FISHERIES & AQUATIC LIFE (2023) 31: 156 - 170
Archives of Polish Fisheries
DOI 10.2478/aopf-2023-0016

RESEARCH ARTICLE

Changes in the fish community of the Czarna Hańcza River (NE Poland) after a fish kill caused by a wastewater treatment plant failure

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Received – 27 April 2023/Accepted – 10 September 2023. Published online: 30 September 2023; ©National Inland Fisheries Research Institute in Olsztyn, Poland

Citation: Wasilewska, A., Ulikowski, D., Traczuk, P., Kalinowska, K., Kropielnicka-Kruk, K. (2023). Changes in the fish community of the Czarna Hańcza River (NE Poland) after a fish kill caused by a wastewater treatment plant failure. Fisheries & Aquatic Life 31, 156-170

Abstract. Mass fish kills caused by wastewater treatment plant (WWTP) failure are uncommon. In this study, we analyzed the recovery of the fish community in the Czarna Hańcza River after a fish kill caused by a WWTP incident in Suwałki in 2018. The research focused on brown trout, the dominant fish species in this river. The incident lasted about six hours and accounted for 7% of the mean river's flow during the accident. The fish population recovered quickly, and ten months after the fish kill, the number of fish species and their abundance were similar to the pre-incident state, but the species structure was different. In subsequent years, fish species richness decreased conspicuously, while their numbers remained at a high, relatively constant level. Species that are more resistant to difficult environmental conditions, such as white bream and European perch, returned to the river first. Concurrently with the improvement of environmental conditions, more demanding species, including brown trout, began to dominate in the river. Fulton's condition factors decreased significantly as the river self-purified and the density of the brown trout population increased ($P < 0.05$). Our results indicated that the brown trout population was able to recover relatively quick, presumably because of stocking. Other species that were not stocked required more time to recover.

Keywords: brown trout, condition factor, dead fish, environment, population recovery, river self-purification.

Introduction

Fish kills occur in every aquatic environment (Hoyer et al. 2009). They can result from natural causes including low or zero dissolved oxygen levels (hypoxia or anoxia, respectively), harmful algal blooms, salinity, floods, and extreme, sudden temperature changes (Rhodes and Hubbs 1992, Chen et al. 2004, Kibria 2014, Hartman et al. 2021). Human activities, such as accidental oil spills and pesticide and herbicide runoff from farmlands, can also induce fish die-offs (Moyle et al. 1983, Kennedy et al. 2012). Human-induced fish kills are considered easy to detect because of point sources of pollution or obvious spills (Hoyer et al. 2009). Mass fish kills are primarily related to low dissolved oxygen concentrations and occur in eutrophic shallow lakes (Townsend and Edwards 2003, Kibria 2014, Sayer et al. 2016). The

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most common fish kills are caused by low oxygen levels related to high monthly rainfall and high water temperature in summer and occur in both lakes and rivers. Winter fish kills are caused by prolonged ice cover and oxygen depletion (i.e., Balayla et al. 2010). The consequences of fish kills, including dead fish and bacterial growth, can deteriorate water quality because they are an additional load of pollution in already polluted aquatic environments.

The major factors influencing water pollution are domestic sewage, industrialization, urbanization, pesticides and fertilizers, and plastic bags (Qadri and Faiq 2020). Human activity impacts the aquatic environment through the regulation of watercourses and interference with longitudinal and transverse sections of them such as dams, weirs, and fords. These modifications cause changes in catchment and outflow regimes and disturb the free flow of rivers. Most of these hydrological structures are not registered in databases, and they hinder or prevent the migration of fish species (Helesic et al. 2014, Branco et al. 2017, Belletti et al. 2020). Anglers exert a different kind of anthropogenic pressure on waters by using groundbaits, which, together with surface runoff from fields, contribute to the acceleration of water eutrophication (Brysiewicz and Czerniejewski 2018).

Effective wastewater treatment is most important for improving water quality by removing or reducing the content of polluting substances. Water can then be reused, and the environmental burden can be reduced. Wastewater treatment includes four main stages: mechanical, biological, tertiary treatment, and nitrification and denitrification processes (Rulik 2014). The discharge of wastewater treatment plant (WWTP) effluent into streams influences the environment and helps to restore or maintain flow, specifically in water-stressed regions. Although, it simultaneously decreases water quality by increasing electrical conductivity and changing temperature (Hamdhani et al. 2020). It is also impossible to remove all disadvantageous sewage compounds. Thus, substances such as excess nutrients, pesticides, detergents, pharmaceuticals, and personal care product ingredients are present at low concentrations in WWTP effluent (Babko et al. 2016, Nikel et al. 2021, Tetreault et al. 2021). In the event of failure, these facilities can pose great threats to aquatic environments, including negative effects on fish populations (Mallin et al. 2007, Tetreault et al. 2013). One example is the WWTP in Suwałki located on the Czarna Hańcza River (54°5′27.802″ N, 22°58′33.038″ E).

An accident at the WWTP in Suwałki happened on July 27, 2018. For six hours, approximately 2,000 m^3 of only mechanically treated wastewater was discharged into the Czarna Hańcza River. The estimated inclusion of sewage constituted about 7% of the mean river's flow during the accident (unpublished data). The large numbers of organic matter-decomposing bacteria in the water caused the rapid consumption of dissolved oxygen and mass fish mortality. Over the next few days, more than 100 kg of dead fish was removed from the river and utilized, which was about 20% of the total dead fish. The dead fishes included specimens of brown trout and lake trout (*Salmo trutta* L.), some with total lengths exceeding 60 cm (Osewski 2019). In this study, we analyzed the recovery of the fish population in the Czarna Hańcza River after a fish kill caused by the WWTP incident. We focused on brown trout, the dominant fish in the area analyzed.

