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Impact assessment of effluents from fish ponds on water quality of the discharge site in the stream Strumyk Goleniowski in Zachodniopomorskie Province, north-western Poland

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ABSTRACT

Fish farming may have a negative impact on the environment through discharge of water containing organic matter, nitrogen and phosphorus. The paper presents the impact of effluents from the Fish Breeding and Stocking Centre (FBSC), located in Goleniowski, Zachodniopomorskie Province in north-western Poland on water quality of the discharge area in the stream Strumyk Goleniowski. FBSC uses rational methods of fish keeping and breeding. The water quality parameters of the input and output water of the centre was monitored. We identified multi-directional processes which shaped the water quality in the study sites with the main factors influencing the water quality being, temperature, alkalinity, total hardness, nutrients, ammonium nitrogen (NH_4^+-N), total reactive phosphorus and total phosphorus. During summer season, decomposition of organic matter decreased oxygen concentration in water and during winter source of DO was diffusion. Increase in concentration of organic matter in outflow from FBSC resulted from culture as well as from primary production. Increase in concentration of NH_4^+-N and phosphorus in outflow water resulted from released metabolites by live fish and from feed decomposition. Ammonification and nitrification influenced seasonal changes in nonorganic nitrogen forms. NH_4^+-N and nitrate nitrogen were substantial source of nitrogen for autotrophs. The hydro-chemical conditions in the water of the FBSC should be regarded as optimum for fish that are sensitive to pollution and it did not deteriorate the quality of the outflow water.

Keywords: Fish farming, Fish ponds, Hydro-chemical parameters, Water quality

Introduction

Pond pisciculture affects the chemical composition of the water; depending on the season, species and size of fish stock (Boyd and Tucker 1998; Brune *et al*., 2003; Quant *et al*., 2009; Sidoruk, 2012; Bonislawska *et al*., 2013; Berlec *et al*., 2015). During fish production, the concentrations of such biogenic substances as nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4^+-N), total nitrogen (TN) and total phosphorus (TP) in the water increases; accompanied by an increase in the content of organic matter and total suspended solids (TSS) (Read and Fernandes, 2003; Quant *et al*., 2009; Wojda and Zygmunt, 2012; Bonislawska *et al*., 2013; Teodorowicz, 2013). The phenomenon is a result of releasing the fish metabolites, feed remains, remains of medicines and disinfectants into the water (Piedrahita, 2003; Sugiura *et al*., 2006; Tucholski and Sidoruk, 2013). Rational fish production requires, among other things, planning of adequate fish stock in the ponds and using high-energy and highly digestible feed. The departure of fish farmers from using wet feed has resulted in a favourable decrease in the quantity of organic substances which are introduced into waters discharged from fish farms (Amirkolaie, 2011; Davidson *et al*., 2013). Ponds with fish production of small intensity do not cause deterioration in the quality of the discharged water (Sidoruk, 2012; Bonislawska *et al*., 2013). In the case of aquaculture ponds with considerably polluted waters, rational innovative fish production management may help improve the water quality (Kolasa-Jaminska, 2004; Crab *et al*., 2007; Kaca *et al*., 2009).

The objective of this study was to assess the impact of the discharge water from a fish farm in Goleniow City, Poland, on the environment in the outflow area.

Materials and methods

Study area

The ponds selected for the present study in the Fish Breeding and Stocking Centre (FBSC) at Goleniow is located in the eastern part of the Zachodniopomorskie

Province (53°33'N; 14°50' E) in north-western Poland. The total surface area of the ponds (18 nos.) is 16.34 ha, depth ranging from 0.6 to 1.4 m (Balinski, 2012). The FBSC in Goleniow serves as production of stocking material and has no commercial or angling (recreational fishing) activities. The FBSC ponds were established in 1962 with carps stocked for breeding and consumption. In 2007-2008, the ponds were modernised and the total production was 11.5 t of fish which was used to stock lakes and rivers.

The ponds are fed by the stream Strumyk Goleniowski through water damming using a one-step weir. The stream flows mainly among meadows and aquaculture farms, far from industrial and agricultural fields. The main pollution of the stream comprises effluents from aquaculture ponds. Individual ponds are supplied with water through outlet boxes from the ditches around the farm (Fig. 1).

