Journal of Elementology ISSN 1644-2296

Sidoruk M., Cymes I., Kobus Sz. 2020.
Impact of trout breeding in a cascade water flow technology on water quality.
J. Elem., 25(2): 399-411. DOI: 10.5601/jelem.2019.24.3.1906

RECEIVED: 10 September 2019
ACCEPTED: 29 December 2019

ORIGINAL PAPER

IMPACT OF TROUT BREEDING IN A CASCADE WATER FLOW TECHNOLOGY ON WATER QUALITY*

Marcin Sidoruk, Ireneusz Cymes, Szymon Kobus

Department of Water Resources,
Climatology and Environmental Management
University of Warmia and Mazury in Olsztyn, Poland

Abstract

Aquaculture needs specific conditions because fish have well-defined threshold water quality parameters within which they can thrive and grow optimally. However, the use of surface waters for fish production may threaten water ecosystems to which water from fish farms is discharged. The aim of this study was to evaluate the effect of rainbow trout production in a cascade flow technology on the water quality management in a fish farm. The research aim was to collect data in order to prevent contamination of natural water bodies by water discharged from fish ponds. The trout farm selected for the study is located in northern Poland. It has four concrete fish ponds, which are continually supplied with water spring water, flowing in a cascade. Spent water, prior to being discharged from the farm, is pre-treated by flowing through a treatment ditch. The study showed that as a result of flowing through the fish ponds, the quality of water deteriorated down to the lowest class on a five-degree scale (WQI_{CCME}), i.e. it was denoted as poor quality. However, it was evidenced that changes in the quality parameters of water after passing through ponds A and B were not large, whereas a more considerable decline in the water quality occurred once it had passed through ponds C and D. The research did not confirm the intended positive influence of a 450-meter-long treatment ditch on the quality of water discharged from the fish farm. Thus, it was demonstrated that water discharged from the fish ponds, despite the implemented system for its pretreatment, creates a risk of polluting water in the receiving water body.

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

Marcin Sidoruk, PhD, DSc. Eng., Department of Water Resources, Climatology and Environmental Management, University of Warmia and Mazury in Olsztyn, Oczapowskiego 2, 10-719 Olsztyn, Poland, e-mail: marcin.sidoruk@uwm.edu.pl

* The study was conducted under the statutory research carried out at UWM in Olsztyn, No 20.610.012-300.

INTRODUCTION

Water is the environment for fish, from which they absorb oxygen, in which they find food to ingest, and to which they excrete faeces. All water living organisms have specific threshold water quality parameters within which they can thrive and grow optimally. An increase or decrease in these parameters both have adverse effects on the functions of fish organisms (Badiola et al. 2018, Becke et al. 2019). The suitability of water for fish production is defined by its physical, chemical and biological parameters. These include temperature, transparency, turbidity, colour, pH, alkalinity and hardness, as well as the water content of cabon dioxide, ammonia, nitrates, nitrites, phosphates, chemical oxygen demand, primary productivity, biological oxygen demand, plankton populations, etc. (Pulkkinen et al. 2018). Thus, it is essential that these environmental parameters are monitored constantly to ensure that they are managed and regulated properly in terms of their impact on the functions and biological diversity of water bodies, hence providing fish with the conditions they need for their survival and optimal growth (Badiola et al. 2018). However, more intensive aquaculture with high stocking density, which is essential to achieve profitable fish farming, may pose a serious threat to the aquatic environment and to fish (Kocer, Sevgili 2014). Data on the release of nutrients by fish, and particularly correlated to the quality of ingested feeds and applied feeding techniques, are limited. Metabolites produced by fish have a significant effect on the chemical system of a pond and the development of natural food resources, which are crucial for the proper functioning of the pond's ecosystem and for the productivity and sustainability of aquaculture (Tahar et al. 2018).

The quality of water discharged from fish farms depends on many factors. These include fish species, breeding technology and quality and quantity of fodder supplied to fish. Wastewater from ponds is usually discharged directly to nearby streams. The water pollutants discharged from ponds are mineralised, which can interfere with the biological balance within water (Dimitroglou et al. 2011).

The above considerations explain why it is so important to protect the quality of water so as to prevent degradation, preserve natural values or even improve ecological condition of water bodies. Many countries have implemented regulations on waste water in aquaculture (Dalsgaard, Pedersen 2011). Deterioration of the quality of water and depletion of the resources of water suitable for trout production have necessitated the implementation of water treatment technologies, which enable repeated use of water in recirculating systems (Dimitroglou et al. 2011).

