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ORIGINAL PAPER

EFFECT OF RAINBOW TROUT PRODUCTION IN A TWO-STAGE CASCADE SYSTEM ON WATER QUALITY*

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Abstract

Rainbow trout (*Oncorhynchus mykiss*) is one of the most important species produced in aquaculture in the European Union. Its culture requires high-quality, well-oxygenated waters. Like any animal production, the fish culture generates waste. Hence, discharge of non-treated waters from fish ponds to a receiving water body may disturb its ecological homeostasis. This study was aimed at evaluating the effect of rainbow trout aquaculture in a two-stage flow system on water quality. The study was conducted at a trout farm composed of two sets of fish ponds made of concrete, which were fed with waters by gravitation in a continuous flow system. Waters inflowing to the fish farm were of good quality. Based on the calculated CCME-WQI values, they were classified to the category of water quality called Fair. Their quality met requirements set in EC Directive no. 2006/44/EC for inland waters constituting the habitat for the Salmonidae fish. Once water had flown through the fish ponds, its quality deteriorated. Water discharged from ponds A had a higher BOD_5 value and higher concentrations of total phosphorus and ammonia nitrogen, which resulted in its quality class decline from Fair to Marginal. In turn, water outflowing from ponds B had higher concentrations of P_{tot} and $N\text{-}NH_3$, which nevertheless did not result in a decrease of its CCME-WQI value. This was mainly due to an increased to 8 $dm^3\ s^{-1}$ flow rate of waters through ponds B compared to ponds A, which facilitated faster water exchange in the ponds, caused higher dilution of contaminants present in the water and, simultaneously, their more rapid discharge outside the ponds. This study did not confirm the expected positive effect of the treatment ditch. Despite pre-treatment, the water discharged from the ponds can pose a threat of receiver waters contamination.

Keywords: trout, fish ponds, water quality, waters pollution.

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INTRODUCTION

Rainbow trout (*Oncorhynchus mykiss*) is one of the most important species produced in aquaculture in the European Union (European Commission 2016). Fish ponds need to be fed with high-quality, cold and well-oxygenated water. They are usually located in the upper parts of a catchment area, therefore even low contamination may significantly deteriorate the quality of water in the watercourse (Sidoruk, Cymes 2018). Fish are entirely dependent on water. Water is their habitat, from which they absorb oxygen, in which they find food to ingest, and to which they excrete faeces (Sirakov et al. 2011, Sidoruk et al. 2014). All water living organisms have specific threshold water quality parameters within which they can thrive and grow optimally. Both an increase or decrease in these parameters have adverse effects on the functions of fish organisms (Bonisławska et al. 2016, Hernández, Roman 2016).

Like any animal production, the fish culture generates waste. Both the quality and volume of waste from fish farms are mainly determined by the system of water management in ponds, genus of the cultured fish, and feedstuff quality. Waste discharged from the intensive aquaculture systems usually includes solid waste and chemical or medical agents. Another significant group of contaminants is represented by bacteria and pathogens discharged from the fish ponds with the outflowing waters (Lin et al. 2002). An increased stock density of fish in the ponds contributes to strong anthropopressure exerted on the natural environment due to the increased load of waste discharged from fish farms (Tacon, Forster 2003).

In aquaculture, waste is discharged with spent waters, although their quantity and quality differ depending on a culture system (Ruiz-Zarzuela et al. 2009, Sugiura 2018). Used water from fish farms is most often discharged directly to nearby water bodies. The pollutants carried by water discharged from fish farms are mineralised, which can interfere with the biological balance within a water body that receives it, hence water from fish farms can be seen as a potential source of pollution (Bergheim, Brinker 2003, Dalsgaard et al. 2015). Spent waters discharged from fish farms may create a serious environmental problem due to the potential pollution of waters of a receiving water body (Bonisławska et al. 2013, Islam et al. 2018). Because they contain substances generated from fish culture, they should undergo a treatment process before they are released to the natural environment. Discharge of untreated spent waters may lead to the eutrophication of water bodies, which in turn can disrupt the ecological homeostasis in the receiver. Treatment of waste generated during fish culture requires high investment inputs and an adequate technology (Michalczyk et al. 2017, Puttock et al. 2018).

This study aimed to assess changes in water quality affected by breeding rainbow trout in a two-stage cascade system.

