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Alterations of the bottom macrofauna of a mountain stream (Wołosaty stream, Bieszczady National Park, southeastern Poland) caused by a tourist hotel

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Abstract – Significant alterations were observed in the structure of communities of benthic invertebrates at all the stations within a stretch of 200 m downstream the sewage discharge. Mayfly, stonefly, and caddis fly larvae were reduced, especially in summer at high water temperatures and low discharge. At the same time, there appeared abundant pollution-resistant organisms, mainly *Chironomus* gr. *thummi-plumosus* and *Eristalis tenax* (L.). The Diptera larvae community was the first to recover. However, disturbances in the composition of the Ephemeroptera, Plecoptera, and Trichoptera larvae assemblages were distinct along the whole investigated stretch.

Key words: mountain stream, benthic macrofauna, pollution, tourist impact.

1. Introduction

The aquatic fauna of the Bieszczady Mountains deserves attention. Among the taxa found here, there were at least 27 endemic species and 11 species which in Poland can be found only in the Bieszczady area (Kłonowska 1987, Szczęsny 1995). Another unique feature of the streams and rivers in this region is a well-preserved continuity of invertebrate communities (Dumnicka and Kukuła 1990, Kukuła 1991*a*, Szczęsny 1995). The main threat to water purity in the streams was in the 70s and 80s sewage from the large farms in this region (Kukuła 1991*b*, 1993). Increasing numbers of tourists every year, especially in summer, pose a new and serious threat to the Bieszczady natural environment. This also refers to the stream water polluted by sewage from tourist facilities.

The aim of the study was to estimate the deterioration in water quality in the Wołosaty stream, using macroinvertebrates as biological indicators of water pollution, and also to establish the scale of changes in the stream fauna in various periods of the tourist season.

2. Study area

The Wołosaty stream (22°48' E, 49°07' N) is the main watercourse in the Bieszczady Wysokie Mountains. It is 27 km long with a mean gradient of 23‰, while its drainage area is 118.2 km^2 (Pasternak 1964). It starts as the Wołosatka stream at an altitude of about 1200 m, below the pass between Tarnica (1346 m) and Szeroki Wierch (1286 m). In the village Ustrzyki Górne (altitude about 630 m) the Wołosatka joins the Rzeczyca and Terebowiec streams, hence forward called the Wołosaty stream. This area belongs to the territory of the Bieszczady National Park (BPN; 278.34 km^2). At the same time, it is the centre of the International Biosphere Reserve "Eastern Carpathians". In respect of their location, Ustrzyki Górne and Wetlina are the most important tourist centres in the Bieszczady Wysokie Mts. Most of the tourist buildings are connected to three sewage plants. The sewage from the Hotel "Górski", the largest one in the BPN, as well as that from the neighbouring camping site and the headquarters of the Volunteer Mountain Rescue Service (GOPR) is conveyed to a container sewage plant (type KOS-2, operation capacity 50 m^3 day^{-1}). This sewage plant is not efficient, hence in recent years a deterioration in water quality in the Wołosaty stream has been observed, especially in periods of very low water level (Kukuła and Kukuła 1996, Kukuła and Stachowicz-Kawalec 1996).

A variable water flow over the year is characteristic for this stream, as well as for most of the others in this region. In the summers of 1993–1995 very low values of discharge were recorded (IMiGW 1995). The chemical composition of the water in the Wołosaty stream up the hotel sewage effluent in 1995 was in accordance with the first class of water purity standards (Ordinance 1991). However, below the sewage effluent there was an increase in the content of nitrate, ammonium, and phosphate with a simultaneous decrease in quantity of dissolved oxygen (to 3.01 mg L^{-1}). This was especially distinct during the summer (Kukuła and Stachowicz-Kawalec 1996) The bacterial count in the stream also increased distinctly below the sewage effluent (Kukuła and Kukuła 1996).

The benthic macrofauna of this stretch includes many interesting and rare species among mayfly, stonefly, and caddis fly (Kukuła 1991*a*, Szczęsny 1995). The brown trout, *Salmo trutta* m. *fario* L., constitutes a great share in the biomass of the local fish community. Numerous spawning sites of this species were found on the same stretch (Kukuła 1995).