The aim of this study was to evaluate the effect of rainbow trout production in a cascade flow technology on the water quality management in a fish farm in order to prevent contamination of natural water bodies by water discharged from fish ponds.

MATERIAL AND METHODS

A trout farm located in northern Poland was selected for this study. The farm has concrete fish ponds, which are constantly supplied with water spring water, which flows in a cascade (Figure 1). Each pond can hold 125 m^3 of water and the average water flow rate through the ponds is 14 dm^3 s^{-1}.

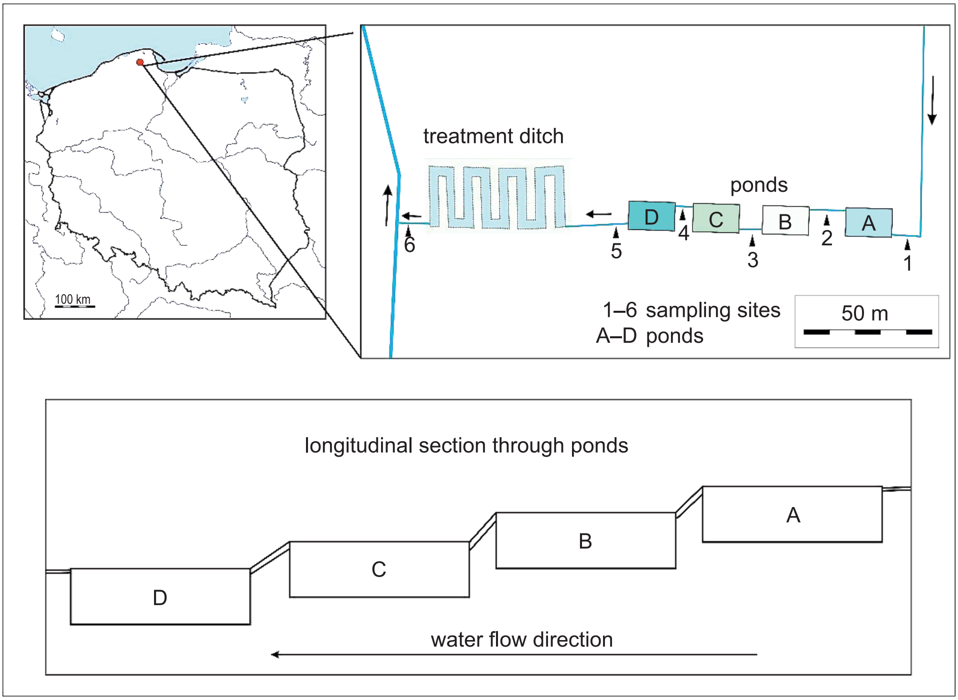


Fig. 1. The layout of the trout farm and localisation of the sampling sites

Spent water, prior to being discharged from the farm, is pretreated by flowing through a treatment ditch, which is 450 m long and has the water surface area of 0.22 ha. The ditch is 5 meters wide and 0.4 m deep. The average speed of water flowing through the ditch was 0.031 m s^{-1} within the current, and slightly above to 0 m s^{-1} in the shoreline zone, overgrown with plants. The ditch was planted with common reed (*Phragmites australis*) and white willow (*Salix alba* L.*)* to improve the effectiveness of nutrient removal. Rush vegetation grew in 2-meter wide belts on each side of the ditch.

The stocking density was 15 kg m^{-3} in ponds A and B, and 32 kg m^{-3} in ponds C and D . The average weight of fish introduced to ponds was 150 g in ponds A and B and 370 g in ponds C and D. The feed conversion ratio (FCR) was 0.97. Trout fish were fed at 9 a.m. and 4 p.m., and the feed was distributed manually. The granulated feed supplied to trout contained 70.4 g N kg^{-1}, 10 g P kg^{-1}, 6 g Na kg^{-1} and 7 g K kg^{-1}.

In order to assess the quality of water, 6 sampling sites were established, including the water inflow to the farm, outflows from the four ponds located at subsequent steps of the water cascade and the outflow from the farm (Figure 1).

