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Sewage management threaten protected Nature 2000 habitats in the Płonia River catchment – North-Western Poland

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Abstract: The article assesses the current condition of two lacustrine habitats of the Natura 2000 PLH32006 site, located within the Płonia River catchment. The state of water and sewage management in this catchment area may seriously affect these habitats. All lakes representing Natura 2000 habitats in this area – mesotrophic lakes and eutrophic lakes were investigated in the vegetational season of 2019. Surface water and sewage of the Płonia River catchment were analysed for NH_4^+, NO_3^-, PO_4^{3-}, Cl^-, electrolytic conductivity (*EC*), and pH in the period 2019–2021. Our research shows that the vast majority (99.5%) of the area of mesotrophic lake habitat is evaluated as unfavourable (U2 = bad). The area of eutrophic lakes has increased from 929.28 ha to 1.127.07 ha, and 91% of this habitat type is also unfavourable state (U2). This general result depends strongly on the negative evaluation obtained for Miedwie Lake. In the tested surface waters, the concentration of NH_4^+, PO_4^{3-} and electrolytic conductivity clearly point to a poor condition of surface water (below class 2). Analysis of the waters from sewage receivers at operating treatment plants (including chloride concentration) indicates that they pollute the waters. Our research discloses the negative influence of water and sewage management on the condition of the protected wetland and water ecosystems in the Plonia Valley Natura 2000 sites.

Keywords: charophyte, Natura 2000 habitats, sewage treatment, surface water, water pollution

INTRODUCTION

The main threats of surface waters are related to inputs of nutrients, changes in geochemical processes in soil and water, which result in changes in ecohydrological conditions of threatened ecosystems (Stratford, Acreman and Rees, 2011; Durkowski and Jarnuszewski, 2015; Kuczyńska *et al.*, 2021). This is also the case of the central and lower parts of the Płonia River valley, which lie within the borders of the Natura 2000 habitat site "PLH320006 Dolina Płoni i Jezioro Miedwie". Among the protected habitats subject to this European protection system are two types of lakes (Natura codes 3140 and 3150). Systematic studies of environmental quality parameters in the Płonia River catchment have intensified in the second half of the 20th century, mainly due to the plans of using Miedwie Lake as a source of drinking water for the city of Szczecin. The pumping started in 1976 (Winkler, Roy and Kamińska, 2001). For some decades, the quality of water in Miedwie, as well as in the other big lakes in the area, has been declining (Wierzchowska, 1997; Tórz, Kubiak and Chojnacki, 2003). A similar situation has been observed with respect to hydrobiological indicators, such as the disappearance of typical lake bottom vegetation, phytoplankton and the spectacular relic organisms, from which once Miedwie Lake was quite famous (Gołdyn, 1986; Żmudziński, 2001; Stańko *et al.*, 2020). Besides the pressure from agriculture, the water ecosystems of the area are influenced by recreation, water sports, angling and commercial fishing.

In the case of the latter, an important role can be played by changes in water organisms' populations, e.g. by reducing the participation of filtrators as well as by stirring up bottom sediments containing large amounts of nutrients and other pollutants (Durkowski and Jarnuszewski, 2019). Pollution of surface waters has been listed among the threats for the Natura 2000 habitat site PLH320006 (GIOŚ, 2003) including the decreasing quality of water in the Płonia River and it has selected tributaries and of the Będgoszcz Lake (data of Voivodeship Inspectorate of Environmental Protection in Szczecin 2004–2016) as well as for the groundwater of the area (Durkowski and Jarnuszewski, 2019). These negative trends have been observed despite measures applied in part of the Płonia River catchment, aiming to reduce water pollution by biogenic sources originating from agriculture. Despite the establishment of the nutrient vulnerable zone (NVZ), no improvement in water quality has been observed (Council Directive, 1991b; Durkowski and Jarnuszewski, 2015; Kuczyńska *et al.*, 2021). It indicates a very low efficiency in introducing passive protection methods based on administrative regulations. Continuation of the negative state of water quality may also be connected to improper water and sewage management in the studied catchment area (Piasecki, 2019). Generally speaking, the deterioration of the ecological conditions of valuable and legally protected ecosystems in the catchment of Miedwie Lake can be related to a set of primary causes. At present, these are: wrong agricultural practices and sewage management, improper location and intensity of building and exploitation areas (Durkowski and Jarnuszewski, 2015; Durkowski and Jarnuszewski, 2019; Kuczyńska *et al.*, 2021). The factors of significant importance are also historical and present interferences with the hydrological system of the whole Płonia River catchment. One of their well-studied consequences is the disappearance of drained organic soils (Meller, 2007), combined with the massive emissions of greenhouse gases.

The research hypothesis assumes that the protected mesotrophic and eutrophic habitats of lake ecosystems in the Natura 2000 site PLH32006 are at risk of degradation as a result of pressure caused by improper sewage management in the Płonia River catchment area.

In this paper, we aim to evaluate the current state of selected lake habitats and the present status of surface waters of the Natura 2000 site PLH32006.

MATERIALS AND METHODS

STUDY MATERIALS

The study was carried out in the central section of the catchment of the Płonia River (Fig. 1). It covers a significant fragment of the Pleistocene sedimentation basin, geomorphologically differentiated into a set of terraces. Mineral soils of the upper terraces are of the black earth type and were formed from silt, clay and loam (Meller, 2007; Durkowski and Jarnuszewski, 2015). These rich soils have been under cultivation for an extended period of time. Ribbon lakes occupy the lowest-lying parts, the largest of which are the Miedwie and Płoń lakes. They are remnants of the so-called Pramiedwie – an extensive relic lake. Its original size has decreased considerably as a result of drainage works, which were initiated by Cistercian monks in the 12th century and intensified in the 18th century. The Płonia River and its tributaries connect the present-day lakes. In the surroundings of these lakes, mostly organic soils have developed, in the central part on top of calcareous lake sediments or on the exposed gyttia layer itself (Meller, 2007). The wetter parts of the shores harbour the elements of protected calciphilous vegetation (Wołejko *et al.*, 2007). Biocenotic values of these ecosystems have been recognised on the local and European scale, which resulted in the establishment of several nature protection areas, including two partly overlapping Natura 2000 sites (Fig. 1).