Material and Methods

Study area

The Czarna Hańcza River is a left inflow of the Niemen River located in Poland and Belarus. It starts in the East Suwałki Lake District, where the main stream flows from Lake Hańcza, the deepest lake in Poland (3.1 km^2 and 108.5 m deep). The catchment area is 1,981.61 km^2 including 358.17 km^2 abroad. The Marycha River is the main inflow of the Czarna Hańcza River. The Czarna Hańcza River sections include a gravel-bed stream, a river connecting the lakes, and lowland gravel-bed river types (Kondracki 2002, Czarnecka 2005, Polesiński 2020).

The average flow rate of the Czarna Hańcza River in 2018 was 1.32 ± 0.40 m^3 s^{-1} at the Sobolewo

Figure 1. Location of the wastewater treatment plant in Suwałki and the studied sites (1, 2, and 3) in the Czarna Hańcza River.

control point (Krzysztofiak et al. 2019). The river is managed by two users: the Polish Angling Association in Suwałki and Wigry National Park, and both manage their sections of the river by, among other measures, stocking fishes. Numerous forms of nature protection, including the Suwałki Landscape Park, the Głazowisko Bachanowo Reserve, Wigry National Park, and Augustów Forest, surround the Czarna Hańcza River. Thanks to its clean, cool, well-oxygenated water, the Czarna Hańcza is a trout river (Sedlar 1990). Białokoz and Chybowski (1997) reported that brown trout (*Salmo trutta* m. *fario* L.) was the dominant fish species in the section of the Czarna Hańcza River belonging to Wigry National Park upstream from Lake Wigry.

The first WWTP in Suwałki began operation in 1964. Initially, only mechanical sewage treatment was conducted. Mechanical-biological treatment was introduced in 1985 after modernization. The management of dried sewage sludge was improved when a dryer was constructed in 2016. Approximately 3.5 million m^3 of sewage is treated annually in this WWTP (PWiK 2016).

The research sites for this study were located in Wigry National Park 5 km from the WWTP on the section of the Czarna Hańcza River from the road bridge in Sobolewo to the mouth of Lake Wigry. Monitoring was conducted in 2019 at three sites (site 1 – N 54°3′36″, E 23°0′24.476″, site 2 – N 54°3′4.396″, E 23°2′17.332″, and site 3 – N 54°2′49.114″, E 23°3′24.555″) and at one site (site 1) in 2018, 2020, 2021, and 2022 (Fig. 1). The research sites were located downstream from the WWTP in Suwałki. Site 1 was a 250-meter section of river where the width of the riverbed was about 3–5 m, the mean depth was 0.7 m, and the maximal depth was 1.7 m. The riverbed was regular, with a few small meanders. Meadows, pastures, and wasteland surrounded site 1. The river bottom was gravel-sandy with a small rocky section. Moderately abundant aquatic vegetation was found mainly along the banks. The river provided plenty of hiding places for fish amid tree roots and stones, with shading below 10%. Sites 2 and 3 were on 300-meter sections of the river where the mean width of the riverbed was approximately 4 m, the mean depth was 1.2 m, and the maximal depth was 2.5 m. The riverbed meandered moderately. The immediate surroundings were forested areas, wet meadows, and agricultural wastelands. The banks were eroded, and numerous plant and tree roots were hanging down. The bottom was clayey and muddy and was covered with a large amount of sediment in the stagnation zones. Aquatic vegetation was moderately abundant both in the current and in the bank zones. The river provided many hiding places for fish mainly among tree roots and foliage. The shading of the river was about 40%.

Data analysis

Prior to sample collection with electrofishing, the physical and chemical water parameters were analyzed at site 1 only. A YSI multiparameter probe (Yellow Spring Instruments, USA) was used to measure water temperature (°C), dissolved oxygen saturation (%) and concentration (mg L^{-1}), and electrical conductivity (μS cm^{-1}). Electrofishing equipment was used to examine the fish community in the river according to European standard protocol PN-EN 14011 (2006). Fishes were identified to the species, measured (to the nearest ± 0.1 cm), weighed (to the nearest ± 0.1 g), and then released back into the water. In 2018 (after the WWTP event), 630 individuals were identified to the species based on photographs of the dead fish collected. The photographs were obtained from Wigry National Park. Data collected from site 1 were used to analyze the Czarna Hańcza River fish community, from 2019 to 2022. The population structure, length-weight relationship, and Fulton's condition factor of the dominant species, brown trout, were examined. The Shannon-Weaver species-diversity index was calculated yearly for fish populations after 2018.

Fulton's condition factor (K) was calculated according to Williams (2000) and Mozsár et al. (2015):

$$K = \frac{W}{L^{-3}} \times 100$$

where K – Fulton's condition factor, W – weight (g), and L – total length (cm).

The Shannon-Weaver species-diversity index (H) was calculated according to Shannon and Weaver (1949):

$$H = -\sum \frac{n_i}{N} \log_2 \frac{n_i}{N}$$

where H – Shannon-Weaver species-diversity index, N – total number of fishes, n_i – number of species i.

Statistical analysis

The nonparametric Kruskal-Wallis test was used to analyze differences in brown trout total length, weight, and Fulton's condition factor among the years 2019, 2020, 2021, and 2022 ($p < 0.05$). The software used was STATISTICA 8.0 (StatSoft, Inc., St Tulsa, OK, USA).

Results

Water parameters

Oxygen saturation in the Czarna Hańcza River was high and ranged from 85.5% in 2022 to 122.7% in 2019 (Table 1). Electrical conductivity was relatively stable (approximately 660 μS cm^{-1} in the 2020–2022 period). Water temperature differed among the studied years because of the different sampling seasons.

