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RESEARCH ARTICLE

Assessment of selected indicators of physicochemical conditions in the Rega River from 2018 to 2022 in accordance with EU regulations

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Abstract. The aim of this study, conducted in accordance with both European Union and national legislation, was to evaluate the physicochemical conditions of the Rega River in northern Poland, where efforts are underway to restore its watershed for migratory fish. From 2018 to 2022, water temperature, dissolved oxygen (DO), pH, total suspended solids (TSS), conductivity, alkalinity, total hardness (TH), biochemical oxygen demand (BOD_5), chemical oxygen demand (COD_{Cr}), nitrite nitrogen (NO_2-N), ammonium nitrogen (NH_4-N), and total phosphorus (TP) were measured at nine monitoring sites. The results showed that TSS and nitrite nitrogen (NO_2-N) were the main factors threatening the suitability of the Rega River as a habitat for salmonid fishes. Additionally, maximum water temperatures occasionally exceeded the tolerance limits for these fishes. Seasonal variations in nitrogen and phosphorus forms, and the dependency of nitrogen forms on DO, indicated disruptions in natural biochemical processes due to surface runoff pollutants from the watershed. This includes fertilizer runoff from agricultural fields and municipal pollution from the towns through which the river flows. The findings underscore the need for continuous monitoring of Rega River waters to safeguard the habitat conditions required by environmentally sensitive fish species.

Keywords: river, sewage treatment plant, water pollution, water quality monitoring

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Introduction

Assessing the quality of river water is a pertinent research topic both globally and in Poland, and one that is discussed frequently in the scientific literature (Wang et al. 2007, Bonisławska et al. 2013, Novita et al. 2020, Wątor and Zdechlik 2021, Bonisławska et al. 2024). In Poland, the status of waters, including rivers, lakes, transitional, and coastal waters is monitored by the Chief Inspectorate of Environmental Protection. The data collected are then presented as the status of water bodies, considering biological, hydromorphological, chemical, and physicochemical factors. Under the Water Framework Directive, three types of monitoring are conducted: diagnostic, operational, and investigative.

Between 2016 and 2021, diagnostic monitoring evaluated 3,678 rivers in Poland. Only one achieved very good ecological status, 207 achieved good ecological status/potential, 1,887 (over half) were of a moderate status/potential, and 1,456 (nearly 40%) were in poor or bad condition (GIOŚ 2022). The physicochemical elements of rivers were below a good status in more than three-quarters of cases (GIOŚ 2022).

Diagnostic monitoring was also performed on the Rega River in northern Poland, covering five measurement points from 2016 to 2021 (GIOŚ 2022). The Rega River is ecologically significant, with most of its valley included in a Natura 2000 area (Dorzecze Regi PLH320049) that provides habitat for valuable fish species such as spined loach, *Cobitis taenia* (L.), bullhead, *Cottus gobio* (L.), bitterling, *Rhodeus sericeus* (Pallas), and river lamprey, *Lampetra fluviatilis* (L.), and European brook lamprey, *Lampetra planeri* (Bloch.). The Rega River watershed encompasses the Rekowa River Nature Reserve, Iński Landscape Park, the Protected Landscape Area of Drawskie Lakeland, and the natural-landscape complex of the Sąpólna River Valley.

In 2012, the Life+ project entitled "Construction of a Blue Ecological Corridor along the Rega River Valley and its Tributaries" began with the aim of enabling the migration of diadromous fish, primarily sea trout and vimba bream. Additionally, the EU co-funded Fisheries and Sea 2014-2020 Operational Program (Priority 2 Innovations, co-financing agreement no. 00001-6521.1-OR1600002/17/18) that implemented activities to create artificial spawning grounds and riffles with gravel beds to promote the natural reproduction of salmonid fishes.

Continuous water quality studies in the Rega River are essential given its high ecological value and the ongoing efforts for the restoration of migratory fishes. Increasing the number of monitoring sites will help monitor both adverse and beneficial changes due to climate change and human impacts on the river. Therefore, the hydrochemical studies conducted from 2018 to 2022 at nine research sites aimed to determine, in accordance with EU regulations, whether the Rega River's water quality meets the standards required for inland waters that serve as natural habitats for fishes.

Materials and methods

Study area

The Rega River, the twenty-fourth longest river in Poland, is one of the largest rivers in the Pomeranian region and the second in terms of flow in the West Pomeranian Voivodeship. Its watershed area covers 2,725 km^2, and the main channel of the Rega River is 179.7 km long, making it the third-longest river discharging directly into the Baltic Sea after the Vistula and Oder rivers (Radke et al. 2010). According to recent studies, the source of the Rega River is located at an elevation of 177.5 meters above sea level in the Połczyn Zdrój municipality near the settlement of Imienko. Previously, Lake Resko Górne in the Drawskie Lakeland was considered the source of the Rega.

The main left-bank tributaries of the Rega include the Stara Rega (26.5 km), Łoźnica (16.3 km), Reska Węgorza (24.5 km), Piaskowa (14.0 km), Ukleja (45.4 km), and Gardominka (26.6 km), while the right-bank tributaries are the Rekowa (21.0 km), Lubieszowa (14.2 km), Mołstowa (54.4 km), and Sarnia (13.5 km) (Radke et al. 2010).

There are eight hydroelectric power plants on the Rega. The river's hydrotechnical infrastructure has resulted in two dam reservoirs – Lake Lisowskie and Lake Rejowickie. This infrastructure has hindered the spawning migration of salmonids, limiting their access to the middle and upper reaches of the Rega above the Rejowice dam.

The farthest fish pass on the Rega, located in Świdwin at kilometer 130+448, has reopened a migration corridor of over 130 km in the Rega itself thanks to the project "Construction of a Blue Ecological Corridor along the Rega River Valley and Its Tributaries." Additionally, the construction of electric fish deterrent barriers near the hydropower plants in Płoty, Likowo, and Rejowice has increased the percentage of fish (mainly smolts) avoiding contact with turbines.

Ichthyofaunal studies of the Rega River, published mainly in the twentieth century, focused on diadromous fishes such as Atlantic salmon, *Salmo salar* (L.), sea trout, *Salmo trutta* (L.) (Chełkowski 1978, Chełkowski and Chełkowska 1981a, 1981b, 1982), vimba bream, *Vimba vimba* (L.) (Pender and Tański 2005, Keszka and Raczyński 2006), brown trout, *Salmo trutta* (L.) (Kaj and Walczak 1954), and river lamprey (Witkowski 2001). Radke et al. (2010) provided a detailed description of the Rega watershed, identifying 32 fish species and two lamprey species. Including angling records, the number of fish and lamprey species found in the Rega basin is 36. The Rega basin, particularly the main channel, is a vital area for fishery management, where restocking efforts include migratory fish species, mainly sea trout, and since 1997, Atlantic salmon (Bartel 2001) and vimba bream (Pender and Tański 2005, Keszka and Raczyński 2006, Bartel et al. 2008).

The Polish Angling Association District in Koszalin (District No. 1) and the Polish Angling Association District in Szczecin (District No. 2) are the fishery users of the Rega River. These centers conduct annual restocking with species such as vimba bream, ide, *Leuciscus idus* (L.), common dace, *Leuciscus leuciscus* (L.), chub, *Squalius cephalus* (L.), grayling, *Thymallus thymallus* (L.), burbot, *Lota lota* (L.), Atlantic salmon, brown trout, and sea trout.

Hydrochemical studies on the Rega River were conducted from September 2018 to April 2022. Water samples were collected four times annually in fall, winter, spring, and summer from nine sites, 20 cm below the surface, in the middle of the river flow (Fig. 1).

The width of the river was measured with a Leica Disto A3 laser distance meter by taking five measurements at the sampling site and calculating the average. At the sampling site, water flow measurements were conducted with a Geopacks hydrometric flowmeter (Geomor Technik Poland), and five measurements were taken and the average was determined.

