Communities of Freshwater Macroinvertebrate and Fish in Mountain Streams and Rivers of the Upper Dunajec Catchment (Western Carpathians) Including Long-Term Human Impact

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Abstract The study aimed to determine natural communities of invertebrates and ichthyofauna on the background of physiographic and geological conditions and water chemistry and to evaluate the influence of human pressure on these communities on the basis of the results of long-term studies carried out since the 1960s in the Upper Dunajec River and its Tatra tributaries (West Carpathians). Here, for the Dunajec River, we present a pattern of human impact on freshwater fauna communities in mountain streams and rivers with stony bottoms and rapid currents.

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The Tatra streams (tributaries of the Dunajec River) have mostly retained their natural character. The source of water pollution was mainly from the tourist shelter and tourism centre nearby. Discharge of untreated or partially treated sewage effluent affected invertebrate communities; however, this impact was only observed over a short river section. On the other hand, dam reservoirs completely changed the character of the Dunajec River. In the Czorsztyn Reservoir, communities of macroinvertebrates and fish developed, which are not typical of mountain rivers, replacing previous taxa with those characteristic of slow-flowing waters.

Keywords Dunajec River · Fish · Geology · Human impact · Macroinvertebrates communities · Pollution · Reservoirs · Tatra streams · Water chemistry

1 Introduction

Southern parts of Poland comprise a series of mountain massifs: the Sudetes, the Western Carpathians and parts of the Eastern Carpathians. The northern slopes of these mountains are drained by rivers and streams belonging to the basins of the Vistula River and the Odra River. Within the Western Carpathians, the alpine-type range of the Tatra Mountains, the highest Carpathian mountain range, is situated. The northern slopes of the Tatra Mts. are drained by the Dunajec River and its tributaries which are typical mountain rivers. The bedrock of the largest part of the catchment is formed by the Carpathian flysch, but the highest part of the catchment, situated in the Tatra Mts., is built of crystalline rocks. Out of the Tatra Mts., the Dunajec River crosses the range of the Pieniny Mountains, built of carbonate rocks. Geological diversity affects water chemistry and indirectly invertebrate and fish communities. Streams and rivers in the Dunajec basin have largely retained their natural character. However, in recent years there has been a growing impact of human activity (sewage from towns and villages and the development of tourism infrastructure) on the biocenosis of this river catchment. Along the river, dam reservoirs: Czorsztyn, Sromowce Wyżne, Rożnów and Czchów were constructed.

Studies of fauna of the Upper Dunajec River date back to the nineteenth century. The first reports were on fish [1–3]. In the 1920s, comprehensive ichthyological and hydrobiological studies of the Dunajec catchment were conducted [4]; however, they were interrupted by the outbreak of the Second World War. In the 1960s, Professor Karol Starmach [5] launched an initiative to conduct complex hydrochemical, hydrobiological (algology, macrofauna) and ichthyological studies in the Dunajec catchment and dam reservoirs located in the Dunajec River. Research initiated by Starmach [5] has been continued up to the present [6–7].

The study aimed (1) to determine natural communities of invertebrates and ichthyofauna on the background of physiographic and geological conditions and water chemistry and (2) to evaluate the influence of human pressure on these communities on the basis of the results of long-term studies carried out since the 1960s in the Dunajec River and its Tatra tributaries. For the Dunajec River, we present a pattern of human impact on freshwater fauna communities in mountain streams and rivers with stony bottoms and rapid currents. The study was based on our own results and rich literature.

2 Characteristics of the Dunajec Catchment Area

2.1 General Characteristics of the Catchment

The catchment of the upper and middle sections of the Dunajec River (length ~175 km) and its largest tributary, the Poprad River (165 km), covers about 5,300 km^2 and is situated within the Western Carpathians (on both sides of Polish-Slovak boundary). Springs of both rivers are located in the Tatra Mts., the highest mountain group in the Carpathians ranging 2,000–2,600 m a.s.l. The upper sections of the Dunajec River and tributaries, characterised by high stream gradients, are no longer than 10–12 km. The lower sections of the river and its tributaries flow through the intermediate mountain groups and intra-mountainous depressions. Consequently, the stream gradient for the upper and middle sections of the Dunajec River out of the Tatra Mts. ranges 4.13 per thousand.

Only the uppermost sections of stream valleys are V-shaped in cross-section, whereas most of the river valleys comprise flat-bottoms type that are partly filled with gravel of the lithological composition, similar to the surrounding rocks and rock occurring directly upstream. Nevertheless, in the sections where the Dunajec River crosses the strongest rocks, such as thick-bedded sandstones and limestones, narrow river gaps have developed, e.g. in the Pieniny Mountains, as well as on the Magura Formation outcrops in the southern zone of the Beskidy Mts. (Beskid Sądecki Mountains) [8–9].

Two pairs of dam reservoirs are located along the Dunajec River: Czorsztyn and Sromowce Wyżne as well as Rożnów and Czchów. The upper pair comprises the Czorsztyn and Sromowce Wyżne, which were constructed in 1970–1997.

Although the mountainous area of the Carpathians is predominately forested, the population density is pretty large in stream and river valleys and their vicinities. The deforested areas have been cultivated or used as pasture for several hundred years. Several relatively large urban agglomerations are situated along the upper and middle sections of the Dunajec river or close to it: Zakopane, a touristic centre and resort in the Tatra foothills; Nowy Targ, an administration-industrial centre in the Podhale Basin, Szczawnica and Krościenko resorts situated directly north of the Pieniny Mts.; and Nowy Sącz, the largest administration-industrial centre in this part of the Beskidy Mts., situated in the Sącz Basin (Kotlina Sądecka).

2.2 Geological Characteristics

In geological terms, the Western Carpathians are divided into two mega-regions: Inner and Outer Carpathians separated by the Pieniny Klippen Belt (Fig. 1a) [8, 10]. In Polish part of the area of the Dunajec River catchment, the Inner Carpathians are represented by the Tatra Mountains and Podhale Basin (in Polish: Obniżenie Podhalańskie).

The crystalline core of the Tatra Mts. is formed of granitoids, as well as schists and other metamorphic rocks, which are overlain on the northern side by several tectonic units (nappes), built of Mesozoic sedimentary rocks with predominant limestones and dolomites and subordinate marls, sandstones, quartzites and shales [8, 11]. In carbonate rocks, a mountainous type of karst has developed [12]. The surrounding depressions are formed of Paleogene siliciclastic-clayey rocks [8].

Flowing generally towards the north, the Dunajec River crosses the narrow geological unit of the Pieniny Klippen Belt, composed of various carbonate rocks: limestones, dolomites and marls with clayey and siliciclastic inserts, which are marked in relief by specific the Pieniny Mountains [8, 11]. The Outer Carpathians, situated to the north of the Pieniny Klippen Belt and in physiographic terms called the Beskidy Mts. (with several smaller mountain groups – [9]), are built of folded and faulted Upper Jurassic to Lower Miocene flysch, siliciclastic-clayey rocks, which form several nappes, thrust towards the north (Fig. 1a). These units principally comprise sequences of thick-bedded sandstone and sandstone-conglomerate series, thin-bedded sandstone-shale series and clayey-silty shale series with a thickness ranging from several tens of metres up to several hundred metres. Thick-bedded sandstones and conglomeratic sandstones of the Magura Formation (Magura Sandstones) within the Magura Unit form mountain massifs and ranges in the southern zone of the Outer Carpathians [8, 10].

2.3 Description of Studied Streams and Rivers

Studies were carried out in the Dunajec River, including a section between Nowy Targ and Nowy Sącz, and its Tatra tributaries – streams: Mnichowy Potok, Rybi Potok, Sucha Woda, as well as Białka Tatrzańska River (Table 1, Figs 1b and 2). In Mnichowy Potok five sites (M1–M5) were located in the alpine zone. In Sucha Woda, an alpine zone above and below Czarny Staw lake (SW1–SW2), the dwarf pine zone (SW3–SW4), the montane forest zone (SW5–SW7) and the submontane zone (SW8) were studied. In Rybi Potok stream, a polluted section below the discharge of domestic sewage from Morskie Oko Shelter (RP1–RP6) was studied. In the Białka Tatrzańska River, a section situated on the boundary between the montane forest and submontane zones (B1), as well as the section in submontane zone (B2–B4), was studied. The study section of the Dunajec River between Nowy Targ and Nowy Sącz (D1–D5) is of sub-mountainous character, largely urbanised.

