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WATER QUALITY AND ICHTHYOFAUNA HABITAT CONDITIONS IN LAKE CZOLNOWSKIE (N-W POLAND)

Abstract: Increasing anthropopressure affects natural ecosystems and may express itself in regional or spot contamination of water and soil environment. The quality of ground and surface waters depends to a large extent on drainage area management, where biogenic substances (i.e. nitrogen, phosphorus and potassium) are transported with surface run-offs to the environment. The article discusses results of studies on the drainage area of Lake Czolnowskie (Zachodniopomorskie Province). Studies covered physical and chemical assessment of soil conditions and water quality; additionally, fish was caught using two independent methods - gillnets and power generator (pursuant to CEN EN 14011 2003 and PN-EN 14011 2006). Results obtained confirm regular run-off of biogenic materials from the surface of farmed drainage area to Lake Czolnowskie. During the period of studies, the reservoir was exposed to i.e. reduction of water oxygen (3.56 mg/dm^3) and permanently elevated level of general phosphorus (0.15-0.27 mg/dm^3) and ammonium acid (0.16-0.27 mg/dm^3), which degraded the quality of life for ichthyofauna inhabiting the lake.

Keywords: drainage area, surface waters, soil, fish, Lake Czolnowskie, physical and chemical parameters

Introduction

Reduction in quality of natural inland waters due to run-off of contaminations is an inseparable aspect of extensive agriculture. This is how i.e. nitrates, phosphates, plant protection chemicals, or soil particles moved due to erosion, ingress water reservoirs [1]. Regular loading of aquatic environment with contaminations from drainage area not only artificially accelerates the eutrophication process, contributing to accumulation of heavy metals in soil [2] and posing a comprehensive threat to complete ecosystems, but also prevents the use of multiple reservoirs for drinking water [3].

Among the most commonly used fertilizers are those rich in nitrogen, potassium and phosphorus compounds. They increase the biomass growth in cultivated plants and improve their immunity to various diseases. Nevertheless, permeating of fertilizers to aquatic ecosystems with surface run-offs is equivalent to their adverse enrichment with nutritional substances, so-called biogenic substances [1]. The response to the excess of biogenic substances in water covers mass blooming of algae, resulting in deposition of dead organic matter at the bottom of reservoirs. Due to excessive consumption of oxygen, for

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decomposition, a large percentage of such matter is decomposed under anaerobic conditions - substances begin to accumulate, such as methane, hydrogen sulphide, and ammonia, with harmful effect to fish and aquatic plants [4].

Pesticides are among the commonly used plant protection chemicals in agriculture. Presently in Poland there are 2348 such substances available for use, and the country is among the EU leaders in sales of pesticides. Biodegradability is assumed to be among the many properties of pesticides. However, pesticides degradation process often advances too slow, causing their accumulation in the environment. This stems mostly form the presence of other substances in the soil or adverse climatic conditions, e.g. drought and excessive rain [5]. In the consequence, plant protection chemicals accumulate in water and soil environment, where their concentrations exceed permitted values [4].

EU Water Framework Directive adopted by Poland in the year 2000 mandates assessment and protection of broadly understood ecologic status of water bodies, not only based on physical and chemical parameters of water, but also based on biological indicators, such as condition of zoobenthos or ichthyofauna [6]. Increase in human population on Earth (with accompanying increase in water demand), increasing intensification of agriculture [7, 8], as well as disturbing climatic changes observed in recent years, i.e. global warming and drought [9], significantly inhibit rational management of available resources of water in Poland, which status, due to multiple indicators (e.g. oxygen, fluorides, biogenic substances) being exceeded, is considered as bad [10].

Human actions affect physical and chemical properties of aquatic ecosystems and have adverse impact on population, development and reproduction of multiple species inhabiting such ecosystems [11]. The method of managing specific drainage area, e.g. for agricultural use, may have adverse effect to local fish population [12]. This takes its toll mostly on the composition of ichthyofauna in specific water reservoirs where susceptible and highly specialised species are replaced by species with higher tolerance margins (e.g. tolerance to low oxygen saturation) [13]. Here we need to stress that although ichthyofauna responds to changes relatively late, it is also a reliable indicator of changes in water fertility level [14].