Site S1. In its initial course, the river channel is 2.5 meters wide, regulated, with banks overgrown with grasses and shrubs and meadows farther away (Table 1). In this area, the river flows mainly through meadows and agricultural fields. The riverbed is predominantly sandy. Upstream of S1, there are salmonid spawning grounds where brown trout redds have been recorded (constructed in 2016 by the Society of Friends of the Rega River).

Site S2. The upper course of the river in the town of Świdwin, the river channel is covered with vegetation. The riverbed consists of 80% gravel, 15% sand, and 5% stones (Brysiewicz et al. 2021). The banks in this section are regulated and overgrown with shrubs and occasional trees. Upstream of the sampling site, there is a scrapyard and agricultural fields.

Site S3. Located in the town of Prusinowo, this section of the river features a sandy riverbed with areas of gravel and stones, forming clusters of natural salmonid spawning grounds. The banks are lined

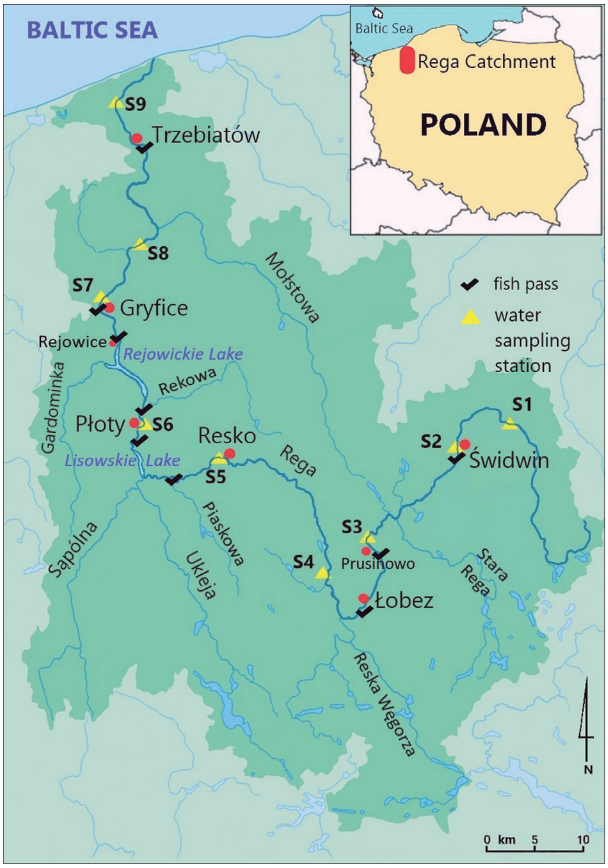

Figure 1. Location of the study area and water sampling sites.

Table 1
GPS coordinates of the sampling sites and the parameters of the Rega River at the sections studied

Parameter Point	GPS coordinates	Mean width (m)	Mean depth (m)	Mean flow (m s^{-1})
1	53°77'94''N, 15°89'42''E	2.5	1.0	0.58
2	53°77'49''N, 15°76'89''E	5.0	0.4	0.69
3	53°68'86''N, 15°63'20''E	15.0	0.5	0.30
4	53°65'64''N, 15°56'14''E	20.0	0.6	0.41
5	53°91'68''N, 15°20'27''E	22.0	0.6	0.58
6	53°80'72''N, 15°27'14''E	20.5	1.5	0.26
7	53°91'68''N, 15°20'26''E	17.0	1.6	0.65
8	53°97'13''N, 15°26'46''E	17.5	1.7	1.20
9	54°09'73''N, 15°22'68''E	19.0	1.9	0.90

with trees. The surrounding area is actively used for agriculture, including crop cultivation and animal husbandry. Additionally, a functioning fish pass is situated 200 meters downstream near the hydroelectric power plant.

Site S4. At this location, the river is 20 m wide (Table 1), with a sandy riverbed and unregulated banks. Numerous fallen trees are present. The river flows predominantly through meadows and forests.

Site S5. Located in the town center of Resko, this section of the river is 22 meters wide (Table 1) and features a diverse riverbed structure, with the most common sediment fractions ranging from 1.0 to 0.10 mm (Brysiewicz et al. 2021). The banks are heavily vegetated with numerous trees. A fish pass is situated just a few meters upstream from the sampling point.

Site S6. Situated in the town of Płoty, this sampling point is approximately 5 km downstream from the Lisowskie reservoir and about 2 km upstream from the Rejowickie reservoir. The riverbed in this section is sandy, with a significant amount of organic matter and emergent vegetation in the backwaters (Brysiewicz et al. 2021). This section of the river has a lowland character.

Site S7. Located in the town of Gryfice, this sampling point is approximately 8 km downstream from the Rejowice reservoir. The riverbed here is firm, with rocky patches and vegetation (Brysiewicz et al. 2021). The river channel is regulated with embankments.

Site S8. In this section, the river meanders significantly. The riverbed is predominantly sandy, with numerous fallen trees. The surrounding watershed consists mainly of agricultural fields. The nearest small villages are about 2 km from the sampling point.

Site S9. Situated about 1 km from the village of Włodarka, this section of the river has a highly regulated and deepened channel, with reed belts along the banks. The surrounding area consists of cultivated meadows and a dense network of drainage channels. The riverbed is primarily sandy, with significant siltation in slower-flowing areas and bends.

Measurement and analysis of water quality

Water quality indicators were measured using standard methods recommended by APHA (1999) (Table 2).

Temperature, conductivity (Elmetron CC-101 conductivity mater) and pH (Elmetron CP-103 waterproof pH-meter) were measured directly at sampling. Biological oxygen demand (BOD_5) was determined with the direct method after incubating samples for five days without light at a constant temperature of 20°C. Chemical oxygen demand (COD_{Cr}) was determined with the dichromate method. Dissolved oxygen (DO) was determined with the Winkler method. Alkalinity, total hardness, and chlorides were determined in water with titrimetric methods. Alkalinity was determined with 0.1 N HCl

Table 2
Laboratory methods used to determine the parameters analyzed in the Rega River

Parameter	Method	Units
Temperature	Standard Method 2550	°C
Conductivity	Standard Method 2510	$\mu S\ cm^{-1}$
pH	Standard Method 4500-H^+	
Total suspended solids (TSS)	Standard Method 2540D	$mg\ L^{-1}$
Alkalinity	Standard Method 2320	mg $CaCO_3$ L^{-1}
Total hardness	Standard Method 2340	mg CO_3 L^{-1}
Dissolved oxygen (DO)	Standard Method 4500-O B	mg O_2 L^{-1}
Biochemical Oxygen Demand (BOD_5)	Standard Method 5210 B	mg O_2 L^{-1}
Chemical Oxygen Demand (COD_{Cr})	Standard Method 5220 B	mg O_2 L^{-1}
Nitrite-nitrogen (NO_2-N)	Standard Method 4500-NO_2^-	mg L^{-1}(as NO_2-N)
Total ammonia nitrogen (NH_4-N)	Standard Method 4500-NH_3	mg L^{-1}(as NH_3-N)
Total phosphorus (TP)	Standard Method 4500-P	mg L^{-1}(as P)

using methyl orange as the indicator. Chloride ions were determined with Mohr's method. Total suspension was determined by weight.

Colorimetric methods were performed with a U-2900 UV-VIS double beam spectrophotometer (Hitachi High-Technologies Corporation, Tokyo, Japan). Nitrite nitrogen was assayed with sulphanilic acid (λ=543 nm). Ammonium nitrogen was assayed with indophenol blue (λ =630 nm). Total phosphorus (TP), (after mineralization with potassium hypersulphate) was determined with the method with ammonium molybdate and ascorbic acid (λ =882 nm).

The evaluation of the water quality indicators analyzed was conducted according to (I) Directive 2006/44/EC of the European Parliament and of the Council of 6 September 2006 on the quality of fresh waters needing protection or improvement to support fish life, Official Journal of the European Union, 25.09.2006, and (II) the Regulation of the Minister of Infrastructure of 25 June 2021 on the classification of ecological status, ecological potential, and chemical status, as well as the method of classifying the status of uniform surface water bodies and environmental quality standards for priority substances (developed based on Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for Community action in the field of water policy) (Table 3).