The fish species stocked in different types of ponds (Fig. 1), were pike *Esox lucius* (L.), sander *Sander lucioperca* (L.), catfish *Siluris glanis* (L.), ide *Leuciscus idus* (L.), vimba *Vimba vimba* (L.), asp *Aspius aspius* (L.), whitefish *Coregonus lavaretus* (L.), tench *Tinca tinca* (L.), crucian carp *Carrasius carrasius* (L.) and common carp *Cyprinus carpio* (L.). Stocking material in the form of fry (summer, spring 1+, autumn) and fingerlings is produced for each fish species; spawners and commercial fish are also produced (Balinski, 2012).

According to the pertinent regulations, the filling and emptying of the ponds is done during different periods. The largest ponds are filled from January to May and spawners as well as larvae and fry are stocked in respective ponds. In summer (May to July), the ponds are filled and stocked with fry while in winter (April to October), the ponds are emptied. The wintering ponds are emptied from April to October. During May-July, the respective ponds are emptied for catches of summer fry and from September to October they are emptied for catches of autumn fry. In winter, the ponds are dried for natural disinfection of the bottom. There is no periodic (annual) bottom cleaning. The remaining fish are kept in temporary holding ponds and transferred to the rearing ponds in spring (Balinski, 2012).

Monthly sampling for water quality parameters was done for 11 months (except in August) in 2013, for 12 months in 2014 and for 8 months from January to September (except in August) in 2015.

Analyses of water quality parameters

Water samples were collected at monthly intervals following standard protocols (APHA, 1999) from two sites *viz*., A) site in retention pond (53°33'52,56" N; 14°51'5,51" E) and B) site located in the end section of the surrounding ditch (53°34'6,35" N; 14°50'35,58" E) (Fig. 1).

During sampling, water temperature, pH (using pH meter with thermometer, Elmetron CP-103, Poland) and conductivity (employing conductometer, Elmetron CC-101, Poland) were measured.

Water quality indices *viz*., TSS, dissolved oxygen (DO), biochemical oxygen demand (BOD_5), chemical oxygen demand (COD_{Cr}), total alkalinity, total hardness (TH), chloride ions, ammonium nitrogen (NH_4^+-N), nitrite nitrogen (NO_2-N), nitrate nitrogen (NO_3-N), TN, total reactive phosphorus (TRP) and TP were determined following standard methods (APHA, 1999).

Statistical analysis

The results were subjected to statistical analyses using Statistica 12.1 software (StatSoft Inc.). One-way

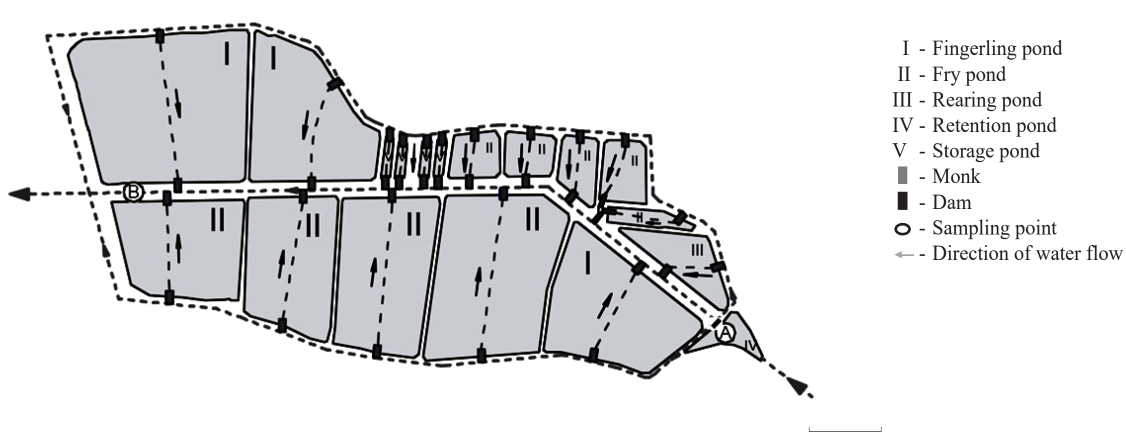

Fig. 1 Diagram showing the stocking ponds at the Fish Breeding and Stocking Centre (FBSC) in Goleniow

analysis of variance (ANOVA, $p<0.01$) and Duncan's *post-hoc* test ($p<0.05$) were used to compare mean values of the studied indices between the seasons and sites (A and B). Principal component analysis (PCA) was used to determine loads of principal components.

Results and discussion

Water temperature varied from 4.0 to 22.3°C (Table 1) and the seasonal variation corresponded to that characteristic of temperate water bodies with minimum in winter and maximum in summer (Table 2).

