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Regeneration of the Molluscan Fauna of a Small Lowland River after Dredging

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Keywords: disturbance, recovery, dredging, diversity, abundance, mollusca.

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Andrzej Zawal [α], Anna Sulikowska-Drozd [σ], Edyta Stępień [ρ], Łukasz Jankowiak [ω] & Agnieszka Szlauer-Łukaszewska [¥]

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Keywords: disturbance, recovery, dredging, diversity, abundance, mollusca.

I. Introduction

Dredging of rivers and canals to enable navigation and agricultural land irrigation is a common practice worldwide. During dredging, macrophytic vegetation and bottom sediment are removed (Stępień at al. 2015; Stępień at al. 2016). These procedures directly and indirectly affect communities of aquatic organisms, by killing or damaging them, destroying their hiding places and feeding places, and altering hydrological conditions. Dredging is a *disturbance* in the river ecosystem according to the definition given by Yount & Niemi (1990), i.e. a relatively discrete event that disrupts community or population structure and changes the availability of resources or the physical environment. Following the initial decreases in benthic diversity and abundance that immediately follow a disturbance, aquatic organisms begin to colonize the sediments. This successional process, called *benthic recovery*, is defined as a return of living resources to pre-impact conditions, a reference condition (of a neighbouring unaffected area), or both (Wilber & Clark 2007).

There are several environmental conditions identified as influencing benthic recovery rates (e.g. sediment type or the time of the disturbance), but it seems that lotic ecosystems regenerate relatively fast, usually within months after dredging (Yount & Niemi 1990; Wilber & Clark 2007). The natural succession of aquatic organisms in dredged areas seems congruent with the process of recovery by benthic invertebrates after natural disturbances such as floods. The evidence shows that pre-flood conditions are usually re established within weeks to months of a flood event which caused substantial losses of invertebrate diversity and reductions in density (Lepori & Hjerdt 2006; Mundahl & Hunt 2011).

Depending on their habitat preferences, mobility, or life cycle characteristics (e.g. winged adult insects), it may be easier or more difficult for various groups of invertebrates to colonize parts of a river that have been dredged. Molluscs, due to their low mobility, potentially belong to groups which are not able to rapidly recolonize dredged river segments (Aldridge 2000), and work carried out in the river bed may lead to the destruction of populations of rare gastropod and bivalve species (Layzer et al. 1993; Rauers et al. 2004). The problem of the destruction of malacofauna during hydraulic engineering work and the process of recolonization of the bottom by molluscs requires in-depth research.

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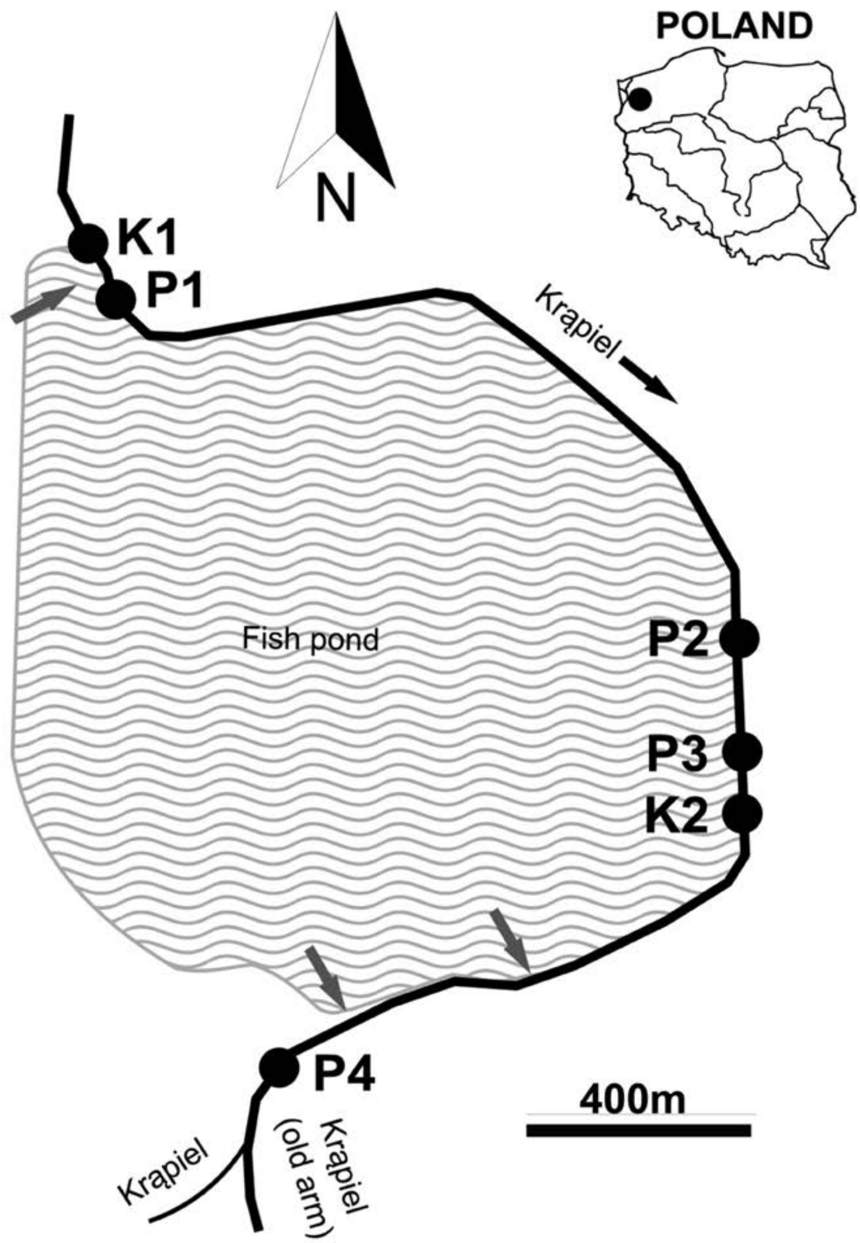

Fig. 1: Sampling localities on the Krąpiel River. K – control sites, undredged; P – dredged sites. Grey arrows indicate the connection between fish pond and the river channel

Assessing the recovery of benthic habitats disturbed by dredging and the disposal of dredged material is an important and growing management issue all over the world (Wilber & Clark 2007). A good understanding of this process may be helpful in selecting methods for maintaining the navigability of rivers that would least affect the diversity and abundance of aquatic invertebrates, and through the food web, of other living resources as well.

