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Drivers of the Structure of Mollusc Communities in the Natural Aquatic Habitats along the Valley of a Lowland River: Implications for Their Conservation through the Buffer Zones

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Abstract: The objectives of our survey were to determine the most important environmental factors within buffer zones that influenced mollusc communities and to evaluate the ecological conservation value of natural aquatic habitats (NAHs) that support mollusc species. Analysis of the spatial structure of buffer zones and catchments was based on a set of landscape metrics. Land cover classes were determined, and buffer zones within a radius of 500 m from a sampling point were marked out. Mollusc samples were collected from each NAHs. Our results showed that the number of patches and mean patch size were most associated with the distribution of mollusc species. Within patches of buffer zones, the length of the catchment boundaries with low-density housing, an increasing area of forest and pH of the water were also significant. Our results proved that landscape metrics provide essential information about catchment anthropogenic transformation. Therefore, landscape metrics and the designated buffer zones should be included in restoration plans for the river, water bodies and adjacent habitats as elements of modern, sustainable water management. NAHs located along a valley of a lowland river provide refuges for molluscs, play an essential role in the dispersal of IAS, create important protective biogeochemical barriers for rivers, constitute necessary sources of moisture and water and support microhabitats for distinct mollusc communities, especially in the context of global warming.

Keywords: environmental factors; landscape metrics; Mollusca; patches; water bodies

1. Introduction

Freshwater ecosystems are particularly sensitive to the effects of urbanisation, industrialisation or agriculture because they receive and transport water and materials from the entire catchment area. The major anthropogenic pressure that impacts freshwater ecosystems globally is pollution, which includes an elevated nutrient concentration in the water, organic substances that are constantly released into the environment, hydrological changes and hydromorphological alterations [1–4].

The degradation of freshwater ecosystems caused by prolonged human activity including lowland rivers is an environmental problem worldwide [3,5–7]. It has been estimated [2] that rivers only in one-third of the territory of the European Union have a good ecological status. Good ecological status of rivers is associated with the presence of natural areas in floodplains, while urbanisation and nutrient pollution are important predictors of ecological degradation. To stop their further degradation, it is essential to limit urban land use and chemical pollution and to maintain and restore nature along rivers [2].

The world's wetland surface area has decreased since 1900. The disappearance of wetlands and the degradation of rivers and the associated shrinkage of freshwater habitats not only constitute an environmental problem in Europe but worldwide. What is worse, anthropogenic pressure such as land conversion and the introduction of alien species, for example, continue to cause their further degradation and loss [8]. Nutrient enrichment alters the structure of macroinvertebrate communities and increases macroinvertebrate abundance, while a greater organic carbon load causes dominance by pollution-tolerant macroinvertebrates in freshwater ecosystems. Many small, natural water bodies were lost in the last century. Those that remain are faced with increasing anthropogenic pressure by many factors including area drainage, field fertilisation, water pollution, urban development, increased transport infrastructure or simply natural succession. Small water bodies are the least investigated part of freshwater ecosystems, and they are largely excluded from water management planning. Despite that, the importance of small water bodies for biodiversity and ecosystem services has been highlighted by Biggs, von Fumetti and Kelly-Quinn [9]. For example, oxbow lakes located within agricultural areas regulate nutrient transfer towards rivers, mainly through the retention of matter. Thus, oxbow lakes prevent rivers from a decrease in water quality [1].

Several studies have shown that lentic waters can contribute more to regional biodiversity than lotic waters. Small water bodies support a greater number of aquatic macroinvertebrate species than running waters, including rare species [8,10]. Restored aquatic floodplain areas including oxbow lakes and newly created wetlands increase heterogeneity and provide new habitats that play key roles in the ecosystem from nutrient removal to carbon storage, pollutant removal, water storage during floods or water provision during droughts, as well as constituting wildlife refuges [11–14]. Oxbow lakes, which constitute an essential part of the river ecosystem, increase biodiversity by providing important habitats for diverse macrophyte and macroinvertebrate species. Even new, temporary ponds can provide diverse and complementary habitats that are important for maintaining macroinvertebrate diversity at the regional scale [15].

Mollusca constitute an important part of the invertebrate fauna of river valleys. It was shown [16] that the heterogeneity of natural aquatic habitats located along river valleys and their isolation within a river valley favour a high species diversity of molluscs at the floodplain scale. Furthermore, floodplain meadow ponds support greater mollusc diversity than rural or urban ponds [16,17]. Freshwater molluscs, which are hololimnic organisms that are present in water throughout their entire life cycle, are especially sensitive and vulnerable to anthropogenic disturbances. About 44% (373 species) of freshwater Mollusca are threatened in Europe, and about 50% are threatened at the level of the 27 Member States of the European Union [18]. The main threats to freshwater molluscs, which lead to a decrease in their populations, are the modification and destruction of habitats, including water pollution, the modification of water sources and changes in the flow regime, the regulation of rivers, habitat loss resulting from drainage, the loss of marshy habitats and the drying up of bogs and the eutrophication of reservoirs including oxbow lakes [1,18,19]. Freshwater molluscs are insufficiently researched and are often not taken into account in conservation planning, management and monitoring of freshwater habitats, despite the relatively high degree of threat and extinction [19]. Several environmental factors can potentially shape the macroinvertebrate communities including molluscs in water bodies such as the concentration of nutrients, the presence of macrophytes and predators, riparian shading, pH, total hardness and the size of the water bodies as well as bottom sediments [1,20,21]. To date, a survey on the landscape metrics within buffer zones alongside local factors that determine the occurrence of molluscs in the natural lentic aquatic habitats located along a valley of a medium-sized lowland river has not been carried out. In contrast, our previous survey [22] concerned the influence of landscape structure and instream environmental factors on mollusc communities in a lotic ecosystem (lowland river).

The objectives of our survey were (1) to analyse the structure of the mollusc communities in the natural aquatic habitats (NAHs) located along a valley of a medium-sized lowland river (lentic habitats), (2) to determine the most important environmental factors within the buffer zones that influence their structure and (3) to evaluate the ecological conservation value of NAHs located along the river that support mollusc species.

2. Materials and Methods

2.1. Study Area

The study was carried out within the lentic natural aquatic habitats (NAHs): pools, oxbow lakes, sedge marshes, flooded alder woods, ponds and springs located along a valley of a medium-sized lowland river (the Krąpiel River). The valley of the Krąpiel River (northwest Poland) is an excellent model for investigating various ecological relationships among different groups of aquatic invertebrates at various spatial scales [22–25].

The Krąpiel River partially flows through a landscape park within a natural physical-geographical region (the West Pomeranian Lakeland), which is part of the Central Plains (Ecoregion 14) according to the EU Water Framework Directive (EU WFD) [26] (Figure 1).

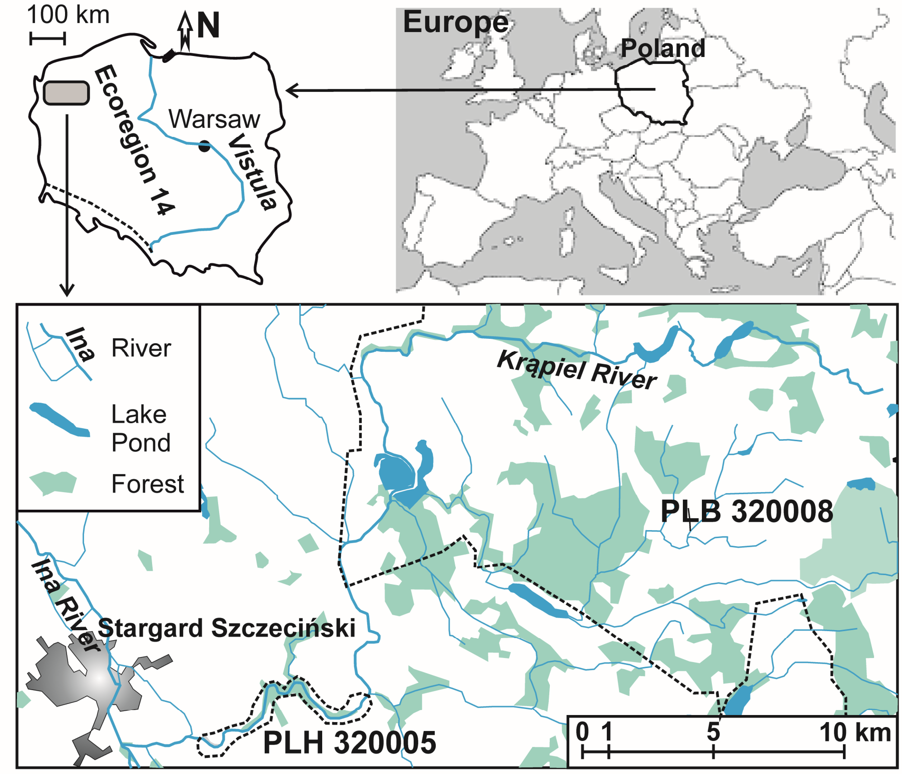


Figure 1. Location of the study area (the Central Plains, Ecoregion 14).

The upper course of the Krąpiel River shares some coverage with the Special Protected Area (PLB 320008), which was established under the Birds Directive [27] 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 (PLH 320005) as a Special Area of Conservation (SAC) that represent areas with natural habitats of the highest value and rare or endangered plant and animal species in the European Community. From 2021 the SAC protects 12 types of natural habitats and also protects several species that are of importance to the Community according to Council Directive 92/43/EEC [28].

2.2. Field and Laboratory Methods

The study was carried out from April to October 2010. Mollusc samples were collected monthly from several sub-sites at each of the natural aquatic habitats (NAHs): pools (5), oxbow lakes (11), sedge marshes (4), flooded alder woods (6), ponds (9) and springs (3) located along a valley of the Krąpiel River. In total, 38 NAHs were sampled.

A metal square frame was used to mark out a 0.5 m^2 sampling area in the bottom sediments, and then the samples of molluscs 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. Three subsamples were collected on each sampling occasion at each type of NAHs at monthly intervals for 7 months. A total of 798 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 [29], Piechocki and Dyduch-Falniowska [30], Glöer and Meier-Brook [31] and Glöer [32]. Empty shells were not taken into account. Species nomenclature was updated according to Piechocki and Wawrzyniak-Wydrowska [33].

