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The influence of the landscape structure within buffer zones, catchment land use and instream environmental variables on mollusc communities in a medium-sized lowland river

Abstract The world's freshwater molluscan fauna is facing unprecedented threats from habitat loss and degradation. Declines in native populations are mostly attributed to the human impact, which results in reduced water quality. The objectives of our survey were to analyse the structure of the mollusc communities in a medium-sized lowland river and to determine the most important environmental variables at different spatial scales, including landscape structure, catchment land use and instream environmental factors that influence their structure. Our survey showed that a medium-sized river, that flows through areas included in the European Ecological Natura 2000 Network Programme of protected sites, provides diverse instream habitats and niches that support 47 mollusc species including *Unio crassus*, a bivalve of Community interest, whose conservation requires the designation of a special conservation area under the Habitats Directive Natura 2000. This survey showed that mollusc communities are impacted by several environmental variables that act together at multiple scales. The landscape structure within buffer zones, catchment land use and instream environmental variables were all important and influenced the structure of mollusc communities. Therefore, they should all be taken into consideration in the future restoration of the river, future management projects and programmes for the conservation of biodiversity in running waters. The results of this study may be directly applicable for the rehabilitation of river ecosystems and are recommended to stakeholders in their future decision concerning landscape planning, monitoring species and their habitats, conservation plans and management in accordance with the requirements of sustainable development.

Keywords Mollusca · Landscape metrics · Environmental factors · Endangered species · Protected area

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Introduction

The primary threats to streams and rivers are habitat alteration, i.e. changes resulting from catchment land use, including deforestation, intensive agriculture or urban development; contaminants, i.e. nutrient enrichment from agriculture, acidification, salinisation, and toxic metals, especially from hard coal mining, and municipal waste; and the occurrence of invasive species (Allan and Castillo 2007). These anthropogenic impacts in the catchment area and instream habitats result in the alteration of energy inputs, increased delivery of sediments and contaminants, elevated turbidity, higher concentrations of nutrients, chlorides, sulphates, trace metals, and decreased dissolved oxygen concentration in the water (Dodds 2002; Jarvie et al. 2008). Therefore, achieving good ecological potential and good chemical status of surface waters by 2015 as was required by the Directive (2000/60/EC) were not possible.

At the landscape scale, human activities are a major threat to the ecological integrity of river ecosystems because they impact the habitats, water quality, and the biota through numerous and complex pathways. Various types of land use impair the suitability of substrates for periphyton and biofilm production, decrease primary production and food quality, which cause bottom-up effects through food webs, accelerate litter breakdown, and favour more tolerant or alien species over more sensitive or native species (Allan 2004; Allan and Castillo 2007).

Intensive multiple land use severely affects the chemical, geomorphological, and, almost importantly, the biological aspects of freshwater ecosystems. Some studies have emphasised the close relationship between biological communities and land use. For example, agriculture and urban-industry land use have been shown to significantly reduce more sensitive macroinvertebrate taxa such as Ephemeroptera while increasing more tolerant taxa (Gao et al. 2014). The types of catchment land use are usually correlated with the physical and chemical parameters of the water and bottom sediments, which in turn affect the structure of lotic macroinvertebrate communities, including molluscs (Sponseller et al. 2001; Erba et al. 2015; Valle Junior et al. 2015). For example, Ciparis et al. (2012) found statistically significant relationships between catchment land use and the concentrations of heavy metals in the bottom sediments and *Mollusca* tissues.

In freshwater ecosystems molluscs play an unquestionably important role by participating in the circulation of organic matter and nutrients, in the self-purification processes of the water, and in the nutrient cycles (accumulation and release of nutrients), in addition to accumulating heavy metals and increasing water clarity. Molluscs also constitute a food resource for macroinvertebrates, fish, waterfowl and mammals (Økland 1990; Vaughn and Hakenkamp 2001; Strayer 2014). Among macroinvertebrates, freshwater molluscs, which are hololimnic organisms and have a limited capability of movement, are especially vulnerable to habitat alternation including water pollution, drainage and changes in the water regime (Cuttelod et al. 2011; Strayer 2014). Environmental factors that have a detrimental effect on mollusc populations, e.g. on their recruitment and life cycle, may work at different spatial scales, and usually include both the catchment areas of rivers and instream characteristics. Changes in the landscape structure and land use within riparian zones, even a change from a deciduous forest to a coniferous forest in the river catchment, can significantly reduce populations of freshwater molluscs. Data concerning both instream and riparian zone land use are useful tools for the evaluation of the population status of freshwater molluscs, including endangered species (Degerman et al. 2013). The world's freshwater molluscan fauna is facing unprecedented threats from habitat loss and degradation, introduced fish and other pests. Declines in native populations are mostly attributed to the human impact, which results in reduced water quality. The human impact is mainly reflected in the regulation of rivers and flow regimes, the fragmentation of suitable habitats, gravel mining and other sources of mine waste pollution, organic pollution, acidification, salinisation, and urban and agricultural development (Bogan 2008; Strong et al. 2008). In Europe, for example, the intensification of agriculture affects 36 % of mollusc species; urbanisation, including poor sewage control, affects 29 % of species; and the over-utilisation of water impacts 33 % of freshwater species. In comparison, invasive species affect about 5 % of species (Cuttelod et al. 2011). In degraded rivers alien mollusc species tend to flourish and usually outnumber the native mollusc taxa or occur alone.

In the face of the problems that are highlighted above and the facts that are related to the degradation of lowland rivers and the unquestionable, functional role of *Mollusca* in freshwater ecosystems, the formulation the following objectives of the survey is justified. The objectives of our survey were to analyse the structure of mollusc communities in a medium-sized lowland river and to determine the most important environmental variables at different spatial scales, including the landscape structure, catchment land use and instream environmental factors that influence their structure. To date, no study has been conducted using a broader, multi-scale approach and included the landscape structure within buffer zones, catchment land use, and instream environmental variables that determine the composition of mollusc communities in a lowland river.