The study was carried out for two years, and the samples were collected once a month. Oxygen dissolved in water and water pH were measured *in situ* at the designated sites, using a multi-parameter probe YSI 6600. At the same time, water samples were taken from the same sites to perform laboratory analyses. The determinations of total suspension, BOD_5, $N\text{-}NO_3$, $N\text{-}NO_2$, $N\text{-}NH_4$, $N_{Kiejdahl}$, P_{og} were made in line with the Standard Methods (1998). The concentration of $N\text{-}NH_3$ in water was calculated from the formula:

$$N\text{-}NH_3 = (a) \cdot TAN\ (\mathrm{mg\ dm^{-3}}),$$

where:
a – mole fraction of unionised ammonia,
TAN – total ammonia nitrogen (mg dm^{-3}),

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

T – temperature of water in a fish pond,
pH – pH of water in a fish pond.

Water Quality Index is an instrument applied to estimate the quality of water in water bodies (CYMES, GLIŃSKA-LEWCZUK 2016, MIRSAEEDGHAZI 2017). The WQI employed for a water quality assesment in fish production can be calculated with different methods. The one selected in this study was developed by the Canadian Council of Ministers of the Environment, and relies on the following equation (Canadian Council ... 2001):

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

The quality of water is determined by referring the calculated value of the WQI_{CCME} to one of the five categories. The eight physicochemical water parameters included in our calculations of the WQI_{CCME} values are the ones which are listed in *Directive 2006/44/EC*.

In the present study, hierarchal cluster analysis was applied to the dataset to detect similarity between the water samples from the fish farm in terms of water quality parameters. The dataset was treated by the Ward's method of linkage with the Euclidean distance as a measure of similarity. In order to assess general differences among the ponds and hydro-chemical data, a non-parametric analysis of variance using the Kruskal-Wallis test was applied, followed by the Dunn‘s multiple comparison *post-hoc* test at $P < 0.05$. Component Analysis (PCA) was performed using default (standard) options. The data (except for pH) were transformed to logarithms log (n+1) to satisfy conditions of normality. The CANOCO 4.5 software was used for the ordination analysis.

RESULTS

The water supplied to the fish farm was drawn from springs, and throughout most of the research period its quality was sufficiently good to satisfy the requirements set by Directive 2006/44/EC (Table 1). An exception was nitrite nitrogen, whose concentrations exceeded the threshold value. Also, the concentrations of the other nitrogen forms, P$_{tot.}$ and SS were the lowest in the water supplied to the farm (Figure 2). A significant relationship between P$_{tot.}$ and one of the nitrogen forms, N-NH$_3$, was demonstrated by the PCA (Figure 3).

Table 1

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

Index	Water quality requirements for salmonid fish	Inflow into the fish farm	Ponds				Outflow from a fish farm
			A	B	C	D	
Temperature*	<21.5	10.4±2.5	10.3±2.5	10.1±2.6	10.9±3.3	10.7±3.2	11.9±4.4
Dissolved oxygen	> 7.0	9.2±1.5	7.4±2.9	8.5±1.9	8.7±3.1	9.1±3.0	8.9±3.2
pH	6.00-9.00	6.88-8.40*	6.80-8.12*	6.82-7.98*	7.08-7.86*	6.95-7.88*	6.90-7.84*
SS	<25	13±12	30±17	19±14	32±31	19±13	39±49
BOD$_5$	<3.0	3.4±1.9	2.8±1.1	3.5±2.4	7.0±1.5	6.4±1.7	6.6±2.0
P$_{tot.}$	<0.2	0.13±0.11	0.13±0.07	0.11±0.04	0.14±0.06	0.18±0.05	0.23±0.03
N-NO$_2$	<0.003	0.007±0.003	0.008±0.004	0.007±0.003	0.041±0.019	0.047±0.016	0.041±0.018
N-NH$_4$	<0.78	0.06±0.02	0.48±0.14	0.41±0.21	1.70±0.29	1.80±0.43	1.70±0.77
N-NH$_3$	<0.020	0.001±0.001	0.006±0.005	0.006±0.005	0.014±0.015	0.019±0.020	0.011±0.009

Key: mean ± standard deviation, * min-max, SS – suspended solids, $P \leq 0.05$ (n=24)

The water delivered to the fish farm had the N$_{tot.}$ concentration of around 0.76 mg dm^{-3}, 60% of which was organic nitrogen and 31% was N-NO$_3$ (Figure 2). Occasionally, the threshold value of BOD$_5$, which was positively correlated with N-NO$_2$ and N-NH$_4$, was exceeded in the tested water samples (Figure 3). The water flowing to the fish ponds was characterised by the highest and most stable oxygenation, which coincided with the highest range of changes in pH (Table 1). The performed PCA revealed significant correlations between these parameters in the tested waters. Higher pH values occurred at times of higher water oxygenation. This was accompanied by a negative correlation with suspended soilds (Figure 3).