The research focused on the impact of dredging on some groups of macroinvertebrates: Hydrachnidia, Ostracoda, Odonata, Heteroptera, Trichoptera and Coleoptera (Szlauer-Łukaszewska & Zawal 2014; Zawal et al. 2015a; Zawal et al. 2015b; Płaska et al. 2016; Dąbkowski et al. 2016). The aim of the study was to assess the effect of dredging of a small lowland river on its Mollusca fauna during the year following this intervention. We describe communities of molluscs in the river before and after the dredging and follow the process of gradual recolonization of the dredged segment by gastropods and bivalves.

II. Study Area

The river Krąpiel is a tributary of the river Ina. The segment studied (coordinates N: 53°25′ 17.38″; E: 15° 11′ 39.25″ – N: 53° 24′ 33.94″; E: 15° 11′ 59.31″) takes the form of a regulated channel 6-8 m wide, running alongside fish ponds (Fig. 1).

Before the dredging the river bed was densely overgrown with macrophytic vegetation, mainly *Phragmites australis*, and the bottom was covered with a thick layer of mud. The intervention involved cleaning out the river bed – removing the mud and vegetation covering it using an excavator with a dredge operating from the bank of the river. The dredging was carried out in December 2008.

Following the dredging, the Krąpiel retained its previous width. All of the rushes and macrophytic vegetation were removed from the river bed (except for the segment under the bridge, which was left untouched). In addition, a 5 m strip of rushes and willow shrubs were removed on both sides of the river, leaving only isolated trees (alders and willows). The spoil was deposited on the banks in the form of excavated sediment. Sediment from the river was removed to such a level as not to interfere with the natural slope of the river bed, to avoid the formation of depressions filled with stagnant water. This resulted in the removal of about 80 % of the mud that had previously filled the river bed, as well as the removal of silt and sand from some places. The openness of the channel increased 20 – 50 % in places that were not previously overgrown and 80 % in places that had been overgrown with reeds (*Phragmites*).

Table 1: Characteristics of the sampled localities along the Krąpiel River; control (undredged) localities in bold

Localities		flow (m s^{-1}) before dredging	flow (m s^{-1}) after dredging	depth (m) before dredging	depth (m) after dredging	bottom before dredging	bottom after dredging	plants (%) before dredging	plants (%) after dredging	shadow before dredging	shadow after dredging
K1	**K1/1**	**0.5**	**0.46–0.51**	**0.7**	**0.7**	**gravel, stones**	**gravel, stones**	**0**	**0**	**lack**	**lack**
	K1/2	**0.01**	**0.002–0.02**	**0.5**	**0.5**	**sand, silt, mud**	**sand, silt, mud**	**70**	**50–70**	**partly**	**partly**
D1	D1/1	0.013	0.09–0.16	0.4	0.5	mud	sand, gravel	30	0–10	lack	lack
	D1/2	0.01	0.002–0.01	0.2	0.2	silt, mud	sand, silt, mud	90	0–40	partly	lack
D2	D2/1	0.02	0.01–0.05	0.2	0.5	silt, mud	silt, mud	90	0–10	partly	lack
	D2/2	0.002	0.001–0.002	0.1	0.2	mud	mud	100	0–40	partly	lack
D3	D3/1	0.02	0.02–0.05	0.3	0.5	silt, mud	sand, silt, mud	20	0–10	partly	lack
	D3/2	0.002	0.001–0.002	0.1	0.2	mud	sand, silt, mud	80	0–40	partly	partly
K2	**K2/1**	**0.14**	**0.09–0.2**	**0.5**	**0.5**	**sand, gravel**	**sand, gravel**	**0**	**0**	**partly**	**partly**
	K2/2	**0.003**	**0.001–0.003**	**0.2**	**0.2**	**sand, mud**	**sand, mud**	**70**	**30–70**	**partly**	**partly**
D4	D4/1	0.001	0.001–0.003	0.5	0.7	mud	mud	40	0–40	partly	lack
	D4/2	0.04	0.03–0.06	0.5	1.0	mud	mud	30	0–20	lack	lack

Six sampling stations were established on a segment of the river about 3 km long (Fig. 1). Two stations were situated at undredged locations (control stations) – K1 upstream from the dredged segment and K2 near the bridge, and the remaining stations were at dredged sites – P1, P2, P3 and P4.

At each station, samples were taken from the lentic (stagnant) and the lotic (drift) zone (Table 1). The former included shallow stretches, in some places strongly overgrown with plants, and the river bottom contained a layer of deoxygenated sediment whose surface was covered with detritus. The latter included stretches devoid of vegetation, with higher proportions of sand and gravel in the sediments.

Additional mollusc samples were collected from fish ponds (four stations) and from a small limnocrene spring.

III. Methods

The investigation of molluscs in the river Krąpiel was carried out in July 2008, before the dredging, and from April to August 2009, after the dredging. One series of samples was collected from the sampling stations before the dredging (total 12 samples), and after the dredging material was collected 5 times in successive months (total 60 samples). Additionally, in July 5 samples were collected in fish ponds and 2 samples in limnocren lying near the river.

The samples were taken using a hand dredge with 50 μm mesh net from a 1 m2 area marked by a metal square frame.

The molluscs collected were preserved in 75 % alcohol. Species identification was carried out by Professor A. Piechocki. The specimens are kept in the collection of the Department of Invertebrate Zoology and Hydrobiology, University of Lodz.

a) Data analysis

The dominance and constancy of mollusc species were classified according to Strzelec (1993). The dominance categories were as follows: D–dominant species, constituting at least 5 % of the total number of specimens, and d – rare species, constituting less than 5 %. The constancy categories were C – constant species, present in at least 50 % of sampling stations, and c – accessory species, with frequency of less than 50 % of the stations.

The mollusc species identified were divided into three ecological groups according to the classification by Ložek (1964): rheophilic species, associated with flowing water (R), species typical of lakes, ponds, and slow-flowing rivers (L), and species typical of small temporary or overgrown pools (S).