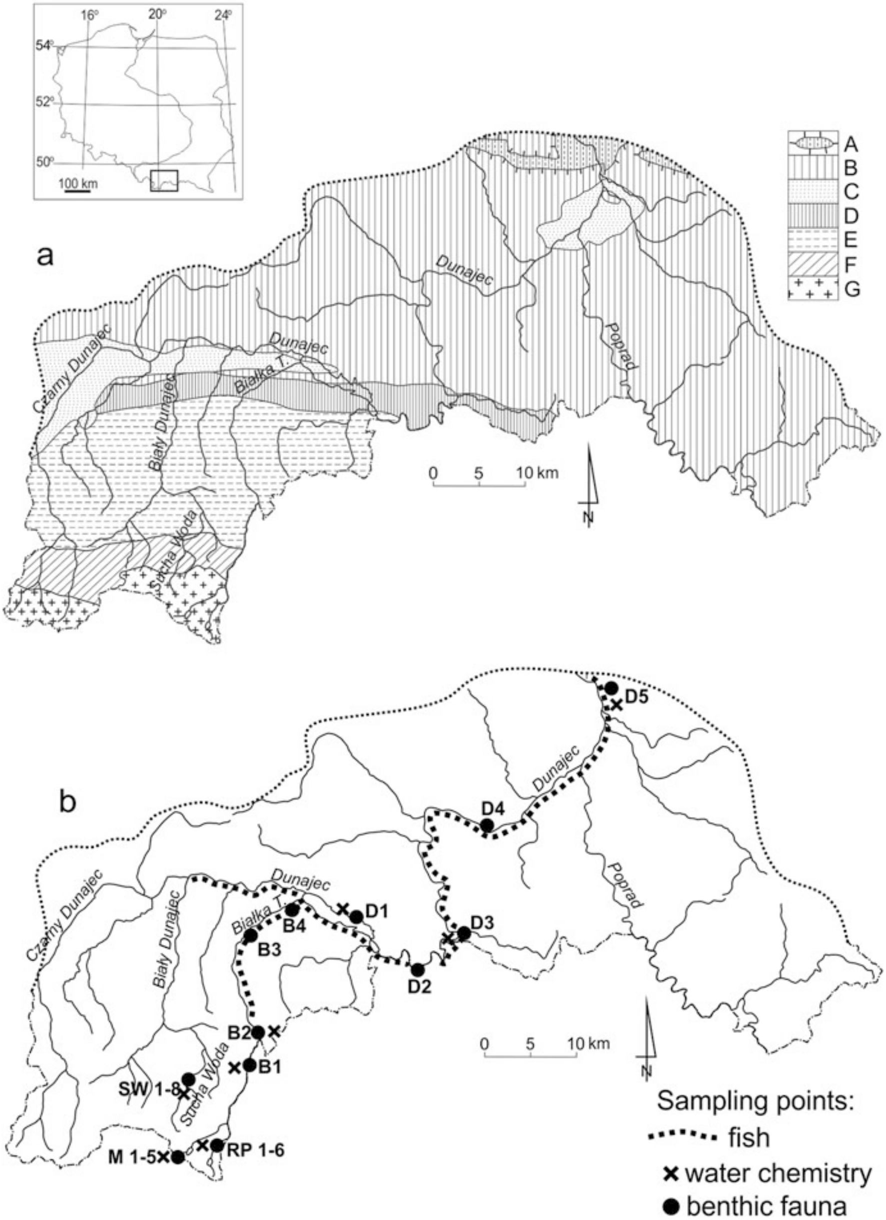


Fig. 1 (**a**) Geology of the Upper Dunajec catchment [A = Outer Carpathians (Beskidy Mts.), Grybów Unit: sandstone, siltstone and claystone flysch (Cretaceous, Palaeogene); with margins of overthrust; B = Outer Carpathians (Beskidy Mts.), Magura Unit: conglomerate, sandstone, siltstone and claystone flysch (Cretaceous, Palaeogene); C = Outer Carpathians (intra-mountainous basins), siltstones and claystones (Neogene); D = Pieniny Clippen Belt (Pieniny, Podhale Basin), limestones, marls, with radiolarites, claystones and siltstones (Jurassic, Cretaceous); E = Inner Carpathians (Podhale Basin), sandstone, siltstone and claystone flysch (Palaeogene); F = Inner Carpathians (Tatra Mts.), sedimentary cover of High-Tatric and Sub-Tatric Nappes: limestones, dolomites, marls with sandstones and claystones (Permian, Triassic, Jurassic, Cretaceous); G = Inner

Table 1 Characteristics of the studied sections of Carpathian streams and rivers

Stream/ rivers	Altitude of springs (m a.s.l.)	Altitude of mouth (m a.s.l.)	Length (km)	Gradient (‰)	Catchment area (km^2)
Mnichowy	2,070	1,900	0.5	400	–
Sucha Woda	1,787	750	15.5	25–105	68
Rybi Potok	1,393	1,100	4.0	10	–
Białka Tatrzańska	1,557	530	40.4	11–67	232
Dunajec	550	283	274	2.9–4.0	in Poland 4,854.1

3 Physico-Chemical Characteristics of Stream and River Waters

Water temperatures of the studied Tatra streams (Rybi Potok, Mnichowy, Sucha Woda) and a mountain river (Białka Tatrzańska) were usually low throughout summer (1.1–6.5°C in the alpine zone, 7–10°C and montane forest zone and 16°C in the submontane zone). They were well-oxygenated (dissolved oxygen usually exceeds 9 mg dm^{-3}, oxygen saturation >90%, frequently >100%) with pH varying from slightly acidic to slightly alkaline (Table 2) [13–17]. Waters belong to the carbonate-calcium type (Table 2). Those flowing through the granite zone were extremely poor in electrolytes (conductivity <10 µS/cm, Ca^{2+} usually <5 mg/L). Water mineralisation (ions SO_4^{2-}, Ca^{2+} and Mg^{2+}) markedly increased in the montane forest zone and submontane zone of the streams (4–6 times in Sucha Woda stream) and rivers as they flow on a substratum built of sedimentary rocks with a high content of carbonate rocks. Water mineralisation was closely related to the geological background, climate and dynamics of water flow [13–14].

In general, stream and river waters were characterized by low contents of nutrients and chemical oxygen demand (COD_{Mn}) (<2 mg O_2/L) values (Table 2) [13–14, 17]. Low nitrate content is associated with the weak washing out of poor mountain soils, while phosphate content is associated with deficiency in the substratum. Elevated contents of nutrients and biochemical oxygen demand (BOD5) and COD_{Mn} values in Rybi Potok stream were a result of human impact (tourist shelter, tourism). Below the sewage effluent outlet from the Morskie Oko tourist shelter, the contents of N–NH_4, PO_4^{3-} and BOD5 values in the stream water increased 6–20 times [15].

Fig. 1 (continued) Carpathians (Tatra Mts.), crystalline core: granitoids, schists, gneisses, with other metamorphic rocks] (according to [8]), (**b**) Locations of the sampling sites in streams and rivers: *M* Mnichowy stream, *RP* Rybi Potok stream, *SW* Sucha Woda stream, *B* Białka Tatrzańska River, *D* Dunajec River