Materials and methods

Study area

The Krąpiel River has a total length of 70 km and a catchment area of 640.2 km^2 (a medium-sized river). It is a typical lowland river (< 200 m a.s.l.) that partially flows through a landscape park within a natural physico-geographical region, the West Pomeranian Lakeland, which is part of the Central Plains (Ecoregion 14) according to the EU Water Framework Directive (EU WFD) (Directive 2000/60/EC) (Fig. 1). The upper course of the Krąpiel River shares some coverage with the special protected area 'Ostoja Ińska' (PLB 320008), which has an area of 87,711.0 ha, and was established under the Bird Directive (2009/147/EC) and Polish legislation. The valley of the lower course of the Krąpiel River is included in the European Ecological Natura 2000 Network Programme of protected sites, that represent areas with natural habitats of the highest value and rare or endangered plant and animal species in the European Community, as 'Dolina Krąpieli' (PLH 320005). This area protects 12 types of natural habitats and also protects several species that are of Community importance according to Council Directive 92/43/EEC, e.g. the otter *Lutra lutra* (Linnaeus, 1758), the thick-
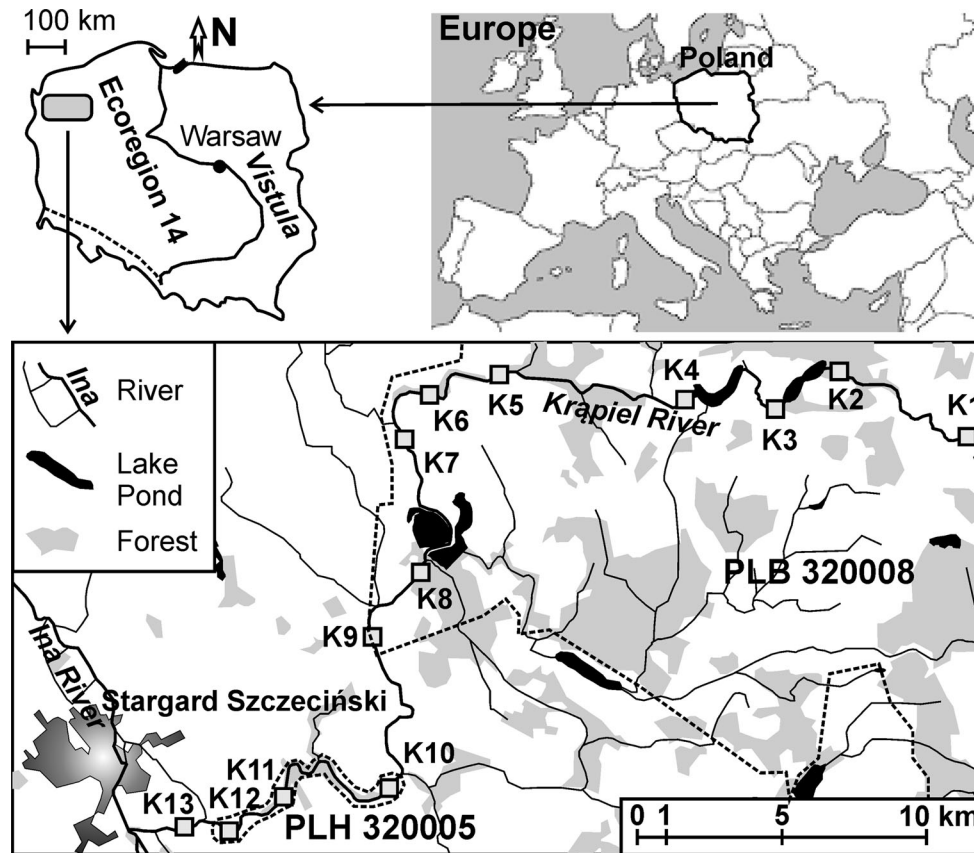
Fig. 1 Location of the study area (Ecoregion 14)

shelled river mussel *Unio crassus* Philipsson, 1788 and the weatherfish *Misgurnus fossilis* (Linnaeus, 1758). Natura 2000 is the largest network of protected areas in the world with more than 26,000 sites and covering about 17.5 % of the European Union land territory (Evans 2012). Among the countries that late joined the European Union (i.e. in 2004), Poland has lagged behind EU-15 in the designation of Natura 2000 sites and the development of the science research concerning the Natura 2000 Network Programme for relatively short time (Blicharska et al. 2016).

A section of the middle course of the Krąpiel River was dredged in January 2009. This involved the restoration of the previously regulated stretch of the river by removing plants and accumulated silt deposits, as well as the partial felling of trees and shrubs that were growing on the river banks (Szlauer-Łukaszewska and Zawal 2014; Zawal et al. 2015).

Methods

The study was carried out from April to October, 2010. Mollusc samples were collected from the head to the mouth on the entire length of the river. A total of 13 sampling sites (macrohabitats) were chosen within the survey area: in the upper (sites K1–K4), middle (sites K5–K9) and lower (sites K10–K13) courses of the river (Fig. 1). Samples were collected from several sub-sites at each of the 13 sites each month (seven times per one sampling sites, i.e. monthly from April to October). The number of sub-sites was determined in accordance with the spatial differentiation of the sampling sites: two at sites K4, K9 and K12, three at K2, K8 and K11, four at K3, K5, K7, K10 and K13, and five at K1 and K6.

A metal square frame was used to mark out a 0.5 m^2 sampling area in the bottom sediments and then the samples were taken using a hand dredge with a 500 μm mesh size. It was not possible to collect samples at certain sub-sites during periods of drought or flooding. A total of 810 samples were collected. The collected material was transported to the laboratory in plastic containers. The samples were washed using a 0.5 mm mesh sieve and then preserved in 75 % ethanol. Molluscs were identified to the species level based on their morphological and anatomical features according to Piechocki (1979), Piechocki and Dyduch-Falniowska (1993), Glöer and Meier-Brook (1998) and Glöer (2002). Species nomenclature follows Glöer and Meier-Brook (1998) and Glöer (2002). Empty shells were excluded from the analyses. The structure of the mollusc communities was analysed using the dominance index D % (Górny and Grüm 1981). The values for the dominance index D were divided into five classes: eudominants

> 10.0 % of sample, dominants 5.1–10.0 % of sample, subdominants 2.1–5.0 % of sample, recedents 1.1–2.0 % of sample and subrecedents ≤ 1.0 % of sample.

Prior to the mollusc sampling, water samples and bottom sediments were collected from each sampling site. The physical and chemical parameters of the water, i.e. temperature, pH, conductivity (EC) and dissolved oxygen concentration were measured in the field using a CX-401 multiparametric sampling probe (Elmetron, Poland). Water flow was measured using an acoustic FlowTracker flow meter (SonTek, USA) and insolation was measured using a DT-1309 light meter (CEM, China). BOD (Winkler's method), ammonium nitrogen, nitrates, phosphates and hardness were analysed in the laboratory using an LF205 photometer (Slandi, Poland) and turbidity was analysed according to the standard methods (Hermanowicz et al. 1999). Three measurements were performed each time and the median values were used for further analyses.

The grain size composition of the bottom sediments was determined using both the sieve and aerometric methods. Particle size classification was characterised according to the Krumbein phi (φ) scale:

$$\varphi = -\log 2D/D_0$$

where φ is the Krumbein phi scale, D is the diameter of the particle, D_0 is the reference diameter equal to 1 mm.

The bottom sediments were categorised as the weight ratios of grain size fractions (expressed as percentages).

Organic matter content in the bottom sediments was determined using the loss on ignition (LOI) method (Myślińska 2001). Individual sediment samples were freeze-dried using an Alpha 1-2 LD Plus freeze dryer (Christ), and then organic matter was removed from each sample by heating the sample in a Nabertherm furnace at 550 °C to obtain a solid mass. The percentages of mineral and organic matter were determined in this manner.

The phytosociological relevé method that was developed by Braun-Blanquet (1964) was used to quantify the degree of vegetation cover.

Analysis of the spatial structure of the buffer zones and catchments was based on a set of landscape metrics that were calculated using TNTmips software by MicroImages. Classification was based on data from Landsat TM7 28-05-2003. Land cover classes were determined according to the Corine classification. Buffer zones with a radius of 500 m from a sampling point were marked out using GPS. The following measures and indices were used to analyse the landscape structure:

1. Measurements of a patch area—area (AREA).
2. Measurements of patch density and size—number of patches (NUMP), mean patch size (MPS), median patch size (MEDPS), patch size standard deviation (PSSD) and patch density (PD).
3. Boundary measurements—total edge length (TE), edge density (ED) and mean edge length (MTE).
4. Shape measurements—mean shape index (MSI), mean patch fractal dimension (MPFD) and the sum of patch shape indices (SUM).
5. Diversity and distribution indices—mean distance to the nearest neighbour (MNN), interspersion and Juxtaposition Index (IJI), the Shannon patch diversity index (SDI), the Shannon evenness index (SEI), catchment area from the sources, catchment area, length of catchment boundaries, roughness (Ra), contagion (Cr), river gradient, distance from source, and distance from the river to each patch (forests, fields, swamps, built-up areas, meadows, shrubs, wasteland and water bodies). After the data were analysed, only the landscape parameters that were shown to have a statistically significant effect on mollusc distribution were selected.