According to the guidelines contained in the aforementioned Regulation of the Minister of Infrastructure 2021, the Rega River is classified as a surface water body – a salmonid river in the lakeland river-lake system (Regulation MI 2021).

Statistical analysis

Statistical analysis was conducted using Statistica 13.3 software from TIBCO Software Inc. Variance analysis (ANOVA, $P < 0.05$) and the Duncan test ($P < 0.05$) were employed to determine statistically significant differences in water quality indicators among the various research sites.

Results and Discussion

The study revealed that the long-term average values for conductivity, TSS, DO, NO_2-N, NH_4-N, and chlorides ($P \leq 0.05$) differed significantly across the selected monitoring points (Tables 4, 5). The long-term average water temperature in the river ranged from 8.1°C in the initial section to 10.5°C in the downstream section (Table 4). At sites 7, 8, and 9, maximum temperatures slightly exceeded the threshold

Table 3
Threshold values for surface water quality contained in Directive 2006/44/EC and the Regulation of the Minister of Infrastructure (Reg. MI 2021) (nc – not classified)

Directive 2006/44/EC	Salmonid waters		Cyprinid waters
Indicator name, unit			
Temperature, °C	<21.5		<28.0
pH		6.0-9.0	
TSS mg L^{-1}		≤ 25	
DO mg O_2 L^{-1}	50% ≥ 9.0		50% ≥ 7.0
	100% ≥ 7.0		100% ≥ 7.0
BOD_5 mg O_2 L^{-1}	≤ 3.0		≤ 6.0
TP mg L^{-1}	≤ 0.2		≤ 0.4
NO_2-N mg L^{-1}	≤ 0.01		≤ 0.03
NH_4-N mg L^{-1}		≤ 1.0	
The Regulation of the Ministry of Infrastructure			
Indicator name, unit	The threshold value for water quality class		
	I	II	III-V
Indicators characterizing oxygen conditions and organic pollution			
DO mgO_2 L^{-1}	≥8.5	≥ 7.5	Not classified – nc
BOD_5 mgO_2 L^{-1}	≤ 3.0	≤ 3.8	
Indicators characterizing salinity			
Conductivity in 20°C μS cm^{-1}	≤ 360	≤ 480	Not classified – nc
Indicators characterizing biogenic conditions			
NH_4-N mg L^{-1}	≤ 0.12	≤ 0.30	Not classified – nc
TP mg L^{-1}	≤ 0.10	≤ 0.30	

for salmonid fishes, which is 21.5°C (Directive 2006/44/EC) (Tables 3, 4).

The increase in temperature observed along the river is attributed to its regulation and the lack of natural riparian vegetation. Water temperature significantly impacts several abiotic parameters, such as oxygen solubility and chemical toxicity (Caissie 2006), as well as biotic elements of the river ecosystem, including the life cycles, activity, reproduction, growth, and migration of aquatic organisms (Beschta et al. 1987, Selong et al. 2001, Benjamin et al. 2016, Wild et al. 2024). Ongoing climate change affects the distribution and abundance of species in rivers (Kärcher et al. 2019, Isaak et al. 2020).

The pH ranged from 7.5 to 7.6, which was statistically significant (Table 4). These values fell within the reference range of 6.0–9.0, which is suitable for fishes (Directive 2006/44/EC) (Tables 3, 4).

Statistically significant differences in long-term average levels of the indicators analyzed were noted for conductivity and TSS (Table 4). Conductivity at the nine monitoring points were within Class I water quality according to the Regulation of the Minister of Infrastructure (2021) (Tables 3, 4). However, TSS in the Rega River exceeded the threshold (25 mg L^{-1}) specified in Directive 2006/44/EC by more than 1.5 times at most sites, except for S7 and S8 (Tables 3, 4). The highest long-term TSS values were recorded at S1 and S3 (52 and 58 mg L^{-1}, respectively), while the lowest were at S7 and S8 (20 and 28 mg L^{-1}, respectively) (Table 5). TSS of 25 mg L^{-1}, the maximum value for waters suitable for salmonid fishes, was recorded only at S7, while at site S8, TSS slightly exceeded this level (Tables 3, 4). It is noteworthy that very high maximum averages of this indicator

Table 4
Indicators measured at selected sites on the Rega River. Average values ± standard deviations and ranges in parentheses from four years

Parameter Point	Temp. (°C)	pH	Conductivity (μS cm^{-1})	TSS (mg L^{-1})	DO (mg O_2 L^{-1})	BOD_5 (mg O_2 L^{-1})
1	8.1±3.7[a]	7.5±0.4[a]I	281±102[c]I	52±34[ab]	9.0±1.4[ab]I	2.4±0.9[a]I
	min-max	min-max	min-max	min-max	min-max	min-max
	1.5-15.1	7.3-8.0	180-531	2-100	6.0-11.1	0.9-4.2
2	8.8±4.5[a]	7.5±0.5[a]I	211±29[a]I	41±19[ab]	7.6±1.8[a]I	1.8±0.6[a]I
	min-max	min-max	min-max	min-max	min-max	min-max
	1.1-16.8	6.8-8.0	174-260	12-74	5.5-10.5	0.9-3.5
3	9.2±4.9[a]	7.6±0.4[a]I	193±23[a]I	58±39[b]	9.0±1.9[ab]I	2.7±0.9[a]I
	min-max	min-max	min-max	min-max	min-max	min-max
	0.5-17.5	6.5-8.0	164-240	10-134	5.9-12.6	1.4-5.2
4	9.5±5.1[a]	7.7±0.5[a]I	212±31[a]I	47±2[5ab]	9.0±1.6[ab]I	2.5±0.8[a]I
	min-max	min-max	min-max	min-max	min-max	min-max
	0.8-18.5	6.8-8.1	162-259	14-118	7.1-12.7	0.9-4.4
5	9.7±5.3[a]	7.7±0.6[a]I	226±24[ac]I	47±40[ab]	9.7±1.6[b]I	2.3±0.9[a]I
	min-max	min-max	min-max	min-max	min-max	min-max
	0.3-19.1	6.7-9.1	185-259	8-176	7.8-12.9	0.9-4.8
6	10.0±5.5[a]	7.6±0.6[a]I	275±96[bc]I	49±35[ab]	9.0±1.4[ab]I	2.0±1.1[a]I
	min-max	min-max	min-max	min-max	min-max	min-max
	2.1-20.6	6.8-8.3	165-511	14-124	6.7-11.5	0.2-3.6
7	10.6±6.1[a]	7.6±0.6[a]I	206±31[a]I	20±14[a]	8.7±1.7[ab]I	2.0±1.0[a]I
	min-max	min-max	min-max	min-max	min-max	min-max
	1.7-22.0	7.3-8.2	156-258	4-64	5.6-11.5	0.6-4.4
8	10.4±6.0[a]	7.6±0.6[a]I	203±30[a]I	28±16[ab]	8.9±1.7[ab]I	2.2±1.1[a]I
	min-max	min-max	min-max	min-max	min-max	min-max
	1.8-22.1	6.6-8.2	144-248	2-56	6.8-12.2	0.2-4.5
9	10.5±5.9[a]	7.6±0.6[a]I	213±34[a]I	48±34[ab]	9.2±1.7[ab]I	2.4±1.3[a]I
	min-max	min-max	min-max	min-max	min-max	min-max
	2.0-21.7	6.5-8.3	146-251	12-130	6.4-12.5	0.2-4.6
p	0.921	0.969	0.000	0.021	0.115	0.232
Mean 1-9 points	9.5±5.2I	7.6±0.5I	224±61I	44±32	8.9±1.7I	2.2±1.0I
	min-max	min-max	min-max	min-max	min-max	min-max
	0.3–22.1	6.1–8.3	144-531	2–132	5.5–12.1	0.5–5.0

Explanations: Averages in columns marked with different uppercase indices are statistically significant at P < 0.05 (Duncan's test). Classification of water according to the Regulation of the Minister of Infrastructure dated June 25, 2021 – Class I, II, nc – not classified. Classification of water according to Directive 2006/44/EC of the European Parliament and of the Council of September 6, 2006 – blue represents waters that meet conditions for salmonid fish habitation, green represents waters that meet conditions for cyprinid fish habitation; red indicates waters that do not meet the requirements for cyprinid fish habitation. Source: own study.

exceeding 100 mg L^{-1} were recorded at five sites (Table 4).