Immediately before mollusc sampling, water samples and bottom sediments were collected from each sampling site. Insolation, temperature of the water, pH, conductivity and dissolved oxygen were measured in the field whereas turbidity, Biochemical Oxygen Demand (BOD), total hardness, concentration of ammonium nitrogen, nitrates, phosphates and iron in the water were analysed in laboratory conditions.

Landscape structure was analysed using the following landscape variables.

1. Metrics of buffer zones: mean patch size (MPS), patch size standard deviation (PSSD), the median of patch size (MEDPS), number of patches (NUMP), total edge length (TE), mean edge length (MTE), the sum of patch shape indices (SUM), mean shape index (MSI), the Shannon patch diversity index (SDI), the Shannon evenness index (SEI), contagion (Cr), edge density (ED) and patch density (PD).

2. Characteristics of patches in buffer zones: area of particular patches (CA), a distance of particular patches from the centre of the buffer zone (L) including built-up areas, peat bogs, fields, meadows and pastures, broadleaf forests, mixed forests, osiers, rivers and water bodies.

3. Characteristics of catchments: area (a) including areas of catchments, forests, meadows and pastures, fields, built-up areas, water bodies, marshland, rivers, shrubs, wasteland, length of catchment boundaries and a river gradient; distance from the river (d) including distances from sources, forests, fields, marshland, meadows and pastures, shrubs, wasteland, water bodies and built-up areas.

The methods of the physical and chemical analyses of the water (field and laboratory procedures), insolation, the organic matter content and grain size composition of the bottom sediments, analysis of the spatial structure of the buffer zones and catchments and measures and indices of the landscape structure are described in our previous paper [22].

2.3. Statistical and Zoocenological Analyses

The structure of the mollusc communities was analysed using the dominance index *D*% divided into five classes [34]: eudominants > 10.0% of a sample, dominants 5.1–10.0% of a sample, subdominants 2.1–5.0% of a sample, recedents 1.1–2.0% of a sample and subrecedents ≤ 1.0% of a sample. The Shannon–Wiener index (H') was calculated according to McCune and Grace [35] and Shannon [36]:

$$H' = -\Sigma\ (P_i)\ (\log_2 P_i) \tag{1}$$

where $P_i = N_i/N$-the proportion of individuals belonging to species i.

Statistical analyses for relating mollusc species composition to the environmental data were carried out using CANOCO for Windows version 4.5 [37]. The appropriate type of analysis was selected to analyse the species data using DCA (Detrended Correspondence Analysis) and the verification of the length of the gradient. Preliminary DCA on the biological data revealed that the gradient length was less than 3 SD (the standard deviation), thus indicating that the biological data exhibited a linear response to the underlying environmental variables. Therefore, a linear direct ordination RDA (Redundancy Analysis) with a forward selection was used to reduce the large set of environmental variables. 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 [35]. Environmental variables including landscape metrics 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) [37]. The significance of the differences in the values of the environmental variables, the number of species and density between NAHs located along a valley of the Krąpiel River was calculated using the Kruskal–Wallis one-way ANOVA and Dunn's multiple comparison post hoc tests using Statistica version 12.

3. Results

3.1. Environmental Variables

The results of landscape metric analyses (measurement units and mean values with standard deviations SD) are shown in Table 1. Only those landscape variables that showed no collinearity (bold font) were used in the further RDA analysis.

Table 1. The landscape variables and their values recorded at each sampling site in NAHs along the valley of the Krąpiel River (* Abbreviations used in RDA analysis).

** Variable	* Abbreviation	Values (Mean ± SD)
1. Metrics of buffer zones		
mean patch size	**MPS**	0.95–3.57 (1.81 ± 0.77)
patch size standard deviation	**PSSD**	1.45–5.37 (3.28 ± 1.39)
the median of patch sizes	**MEDPS**	0.21–0.74 (0.51 ± 0.16)
number of patches	**NUMP**	22–83 (50.8 ± 18.8)
total edge length	TE	25,342–43,174 (33,856.9 ± 5821.4)
mean edge length	**MTE**	520–1152 (726.7 ± 186,5)
sum of patch shape indices	**SUM**	48.35–138.32 (97.17 ± 27.47)
mean shape index	**MSI**	1.67–2.27 (1.98 ± 0.20)
Shannon patch diversity index	**SDI**	1.54–2.20 (2.05 ± 0.15)
Shannon evenness index	**SEI**	0.83–0.92 (0.87 ± 0.03)
contagion	**C_r**	1.20–4.55 (2.30 ± 0.98)
edge density	**ED**	322.88–549.15 (431.04 ± 73.96)
patch density	**PD**	28.03–105.57 (64.72 ± 23.87)
2. Characteristics of patches in buffer zones: CA—the area of particular patches, L—a distance of particular patches from the centre of the buffer zone		
built-up areas	**CA(a)**	0.00–8.15 (1.54 ± 2.84)
	L(a)	0.00–461.60 (113.88 ± 180.78)
peat bogs	CA(b)	0.00–4.32 (1.76 ± 1.44)
	L(b)	0.00–456.25 (271.93 ± 195.17)
fields	CA(c)	3.83–44.80 (22.43 ± 12.24)
	L(c)	2.07–452.92 (361.88 ± 135.21)
meadows and pastures	CA(d)	1.04–37.30 (17.20 ± 12.37)
	L(d)	2.25–433.90 (319.02 ± 122.56)
broadleaf forests	CA(e)	5.17–25.67 (13.64 ± 6.45)
	L(e)	2.68–372.89 (278.02 ± 110.48)
mixed forests	CA(f)	0.00–16.30 (4.88 ± 6.96)
	L(f)	0.00–378.65 (96.11 ± 137.16)

Table 1. *Cont.*

** Variable	* Abbreviation	Values (Mean ± SD)
osiers	CA(g)	0.00–9.79 (1.97 ± 1.82)
	L(g)	0.00–486.03 (262.63 ± 145.90)
rivers	CA(h)	0.19–2.87 (1.34 ± 0.87)
	L(h)	7.36–390.79 (230.22 ± 129.19)
water bodies	CA(i)	0.00–19.88 (2.51 ± 5.02)
	L(i)	0.00–464.64 (217.74 ± 201.59)
3. Characteristics of catchments—a—area, d—distance from the river		
catchment	a cat	469.4–11,065.1 (3621.1 ± 3745.4)
catchmentarea from the sources	**a cat cu**	459.4–60,568.3 (20,928.9 ± 22,428.7)
forests	**a forest**	37.72–4067.95 (912.83 ± 1415.31)
meadows and pastures	a mead	50.86–1787.2 (622.0 ± 610.6)
fields	a field	111.54–4813.03(1957.50 ± 610.63)
built-up	a build	6.96–14.14 (69.64 ± 48.61)
water bodies	**a st wat**	1.63–78.82 (22.18 ± 25.97)
marshland	a marsh	0.00–31.16 (8.47 ± 11.01)
rivers	a river	0.00–5.35 (1.91 ± 1.92)
shrubs	a shrub	0.00–31.98 (6.89 ± 11.36)
wasteland	a wast	0.00–111.30 (19.64 ± 41.02)
length of catchment boundaries	l bord	12,405.64–83,599.36 (38,625.98 ± 24,031.11)
roughness	Ra	9.17–19.84 (12.72 ± 3.21)
river gradient	**river gr**	0.1–4.8 (1.9 ± 1.7)
distance from source	d source	2073–64,380 (25,875 ± 18,695)
forests	d fores	278.05–1166.76 (516.60 ± 259.72)
fields	d field	406.41–912.15 (627.47 ± 181.91)
marshland	d marsh	0.00–1186.32 (489.62 ± 466.32)
meadows and pastures	d mead	206.70–1196.86 (537.88 ± 296.13)
shrubs	**d shrub**	0.00–1073.18 (372.09 ± 350.28)
wasteland	**d wast**	0.00–909.1 (323.04 ± 432.17)
water bodies	d st water	246.97–1553.53 (246.97 ± 375.19)
built-up	d build	213.25–910.61 (534.05 ± 260.05)

** variables that did not show collinearity (in bold) were used in RDA analysis.

The conductivity of the water ranged from 65 $\mu S\ cm^{-1}$ (ponds) to 524 $\mu S\ cm^{-1}$ (oxbow lakes). A high concentration of phosphates up to 2.7 mg $PO_4^{3-}\ dm^{-3}$ was recorded for the sedge marshes (Table 2).

Table 2. The physical and chemical parameters of the water, insolation and organic matter content in the bottom sediments of the NAHs located along a valley of the Krapiel River.

Parameter	Pools	Oxbow Lakes	Sedge Marshes	Flooded Alder Woods	Ponds	Springs
Temperature (°C)	6.4–22.9	9.3–20.3	7.9–18.9	14.0–20.1	7.6–16.9	9.5–19.0
Conductivity ($\mu S\ cm^{-1}$)	159–287	137–524	68–272	99–243	65–278	121–307
Turbidity (mg dm^{-3})	0.0–119.5	0.0–304.0	2.6–96.0	5.1–58.0	6.8–95.0	4.2–21.2
pH	5.3–7.6	2.1–7.8	5.5–7.0	5.3–7.7	2.8–7.6	6.2–7.9
Dissolved oxygen (mg $O_2\ dm^{-3}$)	0.5–9.3	0.2–9.8	0.9–16.1	2.6–15.6	1.3–9.2	0.5–10.3
BOD (mg $O_2\ dm^{-3}$)	4.3–5.7	0.0–10.3	0.4–3.6	3.2–4.9	0.0–4.8	1.9–4.1
Ammonium nitrogen (mg $N\text{–}NH_4^+\ dm^{-3}$)	0.3–2.2	0.1–4.8	0.3–1.6	0.8–3.5	0.2–3.0	0.2–1.2
Nitrates (mg $NO_3^-\ dm^{-3}$)	0.4–2.0	0.1–8.2	0.4–2.0	0.4–1.4	0.1–1.1	0.4–8.2
Phosphates (mg $PO_4^{3-}\ dm^{-3}$)	0.1–1.5	0.1–1.0	0.1–2.7	0.1–1.2	0.01–0.7	0.2–0.8
Total hardness (mg $CaCO_3\ dm^{-3}$)	44–274	103–412	134–226	91–312	3–148	126–168
Iron (mg Fe dm^{-3})	0.0–0.60	0.0–0.20	0.0–0.24	0.0–0.08	0.0–0.36	0.05–0.13
Organic matter (%)	11–53	3–60	52–87	69–76	6–91	3–37
Insolation (%)	87–100	0–100	57–100	2–35	3–100	8–71

The concentration of ammonium nitrogen in the water, total hardness and BOD were high in the oxbow lakes compared to the other types of NAHs. Low minimum values of pH were recorded for the oxbow lakes and ponds. The organic matter content in the bottom sediments ranged from 3% (oxbow lakes and springs) to 91% (ponds) (Table 2). The Kruskal–Wallis one-way ANOVA and Dunn's multiple comparison post hoc tests revealed statistically significant differences in the median values of the following environmental variables (p = 0.0001): temperature of the water (H = 94.36), conductivity (H = 266.71), turbidity (H = 28.65), pH (H = 138.40), dissolved oxygen (H = 36.54), BOD (H = 284.53), ammonium nitrogen (H = 64.72), nitrates (H = 118.77), phosphates (H = 128.68), total hardness (H = 124.63), iron (H = 42.99), organic matter content in the bottom sediments (H = 330.66), insolation (H = 253.46), degree of vegetation cover (H = 236.24) and all of the grain size fractions between all of the types of the NAHs.