MATERIAL AND METHODS

The study was carried out at a trout farm located in northern Poland, which consisted of two sets of culture ponds made of concrete, fed with waters by gravitation in a continuous flow system (Figure 1). Each set

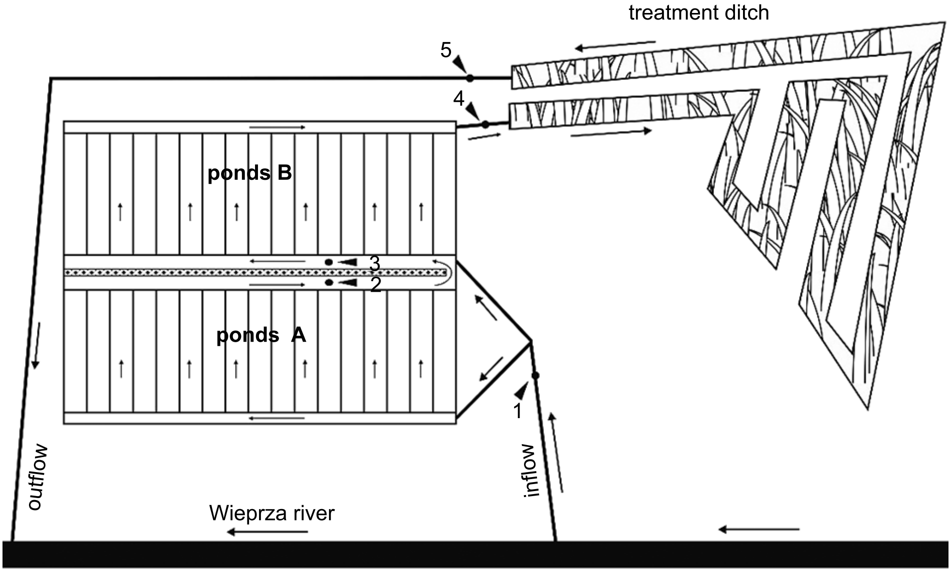

Fig. 1. Location of sampling points

included 17 fish ponds, each of them having the surface area of 130 m^2 and the volume of 130 m^3. The fish farm is located at the 97+295 kilometer of the Wieprza River, the SNQ of which accounts for 4.94 m^3 s^{-1} and SWQ for 18.8 m^3 m^3 s^{-1}. The river's catchment area, mainly afforested and with a small contribution of arable lands, covers 130.8 km^2. Water used to feed the ponds was drawn from a river; 70% of its volume was fed to ponds A, whereas the other 30% flowed to ponds B. Water which had flowed through ponds A was mixed with river water and then fed to ponds B. The average water flow through every pond A was 28 dm^3 s^{-1}, compared to the flow rate of 36 dm^3 s^{-1} in every pond B. Before being discharged from the fish farm, the spent waters passed through a treatment ditch which was 1000 m in length and had the water table area of 0.9 ha. The width of the water treatment ditch was 9 m and the water depth was 0.5 m. The average velocity of water flowing in the ditch was 0.243 m s^{-1} in the central zone, falling down to nearly 0 m s^{-1} in the shoreline zone, overgrown with plants. The amount of bottom sediments was variable and dependent on the flow velocity. In the central zone of the ditch, the depth of sediments was 5-7 cm, and in the zone overgrown with plants it reached 40-50 cm. The plants growing in the ditch received much sunlight. The ditch was planted with common reed (*Phragmites australis)* and white willow *(Salix alba* L.*)* to increase the effectiveness of removal of biogenic substances. Rush plants grew in a 3-meter wide strip on each side of the ditch. White willow was planted every 50 cm at the junction of land and water and in a distance of 50 cm from the shore. The reed density was characteristic of natural habitats of rush lakes and rivers.

The stock of trout in ponds was at the level of 3.5 kg m^{-3}, which corresponded to 570-1440 pcs/pond. Trout fish were fed twice a day with feed pellets composed of fish meal, blood meal, soybean meal, maize meal, wheat meal, as well as poultry and fish fat and soybean oil. In addition, the feed contained 70.4 g N kg^{-1}, 10 g P kg^{-1}, 6 g Na kg^{-1}, and 7 g K kg^{-1}.

The research was conducted in a two-year cycle, and the samples were collected once a month. For water quality assessment, 5 sampling points were established: at the outflow from the fish farm, at the outflow from ponds A, at the inflow to ponds B (after mixing the water outflowing from ponds A with river water), at the outflow from ponds B, and at the outflow from the treatment ditch.