The occurrence of molluscs during the period following the dredging was analysed with respect to the following environmental factors: water flow velocity (FLOW), plant cover (PLANT), dredging impact (DREDGING) and substrate composition (SAND, SILT, MUD/DETRITUS). Flow velocity was measured with a FlowTracker Acoustic Doppler Velocimeter. Vegetation cover was estimated visually by the phytosociological method developed by Braun-Blanquet (1964). Estimated value of the percentage coverage arranged in bands including the lowest value coverage during the spring months to the highest in the summer months (Table 1). Bottom sediment components (stones, gravel, sand, silt and mud) were assessed by allocating a numerical value to each component, where the sum of the values always equaled 5, and the points allotted to respective components reflected their shares in the sediment volume. The shaded area shows the presence of shrubs or trees on the bank of the river, which for part of the day shadowing (partly) locality, or their absence (lack) (Table 1). Dredging impact was scored between 5 and 1; it was highest in April 2009 and lowest in August 2009. Substrate composition was visually estimated as the proportions of fine and coarse sediment and organic matter.

We used the DCA multivariate ordination method (Hill & Gauch 1980; ter Braak & Prentice 1988) to assess the range of the environmental gradient. Having verified by DCA that the environmental gradient covered was sufficiently long, we used CCA (ter Braak 1986; ter Braak & Verdonschot 1995) for community ordination of mollusc assemblages in relation to environmental variables. The species were grouped (ellipses in Fig. 5) using Van Dobben circles (Lepš & Šmilauer 2003).

To assess the impact of dredging on the mollusc community we used 'before-after-control-impact' (BACI) analysis, which makes it possible to compare data obtained in the control stations with data obtained in the impacted stations before and after the intervention, i.e. in July 2008 and July 2009. There are two aspects to be tested: BA – before and after – and CI – control and impact site. BACI is the test for the BA × CI interaction (Smith et al. 1993). The impact of dredging was tested in two ways: (1) by testing Mollusca abundance, expressed as the number of individuals at a given sampling station, with each species analysed separately, and (2) by the Shannon-Wiener Index (Magurran 2004), with the Mollusca biodiversity of each station analysed separately. When the abundance of Mollusca was used as the dependent variable, BACI was tested using a generalized mixed model (GLMM) with a log link and a negative binomial distribution. This should be used when the dependent variable shows high variation. We considered species a random effect (intercept) with scaled identity covariance. In the second analysis, the Shannon-Wiener Index was treated as a dependent variable and BACI was tested by factorial ANOVA.

IV. Results

a) Composition of fauna and community structure

During the entire study period a total of 1,034 live individuals belonging to 36 mollusc species were collected, of which 188 individuals belonging to 18 species were collected in the river before the dredging, 485 individuals belonging to 30 species were collected in the river after the dredging, 314 individuals belonging to 12 species were collected in the fish ponds, and 37 individuals representing 7 species were collected from the limnocrene spring (Table 2).

Taking into account only the samples from the river, 17 mollusc species were present in the samples before and after the dredging. The only species recorded in 2008 but not found later was *Anodonta anatina*. This bivalve was present in the fish ponds. As many as 12 taxa were noted for the first time following dredging of the river. It is worth noting that their abundance was relatively low. Among the species found only after the dredging, only *Gyraulus laevis* and *Physa fontinalis* inhabited the fish ponds near the river, while the genus *Stagnicola* (unidentified juvenile individuals) was also found in the nearby spring. The only species that was found only in the fish ponds was *Unio pictorum*, while *Valvata cristata*, *Bathomphalus contortus* and *Hippeutis complanatus* were present only in the spring.

Taking into account all of the material collected, *Anisus vortex*, *Bithynia tentaculata*, *Lymnea stagnalis*, *Planorbis planorbis* and *Radix balthica* were included among the dominant and constant species (DC) (Table

2). The dominant but accessory species (Dc) were *Galba truncatula*, *Gyraulus laevis* and *Unio crassus*. The remaining species were rare and accessory (dc). Before the dredging, two dominant and constant species were noted in the malacofauna of the river (DC: *Lymnaea stagnalis* and *Planorbis planorbis*), and 5 dominant but accessory species (Dc: *Anisus vortex*, *Galba truncatula*, *Planorbarius corneus*, *Radix balthica* and *Sphaerium corneum*).

The dominance structure of the malacofauna community changed after the dredging. The presence of 5 dominant and constant species was observed (DC: *Bithynia tentaculata*, *Galba truncatula*, *Lymnaea stagnalis*, *Pisidium amnicum* and *Sphaerium corneum*), and three dominant accessory species (Dc: *Anisus vortex*, *Unio crassus* and *Unio tumidus*). Additionally, *Viviparus viviparus* was a rare but constant species (dC).

Table 2: Molluscs overall abundance (ab), dominance (D) and frequency (C) in sampled sites; Ecol – habitat preferences: R – fast flowing waters, L – stagnant and slowly flowing waters, S – ephemeral water bodies; * – only empty shells found