Fish communities in the Czarna Hańcza River

The monitoring of three sites was compared with that conducted by Białokoz and Chybowski (1997) in 1993. The number of fish species in the Czarna

Table 1
Selected physical and chemical parameters in the Czarna Hańcza River at site 1 before fish sampling by electrofishing

Date	Water temperature (°C)	Oxygen saturation (%)	Oxygen concentration (mg L^{-1})	Conductivity (µS cm^{-1})
06.08.2018	17.3	95.5	9.23	n.d.
05.06.2019	16.6	122.7	11.84	n.d.
13.10.2020	12.5	115.4	10.9	666
05.10.2021	10.5	91.3	9.89	672
28.09.2022	11.3	85.5	9.35	642

n.d. – no data

Table 2
List of fish species found at the sites studied in the Czarna Hańcza River by electrofishing (S1– site 1, S2 – site 2, S3 – site 3) and the dead fish collected in 2018

		1993*			2018	2018	2019			2020	2021	2022
Scientific name	Common name	S1	S2	S3	Dead fish	S1	S1	S2	S3	S1	S1	S1
Abramis brama L.	Freshwater bream				X							
Alburnus alburnus L.	Bleak		X	X	X		X					
Anguilla anguilla L.	European eel	X	X	X								
Blicca bjoerkna L.	White bream			X	X	X	X	X				
Coregonus maraena L.	European whitefish				X							
Esox lucius L.	Northern pike				X			X				
Gasterosteus aculeatus L.	Three-spined stickleback	X	X				X					
Gobio gobio L.	Gudgeon		X				X	X				
Gymnocephalus cernua L.	Ruffe			X					X			
Leucaspius delineatus Heckel	Belica						X					
Squalius cephalus L.	Chub							X	X			
Leuciscus leuciscus L.	Common dace		X									
Lota lota L.	Burbot				X							
Misgurnus fossilis L.	Weatherfish	X										
Perca fluviatilis L.	European perch	X	X	X	X	X	X	X	X	X	X	
Phoxinus phoxinus L.	Eurasian minnow	X					X					
Rutilus rutilus L.	Roach	X		X	X		X	X	X			
Salmo trutta m. *fario* L.	Brown trout	X	X		X		X			X	X	X
Salmo trutta m. *lacustris* L.	Lake trout				X		X			X		
Scardinius erythrophthalmus L.	Rudd		X		X			X	X			
Thymallus thymallus L.	Grayling											X
Tinca tinca L.	Tench		X	X			X	X	X			
Number of species		7	9	7	11	2	11	8	6	3	2	2
Number of species in a year		14					15					

*data according to Białokoz and Chybowski (1997)

Hańcza River in 1993 and 2019 was similar (14 and 15 species, respectively; Table 2). A lower number of species (11) was noted in 2018 (dead fish). Six fish species were common in all three years, including brown trout (*S. trutta* m. *fario* L.), European perch (*Perca fluviatilis* L.), roach (*Rutilus rutilus* L.), white bream (*Blicca bjoerkna* L.), rudd (*Scardinius erythrophthalmus* L.), and bleak (*Alburnus alburnus* L.). European eel (*Anguilla anguilla* L.), weatherfish (*Misgurnus fossilis* L.), and common dace (*Leuciscus leuciscus* L.) were caught only in 1993. Freshwater bream (*Abramis brama* L.), burbot (*Lota lota* L.), and European whitefish (*Coregonus maraena* L.) were noted only in 2018 (dead fish). Belica (*Leucaspius delineatus* Heckel) and chub (*Squalius cephalus* L.) were only noted in 2019.

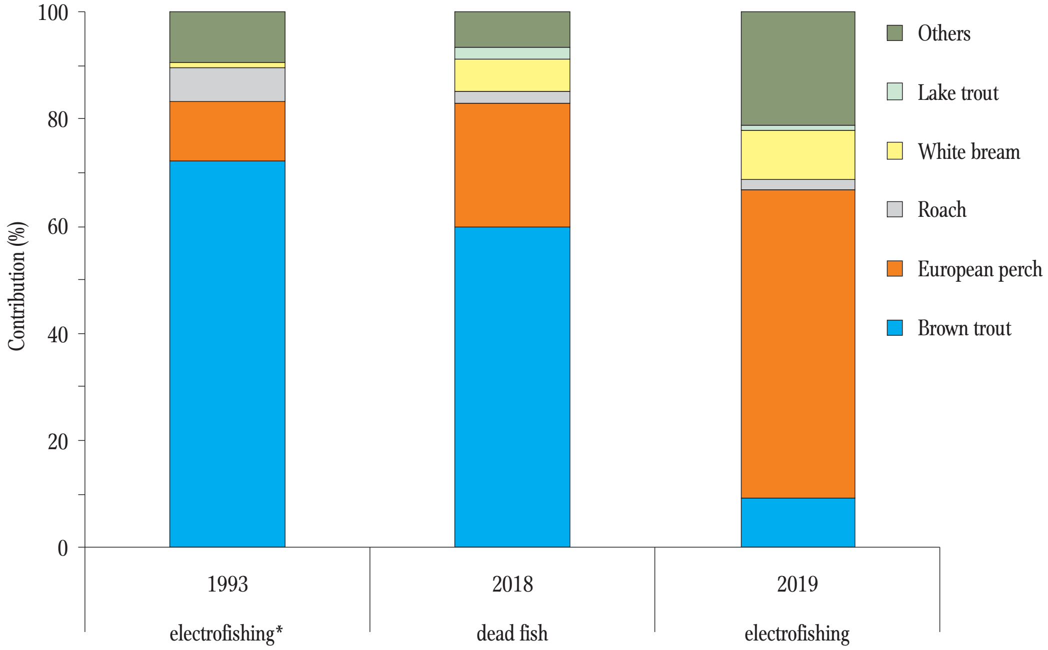

Figure 2. Contribution of fish species to the total numbers of the fish community in the Czarna Hańcza River from site 1 to Lake Wigry in 1993, n = 770, in 2018 (identified from photographs), n = 630, and in 2019, n = 725. *According to Białokoz and Chybowski (1997).