Table 1. Range, mean values and standard deviation (SD) of water quality indices in sites A and B during the study period

Site		T (°C)	pH	TSS (mg dm^{-3})	DO mgO_2 dm^{-3}	BOD_5	COD_{Cr}	Alkalinity mg$CaCO_3$ dm^{-3}	TH mgCO_3^{2-} dm^{-3}
A	Mean ±SD	11.4^{a} ±5.7	7.4^{b} ±0.5	30.1^{c} ±17.3	8.9^{d} ±2.3	2.9^{e} ±1.4	31.1^{f} ±19.9	193.9^{h} ±24.5	263.4^{i} ±25.6
	Range	4.2-22.1	6.5–8.3	10.0-98.0	3.2–12.8	1.0-8.1	5.0-83.6	135–245	190.0-295.5
B	Mean ±SD	11.6^{a} ±5.6	7.4^{b} ±0.4	38.3^{c} ±19.9	9.2^{d} ±1.9	3.4^{e} ±1.8	38.0^{f} ±20.1	183.6^{h} ±31.9	253.0^{i} ±31.7
	Range	4.0-22.3	6.7-8.5	8.0-154	5.4-12.7	1.0-8.5	9.0-95.4	84-231	192.5-297.5
↑	%	1.7	-	21.4	3.3	14.7	18.2	-	-
↓		-	-	-	-	-	-	5.3	3.9
Site		**Cond. (µS cm^{-1})**	**Cl^- (mg Cl^- dm^{-3})**	**NH_4^+-N (mg N dm^{-3})**	**NO_2^--N**	**NO_3^--N**	**TN**	**TRP (mg P dm^{-3})**	**TP**
A	Mean ±SD	552^{g} ±113.7	32.4^{j} ±4.7	0.067^{a} ±0.048	0.030^{b} ±0.011	0.059^{c} ±0.03	0.960^{d} ±0.486	0.057^{e} ±0.024	0.245^{g} ±0.082
	Range	396-847	24.7-42.6	0.017-0.181	0.012-0.055	0.013-0.131	0.315-2.519	0.016-0.153	0.118-0.458
B	Mean ±SD	538±129.3^{g}	32.4^{j} ±5.1	0.092^{a} ±0.070	0.030^{b} ±0.014	0.055^{c} ±0.03	0.854^{d} ±0.554	0.075^{f} ±0.043	0.303^{g} ±0.143
	Range	307-803	24.8-42.6	0.012-0.311	0.007-0.059	0.008-0.123	0.231-2.416	0.012-0.162	0.121-0.609
↑	%	3.0	-	27.2	-	-	-	24.0	19.1
↓		-	-	-	-	6.8	11.0	-	-

T - temperature; TSS - total suspended solids; Cond. - conductivity, TH - total hardness, TN - total nitrogen; TRP - total reactive phosphorus;
* ANOVA - $p<0.05$; mean values bearing different superscripts differ significantly at $p>0.05$ (Duncan's *post-hoc* test)

Table 2. Seasonal variation of water quality indices (mean values) in sites A and B and ANOVA ($p<0.05$) comparing seasons for each site