Canonical ordination analyses for relating mollusc species composition to the environmental variables were carried out using CANOCO for Windows version 4.5 (Ter Braak and Šmilauer 2002). The appropriate type of analysis was chosen to analyse the species data using detrended correspondence analysis (DCA) and the length of the gradient. Preliminary DCA on the biological data revealed that the gradient length exceeded 3 SD (the standard deviation), thus indicating that the biological data exhibited a strong unimodal response to the underlying environmental variables. Therefore, a unimodal direct ordination, canonical correspondence analysis (CCA) with a forward selection, was used to reduce the large set of environmental variables. The following environmental variables were included into the CCA ordination: measures and indices of the landscape structure (measurements of patch area, measurements of patch density and size, boundary measurements, shape measurements, diversity and distribution indices), the instream variables (insolation, macrophytes, the percentage of organic matter in bottom sediments, grain size) as well as the physical and chemical parameters of the water.

Species that occurred at fewer than 10 % of the sampling sites were excluded from the statistical analyses following a preliminary exploration of their influence in the initial DCA analysis (McCune and Grace 2002). Environmental variables that showed collinearity were excluded from further analysis. The statistical significance of the relationship between the mollusc species and the environmental variables was evaluated using the Monte Carlo permutation test (499 permutations) (Ter Braak and Šmilauer 2002).

The significance of the differences in the values of the environmental variables, the number of species and density between sampling sites was calculated using the Kruskal–Wallis one-way ANOVA test (Fovler et al. 1998) and the multiple comparison post hoc test using Statistica version 12. The value of the environmental variables did not reveal a normal distribution according

to the Lilliefors test of normality (Statistica version 12), thus justifying the use of a non-parametric test.

Results

Lower minimum values of conductivity, hardness, dissolved oxygen and BOD were obtained at sampling sites in the upper course of the Krąpiel River compared to the middle and lower courses (Table 1). The concentration of dissolved oxygen in the water was relatively high at some sampling sites in the upper and lower courses (over 10.0 mg dm^{-3}). Turbidity ranged from 0.0 (middle course) to 100.0 (upper course). The concentrations of ammonium nitrogen and phosphates were relatively high in the upper and middle courses of the river (up to 3.0 mg N–NH$_4^+$ dm^{-3} and 2.5 mg PO$_4^{3-}$ dm^{-3}, respectively). The organic matter content in the bottom sediments ranged from 0 to 55 % (Table 1). The Kruskal–Wallis one-way ANOVA test revealed statistically significant differences in the average values of some of the environmental variables: dissolved oxygen ($H = 29.12$, $P = 0.0038$), conductivity ($H = 29.12$, $P = 0.0038$), BOD ($H = 45.70$, $P = 0.0001$, velocity ($H = 53.78$, $P = 0.0001$), insolation ($H = 55.55$, $P = 0.0001$), organic matter content in the bottom sediments ($H = 53.83$, $P = 0.0001$) and in all of the grain fractions between the sampling sites.

A total of 47 mollusc species were recorded in the Krąpiel River: 32 gastropod species and 15 bivalve species (Table 2). The number of species ranged from 9 to 24 at the sampling sites in the upper and middle courses within the special protected area 'Ostoja Ińska' (PLB 3200080) (sites K1–K9) and from 13 to 16 species at the sampling sites in the lower course (sites K10–K12), within 'Dolina Krąpieli' (PLH 320005), and at site K13.

Bithynia tentaculata (Linnaeus, 1758), *Anisus vortex* (Linnaeus, 1758) and *Sphaerium corneum* (Linnaeus, 1758) were eudominants in the mollusc communities in the river (Table 2). A typical fluviatile species, *Unio crassus*, which is a species of interest in the European Union, was a subrecedent in the mollusc communities at one site in the middle course (site K6), while *Pisidium supinum* A. Schmidt, 1851 was dominant or subdominant (middle course), subdominant subrecedent or recedent (lower course). A rheophilous species, *Pisidium amnicum* (OF Müller, 1774), was eudominant and subdominant mainly in the lower course or subrecedent in middle course (sites K7 and K9). Subrecedents: the gastropod species *Myxas glutinosa* (OF Müller, 1774) (site K7) and two bivalve species i.e. *Anodonta cygnea* (Linnaeus, 1758) (sites K3 and K4) and *U. crassus*, were recorded within the special protected area 'Ostoja Ińska'. The alien invasive species *Potamopyrgus antipodarum* (JE Gray, 1843) was eudominant, dominant or subdominant in the mollusc communities in the middle and lower courses of river (Table 2).

The Kruskal–Wallis one-way ANOVA and multiple comparison post hoc tests revealed statistically significant differences in the average number of mollusc species ($H = 43.18$, $P = 0.0001$) between the sampling sites located in the upper and middle courses of the Krąpiel River (Fig. 2a). Differences in the average values of mollusc density ($H = 47.54$, $P = 0.0001$) were statistically significant; the post hoc test showed statistically significant differences between the middle and lower courses (Fig. 2b).

Canonical correspondence analysis (CCA) based on species data and environmental variables showed that the first two axes explained 39.3 % of the variance in the species data and 60.6 % of the variance in the species data and environment relations. The relationship between the taxonomic composition of the mollusc taxa and the environmental variables was statistically significant (Monte Carlo test of significance of the first canonical axis: $P = 0.002$, F-ratio $= 4.690$; test of significance of all canonical axes: $P = 0.002$, F-ratio $= 2.864$). The eigenvalues of axes 1, 2, 3 and 4 were 0.591, 0.283, 0.197 and 0.133, respectively. Figure 3a shows the distribution of mollusc species in relation to the metrics of the buffer zones. Canonical correspondence analysis (CCA) revealed the following patterns of mollusc distribution: pulmonate gastropods, e.g. *Galba truncatula* (OF Müller, 1774), *Stagnicola palustris* (OF Müller, 1774), *Radix balthica* (Linnaeus, 1758), *Bathyomphalus contortus* (Linnaeus, 1758), *A. vortex* and *Planorbis planorbis* (Linnaeus, 1758) were positively influenced by increasing values of edge density (ED), whereas prosobranch gastropods, e.g. *B. tentaculata*, *Valvata piscinalis* (OF Müller, 1774), *Viviparus contectus* (Millet, 1813), the fingernail clam *S. corneum* and pulmonate gastropods, i.e. *Planorbarius corneus* (Linnaeus, 1758), *Physa fontinalis* (Linnaeus, 1758) and *Radix auricularia* (Linnaeus, 1758), were positively influenced by the Shannon patch diversity index (SDI) and the Shannon evenness index (SEI). The median patch size (MEDPS) and patch density (PD) also exerted a significant influence on the distribution of mollusc species (Fig. 3a).

An increasing area of marshes positively affected the abundance of *Bithynia leachii* (Sheppard, 1823), whereas *B. tentaculata*, *S. corneum*, *V. piscinalis*, *P. fontinalis* and *P. corneus* were positively influenced by an increasing area of the forest in the catchment area of the river (Fig. 3b). An area of meadows and pastures and the cumulative area of the catchment influenced the distribution of *R. balthica*, *P. planorbis*, *Lymnaea stagnalis* (Linnaeus, 1758), *S. palustris*, *B. contortus*, *A. vortex*, *Gyraulus albus* (OF Müller, 1774), *Planorbis carinatus* (OF Müller, 1774) and *R. auricularia*. The distribution of molluscs in relation to the river gradient, distance from the sources of the river, distance of particular patches occurring in the catchment from the river are presented in Fig. 3c. Some patterns were found in mollusc distribution: *B. tentaculata*, *S. corneum*, *V. piscinalis*, *P. corneus* and *P. fontinalis* were negatively

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Table 1 The values (ranges) of the environmental variables and the geographic coordinates of the sampling sites located along the Krąpiel River