The dissolved oxygen concentration and water pH were measured at all sampling points using a multi-parameter YSI 6600 probe. At the same time, water samples were collected at these points for laboratory analyses.

Concentrations of total suspended solids, BOD_5, N-NO_3, N-NO_2, N-NH_4, $N_{Kiejdahl}$, and $P_{tot.}$ in water were determined according to the Standard Methods (APHA 1992), whereas N-NH_3 concentration was computed from the following equation (PETIT 1990):

$$\text{N-NH}_3 = (a) \cdot \text{TAN (mg dm}^{-3}),$$

(a) – mole fraction of non-ionized ammonia,

TAN – total ammonia nitrogen (mg dm^{-3}),

$$(a) = \frac{1}{1 + 10^{10.068 - 0.33T - \text{pH}}}$$

T – temperature of water in a fish pond,

pH – pH of water in a fish pond.

In order to calculate the organic nitrogen concentration in water from the $N_{Kiejdahl}$ value, the ammonium nitrogen concentration was subtracted.

To assess the quality of water used in fish production, the Water Quality Index (WQI) values were computed for water samples collected at each sampling point. The WQI was calculated using the method developed by the Canadian Council of Ministers of the Environment, which is based on the following dependency (Canadian Council ... 2001):

$$CCME-WQI = 100 - \left(\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732} \right),$$

where:

F_1 – Scope - number of variables whose objectives are not met:

$$F_1 = \left(\frac{number\ of\ failed\ variables}{total\ number\ of\ variables} \right) \cdot 100,$$

F_2 – Frequency - number of times when the objectives are not met:

$$F_2 = \left(\frac{number\ of\ failed\ tests}{total\ number\ of\ tests} \right) \cdot 100,$$

F_3 – Amplitude - amount by which the objectives are not met:

$$F_3 = \left(\frac{nse}{0.01 \cdot nse + 0.01} \right),$$

where:

nse – normalized sum of excursions – it is calculated from the formula:

$$nse = \frac{\sum_{i=1}^{n} excursion_i}{total\ number\ of\ tests},$$

where:

- when the test value must not exceed the objective:

$$excursion_i = \left(\frac{failed\ test\ value_i}{objective_j} \right) - 1,$$

- for the cases in which the test value must not fall below the objective:

$$excursion_i = \left(\frac{objective_j}{failed\ test\ value_i} \right) - 1.$$

Water quality is identified by referring the computed CCME-WQI value to one of the five categories from the water quality rating (Table 1).

Values of CCME-WQI were computed based on 8 physical and chemical parameters of water for which boundary values enabling the life of the Salmonidae fish were set in the Regulation of the Minister of Environment of the Republic of Poland from 4 October 2012 on requirements that should be met by inland waters representing habitats for fish under natural conditions (Dz.U. 176, item 1455), which is in compliance with EC Directive no. 2006/44/EC on the quality of fresh water requiring protection or improvement to maintain fish life.

Before performing statistical analyses, normality of distribution was established using the Kolmogorov-Smirnov test. Diferrences between the sampling sites and layers were tested with ANOVA. The Kruskals-Wallis test was used when normal distribution did not occur. In the present study, hierarchal cluster analysis has been employed to the data set to detect similarity between the waters of the fish farm in terms of water quality parameters. The Euclidean distances were used as a measure of similarity between the

Table 1

Water quality rating (Canadian Council ... 2001)

WQI value	Water quality category	Description
95-100	excellent	water quality is protected with a virtual absence of threat or impairment, conditions very close to natural or pristine levels
80-94	good	water quality is protected with only a minor degree of threat or impairment, conditions rarely depart from natural or desirable levels
65-79	fair	water quality is usually protected but occasionally threatened or impaired, conditions sometimes depart from natural or desirable levels
45-64	marginal	water quality is frequently threatened or impaired, conditions often depart from natural or desirable levels
0-44	poor	water quality is almost always threatened or impaired, conditions usually depart from natural or desirable levels

water sampling sites, while the Ward's error sum of squares in the hierarchical clustering method was applied to minimise the increase in the intragroup variance. Statistical calculations were performed in Statistica v.13.1 PL. Before employing the PCA, it had been checked whether the variables were correlated. After determining the correlation between the variables, a PCA assessment was performed. Analysis of correlations between physicochemical parameters of the studied waters was based on the PCA method supported by the XLSTAT 2018 software.