3.2. Mollusc Communities

A total of 36 mollusc species were recorded in the NAHs located along the Krąpiel River: 26 gastropod species and 10 bivalve species (Table 3). The number of species ranged from 10 in the flooded alder woods, ponds and springs to 26 in the oxbow lakes of the Krąpiel River. Planorbid species, i.e., *Planorbis planorbis* (Linnaeus, 1758) and *Bathyomphalus contortus* (Linnaeus, 1758), were eudominants; *Planorbarius corneus* (Linnaeus, 1758), *Anisus vortex* (Linnaeus, 1758), *Segmentina nitida* (O.F. Müller, 1774) and *Pisidium globulare* Clessin, 1873 were dominants in the mollusc communities in the NAHs (Table 2). The rare species *Planorbis carinatus* O.F. Müller, 1774 was subrecedent in the mollusc communities in pools whereas *Aplexa hypnorum* (Linnaeus, 1758) was eudominant in the oxbow lakes or was subdominant, recedent and subrecedent in other types of the NAHs. A Near Threatened (NT) species, i.e., *Ladislavella terebra* (Westerlund, 1885), was subdominant and subrecedent in the mollusc communities in the ponds and sedge marshes, respectively (Table 2). *Bithynia leachii* (Sheppard, 1823) and *Gyraulus rossmaessleri* (Auerswald, 1852), which are species endemic to Europe, were subrecedents in the pools, oxbow lakes and ponds. Two invasive alien species (IAS), i.e., *Potamopyrgus antipodarum* (Gray, 1843) and *Dreissena polymorpha* (Pallas, 1771) (subrecedents), were also recorded in a few sites (Table 3). In contrast to the results of our previous survey [22], not any unionid mussels were found. However, several rare species not recorded in the Krąpiel River, e.g., *Stagnicola turricula* (Held, 1836), *G. rossmaessleri* and *Pisidium obtusale* (Lamarck, 1818), occurred in NAHs. The values of the H' index that were calculated for the mollusc communities ranged from 2.02 (sedge marshes) to 3.51 (oxbow lakes).

Table 3. The number of mollusc species, values of the dominance (D%) and the Shannon–Wiener (H') indices calculated for the mollusc communities in the NAHs located along a valley of the Krąpiel River. Conservation status: VU—Vulnerable, NT—Near Threatened, LC—Least Concern, DD—Data Deficient, NA—Not Applicable ([a] The European Red List of Non-marine Molluscs [18]).

Species	Pools	Oxbow Lakes	Sedge Marshes	Flooded Alder Woods	Ponds	Springs	Total	IUCN Red List (EU 27) [a]	Red List Poland
Theodoxus fluviatilis (Linnaeus, 1758)		0.22					0.06	LC	
Viviparus contectus (Millet, 1813)			0.14				0.05	LC	
Bithynia tentaculata (Linnaeus, 1758)	0.05	4.08		31.03			1.52	LC	
Bithynia leachii (Sheppard, 1823)	0.05	0.04					0.02	LC	NT
Potamopyrgus antipodarum (Gray, 1843)		0.04					0.01	NA	
Valvata cristata O.F. Müller, 1774			0.14			8.20	0.59	LC	
Valvata piscinalis (O.F. Müller, 1774)		0.09	0.04				0.04	LC	
Galba truncatula (O.F. Müller, 1774)	1.67	0.75	9.47		1.87	2.32	3.99	LC	
Stagnicola palustris (O.F. Müller, 1774)	2.64	3.95		6.03			1.71	LC	DD
Stagnicola sp.	2.05	2.85	4.92		5.81	1.25	3.54		
Stagnicola turricula (Held, 1836)			0.61				0.20	LC	DD
Ladislavella terebra (Westerlund, 1885)			0.90		4.88		0.84	NT	NT
Stagnicola corvus (Gmelin, 1778)	0.22	0.09					0.07	LC	DD
Radix auricularia (Linnaeus, 1758)				22.41			0.30	LC	

Table 3. *Cont.*

Species	Pools	Oxbow Lakes	Sedge Marshes	Flooded Alder Woods	Ponds	Springs	Total	IUCN Red List (EU 27) [a]	Red List Poland
Radix balthica (Linnaeus, 1758)	1.03	0.31					0.30	LC	
Lymnaea stagnalis (Linnaeus, 1758)	0.54	0.18		4.31			0.22	LC	
Physa fontinalis (Linnaeus, 1758)	0.38	0.04		4.31			0.15	LC	
Aplexa hypnorum (Linnaeus, 1758)	1.19	11.94	0.40	0.86	4.36	0.89	4.13	LC	NT
Planorbarius corneus (Linnaeus, 1758)	6.42	2.98	9.07	27.59	1.35		5.66	LC	
Planorbis planorbis (Linnaeus, 1758)	34.65	25.98	50.72	0.86	15.98		32.70	LC	
Planorbis carinatus O.F. Müller, 1774	0.05						0.01	LC	NT
Anisus leucostoma (Millet, 1813)	0.70	12.07			2.18	1.25	3.70	LC	
Anisus vortex (Linnaeus, 1758)	23.53	11.06					8.06	LC	
Bathyomphalus contortus (Linnaeus, 1758)	1.19	9.17	23.43		1.04	36.19	12.79	LC	
Gyraulus rossmaessleri (Auerswald, 1852)					0.21		0.02	LC	NT
Hippeutis complanatus (Linnaeus, 1758)	0.32	1.58					0.49	LC	
Segmentina nitida (O.F. Müller, 1774)	22.29	4.96	0.04				6.17	LC	
Sphaerium corneum (Linnaeus, 1758)	0.05	1.14	0.11	1.72			0.37	LC	
Pisidium milium Held, 1836		2.02					0.54	LC	
Pisidium subtruncatum Malm, 1855	0.16	0.31				0.18	0.13	LC	
Pisidium nitidum (Jenyns, 1832)	0.27	0.97				0.71	0.36	LC	
Pisidium hibernicum Westerlund, 1894		0.04					0.01	LC	VU
Pisidium obtusale (Lamarck, 1818)		0.48				0.18	0.14	LC	VU
Pisidium personatum Malm, 1855					14.21	35.47	3.93	LC	
Pisidium sp.	0.54	0.48					0.25		
Pisidium casertanum (Poli, 1791)						13.37	0.88	LC	
Pisidium globulare Clessin, 1873		2.19			48.13		6.02	LC	
Dreissena polymorpha (Pallas, 1771)				0.86			0.01	NA	
No of samples taken from particular types of NAHs	105	231	84	126	189	63	798		
No of specimens	1853	2279	2766	116	964	561	8539		
No of species	20	26	12	10	10	10	36		

The Kruskal–Wallis one-way ANOVA and Dunn's multiple comparison post hoc tests revealed statistically significant differences in the median number of mollusc species ($H = 12.43$, $p = 0.03$) between the types of NAHs (Figure 2). The differences in the median densities were not statistically significant ($H = 9.63$, $p = 0.08$).

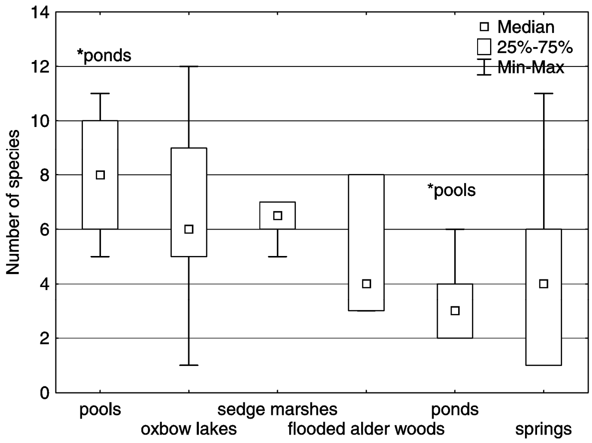
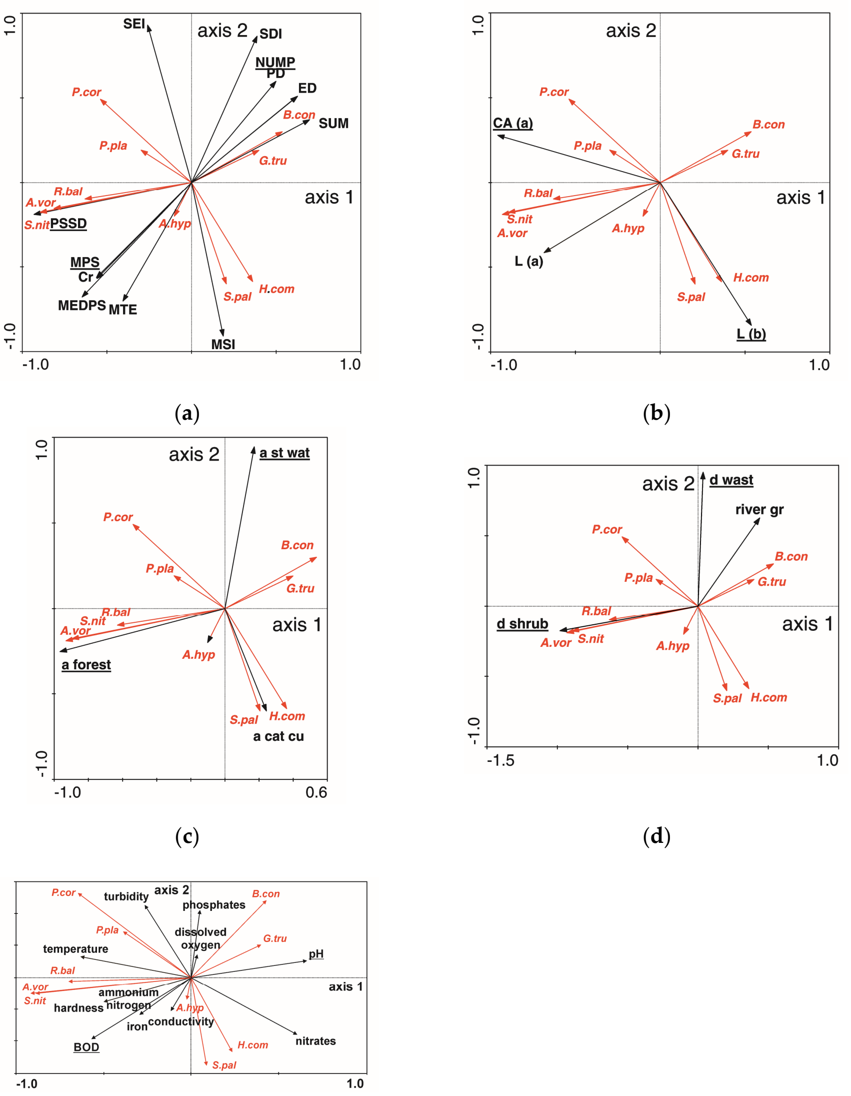