Elevated average annual TSS pose a significant threat to spawning grounds in the Rega riverbed. Suspended particles settle on spawning grounds between stones and hinders oxygen access to the eggs laid on them. This, in turn, may cause disturbances in fish embryonic development, reducing the percentage of fertilization and survival of fish embryos (Newcombe and Jansen 1996, Bonisławska et al. 2011, Kemp et al. 2011).

The accumulation of suspended solids may further shorten the usability of artificial spawning grounds (Bonisławska et al. 2021). Increased amounts of suspended solids are also hazardous to the diverse fauna present in the river (Bilotta and Brazier 2008).

The DO and BOD_5 concentrations recorded in our study generally met the requirements for Class I water quality according to the Regulation of the Polish Minister of Infrastructure (2021), and only at site S2 did DO values slightly exceed that of Class I water quality (Tables 3, 4).

These waters were also deemed suitable for salmonid fish habitation (Directive 2006/44/EC). No variation in BOD_5 was observed along the river course (Table 4). In previous years, BOD_5 remained below 2.0 mg O_2 L^{-1} (WIOŚ 2018).

Average NH_4-N concentrations ranged from 0.042 mg L^{-1} (S9) to 0.104 mg L^{-1} (S3) (Tables 3, 5), meeting Class I requirements under the Ministry of Infrastructure 2021 (Regulation MI 2021), and are thus suitable for salmonid fish habitation (Directive 2006/44/EC). Ammonia in the aquatic environment exists in both dissociated and undissociated molecular forms, the latter of which is toxic to fishes. According to Directive 2006/44/EC, the concentration of undissociated nitrogen with regard to salmonids should not exceed 0.025 mg NH_3 L^{-1}. The proportion of both forms depends on the pH and temperature of the water (Emerson et al. 1975). Based on the results obtained, it should be noted that even under conditions of high water temperature and maximum pH values, the reference value for the undissociated form of ammonia nitrogen for salmonids was not exceeded (maximum concentrations never exceeded 0.010 mg NH_3 L^{-1}).

TP below 0.200 mg L^{-1} classified the waters at the sampling points as suitable for salmonid fish habitation (Directive 2006/44/EC). However, the threshold for Class I water quality of 0.100 mg L^{-1} (Regulation MI 2021) was slightly exceeded. The highest long-term average TP value of 0.125 mg L^{-1} was recorded at S3, while the lowest was 0.093 mg L^{-1} at S8 (Tables 3, 5).

Source data from 2002–2017 indicated that TP at five points, from the mouth of the Mołstowa River to the mouth of the Ukleja River, were below 0.200 mg P L^{-1} and were thus suitable for salmonid fish habitation (WIOŚ 2018, Directive 2006/44/EC). Despite this, the chemical status was rated good at two points and less than good at three, and the overall water status in reference to ecological potential and chemical status was assessed as poor at these five points (WIOŚ 2018).

Long-term average NO_2-N levels at points S1 and S4-S9 ranged from 0.017 mg L^{-1} (S9) to 0.029 mg L^{-1} (S1), indicating waters suitable for cyprinid fish habitation (Directive 2006/44/EC). However, S2 and S3 had levels of 0.32 mg L^{-1} and 0.30 mg L^{-1}, respectively, indicating non-classified waters (statistically significant differences, Tables 3, 5). Elevated NO_2-N concentrations can negatively affect fish health and reduce fertility (Korwin-Kossakowski et al. 1995, Kroupová et al. 2018, Wang et al. 2022). Continuous NO_2-N presence is indicated by maximum long-term levels exceeding the allowable limit of 0.03 mg L^{-1} at all sites (Tables 3, 5). Nitrites in surface waters mainly result from nitrification/denitrification processes, which depend on oxygen conditions. The absence of anoxic conditions in the Rega River during the study period indicated intensive mineralization of organic compounds, releasing oxidized forms of inorganic nitrogen, including NO_2-N (Stein and Klotz 2016). High nitrite levels may indicate water contamination (Kelso et al. 1999). Elevated nitrite levels at S1, S2, and S3 may have resulted from excessive field fertilization, including the application of slurry. The increasing trend in nutrient concentrations in rivers from agricultural activities is a global issue (Hus and Pulikowski 2011, Poikane et al. 2019, Steinhoff-Wrześniewska et al. 2022, Yu et al. 2024).

Our findings align with data from the GIOŚ Report (2022) which indicates that nitrite nitrogen (NO_2-N) norms are most frequently exceeded in Polish rivers, but less so for ammonium nitrogen and total phosphorus (GIOŚ 2022).

In our study, we did not observe an increase in dissolved substances from the river source to its mouth, which is a common phenomenon (Gong et al. 2013, Yu et al. 2024). Point sources of anthropogenic pollution at sites 2 and 3 (upper and middle sections) caused an increase in indicators such as TSS,

Table 5
Indicators measured at selected sites on the Rega River. Average values ± standard deviations and ranges in parentheses from four years

Parameter Point	TP (mg L^{-1})	NO_2-N (mg L^{-1})	NH_4-N (mg L^{-1})	Alkalinity (mg $CaCO_3$ L^{-1})	Total hardness (mg CO_3^{2-} L^{-1})	Chlorides (mg Cl^- L^{-1})
1	0.114±0.032[a] II	0.029±0.007b[d]	0.065±0.040[ac] I	202.2±32.2[a]	251.8±32.6[a]	34.4±20.5[a]b
	min-max	min-max	min-max	min-max	min-max	min-max
	0.063-0.199	0.019-0.040	0.016-0.154	160.0-290.0	140.0-277.5	10.7-88.8
2	0.111±0.028[a] II	0.032±0.010[d]	0.074±0.052[ac] I	201.5±76.2[a]	251.4±33.2[a]	32.0±10.8[ab]
	min-max	min-max	min-max	min-max	min-max	min-max
	0.060-0.155	0.018-0.055	0.020-0.131	160.0-491.0	136.5-297.5	21.3-63.9
3	0.125±0.020[a] II	0.030±0.015[d]	0.104±0.090[bc] I	188.6±17.8[a]	245.1±32.6[a]	27.3±7.9[a]
	min-max	min-max	min-max	min-max	min-max	min-max
	0.081-0.159	0.009-0.065	0.010-0.181	163.0-220.0	130-267.5	14.2-42.6
4	0.123±0.030[a] II	0.027±0.010[bcd]	0.082±0.053[ac] I	199.9±16.0[a]	230.3±32.4[a]	34.2±7.9[ab]
	min-max	min-max	min-max	min-max	min-max	min-max
	0.084-0.176	0.014-0.042	0.029-0.169	162.0-225.0	111.0-260.0	21.3-49.7
5	0.117±0.039[a] II	0.019±0.006[abc]	0.055±0.046[ac] I	211.0±29.6[a]	241.1±33.7[a]	35.3±5.9[ab]
	min-max	min-max	min-max	min-max	min-max	min-max
	0.021-0.183	0.012-0.031	0.013-0.150	165.0-295.0	117.5-277.8	24.9-46.2
6	0.124±0.042[a] II	0.020±0.006[abc]	0.061±0.036[ac] I	198.8±16.5[a]	255.3±21.3[a]	46.0±21.5[c]
	min-max	min-max	min-max	min-max	min-max	min-max
	0.087-0.255	0.007-0.032	0.016-0.150	169.0-222.0	232.5-310.0	28.4-124.3
7	0.106±0.036[a] II	0.023±0.007[abcd]	0.063±0.030[ac] I	202.8±18.0[a]	244.6±22.5[a]	41.1±7.7[bc]
	min-max	min-max	min-max	min-max	min-max	min-max
	0.047-0.182	0.014-0.044	0.021-0.112	164.5-230.0	212.5-295.0	35.5-67.5
8	0.093±0.023[a] I	0.020±0.007[abc]	0.047±0.028[ac] I	195.7±18.7[a]	241.8±20.3[a]	38.0±8.8[bc]
	min-max	min-max	min-max	min-max	min-max	min-max
	0.06-0.135	0.011-0.034	0.019-0.115	138.5-225.0	217.5-287.5	24.9-56.8
9	0.106± 0.028[a] II	0.017±0.008[a]	0.042±0.029[a] I	192.0±14.0[a]	237.6±17.8[a]	38.4±6.4[bc]
	min-max	min-max	min-max	min-max	min-max	min-max
	0.075-0.188	0.005-0.037	0.012-0.117	154.0-210.0	212.5-280	28.4-53.3
p	0.060	0.000	0.011	0.765	0.331	0.005
Mean 1-9 points	0.112±0.035 II	0.024±0.011	0.061±0.048 I	199.0±33.0	244.0±29.0	36.3±13.2
	min-max	min-max	min-max	min-max	min-max	min-max
	0.021-0.255	0.005-0.065	0.010-0.237	154.0-295.0	111.0-310.0	10.7-124.3