The catchment of the Płonia River covers 1,137.5 km^2, including 1,017.1 km^2 of the catchment of the Miedwie Lake alone. An average outflow from the catchment is relatively low, amounting to 2.77 dm^3·s^{-1}·km^{-2}. In the central part of the area, one of the lowest values for the region of yearly rainfall has been registered, amounting to 490 mm (Durkowski, Burczyk and Królak, 2006; Durkowski and Jarnuszewski, 2015). Land use in the catchment of the Płonia River is dominated by agriculture. According to Durkowski, Burczyk and Królak (2006), agricultural land covers 77.3% of the area, in which arable land is 69.0% (or 72% of the catchment of Miedwie Lake alone), permanent meadows and pastures – 12.2%, forests – 10.4%, waters – 5.3%, other types of use (such as build-up areas) – 3.1%. Crop structure is dominated by intensive crop types – cereals (60%), sugar beet (16%) and rapeseed (15%). Nitrogen fertilisation in the catchment area ranges from 41.4 to 133.9 kg N·ha^{-1}, phosphorus from 17.5 to 46.6 kg P·ha^{-1}, and potassium from 22.0 to 62.0 kg K·ha^{-1}. Animal density in the catchment area also varies, ranging from 2.9 to 30.1 large conversion units·(100 ha)$^{-1}$ of agricultural land (GUS, 2022). The agricultural land in the central part of the catchment area (the Płonia valley – including the protected Natura 2000 area site PLH32006 and the area of the Pleistocene Pyrzyce basin is drained mainly by a drainage system (arable land) or a system of drainage ditches (permanent grasslands).

With respect to the preservation of water resources, the location of grasslands and forests in the catchment is somewhat unfavourable. A large part of the areas reclaimed initially for the enlargement of grasslands has eventually been converted into intensively used arable land for such crops as maize and wheat. It leads, among others, to losses of organic matter in soil profiles, increased emission of greenhouse gases, modifications of terrain topography, changes in water conditions, and release of biogenic compounds into surface water. The high agricultural pressure observed in the catchment area was the reason for recognising it as an NVZ in the years 2004–2016. The Miedwie Lake catchment and the analysed Natura 2000 sites are located in the territory of five communes, in which the degree of canalisation is diverse. Based upon an analysis of the Polish Water Law Permits valid for 2019 (based on the Polish Water Law), the types of sewage treatment plants have been identified, as well as the yearly amounts of produced effluent. The obtained data were verified in the field. When facilities were still in operation, the wastewater receivers were identified, and samples were taken for water quality analyses.

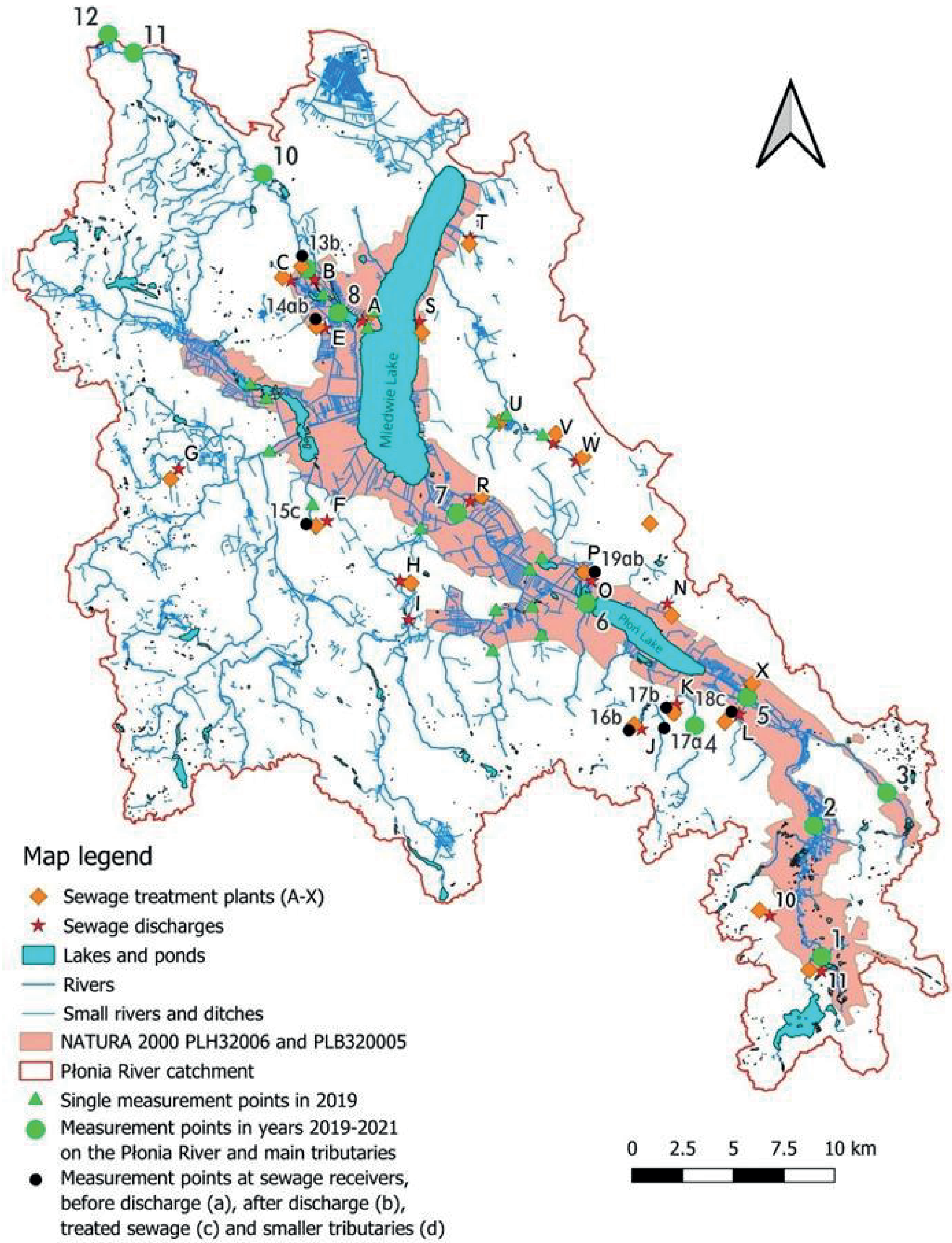

Fig. 1. The sampling points (1–19) of surface water, sewage from treatment plants (A–X, described in Tab. S1) and sewage receivers in the Płonia River catchment; source: own elaboration