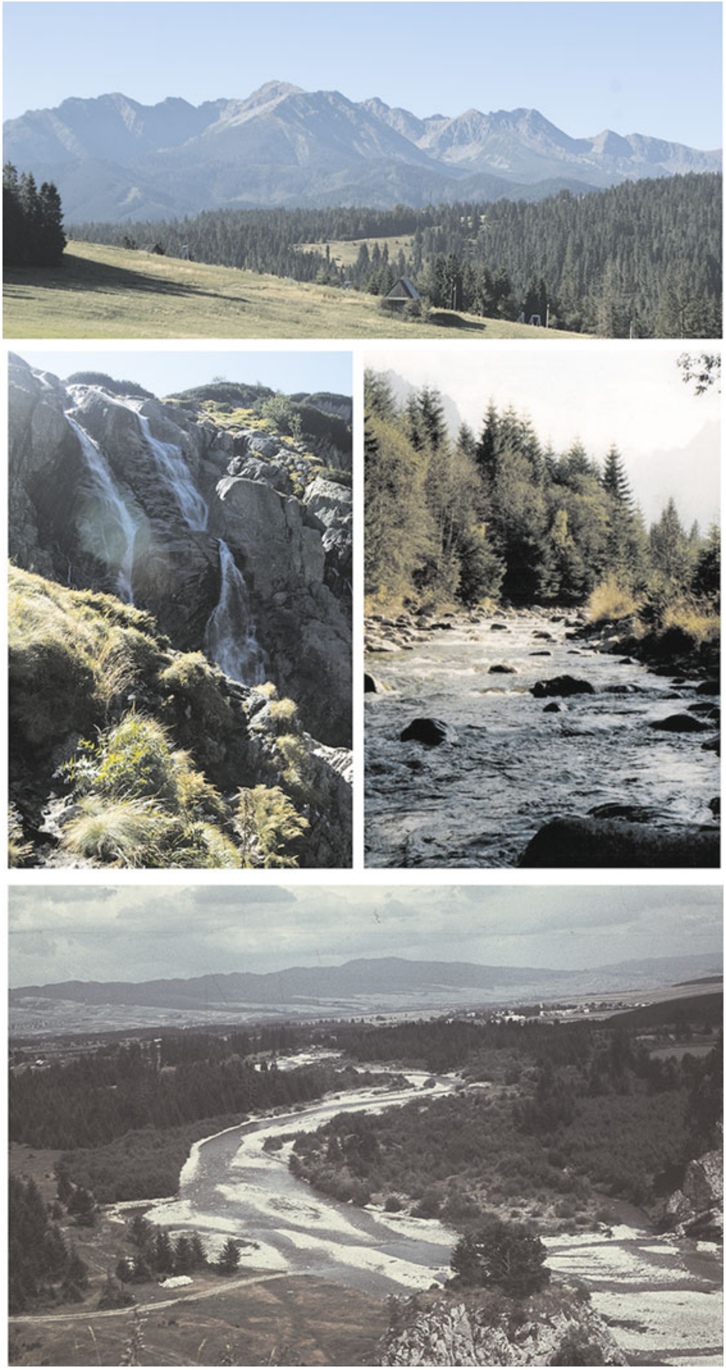


Fig. 2 Photos of Tatra Mts. and type of streams and rivers

Table 2 Water chemistry of the Carpathian streams and river

Parameter	Unit	Streams			River
		Mnichowy	Sucha Woda	Rybi Potok	Białka Tatrzańska
Temperature	°C	1.1–6.5	4.1–8.3	0.8–12.7	2.6–16.5
pH		6.2	6.2–8.2	6.4–7.8	7.1–7.8
Dissolved oxygen	mg/L	10.4	10.9–11.5	6.7–12.3	9.6–12.5
Oxygen saturation	%	–	85–96	64.3–114.5	88–102
Conductivity	μS/cm	–	8.7–62.3	22.4–51.8	–
Chlorides	mg/L	–	0.8–4.5	0.5–2.5	1.4–3.0
Sulphates	mg/L	–	1.5–9.9	1.0–4.32	14.9–20.5
Calcium	mg/L	–	2.5–22.2	4.2–6.4	17.2–32.9
Magnesium	mg/L	–	0.6–4.8	0.5–1.73	3.9–7.8
Potassium	mg/L	–	0.1–0.3	0.05–0.63	0.2–1.1
Sodium	mg/L	–	0.2–0.8	0.08–1.74	0.8–3.0
COD_{Mn}	mg O_2/L	–	0.68–1.92	0.36–2.88	0.64–1.98
$N–NH_4$	mg/L	–	nd–0.08	nd–1.192	nd–0.26
$N–NO_3$	mg/L	–	0.01–0.08	0.21–0.51	0.31–1.75
Orthophosphate	mg/L	–	0.01–0.04	nd–0.27	nd–0.10

Sampling sites were located along the streams and river course. Adapted from [13–16]
nd below detection limit

The Dunajec River was characterised by clean water until 1964 and yielded low BOD5 (<3.5 mg O_2/L) values [18]. We analysed changes in water chemistry of the Dunajec River in years 1977, 1980, 1990, 2000, 2010 and 2015 (Fig. 3) on the basis of data received from the Provincial Inspectorate for Environmental Protection in Krakow. Due to a highly dynamic flow of the river, the suspended matter content in the waters varied over a wide range (from <5 mg/L to 198 mg/L). The waters had temperatures between 10 and 20°C (mean 16°C) during summer, pH 7.2–8.7 and mean annual content of dissolved oxygen usually above 8 mg dm^{-3} (oxygen saturation above 80%).

Conductivity values and contents of major ions (Ca^{2+}, Mg^{2+}, Cl^{-}) and nutrients in the sub-mountain waters of the Dunajec River (sites B1, B3, B5) exceeded a few times those in the streams of alpine, dwarf pine and montane forest zones (Fig. 3). Additionally, water mineralisation (conductivity, Cl^{-}, SO_4^{2-}) was slightly increased along the Dunajec River. The contents of nutrients ($N–NH_4$ and PO_4^{3-}) and BOD5 values showed fluctuations along the river (Fig. 3). They were high below towns situated along the river (Nowy Targ, site D1; Nowy Sącz, site D5). Kownacki et al. [19] also indicated an increase in the values of BOD5, COD_{Cr}, COD_{Mn} and contents of $N–NH_4$, N_{org}, $P–PO_4$ below Nowy Sącz (site B5) associated with sewage effluent discharge from the treatment plant. The maximum content of nutrients ($N–NH_4$, PO_4^{3-}) and BOD5 values were found in years 1980 or 1990 and after that their gradual decrease was observed. Dam reservoirs located in the Dunajec River have influenced the river water chemistry. Downstream of the reservoirs Czorsztyn and

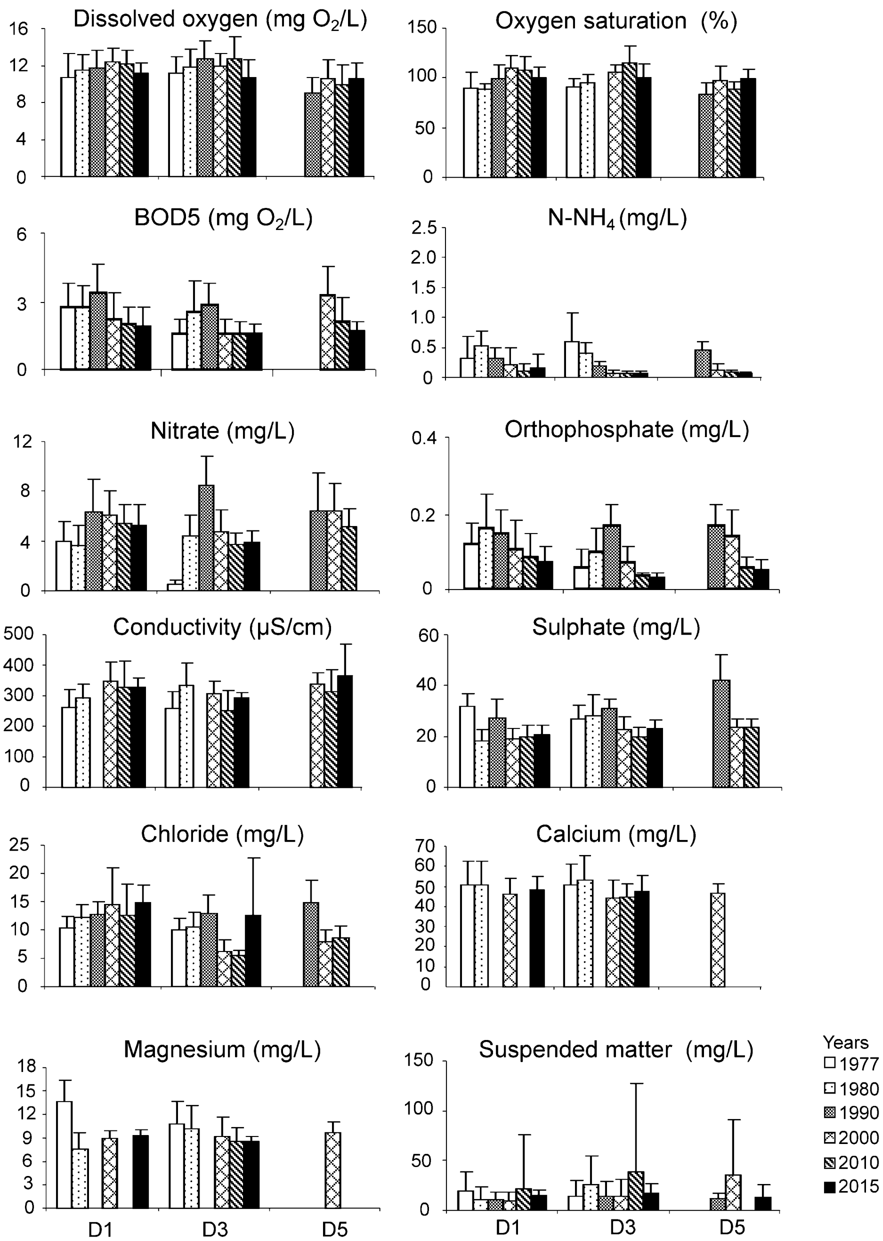


Fig. 3 Changes in the values of physico-chemical parameters (mean ± SD) in the water of the Dunajec River in the period 1977–2015. Adopted from Provincial Inspectorate for Environmental Protection in Krakow

Sromowce Wyżne, a decrease in content of suspended solids, Cl^{-}, PO_4^{3-}, and SO_4^{2-} and changes in water temperatures (decreased in spring and summer but increased in autumn and winter) were observed [20].

4 Macroinvertebrate Communities in Streams and Rivers

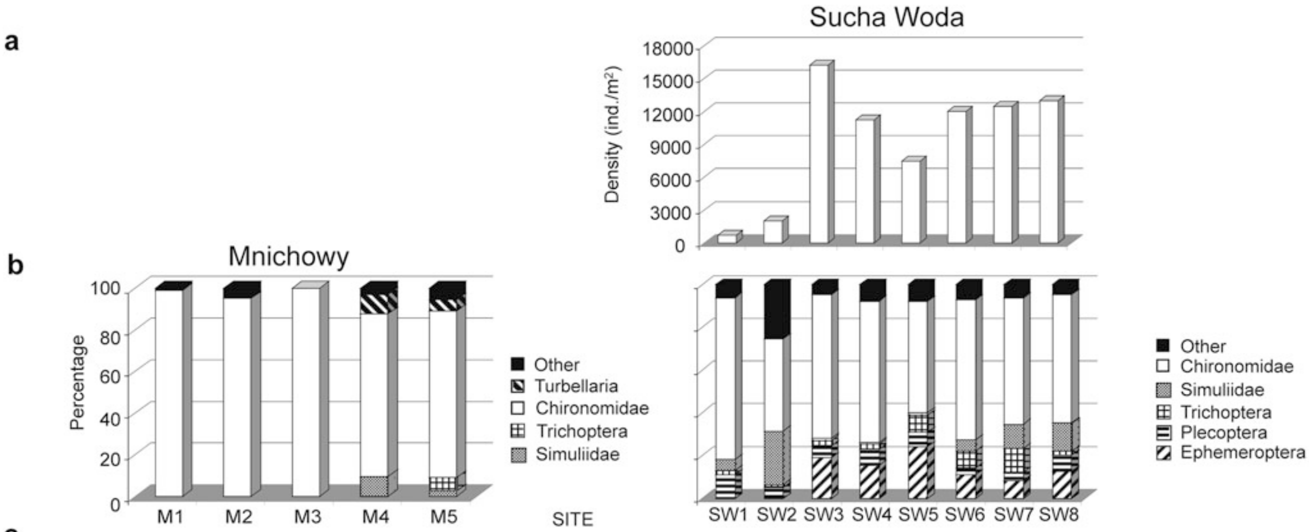
4.1 Macroinvertebrate of the Tatra Mts. Streams