Parameters	Sampling sites (macrohabitats)												
	K1	K2	K3	K4	K5	K6	K7	K8	K9	K10	K11	K12	K13
Geographic N	53.45503	53.47070	53.46524	53.46127	53.46558	53.45886	53.44659	53.40196	53.38773	53.33310	53.33268	53.32028	53.31856
Coordinates E	15.46668	15.41577	15.37936	15.33095	15.24869	15.20485	15.18220	15.19519	15.17051	15.17938	15.13296	15.101255	15.07694
Temperature (°C)	7.7–20.4	7.6–16.8	11.2–21.1	8.2–25.1	11.0–18.4	10.7–17.2	6.4–19.2	11.2–19.0	11.7–20.7	11.6–17.9	7.2–17.8	6.9–18.4	11.3–18.9
Conductivity (μS cm^{-1})	67–256	112–241	111–274	114–210	203–302	187–258	159–287	160–270	179–302	181–273	227–305	143–304	158–263
Turbidity (mg dm^{-3})	1.5–100.0	5.7–78.0	5.2–78.9	14.8–64.2	0.0–48.0	0.7–75.0	0.0–69.5	1.5–11.5	9.8–30.4.	4.5–75.0	1.5–47.7	12.1–122.0	0.1–49.3
pH	5.5–8.6	6.3–8.1	5.8–8.8	6.0–9.8	5.8–8.2	6.0–8.2	5.9–8.7	5.6–7.4	7.0–7.6	7.2–8.0	7.1–7.9	6.8–8.2	6.7–8.0
Diss. oxygen (mg O_2 dm^{-3})	1.1–11.2	1.5–10.2	4.3–11.1	4.8–14.1	2.6–8.7	6.6–8.8	3.8–9.3	2.1–7.5	2.4–8.5	5.3–9.9	5.9–9.8	5.1–10.3	8.3–14.9
BOD (mg O_2 dm^{-3})	0.8–5.1	4.1–7.7	5.0–8.6	4.1–7.2	3.2–7.3	3.8–6.6	3.6–5.9	0.0–3.3	3.3–6.1	4.5–8.5	4.1–7.1	0.0–7.0	3.6–7.4
Ammonium nitrogen (mg N–NH$_4^+$ dm^{-3})	0.1–2.7	0.1–1.4	0.2–3.0	0.4–1.4	0.2–1.2	0.1–0.8	0.2–1.3	0.3–1.8	0.1–2.7	0.3–1.3	0.1–1.5	0.1–1.5	0.2–0.7
Nitrates (mg NO_3^- dm^{-3})	0.2–2.4	0.2–5.3	0.4–3.4	0.4–2.7	0.5–4.2	0.4–3.0	0.4–10.7	0.4–2.5	0.4–8.2	0.4–7.5	0.4–2.8	0.4–8.3	0.4–8.8
Phosphates (mg PO_4^{3-} dm^{-3})	0.1–1.4	0.2–0.9	0.1–2.5	0.1–0.4	0.1–0.5	0.1–0.4	0.1–0.6	0.1–0.4	0.1–1.0	0.1–0.3	0.1–1.0	0.1–0.7	0.1–0.7
Hardness (mg $CaCO_3$ dm^{-3})	25–219	41–365	47–347	58–248	166–231	93–255	95–253	174–223	67–273	133–166	61–290	71–213	151–288
Iron (mg Fe dm^{-3})	0.0–0.36	0.0–0.24	0.0–0.08	0.0–0.08	0.0–0.07	0.0–0.15	0.0–0.40	0.0–0.14	0.0–0.20	0.0–0.20	0.03–1.70	0.0–0.20	0.0–0.50
Velocity (m s^{-1})	0.0008–0.6646	0.0061–0.5472	0.0056–0.9788	0.009–0.1704	0.0016–0.1573	0.0042–0.8712	0.0014–0.2034	0.0031–0.0073	0.0006–0.8637	0.030–0.5838	0.0065–1.1720	0.0019–0.2427	0.0024–0.6634
Organic matter (%)	0–14	0–9	0–7	9–54	33–55	0–13	0–36	7–43	9–18	0–6	0–20	1–12	0–10
Insolation (%)	0–100	0–55	0–100	100	100	0–93	30–100	100	86–100	0–25	1–93	2–100	2–100

Abbreviations for sampling sites along the Krąpiel River: K1–K4 upper course, K5–K9 middle course, K10–K13 lower course (See Fig. 1)

Table 2 The values of the dominance index (D %) calculated for the mollusc communities at the sites located along the Krąpiel River

Taxa	Sampling sites (macrohabitats)													Total	Conservation status	
	K1	K2	K3	K4	K5	K6	K7	K8	K9	K10	K11	K12	K13		A	B
Theodoxus fluviatilis						42.51	0.85		0.41	14.44	14.22	21.62	20.97	2.78	LC	
Viviparus contectus			2.28	0.56	0.11			4.24						0.91	LC	
Viviparus viviparus			0.19						1.64					0.07	LC	
Bithynia tentaculata		1.63	15.21	26.30	59.17	0.22	1.94	14.17	26.64	17.65	26.07	9.46	20.16	24.31	LC	
Bithynia leachii				0.28	4.28			0.06						1.10	LC	NT
Potamopyrgus antipodarum						34.45	2.70			4.28	3.79	5.41	0.81	1.92	NA	
Valvata cristata	0.08													0.01	LC	
Valvata piscinalis			3.21		0.11						2.37		0.81	0.72	LC	
Valvata piscinalis antiqua					0.50									0.12		
Acroloxus lacustris								0.22	0.82					0.06	LC	
Galba truncatula	0.51	0.33	1.14			0.22	0.68		0.41					0.19	LC	
Stagnicola palustris					0.04		11.67	3.31						1.84	LC	DD
Stagnicola occultus	0.25													0.03		NT
Stagnicola corvus							1.10							0.12	LC	DD
Stagnicola sp.	2.04	0.33	1.90	0.19	0.04		0.59	0.72	0.82					0.53		
Radix auricularia			1.14	5.67					5.33		0.47	1.35	0.81	1.31	LC	
Radix ampla			2.28				0.08		1.23		0.47	1.35		0.51	LC	
Radix balthica			1.14		0.04	0.22	2.70	2.54	0.82		0.47			0.80	LC	
Myxas glutinosa							0.08							0.01	LC	VU
Lymnaea stagnalis	0.08		2.70	0.19		0.22	8.28	1.71	9.43		0.47			2.02	LC	
Physa fontinalis		0.38	13.80	1.38			4.06	15.49	2.87					6.20	LC	
Aplexa hypnorum	0.08	0.38			0.11			0.06						0.06	LC	NT
Planorbarius corneus	2.46		15.97	16.68	4.39	0.45	4.82	4.24	0.82	0.53		2.70		6.35	LC	
Planorbis planorbis	2.72	0.65		2.65	0.08		16.23	2.81	3.28	1.07				3.20	LC	
Planorbis carinatus			1.52	0.56	0.04			0.88	0.41					0.31	LC	NT
Anisus spirorbis							0.17	0.99						0.19	LC	DD
Anisus leucostoma							0.08			0.53				0.02	LC	
Anisus vortex			20.53	1.91			37.11	31.53	24.18	2.14	0.95			10.84	LC	
Bathyomphalus contortus	11.13		0.38	0.05			1.01	1.21	4.10				1.61	1.66	LC	
Gyraulus albus			0.19				0.17	0.06	9.02					0.27	LC	
Hippeutis complanatus								0.11						0.02	LC	DD
Segmentina nitida	0.25	0.33							0.41					0.06	LC	
Ancylus fluviatilis							0.34			1.07	0.47			0.06	LC	
Unio tumidus										0.53			0.81	0.02	LC	
Unio crassus						0.45								0.02	VU	EN
Anodonta cygnea			0.76	0.05										0.03	NT	EN
Anodonta anatina										0.53			0.81	0.02	LC	
Anodonta sp.			2.28											0.06		
Sphaerium corneum	0.85		11.03	22.72	29.26	0.45		14.61	2.05	48.13	33.65	12.16	43.55	16.70	LC	
Pisidium amnicum						4.70	0.59		0.41	3.21	14.22	21.62	2.42	0.78	LC	
Pisidium henslowanum						0.22	0.59	0.06		0.53			0.81	0.10	LC	
Pisidium supinum						9.17	2.37			3.21	0.95	1.35	2.42	0.75	LC	
Pisidium subtruncatum	34.49	7.19			0.27	2.91	0.08	0.11	1.64		0.47	2.70		4.24	LC	
Pisidium nitidum	21.41	32.35	23.57			1.79	0.17	0.22		0.53		5.41		4.00	LC	
Pisidium nitidum f. arenicola	7.73	16.34												1.31		
Pisidium hibernicum	0.68	4.25	0.38											0.20	LC	VU
Pisidium personatum		4.58				0.22								0.14	LC	
Pisidium casertanum	12.49	12.09				0.45		0.66	2.87	1.07		10.81	1.61	2.01	LC	
Pisidium ponderosum								0.41				1.61		0.03		
Pisidium moitessierianum						0.89						1.35		0.05	LC	VU
Pisidium sp.	2.72	19.93				0.45	0.34			0.53	0.95	2.70		0.97		
No of specimens	1177	306	263	2152	2618	447	1183	1814	244	187	211	74	124	1080		
No of species	14	9	15	17	15	17	24	22	22	16	14	13	14	47		