	Temperature (°C)				pH				TSS (mg dm^{-3})				Alkalinity mg$CaCO_3$ dm^{-3}			
	W	Sp	Su	A	W	Sp	Su	A	W	Sp	Su	A	W	Sp	Su	A
Site A	5.6^{a}	13.7^{b}	18.1^{c}	8.9^{d}	7.2^{a}	7.6^{a}	7.6^{a}	7.2^{a}	25.6^{a}	39.6^{a}	24.0^{a}	30.0^{a}	174.7^{a}	199.8^{b}	204.9^{b}	201.5b
Site B	5.8^{a}	13.8^{b}	17.9^{c}	9.0^{d}	7.2^{a}	7.6^{a}	7.7^{a}	7.2^{a}	19.1^{a}	36.9^{a}	54.6^{b}	50.3^{b}	173.8^{a}	185.6^{a}	181.6^{a}	197.6a
	DO (mgO_2 dm^{-3})				**BOD_5**				**COD_{Cr}**				**Total hardness mgCO_3^{2-} dm^{-3}**			
	W	Sp	Su	A	W	Sp	Su	A	W	Sp	Su	A	W	Sp	Su	A
Site A	10.7^{a}	7.5^{bc}	8.2^{bc}	9.3^{ac}	2.6^{a}	2.4^{a}	4.1^{b}	2.9^{ab}	25.0^{ab}	36.0^{ab}	43.4^{b}	18.6^{a}	255.7^{a}	256.8^{a}	271.8^{a}	275.1a
Site B	10.3^{b}	8.9^{ab}	8.1^{a}	9.4^{ab}	2.1^{a}	3.2^{a}	5.1^{b}	3.6^{ab}	34.9^{a}	41.6^{ab}	50.0^{b}	23.0^{a}	253.3^{ab}	239.6^{a}	246.1^{b}	280.3b
	TRP (mg P dm^{-3})				**TP**				**Conductivity (µS cm^{-1})**				**Cl^- mgCl^- dm^{-3}**			
	W	Sp	Su	A	W	Sp	Su	A	W	Sp	Su	A	W	Sp	Su	A
Site A	0.062^{a}	0.063^{a}	0.057^{a}	0.057^{a}	0.200^{a}	0.234^{ab}	0.309^{b}	0.254^{ab}	589^{ab}	493^{a}	518^{ab}	625^{b}	32.6^{a}	30.2^{a}	34.5^{a}	31.7a
Site B	0.053^{a}	0.079^{a}	0.085^{a}	0.077^{a}	0.234^{a}	0.268^{a}	0.462^{b}	0.270^{a}	613^{b}	474^{a}	447a	629^{b}	32.5^{a}	31.0^{a}	34.0^{a}	33.8a
	NH_4^+-N (mg N dm^{-3})				**NO_2-N**				**NO_3-N**				**TN**			
	W	Sp	Su	A	W	Sp	Su	A	W	Sp	Su	A	W	Sp	Su	A
Site A	0.065^{a}	0.076^{a}	0.053^{a}	0.078^{a}	0.027^{a}	0.034^{a}	0.034^{a}	0.024^{a}	0.075^{b}	0.038^{a}	0.054^{ab}	0.072^{b}	1.246^{a}	0.598^{a}	0.706^{a}	1.072a
Site B	0.079^{b}	0.088^{a}	0.067^{a}	0.144^{a}	0.027^{a}	0.027^{a}	0.033^{a}	0.031^{a}	0.080^{c}	0.033^{a}	0.042^{ab}	0.063^{bc}	1.170^{b}	0.433^{a}	0.847^{ab}	0.967ab

*Mean values bearing different superscripts in a column differ significantly at $p>0.05$ (Duncan's *post-hoc* test); W - winter; Sp - spring; Su - summer; A - autumm

The temperature in site B was slightly higher than in site A (on an average by 1.7%), but the difference was not statistically significant (Table 1). No significant differences were observed in the water temperature ($p>0.05$) of the compared sites in particular seasons of the year.

The water pH varied from 6.5 to 8.5 and the mean values for the whole study period were the same in the two sampling sites (Table 1). The seasonal variation in pH showed an increase in spring and summer and a decrease in autumn and winter (Table 2). The alkalinity was in the range of 84-245 mg $CaCO_3$ dm^{-3} and insignificantly ($p>0.05$) higher in site A (Table 1). The seasonal variation resulted in a lower alkalinity in winter compared to the remaining seasons (Table 2). Such seasonal variation of pH and alkalinity is typical of surface waters. In summer, with increasing primary production (assimilation), the values of these indices increased while in winter (dissimilation) acidification is observed (Nędzarek *et al*., 2013; Zhao *et al*., 2015).

Positive correlation was observed between pH and water temperature and water temperature and alkalinity, while negative correlation between pH and ammonium nitrogen as well as between pH and nitrate nitrogen (Table 3 and 4) which allow to conclude that the listed processes shaped the hydro-chemical conditions in both the study sites.

The dissolved oxygen concentration was within the range of 3.2-12.8 mg O_2 dm^{-3}; and the concentration at site B was on an average 3.3% higher than at site A. The differences in DO between the sites were not significant, either for the means from the whole study period (Table 1) or for particular seasons of the year.

In both the sites, DO concentration was significantly higher in autumn and winter compared to spring and summer (Table 2). Similar seasonal differences in DO, for example in Chinese lakes, were observed by Zhao *et al*. (2015), who pointed out that the organic matter decomposition, being more intensive in summer, used much oxygen. The negative correlation of DO with water temperature (statistically significant) and with organic matter content (weak correlation), observed in our studies (Tables 3 and 4; Fig. 2), suggests that dissimilation processes also contributed to the shaping of oxygen conditions in the two sites.

The TSS, BOD_5 and COD_{Cr} were higher at site B than at site A (on an average by 21.4, 14.7, and 18.2%, respectively), but the differences were not statistically significant (Table 1). The increase in values of those indices in site B could be attributed to the effect of pisciculture such as feed remains and fish faeces which can cause increase in such indices (Bodvin *et al*., 1996; Nootong *et al*., 2012). It should also be considered that site A was a retention reservoir having very slow water flow where, sedimentation of suspended matter may have taken place analogous to flow lakes (Nedzarek *et al*., 2007). Site B, in contrast, was located on a discharge canal with constant mixing of water.