RESULTS

In the study period, the temperature of water inflowing to the farm was at 12.9 ± 3.6°C (Table 2). For most of the experimental period, its quality met the criteria set for inland waters representing habitats for the Salmonidae fish in EC Directive 2006/44/EC. It was only the $N\text{-}NO_2$ concentration that exceeded the permissible values.

The mean concentration of total nitrogen in the water inflowing to the fish farm reached 0.53 mg dm^{-3} and was the lowest compared to that of waters flowing through particular ponds and that of waters outflowing from the farm. Total nitrogen was mainly composed of organic nitrogen (69%) and $N\text{-}NO_3$ (19%) – Figure 2.

Concentration of BOD_5 in the waters examined exceeded the permissible values sporadically (four times in two years) and was negatively correlated with concentrations of $N\text{-}NO_2$ and $N\text{-}NH_3$ (Figure 3). This may indicate that

Table 2

Chemical composition of waters in the rainbow trout fish farm (mg dm^{-3})

Index	Water quality requirements for Salmonidae fish	Inflow into the fish farm	Ponds A	Water from ponds A + river water	Ponds B	Outflow from the fish farm
Temperature*	<21.5	12.9 ± 3.6^{a}	12.4 ± 3.8^{a}	12.5 ± 3.7^{a}	12.5 ± 3.8^{a}	12.2 ± 3.6^{a}
Dissolved oxygen	> 7.0	10.2 ± 0.43^{a}	8.1 ± 0.63^{ab}	9.8 ± 0.47^{b}	9.0 ± 0.88^{c}	8.6 ± 0.90^{c}
pH	6.0-9.0	$8.0 - 8.7^{a}$ **	$7.1 - 8.2^{a}$ **	$7.7 - 8.6^{a}$ **	$6.9 - 8.4^{ab}$ **	$7.3 - 8.4^{b}$ **
Suspended solids	<25	20.7 ± 7.5^{a}	16.2 ± 6.2^{a}	22.2 ± 8.8^{a}	22.6 ± 7.9^{a}	22.8 ± 17.5^{a}
BOD_5	<3.0	2.1 ± 1.36^{a}	2.7 ± 1.40^{a}	2.5 ± 1.07^{a}	2.4 ± 1.42^{a}	2.9 ± 1.23^{a}
$P_{tot.}$	<0.2	0.096 ± 0.03^{a}	0.133 ± 0.04^{ab}	0.120 ± 0.03^{ab}	0.130 ± 0.04^{ab}	0.120 ± 0.04^{b}
$N\text{-}NO_2$	<0.003	0.006 ± 0.002^{a}	0.007 ± 0.001^{a}	0.012 ± 0.017^{a}	0.007 ± 0.001^{a}	0.008 ± 0.001^{a}
$N\text{-}NH_4$	<0.78	0.059 ± 0.03^{a}	0.076 ± 0.04^{a}	0.061 ± 0.03^{a}	0.062 ± 0.01^{a}	0.063 ± 0.02^{a}
$N\text{-}NH_3$	<0.020	0.004 ± 0.002^{a}	0.002 ± 0.001^{a}	0.003 ± 0.002^{a}	0.002 ± 0.035^{ab}	0.002 ± 0.001^{b}
N_{org}	-	0.369 ± 0.070^{a}	0.665 ± 0.386^{b}	0.404 ± 0.084^{ab}	0.516 ± 0.267^{b}	0.515 ± 0.134^{b}

Key: mean ± standard deviation, * °C, ** min-max; the same letters denote a lack of significant differences at $P \leq 0.05$ (n = 24)