STUDY METHODS

The primary source of data about the original distribution and state of the two studied lacustrine Natura 2000 habitats was: the map in scale 1:10,000 (BULiGL, 2009), elaborated as a study material for the Management Plan (2014) and the Standard Data Form for the Natura 2000 site PLH320006 (GIOŚ, 2003). Additional data sources, published and unpublished, are listed in the References section.

In the vegetational season 2019, all lakes of the Natura 2000 site PLH32006 were investigated according to the methods recommended by the General Directorate for Environmental Protection (Pol.: Generalna Dyrekcja Ochrony Środowiska – GIOŚ) for habitats 3140 – mesotrophic lakes (Gąbka *et al.*, 2015), and 3140 – eutrophic lakes (Wilk-Woźniak *et al.*, 2012).

In the larger lakes, measurement points were set on the measuring lines (transects) while the smaller lakes were treated as a singular study object.

The vegetation composition was described using the Braun-Blanquet approach (Braun-Blanquet, 1964). Depth and transparency of water were assessed by measuring from the boat, sometimes also by diving. It was supplemented by the use of the underwater vegetation gripper and anchor, the latter also used for recognising the extent of the studied vegetation plots. In selected sites, plankton samples were taken and transported to a specialised hydrobiological laboratory for further analyses. In the field, selected water parameters were measured: pH, electrical conductivity (*EC*), water transparency and colour. The parameters and criteria of their evaluations were in accordance with methods recommended by Gąbka *et al.* (2015) and Wilk-Woźniak *et al.* (2012) for each lacustrine habitat.

Preliminary analyses of surface water quality were conducted in 2019. Singular samples of surface water were taken in 17 points and analysed for NH_4^+, NO_3^-, PO_4^{3-} (Fig. 1). For points situated on the Płonia River and its main tributaries, that were considered important for water quality in the catchment (especially within the Natura 2000 area) water samples from locations numbered 4–7 and 9 were collected 3 times in the hydrological year 2019 and 3 times in the hydrological year 2021, from locations numbered 1–3, 8 and 10–12, samples were collected 3 times in the hydrological year 2019. Ten other points, sampled 3–4 times in all periods 2019–2021, were selected in the discharge sites from the sewage treatment facilities: before the discharge (marked with letter a), behind the discharge (marked with letter b) and from the treated sewage (marked with letter c). The following measurements were conducted on site: *EC* was measured using SLANDI SC 300 meter, and pH was measured using SLANDI SP 300 meter. Immediately after transporting water samples to the laboratory, the content of NH_4^+, NO_3^-, PO_4^{3-}, and Cl^- was determined using a photometer (SLANDI LF 300). The water parameters were determined according to the methods proposed by Slandi Sp. z o.o. and specified in the work of Durkowski and Jarnuszewski (2015). Obtained values were recalculated and compared with threshold values for N-NH_4^+, N-NO_3^-, and P-PO_4^{3-} of particular categories of flowing waters, described in the applicable regulations. For parameters measured in surface waters, Pearson correlation was performed at the significance level of $p < 0.05$ and $p < 0.01$ using Statistica 12.0.

RESULTS

3140 HARD OLIGO-MESOTROPHIC WATERS AND 3150 NATURAL EUTROPHIC LAKES

Our results show that the Płonia valley habitat type, mesotrophic lakes (3140), covers 3,470.4 ha. In 2003, this habitat type covered 3696.9 ha (BULiGL, 2009). This drop in area was mainly due to a changed evaluation of the Szybel and Zaborsko lakes, and partly also to the Będgoszcz Lake. These lakes were previously classified as mesotrophic and are now eutrophic lakes.

Only 0.4% of the area of the habitat 3140 in the Natura 2000 site PLH32006 is in a favourable state (FV), and 0.11% is in an unfavourable – inadequate state (U1). The state of the remaining 99.5% of the area of this habitat has been evaluated as unavourable – bad (U2) (Tab. S2). This general result depends strongly on the negative evaluation obtained for Miedwie Lake. Critical parameters for this negative outcome are the scarcity of characteristic species, especially water plants of the characeous type. These species only survived in two out of twelve investigated transects.

According to previous data (GIOŚ, 2003; BULiGL, 2009), eutrophic lakes covered 929.3 ha of the Płonia River catchment. Due to our updated evaluation of some mesotrophic lakes, the current area of eutrophic lakes has increased to 1,127.1 ha. Altogether, 10 eutrophic lakes were analysed with respect to qualitative parameters (Tab. S3). The data show that almost 91% of the eutrophic lake type was classified as unfavourable – bad state (U2), 8.06% in unfavourable – inadequate state (U1), and only 1.07% in favourable state (FV). The vegetation changes in the two largest lakes, Płoń and Będgoszcz, contributed most to the aforementioned negative evaluation. The best condition was obtained for two small lakes: Elżbietka and Racze (12.02 ha, or 1.07% of the eutrophic lake area). They are situated in the upper, morainic and mostly forested part of the catchment, which is predominantly fed by spring water.