Figure 2. Box-and-whisker plot concerning the number of mollusc species in the NAHs located along the valley of the Krąpiel River (* significant differences between the sampling sites in the NAHs, the Kruskal–Wallis one-way ANOVA and Dunn's multiple comparison post hoc tests).

3.3. Mollusc Communities in Relation to the Landscape Metrics and the Physical and Chemical Parameters of the Water

Figure 3 shows the distribution of the mollusc species in relation to the metrics of the buffer zones and the physical and chemical parameters of the water. Based on a redundancy analysis (RDA), the number of patches (NUMP), mean patch size (MPS) and patch size standard deviation (PSSD) were the metrics of the buffer zones most associated (statistically significant) with the distribution of the mollusc species in the NAHs located along a valley of the Krąpiel River (Figure 3a) (*p*-value 0.0200; *F*-ratio 2.70).



(**a**) (**b**)

(**c**) (**d**)

(**e**)

Figure 3. Biplot based on a redundancy analysis (RDA) of the mollusc species and the environmental data (**a**); the patches of specific buffer zones and the length of the catchment boundaries (**b**); the area of forest, stagnant waters and the cumulative area of the catchment (**c**); the river gradient and the distance of specific patches that occur in the catchment from the river (**d**); the physical and chemical parameters of the water (**e**) (statistically significant environmental variables are underlined). Abbreviations: Cr—contagion; ED—edge density; MEDPS—the median of 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—the sum of patch shape indices; SEI—Shannon evenness index; CA(a)—the total surface area of the low-density housing; L(a)—the length of catchment boundaries of low-density housing and peat bog L(b); a cat cu—cumulative catchment area; a forest—an area of a forest; a st wat—an area of stagnant waters; d wastes—distance from the wastes; d shrub—distance from shrubs; river gr—river gradient. Abbreviations for mollusc species: *A. vor*—*Anisus vortex*; *A. hyp*—*Aplexa hypnorum*; *B. con*—*Bathyomphalus contortus*; *G. tru*—*Galba truncatula*; *H. com*—*Hippeutis complanatus*; *P. cor*—*Planorbarius corneum*; *P. pla*—*Planorbis*; *S. nit*—*Segmentina nitida*; *R. bal*—*Radix balthica*; *S. pal*—*Stagnicola palustris*.

Within the patches of specific buffer zones, the area of the low-density housing and the length of catchment boundaries of low-density housing and peat bog exerted a significant effect on the distribution of the mollusc species (Figure 3b) (*p*-value 0.0080; *F*-ratio 3.61). An increasing area of forest positively affected the abundance of *S. nitida*, *A. vortex*, *Radix balthica* (Linnaeus, 1758) and *A. hypnorum*. *B. contortus*, *Galba truncatula* (O.F. Müller, 1774), *P. corneus* and *P. planorbis* were positively influenced by an increasing area of stagnant waters. The cumulative area of the catchment influenced the distribution of *Stagnicola palustris* (O.F. Müller, 1774) and *Hippeutis complanatus* (Linnaeus, 1758) (Figure 3c) (*p*-value 0.0040; *F*-ratio 3.03). The distribution of the molluscs in relation to the river gradient and the distance of the specific patches that occurred in the catchment from the river are displayed in Figure 3d. Some patterns were found in mollusc distribution: *A. vortex*, *S. nitida*, *R. balthica* and *A. hypnorum* were positively influenced by the distance from shrubs. *Aplexa hypnorum*, *S. palustris* and *H. complanatus* were negatively influenced by an increasing distance from the wastes (Figure 3d) (*p*-value 0.0040; *F*-ratio 3.01). Among the physical and chemical parameters of the water, BOD and pH were the parameters most associated (statistically significant according to the forward selection results) with the distribution of the mollusc species. *Galba truncatula* and *B. contortus* occurred at sampling sites that had higher values of pH, whereas *A. vortex*, *S. nitida* and *R. balthica* occurred at sites with lower values of pH (Figure 3e) (*p*-value 0.0020; *F*-ratio 6.49).

4. Discussion

4.1. Natural Aquatic Habitats along the River Valley as Refuges for Molluscs

This research on the structure of the mollusc communities in the natural lentic aquatic habitats located along the valley of a lowland river revealed the occurrence of 36 mollusc species: 26 gastropod and 10 bivalve species (Ecoregion 14: the Central Plains). In contrast, 57 mollusc species were recorded in the floodplain habitats of a large lowland river (Ecoregion 16: the Eastern Plains) [38]. In comparison, 47 mollusc species (32 gastropod and 15 bivalve species, including unionid mussels) occurred in the Krąpiel River according to the results of our previous survey [22].

Up to 26 mollusc species including one invasive alien species, i.e., *P. antipodarum*, occurred in the oxbow lakes located along the Krąpiel River. In comparison, the occurrence of alien mollusc species has been found in the oxbow lakes of both large- and medium-sized lowland rivers [16,39,40].

Thirty-four of the mollusc species that were recorded in the NAHs located along a valley of the Krąpiel River are included in the European Red List of Non-marine Molluscs [18]. Among species found in the NAHs, *P. planorbis*, *Anisus leucostoma* (Millet, 1813), *G. rossmaessleri*, *A. hypnorum*, *G. truncatula*, *B. leachii*, *Pisidium obtusale*, *Pisidium personatum* Malm, 1855 or *P. globulare*, which are resistant to desiccation and are typical for small and ephemeral water bodies, were observed. According to the survey of Piechocki and Wawrzyniak-Wydrowska [33], the gastropod species, *Valvata cristata* O.F. Müller, 1774, which inhabits periodic water bodies, is also frequent in springs and prefers cold and well-oxygenated water. Our results confirmed their survey because *V. cristata* was found in both the sedge marshes and springs located along the Krąpiel River.

The NAHs along a valley of the Krąpiel River also contain a typical lacustrine species, i.e., *P. carinatus*, which is not resistant to drought, as well as *H. complanatus*. *Planorbis carinatus* is sensitive to an environmental anthropogenic impact at different intensities. Thus, the progressive decline of the distribution of *P. carinatus* is related to eutrophication and destruction of rush vegetation in aquatic environments [41,42]. Drainage or water pollution affects the decrease of lymnaeid species distribution. For example, *L. terebra*, which is a drought-resistant gastropod species that is typical for astatic water bodies that freeze to the bottom in winter and dry out in summer, is listed as Near Threatened (NT) at both the EU 27 and local (Poland) level. Our survey revealed the occurrence of *L. terebra* in the sedge marshes and ponds. *Ladislavella terebra* occurs in ponds, swamps, drainage ditches and floodplain meadows in a few European countries, e.g., Germany, Sweden, Slovakia, the Czech Republic and Bosnia and Herzegovina [33]. Some lymnaeid species, which are listed in the European Red List of Non-marine Molluscs [18], are classified as Data Deficient (DD) in accordance with the Polish Red List of Species, i.e., *S. palustris*, *S. turricula* and *Stagnicola corvus* (Gmelin, 1778). These species were recedents and subrecedents, respectively, in the NAHs located along the Krąpiel River. The major threats for these species, which lead to a decrease in their population, are the drying out of swamps and the melioration of river valleys. *Stagnicola turricula*, which is a central-eastern European species, inhabits both permanent and ephemeral freshwater habitats [43,44]. A review of the European Lymnaeidae based on a molecular survey showed that *S. turricula* may not be considered to be a species that is independent from *S. palustris* [45]. However, the result of Pieńkowska et al. [46] confirmed the separate status of *S. turricula* as a species. According to Hill et al. [21], perennial floodplain meadow ponds support more gastropod species than ephemeral ponds including lymnaeid species such *S. palustris* and *R. balthica*.

Global conservation efforts and conservation measures on freshwater Mollusca are primarily focused on gastropods and large bivalves, whereas fingernail clams (Sphaeriidae) are considered to a lesser extent [47]. The ecology and biology of large bivalves are better known compared to fingernail clams [48]. The distribution of fingernail clams, which are gill breathers, is limited by low pH, a low concentration of calcium, a high concentration of nutrients and a higher content of organic matter in bottom sediments. What is more, the aerobic microbial decomposition of organic matter requires more oxygen than is introduced into the environment at the substrate layer. As a result, few macroinvertebrates can survive in such environmental conditions [1,48,49]. The NAHs located along the Krąpiel River contain nine sphaeriid species including rare species, i.e., *P. globulare*. However, more sphaeriid species were recorded in the oxbow lakes and springs. Our results showed lower minimum values of the nutrient concentrations in the water and a lower concentration of organic matter in the bottom sediments in the oxbow lakes or springs compared with the sedge marshes, flooded alder woods or pools.