No.	Species	Abbrev. of name	ab	D	C	river before dragging			river after dragging			fish ponds			limnocren		
						ab	D	C	ab	D	C	ab	D	C	ab	D	ECOL
1	*Theodoxus fluviatilis* (Linnaeus 1758)	*The flu*	21	2.0	0.2	7	3.7	0.2	14	2.8	0.3						R
2	*Viviparus viviparus* (Linnaeus 1758)	*Viv viv*	29	2.8	0.4	7	3.7	0.3	22	4.4	0.7						R
	Viviparus sp., juv.	–	7	0.7	0.1	4	2.1	0.1	3	0.6	0.2						
3	*Potamopyrgus antipodarum* (J. E. Gray 1843)	*Pot ant*	10	1.0	0.2				10	2.0	0.3						R
4	*Bithynia leachii* (Sheppard 1823)	–	1	0.1	0.1				1	0.2	0.1						S
5	*Bithynia tentaculata* (Linnaeus 1758)	*Bit ten*	60	5.8	0.5	20	10.6	0.3	34	6.9	0.6	6	1.9	0.4			L
6	*Valvata cristata* O. F. Müller 1774	–	3	0.3	0.1					0					3	8.1	S
7	*Galba truncatula* (O. F. Müller 1774)	*Gal tru*	89	8.6	0.3	13	6.9	0.4	76	15.4	0.5		0				S
8	*Lymnaea stagnalis* (Linnaeus 1758)	*Lym sta*	100	9.7	0.7	28	14.9	0.7	43	8.7	0.7	29	9.2	0.8			L
9	*Radix ampla* (W. Hartmann 1821)	–	4	0.4	0.1	2	1.1	0.1	2	0.4	0.1						R
10	*Radix auricularia* (Linnaeus 1758)	–	4	0.4	0.1				4	0.8	0.1						L
11	*Radix balthica* (Linnaeus 1758)	*Rad bal*	109	10.5	0.5	12	6.4	0.3	13	2.6	0.3	84	26.8	0.8			L
	Radix sp., juv.	–	19	1.8	0.1				19	3.8	0.2						
12	*Stagnicola* sp., juv.	–	5	0.5	0.2				2	0.4	0.2				3	8.1	S
13	*Planorbis carinatus* O. F. Müller 1774	–	1	0.1	0.1				1	0.2	0.1						L
14	*Planorbis planorbis* (Linnaeus 1758)	*Pla pla*	52	5.0	0.6	19	10.1	0.5	11	2.2	0.3	4	1.3	0.6	18	48.6	S
15	*Anisus vortex* (Linnaeus 1758)	*Ani vor*	167	16.2	0.6	19	10.1	0.2	53	10.7	0.4	95	30.3	0.8			L
16	*Bathyomphalus contortus* (Linnaeus 1758)	–	4	0.4	0.1					0					4	10.8	L
17	*Planorbarius corneus* (Linnaeus 1758)	*Pla cor*	30	2.9	0.4	15	8.0	0.3	4	0.8	0.2	6	1.9	0.6	5	13.5	L
18	*Gyraulus albus* (O. F. Müller 1774)	*Gyr alb*	13	1.3	0.3	5	2.7	0.2	7	1.4	0.3	1	0.3	0.2			L
19	*Gyraulus crista* (Linnaeus 1758)	–	2	0.2	0.1	1	0.5	0.1	1	0.2	0.1						L
20	*Gyraulus laevis* (Alder 1838)	–	73	7.1	0.2				1	0.2	0.1	72	22.9	0.6			L
21	*Hippeutis complanatus* (Linnaeus 1758)	–	3	0.3	0.1					0			0		3	8.1	L
22	*Segmentina nitida* (O. F. Müller 1774)	–	2	0.2	0.1	1	0.5	0.1	1	0.2	0.1						S
23	*Ancylus fluviatilis* O. F. Müller 1774	–	1*							0							R
24	*Physa fontinalis* (Linnaeus 1758)	–	3	0.3	0.2				2	0.4	0.2	1	0.3	0.2			L
25	*Aplexa hypnorum* (Linnaeus 1758)	–	1	0.1	0.1					0					1	2.7	S
26	*Anodonta anatina* (Linnaeus 1758)	–	8	0.8	0.3	2	1.1	0.1		0		6	1.9	0.8			R
27	*Unio crassus* Philipsson 1788	*Uni cra*	54	5.2	0.2	8	4.3	0.2	46	9.3	0.3						R
28	*Unio pictorum* (Linnaeus 1758)	–	5	0.5	0.1					0		5	1.6	0.4			R
29	*Unio tumidus* Philipsson 1788	*Uni tum*	35	3.4	0.3	5	2.7	0.1	25	5.1	0.3	5	1.6	0.4			R
30	*Sphaerium corneum* (Linnaeus 1758)	*Sph cor*	48	4.6	0.4	17	9.0	0.2	31	6.3	0.6						L
31	*Pisidium amnicum* (O. F. Müller 1774)	*Pis amn*	35	3.4	0.4	3	1.6	0.3	32	6.5	0.6						R
32	*Pisidium casertanum casertanum* (Poli 1791)	–	2	0.2	0.1				2	0.4	0.2						L
33	*Pisidium henslowanum* (Sheppard 1823)	–	3	0.3	0.2				3	0.6	0.3						L
34	*Pisidium casertanum ponderosum* (Stelfox 1918)	*Pis pon*	9	0.9	0.2				9	1.8	0.3						L
35	*Pisidium subtruncatum* Malm 1855	*Pis sub*	10	1.0	0.2				10	2.0	0.3						R
36	*Pisidium supinum* A. Schmidt 1851	*Pis sup*	13	1.3	0.3				13	2.6	0.4						R
	TOTAL		1034			188			495			314			37		

b) Changes over time

Before the dredging the presence of 18 mollusc species was noted in the river. Immediately following completion of the work (in April), 10 species were noted in this same segment of the river. A substantial increase in the number of species was noted in May (to 16), then in June the species richness remained at a similar level, and the samples from July and August contained 20 species of molluscs. The number of individuals noted in the samples increased continually from April to August.

The Shannon-Wiener biodiversity index remained at a similar level throughout the study period; seasonal differences were not statistically significant.

Taking into account the habitat preferences of the species (R, L and S), we can observe pronounced changes in the fauna after the dredging (Fig. 2). Before the dredging the mollusc fauna of the Krąpiel consisted mainly of rheophilic species and species characteristic of slow-flowing rivers (39 % and 44 %, respectively), while species associated with temporary or overgrown water bodies accounted for 17 %. Species typical of slow-flowing rivers predominated in the quantitative structure (63 %).

Immediately following the dredging only species from groups R and L were noted (50 % each), with clear predominance of molluscs belonging to the first group (rheophiles) in the quantitative structure (68 %). The species whose dominance indices decreased the most after the intervention are associated with standing or slow-flowing water – *Planorbis planorbis* and *Planorbarius corneus*. In contrast, there was an increase in the percentage of rheophilic bivalves in the community – *Unio crassus*, *Unio tumidus* and *Pisidium amnicum.* The number of species preferring standing and slow-flowing water (L) continually increased after the dredging. In the quantitative structure, such molluscs were more abundant than rheophiles (R) from June to August. In August their share reached 63 %, as before the intervention.