The spring and summer increase in BOD_5 and COD_{Cr} (Table 2) indicates that in those seasons natural processes associated with intensified primary production were the source of organic matter, as shown by the proportional dependence of BOD_5 on temperature (Fig. 2).

Table 3. Linear correlation for relationships between water quality indicators in the study site A

Parameter	TSS	T	DO	pH	BOD_5	COD_{Cr}	Conductivity	Alkalinity	TH	Cl^-	NH_4^+-N	NO_2^+-N	NO_3^+-N	TN	TRP
Temperature	0.11	–													
DO	-0.05	-0.64*	–												
pH	0.05	0.35	-0.27	–											
BOD_5	-0.07	0.60*	-0.06	-0.07	–										
COD_{Cr}	0.05	0.34	-0.28	-0.09	0.12	–									
Conductivity	0.06	-0.57*	0.59*	-0.44*	-0.16	-0.20	–								
Alkalinity	0.35	0.61*	-0.48*	0.12	0.26	0.27	-0.22	–							
TH	0.01	0.07	-0.08	-0.02	-0.01	-0.09	0.33	0.59*	–						
Cl^-	0.02	0.28	-0.26	0.18	0.12	-0.02	-0.35	0.56*	0.55*	–					
NH_4^+-N	0.55*	-0.11	0.03	-0.12	-0.22	0.17	0.16	0.07	0.06	0.03	–				
NO_2^--N	0.08	0.50*	-0.45*	0.14	0.29	0.25	-0.21	0.46*	0.09	0.21	-0.21	–			
NO_3^--N	-0.47*	-0.61*	0.27	-0.30	-0.37	-0.44*	0.35	-0.21	0.39	0.07	-0.17	-0.16	–		
TN	-0.02	0.21	0.02	0.52*	0.04	0.19	-0.18	-0.02	-0.26	-0.10	-0.24	0.16	-0.31	–	
TRP	0.20	0.30	-0.44*	-0.05	-0.09	0.32	-0.31	0.66*	0.32	0.45*	0.03	0.43*	-0.01	0.01	–
TP	0.20	0.59*	-0.26	-0.01	0.53*	0.27	-0.28	0.63*	0.25	0.55*	0.17	0.29	-0.36	-0.19	0.43*

TSS - total suspended solids; DO - dissolved oxygen, T - temperature; TH - total hardness, TN - total nitrogen; TRP - total reactive phosphorus; TP - total phosphorus; *Statistically significant correlations at $p<0.05$

Table 4. Linear correlation for relationships between water quality indicators in the study site B

Parameter	TSS	T	DO	pH	BOD_5	COD_{Cr}	Conductivity	Alkalinity	TH	Cl^-	NH_4^+-N	NO_2^--N	NO_3^--N	TN	TRP
Temperature	0.35	–													
DO	-0.30	-0.63*	–												
pH	0.03	0.23	0.02	–											
BOD_5	0.36	0.57*	-0.29	-0.36	–										
COD_{Cr}	-0.16	0.16	-0.05	-0.16	0.28	–									
Conductivity	-0.30	-0.58*	0.61*	-0.29	-0.30	-0.21	–								
Alkalinity	0.38	0.47*	-0.23	-0.35	0.35	-0.06	-0.20	–							
TH	0.06	-0.10	0.23	-0.25	-0.11	-0.49*	0.42*	0.62*	–						
Cl^-	0.14	0.26	-0.37	-0.16	0.27	-0.12	-0.38	0.21	0.11	–					
NH_4^+-N	0.16	-0.13	-0.03	-0.14	0.01	0.07	0.05	0.23	-0.01	-0.36	–				
NO_2^--N	0.48*	0.41*	-0.35	0.14	0.31	-0.20	-0.20	0.46*	0.29	0.38	-0.16	–			
NO_3^--N	-0.21	-0.64*	0.32	-0.27	-0.43*	-0.34	0.42*	-0.17	0.37	0.09	-0.12	-0.06	–		
TN	-0.35	0.11	0.11	0.60*	-0.16	0.25	-0.11	-0.07	-0.19	-0.23	-0.23	0.14	-0.24	–	
TRP	0.27	0.27	-0.48*	-0.16	0.34	-0.00	-0.27	0.37	0.04	0.14	0.29	0.39	-0.03	0.04	–
TP	0.60*	0.65*	-0.63*	0.06	0.44*	-0.05	-0.48*	0.44*	-0.03	0.32	0.16	0.36	-0.33	-0.19	0.59*

