with the minimum number in August (6 families) and the maximum in June (11 families) (Table 1). In the outflow canal, a total of 9 families of benthic fauna were recorded, with the minimum in September (3 families), while the maximum was reached in July (6 families) (Table 2). The mean monthly number of zoobenthos families was 8.6 ± 2.1 for the inflow canal and 4.8 ± 1.1 for the outflow canal (Fig. 1). The observed difference in the number of zoobenthos families between the studied watercourses was statistically significant (p=0.0108).

The BMWP-PL index calculated for each month separately had values ranging from 34 (August) to 65 (June) for the inflow canal and from 15 (September) to 30 (July) for the outflow canal. The mean of the monthly BMWP-PL index values was 47.6 ± 13.6 for the inflow canal and 24.0 ± 5.5 for the outflow canal (Fig. 2). The difference between the studied watercourses was statistically significant (p=0.0140). The BMWP-PL index calculated for all the months combined was 106 for the inflow canal and 43 for the outflow canal. The Sørensen similarity coefficient calculated for both of the studied watercourses had values ranging from 0.13 (July) to 0.36 (August) (Fig. 3).

Study 2 – Kraków fish farm

Among the benthic invertebrates collected from the studied watercourses, the presence of Turbellaria – 1 family, nematodes (Nematoda) – 1 family, oligochaetes (Oligochaeta) – 1 family, leeches (Hirudinea) – 2 families, gastropods (Gastropoda) – 5 families, insects (Insecta) – 13 families and crustaceans (Crustacea) – 1 family was recorded (Tables 3 and 4). A total of 20 families of zoobenthos were recorded in the inflow canal, with the minimum in September 2018 (5 families) and the maximum number in July 2018 (11 fami-

Table 1

List of zoobenthos families detected in the inflow canal in individual months at the Zaborze fish farm with the assigned BMWP-PL points

Order/class	Family	BMWP-PL points	Sampling date				
			V 2018	VI 2018	VII 2018	VIII 2018	IX 2018
Oligochaeta	Naididae	2					
Bivalvia	Sphaeriidae	4	+	+	+	+	+
Bivalvia	Unionidae	7					
Gastropoda	Lymnaeidae	3	+				
Coleoptera	Elmidae	7			+		
Diptera	Athericidae	8	+		+	+	
Diptera	Ceratopogonidae	4	+	+	+		
Diptera	Chironomidae	3	+	+		+	+
Diptera	Limoniidae	6		+			
Ephemeroptera	Baetidae	6	+	+	+		+
Ephemeroptera	Caenidae	7		+			
Ephemeroptera	Heptageniidae	8			+		
Ephemeroptera	Potamanthidae	7		+			
Hemiptera	Aphelocheiridae	7	+	+	+	+	+
Hemiptera	Corixidae	5			+		
Hemiptera	Nepidae	5					
Megaloptera	Sialidae	3					
Odonata	Gomphidae	7		+		+	+
Trichoptera	Goeridae	9		+			
Trichoptera	Hydropsychidae	5	+	+	+	+	+
Trichoptera	Sericostomatidae	7	+				
Crustacea	Asellidae	3			+		+
Crustacea	Cambaridae	5					

Table 2

List of zoobenthos families detected in the outflow canal in individual months at the Zaborze fish farm with the assigned BMWP-PL points

Order/class	Family	BMWP-PL points	Sampling date				
			V 2018	VI 2018	VII 2018	VIII 2018	IX 2018
Oligochaeta	Naididae	2				+	
Bivalvia	Sphaeriidae	4					
Bivalvia	Unionidae	7	+	+	+	+	+
Gastropoda	Lymnaeidae	3					
Coleoptera	Elmidae	7					
Diptera	Athericidae	8	+				
Diptera	Ceratopogonidae	4					
Diptera	Chironomidae	3	+	+	+	+	+
Diptera	Limoniidae	6					
Ephemeroptera	Baetidae	6					
Ephemeroptera	Caenidae	7					
Ephemeroptera	Heptageniidae	8					
Ephemeroptera	Potamanthidae	7					
Hemiptera	Aphelocheiridae	7		+	+	+	
Hemiptera	Corixidae	5					
Hemiptera	Nepidae	5			+		
Megaloptera	Sialidae	3		+	+		
Odonata	Gomphidae	7					
Trichoptera	Goeridae	9					
Trichoptera	Hydropsychidae	5					
Trichoptera	Sericostomatidae	7					
Crustacea	Asellidae	3	+				
Crustacea	Cambaridae	5	+	+	+	+	+