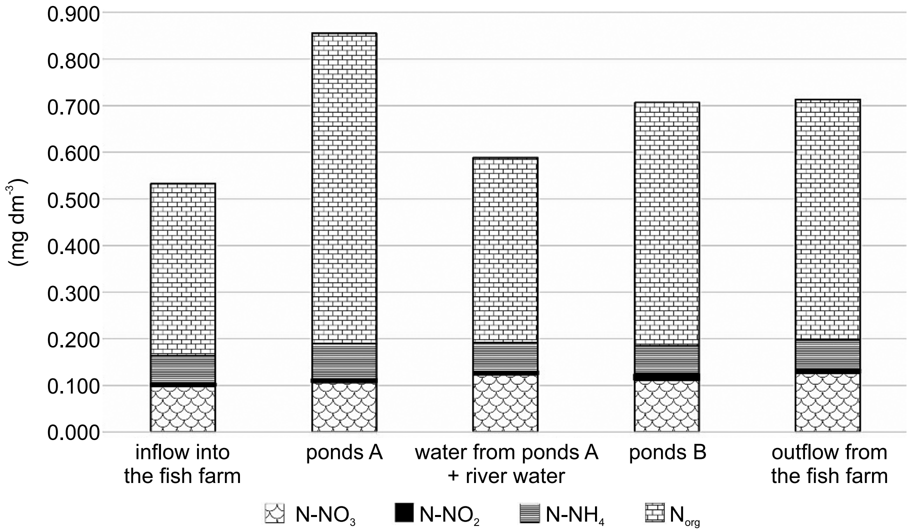

Fig.2. Concentration of individual forms of nitrogen in waters used at the fish farm (mg dm^{-3})

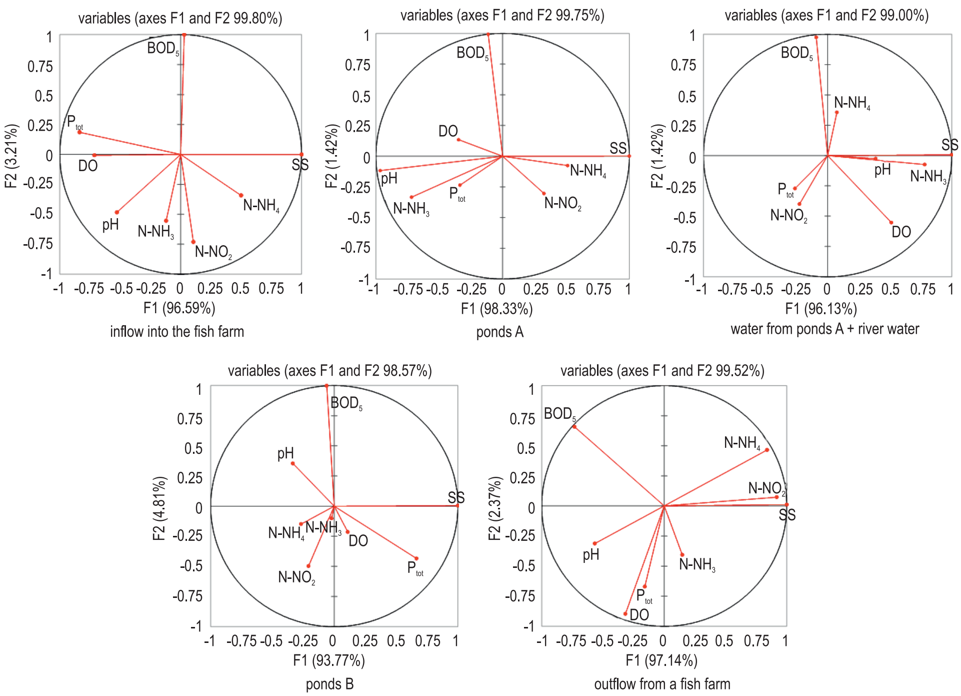

Fig. 3. Principal Component Analysis of correlations between concentrations of selected substances in waters used in trout culture

organic nitrogen is rapidly oxidized to N-NO_3 under high oxygenation conditions.

Permissible values were also periodically exceeded for suspended solids concentration in the waters inflowing to the farm; SS concentration was negatively correlated with dissolved oxygen concentration. The water inflowing to the fish farm was also characterized by the highest and the most stable oxygenation and by the narrowest range of its pH changes (Table 2).

The quality of water inflowing to the fish farm was evaluated in terms of its use for rainbow trout culture as evidenced by the CCME-WQI index. This index refers the physicochemical parameters of water according to the requirements that should be met by inland waters being the habitat for the Salmonidae fish under natural conditions (Dz.U. 176, poz. 1455, Directive 2006/44/EC). The CCME-WQI values calculated in this study for the water inflowing to the fish farm correspond to the water quality class termed as Fair (Table 3). The water quality determined was usually suitable for trout culture, although some of its properties sporadically diverged from the desirable ones.