3. Material and methods

A 200-m stretch of the Wołosaty stream near the Hotel "Górski" in Ustrzyki Górne was chosen for the study. Here, the stream channel is 10–20 m wide. The current is varied, and the bottom stony with short stretches of gravel. The water flow determined by means of the surface float method was 2.6 m^3 s^{-1} in spring, 0.4 m^3 s^{-1} in summer, and 2.2 m^3 s^{-1} in autumn There were 6 sampling points. The first station was located about 5 m above the sewage discharge pipe, while the others were 1, 5, 15, 30, and 100 m below it. In summer two additional sites were established: site 3' close to site 3 in small pools cut out from the main channel by stones and gravel carried by the current, and site 7–200 m below the sewage discharge. The samples were collected in 1995 three times: on 27 May (spring), 10 August (summer) and 7 October (autumn). A 22.5×22.5 cm bottom scraper with a 330 m mesh bolting cloth net was used for sampling. Ten quantitative samples were taken and fixed in 4% formalin.

The statistical data analysis was performed using the χ^2 test (Sobczyk 1996). Taking into account the test limitations, the statistical significance of differences in the structure of benthic macroinvertebrate communities between site 1 and the other ones was estimated. Computation were made in three variants, in which the following groups were included: 1) Oligochaeta, Diptera, Trichoptera, Plecoptera, and Ephemeroptera, 2) Brachycentridae, Odontoceridae, Limnephilidae, and other Trichoptera, and 3) Chironomidae and Limoniidae.

4. Results

In spring, the greatest density of benthic macrofauna was observed at Station 1 (Table I), Chironomidae larvae being the most numerous. Larvae of mayfly, stonefly, and caddis fly formed a significant share in the total number of the identified animals. At Station 2 there was a great decrease in the number of larvae. The number of Diptera larvae decreased less, though distinctly. At the same time a decrease in the number of taxa was observed. Out of 32 taxa recorded at Station 1 there were only 11 present at the next one.

Table I. Density of benthic macrofauna (ind. m^{-2}) in the Wolosaty stream on 27 May 1995.

Taxa	Stations					
	1	2	3	4	5	6
PLECOPTERA						
Dinocras megacephala (Klap.)				3.9	1.9	3.9
Isoperla sp. juv.	1.9					
- *oxylepis* (Despax)			1.9			
Leuctra sp. juv.	5.9		3.9	3.9	25.6	11.8
Nemoura sp. juv.			5.9			
- *monticola* Rauser				25.6	7.9	15.8
Perla sp. juv.	1.9	3.2				5.9
- *burmeisteriana* Claas.	7.9					
- *marginata* (P.)			5.9	3.9	3.9	1.9
- *pallida* Guer.	5.9					
Perlodes microcephala (Pict.)	29.6	3.2	11.8	11.8	7.9	13.8
Protonemura brevistyla (Ris)				25.6	9.8	11.8
Plecoptera juv.	3.9			1.9		
Total	57.0	6.4	29.4	76.6	57.0	64.9
EPHEMEROPTERA						
Baetis alpinus (Pict.)						33.6
- *muticus* (L.)	1.9		9.8	11.8	5.9	23.7
- *rhodani* (Pict.)	15.8		5.9	17.7	9.8	27.6
- *scambus* Etn.					3.9	7.9
Caenis sp. juv.			5.9	7.9	19.7	17.7
- *beskidensis* Sowa	11.8		3.9	7.9	5.9	
Ecdyonurus sp. juv.					7.9	1.7
- *torrentis* Kimm.	7.5					1.9
- *venosus* (Fabr.)	9.8		5.9	3.9	1.9	7.9
Electrogena sp. juv.		6.5	3.9			
Epeorus silvicola (E. Pict.)				1.9		3.9
Ephemera danica O.F. Müll.			3.9		1.9	5.9

Table I. *continued*

Taxa	Stations					
	1	2	3	4	5	6
Ephemerella mucronata (Bengtss.)	1.9					17.7
Habroleptoides confusa Sar. et Jac.	1.9	3.2				7.9
Habrophlebia lauta Eatn.	5.9		3.9	5.9	15.8	1.9
Rhithrogena iridina (Kol.)			1.9			1.9
Total	56.5	9.7	45.0	57.0	72.7	161.2
TRICHOPTERA						
Agapetus sp.	9.8		3.9	11.8		19.7
Annitella sp.	15.8		19.7		5.9	11.8
Brachycentrus montanus Klap.	73.1		13.8		15.8	31.6
Hydropsyche sp.	5.9		1.9	5.9	7.9	5.9
Odontocerum albicorne (Scop.)	53.3		81.0	37.5	55.3	47.4
Potamophylax sp.	13.8		13.8	11.8	1.9	9.9
Rhyacophila sp.	1.9	3.2		1.9	1.9	3.9
Trichoptera juv.	25.7	6.5		33.5	5.9	
Total	199.3	9.7	134.1	102.4	94.6	130.2
DIPTERA						
Chironomidae	1047.0	434.2	272.7	341.8	312.2	565.2
Limoniidae	21.7	3.2	15.8	1.9	7.9	19.7
Muscidae	1.9		3.9			
Simuliidae	9.8		1.9	9.8		9.8
Tipulidae					13.8	9.8
Total	1080.4	437.4	294.3	353.5	333.9	604.5
COLEOPTERA	7.9	3.2	9.8	1.9	23.7	17.7
HYDRACARINA	1.9				3.9	
AMPHIPODA						
Gammarus sp.	1.9					
MOLLUSCA						
Ancylus fluviatilis M.	1.9					
Pisidium sp.			1.9		3.9	1.9
Total	1.9		1.9		3.9	1.9
ANNELIDA						
Oligochaeta	13.8	611.8	39.5	9.8	5.9	15.8
Hirudinea		6.5				
Total	1420.6	1084.7	554.0	601.2	596.6	996.2