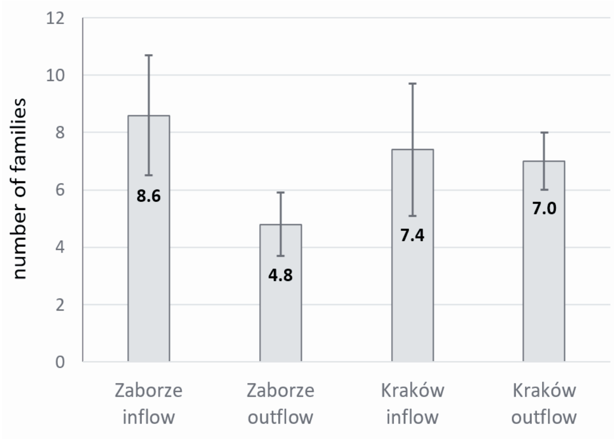

Fig. 1. Monthly number of zoobenthos families (mean ± SD) for the inflow and outflow canals at each fish farm.

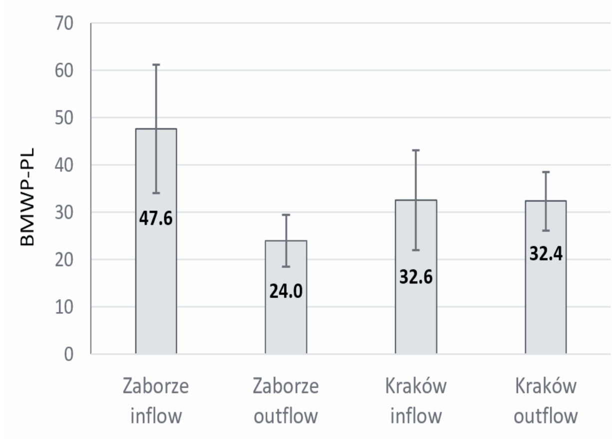

Fig. 2. Monthly BMWP-PL index (mean ± SD) for the inflow and outflow canals at each fish farm.

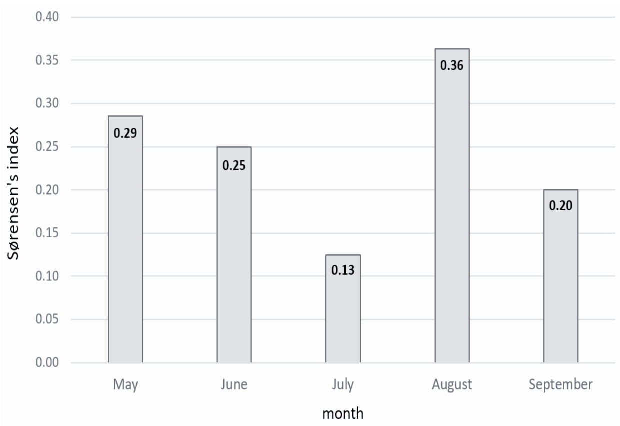

Fig. 3. Sørensen similarity coefficient calculated for both of the studied watercourses located on the Zaborze fish farm.

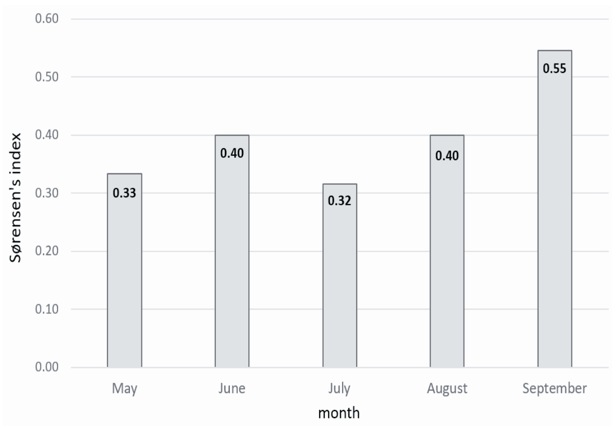

Fig. 4. Sørensen similarity coefficient calculated for both of the studied watercourses located on the Kraków fish farm.

lies) (Table 3). In the outflow canal, a total of 19 families of benthic fauna were recorded, with the minimum in both May and September (6 families), while the maximum was reached in June and July (8 families) (Table 4). The mean monthly number of zoobenthos families for the inflow canal was 7.4 ± 2.3 and 7.0 ± 1.1 for the outflow canal (Fig. 1). This time, the observed difference in the number of zoobenthos families between the studied watercourses was statistically insignificant (p=0.7349).

