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Response of Trichoptera and Oligochaeta Communities to Modifications of Mountain River Channels with Low-Head Barriers

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Abstract: The responses of benthic fauna to channel modifications of mountain rivers by low-head barriers are poorly understood. The study aimed (1) to estimate the impact of two different low-head barrier types: concrete sills and block ramps, on Oligochaeta and Trichoptera communities in two small Carpathian rivers (Porębianka and Mszanka) in southern Poland, and (2) to determine changes in these communities in the mountain Porębianka River after 50 years by comparing current data with historical data. Both types of channel modifications led to a transformation from lotic to more lentic habitats. The research shows that habitat conditions and induced bed siltation greatly influenced the studied communities. In both rivers, the taxa richness and dominant taxa of Oligochaeta and Trichoptera were similar, alongside similar species compositions of Trichoptera. However, the river with the lower bed siltation rate had a higher Trichoptera density and a greater diversity in their density among habitats. After 50 years, the taxonomic richness of Oligochaeta and Trichoptera remained similar, unlike the considerable shift in their species compositions. Many species typical of mountain rivers have been replaced by species more tolerant to siltation, characteristic of lowland rivers. The family Tubificidae (Oli-gochaeta) and the genus *Hydropsyche* (Trichoptera) became dominant in both rivers in the early 2020s. Additionally, the functional feeding group (FFG) of Trichoptera changed considerably. Oligochaeta and Trichoptera communities serve as valuable indicators for moni-toring the environmental changes in these ecosystems.

Keywords: mountain river; in-stream barriers; siltation; channelization; bottom macroinvertebrates

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Academic Editor: Marina Marcella Manca

Received: 27 December 2024
Revised: 28 January 2025
Accepted: 28 January 2025
Published: 1 February 2025

Citation: Szarek-Gwiazda, E.; Dumnicka, E.; Szczęsny, B.; Kownacki, A.; Ciszewski, D. Response of Trichoptera and Oligochaeta Communities to Modifications of Mountain River Channels with Low-Head Barriers. *Water* **2025**, *17*, 404. https://doi.org/10.3390/w17030404

1. Introduction

Most dams and barriers constructed around the world impact the river flow regime, some physicochemical parameters of water, as well as channel morphology and grain size characteristics, inducing modifications of aquatic ecosystems [1–3]. There are about 2.8 million dams all over the world (with an impoundment area >10^3 m^2), which regulate the flow of over 500,000 km of rivers for navigation, irrigation, and water-supply purposes [2]. Solely in Poland, there are over 3500 structures designed for the permanent impoundment of river water, including 327 dams, 2284 weirs used to maintain a constant river level for shipping, 130 shipping locks, and 383 hydroelectric power plants [4]. Most reaches of Carpathian streams and rivers have undergone channelization, resulting in the modification of their slopes, widths, depths, and loads of transported sediment [5,6], similar to many other mountain streams and rivers [7,8]. In the Carpathian part of the Vistula basin, more than 3000 transverse barriers with heights of over 0.5 m were recorded up to the beginning of the XXI century [9].

While the effects of large dams and weirs on hydrochemistry and biocenosis have been extensively studied [3,10–12], the recent research increasingly focuses on the impact of smaller barriers on river biocenosis, including macrophytes, algae, fish, and benthic macroinvertebrates [1,12–15]. Changes in substrate composition, flow velocity, and, to some extent, the physicochemical parameters of streams and rivers, can influence the structure and richness of benthic macroinvertebrates [1,15–18]. However, downstream of small impoundments, both increases and decreases in the abundance and richness of macroinvertebrates were observed, with richness being more sensitive than abundance [19]. Oligochaeta and Trichoptera can potentially be good indicators of such deterioration in mountain rivers, because they include species that show varying tolerance to siltation and pollution. Although many Oligochaeta species inhabit muddy bottoms and are tolerant to various types of pollution, others prefer clean running waters. Many Trichoptera taxa are sensitive to pollution and intolerant or moderately intolerant to siltation [20–22]. While the composition of Oligochaeta communities has been frequently studied in mountain streams and rivers [23–25], the effects of low-head barriers have been poorly studied so far.

The present study aimed (1) to assess the impact of two different river channel modification methods using a cascade of concrete sills and a cascade of block ramps on Oligochaeta and Trichoptera communities in two small Carpathian rivers (Mszanka and Porębianka) in southern Poland, and (2) to determine the changes in these communities after 50 years in the same section of the mountain river (Porębianka) by comparing current data with historical data from the 1970s and 1980s [26–28]. The Mszanka River was channelized with a cascade of concrete and 1 m high sills, whereas the Porębianka River was modified with dozens of block ramps forming 1 m high chutes.

2. Materials and Methods

2.1. Study Area

The study was carried out in the Porębianka and Mszanka rivers in southern Poland, Carpathian tributaries of the Raba River, which is a right-bank tributary of the Vistula River (Figure 1, Table 1). The upper slopes of the river catchments are mostly forested and representative of the relief of middle mountains comprising flysch, with elevations reaching 1300 m a.s.l. Presently, the lower parts of the catchments, 700–400 m a.s.l., are densely inhabited and utilised as meadows and cultivated land. The average annual precipitation is 1000 mm, peaking in the summer months [29].

In the 1970s, the channel of the studied Porębianka River section had a variable width (usually 5–8 m, maximum 15 m). In the middle section, the river was relatively shallow (0.2–0.3 m, maximum 0.6 m), while in reaches with eroded banks, the depth could reach up to 1 m. Similarly to most rivers in the West Carpathians, the riverbed was primarily composed of loosely lying cobbles, predominantly medium-sized, with a significant presence of larger stones (10–30 cm in diameter, usually 15–20 cm). The riverbanks varied in height from 0.3 to 1 m. River floodplain were covered with thicket of shrubs dominated by alders [27]. In the early 2000s, in the lower reach of the Porębianka River on a 3.3 km section, a cascade of 25 boulder ramps ~1 m in height was built. Ramps were designed as structures mimicking natural rapids. Each ramp is constituted of boulders ~1 m in diameter and end in a 5 m long and ~1 m deep stilling basin. The basins undergo intensive erosion during high water discharge and eroded material immediately accumulates downstream, forming central or side bars. The overall slope of the channel has been reduced from 1.25‰ to 0.55‰ [6].