CHARACTERISATION OF WATER AND SEWAGE MANAGEMENT

Significant differences in sewage treatment exist between various communes of the Płonia catchment area (Tab. 1). In 2019, areas with active sewage treatment ranged from 42.8 to 81.4% of the area, while areas with drinking water supply networks covered 96.9 on average. According to the Central Statistical Office (GUS, 2022), in the communes situated within the direct catchment area, the percentage of the population using the sewage system network ranged from 52.1 to 81.4%. In three municipalities, in 2019, there were no sewage treatment plants with advanced biogene treatment, and in two municipalities, less than 25% of the population was served by such plants. Two communes, Kozielice and Bielice, are situated in the western part of the Miedwie Lake catchment. Water from this area is discharged into Będgoszcz Lake through the Krzekna River. In households not connected to sewerage systems, the private septic tanks were used (2,445 objects) or small private wastewater facilities (399); however, these data could be incomplete. The remaining treatment plants in the Miedwie Lake catchment mainly belong to the mechanical-biological type, usually processing less than 100,000 m^3 of sewage (Tab. S1).

SURFACE WATER QUALITY IN THE PŁONIA RIVER CATCHMENT

According to administrative standards (Rozporządzenie, 2021), three surface water types were distinguished in the study area: sandy lowland stream (PNp), river in the lake-river system (R_poj) and lowland river (RzN). The investigations were also aimed at the water quality of Żelewko Lake, classified as a polymictic lake on calcareous bedrock (WSd_b). Threshold values *EC*, N-NH_4^+, N-NO_3^-, and P-PO_4^{3-}, have been assessed for flowing water in rivers, but not for lakes. The mean values of pH of the analysed water samples of the Płonia River and its two tributaries ranged from 7.3 to 7.9, and their maximal values often

Table 1. General characteristics of water and sewage management in selected communes located in the Płonia catchment area in 2019

Commune	Population using waterworks	Population using the sewage system	Population using sewage treatment plants with increased nutrient removal	Number of municipal sewage treatment plants	Number of drainless tanks	Number of domestic sewage treatment plants
	%					
Pyrzyce	92.6	69.2	63.1	3	748	103
Warnice	99.9	55.3	14.3	3	262	n.d.
Przelewice	97.4	74.0	49.3	5	152	77
Kozielice	99.9	52.1	0.0	1	134	7
Bielice	95.0	42.8	0.0	2	394	43
Lipiany	97.3	81.4	21.7	2	38	75
Kobylanka	100.0	60.8	100.0	1	532	77
Stare Czarnowo	92.7	72.5	0.0	7	185	17

Explanation: n.d. = no data.
Source: own elaboration based on data from GUS (2022).

exceeded pH 8. Statistical analysis showed that the increase in pollution affects the decrease in pH in the analysed waters.

The values of *EC* measured in flowing waters ranged between 0.415 and 0.834 $mS \cdot cm^{-1}$, which correspond to the second quality class for upper and lower courses of particular flowing water types. In the middle courses and in the selected tributaries, the values of *EC* exceeded the maximum values acceptable for the second quality class. It was noticed that the *EC* increased along the course of the Płonia River above the lake system Płoń-Miedwie-Żelewko, followed by a drop in *EC* values downstream. From the Żelewko Lake, the *EC* value rose again towards the Płonia River mouth.

The obtained content of Cl^- ion in tested surface waters ranged very widely, from 5.0 $mg \cdot dm^{-3}$ in the measuring point no. 5 (before the Płoń Lake) to 78.2 $mg \cdot dm^{-3}$ in the measuring point no. 9 (in Kołbacz). The high mean value of Cl^- ion (57.9 $mg \cdot dm^{-3}$) may be a result of the input of pollutants, as much lower concentrations were found in the downwards lying points.

The excessive input of nitrates into surface water and groundwater is mainly connected with agricultural activities and non-point source pollution related to fertilisers. In the investigated period (2019–2021), sampled waters did not show pollution with nitrates. The content of NO_3^- ranged from 0.00 $mg \cdot dm^{-3}$ (below the limit of quantification) to 2.17 $mg \cdot dm^{-3}$ (Tab. 2).

Table 2. Selected chemical properties of the Płonia River and its tributaries in 2019–2021

Sample point and water type	Parameter	pH	*EC* ($mS \cdot cm^{-1}$)	NH_4^+	NO_3^-	PO_4^{3-}	Cl^{-*}
				$mg \cdot dm^{-3}$			
1 PNp	**average**	**7.74**	**0.554**	**0.612**	**0.25**	**0.520**	**25.1**
	min.–max.	7.52–8.09	0.497–0.586	0.124–1.584	0.05–0.57	0.023–1.490	21.9–27.0
	SD	0.30	0.050	0.841	0.28	0.840	2.8
2 PNp	**average**	**7.71**	**0.583**	**0.257**	**0.41**	**0.398**	**28.5**
	min.–max.	7.47–7.95	0.531–0.632	0.089-0.439	0.11–0.81	0.045–0.850	23.4–34.1
	SD	0.24	0.051	0.175	0.36	0.840	5.0
3 PNp	**average**	**7.95**	**0.663**	**0.332**	**0.18**	**0.025**	**24.4**
	min.–max.	7.71–8.09	0.595–0.741	0.289–0.409	0.02–0.38	0.013–0.033	22.8–26.6
	SD	0.21	0.074	0.067	0.18	0.010	2.0
4 PNp	**average**	**7.27**	**0.714**	**0.570**	**0.89**	**0.027**	**16.5**
	min.–max.	6.90–7.55	0.666–0.768	0.333–0.755	0.18–0.168	0.024–0.028	9.45–26.9
	SD	0.33	0.051	0.216	0.75	0.002	9.19
5 PNp	**average**	**7.67**	**0.650**	**0.398**	**0.93**	**0.367**	**18.0**
	min.–max.	7.00–8.11	0.594–0.733	0.133–0.693	0.25–2.17	0.210–0.920	5.0–34.9
	SD	0.37	0.049	0.226	0.67	0.278	12.4