Conservation status: *A* according to the European Red List of Non-marine Molluscs (Cuttelod et al. 2011) and *B* according to the Red List of Threatened Animals in Poland. Abbreviation for conservation status: *EN* Endangered, *VU* Vulnerable, *NT* Near Threatened, *LC* Least Concern, *DD* Data Deficient, *NA* Not Applicable

influenced by the river gradient and the distance from the sampling sites to the sources. *P. planorbis*, *P. carinatus*, *S. palustris*, *L. stagnalis*, *B. contortus*, *A. vortex*, *R. balthica*, *V. contectus* and *G. albus* were negatively influenced by an increasing distance from arable land, settlements, meadows and pastures (Fig. 3c).

The distribution of molluscs in relation to the structure of the substratum, velocity, degree of cover of the
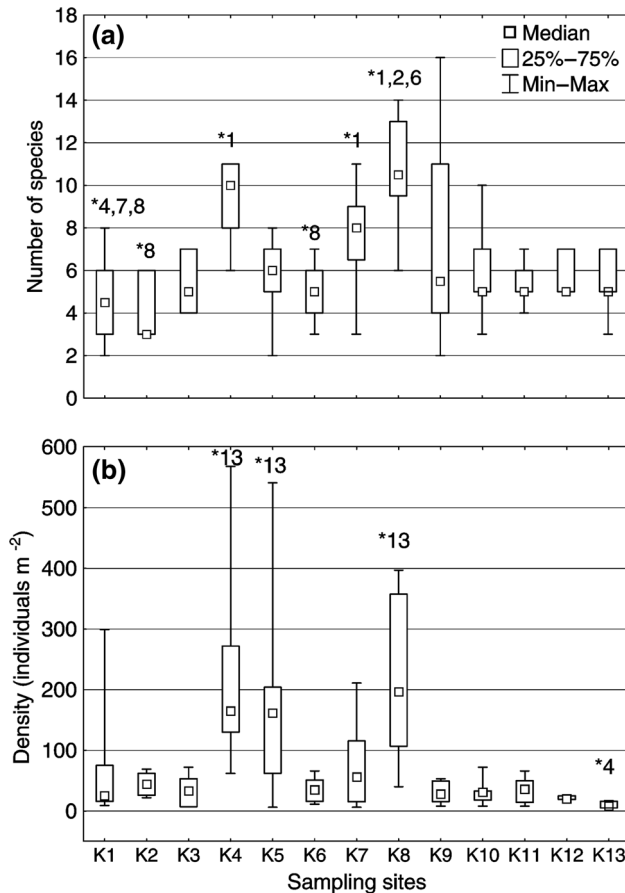
Fig. 2 Box-and-whisker plot showing the number of mollusc species (a) and the density of molluscs (b) in the Krąpiel River (medians, interquartile ranges, minimum and maximum values). Asterisks over a whisker denote significant differences between the sampling sites (the Kruskal–Wallis one-way ANOVA and multiple comparison post hoc tests)

river corridor by macrophytes and insolation are presented in Fig. 4a. Velocity, organic matter content in the bottom sediments, cover by macrophytes and grain diameter were the parameters associated (statistically significant according to the forward selection results) with the distribution of molluscs in the Krąpiel River (Fig. 4a). Increasing velocity positively affected species such as *Theodoxus fluviatilis* (Linnaeus, 1758), *P. supinum*, *P. antipodarum*, *P. amnicum* and *Pisidium casertanum* (Poli, 1791). Increasing percentage cover of the river corridor by macrophytes positively affected the abundance of *G. albus*, *P. carinatus*, *B. contortus*, *A. vortex*, *R. balthica* and *P. planorbis*. *B. leachii* was positively influenced by an increasing organic matter content in the bottom sediments (Fig. 4a). Among the physical and chemical parameters of the water, the turbidity and concentration of dissolved oxygen were the parameters most associated (statistically significant according to the forward selection results) with the distribution of mollusc species. *T. fluviatilis*, *Pisidium subtruncatum* Malm, 1855, *P. supinum* and *P. antipodarum* were negatively influenced by turbidity (Fig. 4b).

Discussion

Selected physical and chemical parameters of the water in relation to the other parameters of lowland rivers

According to the Directive (2000/60/EC), a good ecological potential and good chemical status of surface water were to have been achieved by 2015, generally with regard to temperature and the concentrations of dissolved oxygen and nutrients, pH and salinity. Although the upper and lower courses of the Krąpiel River (Ecoregion 14) are included in the European Ecological Natura 2000 Network Programme of protected sites, our results showed relatively high concentrations of ammonium nitrogen and phosphates in the water. The values for these chemical parameters are comparable to those recorded in sections of the Grabia River catchment (Ecoregion 14), which is heavily impacted by agriculture (Bis et al. 2000). The dissolved oxygen concentration (up to 14.9 mg O_2 dm^{-3}) was also relatively high. Conductivity ranged from 67 to 305 μS cm^{-1} in some stretches of the Krąpiel River, which is low in comparison with the reference conditions for lowland rivers (Nijboer et al. 2006). In contrast, the conductivity of the degraded lowland rivers that flow through the southern part of Ecoregion 14 is as high as 9740 μS cm^{-1} (Lewin et al. 2014).

Threatened and alien species in mollusc communities

This survey revealed the occurrence of 47 mollusc species, a relatively high number, in the Krąpiel River (a medium-sized river according to the catchment area), including one invasive alien species. According to Ciliak et al. (2015), 40 species of molluscs occur in the Hron River (a large river in Slovakia), which is almost four times longer than the Krąpiel River. In contrast, 33 mollusc species were recorded in the 396 km long Serbian section of the Danube River (a very large river) (Martinovic-Vitanovic et al. 2013), and 30 mollusc species, including four alien species, were noted in a degraded lowland river, i.e. the lower Havel River (Germany) (von Oheimb et al. 2007). The Krąpiel River supports fewer alien mollusc species than very large rivers in terms of catchment area (Bódis et al. 2012, 2016; Piechocki and Szlauer-Łukaszewska 2013).