Table 3

Values of CCME-WQI quality indicators for the analyzed water and the classification of water quality

Sampling point	F1	F2	nse	F3	CCME-WQI	Water quality
Inflow into the fish farm	37.5	17.5	0.07	6.5	75.8	fair
Ponds A	62.5	23.7	0.17	14.5	60.5	marginal
Water from ponds A + river water	37.5	20.0	0.42	29.6	70.1	fair
Ponds B	37.5	21.2	0.17	14.5	73.8	fair
Outflow from the fish farm	37.5	20.0	0.23	18.7	73.2	fair

When water had passed through ponds A, its quality deteriorated and thus the value of its CCME-WQI decreased by 15.3, which meant that it declined from Fair to Marginal water quality class (Table 3). This water quality was often insufficient for maintaining a trout culture and diverged from the desirable values. Water outflowing from ponds A had an increased BOD_5 value as well as concentrations of total phosphorus and ammonia nitrogen; however, the values of these parameters did not exceed the thresholds above which the poor water quality poses a threat to fish life. Other changes observed included the doubling of organic nitrogen concentration, which was accompanied by decreased concentrations of dissolved oxygen, suspended solids, and N-NH_3.

To improve the quality of water outflowing from ponds A, it was mixed with river water. This raised its quality, which in turn resulted in a change of quality class from Marginal to Fair (Table 3). The BOD_5 value decreased by 0.2 mg dm^{-3}, whereas the concentration of P_{tot}, which in the analyzed water was negatively correlated with the $N\text{-}NH_4$ concentration, decreased by 0.013 mg dm^{-3} (Figure 3). Further changes included a decrease in the total nitrogen concentration by 0.266 mg dm^{-3}, including decreased concentrations of $N\text{-}NH_4$ by 0.015 mg dm^{-3} and organic nitrogen by 0.261 mg dm^{-3}. In contrast, the concentration of total suspended solids increased to 22.2±8.8 mg dm^{-3}, whereas that of $N\text{-}NH_3$ increased insignificantly and that of $N\text{-}NO_2$ was nearly doubled. These waters, together with the waters inflowing to the fish farm, represented a separate cluster of waters according to the statistical analysis conducted with the Ward's method (Figure 4).

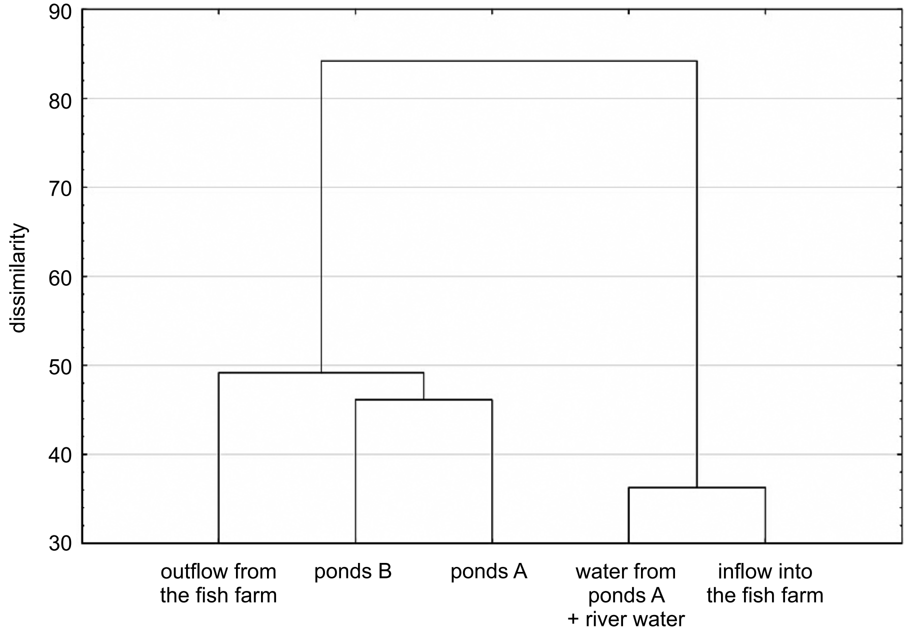

Fig. 4. Tree diagram of cluster analysis of waters from the sampling points based on their physicochemical data, obtained by using the Ward's method as a linkage rule and Euclidean distances as a metric for distance calculation

Waters which had flown through ponds B were characterized by an increased $P_{tot.}$ concentration, which was correlated with dissolved oxygen concentration, as well as by an increased concentration of organic nitrogen and a decreased concentration of $N\text{-}NH_3$. Changes in the other analyzed indicators were small. Despite increased concentrations of some of the indicators, the CCME-WQI value calculated for these waters did not decrease. Water discharged from ponds B remained in the Fair quality class. The main reason was the water flow higher 8 dm^3 s^{-1} for the water passing through ponds B compared to ponds A, which contributed to a more rapid water exchange in the ponds. In ponds A, complete exchange of waters occurred *ca* every 1.5 h, whereas in ponds B it took 1 h. This meant than in ponds A there was greater dilution of pollutants present in water and their discharge from the fish ponds was more rapid.