cont. Tab. 2

Sample point and water type	Parameter	pH	*EC* ($mS\cdot cm^{-1}$)	NH_4^+	NO_3^-	PO_4^{3-}	Cl^{-*}
				$mg\cdot dm^{-3}$			
6 Rpoj	**average**	**7.79**	**0.560**	**0.596**	**0.35**	**0.093**	**29.0**
	min.–max.	6.87–8.24	0.415–0.690	0.118–0.596	0.00–1.44	0.010-0.440	15.0–34.0
	SD	0.49	0.096	0.383	0.54	0.171	7.1
7 Rpoj	**average**	**7.62**	**0.613**	**0.571**	**0.38**	**0.156**	**27.2**
	min.–max	6.97–8.10	0.439–0.834	0.141–1.383	0.01–1.29	0.020–0.390	5.5–35.9
	SD	0.39	**0.132**	0.407	0.45	0.161	11.8
8 WSd_b**	**average**	**8.31**	**0.608**	**0.125**	**0.05**	**0.780**	**43.6**
	min.–max.	8.06–8.60	0.569–0.639	0.057–0.238	0.01–0.08	0.019–2.880	40.9–46.7
	SD	0.27	0.036	0.083	0.03	1.403	2.9
9 RzN	**average**	**7.83**	**0.616**	**0.524**	**0.23**	**0.050**	**57.9**
	min.–max.	6.55–8.50	0.577–0.645	0.118–0.808	0.05–0.64	0.006–0.230	42.8–78.2
	SD	0.66	0.025	0.317	0.21	0.089	16.2
10 RzN	**average**	**7.89**	**0.621**	**0.237**	**0.28**	**0.016**	**45.1**
	min.–max	7.62–8.19	0.596–0.651	0.055–0.401	0.02–0.70	0.010–0.027	40.6–49.1
	SD	0.29	0.028	0.174	0.37	0.010	4.3
11 RzN	**average**	**7.91**	**0.625**	**0.223**	**0.13**	**0.028**	**43.3**
	min.–max.	7.70–8.08	0.610–0.651	0.117–0.360	0.06–0.22	0.013–0.038	41.6–44.9
	SD	0.19	0.022	0.124	0.08	0.013	1.7
12 RzN	**average**	**7.84**	**0.665**	**0.273**	**0.19**	**0.581**	**45.9**
	min.–max.	7.69–8.00	0.592–0.728	0.159–0.437	0.05–0.28	0.041–1.660	43.9–47.1
	SD	0.16	0.068	0.146	0.12	0.934	1.7

Explanations: the colours indicate the quality classes of the specified types of surface water (blue = class I, green = class II, red = below class II) by the Regulation of the Minister of Infrastructure of June 25, 2021 (Rozporządzenie, 2021) for the content of N-NH_4^+, N-NO_3^-, P-PO_4^{3-} after conversion and electrolytic conductivity (*EC*); PNp = sandy lowland stream, R_poj = river in the lake-river system, RzN = lowland river, WSd_b = polymictic lake on calcareous bedrock, *SD* = standard deviation, * = no quality classes are determined for the Cl^- anion, ** = for surface waters of the WSd_b type, the contents of NH_4^+, NO_3^-, PO_4^{3-}, Cl^- and electrolytic conductivity (*EC*) are not determined at high Ca content >100 $mg\cdot dm^{-3}$.
Source: own study.

Concentrations of nitrates in all analysed samples were proper for the first water quality class.

Measurements of NH_4^+ concentrations varied, both in Płonia and its tributaries. The values ranged from 0.055 $mg\cdot dm^{-3}$ to 1.584 $mg\cdot dm^{-3}$ and temporarily exceeded norms for the second quality class in all measuring points (Tab. 2). The highest mean values were noted close to the city of Barlinek and between the Płoń and Miedwie lakes.

The content of phosphates in surface waters ranged from 0.01 $mg\cdot dm^{-3}$ to 1.66 $mg\cdot dm^{-3}$. High concentrations of phosphates (exceeding the norms for the second quality class) were found in the Płonia River water in its upper and middle parts, all the way to the measuring point no. 9 near Kołbacz (before the outflow from the treatment plant). Waters of the better quality were found in the lower part of the river and in the tributaries coming from the lower part of the Płonia catchment (Tab. 2). In the case of singular samples taken in 2019 high concentrations of PO_4^{3-} ions were found in the tributaries of Gowienica Miedwiańska (26.4 $mg\cdot dm^{-3}$) and Płonia (1.89–12.20 $mg\cdot dm^{-3}$).

Analyses of chemical parameters in water samples from sewage facilities before and after sewage discharges (points 14 and 17) show a considerable increase in NH_4^+ and PO_4^{3-} concentrations (Fig. 2). The increase in *EC* and Cl^- values was small. High contents of NH_4^+ and NO_3^- were found in points 17b, 18c and 19c, localised in the central part of the catchment. Very high contents of NH_4^+ in the treated sewage were found in points 18c (14.87 $mg\cdot dm^{-3}$) and 19c (12.71 $mg\cdot dm^{-3}$). The highest average content of NO_3^- (67.04 $mg\cdot dm^{-3}$) was found in point 18c. High values of nitrates were also found in the effluents (points 16b and 17b). High values of PO_4^{3-} were found in all effluents and sewage recipients, but especially in points no. 13b, 14b and 15c where average PO_4^{3-} contents ranged between 15.55 and 19.91 $mg\cdot dm^{-3}$ (max. 42.40 $mg\cdot dm^{-3}$) (Fig. 2). The content of Cl^- ion in the effluents and sewage recipients (ranging from 125 to 306 $mg\cdot dm^{-3}$), was evidently higher than the ones in Płonia and its tributaries. The value of *EC* in effluents and sewage recipients (below the sewage discharge) was high and ranged from 0.858 to 2.500 $mS\cdot cm^{-1}$.