Similar fish population structures were observed in 1993 (electrofishing) and 2018 (dead fish) (Fig. 2). In 1993 (electrofishing) and 2018 (dead fish), the brown trout was the dominant species (72.3 and 59.7% respectively). However, in 2019, ten months after the fish kill, the species structure of the fish population was significantly different; brown trout constituted only 9.4% of abundance, and European perch was the most numerous species (57.4% of abundance).

Fish community changes at site 1

In 1993, the fish community at site 1 was represented by seven fish species (Fig. 3). It was dominated by brown trout, which constituted 86.4% of the fish caught. Ten days after the incident and the fish kill, only two species (white bream and European perch) were found at site 1. In 2019 (ten months after the fish kill), a considerable shift in the structure of the fish population was observed when 11 species were found. European perch was the dominant species (61.7%), while brown trout and white bream constituted 13.3% and 10.2%, respectively, and lake trout constituted a small part of the fish community (1.6%). In subsequent years, a considerable decrease in the richness of the fish community was observed. Brown trout was the dominant species, accounting for 92.2–98.9% of total numbers. The Shannon diversity index (H) varied between 0.06 and 1.37 (Fig. 4). The highest value was recorded in 2019, a year after the incident and the fish kill, while the lowest was noted in 2022.

After the WWTP incident, no live fish were observed in the river (Fig. 5). Observations performed ten days and ten months after the fish kill showed an increase in the number of fish species and individuals. In subsequent years (2019–2022), the number of fish species decreased and the number of individuals remained relatively high (approximately 500 individuals per 1 km).

Brown trout population structure

Brown trout body weight and total body length were analyzsed in 2019–2022 (Table 3), and the mean total body length was similar in all years studied. Body weight and Fulton's condition factor showed

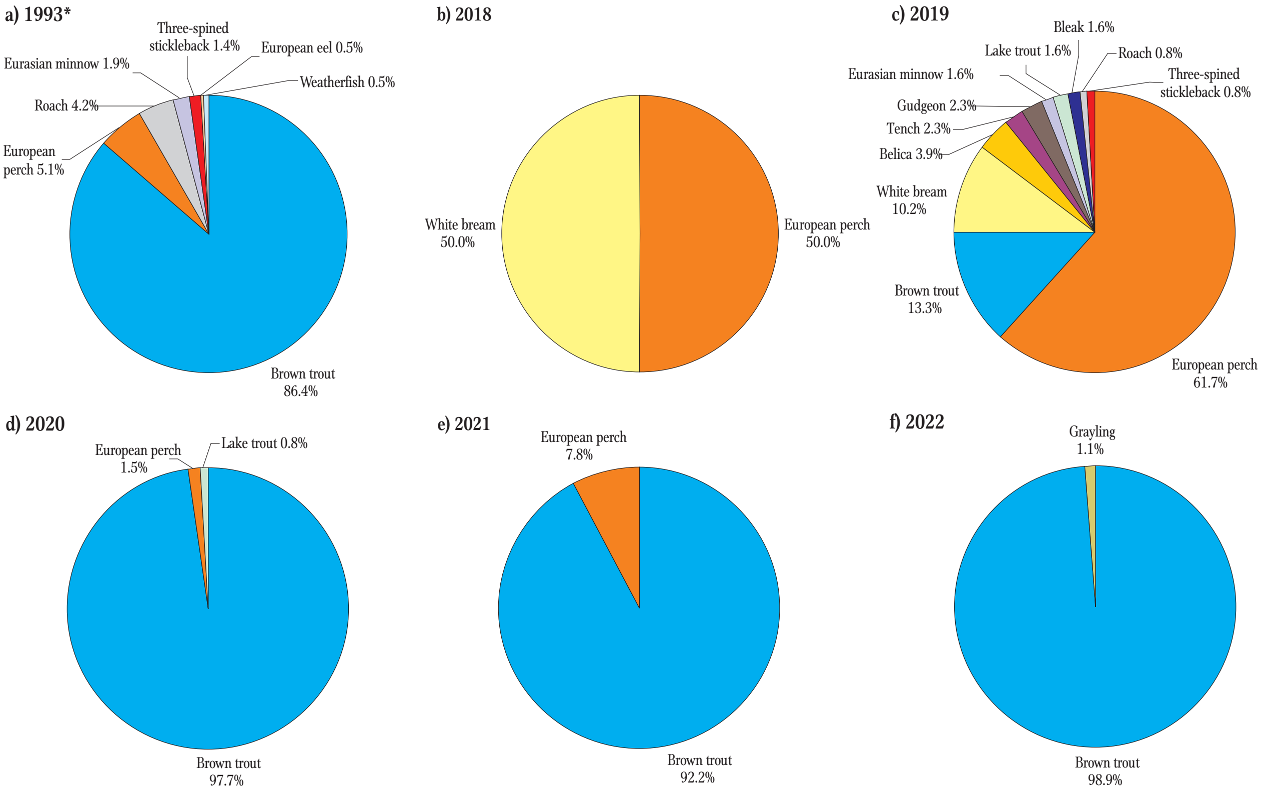

Figure 3. Contribution of fish species to the total fish community numbers at site 1 in the Czarna Hańcza River in 1993 and 2018–2022; n = 555, 32, 512, 532, 512, and 372, respectively. *According to Białokoz and Chybowski (1997).