A substantial increase in the content of both nitrogen forms was observed in the water which had passed through pond A, alongside a double rise in the concentrations of mineral nitrogen and suspended solids, accompanied by a decrease in water-dissolved oxygen and BOD$_5$. Values of the other physicochemical parameters were approximately the same

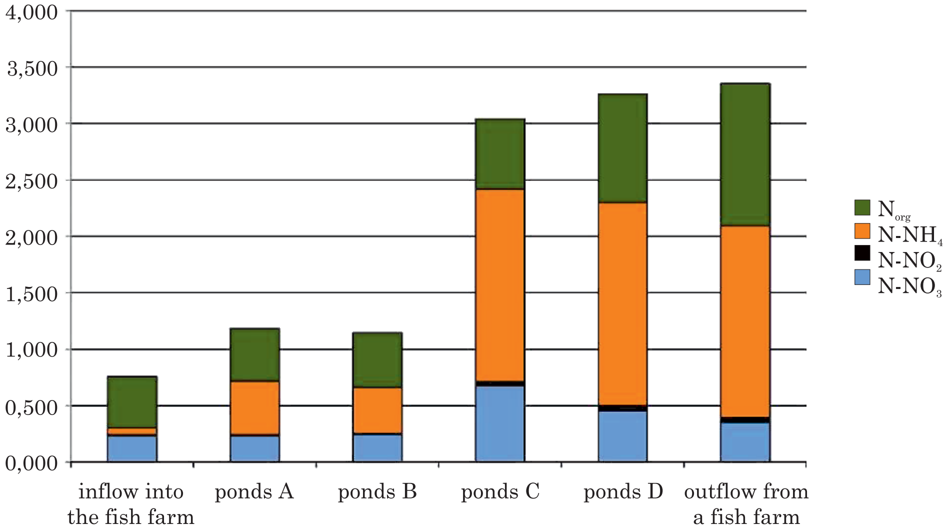
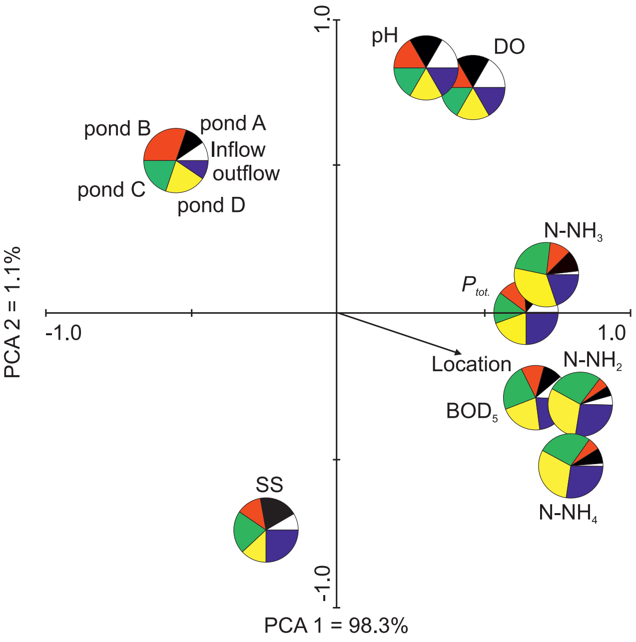


Fig. 2. Shares of individual nitrogen forms in water used in the fish farm (mg dm^{-3})

as in the water flowing into the pond. Water flowing from pond B was characterised by higher oxygenation and lower levels of suspended solids and total phosphorus. Despite the changes in the physicochemical parameters of water flowing to the farm and having passed through ponds A and B, as shown above, all these water samples belonged to the same homogeneous group comprising better quality water (Figure 4).