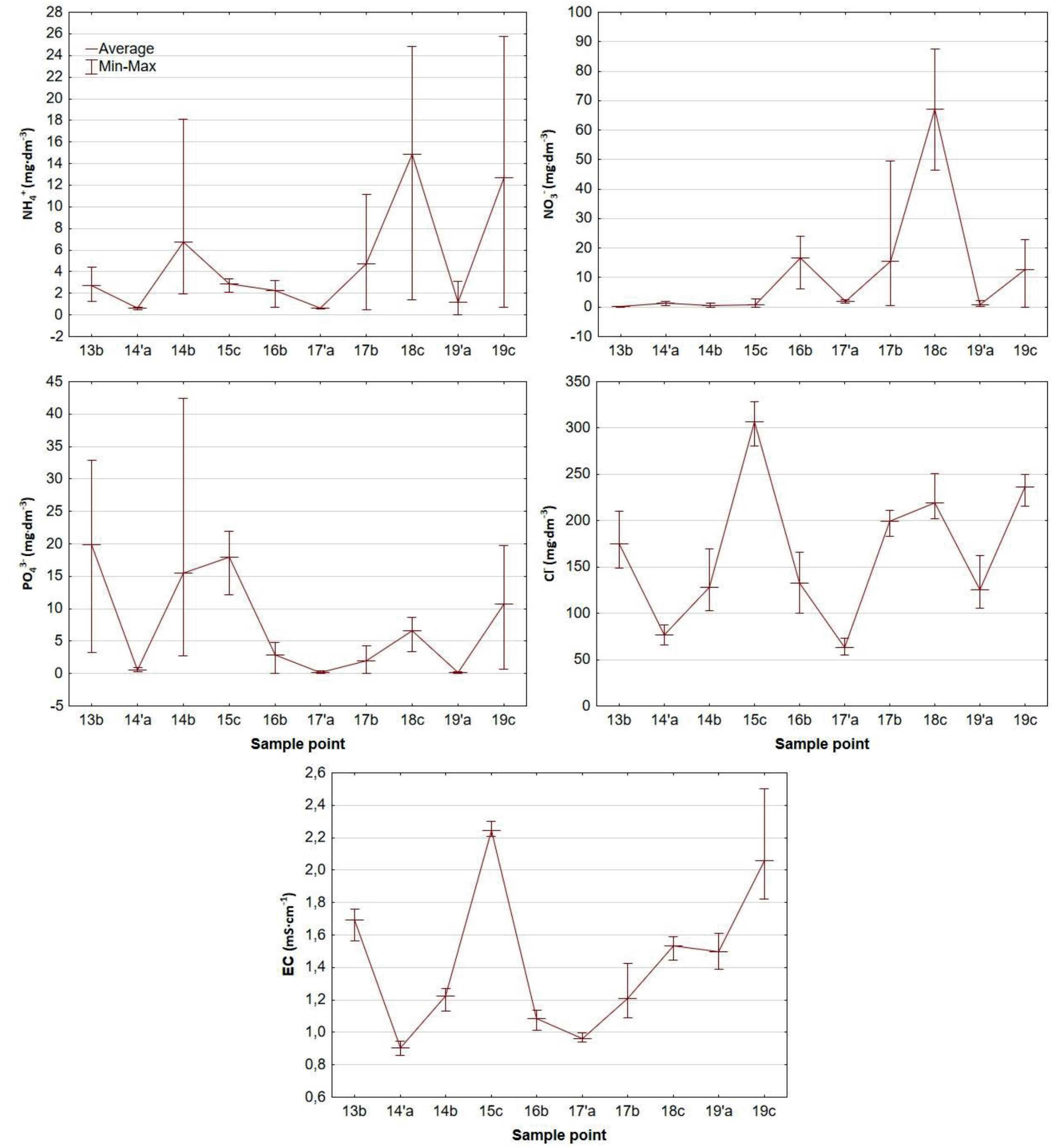

Fig. 2. Concentrations of NH_4^+, NO_3^-, PO_4^{3-}, Cl^- and electrolytic conductivity (*EC*) value in the water recipients; letters at sample points: a) before sewage discharges, b) after sewage discharges, and c) treated sewage; sample points as in Fig. 1; source: own study

DISCUSSION

3140 HARD OLIGO-MESOTROPHIC WATERS AND 3150 NATURAL EUTROPHIC LAKES

The obtained results indicate a decrease in the share and state of mesotrophic lakes in the Natura 2000 site PLH32006. There is a clear contrast with the earlier descriptions of the mesotrophic lakes, which mention the occurrence of extensive underwater *Chara* stands that had developed particularly well in the southern part of Miedwie Lake (Jasnowski, 1971). This knowledge was the background of the proposal to establish a nature reserve in the southeastern part of the Miedwie Lake and part of its coastal zone (Wołejko *et al*., 2007; Jermaczek *et al.,* 2008). Similar propositions were formulated for two other lakes: Koryto and Modre Kłociowisko (Wołejko *et al*., 2007). Based on our data from 2019, a good conservation status (FV) was given to those lakes. However, they seem to deteriorate quickly, and the amount of *Characeae* species growing there is decreasing (Kowalski, 2025). The obtained results of the poor condition of mesotrophic (habitat 3140) and eutrophic lakes (habitat 3150) indicate the sensitivity and deterioration of habitat conditions related to the water quality in reservoirs (Żmudziński, 2001; Durkowski and Jarnuszewski, 2019; Stańko *et al*., 2020). According to Kolada *et al.* (2017), one of the main pressures identified in the case of protected lake habitats (Lobelia Lake) is the increase in eutrophication and dystrophisation. The pressure on the waters of the catchment is related to its character: the share of agricultural land and the intensity of agriculture, sewage management, and the occurrence of organic formations (Lyche-Solheim *et al*., 2010; Kolada *et al*., 2017; Kuczyńska *et al*., 2021; Stępniewski, Karger and Łaszewski, 2024).

CHARACTERISATION OF WATER AND SEWAGE MANAGEMENT

In the studied catchment the efficiency of treatment plants is diverse but usually low, especially in the case of removing nutrients (Durkowski and Jarnuszewski, 2019), which can also be seen in the results of the water quality measurements (Tab. 2). The low percentage of the population using the sewage system network in the catchment, as well as the processing procedure in case of lack of canalisation, are additional problems. Piasecki (2019) states that the development level of water supply systems in the rural areas of Poland is still insufficient to prevent pollution in water bodies. It is also the case in our study area.