There is no doubt that non-sustainable agricultural activities significantly reduce the quality of water resources. There are multiple water bodies in Poland that had not yet been studied for run-off of contaminations from agricultural areas. Furthermore, the majority of studies on ichthyofauna in Polish lakes focuses mostly on individual fish species, rather than on the broad spectrum analysis of the complete species composition in a specific body of water [15].

The example of such a water body is Lake Czolnowskie, located in Mysliborz County (north-western Poland) - although it is surrounded by forests, there is farmland within its drainage area. Therefore, this body of water is exposed to surface run-offs of fertilizers, with biogenic substances being transported to surface waters and adversely affecting physical and chemical parameters of lake water and ichthyofauna inhabiting the lake, as it is also in similar, small lakes [16, 17]. For that very reason, the purpose of this study was to assess physical and chemical properties of water in Lake Czolnowskie in the context of ichthyofauna and estimation of drainage area management impact on the a.m. body of water.

Study area

Lake Czolnowskie (Czolnow) is a small (surface area 21.43 ha) and shallow (maximum depth 4.3 m) body of water. This makes it one of the smallest lakes in Mysliborskie Lakeland [17]. The water body is within the basin of river Mysla, flowing east of Lake Mysliborskie. An expressway (S3) runs near the north-western part of the lake, with farmland on the opposite side. Farmland also spreads along the western and southern part of the lake. Nevertheless, in its majority Lake Czolnowskie is surrounded by woods (especially from south-east). The water body has the shape of a long ellipsis (maximum length 1080 m), wide in the central section (maximum width 495 m). Lake Czolnowskie is characterised with low elongation factor (2.18) and little diverse coastline (WL = 1.37) [17]. There are two large bays - in its north-western part and south-eastern part. The bottom is diverse (depth factor 0.44), and the lake basin is concave [17]. The bottom is sand and silt, with organic silt deeper down - in up to 1.5 m thick layer. Lake shores are accessible only from the west (from the town of Czolnow) and from the north-east.

Methodology of studies

Studies were conducted during the vegetation season (April through October) 2019, consisting in monitoring of the drainage area, few times a year, by way of examining soil samples, taking water samples for hydrochemical analyses, and field measurement of water quality indicators, as well as the assessment of the condition of ichthyofauna in Lake Czolnowskie.

Soil examination

Collective samples for examination of soil were collected form the topsoil-hummus layer in spring 2019, from the depth 0 to 30 cm, at two stations in the Lake Czolnowskie drainage area. The fist station was located on farmland, and the second in the forest (Fig. 1). Once the soils samples were transported to Environmental Chemistry Research Laboratory of ITP in Falenty, water extracts of sample were prepared. Then the following was determined:

- $N\text{-}NH_4$, $N\text{-}NO_3$, $P\text{-}PO_4$, total phosphorus, P_{tot} - by segmented flow analysis and spectrophotometric detection method, using flow AutoAnalyzer by SKALAR;
- Na, K, Mg, Ca, Fe, Mn, Zn - by atomic emission spectroscopy method (UNICAM 939 AAS);
- pH - by potentiometric titration method (HACH multi-parameter portable meter (HQ40D)).

Water examination

Water samples from Lake Czolnowskie ware taken 6 times throughout 2019 vegetation season, from near-surface layer of pelagic zone, at two stations (Fig. 1). Once the samples were collected, they were subjected to physical and chemical examinations in order to determine oxygen content [mg/dm^3], oxygen saturation [%], biochemical oxygen demand, BOD_5, electrolytic conductance, *EC*, pH, water temperature. Oxygen, temperature, pH and *EC* were determined using multi-parameter digital meter HQ40D fitted with LDO sensor by HACH. Results quoted in the study are arithmetic average values.