Twelve mollusc species that are included in the Polish Red Data Book of Animals as Endangered (EN), Vulnerable (VU) or Data Deficient (DD) were recorded at the sampling sites located within the special protected area 'Ostoja Ińska' (PLB320008). Among these, two endangered bivalve species, the thick-shelled river mussel *U. crassus* and the swan mussel *A. cygnea*, are regarded as Vulnerable (VU) and Near Threatened (NT), respectively, in Europe according to the European Red List of Non-marine Molluscs (Cuttelod et al. 2011). The main reasons for the threat are changes in the physical
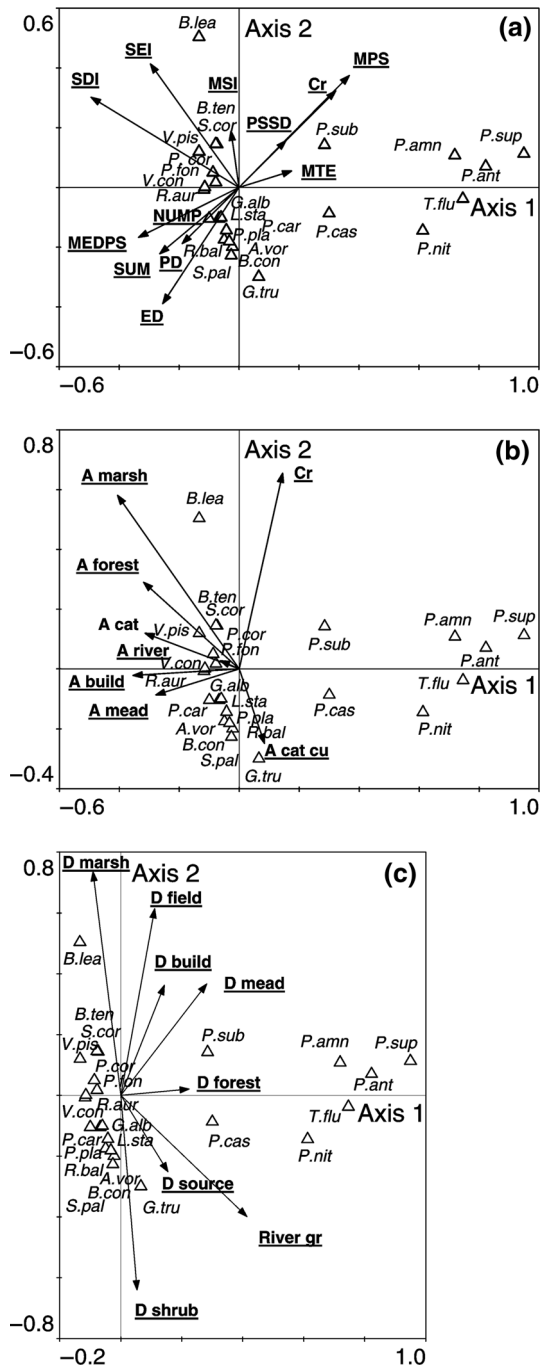
◄**Fig. 3** Ordination diagram (biplot) based on the canonical correspondence analysis (CCA) of the Mollusca data and the metrics of the buffer zones (**a**); the catchment area, contagion and area of specific patches (**b**); the river gradient, distance from the river sources and distance from the river to individual patches occurring in the catchment (**c**) (statistically significant environmental variables are underlined). Abbreviations: *Cr* contagion, *ED* edge density, *MEDPS* median patch size, *MPS* mean patch size, *MSI* mean shape index, *MTE* mean edge length, *NUMP* number of patches, *PD* patch density, *PSSD* patch size standard deviation, *SDI* Shannon patch diversity index, *SUM* sum of patch shape indices, *SEI* Shannon evenness index, *A cat* catchment area, *A cat cu* cumulative catchment area, *A build* area of settlements, *A forest* area of forest, *A marsh* area of marshes, *A mead* area of meadows and pastures, *A river* area of running waters, *Cr* contagion, *D build* distance from the river to settlements, *D field* distance from river to arable fields, *D forest* distance from river to forests, *D marsh* distance from river to marshes, *D mead* distance from river to meadows and pastures, *D shrubs* distance from river to shrubs, *D source* distance from the sources of the river, *River gr* river gradient, *A.vor, Anisus vortex*; *B.con, Bathyomphalus contortus*; *B.lea, Bithynia leachii*; *B.ten, Bithynia tentaculata*; *G.tru, Galba truncatula*; *G.alb, Gyraulus albus*; *L.sta, Lymnaea stagnalis*; *P.fon, Physa fontinalis*; *P.amn, Pisidium amnicum*; *P.cas, Pisidium casertanum*; *P.nit, Pisidium nitidum*; *P.sub, Pisidium subtruncatum*; *P.sup, Pisidium supinum*; *P.cor, Planorbarius corneus*; *P.car, Planorbis carinatus*; *P.pla, Planorbis planorbis*; *P.ant, Potamopyrgus antipodarum*; *R.aur, Radix auricularia*; *R.bal, Radix balthica*; *S.pal, Stagnicola palustris*; *S.cor, Sphaerium corneum*; *T.flu, Theodoxus fluviatilis*; *V.pis, Valvata piscinalis*; *V.con, Viviparus contectus*

and *A. cygnea*, also result from changes in the composition of fish species and the loss of obligate host fish species (Zettler and Jueg 2007; Douda et al. 2012; Schwalb et al. 2013). The dramatic decrease in the population density of the thick-shelled river mussel has led to the consideration of the status of this species in European law. *U. crassus* is one of the species of Community interest whose conservation requires the designation of a special conservation area within the Habitats Directive Natura 2000 (Council Directive 92/43/EEC). According to the Polish Red List of threatened Animals in Poland four gastropod species recorded in the Krąpiel River, *Aplexa hypnorum* (Linnaeus, 1758), *B. leachii*, *Stagnicola occultus* (Jackiewicz, 1959) and *P. carinatus*, are regarded as Near Threatened (NT), and one species, *M. glutinosa*, is listed as Vulnerable (VU). Although the glutinous snail *M. glutinosa* is included on the European Red List of Non-marine Molluscs (Cuttelod et al. 2011) as an LC species, it is rare in many countries. The glutinous snail, which is restricted to very clean water, is protected in Poland (Dz. U. 2014). Although *M. glutinosa* is uncommon in most parts of Denmark, Ireland, England, Sweden and Finland; it has been recorded in ten of the 25 limnofaunistic regions of Europe (Økland 1990; Kerney 1999). Eutrophication, the regulation of rivers, the loss of marshy habitats and removing macrophytes are the main threats to these five gastropod species. For example, 74 % of the gastropods and 72 % of the mussels of the entire fauna in Canada and the USA are imperilled (vulnerable, threatened or endangered) or extinct. According to Johnson et al. (2013), threats to gastropod species, besides channelisation,

and chemical parameters of the water, eutrophication (especially elevated concentration of nitrates in running waters), the regulation of rivers, the exploitation of sand and gravel from the river corridors, dredging and weed cutting as well as habitat modification and destruction (Aldridge 2000; Bogan 2008; Lewin 2014). Freshwater mussels (Unionoidea) are one of the most imperilled faunal groups on a global scale. They are considered to be extinct, endangered or rare worldwide (Vaughn, 2012). Unionoidea require a host fish in order to successfully complete their recruitment. Therefore, the potential threats to mussel species, including *U. crassus*

excessive sedimentation, water pollution (with salts, Cu, Hg, Zn, untreated sewage or agricultural runoff), include the influence of invasive species. The invasive alien species *P. antipodarum*, which originates in New Zealand, and which was recorded at sites along the Krąpiel River, at extremely high densities, may compete for food and for the space that is occupied by native fauna, thus significantly limiting the growth of native gastropod species (Strayer 1999). Even outside its native range, e.g. in Poland, the New Zealand mud snail (*P. antipodarum*) is able to reproduce throughout the year (via parthenogenesis) (Lewin 2012; Regulation (EU) No (1143)/2014.