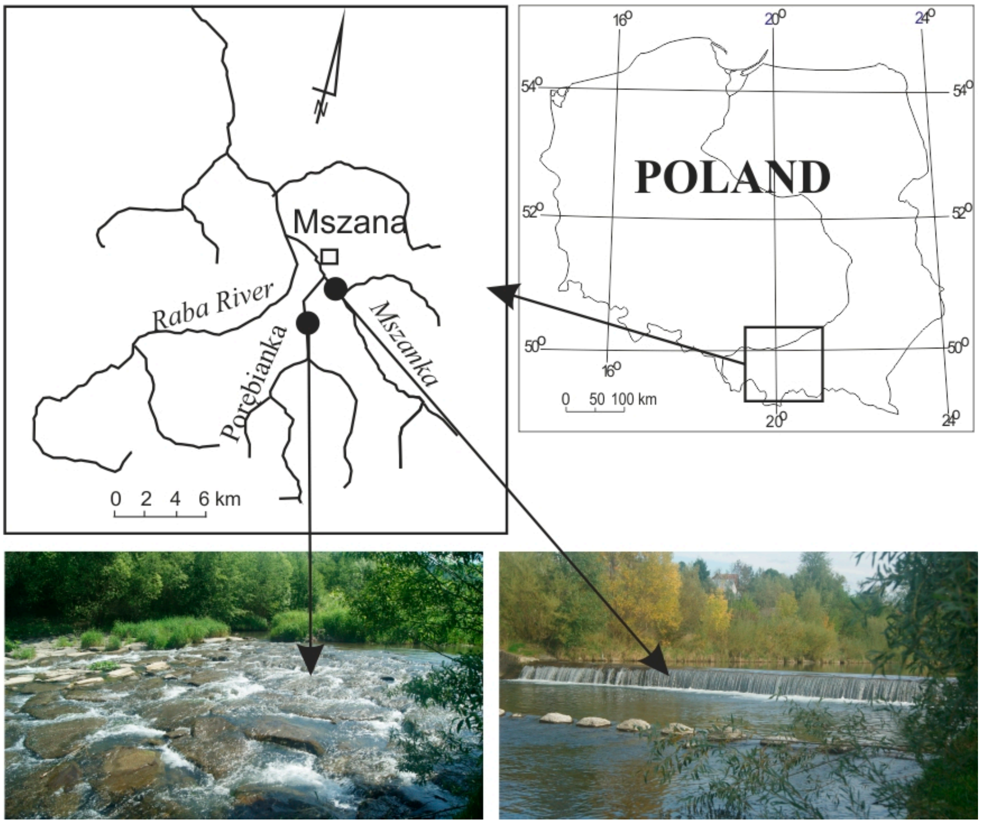

Figure 1. Locations of the study sites and in-stream barriers.

Table 1. The characteristics of the Porębianka and Mszanka rivers (according to [6,29]).

Parameter	Mszanka River	Porębianka River
River length (km)	19.5	15.4
Catchment area (km^2)	175	172
Length of the channelized stream section (km)	5.7	3.3
Average width of the channelized river (m)	30–34	28
Grade control structures	concrete sills	boulder ramps
Number of grade control structures	25	25
Average distance between structures (m)	230	130
Time of construction	since late 1980s	early 21st century

In the lower reaches of the Mszanka River, over a length of 6 km, a cascade of 25 1 m high concrete sills was built between 1977 and 2003, which reduced the channel gradient between the consecutive barriers. Each sill was accompanied by a concrete stilling basin, terminating with a ~0.3 m high sill, designed to slow down water velocity and reduce stream power [29]. Since construction, the channel bed load started to deposit behind the drop structures over 100–150 m long sections, raising the channel bed to the top of the consecutive sills [5].

Despite some differences in the construction of grade control structures, the large scale of channel modifications and their timing resulted in similar flow hydraulics and channel morphologies of both rivers [15]. Channelization with low-head barriers on the Mszanka and Porębianka rivers created channels of uniform widths, with minimised bank and bed erosion and stabilised substrate bottoms. A reduction in channel gradient by 2.5 times in the Mszanka and 7 times in the Porębianka limited riffles to a small area (<5% of the total bottom area). They were found only directly downstream of sills, similar to pools (<3%) (Table 2). The majority of the bottom area in both river channels consisted of runs with a moderate flow velocity and glides with very low flow velocities, favouring siltation of the bed (Table 2). In the Porębianka River, the siltation, expressed by silt–clay sediment content, was highest in glides, while in the Mszanka River it was highest both in glides and runs, covering 53.7% and 92.6% of the channel area, respectively, [15].

Table 2. Types and shares of habitats (according to [15]) and bottom characteristics of the Porębianka and Mszanka rivers in the early 2020s.

Habitat Types	Flow	Depth	Bottom Characteristics		Share of Habitat (%)	
			Mszanka	Porębianka	Mszanka	Porębianka
Glides	Slow current <0.15 m s^{-1}	Relatively shallow areas	Flat muddy cobbles, sand	Side branch, mud at the shore, strongly muddy stones in the central part	26.3	53.7
Runs	Moderate current 0.15–0.6 m s^{-1}	Moderate depth	Flat muddy cobbles, sand	Stones (cobbles) covered with algae or mosses	66.3	43.3
Pools	Slow current <0.15 m s^{-1}	Relatively deep areas >0.6 m	A concrete stilling basin with medium and fine gravels, sometimes stones, covered with thin mud layer	Scour hole with small and medium stones/grained gravels covered or not with mud layer	2.7	1.7
Riffles	Turbulent, rapid current >0.6 m s^{-1}	Relatively shallow areas	Cobbles, some covered with algae or mosses	Cobbles, some covered with algae or mosses	4.7	1.4

2.2. Methods

The studied river sections, sampling sites, and methods were described by [15]. The study was carried out in ca. 100 m long river sections limited by constructed barriers: (1) in the lower reach of the Mszanka River, barriers were constructed at the end of 1980s, and (2) in the Porębianka River, barriers were constructed at the beginning of the twenty-first century (Figure 1). Macroinvertebrate samples were collected from four habitat types of different flow velocities and water depths defined according to [30]: type 1—glides (shallow, with slowly flowing water); type 2—runs (with moderately fast flow); type 3—pools (deep water with slow flow); and type 4—riffles (shallow with fast flowing water) (Table 2).

Samples of Oligochaeta and Trichoptera (bottom macroinvertebrates) were collected with a bottom scraper (a frame of 22.5 × 22.5 cm, with a 0.3 mm net) in autumn (September 2021), spring (March 2022), and summer (August 2022). Each time, three subsamples were collected from each type of habitat (a total of 36 subsamples in each river). The obtained material was preserved in 4% formalin. The specimens were selected using a stereomicroscope (at 10× magnification). Oligochaeta were identified according to [31,32] keys, categorised according to the order-level classification of [33]; Trichoptera were identified according to [34]. The mean density of Oligochaeta and Trichoptera (ind m^{-2}) for each habitat type was calculated based on three subsamples collected during each of the three sampling occasions. Trichoptera inhabiting the Mszanka and Porębianka rivers were classified into five functional feeding groups (FFGs) following [34,35]: shredders, collectors, grazers and scrapers, filter-feeders, and predators.