The BMWP-PL index calculated for each month separately had values ranging from 23 (May and September) to 48 (July) for the inflow canal and from 25 (May) to 41 (August) for outflow canal. The mean of the monthly BMWP-PL index values was 32.6 ± 10.5 for the inflow canal and 32.4 ± 6.2 for the outflow canal (Fig. 2). The difference between the studied watercourses was statistically insignificant (p=0.9718). The BMWP-PL index calculated for all the months combined was 78 for the inflow canal and 81 for the outflow canal, while the Sørensen similarity coefficient calculated for both of the studied watercourses had values ranging from 0.32 (July) to 0.55 (September) (Fig. 4).

Discussion

Based on the results of the conducted research, it can be concluded that semi-intensive carp pond farms might affect the connected watercourses by influencing the diversity of benthic invertebrate fauna. Ponds that feed an outflow canal can affect the watercourse ecosystem. This effect was noticeable in the Zaborze fish farm in the form of a significant decrease in the number of zoobenthos families and the BMWP-PL index in the outflow canal, in comparison to the inflow canal. This result was also confirmed by the Sørensen similarity coefficient, which had lower values than those found in the case of the Kraków fish

Table 3

List of zoobenthos families detected in the inflow canal in individual months at the Kraków fish farm with the assigned BMWP-PL points

Order/class	Family	BMWP-PL points	Sampling date				
			V 2018	VI 2018	VII 2018	VIII 2018	IX 2018
Turbellaria	Dendrocoelidae	not applicable			+		
Nematoda	unspecified	not applicable		+			
Oligochaeta	Tubificidae	2	+	+		+	
Hirudinea	Erpobdellidae	3					
Hirudinea	Glossiphoniidae	3			+		
Gastropoda	Ancylidae	3			+		
Gastropoda	Bithyniidae	6	+				
Gastropoda	Lymnaeidae	3	+				
Gastropoda	Physidae	3				+	
Gastropoda	Valvatidae	4			+	+	
Diptera	Chironomidae	3	+			+	+
Diptera	Culicidae	2	+				+
Diptera	Simuliidae	6		+	+	+	
Diptera	Tabanidae	not applicable			+		
Diptera	Tipulidae	5				+	+
Ephemeroptera	Baetidae	6		+			+
Ephemeroptera	Caenidae	7			+		+
Ephemeroptera	Ephemerellidae	7		+	+	+	
Ephemeroptera	Ephemeridae	7	+		+	+	
Hemiptera	Veliidae	5					
Odonata	Aeshnidae	not applicable					
Odonata	Libellulidae	not applicable					
Trichoptera	Goeridae	9					
Trichoptera	Hydropsychidae	5		+	+		
Trichoptera	Philopotamidae	8					
Trichoptera	Sericostomatidae	7					
Crustacea	Gammaridae	6		+	+		

Table 4

List of zoobenthos families detected in the outflow canal in individual months at the Kraków fish farm with the assigned BMWP-PL points