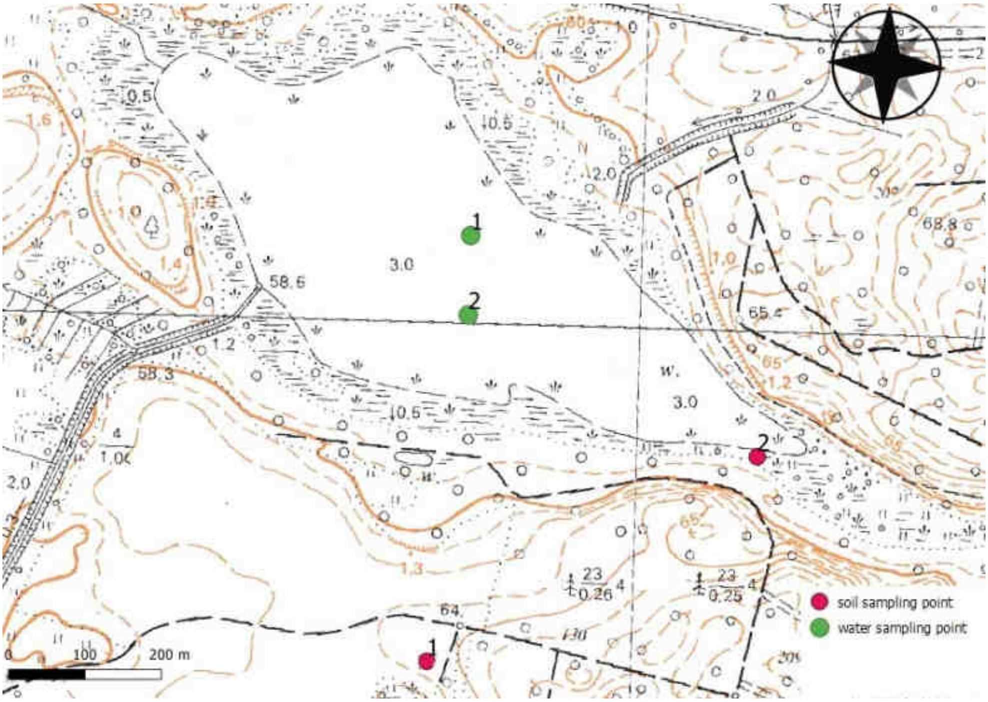

Fig. 1. Sample collection stations in the drainage area of Lake Czolnowskie: water samples - green colour, soil samples - red colour

Water samples taken from two stations in the body of water were subjected to hydrochemical analyses at Environmental Chemistry Research Laboratory of ITP in Falenty. Analysis were conducted to determine $N\text{-}NH_4$, $N\text{-}NO_3$, $P\text{-}PO_4$, P_{tot}, and Cl. The content of nitrogen and phosphorus was determined by automatic SFA method in accordance with Skalar method and PN-EN ISO 13395: 2001; PN-EN ISO 6878: 2006; PN-EN 1484: 1999 [18-20]. In addition, Na, K, Mg, Ca, Fe, Mn, Zn content was determined by atomic emission spectroscopy method (UNICAM 939 AAS).

Catching of fish

Fish were caught in Lake Czolnowskie in autumn 2019. Fishing tools were used - gillnets, with varying mesh size, in order to obtain research material as biodiverse as possible. Once caught, fish was subjected to species determination and population count. In addition, essential morphometric examination was conducted, to measure total length and individual weight, used to calculate the average condition of fish based on Fulton's condition factor, *K*:

$$K = \frac{W \cdot 100}{L^3} \tag{1}$$

where: *W* - individual weight [g]; *L* - total length [mm].

In addition, other fish was caught, independently, from the same lake, using power generator ELT 60 II GI (in accordance with CEN EN 14011 2003 and PN-EN 14011 2006) [21, 22]. The need for this kind of fishing tool was substantiated by the fact that fishing by gillnets is considered as selective fishing, excluding smaller fish. Fishing by means of power generator was conducted along a single research transect - length 60 m and width 2.5 m, in the area of 150 m^2. All individuals caught by this method were counted, their species and population density determined, and once measurements were finished, the fish was released back to where they were caught.

Study findings

Soil examinations on samples from the drainage area

Pursuant to results for the whole season it was observed that soil water extracts for spring and autumn were characterised by the highest variability (Table 1). During the study season, station 1 was characterised with higher content of compounds subject to study (Fig. 1). The largest difference between stations was observed in spring for $P\text{-}PO_4$, and it was 13.1 mg/dm^3. Similar dependence was observed for $N\text{-}NO_3$, the difference was 13.2 $mg \cdot dm^3$.