Insect larvae were the most abundant in the fauna of the high Tatra streams. The most numerous group was Chironomidae (Diptera) represented by the largest number of taxa and specimens. Simuliidae (Diptera) was also important, especially in the alpine and submontane zones. In rivers of the montane forest and submontane zones, most numerous were Ephemeroptera, Plecoptera and Trichoptera. The other groups of insects (Colembola, Coleoptera, Hemiptera and Diptera: Blephariceridae, Empididae, Thaumaleidae, Ceratopogonidae, Tipulidae, Limonidae, Psychodidae) were rare. The percentage of Oligochaeta and Turbellaria usually totalled less than 3%. Single specimens of Hirudinea and Mollusca played a slight role in the whole bottom fauna. Gammaridae was absent from the study streams, despite being abundant in other Carpathian streams.

Mnichowy Stream In the upper part (2,000–2,070 m a.s.l.), below the firn glacieret, *Diamesa steinboecki*, *D. nowickiana* and *D. latitarsis* were predominant (Fig. 4b, c). It is a community typical of glacial streams. In the lower section (1,900 m a.s.l.) of this stream, apart from species of the genus *Diamesa*, *Parorthocladius nudipennis* was prevailing. Some specimens of Diptera from the families of Simuliidae (*Prosimulium* sp.), Blephariceridae, Tipulidae and Plecoptera (*Leuctra* sp.), Trichoptera (*Drusus monticola*) and Turbellaria (*Planaria alpina*) were found. Ephemeroptera was absent [16, 21].

Sucha Woda Stream The fauna of Sucha Woda stream was represented mainly by insect larvae, especially Chironomidae (Diptera) (Fig. 4a, b, c). Above 1,550 m a.s.l., the density was very low and did not exceed 3,000 ind/m^2. There, the *Diamesa latitarsis* group, and, at the outlet of Czarny Staw lake, also Simuliidae, *Prosimulium*, were the predominant taxa. At an altitude of 1,550–1,000 m a.s.l., in the upper forest zone, the density increased rapidly (up to ~12,000–18,000 ind/m^2). *Eukiefferiella minor* and *Parorthocladius nudipennis* (Chironomidae), as well as *Baetis alpinus* and *Rhithrogena loyolaea* (Ephemeroptera), predominated. Below 1,000 m a.s.l. the predominant taxa were larvae of the *Orthocladius (Euorthocladius) rivicola* group and Simuliidae [16, 22–24].

Polluted Stream: Rybi Potok In the 1970s there were comprehensive studies in Rybi Potok stream below the discharge of sewage from the Morskie Oko Shelter [25]. At site RP2 (0–10 m below sewage effluent discharge), faunal density was slightly increased in relation to a control site (RP1) (Fig. 5a). A group of



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Taxa	Site (zone)				
	M1	M2	M3	M4	M5
	A	A	A	A	A
Diamesa steinboecki	**25**	**15**	**27**	**29**	+
Diamesa latitarsis	**11**	**27**	**18**	**31**	**22**
Diamesa nowickiana	**23**	**21**	**32**	3.2	0
Parorthocladius nudipennis	0	0	0	+	**31**
Diamesa sp.	**17**	4.5	5.2	6.2	4.7
Pseudokiefferiella parva	9.7	**19**	**14**	1.6	1.0

Taxa	Site (zone)							
	SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8
	A	A	DP	DP	MF	MF	MF	S
Diamesa latitarsis	**48**	**12**	+	+	1.5	4.5	+	+
Protonemura sp.	**10**	+	3.0	3.1	1.4	1.2	+	1.0
Prosimulium sp.	8.7	**27**	+	1.0	1.8	5.6	**12**	**15**
Eukiefferiella minor	1.5	4.8	**27**	**10**	1.3	3.6	4.5	3.2
Diamesa spp. (juv.)	1.4	+	+	+	3.8	3.2	4.0	2.9
Tvetenia bavarica gr.	+	**15**	3.8	8.9	1.7	1.8	3.1	4.0
Nais variabilis	+	**14**	+	+	+	2.0	0	+
Baetis alpinus gr.	0	+	**17**	9.5	13	**10**	3.4	3.1
Parorthocladius nudipennis	3.1	+	**13**	**12**	**30**	**16**	2.0	1.4
Orthocladius (*Euorthocladius*) gr. *rivicola*	+	+	+	1.1	2.2	9.5	**27**	**31**
Eukiefferiella cyanea	0	0	0	0	0	+	+	+

Fig. 4 Macroinvertebrate of the Tatra streams: Mnichowy stream and Sucha Woda stream. (**a**) density, (**b**) percentage share, (**c**) dominant taxa. *A* alpine zone, *DP* dwarf pine zone, *MF* montane forest zone, *S* submontane zone. Adapted from [16, 22–24]

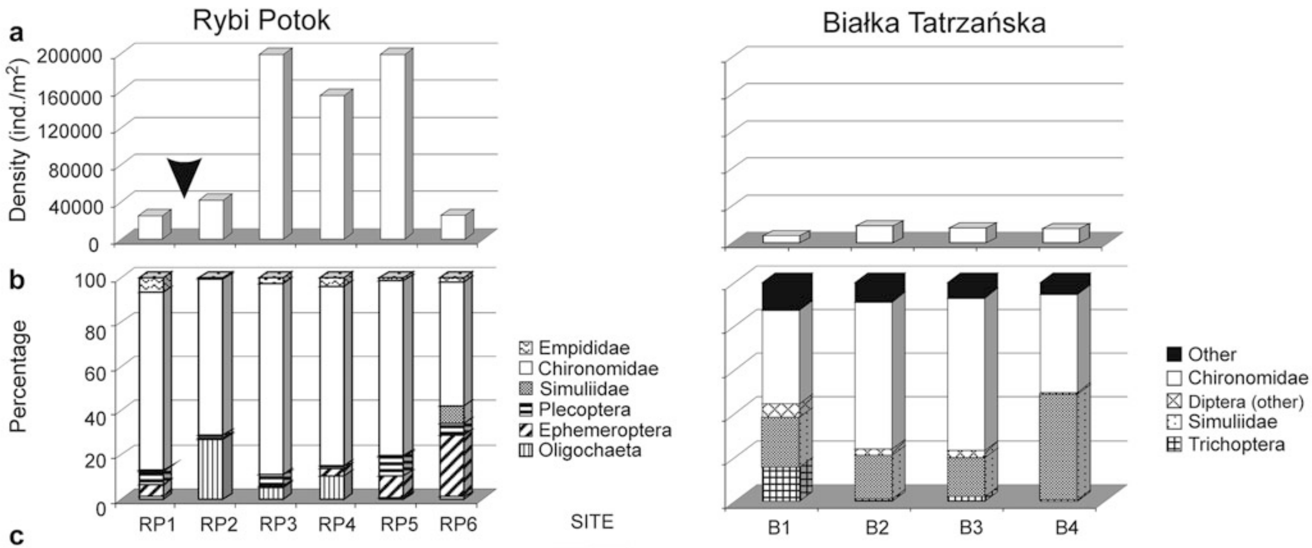
Chironomidae, especially species of genera *Polypedilum* and *Paratanytarsus*, predominated (Fig. 5b, c). The percentage of Oligochaeta increased to 27%, whereas the share of Ephemeroptera decreased to 0.3%, while Trichoptera was absent. Faunal density at RP3 (15–30 m) rapidly increased, reaching the highest values (229,125 ind./m^2). At a distance further from the sewage effluent discharge, the lower fauna density was observed. There Chironomidae predominated, while the share of Oligochaeta decreased. Downstream, about 3 km from the contamination source (site RP6), a community typical of the forest montane zone had developed. Density was lower (25,950 ind./m^2). Larvae of *Baetis alpinus,* an indicator species for this zone, were predominant (25%), and Plecoptera and Trichoptera were more numerous. Yet, the share of Chironomidae (53%) and Oligochaeta (0.8%) was reduced [25].

4.2 Macroinvertebrates of the Mountain Rivers

Białka Tatrzańska River Studies were carried out in the middle and lower course of the river [22–23, 26]. Faunal density at sites B2, B3 and B4 was less than 18,000 ind/m^2 (Fig. 5a). It was only at site B1, on the boundary between the forest montane zone and submontane zone, that density was lower (6,000 ind./m^2). The most dominant group at all sites was Chironomidae (40–60%). Simuliidae was also an important group (20–48%). Apart from Trichoptera at the site B1 (15%), the other faunal groups, for example, Ephemeroptera and Plecoptera, did not exceed a few percent (Fig. 5b). Indicator taxa for this river were Chironomidae larvae of genera *Cricotopus* and *Orthocladius* and *Orthocladius (Euorthocladius)* gr. *rivicola* and Simuliidae (Fig. 5c).