Previous studies on these communities in the same section of the Porębianka River were carried out in the 1970s (Oligochaeta [26], Trichoptera [27]) and in the 1980s (Trichoptera [28]). Similarly to the current study, benthic samples were collected seasonally (spring, summer, and autumn) using a bottom scraper (22.5 × 22.5 cm frame). Trichoptera taxa were identified in all studies by Professor Bronisław Szczęsny, while Oligochaeta taxa were identified in a previous study by Dr. Krzysztof Kasprzak and in the current study by Professor Elżbieta Dumnicka, a leading specialist in these groups. The results have been used as a reference for the current study in the Porębianka River (aim 1).

2.3. Statistics

The mean density of Oligochaeta and Trichoptera in the studied river sections was calculated according to the formula of [36]:

$$Q_M = (Q_I \times \%I + Q_{II} \times \%\,_I I + Q_{III} \times \%_{III} + Q_{VI} \times \%_{IV})/100$$

where Q_I, Q_{II}, Q_{III}, and Q_{IV} were the mean density of Oligochaeta and Trichoptera in different habitats (types 1–4), while $\%_I$, $\%_{II}$, $\%_{III}$, and $\%_{IV}\ldots$ were the percentages of the different habitats in the studied river sections (Table 2). The results are given as an average of the three investigated seasons.

We used the Jaccard similarity index to assess the similarity of Oligochaeta and Trichoptera taxa in the two datasets: Porębianka and Mszanka, as well as within the Porębianka dataset itself, comparing samples from the 1970s and the 2020s. The Jaccard similarity index quantifies the degree of similarity between two datasets, ranging from 0 to 1. A value of 0 indicates no shared elements between the datasets, while a value of 1 signifies that the datasets are identical.

Differences in Oligochaeta and Trichoptera densities between the studied sections of the Mszanka and Porębianka rivers were calculated using the non-parametric Mann–Whitney test. We compared Oligochaeta and Trichoptera densities for the entire dataset, as well as only for glides and runs constituting >92% in the Mszanka River and >96% in the Porębianka River.

The similarities in the structure of Oligochaeta and Trichoptera communities in the studied habitats in both rivers were distinguished according to hierarchical cluster analysis. The Euclidean distance and within-groups linkage were used as grouping methods. We used STATISTICA 13.1 software for the statistical analyses (Statsoft Inc., Tulsa, OK, USA).

3. Results and Discussion

3.1. Oligochaeta in the Porębianka and Mszanka Rivers

The taxonomic richness of Oligochaeta was similar in the Mszanka and Porębianka rivers (25 and 24 taxa, respectively). The family Naididae was represented by 10 and 13 species, respectively, whereas the family Tubificidae included 6 taxa and numerous juvenile individuals in each river (Tables 3 and S1). The other families were less numerous. A greater diversity of common, primarily semi-aquatic Enchytraeidae taxa was found in the Mszanka River (5 taxa) compared to the Porębianka River (1 taxon). In both rivers, the Lumbriculidae and Lumbricidae families were represented by single species. In both rivers, the dominant families were Tubificidae and Naididae, which accounted for 94.5–100% of the total in the studied habitats (Figure 2). Tubificidae, which are typically associated with muddy substrates [20,22], were present in all habitats, although particular species were usually restricted to site-specific distribution. They were particularly abundant in the most silted habitats; in the glides and pools of the Porębianka River and in the glides and runs of the Mszanka River (up to 81.7%) (Figure 2, Table S1) [15]. Inversely, Naididae were more common on stony or gravelly bottoms in both rivers (up to 90.7% in the riffles of the Mszanka River) (Figure 2, Table S1). Within this family, *Nais elinguis*, a species known for being resistant to extreme environmental conditions [31], dominated (Table 4). This species prevailed in the runs and riffles of the Porębianka River and in most habitats of the Mszanka River. Despite having the same dominant species, both rivers shared only 14 species, resulting in a Jaccard index of 0.56, indicating a moderate similarity in species composition.

The dendrogram of similarities revealed three distinct groups of habitats based on the share of Oligochaeta families (Figure 3). Group I consisted of the runs and glides in the Mszanka River with muddy stones on the bottom. Group II included the runs and riffles of the Porębianka River, as well as the riffles of the Mszanka River, where stones were covered by algae and mosses, alongside pools of the Porębianka River, including small to medium stones or gravels with or without a mud layer. Group III comprised pools and glides of the Porębianka River, characterised by a higher content of mud and silted stones at the bottom. In Group I, the share of Tubificidae and Naididae families were similar; Group II was dominated by Naididae, while Tubificidae predominated in the Group III. The above results indicate the joint influence of habitats and silting on the distribution of Oligochaeta families.

The density of Oligochaeta in the Porębianka and Mszanka rivers showed no statistically significant differences. The mean density in both rivers (1166 and 1076 ind m^{-2}, respectively) exceeded that typically found in natural streams with non-silted bottoms [37]. In the Porębianka River, the density of oligochaetes ranged from 90 to 1945 ind m^{-2}, and in the silted habitats, it was considerably higher (>10 times) than on stony bottoms covered with algae and moss (Figure 2). In contrast, the density of Oligochaeta in the Mszanka River showed less variation among habitats (538–1312 ind m^{-2}), likely due to substantial bottom siltation. This finding confirmed that Oligochaeta density tends to increase with higher siltation levels on river bottoms [38,39].

Table 3. Oligochaeta taxa composition in the Porębianka and Mszanka rivers in the early 2020s and in the Porębianka River in the 1970s (according to [26]).