Similarly to spring season, in summer the difference was observed in $N\text{-}NO_3$ content. Samples from station 1 were characterised with $N\text{-}NO_3$ content higher by 14.0 $mg \cdot dm^3$ as compared with station 2. The analysis of results demonstrated that in autumn $N\text{-}NO_3$ and $N\text{-}NH_4$ values were also higher at station 1, and the difference between stations for $N\text{-}NO_3$ was 10.8 $mg \cdot dm^3$, and for $N\text{-}NH_4^3$ it was 12.4 mg/dm^3. In addition, rapid drop in $P\text{-}PO_4/dm^3$ content was observed throughout the study season.

Table 1

The content of compounds subject to study in the water extract of soil samples collected from the drainage area of Lake Czolnowskie

Season	$N\text{-}NH_4$ [mg/dm^3]	$N\text{-}NO_3$ [mg/dm^3]	$P\text{-}PO_4$ [mg/dm^3]
Spring St1	11.0	16.0	16.2
Spring St2	0.65	2.82	3.06
Summer St1	15.0	17.8	4.27
Summer St2	12.2	3.80	2.58
Autumn St1	11.5	13.4	7.74
Autumn St2	0.71	1.03	2.99

All micro- and macroelements determined in the water extract of soil from the whole study period are listed in Table 2. Potassium share among all other elements was the highest in station 1 in the summer (62.2 mg/dm^3). In addition, this element also featured the highest variability in the soil water extract throughout the whole study period. This may be due to its high soil-to-water mobility [23]. pH reaction of the water extract changed with the change of seasons. Other elements demonstrated high fluctuations throughout the whole season.

Table 2

Results of soil water extract analysis for elements subject to study

Season	K [mg/dm^3]	Na [mg/dm^3]	Ca [mg/dm^3]	Mg [mg/dm^3]	Fe [mg/dm^3]	Zn [mg/dm^3]	Mn [mg/dm^3]	pH_{H2O} [-]
Spring St1	43.0	37.2	9.92	6.18	1.99	0.12	0.01	4.59
Spring St2	9.18	29.1	0.97	0.29	2.51	0.06	0.04	4.67
Summer St1	62.2	5.00	3.72	1.33	6.18	0.13	0.64	5.05
Summer St2	22.8	4.88	2.12	1.08	1.73	0.11	0.07	5.36
Autumn St1	51.3	49.2	2.17	4.16	4.21	0.13	0.09	4.95
Autumn St2	7.88	31.1	1.23	0.32	3.08	0.04	0.06	5.03

Lake surface waters

Oxygenation of waters collected from Lake Czolnowskie fluctuated throughout three study seasons (spring, summer, autumn). The highest oxygen content and oxygen saturation was observed in spring and in autumn, 9.24 mg/dm^3 and 88.7 %, and 8.64 mg/dm^3 and 82.6 %, respectively. Oxygen saturation in spring and in autumn complied with values included in the Regulation by Minister of Environment of 21 July 2016 on classification of the state of uniform parts of surface waters and on environmental quality standards for priority substances [24]. In summer, however, significant drop in O_2 content was observed. Drop in oxygen content in lakes at this time of year is connected with increase in the content of P-PO_4 and P_{tot} [3, 25], which is evidenced by P-PO_4 contents in Lake Czolnowskie in summer. Furthermore, in summer aquatic plants decompose and later the dead matter is deposited at the bottom, thus reducing the oxygen content in water [26]. Availability of oxygen in water bodies also depends on temperature. In summer, when average daily temperature increases , water heats up and its oxygenation drops [27].

Water pH from the lake fluctuated a little, but generally stayed neutral. Conductivity of tests remained within the range 0.62-0.61 mS/cm. Thus, it stayed within the standard range for water quality as included in the Regulation by Minister of Environment of 21 July 2016 on classification of the state of uniform parts of surface waters and on environmental quality standards for priority substances [24]. The highest mean concentration of ammonium nitrogen, was observed in autumn, and the lowest in summer (Table 3).