It is worth noting that the average level of the population using the sewage system network is low (63.5%); for instance, for the Bielice commune, it is only 42.8% (GUS, 2022). It implies that household sewage in this area should be collected in septic tanks or treated in individual wastewater treatment plants (Tab. 1). The first are often leaky, and the second are not fully effective due to improper exploitation (Piasecki, 2019).

Kuczyńska *et al.* (2021) working in the Gowienica Miedwiańska catchment (a part of the Płonia River catchment) have shown that some unregistered sewage discharge occurs, which originates from private households and agricultural sources. This untreated sewage water is discharged directly into the rivers. However, despite the low efficiency of sewage treatment in this area with respect to the biogenes, the nitrogen from the households constituted only 7% of total N transported through the Gowienica River to the Miedwie Lake (Kuczyńska *et al.*, 2021). Thus, the remaining part of the load originated mainly from the agricultural non-point sources connected with intensive crop production. With respect to phosphorus and its compounds, no considerable loads were found by Kuczyńska *et al.* (2021). However, high amounts of PO_4^{3-} were registered in the present research, both in the effluent from the treatment plants and in the Płonia River itself.

SURFACE WATER QUALITY IN THE PŁONIA RIVER CATCHMENT

The measured pH values in the tested surface waters are typical for surface water found in catchments, covered with rocks rich in carbonates like limnic deposits, which occur in the central part of the Płonia catchments (Meller, 2007; Durkowski and Jarnuszewski, 2015).

High values of *EC* in river waters often reflect inflow of polluted waters containing dissolved salts and chloride ions, which are characteristic of agricultural activity and communal sewage (Schäfer *et al.*, 2021). It is confirmed by the obtained significant correlations (Tab. 3) between the Cl^- content and the *EC* (r = 0.927) as well as between PO_4^{3-} and *EC* (r = 0.745) in the surface waters. The *EC* value was the highest above the Płoń Lake, as were the values for nitrate nitrogen, ammonium nitrogen, and phosphate phosphorus. In contrast to our results, Brysiewicz *et al.* (2019) reported the narrower range (0.552–0.585 $mS \cdot cm^{-1}$) of *EC* values in the Płonia River waters, but as Durkowski and Jarnuszewski (2019) point out, the values of *EC* measured in surface waters in the Płonia catchment for the years 2000–2004 had a much wider range (0.426–1.297 $mS \cdot cm^{-1}$). Periodic fluctuations of the *EC* value may be caused by surface water

Table 3. Pearson's correlation coefficients between parameters analysed in surface waters in the Płonia River catchment (n = 77)

Parameter	NO_3^-	PO_4^{3-}	Cl^-	*EC*	pH
NH_4^+	0.689**	0.338**	0.552**	0.519**	–0.235*
NO_3^-		0.170	0.498**	0.384**	–0.249*
PO_4^{3-}			0.658**	0.745**	–0.247*
Cl^-				0.927**	–0.358**
EC					–0.410**

Explanations: *EC* = electrical conductivity, * = significant correlation coefficient for $p < 0.05$, ** = significant correlation coefficient for $p < 0.01$.
Source: own study.

runoff after rainfall, agricultural activity in the catchment area and the inflow of municipal sewage (Schäfer *et al.*, 2021).

Concentrations of Cl^- were not taken into account in an evaluation of water quality classes (Rozporządzenie, 2021). Despite that, it is a good indicator of water pollution due to its properties (e.g. it is not absorbed in soil). The content of Cl^- ion in the analysed flowing waters increased down the river course (Tab. 2), which is typical for river water and, for the most part, relates to the leaching of chlorine from the rocks of the catchment. High concentrations of Cl^- ions, besides their natural inflow, should be linked to the use of artificial fertilisers (KCl), leaching from manure and silage, inflow of communal sewage and the use of salt for defrosting roads (Beom *et al.*, 2021; Kuczyńska *et al.*, 2021). According to Beom *et al.* (2021), the highest inflow of Cl^- ions occurs in parts of catchments where agricultural activity is intense and drainage networks are well developed.

In the investigated surface water in the Płonia River catchment, no pollution with nitrates was found. These results were similar to those obtained by Durkowski, Burczyk and Królak (2006) in 2001–2004 for the Płonia River, but these authors showed higher nitrate contents in smaller tributaries. However, Durkowski and Jarnuszewski (2015) in earlier studies (period 2003–2011) indicated higher nitrate concentrations in surface (average to 30.0 $mg \cdot dm^{-3}$) and groundwater (average to 41.2 $mg \cdot dm^{-3}$) in the Gowienica Miedwiańska catchment (a tributary of the Miedwie Lake, part of the Płonia River catchment). Even higher nitrate contents were found in this catchment by Kuczyńska *et al.* (2021) for years 2017–2020 in surface waters (to 89.7 $mg \cdot dm^{-3}$) and groundwaters (to 330.0 $mg \cdot dm^{-3}$). This variation in nitrate content in surface waters indicates different nitrate runoff loads in individual parts of the catchment and the periodicity of this component's inflow to the waters, as indicated by Durkowski and Jarnuszewski (2015) and Kuczyńska *et al.* (2021), with the maximum occurring in the spring period, associated with agricultural activity. At the same time, a significant correlation between NH_4^+ and NO_3^- (r = 0.689) indicates a significant share of nitrates originating from nitrification.

Pollution of water with ammonium is mainly connected with inflows of communal sewage, as well as with the use and storage of natural fertilisers (Bednarek, Szklarek and Zalewski, 2014; Stępniewski, Karger and Łaszewski, 2024). The obtained results indicate ammonium pollution of surface waters. For the

Płonia River catchment, as a whole, the problem of high content of ammonium ions in the groundwater was described earlier by Durkowski and Jarnuszewski (2016). They assessed the relation between NH_4^+ concentration (ca. 35 mg·dm^{-3}), farm infrastructure condition, and the way in which manure was stored. Kuczyńska *et al.* (2021) found high concentrations of NH_4^+ ions (even over 32 mg·dm^{-3}) in the waters of Gowienica Miedwiańska as a result of sewage discharge from municipal treatment plants.