4.2. Mollusc Species of the Natural Aquatic Habitats along the River Valley: The Threat and the Conservation Status

In Europe, according to the IUCN Red List [50], the intensification of agriculture impacts 36% of the freshwater molluscs; urbanisation including poor sewage control impacts 29%, whereas the occurrence of invasive species impacts less than 5%. There is no single threat to each mollusc species, but usually, combined multiple threats lead to declining populations. Our results revealed the occurrence of two IAS, i.e., the gastropod species *P. antipodarum* and the bivalve species *D. polymorpha*. They were recorded in 1933 and 1824 for the first time in Poland, respectively [33]. Although they were subrecedents in the mollusc communities of the NAHs along a valley of the Krąpiel River, their impact on native species may be more visible in the future. In comparison with the lotic habitat, *D. polymorpha* was not recorded in the Krąpiel River [22]. *Dreissena polymorpha* prefers water hardness above 300 mg $CaCO_3$ dm^{-3} and pH above 7.0 [33]. More favourable environmental condition for *D. polymorpha* was recorded in the NAHs (flooded alder woods) in comparison with the Krąpiel River. Therefore, the NAHs should be taken into consideration as hotspots for the spread of IAS in the entire valley of the Krąpiel River in conservation plans.

According to Böhm et al. [19], the threat level for freshwater gastropods is the highest in Europe; in contrast, the threat level for freshwater bivalves is the highest in North America. Considering the EU 27 level, 667 freshwater mollusc species are included in the IUCN Red List [50]. Among them 21.0% are classified as Vulnerable (VU); 8.4% are classified as Near Threatened (NT), and 25.8% are classified as Least Concern (LC). Near Threatened (NT) species constitute 6.3% of the total number of freshwater gastropod species, whereas Vulnerable (VU) species constitute 6.7% of the total number of bivalve species on the IUCN Red List [50]. For example, 4.0% of the freshwater molluscs that occur in Poland are threatened, and 6.0% are Near Threatened at the European level. Habitat loss, fragmentation and degradation are the most significant threats to these molluscs. Our survey showed the occurrence of 5 gastropod species that are classified as Near Threatened (NT) at a local scale, e.g., *B. leachii*, *P. carinatus* or *G. rossmaeslerii.* In Poland, freshwater gastropods suffer from the eutrophication and pollution of water, the regulation of rivers and the loss of marshy habitats. Anthropogenic changes affect 70% of the bivalve species. Bivalves, especially from the family Sphaeriidae, are threatened by the degradation and pollution of rivers, water reservoirs and their nearest surroundings [33,50].

4.3. Landscape Metrics as Drivers of Mollusc Community Changes

The results of the RDA ordinations showed that both landscape metrics within the buffer zones and the chemical parameters of the water influenced the structure of the mollusc communities in the NAHs located along a valley of the Krąpiel River. Among them, the number of patches and their size, the structure of the patches of specific buffer zones and land use including riparian forests or shrubs were essential. These results are consistent with the survey of Thornhill et al. [51] who highlighted the importance of the local and landscape-scale factors in structuring freshwater biota. According to Thornhill et al. [51], both local factors (e.g., the number of macrophyte species, shading and some physical and chemical parameters of the water) and landscape-scale factors (scrubs and ponds) play key roles in structuring macroinvertebrate communities including molluscs in water bodies. Some other landscape-scale factors, such as the area of the water bodies and their management processes, are most important in structuring macroinvertebrate communities including molluscs according to the surveys of Sayer et al. [52] and Hill et al. [17].

Riparian forests and shrubs supply streams, rivers and ponds with water by slowing down the outflow of rainwater into the forest soils and thus regulate water relations in river catchments. By intercepting and utilising the nutrients from agricultural areas, they protect freshwater ecosystems against eutrophication [53]. A riparian forest modifies the fuelling sources for stream food in which allochthonous carbon sustains the macroinvertebrate biomass [54], retains fine sediments, nutrients and pesticides and controls water temperature and primary production [55]. The smaller cover of a riparian forest is associated with a significantly greater percentage of silt and very fine organics in the substratum [56]. *Segmentina nitida*, *A. vortex*, *A. hypnorum* and *R. balthica* rarely occur on fine-grained sediments. These species prefer a coarser substratum, rotting leaves and poorly fragmented detritus and shaded sites (*A. hypnorum*) where they feed on the periphyton that is scraped from the hard substratum, especially diatoms and the tissues of rotting vascular plants [33]. Thus, the positive correlations between the area of a riparian forest or shrubs and the distribution of some mollusc species in the NAHs located along the Krąpiel River may be explained by their ecological make up. In contrast, the density and biomass of active filterers, primarily fingernail clams (Sphaeriidae), decrease with an increase in the coverage of a riparian forest [22].

The results of the RDA ordinations suggested that among the environmental variables, pH was the parameter associated with the distribution of *G. truncatula*, *B. contortus*, *R. balthica*, *S. nitida* and *A. vortex*. However, the distribution of *R. balthica* and *A. vortex* was negatively related to increasing pH. According to Piechocki and Wawrzyniak-Wydrowska [33], species that are most tolerant to acidity include *G. truncatula*, *B. contortus* and *R. balthica* as well as some bivalve species, i.e., *Pisidium casertanum* (Poli, 1791), *P. obtusale* and *Pisidium milium* Held, 1836. These species inhabit both very acid as well as alkaline freshwater environments. Our result is consistent with the surveys of Spyra [57], who revealed the occurrence of *R. balthica* and *A. vortex* in the most acidified ponds. Acidification of freshwater environments has a serious, adverse impact on the occurrence of flora and fauna, and it constitutes a persistent threat at the global scale [58,59]. Bicarbonates, a key source of both an acid-neutralising capacity and inorganic carbon for photosynthesis in water at pH between 5.5 and 6.5, become rapidly depleted and then are lost. Low pH releases toxic heavy metals from the bottom sediments [33,58]. Gastropods are among the most acid-sensitive groups of freshwater organisms. They are even more sensitive to pH changes than fish. At a low pH value, calcium is not easily accessible to gastropods [60]. With an increasing calcium concentration, lower pH values may be tolerated by gastropods since calcium ameliorates acidic stress. The acidification of water influences adult shell erosion and recruitment failure due to the mortality of eggs and juveniles. A shortage of calcium causes osmotic dysfunction and affects the shells or cuticle secretion. What is more, macrophytes and algae are more common, and particles of detritus decompose more rapidly thus enhancing the supply of fine particulate organic matter (FPOM) (sources of food for molluscs) in less acidic water bodies. According to Økland [60,61], decreases in gastropod species are particularly noticeable at pH of around 6.0. Thus, in our survey, the relationship between the distribution of mollusc species and pH of the water may be explained by their physiological make up. In contrast to the lentic habitat, the turbidity and concentration of dissolved oxygen in the water were most associated (statistically significant) with mollusc distribution in the Krąpiel River [22].

4.4. Implications for Management and Conservation of Freshwater Molluscs through the Buffer Zones

Landscape metrics provide essential data about watersheds and their anthropogenic transformations, and therefore they are indispensable tools in management processes [62]. Land use within 100 m of water bodies has a strong influence on the freshwater biota. The survey of Joniak, Kuczyńska-Kippen and Gąbka [63] showed that both the catchment and buffer attributes (e.g., shrubs and tree vegetation in the buffer zone) determine the hydrobiota structure and the quality of water in small aquatic ecosystems. Moreover, in buffer zones that combine herbage and trees, the effectiveness of retaining or removing nitrates through plant uptake or denitrification may reach up to 99%. According to Nieto et al. [64], buffer areas of 50 m on each margin are the minimum size that is necessary to significantly reduce the input of nutrients and agrochemicals into the rivers. Comparing the results of our previous survey [22], the concentrations of phosphates and ammonium nitrogen were higher in the NAHs located along a valley of the Krąpiel River than in the Krąpiel River. The total hardness, conductivity and BOD were higher in the NAHs than in the river, especially in oxbow lakes. This result confirms that the NAHs constitute a significant protective barrier for the Krąpiel River retaining significant amounts of nutrients and organic matter. Our result is consistent with the survey of Biggs, von Fumetti and Kelly-Quinn [9] who obtained a higher concentration of phosphates in water bodies than in the rivers that flow through the same landscape areas.

Species richness depends on two components: type and intensity of land use and heterogeneity of habitats [65]. Low-intensity land use and heterogeneity are drivers for species-rich groups that include wetland plants, plant habitat indicators, upland birds and rare invertebrates, whereas farmland birds and invertebrates are associated with the higher intensity of land use. The buffer zones within a radius of 500 m from a sampling point take into account the share of different types of land use: agricultural areas, semi-natural areas, urban areas, etc. The type of land use within the buffer zone directly influences habitats along the river valleys and stream communities. According to Grimstead, Krynak and Yates [66], riparian forest, for example, effectively buffers streams from agricultural activity and protects stream organisms even if the agriculture exceeds 80% of the catchment.

Conservation means a series of measures that are required to maintain or restore natural habitats and wild plants and animals. According to the Council Directive 92/43/EEC [28], the Member States of the European Union should endeavour to encourage the management of the landscape features which are of importance for wild fauna and flora. The land use planning and development policies should also take into account those activities that lead to the improvement of the ecological coherence of the Natura 2000 network. These landscape features which include rivers and their banks, ponds and small woods, etc., are essential for the migration, dispersal and genetic exchange of wild species. River valleys, for example, are regarded as hotspots of biodiversity and constitute important natural corridors for the migration of organisms [67]. In developed countries where landscapes are deteriorated by human pressure, water bodies comprise almost exclusively ponds of the anthropogenic original. Therefore, the conservation measure should be first focused on the remaining ones that are of natural origin, e.g., by restoring the natural functioning of floodplains within valleys of rivers [68].

The results of the RDA highlighted the direct influence of landscape features (metrics) and different types of land use (semi-natural areas or urban areas, e.g., forest and shrubs versus low-density housing) on the distribution of molluscs in the NAHs along the valley of the Krąpiel River. Some changes within buffer zones, e.g., reduction of the number of patches or patches size, reduction of area of peat bog, stagnant waters (ponds), riparian forest or shrubs will trigger negative changes in the structure of mollusc communities. Therefore, these attributes of landscape features (landscape metrics) should be taken into consideration in case of future land use planning and development policies and the future management and conservation processes within the river valley and adjacent areas including buffer zones.