Table 3

Values of hydrochemical parameters of water in Lake Czolnowskie

Season	*EC* [mS/cm]	pH [-]	O_2		BOD_5	N-NH_4 [mg/dm^3]	P-PO_4 [mg/dm^3]	N-NO_3 [mg/dm^3]
			Content [mg/dm^3]	Saturation [%]				
Spring	0.62	7.89	9.24	88.7	4.71	0.25	0.01	0.02
Summer	0.61	7.91	3.56	37.7	2.71	0.16	0.11	0.07
Autumn	0.61	7.75	8.64	82.6	5.82	0.61	0.01	0.09

As regards other chemical parameters of water in Lake Czolnowskie, increase in average values of Ca, Mn, Mg and Cl^- was observed throughout the study season (Table 4). The highest concentrations of chloride, magnesium and calcium (respectively: Cl^- 40.8 mg/dm^3, Mg 16.2 mg/dm^3 and Ca 31.0 mg/dm^3) were determined in the autumn period (Table 4). Chloride concentration in samples of water from the lake increased by 6.8 mg/dm^3, with the highest value recorded in autumn (40.8 mg/dm^3). Throughout the whole study season, increase in concentration of P_{tot} [mg/dm^3] occurred, with the highest value recorded in autumn. This may be due to increase in concentration of $P\text{-}PO_4$ released from bottom deposits in summer, with oxygen deficit contributing to that.

The scope of biochemical demand for oxygen (BOD_5) throughout the period of study was between 2.71 and 5.82, which satisfies requirements concerning living conditions of cyprinids only. Concentration of total phosphorus (P_{tot}) in summer and autumn (0.15-0.27 mg/dm^3) was very high and failed to comply with living conditions specific for cyprinids (no more than 0.4 mg/dm^3). The content of ammonium nitrogen ($N\text{-}NH_4$) in Lake Czolnowskie was between 0.16 and 0.25 mg/dm^3 throughout the whole study season.

For the whole study season the increase in Ca content was observed. According to Bhateria and Jain [26] lakes surround by forests are characterised by lower calcium content, with water concentration below 35 mg/dm^3. This may be the evidence of forest reducing run-offs from agricultural land.

Table 4

Values of chemical parameters of water in Lake Czolnowskie

Season	P_{tot} [mg/dm^3]	Cl^- [mg/dm^3]	Na [mg/dm^3]	K [mg/dm^3]	Mg [mg/dm^3]	Ca [mg/dm^3]	Fe [mg/dm^3]	Mn [mg/dm^3]
Spring	0.03	34.0	25.6	9.79	14.3	24.1	0.01	0.01
Summer	0.15	32.4	20.4	6.81	15.9	25.2	0.24	0.00
Autumn	0.27	40.8	22.8	8.53	16.2	31.0	0.01	0.01

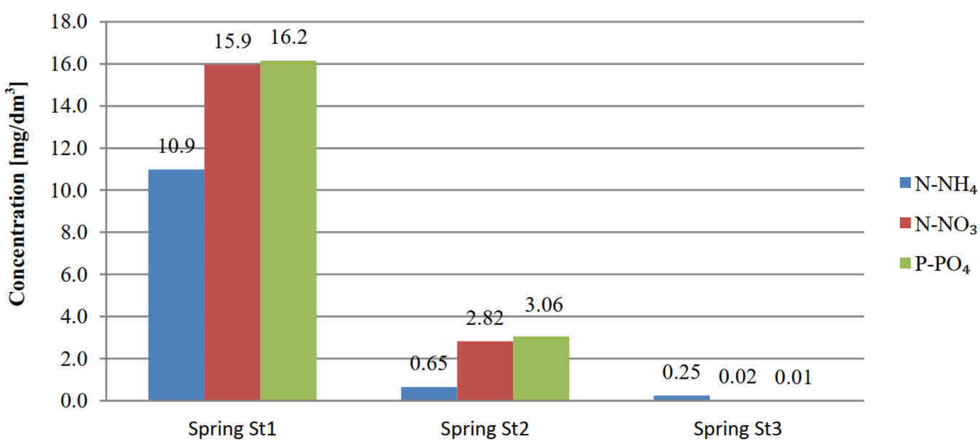

Fig. 2. Run-off of biogenic compounds ($N\text{-}NH_4$, $N\text{-}NO_3$, and $P\text{-}PO_4$) along the drainage area of Lake Czolnowskie in spring

Below charts present surface run-off of biogenic substances, i.e. $N\text{-}NH_4$, $N\text{-}NO_3$ and $P\text{-}PO_4$ from the direct drainage area of Lake Czolnowskie. Biogenic substances were transported from agricultural land (St1) towards the lake basin (St3), and, in smaller quantities, also through the forest (St2). When analysing results from the whole study period (Fig. 2-4) one may conclude that the forest surrounding Lake Czolnowskie is a universal biofilter for biogenic substances moving with surface run-offs from nearby agricultural areas.