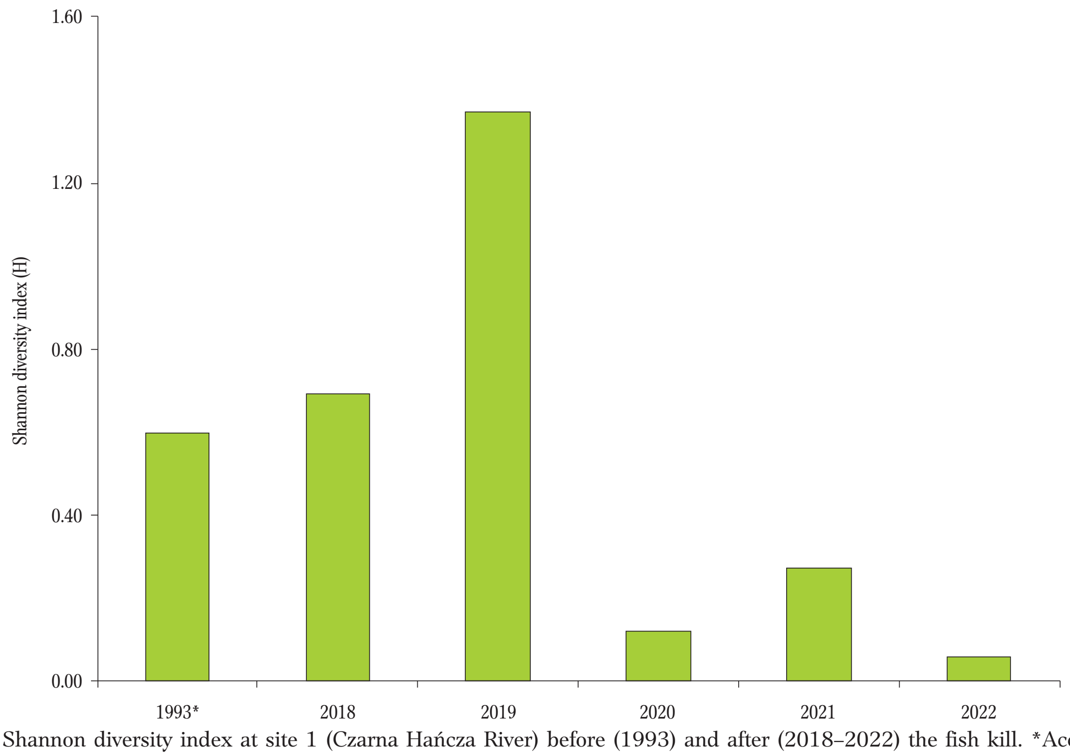

Figure 4. Shannon diversity index at site 1 (Czarna Hańcza River) before (1993) and after (2018–2022) the fish kill. *According to Białokoz and Chybowski (1997).

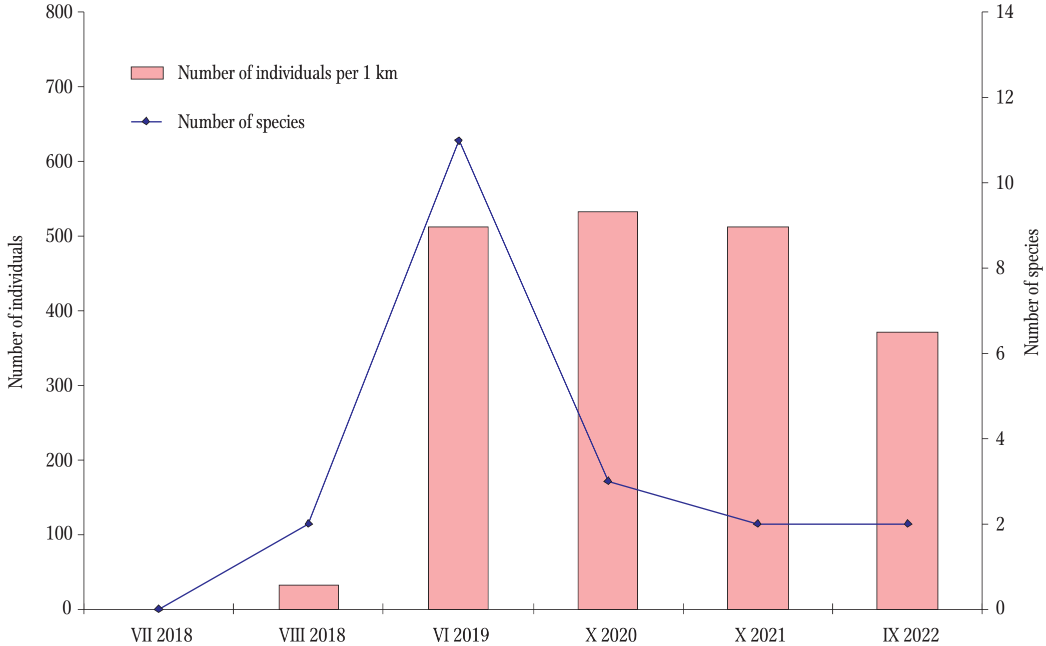

Figure 5. Fish density and diversity at site 1 (Czarna Hańcza River) after the fish kill (2018–2022).