In summer, total density of bottom fauna at each station was generally higher than in spring (Table II). However, at Stations 2 and 3, located nearest the sewage effluent, macrofauna density fell in comparison with that recorded in the spring. At Stations 2, 3, and 4 there was also a dramatic reduction in the number of taxa: from 46 at Station 1 to 4, 13, and 21 at following stations, respectively. All Chironomidae larvae collected at Stations 2 and 3 belonged to *Chironomus* gr.

Table II. Density of benthic macrofauna (ind. m^{-2}) in the Wolosaty stream on 9 August 1995

Taxa	Stations							
	1	2	3	3'	4	5	6	7
PLECOPTERA								
Dinocras megacephala (Klap.)						3.9	1.9	9 9
Leuctra sp	191 7				49.4	152.2	300.4	330.1
Nemoura sp							3.9	5.9
Perla sp.	3.9					1 9		
- *burmeisteriana* Claas.						7 9		5 9
Protonemura brevistyla (Ris)								11 8
Plecoptera juv.			1 9					
Total	195 6		1 9		49.4	165.9	306 2	363 6
EPHEMEROPTERA								
Baetis spp. juv.			3.9					
- *alpinus* (Pict)	1.9					5.9		67.2
- *muticus* (L.)	3 9				1.9	3 9	17.8	53 3
- *rhodani* (Pict.)	3 9				1 9		1.9	1.9
- *scambus* Etn							9 9	3.9
Caenis sp juv.	1.9							3.9
- *beskidensis* Sowa	7.9					3.9	23.7	13.8
Ecdyonurus sp. juv.	15.8						23.7	17.8
- *torrentis* Kimm.					3 9		15 8	9.9
- *venosus* (Fabr.)	23 7					7.9	47.4	81.1
Ephemera danica O F Müll.	3.9							
Ephemerella sp juv.	1.9							
- *ignita* (Poda)	29.6						19 7	49.4
Habroleptoides confusa Sar. et Jac	1 9					1.9		
Habrophlebia lauta Eatn.						1 9	1.9	
Rhithrogena sp juv	3.9							
Total	100.2		3 9		7.7	25.4	161 8	302.2
TRICHOPTERA								
Agapetus sp								3 9
Annitella sp.							1 9	
Brachycentrus montanus Klap	1816.2		11 8		181.8	191 6	2727.2	6525.7
Hydropsyche sp	7 9				3.9	5.9	25.7	316.2
Micrasema setiferum (Pict.)	88 9						15 8	
Odontocerum albicorne (Scop)	573 1		13.8		96.8	102 7	223 3	142 3
Potamophylax sp						1.9	191 6	77 0
Rhyacophila sp	9.9					1 9	9.9	55.3
Trichoptera juv					9 9			63.2
Total	2496.0		25 6		292.4	304.0	3195.4	7183.6
DIPTERA								
Chironomidae	1249.0	108.5	403 1	457 2	9193 6	4824.1	1464.4	1588.4
Culicidae				786.2		1.9		
Limoniidae	94 8	13.1	11.8		29 6	47 4	132.4	142.3
Muscidae	9 9				3 9		1.9	