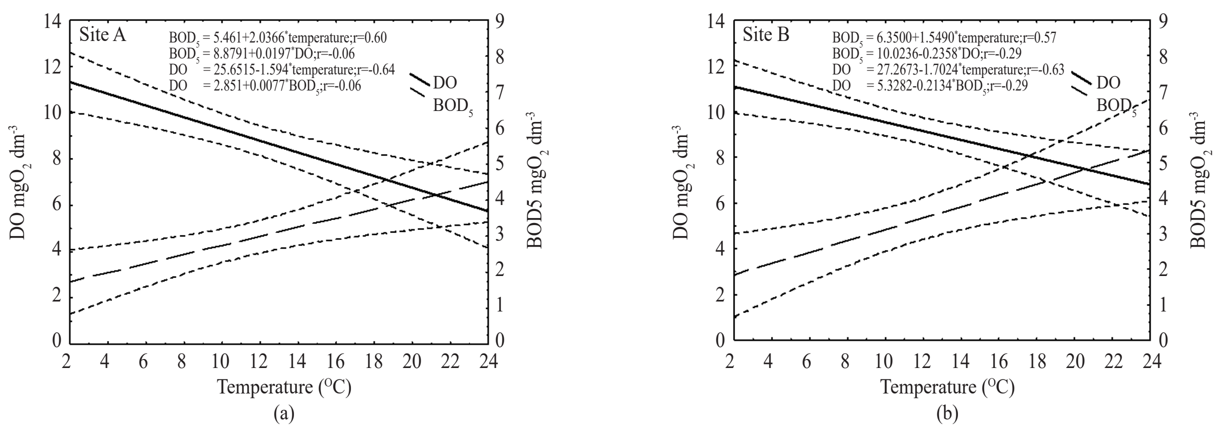

Fig. 2. Dependence of dissolved oxygen (DO) and BOD_5 on water temperature at sites A and B

Forms of inorganic nitrogen can be arranged according to their mean concentration: NO_3-N>NH_4^+-N >NO_2-N. The mean concentrations of NO_2-N in both sites were the same (0.030 mg N dm^{-3}). The mean concentration of NO_3-N in site A was higher than in site B (0.059 and 0.055 mg N dm^{-3}, respectively) and the mean concentration of NH_4^+-N in site A was lower than in site B (0.067 and 0.092 mg N dm^{-3}, respectively). However, the differences were not statistically significant (Table 1).

The increase in the ammonium form of nitrogen at site B may have resulted from fish production in FBSC. The source of ammonium nitrogen are excretion of metabolites by the fish and release of organic nitrogen compounds from the feed (Nedzarek *et al*., 2009; Nootong *et al*., 2012).

The concentrations of NO_2-N in spring and summer were insignificantly higher than those recorded in autumn and winter. The concentrations of NO_3-N were higher in autumn and winter and lower in spring and summer, whereas the values for NH_4^+-N were higher in spring and autumn than in winter and summer (Table 2).

Seasonal fluctuations of such indices depend on such factors as inorganic forms of nitrogen from the catchment area, mainly ammonia released from cultivated fields during spring (Zhao *et al*., 2015) and on ammonification and nitrification processes (Torz and Nedzarek, 2010). Those two processes are indicated by the observed dependence between inorganic forms of nitrogen, DO and temperature. NO_3-N was significantly negatively correlated with temperature (r = -0.61 in site A and r = -0.64 in site B) and positively correlated with DO (r = 0.27 in site A and r = 0.32 in site B). NO_2-N was significantly positively correlated with temperature and negatively correlated with DO (Tables 3 and 4; Fig. 3).

The weak negative correlations (r from -0.23 to -0.31) of TN with NO_3-N and NH_4^+-N (Tables 3 and 4)