The remaining waters fell to the second category. Once the water had passed through pond C, its quality deteriorated substantially, mainly because of an increase in all nitrogen forms, most of which permanently exceeded the thresholds set as the requirements to be met by inland waters to serve as habitats of salmonid fish living in natural conditions (Table 1, Figure 2). The increase in concentrations ranged from around 30% for organic nitrogen to nearly 500% for nitrate nitrogen. Overall, it was noted that the total nitrogen concentration rose by 163%. Likewise, BOD_5, suspended solids and total phosphorus were evelated. The water discharged from pond D had the highest concentration of nitrite nitrogen $N\text{-}NH_3$ and $N\text{-}NH_4$ among all tested water samples.

There is a 450-meter-long ditch between pond D and the sampling site located at the discharge outflow of water to a receiving river. Its role is to improve the quality of water flowing from the farm before it reaches the river. However, our study showed that the effect of the ditch was dubious. While the content of mineral nitrogen decreased ($N\text{-}NO_3$ and $N\text{-}NH_3$ by 30% and $N\text{-}NH_4$ by 6%), the content of organic nitrogen increased (by 25%), which eventually meant that the concentration of total nitrogen in water discharged from the farm was the highest. The ditch did not have a positive effect on the content of water DO, BOD_5, SS or $P_{tot.}$ either. In order to make



Axes	PCA 1	PCA 2	PCA 3	PCA 4	Total variance
Eigenvalues:	0.983	0.011	0.005	0.001	1.000
Species-environment correlations:	0.213	0.553	0.320	0.480	
Cumulative percentage variance					
of species data:	98.3	99.4	99.9	100.0	
of species-environment relation:	91.5	98.7	99.7	100.0	
Sun of all eigenvalues					1.000
Sun of all canonical eigenvalues					0.048

Fig. 3. Analysis of the relationship between physicochemical parameters of water in the fish farm using the PCA method

an equivocal assessment of the water quality on the trout producing farm, the WQI_{CCME} was calculated. The values of this index justify the conclusion that water flowing to the fish farm was of satisfactory quality (Table 2).

As the water continued flowing through the consecutive trout ponds in the cascade, its quality was deteriorating. Once it had passed through pond B, the WQI_{CCME} value increased by 8.83, which meant that the quality of water fell from the marginal to fair category. The higher index value was due to the increase in water oxygenation by an average 1.1 mg dm^{-3} and a decrease in the amounts of suspended solids by 11 mg dm^{-3}. The above set of data shows a distinct division of the waters at the fish farm into two

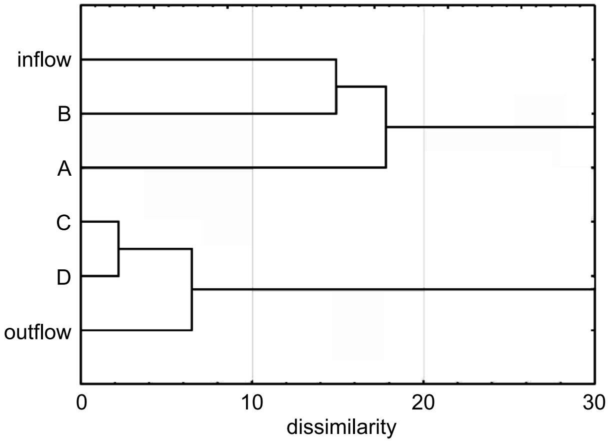


Fig. 4. Grouping of waters in the fish farm with the Ward hierarchical method

Table 2

The values of WQI_{CCME} quality indicators for the analysed water and the classification of water quality

Parameter	Inflow into the fish farm	Ponds				Outflow from a fish farm
		A	B	C	D	
F1	37.50	62.50	50.00	87.50	87.50	87.50
F2	18.75	31.25	22.92	54.17	54.17	60.42
nse	0.24	0.30	0.24	1.98	2.18	2.00
F3	19.35	23.08	19.35	66.44	68.55	66.67
WQI_{CCME}	73.34	57.51	66.34	29.28	28.61	27.54
Water quality	fair	marginal	fair	poor	poor	poor

groups: one, with better quality waters, comprises the waters flowing to the farm and sampled in ponds A and B, while the other one, with much worse water quality, consists of wasters sampled from ponds C and D and flowing out of the farm. This is confirmed by results of the statistical analysis of water quality parameters made according to the Ward method.

DISCUSSION

Water quality is a crucial factor in planning fish production in aquaculture (SIDORUK, CYMES 2018). It affects the general condition of the fish, thus determining their growth and health. A water environment is a complex system consisting of many variables that affect water quality, but only a few play an essential role in fish production. The most important parameter is dissolved oxygen, a supply of which is required to sustain fish metabolism.