Dunajec River Until 1964, the Dunajec River section between the towns of Nowy Targ and Nowy Sącz was of class I quality (three-class water quality classification of rivers was in force). In 1963, the first study on the Dunajec river bottom fauna was conducted [27]. Faunal density on the river current and stone bottom was low (from approx. 6,600 ind./m^2 at the site D3 to 4,000 ind./m^2 at the site D5). The lowest values (3,300 ind./m^2) were found below Nowy Sącz (D5). Higher density was observed in the silt pools, especially below Nowy Sącz (26,700 ind./m^2) (Fig. 6a). In macroinvertebrate communities at the sites D1, D2, D3 and D4, Chironomidae (35–45%), Trichoptera (12–40%), Ephemeroptera (10–25%) and, at the site D3, Simuliidae (32%) were predominant. The share of Oligochaeta at these sites averaged less than 1%. At the site below Nowy Sącz, the faunal composition changed. Chironomidae (75%) were the most abundant, the share of Oligochaeta rose to 6%, while the share of Trichoptera was reduced to 3% and Ephemeroptera to 8% (Fig. 6b). It clearly indicated that pollution from Nowy Sącz had some influence on the bottom fauna as early as in the 1960s.

Further studies conducted in the 1970s at the sites below Nowy Targ (D1, D2 < D3) showed a rapid deterioration in water quality in the Dunajec River [28]. Below



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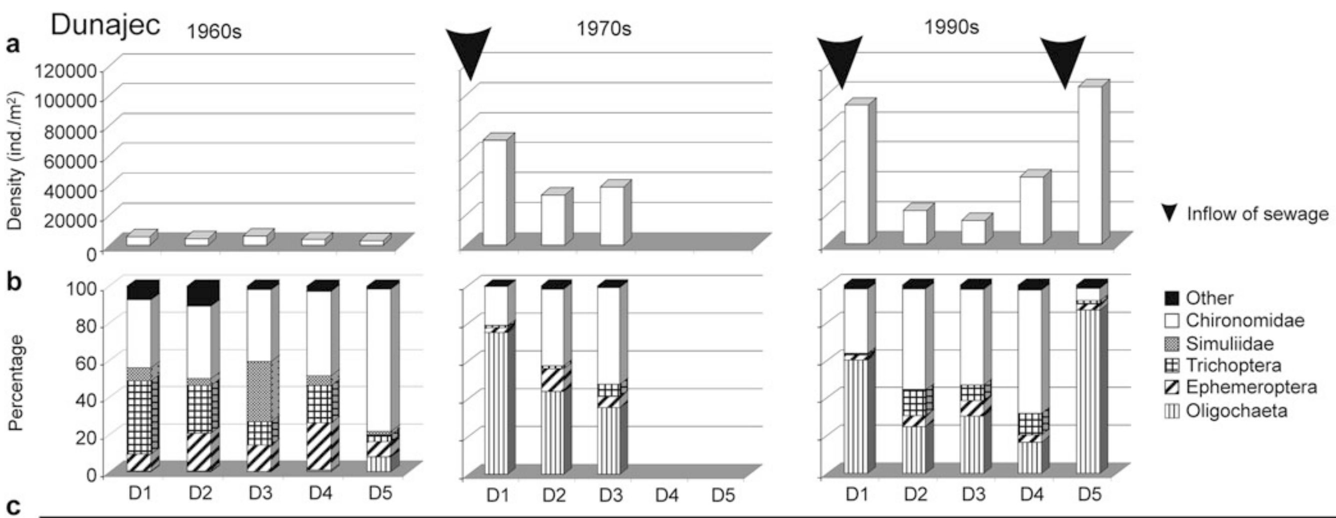
Taxa	Site RP1 MF	RP2 MF	RP3 MF	RP4 MF	RP5 MF	RP6 MF
Micropsectra sp.	**19,6**	1,4	2,2	2,2	0,6	0,0
Oligochaeta	0,9	**26,6**	4,8	**10,0**	0,4	0,8
Polypedilum sp.	0,0	**11,6**	1,2	1,6	0,4	0,0
Diamesa spp.	0,6	**11,2**	3,9	1,3	**10,7**	**11,9**
Microcricotopus sp.	1,5	0	3,1	**26,8**	4,2	0,1
Baetis alpinus	0,0	0	0	0,2	0,4	**25,5**
Baetis spp.(other)	5,4	0,4	0,9	3,6	9,4	0,4
Synorthocladius semivirens	7,5	1,8	1,7	1,9	0,6	0,3
Empididae	6,2	0,5	2,2	4,1	1,2	1,4
Paratanytarsus sp.	0,1	9,2	1,0	0,3	0,1	0
Thienemanniella sp.	0,9	0,1	6,4	3,4	7,1	0,4
Tvetenia bavarica	1,1	0	0,7	6,8	1,5	1,3
Eukiefferiella spp.	2,7	0,3	1,1	5,0	1,5	6,5
Simuliidae	0,3	0,5	0,0	0,0	0,9	8,1

Taxa	Site B1 S	B2 S	B3 S	B4 S
Cricotopus spp. + *Orthocladius* spp.	**43.5**	**28.9**	**27.0**	9.2
Orthocladius (*Euorthocladius*) gr. *rivicola*	**20.8**	**31.3**	**43.3**	**41.3**
Simuliidae	**22.8**	**19.8**	**17.7**	**48.3**

Fig. 5 Macroinvertebrate of the Białka Tatrzańska catchment: Rybi Potok stream and Białka Tatrzańska River. (**a**) density, (**b**) percentage share, (**c**) dominant taxa. *A* alpine zone, *DP* dwarf pine zone, *MF* montane forest zone, *S* submontane zone. Adapted from [25–26]



c

Taxa	1960s					1970s			1990s				
	D1	D2	D3	D4	D5	D1	D2	D3	D1	D2	D3	D4	D5
	S	S	S	S	S	S	S	S	S	S	S	S	S
Hydropsyche spp.	**18,7**	**15,6**	7,5	**12,0**	5,1	1,0	1,2	1,2	0,3	1,8	0,6	3,1	0,9
Psychomyia pusilla	**17,6**	5,7	3,8	5,8	1,6	2,7	1,5	3,9	0,0	3,3	2,3	1,0	0,1
Cricotopus spp. + *Orthoclaius* spp.	**16,0**	**12,4**	6,3	**17,6**	**35,4**	6,5	**10,7**	**18,5**	**10,7**	**18,8**	**10,3**	**13,4**	4,7
Simulidae	6,9	3,6	**32,3**	4,5	2,5	0,2	1,4	0,3	1,9	0,8	1,1	0,4	1,1
Baetis spp.	4,9	**10,9**	4,9	**14,4**	5,7	1,4	6,8	3,7	2,8	5,3	7,2	2,5	2,3
Nais elinguis	+	+	+	+	+++	**42,9**	**31,1**	**15,5**	**10,8**	4,1	**11,2**	0,0	**27,1**
Nais bretscheri	+	+	+	+	+	**25,0**	6,4	**11,0**	**10,6**	8,4	7,4	**10,1**	0,4
Orthocladius (*Euorthocladius*) gr. *rivicola*	+++	+++	+++	+++	+++	5,6	**12,6**	4,9	4,2	**12,4**	**11,2**	1,1	0,5
Nais barbata	0	0	0	0	0	0,9	0,0	0,1	**28,6**	2,0	1,7	0,6	**37,9**
Polypedilum spp.	+++	+++	+++	+++	+++	0,4	1,5	1,3	0,3	4,8	7,3	**16,9**	3,7
Eukiefferiella spp.	+++	+++	+++	+++	+++	1,8	4,5	9,1	2,3	3,8	5,1	1,6	0,8
Nais alpina	0	0	0	0	0	3,6	3,1	6,5	0,2	3,4	0,6	1,5	0,0

Fig. 6 Macroinvertebrate of the Dunajec River in the years 1960s, 1970s and 1990s. (**a**) density, (**b**) percentage share, (**c**) dominant taxa. *A* alpine zone, *DP* dwarf pine zone, *MF* montane forest zone, *S* submontane zone. Adapted from [19, 27–29]

Nowy Targ (D1), density rose to 70,000 ind./m^2. Oligochaeta: *Nais elinguis* (43%), *Nais bretscheri* (25%) and Chironomidae (20%) dominated (Fig. 6c). Apart from Ephemera (2.5%) and Trichoptera (1%), the share of the other groups ranged less than 1%. The situation at the subsequent sites (D2, D3) improved, nevertheless, high abundance (above 30,000 ind./m^2), and the share of Oligochaeta (35–45%) indicated a strong human pressure.