Explanations: Designations as in Table 4. Source: own study.

NO_2-N, and NH_4-N, which were up to twice as high as those at site 9 (lower section) (Tables 4, 5). Sites 2 and 3 are located where the river flows through the towns of Świdwin and Prusinowo and agricultural areas, likely contributing to elevated nutrient concentrations.

Long-term average alkalinity during the study ranged from 188.6 to 211.0 mg $CaCO_3$ L^{-1}, with no statistically significant differences among sites (Table 5). Water hardness ranged from 230.3 to 255.0 mg CO_3^{2-} L^{-1}, which was also without any significant differences (Table 5). These levels indicated moderately hard water.

Long-term average chloride levels in the Rega River ranged from 27.3 to 46.0 mg Cl^- l^{-1}, which were statistically significantly different among sites (Table 5). Although these levels occur naturally in watercourses, the elevated maximum levels of this

Table 6
Long-term average for each season, including minimum, maximum, and standard deviation of the water quality indicators analyzed for the Rega River (average of nine measurement points)

Parameter Season	Temp. (°C)	pH	Conductivity (µS cm^{-1})	TSS (mg L^{-1})	DO (mgO_2 L^{-1})	BOD5 (mgO_2 L^{-1})
Spring	9.3±2.9[b]	7.8±0.3[b]	216.3±65.2[a] I	60±40[b]	8.9±0.9[b] I	2.0±0.9[a] I
	min-max	min-max	min-max	min-max	min-max	min-max
	4.8-14.5	7.5-8.3	144-450	8-176	7.1-10.8	0.4-4.5
Summer	17.6±2.3[c]	7.4±0.7[a]	219.6±63.0[a] I	25±14[a]	7.2±0.9[a] nc	1.9±0.9[a] I
	min-max	min-max	min-max	min-max	min-max	min-max
	16.0-22.1	6.1-9.1	146-531	2-50	5.5-9.2	0.4-4.2
Autumn	10.3±2.4[b]	7.5±0.6[a]	235.7±70.2[a] I	32±25[a]	8.8±1.7[b] I	2.1±0.8[a] I
	min-max	min-max	min-max	min-max	min-max	min-max
	8.5-15.2	6.3-8.1	174-511	2-116	5.6-12.5	0.6-4.4
Winter	3.2±1.6[a]	7.7±0.4[ab]	225.9±44.3[a] I	56±29[b]	10.6±1.1[c] I	3.0±1.1[b] I
	min-max	min-max	min-max	min-max	min-max	min-max
	0.3-5.6	6.8-8.2	176-363	10-130	7.9-12.9	0.9-4.8
p	0.000	0.000	0.557	0.000	0.000	0.000

Explanations: Designations as in Table 4. Source: own study

indicator, up to 88.8 mg Cl^{-} l^{-1} (S1) and 124.3 mg Cl^{-} l^{-1} (S6), indicated pollution. Sources of Cl^{-} ions in river water can include atmospheric precipitation, mining water, industrial and agricultural production, domestic activities, and de-icing of roads. High chloride concentrations may result from using artificial potassium fertilizers (potassium chloride KCl) and natural fertilizers (slurry), which leach into rivers (Krapac et al. 2002, Panno et al. 2005, Oberhelman and Peterson 2020).

Rega River water quality by season

Seasonal variability was observed in the indicators monitored (Tables 6, 7). Significant differences between spring, summer, fall, and winter were noted in most of the analyzed indicators, except for conductivity, TP, and chlorides (Tables 6, 7).

Water temperature was the highest in summer and the lowest in winter. In contrast, DO concentrations reached the highest value in winter and the lowest in summer (Tables 6, 7). Water temperature variability followed the seasonal cycle of the temperate climate, indicating no thermal pollution at the sites studied on the Rega River (Nędzarek and Chojnacki 2003, Nędzarek and Tórz 2009).

The lowest long-term DO average was recorded in the summer, which correlated with higher temperatures during this period (Table 6). It was 7.2 mg O_2 L^{-1}, which was slightly lower than the 7.5 mgO_2 L^{-1} level required for Class II standards according to the Ministry of Infrastructure 2021 (Regulation MI 2021).

The pH varied seasonally from 7.4 to 7.8 (Table 6). Significant pH differences were observed across the seasons. The minimum pH levels were recorded in summer (7.4) and fall (7.5; Table 6). This could be due to atmospheric precipitation and pollutants washed into waters by rain from the watershed area.

High TSS content observed in spring and winter, which exceeded the annual threshold value of 25 mg L^{-1} required by Directive 2006/44/EC by more than twice, may have resulted from snowmelt, heavy rainfall, and anthropogenic pollution. Elevated TSS levels increase water turbidity, hindering sunlight penetration and thus inhibiting photosynthesis. Increased TSS and sedimentation pose a threat to the habitat of many invertebrates (Kaller and Hartman 2004, Harrison et al. 2007) and fishes (Newcombe and Jansen

Table 7
Long-term average for each season, including minimum, maximum, and standard deviation of the analyzed water quality indicators of the Rega River (average of nine measurement points)

Parameter Season	TP (mg L^{-1})	NO_2-N (mg L^{-1})	NH_4-N (mg L^{-1})	Alkalinity (mg $CaCO_3$ L^{-1})	Total hardness (mg CO_3^{2} L^{-1})	Chlorides (mg Cl^- L^{-1})
Spring	0.115±0.032[a]II min-max 0.070-0.199	0.026±0.008[abc] min-max 0.012-0.053	0.091±0.068[b]I min-max 0.013-0.291	195.1±22.3[a] min-max 160-220	249.9±13.5[b] min-max 215-280	34.2±8.7[a] min-max 14.2-49.7
Summer	0.108±0.038[a]II min-max 0.021-0.195	0.028±0.013[bc] min-max 0.011-0.058	0.045±0.033[a]I min-max 0.016-0.181	204.4±19.3[bc] min-max 185-290	226.6±45.2[a] min-max 111-298	38.9±12.0[a] min-max 21.1-88.8
Autumn	0.111±0.028[a]II min-max 0.060-0.176	0.023±0.012[abc] min-max 0.007-0.065	0.040±0.028[a]I min-max 0.012-0.143	217.0±49.5[bc] min-max 160-491	251.0±19.8[b] min-max 215-286	38.3±17.6[a] min-max 17.8-124.3
Winter	0.117±0.034[a]II min-max 0.059-0.255	0.021±0.005[a] min-max 0.006-0.034	0.083±0.050[b]I min-max 0.012-0.207	180.0±19.8[a] min-max 154-230	252.7±10.1[b] min-max 217-310	33.7±12.9[a] min-max 10.7-63.9
p	0.685	0.023	0.000	0.000	0.000	0.224

Explanations: Designations as in Table 4. Source: own study.