Taxa/Species	Mszanka River	Porębianka River	
	Years		
	2020s	2020s	1970s
Pristina bilobata (Bretscher, 1903)			X
Pristina menoni (Aiyer, 1929)			X
Propappus volki (Michaelsen, 1916)			X
Cernosvitoviella atrata (Bretscher, 1903)			X
Enchytraeidae n. det.			X
Haplotaxis gordioides (Hartmann, 1819)			X
Stylodrilus heringianus Claparède, 1862			X
Lumbriculidae n. det			X
Stylodrilus sp. juv.	X	X	
Stylodrilus parvus (Hrabě and Černosvitov, 1927)	X	X	
Nais barbata O.F. Müller, 1774		X	X
Nais communis Piguet, 1906		X	X
Eiseniella tetraedra (Savigny, 1826)		X	X
Tubificinae gen. spp. juv.	X	X	X
Limnodrilus hoffmeisteri Claparède, 1862	X	X	X
Nais elinguis O.F. Müller, 1774	X	X	X
Nais bretscheri Michaelsen, 1899	X	X	X
Nais pardalis Piguet, 1906	X	X	X
Nais pseudobtusa Piguet, 1906	X	X	X
Nais alpina Sperber, 1948	X	X	X
Limnodrilus claparedeanus Ratzel, 1869	X		X
Lumbricidae n.det.	X		X
Henlea ventriculosa (d'Udekem, 1854)	X		X
Marionina riparia Bretscher, 1899	X		X
Aulodrilus japonicus Yamaguchi, 1953	X	X	
Nais variabilis Piguet, 1906	X	X	
Pristina jenkinae Stephenson, 1932	X	X	
Pristina aequiseta Bourne, 1891	X	X	
Chaetogaster diastrophus (Gruith, 1828)	X	X	
Limnodrilus profundicola (Verrill, 1871)		X	
Aulodrilus pluriseta (Piguet, 1906)		X	
Potamothrix bedoti (Piguet, 1913)		X	
Psammoryctides sp. juv.		X	
Ophidonais serpentina (O.F. Müller, 1774)		X	
Vejdovskyella intermedia (Bretscher, 1896)		X	
Cognettia sp.		X	
Tubifex tubifex (O.F. Müller, 1774)	X		
Tubifex blanchardi Vejdovsky, 1891	X		
Spirosperma ferox (Eisen, 1879)	X		
Nais christinae Kasprzak, 1973	X		
Enchytraeus buchholzi Vejdovsky, 1879	X		
Enchytraeus sp.	X		
Fridericia sp.	X		
Total	25	24	22

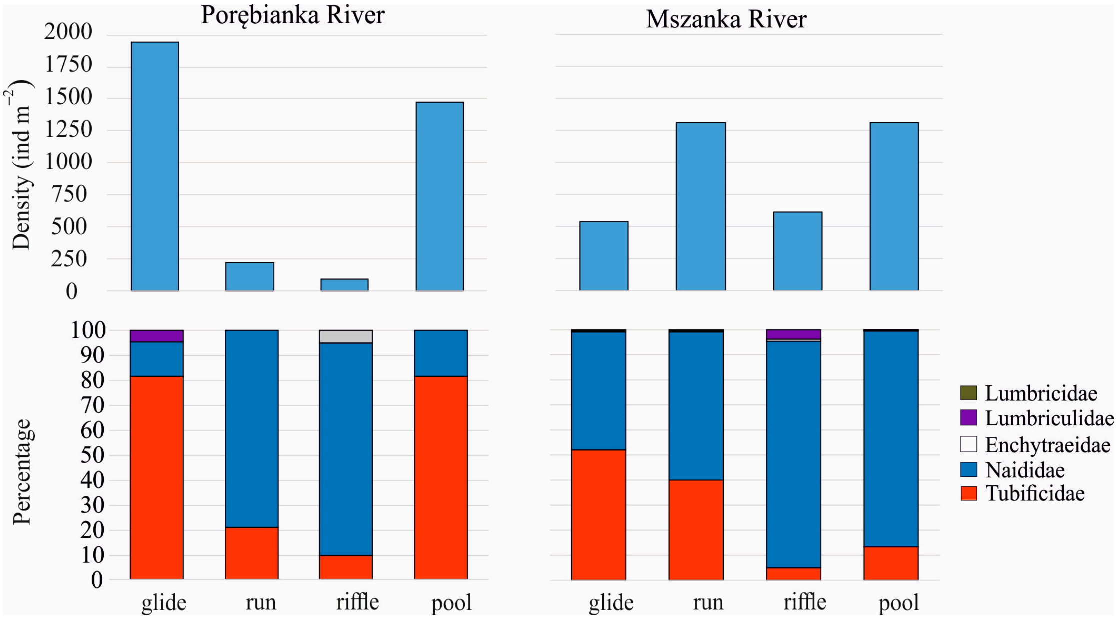

Figure 2. The density and dominant families of Oligochaeta in the studied habitats of the Porębianka and Mszanka rivers in the early 2020s.

Table 4. The percentage of more numerous (>2%) oligochaete taxa in the habitats of the Porębianka and Mszanka rivers in the early 2020s and in the Porębianka River in the 1970s (according to [26]).

Taxa	**Mszanka River**				**Porębianka River**					
	Years									
	2020s				**2020s**				**1970s**	
	Glides	**Runs**	**Riffles**	**Pools**	**Glides**	**Runs**	**Riffles**	**Pools**	**Riffles ***	**Pools ****
Tubificinae gen. spp. juv.	47.3	35.8	3.6	11.7	77.7	16.0	9.8	76.6		x
Limnodrilus hoffmeisteri	x	2.0	1.4	x	3.7	5.0		2.5		
Nais elinguis	33.5	52.0	73.2	77.2	10.6	43.0	34.1	11.8	1.3	x
Nais bretscheri	2.0	x	1.4	x	x	10.0	22.0	2.7	57.8	59.4
Nais barbata					x	4.0		x	x	
Nais communis					x	7.0			x	x
Nais pardalis	4.1	1.7	4.3	2.5	x	3.0		1.6	15.7	15.7
Nais pseudobtusa	x	x	9.3	1.0		6.0	9.8	0.3		x
Nais christinae	1.2	3.0								
Nais alpina	x	x	1.4	x				0.4	20.2	14.9
Nais variabilis	2.9	x	x	4.0	1.0	6.0	14.6	0.9		
Pristina jenkinae	1.6	x	x	x			2.4			
Ophidonais serpentina							2.4			
Stylodrilus sp. juv.			3.6	x	3.4					
Eiseniella tetraedra							4.9			
Propappus volki									1.5	2.1

Notes: * riffles—fast current, ** pools—with or without slow current, x—species present in very low number