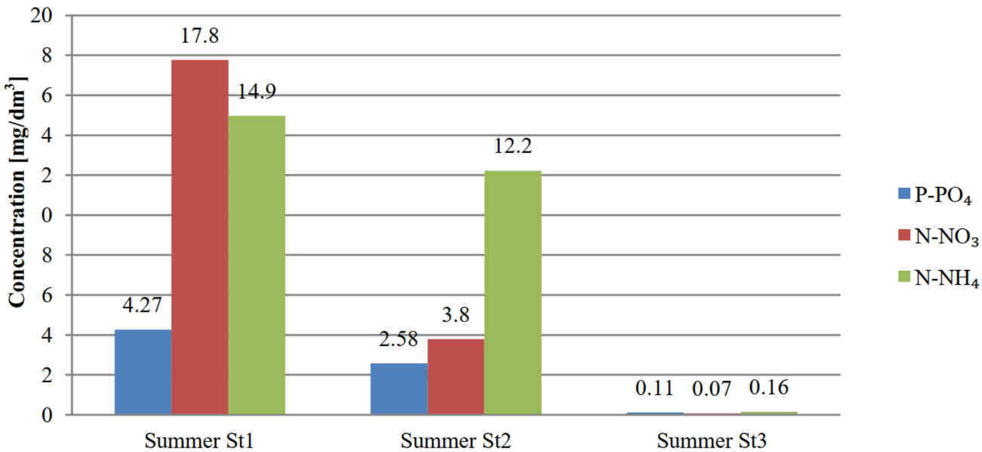

Fig. 3. Run-off of biogenic compounds (N-NH$_4$, N-NO$_3$, and P-PO$_4$) along the drainage area of Lake Czolnowskie in summer

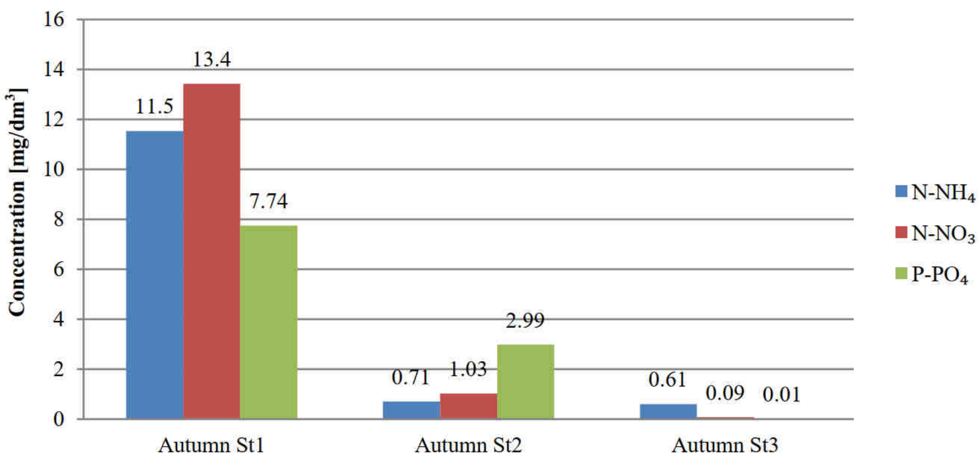

Fig. 4. Run-off of biogenic compounds (N-NH$_4$, N-NO$_3$, and P-PO$_4$) along the basin of Lake Czolnowskie in autumn

Studies on ichthyofauna using gillnet fishing

During gillnet fishing, a total of 49 fish was caught, distributed between 6 different species. The most numerous included roach (*Rutilus rutilus* L.) (22.5 %), pike (*Esox lucius* L.) (20.4 %) and tench (*Tinca tinca* L.) (18.4 %). The total weight of all individual fish caught was 1586 kg. Pike (53.2 %) and tench (24.1 %) dominated other species in ichthyofauna structure. The largest Fulton condition factor was determined for the crucian carp (*Carassius carassius*) (2.08 g/mm^3) and then for the tench (*Tinca tinca*) (1.37 g/mm^3) (Table 5).