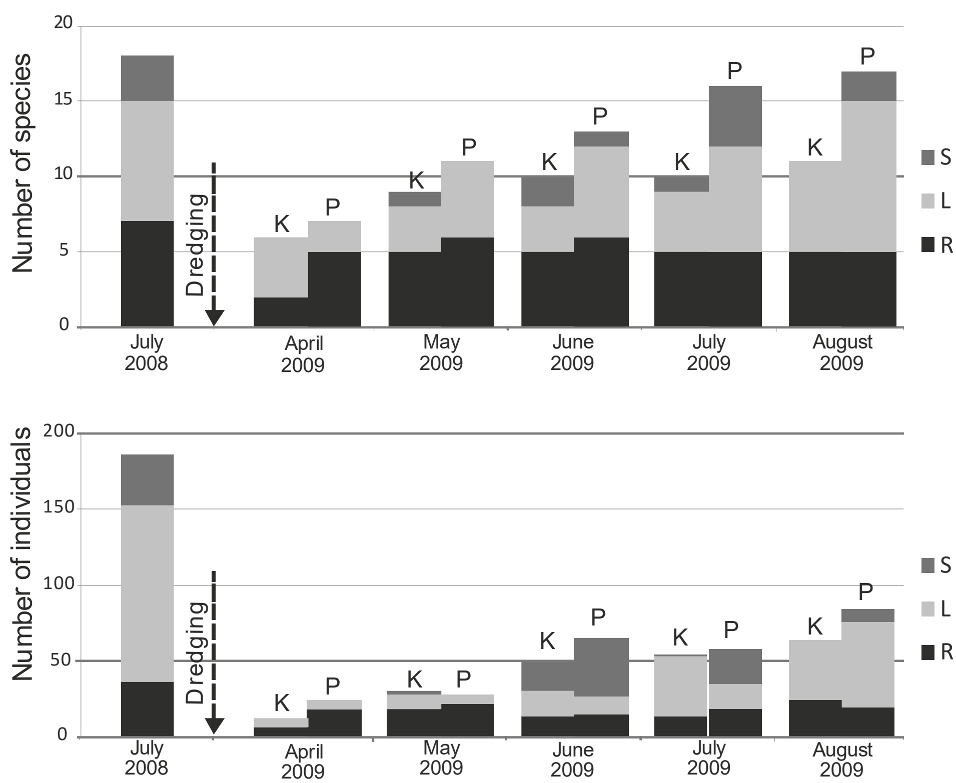

Fig. 2: Changes in species number and abundance of molluscs typical for fast flowing waters (R), stagnant and slowly flowing waters (L), and ephemeral water bodies (S) in control sites (K) and dredged (P) sampling sites

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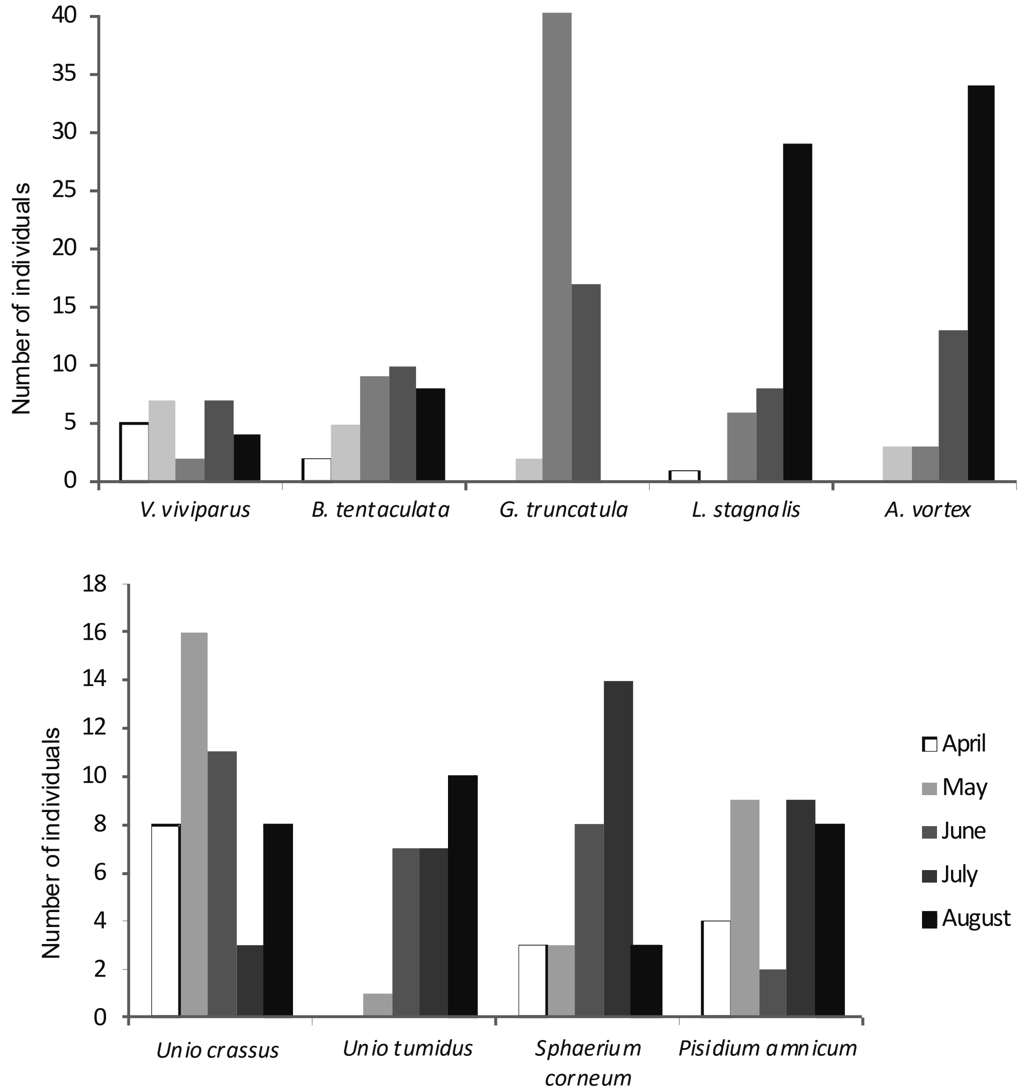

Fig. 3: Changes in total number of specimens of selected gastropod and bivalve species after dredging

After the dredging, from 1 to 4 species associated with small temporary and overgrown pools (S) were recorded in the river segment investigated. These were not detected immediately after the intervention. Their presence was noted from May, and they reached their greatest share of the quantitative structure in June (50 %). This was linked to the increase in abundance of *Galba truncatula* – this snail was present in very high numbers in single samples from June and July, but was not detected in August (Fig. 3).

The direction of the changes in the composition of the fauna was similar at the dredged and undredged sampling stations. The greatest differences were noted during the period immediately following the intervention (April-May), when the dredged sampling stations had a higher percentage of rheophilic species than the control stations (Fig. 2).

The increase in the total number of molluscs in the period from May to August is linked to changes in the abundance of species preferring standing and slow-flowing water, such as *Anisus vortex*, *Lymnaea stagnalis*, *Sphaerium corneum* and *Unio tumidus*. In contrast, the changes in the abundance of typically rheophilic molluscs (*V. viviparus*, *Unio crassus* and *P. amnicum*) showed no constant tendencies (Fig. 3).