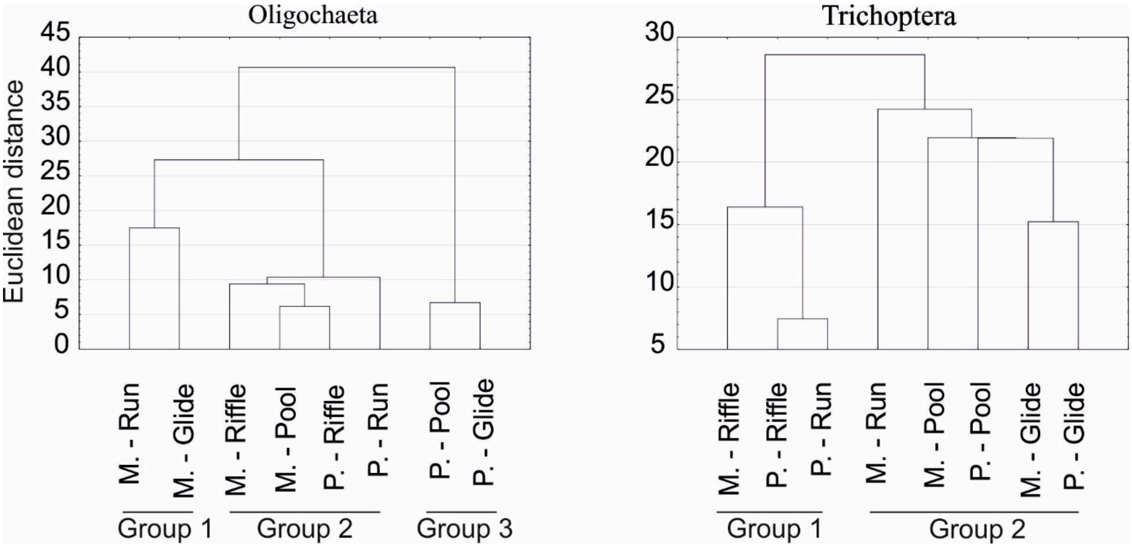

Figure 3. Hierarchical cluster analysis based on the percentage share of Oligochaeta and Trichoptera families in the Porębianka and Mszanka rivers.

3.2. Trichoptera of the Porębianka and Mszanka Rivers

The taxa richness of Trichoptera was comparable in both rivers, with 15 species in Mszanka and 18 species in Porębianka. Notably, 13 species were common in both streams, resulting in a Jaccard similarity index of 0.79, indicating a high similarity in species composition. The Trichoptera community comprised 12 genera from 9 families, as well as several early-stage *Mystacides* sp. larvae (Table 5). The families Limnephilidae and Hydropsychidae exhibited the highest taxa richness. In both rivers, Hydropsychidae dominated, especially the genus *Hydropsyche* (Figure 4, Table 6), which is known for its tolerance to fine sediment [20,22]. Additionally, the families Rhyacophilidae, Psychomyidae, Hydroptilidae, and Polycentropodidae in both rivers, Goeridae in the Porębianka River, and Limnephilidae and Leptoceridae in the Mszanka River, contributed a share of 5–11% (Table S2 and Figure 4).

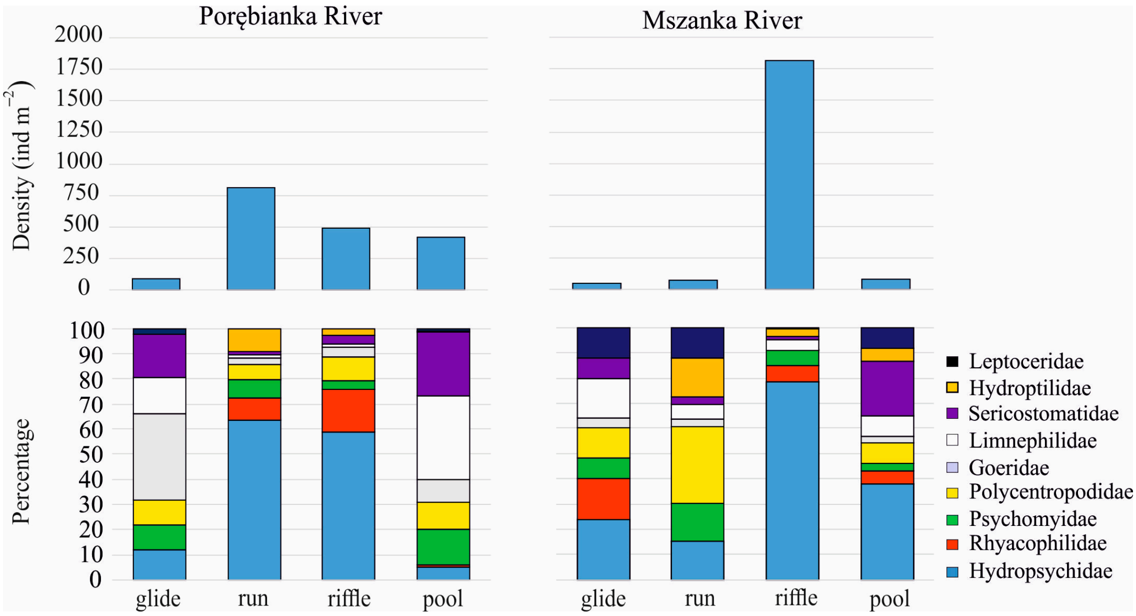

Figure 4. The density and dominant families of Trichoptera in the studied habitats of the Porębianka and Mszanka rivers in the early 2020s.

Table 5. Trichoptera taxa composition in the Porębianka and Mszanka rivers in the early 2020s and in the Porębianka River in the 1970s and 1980s (according to [27,28]).

Taxa	Mszanka	Porębianka		
	Years			
	2020s	**2020s**	**1980s**	**1970s**
Rhyacophila obliterata McLachlan, 1863				X
Ecclisopteryx dalecarlica Kolenati, 1848				X
Rhyacophila mocsaryi Klapalek, 1898				X
Rhyacophila tristis Pictet, 1834				X
Odontocerum albicorne (Scopoli, 1763)				X
Polycentropus schmidi Novak and Botosaneanu, 1965				X
Rhyacophila philopotamoides McLachlan, 1879				X
Notidobia ciliaris (Linnaeus, 1761)				X
Philopotamus variegatus (Scopoli, 1763)				X
Annitella obscurata (McLachlan, 1876)			X	X
Micrasema minimum McLachlan, 1876				X
Hydropsyche instabilis (Curtis, 1834)			X	X
Glossosoma conforme Neboiss, 1963			X	
Hydropsyche saxonica McLachlan, 1884		X		
Chaetopteryx fusca Brauer, 1857		X	X	X
Allogamus brauerii (Kolenati, 1859)		X		X
Potamophylax depilis Szczęsny, 1994	X	X	X	
Potamophylax latipennis (Curtis, 1834)		X		
Rhyacophila nubila Zetterstedt, 1840	X	X	X	X
Psychomyia pusilla (Fabricius, 1781)	X	X	X	X
Hydroptila forcipata (Eaton, 1873)	X	X		X
Polycentropus flavomaculatus (Pictet, 1834)	X	X	X	X
Hydropsyche pellucidula (Curtis, 1834)	X	X	X	X
Hydropsyche incognita Pitsch, 1993	X	X	X	X
Hydropsyche bulbifera McLachlan, 1878	X	X	X	X
Agapetus delicatulus McLachlan, 1884			X	
Athripsodes bilineatus (Linnaeus, 1758)	X	X	X	
Halesus digitatus (von Paula Schrank, 1781)	X	X	X	
Brachycentrus maculatus (Fourcroy, 1785)			X	
Lepidostoma hirtum (Fabricius, 1775)			X	
Sericostoma schneideri (Kolenati, 1848)	X	X	X	
Goera pilosa (Fabricius, 1775)	X	X		
Hydroptila vectis Curtis, 1834		X		
Halesus tesselatus (Rambur, 1842)	X	X		
Philopotamus montanus (Donovan, 1813)	X			
Mystacides spp. juv.	X			
Hydropsyche spp. juv.	X	X	X	
Stenophylacini+Chaetopterygini juv.n.det.	X	X		
Number of species:	15	18	17	20