The rainbow trout farming needs an oxygen content in water of no less than 3 mg dm^{-3}. Trout tolerate a short-term drop in water oxygenation below this value. However, if the oxygen content in water is below 3 mg dm^{-3} for a long time, it causes stress to the fish. As a result, food intake can be reduced, leading to a lower fish mass growth. An insufficient oxygen content also weakens fish immunity, thus increasing their susceptibility to the occurrence of a number of diseases that can even cause death (KOCER, SEVGILI 2014).

The quality of the water flowing to the fish farm was typical for natural surface water in this part of Europe. It was only in the case of BOD_5 and $N\text{-}NO_2$ concentrations that they were slightly higher, which may indicate water pollution (*Directive 2006/44/EC*). In the analysed farm, high oxygenation of water in all breeding ponds was assessed throughout the study period. There was a significant relationship between the concentration of dissolved oxygen in water and the pH of water, which was due to the photosynthesis conducted by phytoplankton. Photosynthesising phytoplankton absorbs large amounts of CO_2, which raises water pH, and more intensive photosynthesis parallels an increase in the oxygen content in water (FETHERMAN et al. 2016, NULL et al. 2017, BOYD 2018). Low pH in the analysed waters most often occurred in the spring, when two factors coincided: the inflow of melted snow water from the catchment and a low intensity of ongoing photosynthesis, the latter resulting from the low accessibility of sunlight due to the periodically abundant suspended solids in water (FETHERMAN et al. 2016). This assumption was confirmed by our findings, such as negative correlations with the water dissolved oxygen and water pH.

Another essential factor which decides whether waters are suitable for trout production is the quantity of organic matter in water, expressed with the BOD_5 parameter. It is assumed that the value of BOD_5 in water intended for the rearing of salmonid fish should not exceed 3.0 mg dm^{-3} (SIDORUK, CYMES 2018). The fish farm selected for this research carries out trout production in ponds with a cascade-like water flow system, which means that spent water from one pond is directed to the subsequent ones without any pretreatment. In consequence, the content of fish metabolites or undigested feed residues increases gradually and contributes to the growing amounts of organic matter. Bacteria that decompose organic substance in the presence of oxygen become more active, as a result of which the BOD_5 value is higher (BOYD et al. 2018). This can be confirmed by the determined positive correlation between BOD5 and the content of $N\text{-}NO_2$ and $N\text{-}NH_4$. Nitrites can be associated with the concentration of ammonia in water (CHRISTIANSON et al. 2015, BOYD et al. 2018).

The water passing through the subsequent ponds had a changing content of particular forms of nitrogen. An increase in the content of ammonia nitrogen was observed, in parallel to the diminishing share of organic nitrogen. Nitrogen (N) waste is of major concern in RAS fish farming systems, both with respect to water quality within the systems and a potential environmental impact of the effluents (DALSGAARD et al. 2015). Fish digest protein in their feed and excrete ammonia through their gills and in their faeces. The amount of ammonia excreted by fish varies, depending on amounts of feed put into a pond or a culture system, increasing as feeding rates increase. Ammonia also occurs in a pond as a consequence of bacterial decomposition of organic matter such as uneaten feed or dead algae and aquatic plants, which also causes an increase in the concentration of $N\text{-}NH_4$ (Christianson et al. 2015).

However, while the content of ammonia nitrogen continued to rise, its unionised form was not observed to have increased. Moreover, the concentration of unionised ammonia was never high enough to threaten the survival of fish. It is assumed that the toxicity of $N\text{-}NH_3$ at the level of LC 50 persisting for 24 h occurs at a concentration of this compound as low as 0.07-0.39 mg dm^{-3} (Dalsgaard et al. 2015). In our investigations, high values of unionised form of ammonia and total phosphorus concentration were obserwed. A higher amount of oxygen in water at lower temperatures and lower metabolic rates of fish at lower temperatures might render nitrite a less potent toxin at lower temperatures. However, it is also assumed that lower temperatures reduce the efficiency of detoxification mechanisms (Becke et al. 2019). The composition of fish feeds, which contained 70.4 g N kg^{-1} and 10.0 g P kg^{-1}, suggests that the main source of biogenic substances in the analysed waters was the intensive feeding of trouts. Our conclusion can be supported by other researchers who state that the amounts of nitrogen and phosphorus retained by fish vary, with an average quantity of retained nitrogen ranging between 25%-49%, and that of phosphorus being within 17-40% (Boyd 2018). Piedrahita (2003) said that fish faecal droppings contained 3.6%-35% N and 15%-70% P, while the amounts of N and P as excretory products were 37%-72% and 1%-62%, respectively. Nitrogen is mainly excreted in a dissolved form as ammonia, while phosphorus is excreted as particulate matter. RAS solids and sludge are typically removed by sedimentation or physical filtration (Spiliotopoulou et al. 2018). This uneaten food along with faeces (solid waste) may increase sedimentation and enrich the nutrient pool of receiving water bodies (Rana et al. 2018). This, in turn, may explain why the ability of water to self-purify diminishes drastically at the second step of the cascade, and therefore an increase in the concentration of nitrogen occurs there.