Table 3

Characteristics of brown trout caught at site 1 in the Czarna Hańcza River in the years following the fish kill in 2018. Data are presented as means ± SD (standard deviations) with ranges in parentheses. The same letters indicate no significant differences (P > 0.05, Kruskal-Wallis test)

Date	05.06.2019	13.10.2020	05.10.2021	28.09.2022
Number of measured individuals	17	130	118	92
Body weight (g)	110.9 ± 147.0^{a} (1.4-384.1)	78.5 ± 73.5^{a} (6.4-252.8)	59.3 ± 65.5^{a} (5.5-399.2)	62.5 ± 59.8^{a} (2.8-267.3)
Total body length (cm)	16.1 ± 11.5^{a} (5.2-34.0)	17.6 ± 6.5^{a} (8.8-29.6)	16.2 ± 6.1^{a} (8.0-34.5)	16.6 ± 6.0^{a} (7.2-29.4)
Fulton's condition factor	1.05 ± 0.12^{a} (0.80-1.26)	1.01 ± 0.09^{a} (0.82-1.22)	0.94 ± 0.11^{b} (0.63-1.25)	0.96 ± 0.11^{b} (0.65-1.42)

decreasing trends. In 2019, the brown trout population was represented mainly by small specimens (total length ≤ 10 cm, weight ≤ 100 g) (Fig. 6a and 6b). In subsequent years, medium-sized individuals (total length 11–30 cm, weight 101–300 g) were most numerous, and a few specimens were large-sized (total length 31–40 cm, weight 301–400 g), but they were observed only in 2019 and 2021. Most individuals weighed ≤ 100 g (Fig. 6b) regardless of the year of the study. The few individuals weighing 100–200 g were mainly observed in 2020–2022, and fish weighing more than 200 g were rare. Significant positive relationships were found between the total length and weight in all the years studied (Fig. 7). There were no significant differences among the studied years in the length and weight of brown trout (P > 0.05); however, significant differences were noted in Fulton's condition factor (P < 0.0001) (Table 2).

Discussion

The physical and chemical parameters of water that were measured monthly did not reveal an abrupt

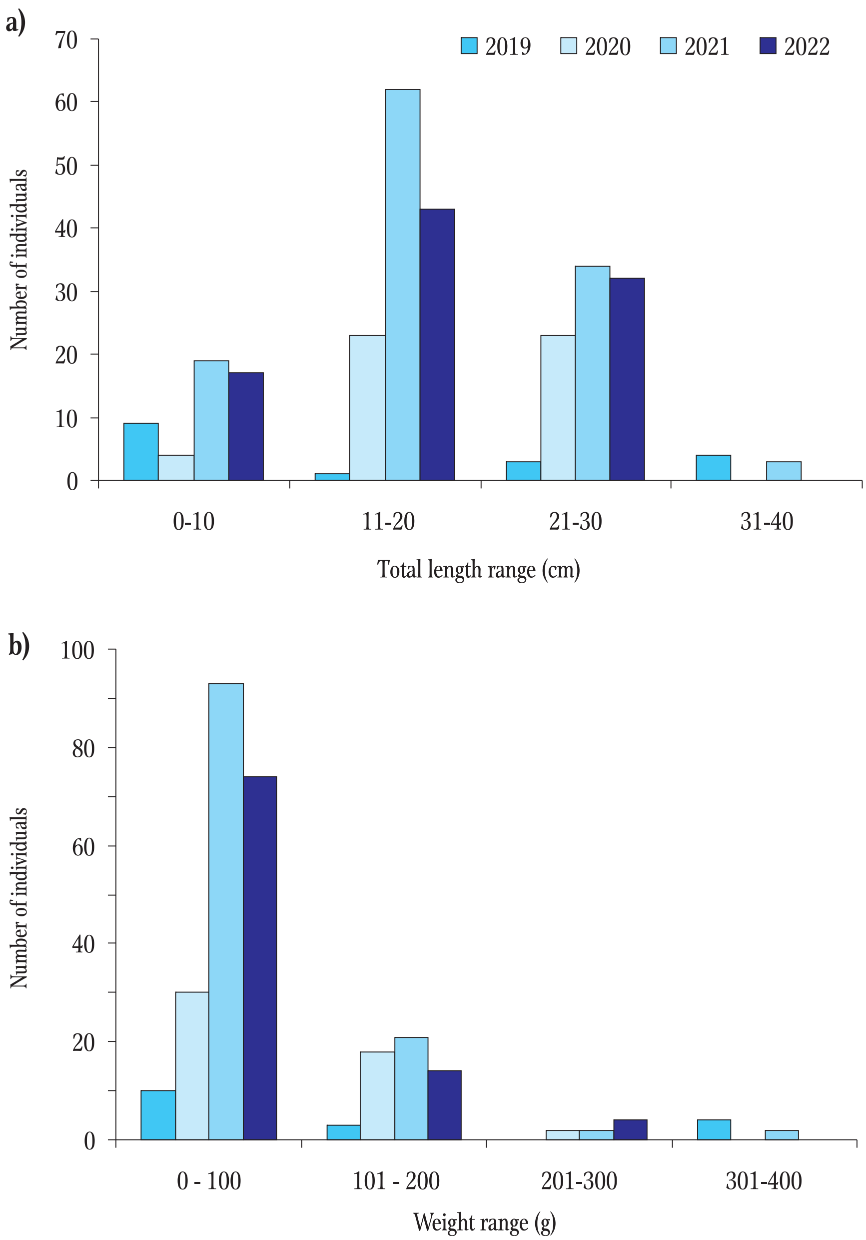

Figure 6. Distribution of total length (a) and body weight (b) of brown trout (*Salmo trutta* m. *fario* L.) in 2019–2022 at site 1 (Czarna Hańcza River).

deterioration of water quality after the incident. There were no significant differences between the data collected 24 days before and 25 days after the WWTP failure (Krzysztofiak et al. 2019). Our study performed ten days after the fish kill did not indicate a decrease in dissolved oxygen concentration. The water flow in Czarna Hańcza River (mean value 1.12 ± 0.20 m^3 s^{-1} during the 2015–2021 study period) was conducive of self-cleaning processes and the improvement of environmental conditions after the incident and the fish kill (Krzysztofiak et al. 2016, 2017, 2018, 2019, 2020, 2021, 2022). Prior to the WWTP failure, Pietryczuk et al. (2018) observed low concentrations of carbon, nitrogen, phosphorus, sulphate, and chloride ions in the Czarna Hańcza River. After the failure, these parameters remained at similar levels (Krzysztofiak et al. 2019). WWTP pollution involves an increase in trophic status (Rulik et al.