Studies carried out in the 1990s [19, 29] showed considerable contamination of the Dunajec River in some sections. At the sites D1 (below Nowy Targ) and D5 (below Nowy Sącz), the density of macroinvertebrates was very high, 93,000 and 105,000 ind./m^2, respectively (Fig. 6a, b, c), and Oligochaeta, *Nais barbata*, *Nais elinguis* and *Nais bretscheri*, predominated. At sites D2 and D3, density was lower, 22,000 and 16,000 ind./m^2, respectively. The predominant group was Chironomidae, approx. 60% at both sites, and mayflies (Ephemeroptera), stoneflies (Plecoptera) and caddisflies (Trichoptera) together accounted for 20% and 15%, respectively, and yet the percentage of Oligochaeta dropped to 20%. This indicated a significant improvement in water quality of the Dunajec River. At site D4, zoobenthos density rose (45,000 ind./m^2), whereas its dominance structure was similar to that at sites D2 and D3.

5 Communities of Fish in Streams and Rivers

The Tatra Streams Ichthyofauna of the Tatra streams was represented mainly by two rheophilic species: *Cottus poecilopus* and *Salmo trutta* m. *fario* [30–31]. These species usually do not exceed an altitude of 1,000 m a.s.l., but *Salmo trutta* m. *fario* was found at 1,395 m a.s.l. (Rybi Potok stream) [32] and *Cottus poecilopus* at 1,077 m a.s.l. (Chochołowski Stream) [31]. The irregular occurrence of *Thymallus thymallus* and *Phoxinus phoxinus* were observed sporadically in the lower sections of some Tatra streams. Sea trout *Salmo trutta* m. *trutta*, which had migrated for spawning from the Baltic Sea to the upper part of Rybi Potok stream reaching Morskie Oko lake (1,372 m a.s.l.) [1], was no longer found in the Tatra Mts. Alien species that were introduced into the Tatra streams are *Salvelinus fontinalis* and *Oncorhynchus mykiss*.

Białka Tatrzańska River In the 1960s, in the middle and lower sections of the Białka Tatrzańska River, eight species of rheophilic fish occurred [33]. At two sites, two species were recorded, *Salmo trutta* m. *fario* and *Cottus poecilopus*, and except for the first site, at the boundary between the forest montane zone and submontane zone, *Barbatula barbatula*, *Thymallus thymallus* and *Phoxinus phoxinus* were found. Only at the estuary site, *Squalius cephalus* occurred, whereas *Barbus carpathicus* was absent (Table 3). After 20 years, at the same river section, only five species out of those found there earlier occurred: *Salmo trutta* m. *fario*, *Cottus poecilopus*, *Phoxinus phoxinus*, *Barbatula barbatula* and *Barbus carpathicus* [30]. In fish harvesting taking place in 2002, after the construction of the Czorsztyn

Table 3 Ichthyofauna of the Białka Tatrzańska River before (1962) and after (2002) the creation of the Czorsztyn Reservoir

Name of site (km downwards from the river source)	1962 (Solewski 1965)	2002 (Augustyn 2006)
Jurgów (17.7 km)	*Salmo trutta* m. *fario* *Cottus poecilopus* *Barbus carpathicus*	*Salmo trutta* m. *fario* *Cottus poecilopus* –
Trybsz (28.45 km)	*Salmo trutta* m. *fario* *Cottus poecilopus* *Barbus carpathicus* *Barbus waleckii* *Phoxinus phoxinus* *Thymallus thymallus* *Barbatula barbatula*	*Salmo trutta m. fario* *Cottus poecilopus* – – – – –
Nowa Biała (30.45 km)	*Salmo trutta* m. *fario* *Cottus poecilopus* *Barbus carpathicus* *Barbus waleckii* *Thymallus thymallus* *Barbatula barbatula* *Squalius cephalus*	*Salmo trutta* m. *fario* *Cottus poecilopus* *Barbus carpathicus* – *Thymallus thymallus* *Barbatula barbatula* –
Krempachy (32.45 km)	*Salmo trutta* m. *fario* *Cottus poecilopus* *Barbus carpathicus* *Barbus waleckii* *Phoxinus phoxinus* *Thymallus thymallus* *Barbatula barbatula*	*Salmo trutta m. fario* *Cottus poecilopus* *Barbus carpathicus* – – *Thymallus thymallus* *Barbatula barbatula*
Frydman (40 km)	*Salmo trutta* m. *fario* *Cottus poecilopus* *Phoxinus phoxinus* *Thymallus thymallus* *Barbatula barbatula* *Squalius cephalus* – –	*Salmo trutta* m. *fario* *Cottus poecilopus* *Phoxinus phoxinus* *Thymallus thymallus* – *Squalius cephalus* *Rutilus rutilus* *Perca fluviatilis*

Adapted from [7, 33]

and Sromowce reservoirs, nine fish species were present [7]. Brown trout *Salmo trutta* m. *fario* and *Cottus poecilopus* still occurred at all sites, and at the first two sites, they were the only fish species. At the other sites, the following species have been recorded: *Thymallus thymallus*, *Barbus carpaticus* and *Barbatula barbatula.* At the estuary section of the river, apart from *Squalius cephalus*, some limnophilic species from the Czorsztyn Reservoir, *Rutilus rutilus* and *Perca fluviatilis*, were present, whereas they had not been observed there before the dam construction.

Dunajec River A 97-km long section of river, between Nowy Targ and Nowy Sącz, had been divided into two fish zones: a trout zone and a barbel zone [2]. According to Kołder [34] (as cited in [30]), this border existed until the 1960s. However, changes caused by human impact affected the structure of fish species considerably. Fish that are typical of the barbel zone moved markedly upstream. Consequently, there was a sharp decrease in the trout zone of fish such as *Salmo trutta* m. *fario* and *Thymallus thymallus.* At the same time, there was an increase in the fish taxa typical for the barbel zone: *Barbus waleckii* and *Chondrostoma nasus*. A vast area is cohabited by two species characteristic of both trout and barbel zones.

The biggest changes in ichthyofauna took place after the construction of the Czorsztyn and Sromowce Wyżne reservoirs (Table 4). In fish harvesting between 2001 and 2002 in the Dunajec River above the Czorsztyn Reservoir, 18 species were found. The predominant species were as follows: *Rutilus rutilus* (21%), *Squalius cephalus* (16%), *Barbus carpathicus* (10%) and *Alburnus alburnus* (11%). The percentage of other fish species was less than 5%, including those of the salmonids: *Salmo trutta* m. *fario*, *Thymallus thymallus* and cyprinids (*Phoxinus phoxinus*) and cottids (*Cottus poecilopus)*, species typical of the trout zone. Below the reservoir, in the Pieniny segment of the Dunajec River, 17 fish species occurred. The dominant ones were *Thymallus thymallus* (27%), *Alburnus alburnus* (23%) and *Salmo trutta* m. *fario* (20%). Yet, the share of fish dominating above the reservoir was each lower than 10%: *Squalius cephalus* (8%), *Barbus* carpathicus (7%) and *Rutilus rutilus* (2%). The lower course was again dominated by cyprinids species: *Alburnus alburnus* (28%), *Squalius cephalus* (24%) and those of the family Percidae (*Perca fluviatilis* 12%). In an electrofishing study, 20 fish species were found; however, this number may be higher because in an angling fishing study, nine other species were harvested, for example, *Vimba vimba*, *Silurus glanis* and *Tinca tinca* [7, 30].

6 Ecological Characteristics of Macroinvertebrates and Fish Communities

Analysing the distribution of fauna along the natural mountain streams and rivers, a number of faunal communities characteristic of each zone associated with altitude, gradient (slope), velocity and substratum could be distinguished (Fig. 7).

In the uppermost sections of the streams, flowing in the alpine zone, above 2,000 m a.s.l., a characteristic community composed mainly of Chironomidae larvae with the dominant *Diamesa steinboecki* was developed, a species typical of glacial streams. At an altitude of 1,700–2,000 m a.s.l., in the alpine zone, a community of different species was developed with the dominant larvae of *Diamesa* gr. *latitarsis*, but also other species of Chironomidae occurred, for example, *Parorthocladius nudipennis*, *Chaetocladius*, *Eukiefferiella* and larvae of Simuliidae.