Table II *continued*

Taxa	Stations							
	1	2	3	3'	4	5	6	7
Simuliidae	3.9							
Tipulidae					5.9	7.9	9.9	1.9
Eristalis tenax (L.)		3.2	5.9	118.4				
Total	1357.6	124.8	420.8	1361.8	9233.0	4881.3	1608.6	1732.6
COLEOPTERA	39.9		1.9		1.9	9.9	69.1	21.7
HYDRACARINA	3.9						29.6	9.9
MOLLUSCA								
Ancylus fluviatilis M						17.8	19.7	1.9
Pisidium sp.	3.9						11.9	1.9
Total	3.9					17.8	31.6	3.8
OLIGOCHAETA	41.5	6.5	3.9			11.8	7.9	1.9
Total	4238.6	131.3	458.0	1361.8	9584.4	5416.1	5410.2	9619.3

thummi-plumosus. At the same time, Chironomidae larvae dominated at Stations 4 and 5. In shallow pools separated from the main stream channel by narrow stony and gravel stretches (site 3') only Diptera larvae – *Chironomus* gr. *thummi-plumosus*, *Eristalis tenax* (L.), and numerous Culicidae were found. In communities at Stations 6 and 7 there were a few more taxa than at Station 1 with a simultaneous distinct increase in the numbers of mayfly, stonefly, and caddis fly larvae.

In autumn, there were 31 taxa at Station 1, among which caddis flies were prevalent (Table III). There were also a large number of Diptera and Ephemeroptera larvae. At the next stations, up to Station 5, the number of taxa was smaller than at Station 1. At Station 2, Oligochaeta prevailed, while Chironomidae larvae were the most numerous group at Stations 3–5.

Considering the density of Oligochaeta, Diptera, Trichoptera, Plecoptera, and Ephemeroptera some statistically significant differences were observed between the structure of benthic macroinvertebrates at Station 1 and the other investigated stations in all the three seasons (Table IV). Similar results of the χ^2 test were obtained when comparing the densities of Trichoptera larvae. On the basis of density of the most numerous families of Chironomidae and Limoniidae, statistically significant differences were observed in spring between Station 1 and Stations 3 and 6, in summer between Station 1 and Stations 3–5, and in autumn between Station 1 and Stations 3–6.

In the bottom macrofauna of the investigated stretch of the Wołosaty stream, distinct quantitative and qualitative changes due to pollution took place. As a result, the most vulnerable groups such as mayfly, stonefly, and caddis fly larvae were eliminated first. In summer, at a high water temperature and low discharge, there was a distinct quantitative decrease within the vulnerable groups. At the same time organisms connected with polluted waters appeared abundantly. At the stations distant from the sewage effluent most of the groups living above it were found. However, the equilibrium between them was visibly disturbed (Tables I–III).

Table III. Density of benthic macrofauna (ind. m^{-2}) in the Wolosaty stream on 7 October 1995.

Taxa	Stations					
	1	2	3	4	5	6
PLECOPTERA						
Dinocras megacephala (Klap.)				1.9		9.9
Isoperla oxylepis (Despax)	19.7					
Leuctra sp.	25.7		5.9	2.0		1.9
- *major* Brinck	3.9			1.9	1.9	1.9
Nemoura sp.	51.4		9.9	2.0	7.9	21.7
Perla burmeisteriana Claas.			1.9			9.9
Perlodes sp.	9.9					
Total	110.6		17.7	7.8	9.8	45.3
EPHEMEROPTERA						
Baetis alpinus (Pict.)	1.9			3.9	11.8	11.8
- *muticus* (L.)	9.9				5.9	47.4
- *rhodani* (Pict.)	9.9		9.9	13.8	11.8	37.5
- *scambus* Etn.	9.9		1.9	5.9	7.9	9.9
Caenis sp. juv.	45.4					3.9
Ecdyonurus sp. juv.	126.5			33.6	9.9	31.6
- *submontanus* Landa	49.4		3.9		13.8	13.8
- *torrentis* Kimm.	5.9			3.9		
- *venosus* (Fabr.)	67.2		7.9	13.8	21.7	21.7
Electrogena sp. juv.			1.9	3.9	5.9	45.4
- *lateralis* (Curtis)				1.9		
Epeorus silvicola (E. Pict.)			1.9	1.9		41.5
Ephemera danica O.F. Müll.						7.9
Ephemerella sp. juv.	11.8					3.9
- *ignita* (Poda)	9.9					1.9
Habroleptoides confusa Sar. et Jac.	9.9			5.9	1.9	1.9
Habrophlebia lauta Eatn.	13.8			1.9		23.7
Rhithrogena sp. juv.	75.1				5.9	7.9
Total	446.5		116.5	90.4	96.5	311.7
TRICHOPTERA						
Agapetus sp.					3.9	5.9
Annitella sp.			1.9			5.9
Brachycentrus montanus Klap.	1438.7	3.2	69.2	300.4	258.9	1422.9
Hydropsyche sp.	13.8		7.9	1.9	1.9	104.7
Odontocerum albicorne (Scop.)	278.6	9.8	136.3	94.8	45.4	496.0
Potamophylax sp.	11.8				7.9	124.5
Rhyacophila sp.	7.9					29.6
Trichoptera juv.				1.9		17.8
Total	1750.8	13.0	215.3	399.0	318.0	2207.3
DIPTERA						
Chironomidae	468.3		549.4	926.8	1027.6	458.5
Limoniidae	31.5	16.4	3.9	1.9	13.8	19.7
Simuliidae					1.9	7.9
Tipulidae	7.9					3.9
Total	507.7	16.4	553.3	928.7	1043.3	490.0