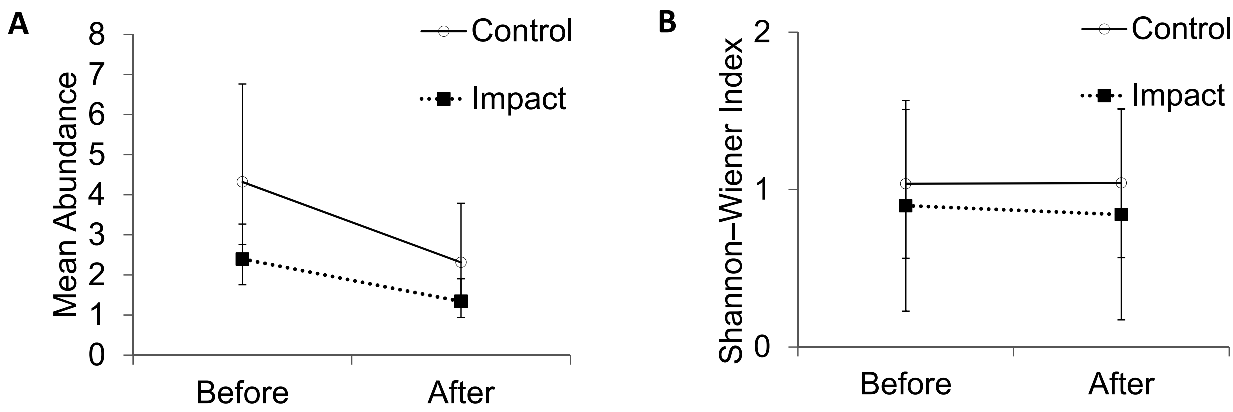

Fig. 4: BACI analysis. A – Mean abundance of molluscs ± 1 SD; the interaction is not significant (p = 0.919); B – Shannon-Wiener Index of molluscs diversity; the interaction was not significant (p > 0.05)

Table 3: BACI analysis of impact of dredging on Mollusca abundance. The tests of effects of GLMM model

Source	F-statistics	df1	df2	Significance
Corrected Model	5.634	3	128	0.001
Before-after	8.544	1	128	0.004
Control-impact	7.596	1	128	0.007
BA × CI	0.010	1	128	0.919

Table 4: BACI analysis of impact of dredging on Mollusca biodiversity expressed by Shannon-Wiener Index. The tests of effects of factorial ANOVA

Source	Sum of squares	df	Mean square	F-statistic	*p*
	19.421	1	19.421	47.160	0.000
Before-after	0.004	1	0.004	0.009	0.927
Control-impact	0.154	1	0.154	0.373	0.548
BA × CI	0.005	1	0.005	0.012	0.914
Error	8.236	20	8.236		

The BACI analysis showed no effect of the intervention on the total abundance and diversity of the molluscs (Tables 3 – 4, Fig. 4ab). Abundance decreased both at the dredged and control stations, and the Shannon diversity index remained at the same level.

c) Ecological preferences of molluscs

The DCA for the mollusc species after the intervention showed that the length of the gradient represented by the first ordination axis is 5.426, which means that the species covered a full Gaussian spectrum. This in turn made it possible to conduct direct ordination analyses (CCA) to determine the relationships between the occurrence of species and the environmental parameters tested in the Krąpiel. The eigenvalues of the axes show that the gradient represented by the first ordination axis substantially differentiates the occurrence of species (0.871), as its eigenvalue is greater than 0.5. The first axis explains 11.1 % of the variation in the mollusc species composition, and the second 7.6 %.

The results of the CCA for the samples collected from the Krąpiel following the dredging show that the variables used in the ordination explain 20 % of the total variance of the mollusc species (Table 5).

The results of the stepwise selection of environmental variables showed that of all the environmental parameters considered only the degree of bottom overgrowth by macrophytic vegetation (PLANTS), dredging, silt content in bottom sediments significantly statistically explained ($p \leq 0.05$) the range of variance of occurrence of species, being responsible respectively for 7.8 – 4.6, 3 % of the variance (Table 6).

The ordination diagram illustrating results of the CCA shows that the first group of species is the most strongly positively correlated with the plants coverage and negatively correlated with flow, and the third group is the most strongly negatively correlated with plants and positively correlated with flow, but flow is not statistically significant. The second group of species is the most strongly positively correlated with dredging process (Fig. 5). It consists of species that attained their greatest abundance in the first period following the dredging. These are mainly mollusks preferring a substrate devoid of macrophytes and a stronger current. This group of molluscs gains a favourable habitat when work that deepens the river bed and removes vegetation is carried out, and many of the species found here were not noted before the intervention (*P. subtruncatum*, *P. supinum* and *P. ponderosum*), or were less abundant (e.g. *U. tumidus*, *Pisidium amnicum*, and *V. viviparus*).

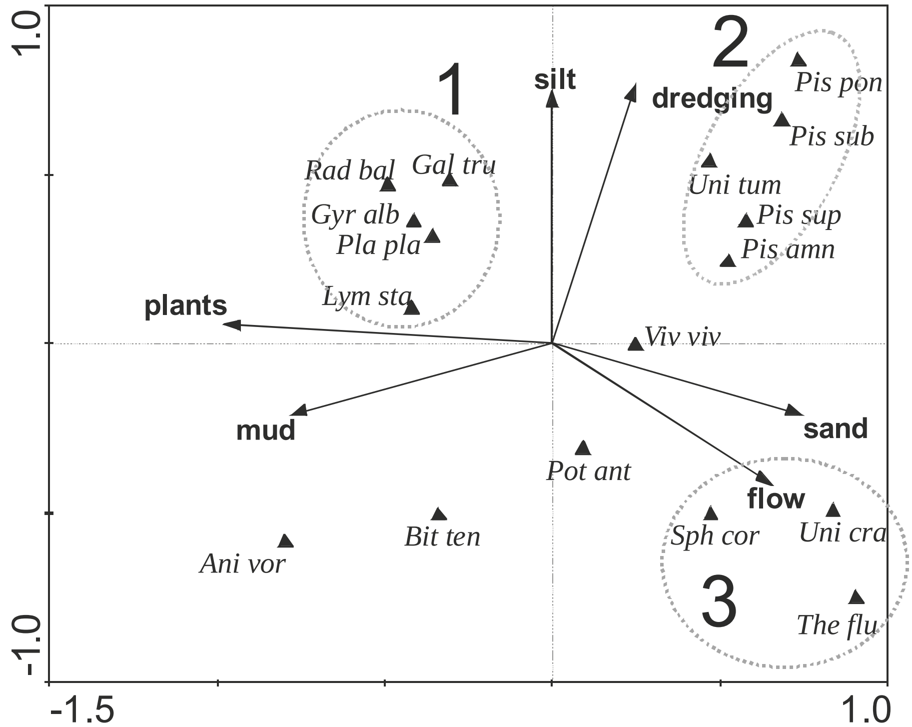

Fig. 5: CCA diagram for molluscs collected after dredging from the studied section of the Krąpiel River, species abbreviations–see Table 2 (species represented in the river by 5 or more individuals are shown on the diagram)