In the streams flowing from high mountain lakes and periodical springs in the dwarf pine zone (1,550–1,700 m a.s.l.), larvae of *Diamesa* gr. *latitarsis* still predominated. However, there was an increase in fauna diversity. Apart from larvae of Chironomidae and Simuliidae, some other larvae of Plecoptera, mainly of genera *Protonemura*; *Amphinemura*; *Leuctra*; Trichoptera, *Rhyacophila*; and *Drusus*, occurred. Pools were inhabited by numerous Oligochaeta – *Nais variabilis.*

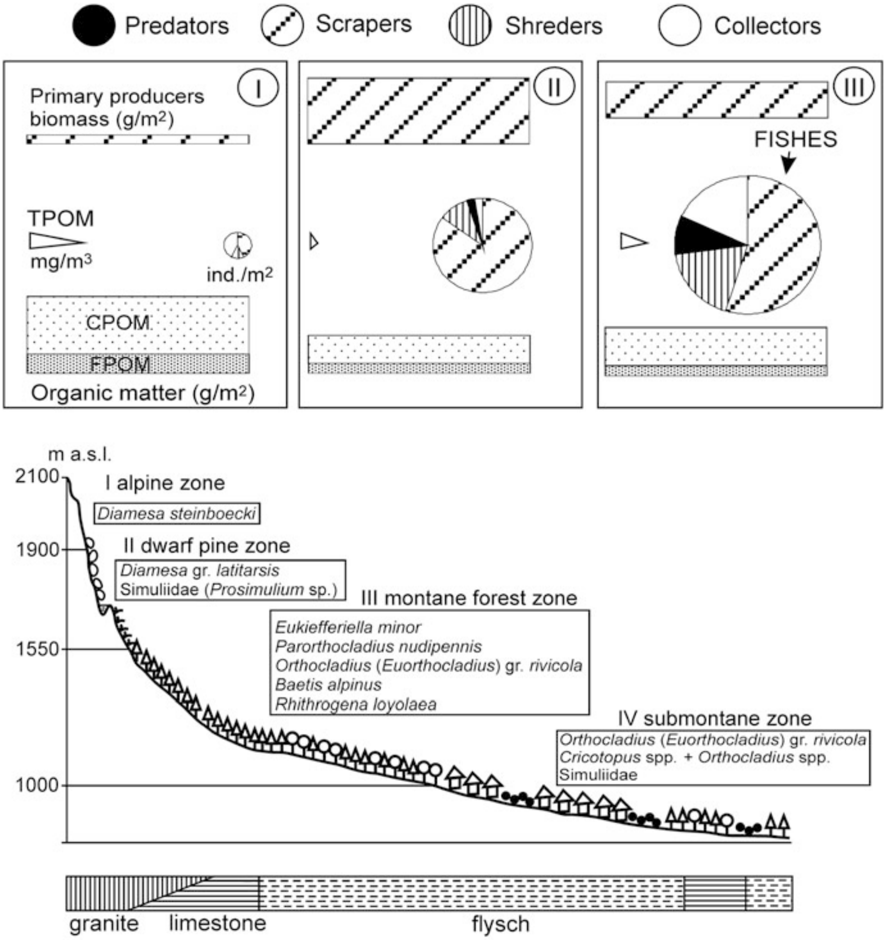
Table 4 Species structure (%) of ichthyofauna of the Upper Dunajec in 2002

	Sampling sites (km)													
Species	0–3	8	11	12	13–22	23	35	45	49	74	82	87	95	97
Salmo trutta m. *fario*	6.2	[a]	[a]	[a]	Reservoirs Czorsztyn and Sromowce Wyżne	24.0	29.0	8.8	13.0	6.4	[a]	11.8	[a]	[a]
Thymallus thymallus	8.8	[a]	[a]	[a]		32.7	36.2	14.3	16.0	22.0	28.2	[a]	[a]	[a]
Phoxinus phoxinus	18.3	[a]		[a]		[a]	[a]	8.8	[a]	[a]		[a]	[a]	
Cottus gobio	6.5	[a]	[a]	[a]		[a]	[a]							
Barbatula barbatula	42	16.3	[a]	9.5		[a]	[a]	[a]	[a]	[a]		[a]	[a]	[a]
Barbus carpathicus		27.7	7.7	8.9						22.4	14.7	[a]	[a]	[a]
Barbus waleckii		5.3		[a]				[a]	[a]	14.8	27.4	17.9	[a]	[a]
Squalius cephalus	15.0	15.3	17.7	17.2		[a]	[a]	19.0	13.3	21.7	9.8	24.3	8.1	36.0
Rutilus rutilus		14.0	39.9	17.7			[a]	[a]	[a]		[a]		[a]	7.1
Alburnus alburnus	[a]	[a]	21.7	13.4		[a]	[a]			6.9	5.1	16.3	51.9	36.3
Perca fluviatilis		[a]	[a]	21.4		[a]	[a]	[a]		[a]	11.7	13.7	17.6	13.4
Leuciscus leuciscus		[a]	[a]	[a]		[a]	6.3	8.3	16.0	[a]				[a]
Abramis brama		[a]	[a]			24.3	10.9	32.9	36.5				[a]	[a]
Esox lucius		[a]	[a]			5.3	[a]							
Other[b]	3.2	21.4	13.0	11.8		13.7	16.7	7.9	5.1	5.7	3.2	14.8	20.5	7.2
Number of species	8	17	14	14		14	15	10	9	10	12	10	16	12
Number of specimens	759	812	1,445	797		395	431	216	293	419	632	263	655	2,618

Adapted from [7], modified

[a]Value below 5%

[b]Species below 5% (km): *Cottus poecilopus* (0–3, 23–35), *Hucho hucho* (8–35, 82, 95–97), *Gobio gobio* (8, 12, 95), *Oncorhynchus mykiss* (95), *Sander lucioperca* (82, 95), *Anguilla anguilla* (74), *Lota lota* (82), *Chondrostoma nasus* (23, 35)



Site	Unit	I	II	III	IV
Altitude	m a.s.l.	1700-2100	1550-1700	1000-1550	<1000
Gradient	‰	200-600	100-200	20-100	usually < 10
Wide	m	1-2.5	2-5	4.5-8.5	6-100
Current velocity	m3/sek	0.5-0.9	0.4-1.3	0.2-1.5	0.4-1.5
Temperature	°C	0.9-9.5	2.4-12.3	1.0-9.1	0.2-12.8
pH		5.3-6.4	6.0-6.5	6.3-6.8	7.2-8.5
Conductivity	μS/cm	16-19	18-26	21-69	69-215
Oxygen saturation		79-85	82-89	84-89	78.8-94.1
Ca^{2+}	mg/L	2.4-4.4	2.6-4.9	3.3-8.6	12.9-41.0
$N\text{-}NO_3$	mg/L	0.31-1.06	0.6-1.13	0.56-1.09	0.51-1.06
PO_4^{3-}	mg/L	0.02-0.14	0.01-0.04	0.01-0.07	0.01-0.04

Fig. 7 The model of structure and function of the mountain stream and rivers in the light of the "River Continuum Concept". Adapted from [35, 39], modified

Ephemeroptera was still absent. These communities were characterised by very low biodiversity and abundance.

At an altitude of 1,500–1,550 m a.s.l., where the streams are fed by a number of springs of the moraine type, faunal abundance and biodiversity sharply rose. The predominant species were Chironomidae, *Eukiefferiella minor* and *Parorthocladius nudipennis* and Ephemeroptera, *Baetis alpinus* and *Rhithrogena loyolaea.* Also Plecoptera, *Protonemura*, *Capnia* and *Isoperla*; Trichoptera, *Rhyacophila*; and Tricladida, *Crenobia alpina* were numerous there.

In the streams of the forest montane zone (1,000–1,500 m a.s.l.), fauna composition displayed small changes in relation to the above described section. Chironomidae, *Parorthocladius nudipennis* or *Orthocladius* (*Euorthocladius*) *rivicola*, and Ephemeroptera, *Baetis alpinus* and *Rhithrogena loyolaea*, were still predominant. Also Plecoptera, especially species of genera *Leuctra* and *Protonemura*, and Trichoptera, *Rhacophila*, *Druzus* and *Allogamus*, were numerous. Oligochaeta occurred sporadically, mostly in pools. Fish (*Salmo trutta* m. *fario*, *Cottus poecilopus*) occurred in the lower sections of this zone.

Below 1,000 m a.s.l., in streams and rivers flowing at the foot of the Tatra Mts., Chironomidae – *Orthocladius* (*Euorthocladius*) gr. *rivicola* – and larvae of the genera *Cricotopus* and *Orthocladius* were still predominant. Larvae of Simuliidae were also abundant. A number of new species of Ephemeroptera, Plecoptera and Trichoptera occurred. Fish, mainly *Salmo trutta* m. *fario*, *Cottus poecilopus*, *Phoxinus phoxinus* and *Thymallus thymallus*, were regularly found in this zone.

Along the study rivers and streams, a few schemes of functioning of ecosystems can be distinguished [35] (Fig. 7).

In the upper montane zone (zones: alpine and dwarf pine) of the streams, the flow is periodical. The content of major cations and anions, as well as nitrogen and phosphorus compounds, was very low. This resulted in a limited development of algae. The amount of bottom particulate organic matter (BPOM) and transported particulate organic matter (TPOM) were relatively high. However, coarse particulate organic matter (CPOM) prevailed, which is weakly available to the juvenile stages of shredders and collectors that appear when the stream starts to flow. The abundance of invertebrate fauna was very low. Larvae of Chironomidae of the genus *Diamesa* predominated and feed on BPOM and algae. Simuliidae, which are collectors, live on TPOM from lake outlets. There were no predators: fish and insects. In this zone, an element creating the development of biocenosis is a periodic water flow which excludes a lot of species with 1-year life cycles.

In the montane forest zone, where streams flow the whole year, plant cover composed of mosses and algae developed abundantly. However, the content of organic matter BPOM and TPOM was low. This situation caused the strong development of scrapers, while the number of collectors feeding on organic matter was relatively low. In this zone fish were absent, but insect predators were present.

In the submontane zone, concentrations of most chemical elements, especially of Ca and Mg, were increased, but the contents of phosphorous and nitrogen compounds were still low. The content of organic matter BPOM and TPOM increased, yet the development of algae cover was lower than in the montane forest zone. The zoocenosis was composed mainly of scrapers; the share of shredders and collectors reached up to 40%. The first-order consumers were controlled by fish, which were the top predators controlling the whole zoocenosis.