The influence of landscape structure within buffer zones and catchment land use on mollusc communities

Our survey showed that the mollusc communities in the Krąpiel River are influenced by several environmental variables that are related to the landscape features of buffer zones, land use, and instream environmental variables acting together. According to Cortes et al. (2011), the environmental variables that exert a significant influence on a river system are distributed over a hierarchically organised spatial scale. They assessed and identified the most predictive fractal metrics of landscape descriptors within buffer zones that explained the changes in the composition of macroinvertebrate communities. The most important of these were the area-weighted patch fractal dimensions of agriculture and forest and the number of patches. In contrast, our results revealed the importance of landscape descriptors within buffer zones in relation to the composition of mollusc communities, such as the Shannon patch diversity index (SDI), the Shannon evenness index (SEI), the distance from the centre of the buffer zones of lowland peatbogs and of running waters, the area of arable fields and the distance from the centre of the buffer zones of a mixed forest. In contrast, Death and Joy (2004) showed that the physical and chemical parameters of the water, substrate composition and riparian vegetation were better predictors of the macroinvertebrate community structure, including Mollusca, than the land use categories. However, they showed that of 52 catchment variables, the area of pastures and forest was most associated with the distribution of macroinvertebrates.

According to Kerney (1999), mollusc distribution is rarely controlled by a single factor. Our results for the CCA ordinations suggested that in contrast to some fingernail clam species, *P. planorbis*, *P. carinatus*, *S. palustris*, *B. contortus*, *A. vortex*, *R. balthica*, *V. contectus* and *G. albus* were negatively influenced by an increasing distance from arable land, meadows and pastures. These gastropod species feed mainly on periphytic algae. For example, algae constitute over 66 % of the food sources consumed by *G. albus* and *A. vortex*, over 20 % of the food sources consumed by *V. contec-*
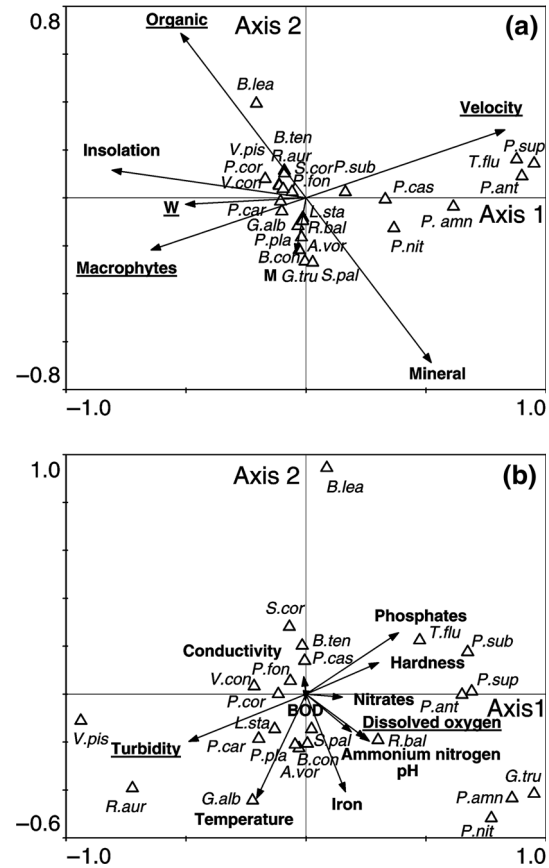
Fig. 4 Ordination diagram (biplot) based on the canonical correspondence analysis (CCA) of the Mollusca data and velocity, substratum and insolation (**a**) or selected physical and chemical parameters of the water (**b**) (statistically significant environmental variables are underlined). Abbreviations: *M* mean grain size, *Mineral* mineral fraction of bottom sediments, *Organic* organic matter in bottom sediments, *Macrophytes* degree of macrophyte cover of the river corridor, *Velocity* water current velocity, *W* sediment sorting, *A.vor*, *Anisus vortex*; *B.con*, *Bathyomphalus contortus*; *B.lea*, *Bithynia leachii*; *B.ten*, *Bithynia tentaculata*; *G.tru*, *Galba truncatula*; *G.alb*, *Gyraulus albus*; *L.sta*, *Lymnaea stagnalis*; *P.fon*, *Physa fontinalis*; *P.amn*, *Pisidium amnicum*; *P.cas*, *Pisidium casertanum*; *P.nit*, *Pisidium nitidum*; *P.sub*, *Pisidium subtruncatum*; *P.sup*, *Pisidium supinum*; *P.cor*, *Planorbarius corneus*; *P.car*, *Planorbis carinatus*; *P.pla*, *Planorbis planorbis*; *P.ant*, *Potamopyrgus antipodarum*; *R.aur*, *Radix auricularia*; *R.bal*, *Radix balthica*; *S.pal*, *Stagnicola palustris*; *S.cor*, *Sphaerium corneum*; *T.flu*, *Theodoxus fluviatilis*; *V.pis*, *Valvata piscinalis*; *V.con*, *Viviparus contectus*. Abbreviations for mollusc species, see Fig. 3

tus, *S. palustris*, *P. planorbis* and almost 40 % of the food sources consumed by *R. balthica* (Tsikhon-Lukanina et al. 1998). Although algae assimilate orthophosphates directly, other forms of phosphorus must be transformed into orthophosphates by phosphomonoesterase before they can be assimilated. The relatively high concentration of phosphates recorded in the Krąpiel River may increase the development of algae, which in turns provides food for these gastropod species. This result is consistent with those obtained by Robinson et al. (2014), who showed a relationship between macroinvertebrates, including molluscs, and arable (agricultural) land use. Algal biomass, as well as that

of bacteria and fungi, which also constitute food resources for molluscs, increases with the nutrients that flow off agricultural lands. Therefore, an increase in mollusc growth, fecundity and population abundance can be observed, but only up to the threshold value of the nutrient concentration in the water (Lewin 2014; Strayer 2014). Our results also confirmed and supported those obtained by Theodoropoulos et al. (2015), who found that agriculture and development were positively correlated with the distribution of molluscs, including Lymnaeidae and Planorbidae. However, they recorded higher concentrations of phosphates (up to 3.99 mg dm^{-3}) in the water of an agricultural river catchment than was observed in the Krąpiel River.

The influence of instream environmental variables on mollusc communities: substratum

Our results revealed that an increasing cover of the river corridor by macrophytes was one of the predictive environmental factors of mollusc distribution, including pulmonate species, e.g. *P. carinatus*, *G. albus*, *B. contortus*, *P. planorbis* and *A. vortex*. Freshwater gastropods feed mainly on periphytic algae, bacteria, detritus and decaying macrophyte tissues, while living macrophytes usually constitute a negligible part of their diet. However, *P. planorbis*, for example, feeds on periphytic algae but also consumes macrophytes, which account for up to 48.1 % of its entire food resources (Tsikhon-Lukanina et al. 1998). Submersed macrophytes provide a substratum for epiphytic algae, which can have an adverse effect on the growth rate of their macrophyte hosts. Epiphytic algae reduce the light that reaches the macrophytes, compete for nutrients, and create high pH or anoxia in darkness. Gastropods that graze on submersed macrophytes remove the epiphytic cover and decaying tissues (Brönmark 1989). Increased macrophyte growth also increases the surface area of epiphyton, which gastropods feed on, as well as the sites for shelter and oviposition. It has been shown (Underwood et al. 1992) that the growth of *Ceratophyllum demersum* (L.), for example, was significantly enhanced in the presence of grazing pulmonate gastropods because they reduced the density of the algal and bacterial epiphyton, which are potentially deleterious to macrophytes, and provided nutrients such as phosphates and ammonia. Therefore, the interactions between submersed macrophytes, gastropods, epiphytic algae and bacteria can be regarded as mutualistic. Moreover, pulmonate gastropods are able to achieve a net uptake of the dissolved organic carbon (DOC) that is produced by living macrophytes and then metabolise it (Thomas and Kowalczyk 1997). Therefore, the positive relationship between macrophytes and gastropods may be explained by their feeding mode. Furthermore, some evidence suggests that gastropods are attracted to macrophytes not only as food sources and a substratum but also as a shelter against velocity (Dillon 2000). Our

result is consistent with a study by Brown and Lodge (1993), who showed that gastropod distribution, is positively correlated with an increase in the macrophyte cover of a river corridor.