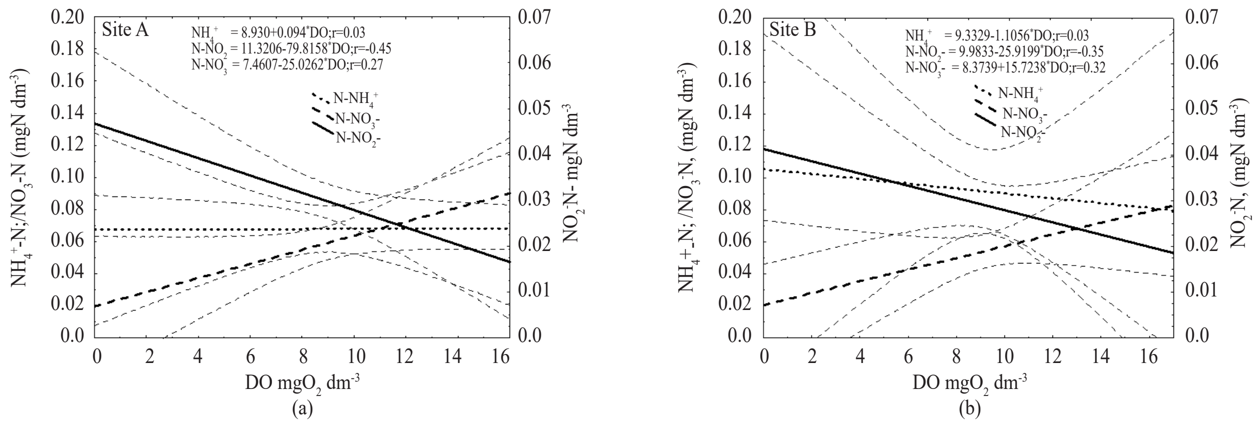

Fig. 3. Dependence of concentration of NH_4^+-N; NO_3^-N and NO_2^-N on dissolved oxygen (DO) at sites A and B

indicate that both forms of inorganic nitrogen constituted equivalent nitrogen sources for autotrophic organisms. The situation is typical of ecosystems with small concentration of inorganic nitrogen (Anderson *et al*., 2002; Richmond, 2004).

The TRP and TP concentrations in the two sampling sites were typical of eutrophic waters (Torz and Nedzarek, 2009) and were higher in site B (Table 1). The increase in phosphorus concentration in the water discharged from the FBSC may have been caused by the same factors as the increase in ammonium nitrogen. Phosphorus may have been also released from internal sources of the fish ponds (*e.g.* recirculation from bottom deposits or excretion of TRP by zooplankton) (Anderson *et al.,* 2002). TP (in site B) was significantly correlated with temperature (r = 0.65), BOD_5 (r = 0.44) and DO (r = - 0.63) (Table 4; Fig. 4).

The conductivity varied within the range 307-847 µS cm^{-1} and on average 3% higher at site A (Table 1). In both sites it was higher in autumn and winter than in spring and summer (Table 2). During the whole study period, since no significant seasonal differences were observed in the concentration of chloride or carbonate ions, it can be concluded that other inorganic salts were provided from the source water and shaped the seasonal changes in conductivity. For example, in the waters of the Ina River (N-W Poland), Nedzarek *et al*. (2015) observed an increased conductivity and concentration of chloride ions in winter, resulting from the inflow of thaw waters enriched with NaCl from roads.

The concentration of chloride ions in both sites was the same (mean 32.4 mg dm^{-3}) and the concentration of carbonate ions based on total hardness was insignificantly higher by 3.9% in site A (mean concentration 263.4 mg CO_3^{2-} dm^{-3}) (Tables 1 and 2). Based on these indices the water at the study sites can be classified as of medium-salinity as well as resistant to acidification (Pyka *et al*., 2007; Nedzarek *et al*., 2015). Water from study sites is rich in cations (alkali) and can stabilise pH, for *e.g.* in cases when concentration of acid pollutants increase.

PCA analysis showed that three components explained 53.08% of total variance in the data matrix (Table 5). Component 1 was dominated by water