Order/class	Family	BMWP-PL points	Sampling date				
			V 2018	VI 2018	VII 2018	VIII 2018	IX 2018
Turbellaria	Dendrocoelidae	not applicable					
Nematoda	Unspecified	not applicable	+		+		
Oligochaeta	Tubificidae	2	+			+	
Hirudinea	Erpobdellidae	3			+		
Hirudinea	Glossiphoniidae	3					
Gastropoda	Ancylidae	3					
Gastropoda	Bithyniidae	6		+			
Gastropoda	Lymnaeidae	3		+			
Gastropoda	Physidae	3			+		
Gastropoda	Valvatidae	4					
Diptera	Chironomidae	3	+			+	+
Diptera	Culicidae	2			+		
Diptera	Simuliidae	6	+				+
Diptera	Tabanidae	not applicable		+			+
Diptera	Tipulidae	5			+		+
Ephemeroptera	Baetidae	6		+		+	
Ephemeroptera	Caenidae	7	+		+	+	+
Ephemeroptera	Ephemerellidae	7	+	+	+		+
Ephemeroptera	Ephemeridae	7			+	+	
Hemiptera	Veliidae	5					
Odonata	Aeshnidae	not applicable					
Odonata	Libellulidae	not applicable		+			
Trichoptera	Goeridae	9				+	
Trichoptera	Hydropsychidae	5		+			
Trichoptera	Philopotamidae	8					
Trichoptera	Sericostomatidae	7		+		+	
Crustacea	Gammaridae	6					

farm. The intensity of this impact may be related to the farm size or to other factors not recognised in the present study. The reduced number of zoobenthos families in the outflow canal and lower value of the BMWP-PL index may potentially indicate a deterioration of the water quality due to its flow through the fishponds. However, this conclusion should be considered as tentative and requires confirmation through further studies, particularly since most of the works published so far concerning this issue indicate a beneficial effect of carp ponds on the water quality.

A chemical analysis of water from the farm located in Kraków conducted by KANOWNIK & WIŚNIOS (2015) demonstrated that the concentrations of biogenic compounds (phosphate, nitrite and nitrate nitrogen), dissolved solids, calcium and water conductivity in the fish ponds decreased, by between 30 and 87% on average, in comparison with the water in the watercourse supplying the fish farm. This was confirmed by analyses conducted by BERLEĆ *et al.* (2015) at a fish farm in Ślesin, who showed that the pond farming of carp can result in a reduction in fungal numbers (to a minor extent) and can improve some physicochemical parameters of the water. Similarly, CIEŚLIŃSKI *et al.* (2019) studied the influence of freshwater fish farming on the chemical status of water in a catchment of the Wąska River. Reductions in the concentrations of total nitrogen by 66%, ammonia by 52%, sulphate by 50%, nitrate by 46% and phosphate by 28% were recorded below the discharge of water from the ponds in relation to the supplying waters. Thus, the authors concluded that fish farming can positively affect the water purification process and improve both the physical and chemical parameters of the water.

On the other hand, a study by SIDORUK *et al.* (2013) showed that trout production can contribute to a deterioration of the water quality. However, these authors noticed that the changes in the parameters were not significant enough to result in a decrease in the water quality class (in most cases). Similarly, a negative impact of trout farm effluent on the water quality was observed by KİRKAĞAÇ *et al.* (2009). Moreover, LOCH *et al*. (1996) demonstrated that trout farm effluent caused a reduction in Ephemeroptera, Plecoptera and Trichoptera taxa richness, which indicates a deterioration of the water quality. Nevertheless, GUILPART *et al.* (2012) investigated the influence of selected salmonid farms on rivers and observed that the total abundance of benthic invertebrates had increased downstream of the effluent outlets.

The results obtained in the current study indicate a possible negative impact of carp ponds on the taxonomic diversity of the invertebrate benthic fauna in the outflow canal. This may potentially indicate a deterioration of the water quality due to fish production practices. However, taking into account the fact that the results presented by other authors, to some extent, contradict the results presented here, the authors believe that it is necessary to conduct more detailed research on this issue. Therefore, further research is planned to include an analysis of various types of fish farms (carp, trout) and diverse types of fish rearing (extensive, semi-intensive and intensive). In addition, the planned research will be enhanced by a quantitative analysis of the zoobenthos and an assessment of the physicochemical parameters of the water in the inflow and outflow canals, fish ponds, as well as in the adjacent natural watercourses supplying and receiving water from the fish farms.

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Author Contributions

Research concept and design: M.J., B.B.; Collection and/or assembly of the data: M.J., B.B., M.B., P.O.; Data analysis and interpretation: M.J., B.B., M.B., B.S., P.O.; Writing the article: M.J., B.B., B.S., P.O.; Critical revision of the article: M.J., B.B.; Final approval of the article: M.J., B.B., M.B., P.O.

Conflict of Interest

The authors declare no conflict of interest.

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