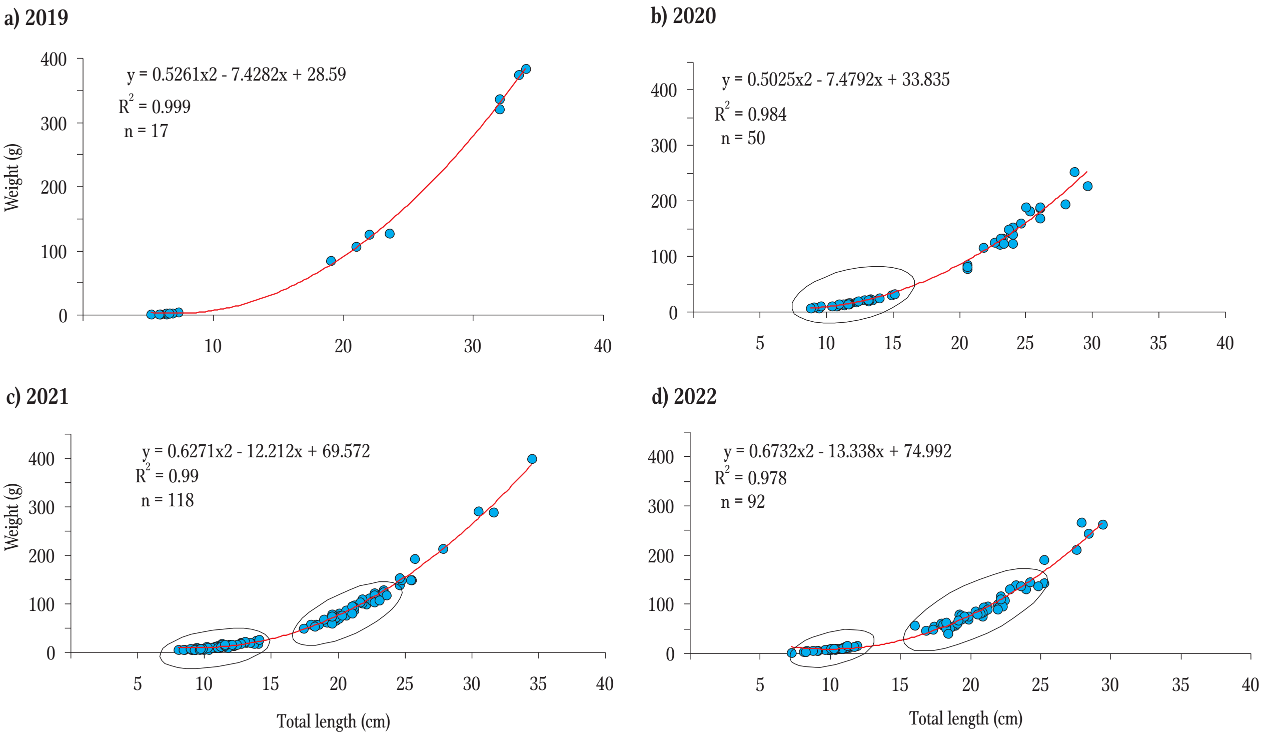

Figure 7. Weight–length relationships for brown trout (*Salmo trutta* m. *fario* L.) caught at site 1 (Czarna Hańcza River) after the fish kill in 2019–2022. Fish probably originating from stocking are marked with circles.

2014). Both organic and inorganic compounds originating from sewage can accumulate in river bottom sediments and affect their quality (Drury et al. 2013).

Assessments of aquatic habitat degradation and flow alternations are possible because of the high potential for fish dispersal in comparison to other biotic components (Baldan et al. 2022). Increased abundances of European perch and roach indicate environmental degradation (Kruk and Penczak 2003), and this corresponded with our observations of the fish community structure. European perch and white bream were the first species to return to the self-purifying waters when they appeared ten days after the WWTP incident. In the following year (2019), the number of species increased but then decreased in the subsequent year (2020). This could indicate that the Czarna Hańcza River section returned to its initial state from before the incident. Rivers are capable of self-purifying from organic pollution, including total nitrogen and total phosphorus, moreover, aquatic plants can absorb some of the contamination and improve purifying processes (Shimin et al. 2011). Self-purification occurs when allochthonous organic matter containing nutrients is decomposed and finally mineralized (Lampert and Sommer 2001, Rulik and Helesic 2014). This process was reflected in our study by Fulton's condition factor, the value which for brown trout was highest immediately after the catastrophe and decreased significantly with progressing processes of river self-purification and increases in trout population density. In contrast, Dambo and Rana (1993) demonstrated insignificant differences between Fulton's condition factor and the stocking density of *Oreochromis niloticus* L. fry. However, Fatima et al. (2018) found that Fulton's condition factors for *Catla catla* Hamilton and *Labeo rohita* Hamilton were significantly lower at high stocking densities. Differences in Fulton's condition factors result from food availability, differences in gonad development, and seasons (Hamid et al. 2015). Fulton's condition factors for European whitefish increased from summer to fall (Hayden et al. 2014), while for Prussian carp (*Carassius gibelio* Bloch) they were the highest in fall and the lowest in summer after the spawning season (De Giosa et al. 2014). In our study, Fulton's condition factors were the lowest in fall and the highest in summer.