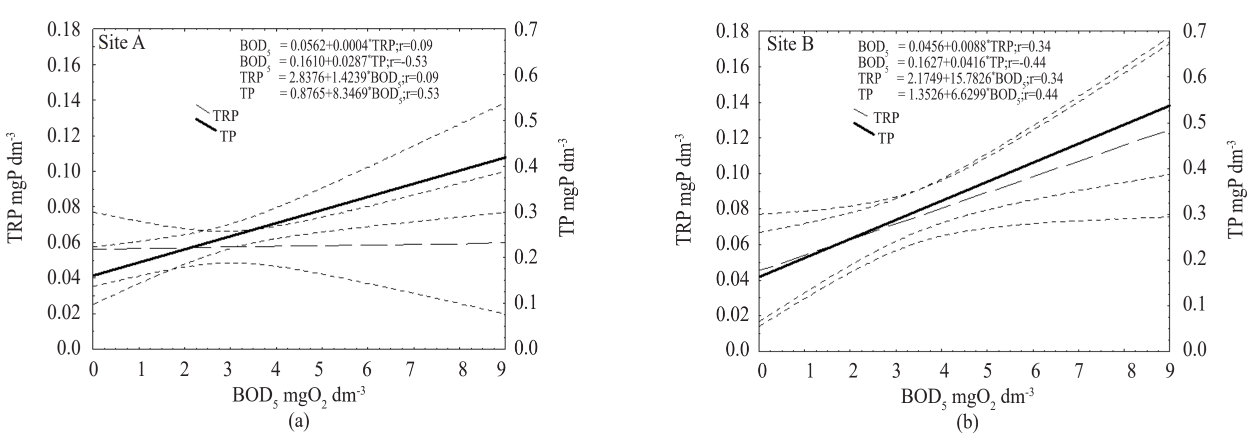

Fig. 4. Dependence of concentration of TRP and TP on BOD_5 at sites A and B

Table 5. Component matrix and rotated component matrix varimax rotation

Indicator	PC1	PC2	PC3
Temperature	0.7901	-0.2948	-0.2606
pH	0.0734	-0.3854	-0.3736
TSS	0.5525	0.2721	0.3122
DO	-0.6999	0.0299	0.2508
BOD_5	0.5518	-0.0696	0.2057
COD_{Cr}	0.2977	-0.5209	0.0901
Conductivity	-0.5416	0.5286	0.3151
Alkalinity	0.4983	0.6531	-0.1709
Total hardness	0.0349	0.7994	-0.2404
Cl^-	0.3196	0.3600	-0.4094
$N\text{-}NH_4^+$	0.1461	0.1687	0.6968
$N\text{-}NO_2^-$	0.3939	0.4584	-0.3551
$N\text{-}NO_3^-$	-0.5963	0.4732	-0.1537
TN	-0.3480	0.3957	-0.0654
TP	0.7470	0.1900	0.2733
TRP	0.6038	0.3575	0.3487
Percent variance	25.245	17.779	10.053

temperature, TSS, DO, BOD_5, TRP and TP (25.25% of total variance). while component 2 was dominated by conductivity, alkalinity, TH, NO_2^-N, NO_3^-N and TN (17.78% of total variance). Component 3 was dominated by DO and NH_4^+-N (10.05334% of total variance). Such a varied effect of individual water quality indices on the components indicates multi-directional (and hardly definable) processes which shaped the water quality in the sampling sites. Following Zhao *et al*. (2015) it can be concluded that the main contributing factors (eigenvalues >0.6) were natural parameters (temperature, alkalinity and TH) and nutrient components (NH_4^+-N, TRP and TP).

The thermal and oxygen conditions as well as pH of the water during the study period can be regarded as adequate for fishes, including salmonids. The adequate temperature for those species is below 10°C and oxygenation should exceed 7.0 mgO_2 dm^{-3} (Muller and Stadelmann, 2004). Small concentrations of inorganic forms of nitrogen indicate that, in the water nitrification took place which decreased the concentration of ammonium nitrogen. Besides, the low pH maintained the dissociated form of ammonium nitrogen which is safe for fishes (Eddy, 2005; Arrendondo-Figueroa *et al*., 2007; Nootong *et al*., 2012). The organic matter content in the water of FBSC was found to be appropriate for fishes as suggested by Ekubo and Abowei, (2011).

Following EIFAC (1965) and NAS (1972) it can be concluded that the TSS concentration exceeding 25 mg dm^{-3}, recorded in the FBSC, allows to maintain the fish production at a fairly good level. Also the indices of salinity (conductivity, concentration of chloride ions 60-100 $mgCl^-dm^{-3}$) and indices of buffering capacity of the water (alkalinity: 50-300 mg $CaCO_3$ dm^{-3}, TH: 75-150 mg dm^{-3} are optimum for fish culture and >300 mg dm^{-3} is lethal to fish life as it increases pH) indicate that the water in the FBSC ensures optimum conditions for fishes (Bhatnagar *et al*., 2004; Stone and Thomforde, 2004).

Fish production in the FBSC had no effect on the thermal properties of the water used for pisciculture. Water pH was shaped by biochemical processes which are typical of surface waters under moderate anthropopressure. The concentration of dissolved oxygen should be regarded as optimal for fishes with high habitat requirements. Nitrification maintained the ammonium nitrogen at a low level and the neutral water pH resulted in that form of nitrogen being mostly dissociated. The hydro-chemical conditions in the studied sites can be regarded as optimal for growth and rearing of fry of species with high habitat requirements. Balanced fish breeding and keeping as practised in FBSC was found to have no negative effect on the quality of water discharged from the fish production ponds.

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