For the Trichoptera community, the dendrogram of similarity identified two main habitat groups (Figure 3): Group I included riffles and runs of the Porębianka River and riffles of the Mszanka River, characterised by stony bottoms covered with algae and moss, whereas Group II included other sites with varying degrees of siltation. Group I was primarily dominated by Hydropsychidae, with a higher representation of Rhyacophilidae, while the second group exhibited a more diverse family composition. Hydropsychidae and Rhyacophilidae accounted for 72.3–84.6% of the total Trichoptera community in habitats with stony bottoms covered with algae and mosses.

Table 6. The most numerous Trichoptera taxa in the habitats of the Porębianka and Mszanka rivers in the early 2020s and in the Porębianka River in the 1970s and 1980s (according to [27]).

Taxa	Mszanka River				Porębianka River					
	Years									
	2020s				2020s				1980s	1970s
	Glides	Runs	Riffles	Pools	Glides	Runs	Riffles	Pools		
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(ind m^{-2})
Hydropsyche spp. juv.		6.1	57.1	18.9	4.9	21.7	44.2		13	
Hydropsyche pellucidula	8.0	6.1	13.9	18.9	2.4	29.9	9.8	3.6	12.4	>100
Hydropsyche instabilis									25.1	>100
Hydropsyche incognita	16.0	3.0	6.5		4.9	10.6	4.9	1.6		≤10
Hydropsyche bulbifera			1.0			0.8			1	11–100
Rhyacophila nubila	16.0		6.2	5.4		9.0	17.0	1.0	31.6	>100
Hydroptila forcipata		15.2	2.9	5.4		6.0	2.7	0.5		11–100
Hydroptila vectis						3.3				
Polycentropus flavomaculatus	12.0	30.3	0.1	8.1	9.8	5.7	9.4	10.4	7.8	11–100
Psychomyia pusilla	8.0	15.2	6.2	2.7	9.8	7.6	3.6	14.1	0.7	11–100
Goera pilosa	4.0	3.0		2.7	34.1	2.4	3.6	9.4		
Halesus digitatus	12.0		0.6			0.5			0.7	
Halesus tesselatus	4.0	6.1		5.4				0.5		
Potamophylax depilis			3.4			0.3			0.5	
Annitella obscurata									1.3	x
Allogamus brauerii								6.8		x
Chaetopteryx fusca						0.5	0.4	9.9	1	x
Stenoph. + Chaetopt. juv *				2.7	14.6	0.3	0.9	15.6		
Sericostoma schneideri	8.0	3.0	1.5	21.6	17.1	1.1	3.6	25.0	3.2	
Athripsodes bilineatus	12.0	9.1	0.6	5.4	2.4			1.0	0.7	

Notes: * Stenoph. + Chaetopt. juv—Stenophylacini + Chaetopterygini juv.

The density of Trichoptera in glides and runs was significantly higher (Mann–Whitney test; $Z = -2.00$, $p < 0.045$) in the Porębianka River compared to the Mszanka River (Figure 4, Table S2). The above densities were lower than those recorded in a Carpathian mountain stream with a rocky substrate in the western Bieszczady Mountains [40]. In the Mszanka River, Trichoptera densities were relatively low and uniform across silted habitats (glides, runs, and pools; 55–81 ind m^{-2}) with a marked increase in riffles (1815 ind m^{-2}) (Table S1, Figure 2) due to the predominance of algae-covered stones in the riverbed, which provide suitable living conditions for many caddisfly species [28]. In the Porębianka River, the density of Trichoptera (90–492 ind m^{-2}) varied considerably among different habitats. Inversely to the Mszanka River, it was the highest in the runs (43.3% of the river area) and also high in the riffles with algae-covered stones in the riverbed. Both rivers exhibited the lowest Trichoptera densities in glides, indicating a decline in density in areas with substantial bottom siltation. River sediments play a vital role in fluvial and ecosystem processes [41]. Streambed colmation, defined as the accumulation and prolonged retention of fine sediments at the stream bottom [39], is known as an important factor that adversely affects the abundance and community composition of benthic macroinvertebrates [22,39,42]. The obtained results are consistent with previous studies demonstrating that the increased deposition of fine sediments leads to a decline in the density of Ephemeroptera, Plecoptera, and Trichoptera (EPT) in rivers with coarse substrates [21]. Macroinvertebrates that favour coarse substrates were also found to be highly sensitive to rising fine sediment contents in alpine streams [43].

To sum up, the results showed similar taxa richness and dominant taxa of Oligochaeta and Trichoptera in both studied Carpathian rivers, alongside similar species compositions of Trichoptera (expressed by the Jaccard similarity index). Among oligochaetes, the family Tubificidae, characteristic of muddy bottoms, dominated, and among Trichoptera, the genus *Hydropsyche*, tolerant of fine sediment, was the most numerous. This suggest that the

Oligochaeta and Trichoptera communities in both rivers were strongly influenced by the consequences of channel modifications, particularly siltation of the bottom, which seems here to be the primary environmental factor. The higher degree of runs and riffles siltation (by 40% and 50%, respectively) of the Mszanka River [15] was likely a major reason for the lower density of Trichopera and reduced variability in density among habitats. It is worth noting that the relative percentage of runs was higher in the Mszanka River compared to the Porębianka River (66.3% and 26.3%, respectively). However, the Porębianka riverbed in the runs consisted of flat stones covered with moss and lichens, which was more favourable for Trichoptera development, while the stones in the Mszanka riverbed were silted up. Increased sediment supply to the studied rivers from agricultural runoff is unlikely after channel modification works, given the recent trend in the Polish Carpathians towards the abandonment of arable fields, leading to their transformation into meadows or progressive afforestation. Also, the water quality currently has a minor impact on the macroinvertebrate communities in both rivers. The waters were well oxygenated, had a slightly alkaline pH and low nutrient contents (NO_3^-, NH_4^+, PO_4^{3-}). Only conductivity and concentrations of $Cl-$ and $Na+$ were higher in the Mszanka River than in the Porębianka River, which resulted from the natural geochemical background [15]. However, other catchment factors such as the periodic removal of riparian coppices could have also shaped the Trichoptera and Oligochaeta communities in these streams.