1996, Bonisławska et al. 2011, Kemp et al. 2011). This is noted particularly in winter for salmonid fishes since excessive siltation of gravel from high amounts of silt and fine sand creates unfavorable oxygen conditions and disrupts flow in nests, increasing the mortality of eggs and larvae (Soulsby et al. 2001, Levasseur et al. 2006, Smialek et al. 2021).

A weak negative correlation was observed between ammonium nitrogen and nitrite nitrogen (III) with seasons (Fig. 2). Additionally, nitrite nitrogen variability was negatively correlated with DO, while ammonium nitrogen was positively correlated with DO (Fig. 3). During the long-term study, in the summer when the DO concentration was the lowest, the

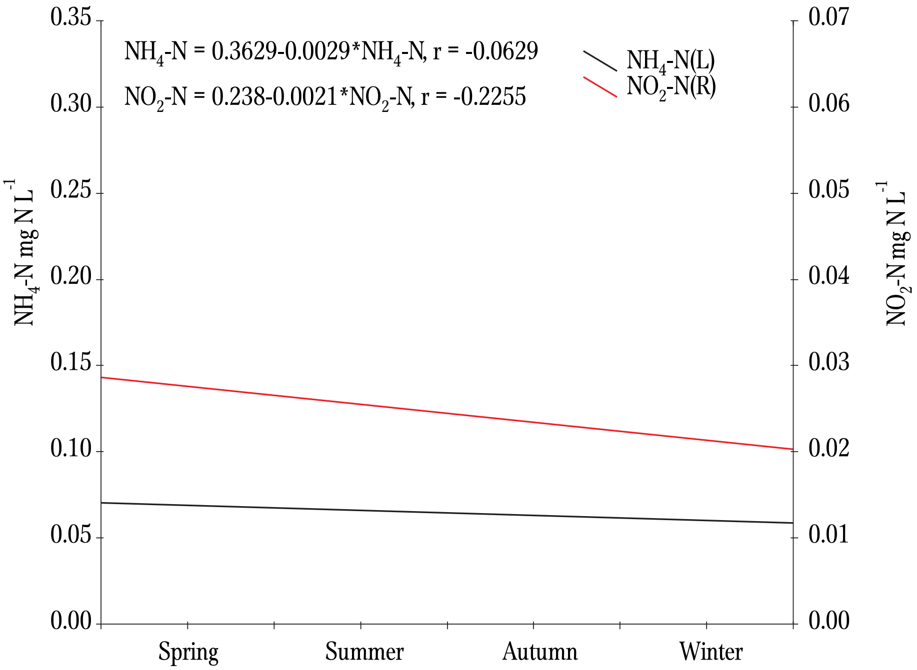

Figure 2. Seasonal variability of ammonium nitrogen and nitrite nitrogen concentrations.

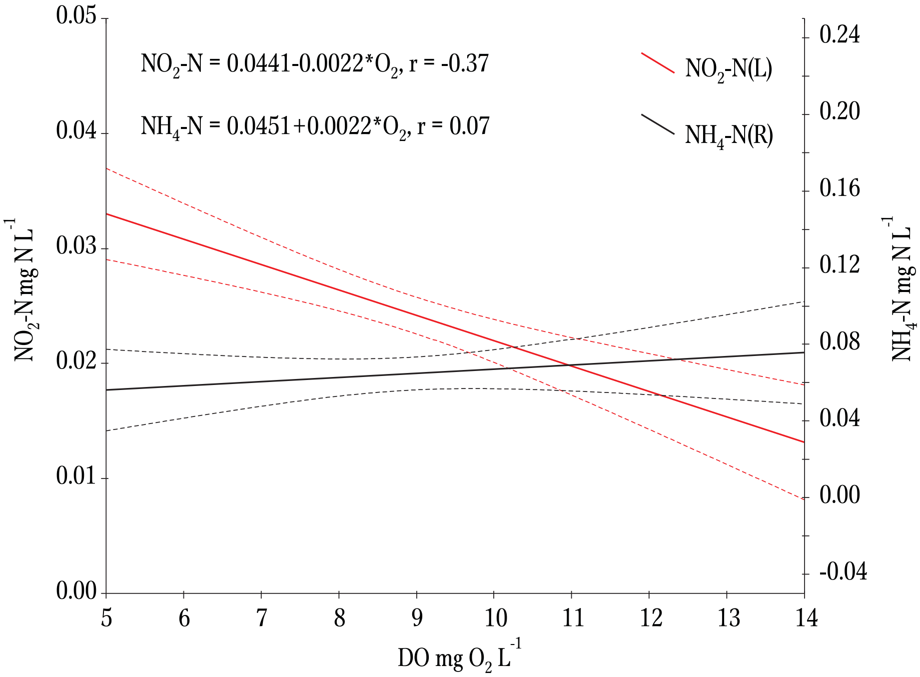

Figure 3. Linear regressions of ammonium nitrogen (NH_4-N) and nitrite nitrogen (NO_2-N) with dissolved oxygen (DO) in water.

NO_2-N concentration reached its highest levels, whereas NH_4-N concentration was low (Table 7). This indicated a disruption in the natural nitrogen and phosphorus transformation cycle in the ecosystem that was not driven solely by seasonal primary production variability. Our study showed that in winter, when the vegetation process is halted, there was an increase in TP and NH_4-N concentrations, indicating the release of these nutrients from biomass. However, in the spring-summer months, these nutrients should be used up in biomass formation, which was not observed in the spring for TP or NH_4^+-N or in the spring or summer for NO_2-N (Table 7). This phenomenon may be caused by nutrient input from fertilizers running off fields and other anthropogenic pollutants (Steinhoff-Wrześniewska et al. 2022, Bonisławska et al. 2024, Yu et al. 2024).

Seasonal variability of the remaining indicators is presented in Figure 4. The study revealed that the long-term average electrical conductivity in the Rega River increased from spring to fall and then decreased in winter, ranging from 216.3 to 235.7 μS cm^{-1}. Given that surface waters typically have conductivity between 100 and 1,000 μS cm^{-1} (Wetzel 2001), these levels do not indicate mineral pollution in the Rega River (Table 7, Fig. 4).

Chloride ion concentrations ranged from 38.3–38.9 mg Cl^- L^{-1} in fall and summer, and 33.7–34.2 mg Cl^- L^{-1} in winter and spring (no significant differences; Table 7, Fig. 4).