This results of the CCA ordination showed that the distribution of some pill clams, e.g. *P. subtruncatum*, *P. casertanum*, *P. supinum*, *Pisidium nitidum* Jenyns, 1832 and *P. antipodarum*, were negatively influenced by increasing macrophyte cover and particle size of bottom sediments. Some species of Pisidium species prefer a coarser, sandy substrata because the large-pored interstitial spaces enable them to take up oxygen-rich water while at the same time preventing them from sinking as they crawl on the surface of the substratum (Meier-Brook 1969). Moreover, pisidiids can feed directly on deposited organic matter rather than on suspended particles. They supplement suspension feeding in the water column by feeding on organic detritus and bacteria in the sediments, by filtering interstitial water, and by deposit feeding (Dillon 2000; Vaughn and Hakenkamp 2001). According to Piechocki and Strzelec (1999), pill clams that are typical of sandy sediments, i.e. *P. subtruncatum*, *P. casertanum*, *P. nitidum*, prefer coarse and medium-grained sand (particle size 0.25–1.0 mm). Their results showed that substratum preference is one of the major factors that limit the distribution of clams. It has been shown (Collier 2004) that the New Zealand mud snail prefers an inorganic, sand–silt substratum over macrophytes in running waters. This phenomenon can be explained by its dietary requirements, which involve deriving trace elements from ingested sediments.

The influence of instream environmental variables on mollusc communities: current velocity and turbidity

Our research found that velocity was positively correlated with the distribution of *T. fluviatilis* and pill clams, i.e. *P. nitidum*, *P. subtruncatum*, *P. casertanum* as well as the typical fluviatile species *P. supinum* and *P. amnicum*. *Pisidium* species, which live buried within sediments, are dependent on the interstitial conditions. A higher current velocity ensures the better ventilation of sediments, prevents the accumulation of pollutants and reduces the sedimentation of fine-grained material that may clog the interstitium. For example, the fingernail clam *P. amnicum* uses pedal feeding to extract organic matter from the interstitial water and sediment, which can be rich in macroalgae detritus, submerged vegetation detritus and bacteria. Our result is consistent with a study by Beisel et al. (1998), who found the substratum and velocity to be the most important factors. They showed a positive correlation between velocity and the distribution of macroinvertebrates, including *T. fluviatilis* and pill clams.

Our results for the CCA ordination revealed that among the physical and chemical parameters of the water, turbidity and the concentration of dissolved

oxygen in the water were most associated (statistically significantly) with the distribution of mollusc species. Turbidity was negatively correlated with the distribution of gill-breathing prosobranch species, i.e. *T. fluviatilis* and *P. antipodarum*, as well as fingernail clams, i.e. *P. subtruncatum* and *P. supinum*. This result is consistent with a survey by Pérez-Quintero (2011), who used CCA analysis to show that turbidity was one of the most important (statistically significant) factors that negatively correlated with the distribution of prosobranch gastropod species and fingernail clams. Turbidity may be defined as the optical property of suspended fine particles in the water that causes light to be scattered. Turbidity is caused by the presence of undissolved and dissolved organic and inorganic compounds, such as clay, loam, precipitated iron, manganese and aluminium compounds, humic and fulvic acids, phytoplankton or any suspended solids. The river supply of sediments is variable and depends on factors such as soil erodibility, land use and land management practices or geographical features. Suspended solids and food concentrations influence the respiration of bivalves, and a decrease in oxygen consumption was observed as turbidity increased. Higher concentrations of suspended solids cause a drop in bivalve growth rates by overloading the gut and gills with inorganic solids. Suspended solids may affect respiration and filter-feeding by fouling the currents of water that pass over the gills and by physically impeding gas exchange across the cell membranes of the epithelial cells lining respiratory surfaces (Alexander et al. 1997). A higher concentration of suspended loads involves the formation of pseudofaeces that clear the gills for respiratory and filter-feeding purposes (Alexander et al. 1997; Argente et al. 2014). According to Neves et al. (2014), increased turbidity immobilises the valves, which disables the filtering and feeding processes, thereby contributing to lethargy in bivalves. As a result, fine sediments enter the pallial cavity, thus eventually leading to the death of the animal. Increased sedimentation and turbidity affect the lotic food webs, e.g. by decreasing the filtration rate of bivalves, thereby causing them to starve (Henley et al. 2000). Hence, the clear negative correlation between the distribution of prosobranch species and gill-breathing fingernail clams and turbidity may be explained by their physiological make-up. They require fairly well oxygenated water that is free from particles that can choke their gills (Dillon 2000).

Conclusions

The Krąpiel River, which flows through areas included in the European Ecological Natura 2000 Network Programme of protected sites, provides diverse instream habitats and niches that support the occurrence of 47 mollusc species. The number of mollusc species is higher in the Krąpiel River than in large and very large rivers in Europe, and includes *U. crassus*, a bivalve species of Community interest whose conservation requires the designation of a special conservation area under the Habitats Directive Natura 2000.

Mollusc species from different categories of threat, including Endangered (EN), Vulnerable (VU), Near Threatened (NT) and Data Deficient (DD), were recorded in the Krąpiel River. Thus, the importance and the unquestionable, functional role of *Mollusca* in freshwater ecosystems and their conservation status should be taken into consideration in any future plans in both land and rivers management and restoration. Monitoring the occurrence, population size, distribution and trend should be undertaken for threatened and data deficient mollusc species.

P. antipodarum, a non-indigenous invasive gastropod species that flourishes in degraded rivers, was also recorded in the Krąpiel River. As the ability to predict the effect of biotic invasions into aquatic ecosystems is still limited, research on the occurrence of *P. antipodarum* so as to control and reduce its possible impact on the native fauna in the Krąpiel River should be continued.

The analysis of physical and chemical parameters of the water suggests that it was not possible to achieve a good ecological potential and good surface water chemical status by 2015 as was mandated by Directive 2000/60/EC. Therefore, the water management should be improved, especially regarding the pollution that results from different types of catchment land use including agriculture (arable land, meadows, pastures) and settlements.

Our results support a broader, multiple scale approach to mollusc communities-ecosystem linkages in medium-sized lowland river. This survey showed that mollusc communities are impacted by several environmental variables acting together. The landscape structure within buffer zones, catchment land use and instream environmental variables were all important and influenced the structure of mollusc communities. Thus, alternation in catchment land use, areas of specific patches, distances to each patch from the river (forests, fields, meadows and settlements), velocity, the macrophyte cover of the river corridor, or turbidity may affect the distribution of molluscs. Therefore, they should all be taken into consideration in any future restoration of the river, future management projects, and strategies and programmes for the conservation of biodiversity in running waters. However, the occurrence of some mollusc species, i.e. the prosobranch gastropods *T. fluviatilis* and *P. antipodarum* and fingernail clams *P. supinum*, *P. amnicum* and *P. nitidum*, were more impacted by instream variables than by the landscape structure within buffer zones or catchment land use.

The multiple scale analysis of the relationships between environmental factors (landscape structure, land use and instream variables) and *Mollusca* is useful tool for the conservation of biodiversity, which constitutes an essential component of the responsible, sustainable management of the environment and natural resources. The results of this study may be directly

applicable for the rehabilitation of river ecosystems and are recommended to stakeholders when making their future decisions concerning landscape planning, habitat transformations, monitoring species and their habitats, conservation plans and management in accordance with the requirements of sustainable development.

Compliance with ethical standards

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