3.3. Changes After 50 Years

The study of Oligochaeta and Trichoptera communities was carried out in the same section of the Porębianka river as in the 1970s or 1980s (at the height of 420 *m a.s.l.*) and provided a unique opportunity to reveal changes in these groups' composition after ~50 years of channel modifications.

3.3.1. Oligochaeta

After 50 years, the taxonomic richness of Oligochaeta in the river remained comparable, with 24 taxa identified in the current study and 18 species (including three semi-aquatic Enchytraeidae species) and undetermined young individuals from the families Lumbriculidae, Lumbricidae, Enchytraeidae, and Tubificidae recorded in the 1970s (Table 3) [26]. However, the species composition underwent considerable changes, with only nine of the same species in both datasets (Table 3, Figure 5). In the 1970s, the Naididae family constituted over 90% of the oligochaete community, similar to other mountain rivers (even eutrophicated ones) without any modifications to the river channel [44]. The species typical for natural running waters, such as *Nais bretscheri*, *N. alpina*, and *N. pardalis*, dominated (Table 4) [26,45]. After 50 years, their percentage strongly diminished, and in the 2020s, *N. elinguis*, a species resistant to extreme environmental conditions [31], became the dominant species, whereas the species *Propappus volki* (sensitive to siltation, [46]), *Cernosvitoviella atrata*, and *Haplotaxis gordioides* (found in the Porębianka River in the 1970s [26] and in other natural Carpathian streams and rivers [23]) were not observed in the current study.

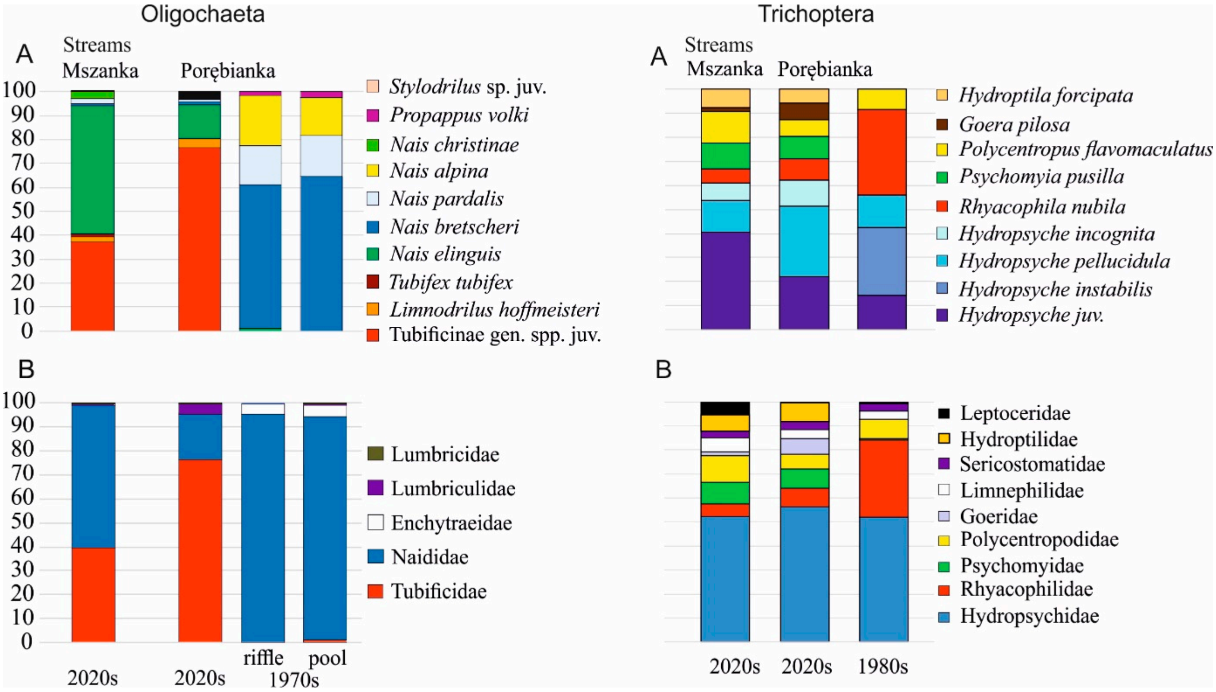

Figure 5. The dominant taxa (**A**) and families (**B**) of Oligochaeta and Trichoptera in the studied section of the Porębianka and Mszanka rivers (according to the formula of [36]) in the early 2020s, as well as in the Porębianka River in the 1970s or 1980s (according to [26,28]).

Inversely, the percentage of Tubificidae, which are tolerant to large amounts of fine sediment in mountain [22] and intermountain [47] rivers, increased in the Porębianka River from 1.3% in the 1970s [26] (Figure 5) to ~77% by the early 2020s. In the early 2020s, in addition to common Tubificidae species with broad ecological tolerances (such as *Tubifex tubifex*, three *Limnodrilus* species, and *Aulodrilus pluriseta*), other taxa atypical of mountain rivers, including *Spirosperma ferox* and juvenile *Psammoryctides* sp., as well as alien species like *Potamothrix bedoti*, *Tubifex blanchardi*, and *Aulodrilus japonicas*, were also identified. These changes were largely caused by the ongoing siltation of the riverbed.