Phosphorus and its compounds affect water eutrophication (Correll, 1998; Lyche-Solheim *et al.*, 2010). At the same time, river sediments and water basins may retain phosphorus compounds and thus improve the quality of water (Vermaat *et al.*, 2020). The Płonia River catchment surface water testing showed phosphate pollution at points 1, 2, 5–7 and 12. The lowest phosphate contents were found in tributaries and sections of the Płonia River flowing through forest areas, as well as in the section behind the system of flow-through lakes (Miedwie, Żelewko, Płonno). In Lake Żelewko (point 8), the concentration of phosphates was over 15 times higher than in the Płonia waters downstream of the lake (point 9). High concentrations of phosphorus compounds were earlier identified in the groundwater and surface water of the part Płonia catchment–Gowienica Miedwiańska catchment (Durkowski, Burczyk and Królak, 2006; Durkowski and Jarnuszewski, 2015; Durkowski and Jarnuszewski, 2016). It was considered connected to the wrong way of storing manure and to unorganised sewage and water management. In the investigations carried out in the middle section of the Płonia River in 2018, the water condition was assessed again (Brysiewicz *et al.*, 2019). It included a 15-fold encroachment of the norms for the second water quality class with respect to the $P\text{-}PO_4^{3-}$ content. These values were the highest among the four remaining analysed Odra River tributaries. According to Jarvie, Neal and Withers (2006), it is actually phosphorus originating from water and sewage management that is increasing the risk of eutrophication in flowing water, especially during spring and summer droughts. The obtained results of phosphate content in the surface waters of the Płonia River basin, in comparison with the studies of other authors, point to sewage management as a primary source of the phosphorus compounds.

From the point of view of the deteriorating condition of protected lake habitats (3140 and 3150) described in this paper, the retention function of reservoirs against pollutants, mainly phosphorus compounds, is important. According to Vermaat *et al.* (2020), lakes play a positive role in cleaning inland waters from organic pollution, but this occurs at the expense of these ecosystems and the increased risk of accelerated eutrophication. This is a case of Miedwie and other lakes of the Natura 2000 site PLH32006, where the monitoring carried out in the years 1971–1994 has shown the increasing amounts of phosphorus (Wierzchowska, 1997; Tórz, Kubiak and Chojnacki, 2003). Studies of Durkowski and Jarnuszewski (2019) show that the lakes situated upstream of the Miedwie Lake intercept part of the biogenes' load: Płoń Lake takes 28.8% of total nitrogen and 21.5% of total phosphorous; Będgoszcz Lake: from 27.4% to 62.1% of total nitrogen and 37.5% to 66.7% of total phosphorous (depending on the tributary). Nevertheless, enormous loads of biogenes are brought to the southern part of Miedwie with waters of the Płonia River (constituting 73% of the surface water supply to the lake) and Ostrawica (18% of the total inflow).

According to Vermaat *et al.* (2020), an important part in the process of phosphorus removal from waters is played by charophytic and littoral vegetation. Phosphorus is immobilised in the process of carbonate precipitation, and the dense littoral vegetation limits the suspension of sediments, secondary dissolution of biogenes and potential algae bloom. Thus, it can be presumed that the disappearance of underwater charophytic vegetation in the southern part of Miedwie Lake will result in an increased amount of dissolvable forms of phosphorus in the lake and higher intensity and frequency of water blooms.

The obtained results (Fig. 2) point to an important negative influence of operating sewage infrastructure on the quality of surface waters in the catchment, especially in terms of ammonium and phosphorus ion content. Durkowski and Jarnuszewski (2016) and Kuczyńska *et al.* (2021) have earlier reported on the low efficiency of sewage treatment plants in the Gowienica Miedwiańska catchment. They also pointed to irregular sewage discharges from the households. According to Piasecki (2019), in spite to general improvement of efficiency of the communal sewage treatment in Poland and the decreasing load of pollutants discharge to waters due to the implementation of the Wastewater Directive (Council Directive, 1991a), the Water Law (Ustawa, 2017) and The National Municipal Wastewater Treatment Program (MŚ, 2023) in rural areas opposite trends have been observed.

CONCLUSIONS

The obtained results indicate the poor condition of mesotrophic and eutrophic lakes of the Natura 2000 site PLH32006: a decrease in the area of the habitat 3140 area and a deterioration in the condition of both habitats. The leading cause of unfavourable changes in protected habitats is the persistent water pollution related to anthropogenic pressure in the catchment area. Our research points to the continuation of the bad condition of the waters supplying the lakes of the Natura 2000 site PLH32006. Pollution of surface waters with ammonium ions and phosphates, and the lack of nitrate pollution, confirms the research hypothesis about the significant negative role of sewage management in the catchment area as the cause of the poor condition of waters. The state of water and sewage management in the Płonia River catchment is one of the main reasons for the eutrophication of surface waters and degradation of natural habitats.

The deteriorating condition of protected habitats near the inflow of river waters to flow-through lakes may result in an increased amount of dissolved forms of phosphorus in the lake and higher intensity and frequency of water blooms. In the absence of improvement in the efficiency of sewage treatment in the studied catchment area and in the face of changes in the quantity and circulation of water in the catchment area caused by climate change, deterioration of water status and further degradation of protected habitats, including the risk of their complete disappearance, should be expected.

To secure more effective protection of these valuable habitats, further research is needed to evaluate more precisely the participation of pollution originating from agriculture and from the water and sewage management.

SUPPLEMENTARY MATERIAL

Supplementary material to this article can be found online at: https://www.jwld.pl/files/Supplementary_material_67_Jarnuszewski.pdf.

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CONFLICT OF INTERESTS

All authors declare that they have no conflict of interests.

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