7 Influence of Human Impact on Streams and Rivers Fauna Communities

7.1 Effect of Pollution

The above-presented scheme of structural and functional diversity of faunal communities along the streams and rivers was disturbed by human impact. The Upper Dunajec River, which retained its natural character until the 1960s, has been contaminated by sewage from villages and the towns of Nowy Targ and Nowy Sącz and developing tourist infrastructure in this area. Most of the Tatra streams have retained their natural character. The only source of pollution of these streams comes from tourist shelters and tourism (Table 2 and Fig. 5).

The inflow of sewage caused a drastic increase in nutrient content, as well as BOD5 and COD values (see Chap. 3, Table 2, Fig. 3 [15, 19]) in the same range, and affected invertebrate communities in streams below the tourist shelters in the forest zone and in the river below towns in the submontane zone (Figs. 5 and 6). Below the sewage effluent discharge, the faunal density grew from a few or several thousand per square metre to a few dozen thousand or even 200,000 ind./m^2 [19, 25, 28–29]. Oligochaeta, whose percentage in mountain streams and rivers ranged less than 3% of the total faunal abundance, below the sewage effluent inflow rose to 20% in the Tatra Mts. and to 80% in the Dunajec River, below the towns. Naididae (*Nais elinguis*, *Nais bretscheri and Nais barbata*), the species that feed on algae and fine detritus, were dominant there. Although the percentage of other faunal groups decreased, their density rose. For example, the density of *Ephemeroptera* in Rybi Potok at the first control site was 1,475 ind./m^2; 30 m below the sewage outflow, 2,100 ind./m^2; and 100 m below, 5,800 ind./m^2. Also biodiversity at the site above and below the discharge of sewage effluent was similar. In the Dunajec River above Nowy Sącz, 118 taxa of invertebrates were recorded, and below the discharge, there were 137. Processes of self-purification in mountain streams and rivers proceeded rapidly, in the Tatra streams over the distance of a few hundred metres and in the Dunajec River – a few kilometres. As a result of these processes, the further the distance from the sewage source, the lower faunal density and the percentage of Oligochaeta were observed, but the percentage of Chironomidae increased. Some differences in this phenomenon were observed in the Dunajec River. In the 1970s at sites D1 and D2, density was over 30,000 ind./m^2, and the percentage of Oligochaeta was from

35 to 40%, whereas in the 1990s, density was lower than 20,000 ind./m^2, and the percentage of Oligochaeta was 20%.

In the study section of the Dunajec River, Nowicki [2] distinguished two fish zones: the trout zone where rheophilic fish require well-oxygenated water and the barbel zone, where fish occur in warmer water with lower dissolved oxygen content and a higher amount of suspended matter. The boundary between these two zones in the nineteenth century was at the site of the Poprad River inflow into the Dunajec River. Due to the increase in water contamination of the Dunajec River after 1964, the boundary shifted upstream, and the fish characteristics of the barbel zone moved upstream. The barbel and nase grew in abundance in this section [30].

7.2 Reservoirs

Constructed in 1997, reservoirs of Czorsztyn and Sromowce Wyżne on the Dunajec River considerable changed the hydrological character of the river and the communities of macroinvertebrates and fish. Before the reservoirs construction, the macroinvertebrate community was characterised by high biodiversity, and the rheophilic species Ephemeroptera, Plecoptera and Trichoptera were very abundant. Inversely, the invertebrate community in the Czorsztyn Reservoir was composed of 13 species of Oligochaeta and two species of Chironomidae: *Chironomus plumosus* and *Chironomus bernensis* [36, 37]. Water dammed up in the reservoir made the river flow more slowly above the reservoir, and consequently, there was an increase in the amount of sediment deposited in the river bed. Muddy sediments were inhabited by larvae of *Prodiamesa olivacea* and taxa of the subfamily Chironominae, not typical of rivers with a stone bottom and high velocity.

The structure of ichthyofauna in the Dunajec segment of the Czorsztyn reservoir had been investigated immediately before it was filled [38]. In this segment, 16 fish species occurred. The dominant species were *Phoxinus phoxinus*, *Barbus carpathicus*, *Barbus waleckii*, *Squalius cephalus*, *Leuciscus leuciscus* and *Alburnus alburnus*. The percentage of the other species ranged from 0.5 to 5% of the total number of all fish recorded (Fig. 8).

After the Czorsztyn Reservoir was filled with water, there was a considerable change in the ichthyofauna community. Studies carried out in 2002 showed the occurrence of eight fish species [36]. The dominant species were *Rutilus rutilus* (50%), *Abramis brama* (20%) and *Perca fluviatilis* (10%). The other species, such as *Alburnus alburnus*, *Leuciscus leuciscus*, *Carasius carasius*, *Gymnocephalus cernua* and *Esox lucius*, were less than 5% (Fig. 8). Four species, *Abramis brama*, *Carassius carassius*, *Gymnocephalus cernua*, *Esox lucius*, had not been recorded before dam construction in this Dunajec section.

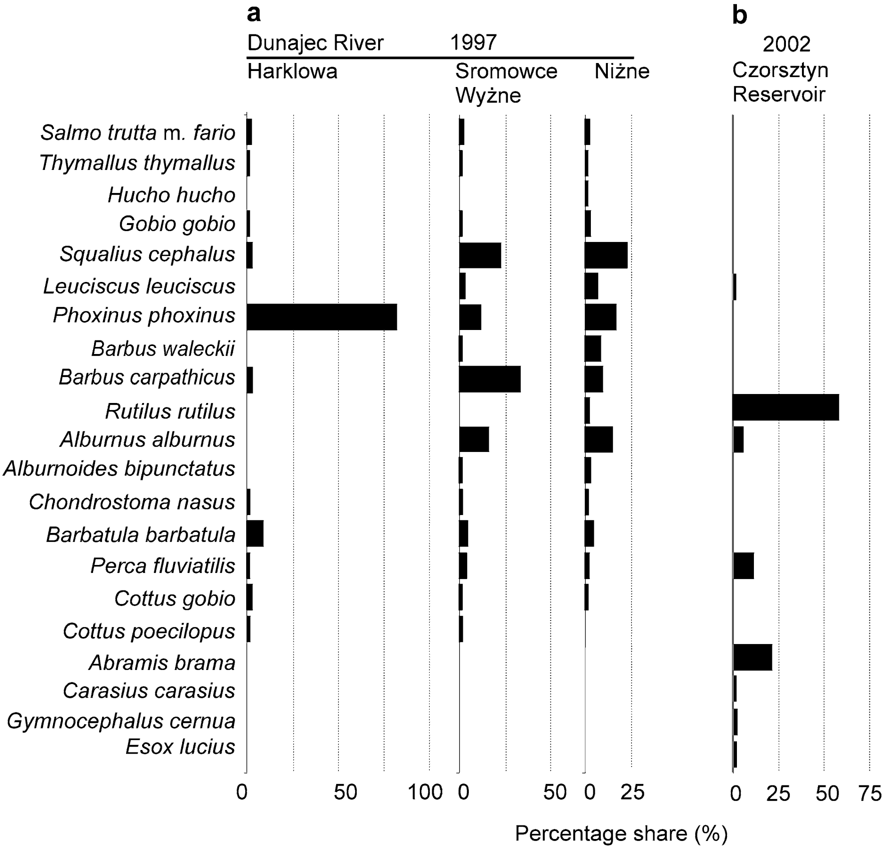


Fig. 8 Change of ichthyofauna of the Dunajec River before (**a**) and after (**b**) the creation of the Czorsztyn Reservoir [36, 38]

8 Conclusions

The Tatra streams (tributaries of the Dunajec River) have mostly retained their natural character and developing faunal communities are characteristic of these types of biotopes. The source of water pollution comes mainly from the tourist shelter and tourism centre around them. Discharge of untreated or partially treated sewage effluent affected invertebrate communities; however, this impact was only observed over a short river section.

Until 1964, the water of the Dunajec River, between the towns of Nowy Targ and Nowy Sącz, preserved its natural character with little human impact. An increase in sewage effluent inflow, mostly untreated, from Nowy Targ, Nowy Sącz and numerous recreational centres and villages, observed in the 1970s, resulted in the increasing contamination of the river and consequently changed natural communities of macroinvertebrates and fish. Since the beginning of the 1990s, there has been a decrease in nutrient contents and BOD5, which has been reflected in changes in invertebrate communities. However, the course of these changes is different from that in the lowland rivers [40].

The waters of mountain rivers with stone bottoms and rapid, turbulent flows were well oxygenated below the sewage effluent inflow. The inflow of nutrients resulted in the development of algae mats on the surface of stones, where Oligochaeta of the family *Naididae* have developed abundantly. On bottom stone surfaces, Ephemeroptera, Plecoptera and Trichoptera, characteristic of mountain rivers occur. Taxa characteristic of polluted waters may develop under stones, where water flow is slow or very slow, which favours the deposition of sediments, as well as in pools. However, this habitat is very rare.

Dam reservoirs completely changed the character of the Dunajec River. In the Czorsztyn Reservoir, communities of macroinvertebrates and fish developed, which are not typical of mountain rivers. Rheophilic communities were replaced with taxa characteristic of slow-flowing waters. Also below and above the reservoir, changes in communities were observed.

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