Alkalinity was lowest in winter and highest in fall, while water hardness was highest in spring, fall, and winter, and lowest in summer (significant differences) (Table 7, Fig. 4)

Conclusion

The results of this long-term study led to the following conclusions:

1) Among the 12 water quality indicators analyzed, the long-term average values of TSS and NO_2^--N did not meet the requirements of current EU regulations. The exceedance of these values threatens the flora and fauna species living in the stream, negatively impacting its biodiversity.
2) Incidental high values of conductivity, TSS, BOD_5, NO_2-N, and chlorides indicate sewage discharges

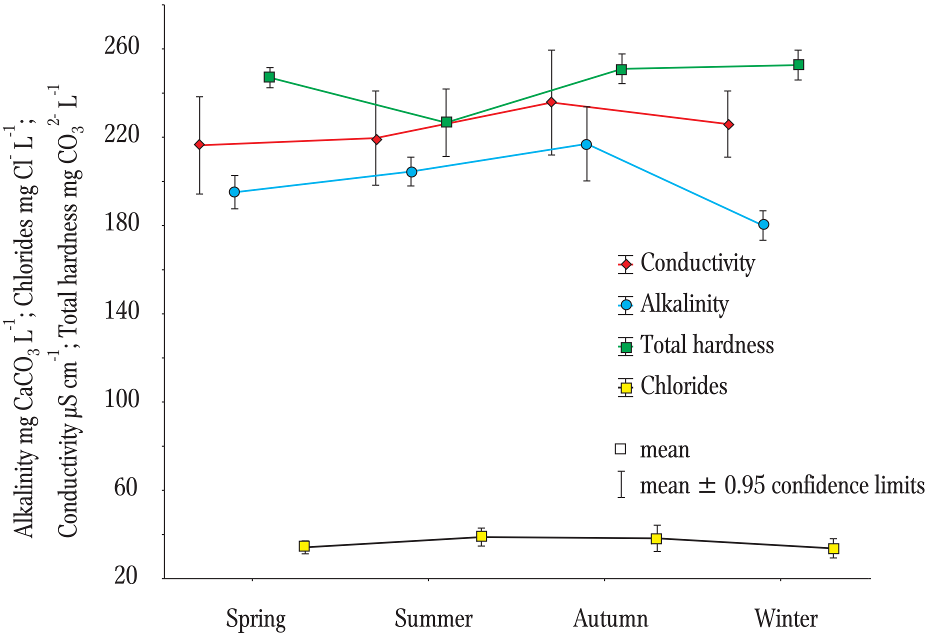

Figure 4. Seasonal variability of alkalinity, chloride ions, conductivity, and total hardness.

that disrupt ecosystem recovery processes (Niemi et al. 1990).

3) In the Rega River, these pollutants primarily originate from large cities along the river and surface runoff from agricultural areas.

4) Given the revitalization undertaken over ten years ago in the Rega River, continued efforts should be made to improve water quality. Regulating sewage management in the watershed, controlling pollution runoff from urban areas, and limiting excessive use of artificial and natural fertilizers in the agricultural regions of the Rega watershed could improve the situation.

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References

APHA (1999). Standard methods for examination of water and wastewater. 20th ed. Washington D.C., USA. American Public Health Association.

Bartel, R. (2001). Return of salmon back to Polish waters. Ecohydrology & Hydrobiology, 1, 377-392.

Bartel, R., Pender, R., Tański, A., Potkański, Ł., Pilch, E. (2008). Catches of vimba bream spawners from the Rega River in 2008. Komunikaty Rybackie, 6, 11-13 (in Polish).

Benjamin, J. R., Heltzel, J. M., Dunham, J. B., Heck, M., Banish, N. (2016). Thermal regimes, nonnative trout, and their influences on native Bull Trout in the Upper Klamath River Basin, Oregon. Transactions of the American Fisheries Society, 145(6), 1318-1330.

Beschta, R. L., Bilby, R. E., Brown, G. W., Holtby, L. B., Hofstra, T. D. (1987). Stream temperatures and aquatic habitat: fisheries and forestry Interactions. In: Stream-side Management: Forestry and Fishery Interactions (Ed.) E. O. Salo, T. W. Cundy, University of Washington, Washington, 191-232.

Bilotta, G. S., Brazier, R. E. (2008). Understanding the influence of suspended solids on water quality and aquatic biota. Water Research, 42 (12), 2849-2861.

Bonisławska, M., Formicki, K., Smaruj, I., Szulc, J. (2011). Total suspended solids in surface waters versus embryonic development of pike (*Esox lucius* L.). Electronic Journal of Polish Agricultural Universities, 14(1), 07.

Bonisławska, M., Tański, A., Mokrzycka, M., Brysiewicz, A., Nędzarek, A., Tórz, A. (2013). The effect of effluents from rainbow trout ponds on water quality in the Gowienica River. , 19 (VII–XII), 23-30.

Bonisławska, M., Tański, A., Nędzarek, A., Tórz, A., Formicki, K., Korzelecka-Orkisz, A. (2021). Suitability of waters of the Rega River catchment for the construction and operation of artificial spawning grounds for migratory salmonids. In: Aquaculture as a tool for protecting ichthyofauna. (Ed.) Z. Zakęś, K. Demska-Zakęś, IRS, Olsztyn: 119-128 (in Polish).

Bonisławska, M., Nędzarek, A., Rybczyk, A., Tański, A. (2024). The influence of anthropogenic pollution on the physicochemical conditions of the waters of the lower section of the Sąpólna River. Water, 16, 35.

Brysiewicz, A., Korzelecka-Orkisz A., Tański, A., Formicki, K. (2021). Characterization of habitat conditions through substrate granulation assessment as a spawning substrate for salmonid fish in the Rega River (NW Poland). In: Infrastructure and Environment in the Circular Economy (Ed.) A. Krakowiak-Bal, M. Malinowski, J. Sikora, IGSMiE PAN, Kraków: 88-100 (in Polish).

Caissie, D. (2006). The thermal regime of rivers: a review. Freshwater Biology, 51, 1389-1406.

Chełkowski, Z. (1978). Studies on trout (*Salmo trutta* L.) wild smolts of the river Rega. Acta Ichthyologica et Piscatoria, 8, 43-58.

Chełkowski, Z., Chełkowska, B. (1981a). Juvenile trout (*Salmo trutta* L.) survival rate from hatched fish release to smolting in River Mołstowa basin. Acta Ichthyologica et Piscatoria, 11, 47-56.

Chełkowski, Z., Chełkowska, B. (1981b). Descent of trout (*Salmo trutta* L.) smolts grown in River Mołstowa catchment area. Acta Ichthyologica et Piscatoria, 11, 57-67.

Chełkowski Z., Chełkowska, B. (1982). Biological characteristics of trout (*Salmo trutta* L.) smolts grown in River Mołstowa catchment area. Acta Ichthyologica et Piscatoria, 12, 57-66.

Directive 2000/60/EC of the European Parliament and of 23 October 2000 the Council establishing a framework for Community action in the field of water police. Official Journal L 327, 21.12.2000.

Directive 2006/44/EC of the European Parliament and of the Council of 6 September 2006 on the quality of fresh waters needing protection or improvement in order to support fish life. Official Journal of the European Union 25.9.2006.

Emerson, K., Russo, R. C., Lund, R. E., Thurston, R. V. (1975). Aqueous Ammonia Equilibrium Calculations: Effect of pH and Temperature. Journal of the Fisheries Research Board of Canada, 32: 2379-2383.

GIOŚ (2022). Chief Inspectorate of Environmental Protection. State of the Environment in Poland. Report 2022. Water Quality. Environmental Monitoring Library, Warsaw: 61-91 (in Polish).

Gong, D., Gao, X., Ntakirutimana, T., Guo, J., Li, K. (2013). Water quality status along the Liangtan River and control planning alternatives for pollution reduction. Polish Journal of Environmental Studies, 22(4), 1061-1067.

Harrison, E. T., Norrisand, R. H., Wilkinson, S. N. (2007). The impact of fine sediment accumulation on benthic macroinvertebrates: implications for river management. In: Proceedings of the 5th Australian Stream Management Conference. Australian rivers: making a difference (Ed.) A. L. Wilson, R. L. Dehaan, R. J., Watts, K. J. Page, K. H. Bowmer, A. Curtis, Charles Sturt University, Thurgoona, New South Wales. 139-144.

Hus, T., Pulikowski, K. (2011). Content of nitrogen compounds in waters flowing out of small agricultural catchments. Polish Journal of Environmental Studies, 20, 895-902.

Isaak, D. J., Luce, C. H., Horan, D. L., Chandler, G. L., Wollrab, S. P., Dubois, W. B., Nagel, D. E. (2020). Thermal regimes of perennial rivers and streams in the Western United States. JAWRA Journal of the American Water Resources Association, 56(5), 842-867.