3.3.2. Trichoptera

After 50 years, the Trichoptera composition in the Porębianka River underwent considerable changes, despite the taxonomic richness remaining similar in the early 2020s (18 taxa), 1980s (17 taxa [28]), and 1970s (20 taxa [27]) (Table 5). Increased siltation of the riverbed has not adversely impacted taxon richness in the Porębianka River, although previous research suggests that a rise in fine sediment deposition typically leads to a reduction in the taxa richness of Ephemeroptera, Plecoptera, and Trichoptera (EPT) [21,43]. In the 1970s and 1980s, the Porębianka River was dominated by two families, Hydropsychidae and Rhyacophilidae (51.5 and 31.6%, respectively), with the dominant species being *Rhyacophila nubila*, *Hydropsyche instabilis*, and *H. pellucidula* (Table 5, Figure 5). During the 1980s, several typical mountain species like *Rhacophila mocsaryi*, *R. tristis*, *R. philopotamoides*, *Odontocerum albicorne*, *Ecclisopteryx dalecarlica*, and *Micrasema minimum* became extinct, while some new species less typical of this river section appeared (Table 5) [27,28]. This may be linked to the potential inflow of nutrients from illegal sewage discharges originating from scattered buildings within the river catchments and, to a lesser extent, runoff from agricultural fields. The further changes in the species composition of Trichoptera observed in the current study seem to be closely related to river channel modification works, due to the general improvement in effluent management because of the construction of a sewerage system and a reduction in the area of intensively cultivated land. The current study found no species intolerant or moderately intolerant to fine sediment, such as *Brachycentrus maculatus*, *Glossosoma conformis*, *Agapetus delicatulus*, or *Hydropsyche instabilis.* Species exhibiting tolerance to two or three substratum types (Akal, Macrolithal, orMicrolithal) [48] like *Micrasema minimum*, *Lepidostoma hirtum*, *Glossosoma conformis*, or *Ecclisopteryx dalecarlica* were also absent. Most species constantly present in the Porębianka River, such as *Hydropsyche pellucidula*, *Psychomyia pussila*, *Polycentropus flavomaculatus*, and *Sericostoma schneideri*, as well as those determined only in the early 2020s, such as *Halesus digitatus*, *H. tesselatus*, *Goera Pilosa*, and *Hydroptila vectis,* are widespread species adapted to a wide spectrum of flows and substrate bottoms, including fine-grained ones [48]. These species are typical for lower, submontane sections rather than mountain sections of major Carpathian streams and rivers [28,34,49].

The considerable changes in the Oligochaeta and Trichoptera communities of the Porębianka River between the 1970s and 2020s are evidenced by the relatively low Jaccard similarity index values of 0.45 and 0.47, respectively.

3.4. Functional Feeding Groups (FFGs) of Trichoptera

The Trichoptera in this study were classified into four functional feeding groups (FFGs) in the Porębianka River and five in the Mszanka River. The pattern of Trichoptera FFGs was quite similar in both rivers: in the Porębianka River, the order was filter-feeders > grazers + scrapers > predators > shredders (56.2, 22.2, 14.2, and 7.3%, respectively), while in the Mszanka River, it was filter-feeders > grazers + scrapers > predators > shredders > collectors (52.5, 17.1, 16.2, 13.2, and 1%, respectively). In the 1980s, in the Porębianka River, the FFGs of caddisflies exhibited a different pattern—filter feeders (51.5%) and predators (39.4%) dominated over shredders (6.5%) and grazers and scrapers (2.6%). The dominance of these groups was also observed in other natural Carpathian rivers [50]. The filter-feeding *Hydropsyche* larvae, tolerant to fine sediments [20,22] and common in both study years in the Porębianka River, indicate a moderately stressed river ecosystem [28]. The percentage of predators has decreased (2.8 times) over the years. Rhyacophilidae was no longer dominant, likely due to the loss of suitable habitats for predatory *Rhacophila* larvae, such as spaces under loosely lying stones where they live and hunt, resulting from reduced bottom erosion and increased siltation. Inversely, the proportion of grazers and scrapers in the river increased (8.5 times) after 50 years, likely due to an increase in areas with more stable conditions and moderate to low flow velocities. The share of shredders remained low during both studied periods.

Earlier research on the effects of small, in-channel barriers and the channelization of mountain rivers primarily concentrated on benthic macroinvertebrate groups [1,13,15], but not on species composition, making direct comparison with the present study difficult. While studies examining species composition are time-consuming, they provide a more detailed understanding of environmental changes in running waters in comparison to analyses focused solely on macroinvertebrate groups. Recent studies have reinforced this perspective, highlighting the significance of species variability in assessing ecological impacts.

4. Conclusions

The obtained results indicate that channel modifications negatively influenced the Trichoptera and Oligochaeta communities in the studied mountain rivers. This was indicated by the extinction of several typical mountain species of Trichoptera and of Oligochaeta sensitive to siltation. Low-head barriers in both river channels directly affected aquatic habitats by reducing channel gradients and flow velocities, which ultimately led to bottom siltation. These changes have caused shifts towards more lentic species compositions, and the alteration of the dominant taxa of Trichoptera and Oligochaeta, as well as in the functional feeding group (FFG) of Trichoptera. River deterioration has not been reflected in the taxonomic richness of these communities. The growing prevalence of more lentic habitats favoured the occurrence of Trichoptera and Oligochaeta species that are more tolerant to bottom siltation, and widespread in the lowland sections of Carpathian running waters.

Trichoptera and Oligochaeta communities in mountain rivers were sensitive to habitat changes caused by channel modifications by low-head barriers. They were good indicators of physical alterations, including siltation. Their sensitivity to environmental stressors makes them valuable tools for monitoring and assessing the health of mountain river ecosystems. The knowledge on the negative effects of the channelization of mountain riverbeds on benthic fauna is particularly important at the decision-making level against unjustified interference with riverbed ecosystems. The observed changes may also occur in other Carpathian rivers that have been modified by river channelization works. Therefore, more detailed studies are necessary to evaluate the impact of such low-head barrier types on benthic communities.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/w17030404/s1. Table S1: The density (ind m^{-2}) of Oligochaeta taxa in the habitats of the Mszanka and Porębianka rivers in the early 2020s; Table S2: The density (ind m^{-2}) of Trichoptera taxa in the habitats of the Mszanka and Porębianka rivers in the early 2020s.

Author Contributions: Conceptualization, E.S.-G., A.K. and D.C.; Methodology, E.D., B.S. and A.K.; Determination and elaboration of Oligochaeta, E.D. and Trichoptera, B.S.; Visualization and statistics, E.S.-G.; Writing—Original draft preparation, E.S.-G., E.D., B.S., A.K. and D.C.; Literature Search, E.S.-G., E.D., B.S., A.K. and D.C.; Writing—Review & Editing, E.S.-G., E.D., B.S., A.K. and D.C.; supervision, E.S.-G., E.D., B.S., A.K. and D.C.; funding acquisition, E.S.-G. and D.C. All authors have read and agreed to the published version of the manuscript.

Funding: The research was founded by the AGH University of Science and Technology (project no. 16.16.140.315 (D.C.)) and by subvention of the Institute of Nature Conservation, Polish Academy of Sciences (E.S.-G.).

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Acknowledgments: We would like to thank Maria Profus for preparing the samples of benthic fauna.

Conflicts of Interest: The authors declare no conflict of interest.

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