Before the spent water had been discharged to the receiver, it passed through a 1000-meter-long treatment ditch overgrown with plants. The ditch was intended to improve the quality of water before its being discharged to the river. However, the study did not show improvement in the quality of water after passing through the treatment ditch. Some reduction was only observed in the total phosphorus concentration (by 0.01 mg dm^{-3}), which was negatively correlated with the $N\text{-}NH_4$ concentration. In contrast, the BOD_5 value in the water outflowing from the fish farm increased by 20% and ultimately was the highest among all water samples analyzed. In addition, the ditch had no positive effect on the concentrations of dissolved oxygen, suspended solids and $N\text{-}NO_2$. In turn, concentrations of $N\text{-}NH_4$ and $N\text{-}NH_3$ in water sampled at the beginning and at the end of the ditch did not differ. The CCME-WQI value of water discharged from the fish farm decreased by 0.6, which caused no change in its quality class.

When comparing quality of river water flowing to the farm and of water discharged from the farm, it may be concluded that the water quality has deteriorated. This was indicated by an almost 35% increase in the concentration of total nitrogen, 40% increase in the BOD_5 value, 20% increase in $P_{tot.}$, and *ca* 10% increase in the concentration of suspended solids. Only the $N\text{-}NH_4$ concentration remained the same as in the river water, whereas that of $N\text{-}NH_3$ decreased inconsiderably.

DISCUSSION

Water quality needs to be taken into consideration when planning fish production in aquaculture (Ntengwe, Edema 2008, Islam et al. 2018). It affects the overall condition of fish by determining their growth and health conditions. The aquatic environment is a complex system, composed of multiple variables which influence water quality, although only a few play a key role in fish production. The most important parameters which determine the feasibility of trout culture include: temperature, concentrations of suspended solids, dissolved oxygen, ammonia, and nitrates, as well as BOD_5 and pH values. However, dissolved oxygen is the key one, as it is indispensable for fish metabolism. Rainbow trout culture requires an oxygen concentration in water at the level of at least 5-8 mg O_2 mg dm^{-3} and no less than 3 mg dm^{-3} (Sidoruk et al. 2014, Fetherman et al. 2016), but trout are able to tolerate short-lasting decreases in water oxygenation below this value. Nevertheless, a longer period of oxygen concentration below the required level induces stress to fish. This may lead to diminished feed intake and, consequently, to lower body weight gains of fish. In addition, the low concentration of oxygen suppresses fish immunity, thereby increasing their susceptibility to the development of many diseases, likely to be fatal to fish (SIRAKOV et al. 2011, ROZE et al. 2013). At the studied fish farm, the concentration of oxygen in water used in trout culture was maintained at the optimal level throughout the experimental period. This was achiveable owing to the implementation of a system for water aeration with pure oxygen in periods when the oxygen concentration decreased below the optimal values.

Apart from water oxygenation, a significant factor in trout culture is the concentration of ammonia nitrogen. Its value in waters intended for the culture of the Salmonidae fish should not exceed 0.78 mg dm^{-3} (Directive 2006/44/EC, Dz.U. 176, poz. 1455). A high concentration of $N\text{-}NH_4$ in water causes lower energy absorption from feed by fish and their suppressed immunity. If its concentration exceeds the critical value, fish become lethargic, fall into coma and dye (HARGREAVES, TUCKER 2004), At trout culture farms using the cascade system of water management, the content of fish metabolites and undigested feed residues successively increases in water. This contributes to an increased concentration of nitrogen in water. It is assumed that only about 20-40% of nitrogen introduced to water with feed in the aquaculture is incorporated into fish biomass. The remaining nitrogen is lost and claimed to raise nitrogen concentration in water; 62% of this nitrogen occurs in the dissolved form and 13% is present in the colloidal form (DALSGAARD et al. 2015).