4.5. A Roadmap for the Conservation and Management Plans for the River, NAHs and the Adjacent Habitats through the Buffer Zones

These results and our previous survey [22] showed high concentrations of nutrients, especially ammonium nitrogen and phosphates, in oxbow lakes, flooded alder woods and ponds as well as along the Krąpiel River. Organic pollution of the water reflected by the values of the BOD was high, especially in oxbow lakes. The sources of ammonium nitrogen in surface waters can be the biochemical decomposition of plant and animal organic nitrogen compounds, industrial and municipal wastewater discharges and the biochemical process of nitrate reduction. The anthropogenic supply of phosphates into surface waters includes runoff from the use of fertilisers in agricultural areas or runoff from farmyards, municipal sewage and industrial wastewater pollution.

European countries including Poland still struggle with excessive nitrates and phosphates in surface waters which pose a threat to freshwater biodiversity [1,69–71]. Despite the need for the implementation of the Nitrates Directive (Directive 91/676/EEC) [72] concerning the protection of waters against pollution caused by nitrates from agricultural sources and the establishment of the Nitrates Vulnerable Zones (NVZs) in the entirity of Europe, the concentration of nitrates in surface waters of the Czech Republic, Finland, Denmark, Luxemburg, Belgium, Germany, Latvia and Poland is still too high. The Nitrates Directive is a key piece of legislation to achieve the objectives of the EU Green Deal, which priorities include protecting biodiversity and ecosystems and reducing water pollution [73]. The Nitrates Directive is an essential tool for supporting the EU WFD to achieve good chemical and ecological status of all water bodies in the EU by 2027 at the latest. For reducing ammonium nitrogen, nitrate and phosphate emissions of agricultural origin (livestock feeding, animal housing, manure storage, manure spreading or non-organic fertilisers) the Best Environmental Management Practice (BEMP) for the agriculture sector should be implemented more effectively and restrictively not only in Poland but in all European countries [74,75]. The BEMP for the agriculture sector should focus on the reduction and prevention of diffuse (non-point) sources of pollution from crop and animal production, including the Krąpiel River catchment to help achieve goals of better water quality. Compared to the Krąpiel River, the NAHs located along the river, are more influenced by nutrient input from diffuse and point sources of pollution (higher concentration of ammonium nitrogen and phosphates in the water). Among pollution of surface waters, anthropogenically elevated nutrient concentration negatively influences the structure of mollusc communities, especially large bivalves of the family Unionidae [1,69,76]. The eutrophication and the input of nutrients from agricultural run-off are considered major threat to European freshwater mussels [47]. Our results showed that Unionidae occurred rarely only at a few sampling sites in the Krąpiel River and they were absent from the NAHs located in the Krąpiel River valley. This phenomenon can be a direct result of the nutrient enrichment in the catchment area of the Krąpiel River or an indirect result, e.g., lack of primary or appropriate host fishes for unionid mussels. In Europe, the Lutter River (Germany) and the Biała Tarnowska River (Poland) are examples of the successful restoration of habitats and the restoration or reintroduction of unionid mussels [77,78]. To date, about 49 LIFE programs, which are the only financial instrument of the European Union dedicated exclusively to co-financing projects in the field of environmental and climate protection, are devoted to the restoration of freshwater mussel habitats with a total funding of over 90 million Euros [78]. Considering the results of our research, the implementation of a similar LIFE project will enable the reducing water pollution, especially nitrogen and phosphorus compounds, and the restoration and improvement of habitats for molluscs, especially unionid mussels including *Unio crassus* (Philipsson, 1788), one of the species of Community interest whose conservation requires designation of special conservation areas within the Habitats Directive Natura 2000.

According to the methodology of our research, buffer zones with a radius of 500 m from a sampling point were designated [22]. This result showed the relationship between the distribution of the mollusc species, the metrics of the buffer zones including the number of patches, size of patches, the distance from shrubs, the increasing area of forest and the physical and chemical parameters of the water. The riparian buffer zones play an unquestionable role in intercepting precipitation and slowing surface runoff, filtering sediments, heavy metals, agrochemicals, organic and non-organic pollution and pathogens preventing these pollutants from the entrance to the surface and groundwaters. These functions of buffer zones are essential, particularly in catchments of urban and agricultural land use of intense diffuse sources of pollution. Riparian zones provide habitats and refuges for various groups of organisms. For example, riparian buffer zones account for less than 5% of the land area in the USA providing habitat for over 70% of vertebrate species; therefore, they constitute keystone habitats [79]. Woody riparian buffers are highlighted as important instruments in the mitigation of the effects of pollution stressors on aquatic ecosystems, and buffers should be established along longer river stretches [80]. Although riparian forest buffers have many advantages for biodiversity and ecosystem services, they are rarely considered in the management of aquatic ecosystems. The higher probability of better ecological status of the water will be achieved when the reach-scale riparian vegetation is at least deciduous tree dominated with small tree dominated (2–5 m) or the forest plantation with less than 25% cover of more than 5 m trees or natural grassy vegetation [81]. Macrophyte species are efficiently involved in the removal of nutrients (ammonium nitrogen, nitrates and phosphates) through direct uptake and microbial processes reducing N and P loads in the water. Macrophytes can assimilate nitrogen and phosphorus from both the water column through their foliage and the river sediments through their roots. *Lemna minor* L. and *Phragmites australis* (Cav.) Trin. ex Steud. are recommended as "green filters" to reduce nutrients and heavy metal pollution [82,83]. However, the protected site (PLH 320005) as the Special Area of Conservation (SAC) was designated in the lower course of the Krąpiel River; the maximum concentrations of ammonia nitrogen and phosphates were higher in the upper and middle courses of the river [22]. In addition, our results showed that the maximum concentrations of nutrients, total hardness, conductivity and BOD were higher in NAHs than in the Krąpiel River. Therefore, the buffer zones should be designated not only within the protected site but along the entire course of the Krąpiel River including NAHs.

5. Conclusions

The natural aquatic habitats (NAHs) located along a valley of a medium-sized lowland river (the Krąpiel River) create a unique valuable ecosystem that contributes to the natural diversity of its entire catchment area. The present results showed the occurrence of 36 mollusc species: 26 gastropod and 10 bivalve species. Among them, the lymnaeid species *L. terebra* is classified as Near Threatened (NT) at both the EU 27 level and the local level. The NAHs located along a valley of the Krąpiel River provide refuges for rare, endemic to Europe and threatened mollusc species that are classified into different categories of threat in accordance with the IUCN Red List. Invasive alien species of Mollusca, i.e., *P. antipodarum* and *D. polymorpha* were recorded only at a few sites. The NAHs located along a valley of a river also play an essential role in the dispersal of IAS. Therefore, in the future, the occurrence and the spread of IAS should be monitored. The mollusc communities in the NAHs are influenced by several environmental variables acting together. In addition to the landscape metrics within the buffer zones, pH and BOD are the most important. The occurrence of mollusc species in the NAHs is also associated with riparian forests and shrubs, which can play an essential role in preserving both aquatic and terrestrial ecosystems and protecting them against pollution. The NAHs including ponds, pools, oxbow lakes or sedge marshes can create important protective biogeochemical barriers that effectively restrict the free migration of minerals and organic substances into a river. They also constitute important sources of moisture and water and support microhabitats for distinct mollusc communities, especially in the context of global warming. Therefore, both the landscape scale factors (landscape metrics within buffer zones) and the local factors (physical and chemical parameters of the water) should be considered by stakeholders in the rehabilitation of river ecosystems, conservation planning and monitoring the management in river valleys.

Management aimed at improving the ecological status of waters within the Krąpiel River catchment should be twofold: reduction of sources of pollutants in the water and limitation of surface runoff of nutrients by creating buffer zones. The buffer zones, specially created around the NAHs, could be considered as the basic water protection treatment against pollution from the agricultural catchment area. The designated buffer zones should be included in the management and restoration plans for the river, water bodies and adjacent habitats as elements of modern, sustainable water management. The properly designated and targeted buffer zones could have significant multiple benefits for improving the quality of the water, increasing the biodiversity or moisture retention not only in the catchment of the Krąpiel River but also in river valleys in other countries. The quality of the waters of the Krąpiel River and in the NAHs in the valley of the river is insufficient in accordance with the requirements of the EU WFD and far from good ecological status, which should be achieved by 2027. Supervision over waters in Poland by specially appointed state services, i.e., the State Water Holding Polish Waters, the main entity responsible for water management in Poland, seems to be insufficient, especially in the context of the ecological disaster in Poland, in the Odra River, in summer 2022.