Table III continued

Taxa	Stations					
	1	2	3	4	5	6
COLEOPTERA	37.5			1.9		11.8
MOLLUSCA						
Ancylus fluviatilis M	3.9				1.9	1.9
Pisidium sp.						17.8
Total	3.9				1.9	19.7
OLIGOCHAETA	43.4	128.3	498.0	71.1	83.0	144.2
Total	2900.4	157.7	1400.8	1498.9	1552.5	3230.0

Table IV Significance (χ^2-test) of the differences in the composition of benthic macrofauna between the station above the sewage effluent (1) and the stations on the polluted sector (2–7) of the Wołosaty Stream in 1995

Sampling dates	Stations					
	2	3	4	5	6	7
Plecoptera, Ephemeroptera, Trichoptera, Diptera and Oligochaeta						
27 May	34660.3***	325.5***	188.8***	187.1***	428.4***	
10 August		749.7***		8407.9***	69.1***	1117.9***
7 October		11614.7***	2179.5***	2841.6***	351.0***	
Trichoptera						
27 May		112.2***		49.7***	10.5*	
10 August			86.6***	48.7***	2268.1***	5784.7***
7 October		379.9***		16.9***	1664.9***	
Chironomidae and Limoniidae						
27 May	ns	17.2***	ns	ns	5.3*	
10 August	ns	11.2**	637.8***	274.8***	ns	ns
7 October		29.4***	58.5***	43.7***	3.9*	

Significance levels: * – $P<0.05$; ** – $P<0.01$, *** – $P<0.001$, ns – not significant.

The elimination of vulnerable species and appearance of numerous, pollution-resistant ones at stations located close to the sewage effluent, as well as an excessive increase in the density of some taxa at those further from the source of pollution, resulted in significant differences in the structure of the community of benthic macroinvertebrates at these stations. However, the community structure recorded at Station 1 was not reconstructed in the 200 m stretch. The recovery of the assemblage of Diptera larvae was fairly rapid, while disturbances in those of Trichoptera larvae were observed along the entire length of the stretch under study (Table IV).

5. Discussion

Mayfly, stonefly, and caddis fly larvae are known to be organisms intolerant of pollution (Zelinka 1969, Olive and Smith 1975, Bervoets et al. 1989, Braasch and Joost 1989, Lenat 1993, Lang and Reymond 1995) and therefore avoided the polluted stretch of the Wołosaty stream. At the same time, in the area below the sewage effluent there was an increase in the density of *Chironomus* gr. *thummi-plumosus*, *Eristalis tenax*, and oligochaetes. Their presence may evidence distinct pollution of the water (Saether 1979, Dratnal and Kasprzak 1980). At stations further from the sewage effluent the proportion between particular groups differed from the typical structure of the undisturbed stretch of the stream. This may be a result of a trophic effect of sewage in the self-purification sector. Similar inter-dependencies were recorded below the mountain hostel near Morskie Oko in the Tatra Mts (Kownacki 1977).

The varied vulnerability to pollution of particular groups of benthic macro-invertebrates is used in compiling biotic indices for estimating the level of water pollution (De Pauw and Vanhooren 1983, Bervoets et al. 1989, Lenat 1993, Lang and Reymond 1995). In each of these indices, Trichoptera, Plecoptera and Ephemeroptera are the organisms regarded as vulnerable to water pollution. In the fauna of the Wołosaty stream, the most interesting species belong in fact to these groups (Szczęsny 1995). Increasing tourist activity and the increase in sewage quantity related with it is a serious threat to these species. About 80% of tourists visiting the Bieszczady Mts stay there in June and August. Therefore, the level of deterioration of the water was highest in summer. However, even in spring and autumn, with a quite high discharge, the impact of pollution could also be observed. The farther from the sewage effluent the more is the list of vulnerable taxa similar to that of an unpolluted habitat. Nevertheless, the community structure still remains different from the undisturbed one. In summer, when a low water level coincided with the peak of tourist activity, many taxa disappeared and the unique continuity of invertebrate communities was disrupted.

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