Table 5: Summary of CCA analysis between molluscs and environmental variables

Axes	1	2	3	4	Total inertia
Eigenvalues:	0.626	0.440	0.210	0.193	7.858
Species-environment correlations:	0.907	0.837	0.701	0.661	
Cumulative percentage variance					
of species data:	8.0	13.6	16.2	18.7	
of species-environment relation:	40.1	68.2	81.7	94.0	
Sum of all eigenvalues					7.858
Sum of all canonical eigenvalues					1.563

Table 6: Result of forward selection of environmental variables, using 499 permutations

Variable	**Conditional effects** LambdaA	P	F
plants	0.61	**0.002**	4.20
dredging	0.36	**0.002**	2.58
silt	0.24	**0.020**	1.74
flow	0.18	0.210	1.30
sand	0.17	0.206	1.26

V. Discussion

During the period before the dredging the mollusc fauna of the river Krąpiel was relatively poor in qualitative terms (19 species; 2 –7 per sampling station) and quantitatively very poor (average mollusc density of 17 ind. m^{-2}). Species typical of standing water and severely eutrophic water were dominant. This was probably due to unfavourable oxygen conditions and a thick layer of deoxygenated mud on the bottom. A study of molluscs in a near-shore zone of the Włocławek Dam reservoir showed that on the muddy substrate greater mollusc species richness was associated with a stronger current, which probably meant better oxygenation of the water (Żbikowski et al. 2007). Richer malacofauna has usually been noted in lowland rivers with a natural river bed, e.g. 38 species in the river Krutynia (Jakubik & Lewandowski 2011) and 40 species in the river Wkra (Lewin 2014). The samples collected in the Krąpiel after the dredging contained 31 mollusc species. Because Krapiel is a small river, and studies have been conducted over a very short distance, species richness is considered as high. The increase in the number of species recorded may have resulted from an improvement in living conditions in the river and the restoration of the fauna (see below), but also from the fact that more samples were taken during this period.

Despite the small number of species, the malacofauna of the Krapiel is interesting. It includes a population of the mussel *Unio crassus*, typical of clean water (Zając 2004), which is protected in the EU (Annex II and IV of the EU Habitats and Species Directive). *Unio crassus* was found both before and after the dredging of the river. Sampling stations K1 and K2, where this mussel was recorded in July 2008, were not dredged. After the intervention *Unio crassus* colonized the same two places, and single individuals were also collected at stations P1 and P3. The highest population density reached was 8 ind. m^{-2}. It appears that the occurrence of this species can be linked primarily to the increased current in certain segments of the river (0.1– 0.5 m s^{-1}). By comparison, in the river Wkra *Unio crassus* was recorded where the current was 0.06 – 0.6 m s^{-1}, and its density reached a maximum 20 ind. m^{-2} (Lewin 2014).

VI. Disturbance

Management of the river with the dredge affected the mollusc community in many ways. Molluscs were physically eliminated from the dredged sites, which reduced overall abundance and species richness (samples from April 2009 included only 10 species; mean mollusc density was 5.5 ind. m^{-2}). The removal of the vegetation and deepening of the river bed caused an increase in the speed of the current, which in turn led to an increase in the surface area of habitats preferred by rheophilic species such as *Viviparus viviparus*, *Unio tumidus* and *Pisidium amnicum*. This was accompanied by a marked decrease in the share of stagnophilic species in the community, as their microhabitats were destroyed.

Monahan & Caffrey (1996) showed that benthic invertebrates are negatively affected by removal of plants from the channel even if the bottom sediment has not been removed. Aquatic plants provide shelter from disturbances and predators, as well as a large surface area for epiphytic algae, which molluscs utilize as a source of food, and sites for deposition of eggs.

A dramatic loss in the mussel population after dredging of a navigable waterway in England (up to 23 % of the unionid population found in the spoil on the river bank) was reported by Aldridge (2000).

The high concentration of suspended sediment mobilized by dredging can alter the survival, growth and behaviour of stream biota. Increased water turbidity may have hindered respiration and food collection by molluscs (especially suspension feeders) (Gulati et al. 2008). This factor influenced both dredged sites and the undredged sites downstream. The undredged sampling station K2, situated between two dredged segments, can be presumed to have been affected by the changes caused by the intervention, including the temporary increase in the flow rate and the amount of suspended sediment in the water. Only sampling site K1 was situated upstream from the intervention and was not directly subject to the effect of the dredging. According to Diaz (1994), the effect of higher water turbidity could range from minor irritation or death for non-motile forms unable to escape, to benefits for motile forms that enter the turbid water in search for food or protection. Layzer et al. (1993) pointed out that silt deposition associated with turbidity caused by dredging was a major factor in the decline of mussels in regulated rivers, with juveniles being most heavily affected. It seems that filter feeding snail species such as *B. tentaculata* also suffered from the increase in water turbidity (Jokinen 1992). Finally, channel management may result in a reduction in the number of potential host fish to which the mussels' glochidia must attach to fulfil their life cycle, thus disrupting the recruitment in the mussel population (Aldridge 2000).

VII. Recovery

In the river investigated, after a pronounced decrease in the occurrence of molluscs immediately following the dredging, a gradual regeneration of the malacofauna was observed. In the summer (July–August 2009) the mollusc community in the investigated segment of the Krąpiel did not differ significantly (BACI analysis) in terms of species richness and abundance from its pre-dredging state (July 2008). The percentages of rheophilic species and species associated with standing water also returned to their prior state. The regeneration process of the malacofauna of this segment of the Krąpiel lasted about 7 months.