Table 5

Total number, weight and percent share of fish caught by gillnet method

Species	Number		Weight		Average condition (Fulton condition factor) [g/mm^3]
	Quantity	[%]	[g]	[%]	
Tench (*Tinca tinca*)	9	18.4	3815	24.1	1.37
Crucian carp (*Carassius carassius*)	8	16.3	1559	9.82	2.08
Perch (*Perca fluviatilis*)	5	10.2	846	5.34	1.31
Rudd (*Scardinius erythrophthalmus*)	6	12.2	523	3.30	1.19
Roach (*Rutilus rutilus*)	11	22.5	672	4.24	0.86
Pike (*Esox lucius*)	10	20.4	8441	53.2	0.77
Total	49	100	15856	100	-

As regards biomass, pike (53.2 %) and tench (24.1 %) dominated other species of caught fish. As for the former, both grown individuals (over 55 cm), evidencing low angling pressure on Lake Czolnowskie, and smaller individuals (less than 45 cm) were observed. The latter may be the evidence of successful (re)stocking of pike or good results of natural spawning. In general, the average condition of caught fish was good.

Studies on ichthyofauna using power generator

During fishing by means of power generator, a total of 290 fish was caught, distributed between 12 different species. Their total population density was 1.93 per 1 m^2, and the highest value was recorded for roach (0.90 individual per m^2), common rudd (0.29 individual per m^2) and white bream (0.24 individual per m^2). Furthermore, thanks to this method, two species subject to partial species protection, namely spined loach (*Cobitis taenia* L.) and weatherfish (*Misgurnus fossilis* L.), not represented in gillnet catch.

Table 6

Results of power generator fishing in Lake Czolnowskie

Species	Number of fish caught	Density [fish/m^2]
Perch (*Perca fluviatilis*)	3	0.02
Ruffe (*Gymnocephalus cernua*)	2	0.01
Pike (*Esox lucius*)	1	0.01
Spined loach (*Cobitis taenia*)	2	0.01
Weatherfish (*Misgurnus fossilis*)	6	0.04
Freshwater bream (*Abramis brama*)	21	0.14
White bream (*Blicca bjoerkna*)	36	0.24
Roach (*Rutilus rutilus*)	135	0.90
Rudd (*Scardinius erythrophthalmus*)	43	0.29
Tench (*Tinca tinca*)	16	0.11
Crucian carp (*Carassius carassius*)	11	0.07
Stickleback (*Gasterosteus aculeatus*)	14	0.09
Total	290	1.93

Differences in species composition between fishing methods (power generator vs. gillnets) are due to specific properties of each fishing method, different place of application, and different selectivity level. In the case of gillnet fishing, gillnet eyes were too large to catch smaller species (e.g. weatherfish or spined loach). On the other hand, fishing from the shore using power generator, prevents catching larger fish that inhabit the depths of the lake.

Conclusion

Based on the results of studies we may conclude that Lake Czolnowskie is exposed to regular run-offs with biogenic substances used at nearby agricultural land, even though the body of water is surrounded by buffer zone comprising rushes, forest and tree stands. Having considering a number of parameters, we concluded that physical and chemical properties of water in this lake disqualify living conditions in this body of water even for cyprinids, which is evidenced by period drops in oxygen level in water, as well as excessive concentration of ammonium nitrogen and total phosphorus. Present concentration of physical and chemical parameters as well as condition and structure of ichthyofauna are the result of many years' run-offs of biogenic substances (primarily N, P, K) from the direct drainage area of the lake. Consequently, run-offs form nearby agricultural land has to be reduced by implementation of protective measures. Extending the range of buffer zones (tree stand areas) and implementing rational use of fertilizers that are the major pollutant of soil environment and surface waters in the drainage area, seem like a good solution.

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