The study showed that the use of a four-stage cascade system in trout farming significantly affects water quality. The stocking density in ponds C and D was about twice as high (32 kg m^{-3}) as in ponds A and B (15 kg m^{-3}). This caused a decrease in water quality due to the greater amount of metabolites entering the water. The distribution of metabolites caused periodic excess of certain parameters above the fish life-threatening values, especially with respect to BOD_5, $N\text{-}NH_4$, $N\text{-}NH_3$, $N\text{-}NO_2$ (Tahar et al. 2018).

The research demonstrated that after the water had passsed through the trout ponds its quality deteriorated, although it was better than observed at an outflow at other farms using RAS systems (Becke et al. 2019). Despite being exposed to pretreatment in the treatment ditch, its quality did not improve significantly. When such water is discharged directly to the environment, without effective treatment, it can pose a threat to water habitats (Mirsaeedghazi 2017).

The lack of a significant improvement of water quality parameters, and even their deterioration, could be due to the low water treatment capacity in the treatment ditch. The stricture of the ditch, i.e. excessively thick layer of water, low turbulent water flow, limited contact with the plants' absorption surface in addition to the low plant density, makes it difficult to sufficiently retain the nutrients in the treatment ditch. The low efficiency of water treatment is further explained by the infrequent removal of organic matter accumulated in the aerial parts of plants. In order to improve the efficiency of the pretreatment of water leaving the fish ponds, the active surface of the bottom of the ditch should be increased, which will mean a better contact of the flowing water with the absorbing parts of the plants. This can be achieved by lowering the water level in the ditch down to a few cm and directing water only to the root zone of plants. Simultaneously, the plants should grow to cover the entire surface of the ditch bed. It is recommended to periodically (at least once every two years) remove aerial parts of plants. The implementation of the above recommendations should improve the quality of waters leaving the fish farm (Konnerup et al. 2011).

CONCLUSIONS

As a result of flowing through the fish ponds, arranged in a cascade system, the quality of water deteriorated to the lowest class on a five-degree scale, thus being denoted as poor quality. However, it was evidenced that changes in the quality parameters of water after passing through ponds A and B were not large, whereas a more considerable decrease in the water quality occurred once it had passed through ponds C and D. The threshold values of nitrite and ammonia nitrogen as well as BOD_5 were exceeded constantly, while the concentrations of the SS, $P_{tot.}$, $N\text{-}NH_3$ were periodically above the quality norms. The nitrogen balance determined in the analysed waters showed a gradual increase in the concentration of ammonia nitrogen at the expense of the organic nitrogen share.

The research did not confirm the intended positive influence on the quality of water discharged from the fish farm by the 450-meter-long ditch situated between the lowest fish pond in the cascade (pond D) and the outlet of water from the farm. After water had passed through the ditch, its quality class remained in the poor category. Thus, it was demonstrated that water discharged from the fish ponds, despite the implemented system for its pretreatment, creates a risk of polluting water in the receiving water body. Therefore, more efficient measures should be taken to protect water quality.

This can be achieved by lowering the water level in the ditch and directing water only to the root zone of plants. Simultaneously, the plants should cover the entire surface of the ditch bed. It is recommended at least once every two years remove aerial parts of plants and dredging the bottom of the ditch. The above treatments should improve the quality of waters leaving the fish farm.

ACKNOWLEDGEMENTS

Project financially supported by Minister of Science and Higher Education in the range of the program entitled "Regional Initiative of Excellence" for the years 2019-2022, Project No. 010/RID/2018/19, amount of funding 12.000.000 PLN.

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