The process of regeneration of benthic communities following various types of disturbances (such as dredging, dredged spoil disposal or severe floods) has been described for flowing water bodies (Yount & Niemi 1990, Mundahl & Hunt 2011) as well as for estuaries and tidal areas (Diaz 1994). It has been observed that in the case of hydraulic engineering work the regeneration time for the benthos depends on the method of dredging and removal of macrophytic vegetation (Darby & Thorne 1995, Monahan & Caffrey 1996, Aldridge 2000). According to McCabe et al. (1998), the negative effect of dredging on invertebrates was found to be apparent only immediately afterwards, whereas a year later the same species of macroinvertebrates were common in the dredged area as well as in the reference area, and the total benthic invertebrate densities and biodiversity indices did not differ, indicating that the dredging did not have a statistically significant effect on these parameters.

The most invasive dredging methods (removal of macrophytes and a thick layer of bottom sediment in the entire river bed) cause the river bottom to be essentially devoid of macroinvertebrates, but many macroinvertebrates may recover relatively quickly owing to their motility, which enables them to escape during the management regime and to recolonize afterwards (Aldridge 2000). Recolonization of the river bottom takes place in many ways, including via migration from undredged segments of the river upstream and downstream from the site of the dredging (Williams & Hynes 1976).

According to Williams & Hynes (1976), most colonizing macroinvertebrates come from drift (over 40 %). This kind of passive dispersal occurs in mollusks and is not limited to their larval stages (only a few freshwater molluscs have free living larvae, e.g. *Dreissena polymorpha*), but also affects juvenile and adult individuals (Kappes & Haase 2012). Natural active upstream movement is slow in molluscs. It is estimated at 0.3 –1.0 km year–1 for most snails and below 0.1 km year–1 for bivalves (Kappes & Haase 2012). Observations by Aldridge (2000) indicate slow recolonization of dredged areas by adult mussels. The author reports that the fastest migration noted for European Unionidae species is ca. 5 m day^{-1}, although this is a response to environmental stress factors, such as high temperature or low dissolved oxygen. Similar results were obtained by Zając & Zając (2011), who showed that adult specimens of *U. crassus* experimentally distributed in fast-flowing parts of the river channel moved shorter distances than mussels distributed in slow deep parts, which try to move actively toward more preferable environmental conditions (the maximum distance recorded was 5.15 m).

Another potential means of recolonization of the river is movement of organisms up from within the substrate. This direction is important, as the hyporheos has been shown to consist of immature stages of many invertebrates, including unionids, which after leaving fish live for 2 – 5 years buried in the bottom sediment (Piechocki & Dyduch-Falniowska 1993). Many adult molluscs (e.g. *Viviparus*, *Theodoxus* or *Bithynia*) also spend the winter in the sediment of deeper zones of rivers and lakes (Piechocki 1979; Jakubik 2012). If the dredging of the river is carried out in the winter (as in the river we investigated), these seasonal migrations of snails deep into the sediment may be conducive to the survival of some individuals *in situ*, which is highly significant for the restoration of the population.

The composition and abundance of the fauna that remains in the river (remnant species) depends on the dredging method used (equipment and duration of the work). This is of fundamental importance in the process of regeneration of the benthic community. According to Ledger et al. (2006), remnant species potentially facilitate or inhibit settlement of other invertebrates or algae. The effect of remnant species on immigrant colonization echoes differences in their life-history traits and foraging behaviour. For example, the authors cited experimentally showed that *Radix* scraping epilithon promoted settlement of filter feeders and invertebrate predators, and strongly deterred settlement of nonpredatory chironomids.

The final potential means of colonization of a dredged river segment by molluscs is passive dispersal, which not only functions on a local scale, but also affects the spread of invasive species over a large area. Molluscs are transported with fish (the parasitic Unionidae larva – the glochidium) and by ships. Transport can even take place outside of the aquatic environment. It cannot be ruled out that aerial dispersal from other streams nearby played a role in the colonization of the Krąpiel by molluscs. In the direct vicinity of the river there are fish ponds inhabited by molluscs. The literature contains reports of the spread of small bivalves and gastropods by birds, mammals and aquatic insects. This usually involves shells attaching themselves to feathers or insect limbs, but cases have also been confirmed of molluscs being carried in the digestive tracts of other animals (Piechocki 1979; Kappes & Haase 2012 and literature cited within).

The rapidity of the regeneration of the malacofauna observed in the investigated segment of the Krąpiel is within the time range reported in the literature for flowing water affected by severe disturbances. For example, Mundahl & Hunt (2011) showed that taxa richness and community structure returned to pre-flood levels at most sites within a year. These researchers observed that the recovery of invertebrates (excluding flying insects) depends largely on their ability to survive the disturbance and on how quickly they reproduce. Thus, densities of some invertebrate groups recovered within months of the flood Baetidae mayflies, Chironimidae midges, Simulidae blackflies), while others (Ephemerellidae mayflies, Hydropsychidae caddisflies and Gammarus amphipods), required more than 2 years (Mundahl & Hunt 2011 and literature cited within).

Yount & Niemi (1990) enumerated several reasons for short recovery times of river communities: life history traits enabling rapid repopulation, accessibility of unaffected upstream and downstream areas serving as sources of organisms, or high flushing rates of lotic systems that allowed them to quickly dilute or replace waters. According to the authors cited, the river biota possesses adaptations enabling it to survive disturbances such as natural floods. Similarly, fauna of other aquatic habitats exposed to regular natural disturbances, such as tidal freshwater, exhibits eurytopic tolerance and may recover within three weeks after a disturbance caused by dredged spoil disposal (Diaz 1994). The rapidity of fauna regeneration is affected not only by the fertility of individual species, but also by a certain elasticity in their reproductive strategy. In *Viviparus viviparus*, for example, earlier reproduction (smaller females) was observed in individuals living in more unstable habitats (Jakubik 2012).

Our results and the review of the literature presented above indicate that in flowing water bodies communities of the benthos, including molluscs, have the ability to regenerate quickly following disturbances, both natural and of human origin. Although it was evident that molluscs were adversely impacted immediately after the dredging, our study indicated that after a year the malacofauna of the Krąpiel recovered to its premanagement state or was even enriched. The removal of a layer of deoxygenated sediments from the channel provided an opportunity for the establishment of more diverse and abundant mollusc assemblages.

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