The species structure and abundance of the dead fish photographed in 2018 was underestimated compared to the actual structure of the fish kill. Because of the lush aquatic vegetation, riverbank plants, and hard-to-reach places, most dead fish, including small-sized specimens, were not removed from the river (Osewski 2019). This corresponded with the natural mortality of fish in a small lake investigated by Schneider (1998), who showed that only 22% of dead fish were recovered. A portion of the dead fish could also have gone undetected and decomposed in deep water. According to research by Labay and Buzan (1999), the number of dead fish in the stream constituted 39% of all dead fish. Smaller individuals and less abundant species could have been underestimated to a greater degree than larger individuals and more abundant species. Other authors reported comparable results (Ryon et al. 2000, Muhametsafina et al. 2014, Havn et al. 2017) in studies performed in streams. Furthermore, according to Schneider (1998) and Labay and Buzan (1999), the majority of carcasses are likely removed by scavengers.

In our study, the fish population returned rapidly to the location of the incident. The first individuals were observed after ten days. Ten months after the incident, a considerable shift in the fish structure was observed concurrently with the return of high abundance. In the first year, the fish observed included species migrating downstream or upstream the Czarna Hańcza River. In subsequent years, the species composition of the fish changed markedly, while abundance remained at a high level, which corresponded with Rhodes and Hubbs (1992), who reported the recovery of a fish population two months after a bloom of harmful *Prymnesium parvum*. Similarly, Hartman et al. (2021) described nearly complete fish mortality after toxic *P. parvum* blooms, and then a month after the fish kill, only several fish individuals were observed in Dunkard Creek (USA). Natural improvements in the status of the fish community were observed over the next ten years, with some fish species recovering to pre-kill levels or even higher abundances. It was concluded that most of the species returned, but not all of them, including flathead catfish (*Pylodictus olivaris* Rafinesque) and green sunfish (*Lepomis cyanellus* Rafinesque) (Hartman et al. 2021). Similarly to Schnaser and Mundhal (2022), our observations indicated that the transient fish kill factor destroyed the population rapidly. The disappearance of lethal conditions allows for the recovery of the population, migration of adult fishes, and reproduction. Recovering pre-kill richness, abundance, and composition is possible as quickly as in six months (Zamor et al. 2014). Kennedy et al. (2012) reported that salmonid abundance returned within a year, while biomass recovery required two years and population structure three years to reach pre-kill levels. In addition, natural disturbances, including landslides and debris flows can affect fish communities (Chen et al. 2004). Under such conditions, fish fauna structure changes in abundance but less in species richness (Chen et al. 2004). Intentional fish poisoning shows similar outcomes, with rapid returns to pre-poisoning abundance (Moyle et al. 1983). In contrast, our pre- and post-incident results indicated fish fauna structure changes in species richness but fewer changes in abundance.

Three biological types of trout (*Salmo trutta* L.) inhabit Polish inland waters. Their habitats and morphological features vary. Lake trout are usually caught in lakes, and brown trout in rivers, and they are both valued for their organoleptic qualities and attractiveness to anglers. Predominantly, 200–800 g brown trout and 800–3000 g lake trout are fished (Brylińska 2000). Brown trout is a predatory fish of the Salmonidae family, adapted to freshwater habitats, and inhabits the northern and southern rivers in Poland. Brown trout populations are maintained by stocking, protective seasons and sizes, and catch limits (Grabarczyk 1981, Brylińska 2000). The gravel river bottoms are necessary for the spawning of these species. Therefore, the section of Czarna Hańcza

River above Lake Wigry is a potential spawning ground for these fishes (Brylińska 2000, Wziątek et al. 2008).

Our results showed that no sexually mature trout were caught during the four years of post-kill observations. In 2019, a small number of trout were found thanks to natural recolonization from the upper section of the river. In the next year, a considerable number of juvenile individuals of brown trout was noted. The juveniles could have come from stocking, and in 2021 and 2022, more of this type of fish was observed. This indicated that stocking was the most important factor in restoring the brown trout population. The stocking Wigry National Park and the Polish Angling Association in Suwałki performed in the Czarna Hańcza River and Lake Wigry in 2015–2022 was analyzed. Until the fish kill in 2018, stocking was carried out by both entities at a constant level of 4,000 to 6,000 brown trout fry per year on the section from the wastewater treatment plant in Suwałki to Lake Wigry. In 2019, the Polish Angling Association section was stocked with 45,500 brown trout fry. In subsequent years, from 4,000 to 5,000 fry were released into the Czarna Hańcza River. The section below site 1, which is managed by Wigry National Park, was stocked annually with 2,000 lake trout fry. Moreover, 2,000 individuals of lake trout smolt were released into Lake Wigry in 2015 and 2016, and by Wigry National Park in 2019 and 2020 (Osewski 2016–2022; R. Stabiński – personal communication).

Conclusions

The present study indicated that the fish population recovered quickly within ten months of the fish kill. In subsequent years, the species richness of the fish community was considerably reduced, but abundance remained high. Environmentally undemanding species returned to the river first. As the environmental conditions of the water improved, more demanding species such as brown trout began to dominate the river. No sexually mature trout were caught during the four years of post-kill observations. The valuable brown trout population recovered with the support of stocking, but the return of other species that were not supported by stocking to pre-kill levels needs more time. Since species succession occurs very quickly, monitoring changes in fish structure should be conducted more frequently than annually. In order to prevent similar malfunctions in the future, a text message notification system was implemented at the WIGRY Base Station that sends messages when water conductivity exceeds 800 μS cm^{-1}.

Acknowledgments. The study was conducted as part of statutory project no. S-016 at the National Inland Fisheries Research Institute in Olsztyn. We would like to thank Michał Osewski and Aleksandra Mackiewicz from Wigry National Park for their help in preparing this work.

Author contributions. D.U. idea of the study; D.U., A.W., P.T. field investigations; A.W., D.U. statistical analysis; A.W., D.U., K.K. data analysis and interpretation; A.W., D.U., K.K., P.T., K.K.K. writing and revising the manuscript; K.K.K. initial language correction; All authors contributed to writing the manuscript and approved the final version that was submitted.

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