The contribution of individual forms of nitrogen was changing in the water outflowing from the fish ponds. Concentrations of organic and ammonia nitrogen were observed to increase, due to the fact that they are fish metabolites. Fish urine and excreta increase concentrations of both ammonia and organic nitrogen in water. In addition, the increased ammonia nitrogen concentration could be an effect of the ammonification of nitrogen contained in organic compounds present in water and in administered feed (RUIZ-ZARZUELA et al. 2009, HERNÁNDEZ, ROMAN 2016). Despite the increased concentration of ammonia nitrogen, the concentration of its non-ionized form did not rise. It is assumed that $N\text{-}NH_3$ toxicity at the level of LC50 within 24 h occurs at its concentration of 0.07-0.39 mg dm^{-3} (SOLBÉ, SHURBEN 1989, RANDALL, TSUI 2002). The $N\text{-}NH_3$ concentration in water of the analyzed ponds was significantly lower from hazardous values and posed no threat to fish life.

This study demonstrated also an increase in the concentration of total phosphorus in waters discharged from the fish ponds. Its main source in the analyzed waters was the feed pellet, which contained 10.0 g P kg^{-1}. Phosphorus is indispensable for the optimal growth, bone development, and maintaining the acid-base homeostasis in a fish body (MORTULA, GAGNON 2007), hence its contribution in the feedstuff is high. Investigations conducted by many scientists have demonstrated that only a small part of phosphorus from a feed mixture is incorporated in the fish biomass (HERNÁNDEZ, ROMAN 2016, SUGIURA 2018). The remaining part is not utilized by fish and ultimately migrates from undigested feed and from fish excreta to water. Bureau and Cho (1999) reported that 71-83% of phosphorus introduced to fish ponds with feedstuffs are ot unabsorbed by fish and discharged outside the ponds with spent waters.

Waters used in trout production have significant concentrations of organic matter, biogenes, and non-dissolved substances (Cripps, Bergheim 2000, Bergheim, Brinker 2003, Bonisławska et al. 2013). When directly discharged to a receiver untreated, they constitute a significant source of contamination of surface waters (Davidson et al. 2013, Bonisławska et al. 2016). A high concentration of biogenes in waters discharged from fish farms may accelerate eutrophication of waters in the receiver, thus disturbing its ecological homeostasis. However, this may be avoided by using various systems for the treatment of these waters. At the analyzed farm, a 1000-meter-long treatment ditch was used for this purpose. To increase the effectiveness of biogene removal, the ditch was planted with common reed (*Phragmites australis)* and white willow *(Salix alba* L.*)*. The conducted study did not confirm the expected positive effect of the treatment ditch on the quality of waters discharged to the receiver. It was only the total phosphorus concentration which was reduced by 0.01 mg dm^{-3}, whereas concentrations of the other indicators (BOD_5, SS, DO, N-NO_2, N-NH_4) were observed to increase. This could be due to the activation of biogenes accumulated in bottom sediments of the ditch (Glendell et al. 2014, Glińska-Lewczuk et al. 2014). This study demonstrated that despite the pre-treatment the waters discharged from the fish ponds might pose a threat of receiver waters contamination. Therefore, more effective measures should be taken for their successful treatment. Apart from the treatment ditch, some additional elements of a spent water treatment system should be implemented to mitigate the adverse impact of the trout farm on waters of the receiver. Such a system should consist of a biological reactor with a denitrification stage, which will enable reduction of biogenes likely to have a negative effect on the receiver's ecosystem.

CONCLUSIONS

Waters inflowing to the fish farm were of good quality and based on the calculated CCME-WQI values were classified to the Fair category of water quality. Their quality met the requirements for the inland waters constituting habitats for the Salmonidae fish set in EC Directive 2006/44/EC. The permissible concentration was negligibly exceeded only in the case of N-NO_2. The quality of waters which had passed through the fish ponds was observed to decrease. Waters used in ponds A caused an increase in its BOD_5 value and in concentrations of total phosphorus and ammonia nitrogen, which resulted in their quality class reduction from Fair to Marginal. In turn, waters outflowing from ponds B were characterized by increased concentrations of $P_{tot.}$ and N-NH_3, which did not contribute to their CCME-WQI value decrease. This was mainly because of the water flow through ponds B increased by 8 dm^3 s^{-1} compared to ponds A, which contributed to faster water exchange in the former ponds. Simultaneously, it resulted in greater dilution of pollutants present in water and their more rapid discharge outside the fish ponds. This study did not confirm the expected positive effect of the treatment ditch. Despite pre-treatment, the waters discharged from the ponds posed a threat of the receiver's waters; hence, more effective measures should be taken to improve their quality.

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