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References

1. Lewin, I. Mollusc communities of lowland rivers and oxbow lakes in agricultural areas with anthropogenically elevated nutrient concentration. *Folia Malacol.* **2014**, *22*, 87–159. [CrossRef]
2. Grizzetti, B.; Pistocchi, A.; Liquete, C.; Udias, A.; Bouraoui, F.; van de Bund, W. Human pressures and ecological status of European rivers. *Sci. Rep.* **2017**, *7*, 205. [CrossRef] [PubMed]
3. Lemm, J.U.; Feld, C.K. Identification and interaction of multiple stressors in central European lowland rivers. *Sci. Total Environ.* **2017**, *603–604*, 148–154. [CrossRef] [PubMed]
4. Sousa, J.C.G.; Ribeiro, A.R.; Barbosa, M.O.; Pereira, M.F.R.; Silva, A.M.T. A review on environmental monitoring of water organic pollutants identified by EU guidelines. *J. Hazard. Mater.* **2017**, *344*, 146–162. [CrossRef] [PubMed]
5. Woodward, G.; Gessner, M.O.; Giller, P.S.; Gulis, V.; Hladyz, S.; Lecerf, A.; Malmqvist, B.; McKie, B.G.; Tiegs, S.D.; Cariss, H.; et al. Continental-scale effects of nutrient pollution on stream ecosystem functioning. *Science* **2012**, *336*, 1438–1440. [CrossRef]
6. Liu, X.; Zhang, J.; Shi, W.; Wang, M.; Chen, K.; Wang, L. Priority Pollutants in Water and Sediments of a River for Control Basing on Benthic Macroinvertebrate Community Structure. *Water* **2019**, *11*, 1267. [CrossRef]
7. Doaemo, W.; Betasolo, M.; Montenegro, J.F.; Pizzigoni, S.; Kvashuk, A.; Femeena, P.V.; Mohan, M. Evaluating the Impacts of Environmental and Anthropogenic Factors on Water Quality in the Bumbu River Watershed, Papua New Guinea. *Water* **2023**, *15*, 489. [CrossRef]
8. Davidson, N.C. How much wetland has the world lost? Long-term and recent trends in global wetland area. *Mar. Freshwater Res.* **2014**, *65*, 934–941. [CrossRef]
9. Biggs, J.; von Fumetti, S.; Kelly-Quinn, M. The importance of small waterbodies for biodiversity and ecosystem services: Implications for policy makers. *Hydrobiologia* **2017**, *793*, 3–39. [CrossRef]
10. Wood, P.J.; Greenwood, M.T.; Agnew, M.D. Pond biodiversity and habitat loss in the UK. *Area* **2003**, *35*, 206–216. [CrossRef]
11. Gallardo, B.; Cabezas, Á.; González, E.; Comín, F.A. Effectiveness of a newly created oxbow lake to mitigate habitat loss and increase biodiversity in regulated floodplain. *Restor. Ecol.* **2012**, *20*, 387–394. [CrossRef]
12. Obolewski, K.; Glińska-Lewczuk, K.; Bąkowska, M. From isolation to connectivity: The effect of floodplain lake restoration on sediments as habitats for macroinvertebrate communities. *Aquat. Sci.* **2018**, *80*, 4. [CrossRef]
13. Pander, J.; Mueller, M.; Geist, J. Habitat diversity and connectivity govern the conservation value of restored aquatic floodplain habitats. *Biol. Conserv.* **2018**, *217*, 1–10. [CrossRef]
14. Petsch, D.K.; de Mello Cionek, V.; Thomaz, S.M.; dos Santos, N.C.L. Ecosystem services provided by river-floodplain ecosystems. *Hydrobiologia* **2022**. [CrossRef]
15. Coccia, C.; Vanschoenwinkel, B.; Brendonck, L.; Boyero, L.; Green, A.J. Newly created ponds complement natural waterbodies for restoration of macroinvertebrate assemblages. *Freshwater Biol.* **2016**, *61*, 1640–1654. [CrossRef]
16. Jurkiewicz-Karnkowska, E. Diversity of aquatic malacofauna within a floodplain of a large lowland river (lower Bug River, Eastern Poland). *J. Mollus Stud.* **2009**, *75*, 223–234. [CrossRef]
17. Hill, M.J.; Ryves, D.B.; White, J.C.; Wood, P.J. Macroinvertebrate diversity in urban and rural ponds: Implications for freshwater biodiversity conservation. *Biol. Conserv.* **2016**, *201*, 50–59. [CrossRef]
18. Cuttelod, A.; Seddon, M.; Neubert, E. *European Red List of Non-Marine Molluscs*; Publications Office of the European Union: Luxembourg, 2011.
19. Böhm, M.; Dewhurst-Richman, N.I.; Seddon, M.; Ledger, S.E.H.; Albrecht, C.; Allen, D.; Bogan, A.E.; Cordeiri, J.; Cummings, K.S.; Cuttelod, A.; et al. The conservation status of the world's freshwater molluscs. *Hydrobiologia* **2021**, *848*, 3231–3254. [CrossRef]
20. Heino, J. Lentic macroinvertebrate assemblage structure along gradients in spatial heterogeneity, habitat size and water chemistry. *Hydrobiologia* **2000**, *418*, 229–242. [CrossRef]
21. Hill, M.J.; Death, R.G.; Mathers, K.L.; Ryves, D.B.; White, J.C.; Wood, P.J. Macroinvertebrate community composition and diversity in ephemeral and perennial ponds on unregulated floodplain meadows in the UK. *Hydrobiologia* **2017**, *793*, 95–108. [CrossRef]
22. Zawal, A.; Lewin, I.; Stępień, E.; Szlauer-Łukaszewska, A.; Buczyńska, E.; Buczyński, P.; Stryjecki, R. 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. *Ecol. Res.* **2016**, *31*, 853–867. [CrossRef]
23. Pakulnicka, J.; Buczyński, P.; Dąbkowski, P.; Buczyńska, E.; Stępień, E.; Szlauer-Łukaszewska, A.; Zawal, A. Development of fauna of water beetles (Coleoptera) in waters bodies of a river valley habitat factors, landscape and geomorphology. *Knowl. Manag. Aquat. Ecosyst.* **2016**, *417*, 40. [CrossRef]
24. Stryjecki, R.; Zawal, A.; Stępień, E.; Buczyńska, E.; Buczyński, P.; Czachorowski, S.; Szenejko, M.; Śmietana, P. Water mites (Acari, Hydrachnidia) of water bodies of the Krąpiel River valley: Interactions in the spatial arrangement of a river valley. *Limnology* **2016**, *17*, 24–261. [CrossRef]
25. Stryjecki, R.; Zawal, A.; Krepski, T.; Stępień, E.; Buczyńska, E.; Buczyński, P.; Czachorowski, S.; Jankowiak, Ł.; Pakulnicka, J.; Sulikowska-Drozd, A.; et al. Anthropogenic transformations of river ecosystems are not always bad for the environment: Multi-taxa analyses of changes in aquatic and terrestrial environments after dredging of a small lowland river. *PeerJ* **2021**, *9*, e12224. [CrossRef] [PubMed]
26. *Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 Establishing a Framework for Community Action in the Field of Water Policy*; Official Journal of the European Communities (L327); Publications Office of the European Union: Luxembourg, 2000; pp. 1–72.

27. *Directive 2009/147/EC of the European Parliament and of the Council of 30 November 2009 on the Conservation of Wild Birds (Codified Version)*; Official Journal of the European Union (L20/7); Publications Office of the European Union: Luxembourg, 2009; pp. 1–19.
28. *Council Directive 92/43/EEC of 21 May 1992 on the Conservation of Natural Habitats and Wild Fauna and Flora*; Council of the European Communities: Brussels, Belgium, 1992.
29. Piechocki, A. *Mięczaki (Mollusca). Ślimaki (Gastropoda). Fauna Słodkowodna Polski. Zeszyt 7*; Państwowe Wydawnictwo Naukowe: Warszawa, Poland, 1979.
30. Piechocki, A.; Dyduch-Falniowska, A. *Mięczaki (Mollusca). Małże (Bivalvia). Fauna Słodkowodna Polski 7A*; Wydawnictwo Naukowe PWN: Warszawa, Poland, 1993.
31. Glöer, P.; Meier-Brook, C. *Süsswassermollusken. Ein Bestimmungsschlüssel für die Bundesrepublik Deutschland*; Deutscher Jugendbund für Naturbeobachtung DJN: Hamburg, Germany, 1998; ISBN 9783923376025.
32. Glöer, P. *Süsswassergastropoden. Nord-und Mitteleuropas Bestimmungsschlüssel, Lebensweise, Verbreitung*, 2nd ed.; ConchBooks: Hackenheim, Germany, 2002; ISBN 13: 9783925919602.
33. Piechocki, A.; Wawrzyniak-Wydrowska, B. *Guide to Freshwater and Marine Mollusca of Poland*; Bogucki Wydawnictwo Naukowe: Poznań, Poland, 2016.
34. Górny, M.; Grüm, L. *Metody Stosowane w Zoologii Gleby*; Państwowe Wydawnictwo Naukowe: Warszawa, Poland, 1981.
35. McCune, B.; Grace, J.B. *Analysis of Ecological Communities*; MjM Software Design: Gleneden Beach, OR, USA, 2002; ISBN 0-9721290-0-6.
36. Shannon, C.E. A Mathematical Theory of Communication. *Bell Syst. Tech. J.* **1948**, *27*, 379–423. [CrossRef]
37. Ter Braak, C.J.F.; Šmilauer, P. *CANOCO Reference Manual and CanoDraw for Windows User's Guide: Software for Canonical Community Ordination (Version 4.5)*, 2nd ed.; Microcomputer Power: Ithaca, NY, USA, 2002.
38. Jurkiewicz-Karnkowska, E.; Karnkowski, P. GIS analysis reveals the high diversity and conservation value of mollusc assemblages in the floodplain wetlands of the lower Bug River (East Poland). *Aquat. Conserv.* **2013**, *23*, 952–963. [CrossRef]
39. Reckendorfer, W.; Baranyi, C.; Funk, A.; Schiemer, F. Floodplain restoration by reinforcing hydrological connectivity: Expected effects on aquatic mollusc communities. *J. Appl. Ecol.* **2006**, *43*, 474–484. [CrossRef]
40. Obolewski, K.; Glińska-Lewczuk, K.; Kobus, S. Effect of hydrological connectivity on the molluscan community structure in oxbow lakes of the Łyna River. *Oceanol. Hydrobiol. Stud.* **2009**, *38*, 75–88. [CrossRef]
41. Lewin, I.; Smoliński, A. Rare, threatened and alien species in the gastropod communities in the clay pit ponds in relation to the environmental factors (The Ciechanowska Upland, Central Poland). *Biodivers. Conserv.* **2006**, *15*, 3617–3635. [CrossRef]
42. Pérez-Quintero, J.C. Freshwater mollusc biodiversity and conservation in two stressed Mediterranean basins. *Limnologica* **2011**, *41*, 201–212. [CrossRef]
43. Vadadi-Fülöp, C.; Mészáros, G.; Jablonszky, G.; Hufnagel, L. Ecology of the Ráckeve-Soroksár Danube—A review. *Appl. Ecol. Environ. Res.* **2007**, *5*, 133–163. [CrossRef]
44. Skowrońska-Ochmann, K.; Cuber, P.; Lewin, I. The first record and occurrence of *Stagnicola turricula* (Held, 1836) (Gastropoda: Pulmonata: Lymnaeidae) in Upper Silesia (Southern Poland) in relation to different environmental factors. *Zool. Anz.* **2012**, *251*, 357–363. [CrossRef]
45. Bargues, M.D.; Vigo, M.; Horak, P.; Dvorak, J.; Patzner, R.A.; Pointier, J.P.; Jackiewicz, M.; Meier-Brook, C.; Mas-Coma, S. European Lymnaeidae (Mollusca: Gastropoda), intermediate hosts of trematodiases, based on nuclear ribosomal DNA ITS-2 sequences. *Infect. Genet. Evol.* **2001**, *1*, 85–107. [CrossRef]
46. Pieńkowska, J.R.; Rybska, E.; Banasiak, J.; Wesołowska, M.; Lesicki, A. Taxonomic status of *Stagnicola palustris* (O. F. Müller, 1774) and *S. turricula* (Held, 1836) (Gastropoda: Pulmonata: Lymnaeidae) in view of new molecular and chorological data. *Folia Malacol.* **2015**, *23*, 3–18. [CrossRef]
47. Lopes-Lima, M.; Sousa, R.; Geist, J.; Aldridge, D.C.; Araujo, R.; Bergengren, J.; Bespalaya, Y.; Bódis, E.; Burlakova, L.; Van Damme, D.; et al. Conservation status of freshwater mussels in Europe: State of the art and future challenges. *Biol. Rev.* **2017**, *92*, 572–607. [CrossRef]
48. Watson, A.M.; Ormerod, S.J. The distribution and conservation of threatened Sphaeriidae on British grazing marshland. *Biodivers. Conserv.* **2005**, *14*, 2207–2220. [CrossRef]
49. Watson, A.M.; Ormerod, S.J. The distribution of three uncommon freshwater gastropods in the drainage ditches of British grazing marshes. *Biol. Conserv.* **2004**, *118*, 455–466. [CrossRef]
50. IUCN Red List. Poland's Biodiversity at Risk. A Call for Action. Available online: https://www.cbd.int/countries/profile/?country=pl (accessed on 22 January 2018).
51. Thornhill, I.; Batty, L.; Death, R.G.; Friberg, N.R.; Ledger, M.E. Local and landscape scale determinants of macroinvertebrate assemblages and their conservation value in ponds across an urban land-use gradient. *Biodivers. Conserv.* **2017**, *26*, 1065–1086. [CrossRef]
52. Sayer, C.; Andrews, K.; Shilland, E.; Edmonds, N.; Edmonds-Brown, R.; Patmore, J.; Emson, D.; Axmacher, J. The role of pond management for biodiversity conservation in an agricultural landscape. *Aquat. Conserv.* **2012**, *22*, 626–638. [CrossRef]
53. Fail, J.L.; Haines, B.L.; Todd, R.L. Riparian forest communities and their role in nutrient conservation in an agricultural watershed. *Am. J. Altern. Agric.* **2009**, *2*, 114–121. [CrossRef]