Kaj, J., Walczak, J. (1954). Distribution of brown trout in Western Pomeranian waters. Roczniki Nauk Rolniczych, 68, B4, 513-536 (in Polish).

Kaller, M. D., Hartman, K. J. (2004). Evidence of a threshold level of fine sediment accumulation for altering benthic macroinvertebrate communities. Hydrobiologia, 518, 95-104.

Kelso, B. H. L., Smith, R. V., Laughlin, R. J. (1999). Effects of carbon substrates on nitrite accumulation in freshwater sediments. Applied and Environmental Microbiology, 65(1), 61-66.

Kemp, P., Sear, D., Collins, A., Naden, P., Jones, I. (2011). The impacts of fine sediment on riverine fish. Hydrological Processes, 25 (11), 1800-1821.

Keszka, S., Raczyński, M. (2006). Characteristics of measurable traits of vimba bream (*Vimba vimba*) obtained for artificial spawning from the Rega River. In: Reproduction, Rearing, and Prophylaxis of Cyprinids and Other Species (Ed.). Z. Zakęś, K. Demska-Zakęś, J. Wolnicki, IRS, Olsztyn: 157-166 (in Polish).

Korwin-Kossakowski, M., Myszkowski, L., Kazuń, K. (1995). Acute toxicity of nitrite to tench (*Tinca tinca* L.) larvae. Polish Archives of Hydrobiology, 42 (1-2), 213-216.

Krapac, G., Dey, W. S., Smyth, C. A., Storment, E., Sargent, S. L., Steele, J. D. (2002). Impacts of swine manure pits on groundwater quality. Environmental Pollution, 120, 475-492.

Kroupová, H., Valentová, O., Svobodová, Z., Šauer, P., Machova, J. (2018). Toxic effects of nitrite on freshwater organisms: a review. Reviews in Aquaculture, 10, 525-542

Kärcher, O., Hering, D., Frank, K., Markovic, D. (2019). Freshwater species distributions along thermal gradients. Ecology and Evolution, 9, 111-24.

Levasseur, M., Bergeron, N. E., Lapointe, M. F., Bérubé, F. (2006). Effects of silt and very fine sand dynamics in Atlantic salmon (*Salmo salar*) redds on embryo hatching success. Canadian Journal of Fisheries and Aquatic Sciences, 63(7), 1450-1459.

Nędzarek, A., Chojnacki, J. C. (2003). Variability of selected hydrochemical parameters of the 3RD Order river Odra estuary in relation to hydrology of the area in 1997-2000, Electronic Journal of Polish Agricultural Universities, Fisheries, 6, 1.

Nędzarek, A., Tórz, A. (2009). The primary production of Tertiary estuary (Dąbie Lake, Poland). Limnological Review, 9, 1, 17–26.

Niemi, G. J., DeVore, P., Detenbeck, N., Taylor, D., Lima, A., Pastor, J., Yount, D., Naiman, R. J. (1990). Overview of case studies on recovery of aquatic systems from disturbance. Environmental Management, 14, 571-587.

Newcombe, C. P., Jensen, J. O. T. (1996). Channel suspended sediment and fisheries: a synthesis for quantitative assessment of risk and impact. North American Journal of Fisheries Management, 16 (4), 693-727.

Novita, E., Pradana, H. A., Purnomo, B. H., Puspitasari, A. I. (2020). River water quality assessment in East Java, Indonesia. Journal of Water and Land Development, 47, 135-141.

Oberhelman, A., Peterson, E. W. (2020). Chloride source delineation in an urban-agricultural watershed: Deicing agents versus agricultural contributions. Hydrological Processes, 34(20), 4017-4029.

Panno, S. V., Hackley, K. C, Hwang, H. H., Greenberg, S. E., Krapac, I. G., Landsberger, S., O'Kelly, D. J. (2005). Database for the characterization and identification of sources of sodium and chloride in natural waters of Illinois. Open File Series 2005-1, Illinois State Geological Survey.

Pender, R., Tański, A. (2005). Results of artificial spawning of vimba bream (*Vimba vimba* (L.)) from the Rega River. In: Reproduction, Rearing, and Prophylaxis of Catfish-like and Other Species (Ed.) Z. Zakęś, IRS, Olsztyn: 207-212 (in Polish).

Poikane, S., Kelly, M. G., Salas Herrero, F., Pitt J. A., Jarvie, H. P., Claussen, U., Leujak, W., Lyche Solheim, A., Teixeira, H., Phillips, G. (2019). Nutrient criteria for surface waters under the European Water Framework Directive: Current state-of-the-art, challenges and future outlook. Science of The Total Environment, 695, 133888.

Radtke, G., Bernaś, R., Dębowski, P., Skóra, M. (2010). Ichtiofauna dorzecza Regi. (The ichthyo-fauna of the Rega river system), Roczniki Naukowe PZW, 23, 51-78 (in Polish).

Regulation MI (2021). Regulation of the Ministry of Infrastructure of June 25, 2021 on the classification of ecological status, ecological potential and chemical status, and the method of classification of the status of surface water bodies, as well as environmental quality standards for priority substances. Journal of Laws, 2021 item 1475.

Selong, J. H., McMahon, T. E., Zale, A. V., Barrows, F. T. (2001). Effect of temperature on growth and survival of bull trout, with application of an improved method for determining thermal tolerance in fishes. Transactions of the American Fisheries Society, 130, 1026-1037.

Smialek, N., Pander, J., Geist, J. (2021). Environmental threats and conservation implications for Atlantic salmon and brown trout during their critical freshwater phases of spawning, egg development and juvenile emergence. Fisheries Management and Ecology, 28(5), 437-467.

Soulsby, C., Youngson, A. F., Moir, H. J., Malcolm, I. A. (2001). Fine sediment influence on salmonid spawning habitat in a lowland agricultural stream: a preliminary assessment. Science of the Total Environment, 265(1-3), 295-307.

Stein, L. Y., Klotz, M. G. (2016). The nitrogen cycle. Current Biology, 26(3), 94-98.

Steinhoff-Wrześniewska, A., Strzelczyk, M., Helis, M., Paszkiewicz-Jasińska, A., Gruss, Ł., Pulikowski, K., Skorulski, W. (2022). Identification of catchment areas with nitrogen pollution risk for lowland river water quality. Archives of Environmental Protection, 48, 53-64.

Wang, H., Liu, Y., Chai, L., Wang, H. (2022). Effects of nitrite exposure on metamorphosis and skeletal development of Bufo gargarizans. Environmental Science and Pollution Research, 29(34), 51847-51859.

Wang, X.L., Lu, Y.L., Han, J.Y., He, G.Z, Wang, T.Y. (2007). Identification of anthropogenic influences on water quality of rivers in Taihu watershed. Journal of Environmental Sciences, 19(4), 475-481.

Wątor, K., Zdechlik, R. (2021). Application of water quality indices to the assessment of the effect of geothermal water discharge on river water quality – case study from the Podhale region (Southern Poland). Ecological Indicators, 121, 107098.

Wetzel, R. G. (2001). Limnology, Lake and River Ecosystems. Elsevier, Amsterdam, The Netherlands.

Wild, R., Nagel, C., Geist, J. (2024). Multiple climate change stressors reduce the emergence success of gravel-spawning fish species and alter temporal emergence patterns. Science of the Total Environment, 949, 175054.

WIOŚ in Szczecin (2018). Provincial Inspectorate of Environmental Protection. The State of the Environment in the West Pomeranian Voivodeship. Report 2018 (in Polish).

Witkowski, A. (2001). *Lampetra fluviatilis* (Linnaeus, 1758) (river lamprey). In: Polish Red Data Book of Animals. Vertebrates (Ed.) Z. Głowaciński, PWRiL, Warszawa: 323–325.

Yu, J., Mo, L., Dai, J., Bai, K., Mo, J., Zhang, S. (2024). Nitrogen and phosphorus pollution discharge and water quality evaluation in a small basin of the upper reaches of Lijiang River. Water, 16, 104.