54. González-Bergonzoni, I.; Kristensen, P.B.; Baattrup-Pedersen, A.; Kristensen, E.A.; Alnoee, A.B.; Riis, T. Riparian forest modifies fuelling sources for stream food webs but not food-chain length in lowland streams of Denmark. *Hydrobiologia* **2018**, *805*, 291–310. [CrossRef]
55. Palt, M.; Le Gall, M.; Piffady, J.; Hering, D.; Kail, J. A metric-based analysis on the effects of riparian and catchment landuse on macroinvertebrates. *Sci. Total Environ.* **2022**, *816*, 151590. [CrossRef] [PubMed]
56. Stone, M.L.; Whiles, M.R.; Webber, J.A.; Williard, K.W.J.; Reeve, J.D. Macroinvertebrate communities in agriculturally impacted Southern Illinois streams: Patterns with riparian vegetation, water quality, and in-stream habitat quality. *J. Environ. Qual.* **2005**, *34*, 907–917. [CrossRef] [PubMed]
57. Spyra, A. Acidic, neutral and alkaline forest ponds as a landscape element affecting the biodiversity of freshwater snails. *Sci. Nat.* **2017**, *104*, 73. [CrossRef]
58. Lacoul, P.; Freedman, B.; Clair, T. Effects of acidification on aquatic biota in Atlantic Canada. *Environ. Rev.* **2011**, *19*, 429–460. [CrossRef]
59. Hasler, C.T.; Jeffrey, J.D.; Schneider, E.V.C.; Hannan, K.D.; Tix, J.A.; Suski, C.D. Biological consequences of weak acidification caused by elevated carbon dioxide in freshwater ecosystems. *Hydrobiologia* **2018**, *806*, 1–12. [CrossRef]
60. Økland, J. Factors regulating the distribution of fresh-water snails (Gastropoda) in Norway. *Malacologia* **1983**, *24*, 277–288.
61. Økland, J. *Lakes and Snails. Environment and Gastropoda in 1500 Norwegian Lakes, Ponds and Rivers*; Universal Book Services/Dr. W. Backhuys: Oegstgeest, The Netherlands, 1990; ISBN 13: 9789073348028.
62. Kearns, F.R.; Kelly, N.M.; Carter, J.L.; Resh, V.H. A method for the use of landscape metrics in freshwater research and management. *Landsc. Ecol.* **2005**, *20*, 113–125. [CrossRef]
63. Joniak, T.; Kuczyńska-Kippen, N.; Gąbka, M. Effect of agricultural landscape characteristics on the hydrobiota structure in small water bodies. *Hydrobiologia* **2017**, *793*, 121–133. [CrossRef]
64. Nieto, C.; Ovando, X.M.C.; Loyola, R.; Izquierdo, A.; Romero, F.; Molineri, C.; Rodríguez, J.; Rueda Martín, P.; Fernández, H.; Manzo, V.; et al. The role of macroinvertebrates for conservation of freshwater systems. *Ecol. Evol.* **2017**, *7*, 5502–5513. [CrossRef]
65. Maskell, L.; Botham, C.M.; Henrys, P.; Jarvis, S.; Maxwell, D.; Robinson, D.A.; Rowland, C.S.; Siriwardena, G.; Smart, S.; Skates, J.; et al. Exploring relationships between land use intensity, habitat heterogeneity and biodiversity to identify and monitor areas of High Nature Value farming. *Biol. Conserv.* **2019**, *231*, 30–38. [CrossRef]
66. Grimstead, J.P.; Krynak, E.M.; Yates, A.G. Scale-specific land cover thresholds for conservation of stream invertebrate communities in agricultural landscapes. *Landsc. Ecol.* **2018**, *33*, 2239–2252. [CrossRef]
67. Nobis, A.; Rola, K.; Węgrzyn, M. Detailed study of a river corridor plant distribution pattern provides implications for river valley conservation. *Ecol. Indic.* **2017**, *8*, 314–322. [CrossRef]
68. Oertli, B. Freshwater biodiversity conservation: The role of artificial ponds in the 21st century. *Aquat. Conserv.* **2018**, *28*, 264–269. [CrossRef]
69. Douda, K. Effects of nitrate nitrogen pollution on Central European unionid bivalves revealed by distributional data and acute toxicity testing. *Aquat. Conserv.* **2010**, *20*, 189–197. [CrossRef]
70. Kupiec, J.M.; Staniszewski, R.; Kayzer, D. Assessment of Water Quality Indicators in the Orla River Nitrate Vulnerable Zone in the Context of New Threats in Poland. *Water* **2022**, *14*, 2287. [CrossRef]
71. Severini, E.; Bartoli, M.; Pinardi, M.; Celico, F. Short-Term Effects of the EU Nitrate Directive Reintroduction: Reduced N Loads to River from an Alluvial Aquifer in Northern Italy. *Hydrology* **2022**, *9*, 44. [CrossRef]
72. *Council Directive of 12 December 1991 Concerning the Protection of Waters against Pollution Caused by Nitrates from Agricultural Sources (91/676/EEC)*; Directive 91/676/EEC; Council of the European Communities: Brussels, Belgium, 1991.
73. *Report from the Commission to the Council and the European Parliament on the Implementation of Council Directive 91/676/EEC Concerning the Protection of Waters against Pollution Caused by Nitrates from Agricultural Sources Based on Member State Reports for the Period 2016–2019*; European Commission: Brussels, Belgium, 2021.
74. *Commission Decision (EU) 2018/813 of 14 May 2018 on the Sectoral Reference Document on Best Environmental Management Practices, Sector Environmental Performance Indicators and Benchmarks of Excellence for the Agriculture Sector under Regulation (EC) No 1221/2009 of the European Parliament and of the Council on the Voluntary Participation by Organisations in a Community Eco-Management and Audit Scheme (EMAS)*; European Commission: Brussels, Belgium, 2018.
75. Drizo, A.; Johnston, C.; Guðmundsson, J. An Inventory of Good Management Practices for Nutrient Reduction, Recycling and Recovery from Agricultural Runoff in Europe's Northern Periphery and Arctic Region. *Water* **2022**, *14*, 2132. [CrossRef]
76. Alonso, Á.; Gómez-de-Prado, G.; Romero-Blanco, A. Behavioral Variables to Assess the Toxicity of Unionized Ammonia in Aquatic Snails: Integrating Movement and Feeding Parameters. *Arch. Environ. Contam. Toxicol.* **2022**, *82*, 429–438. [CrossRef]
77. Zając, K.; Florek, J.; Zając, T.; Adamski, P.; Bielański, W.; Ćmiel, A.M.; Klich, M.; Lipińska, A.M. On the reintroduction of the endangered thick-shelled river mussel *Unio crassus*: The importance of the river's longitudinal profile. *Sci. Total Environ.* **2018**, *624*, 273–282. [CrossRef]
78. Soroka, M.; Wasowicz, B.; Zając, K. Conservation status and a novel restoration of the endangered freshwater mussel *Unio crassus* Philipsson, 1788: Poland case. *Knowl. Manag. Aquat. Ecosyst.* **2021**, *422*, 3. [CrossRef]
79. Graziano, M.P.; Deguire, A.K.; Surasinghe, T.D. Riparian Buffers as a Critical Landscape Feature: Insights for Riverscape Conservation and Policy Renovations. *Diversity* **2022**, *14*, 172. [CrossRef]

80. Le Gall, M.; Palt, M.; Kail, J.; Hering, D.; Piffady, J. Woody riparian buffers have indirect effects on macroinvertebrate assemblages of French rivers, but land use effects are much stronger. *J. Appl. Ecol.* **2022**, *59*, 526–536. [CrossRef]
81. Forio, M.A.E.; Burdon, F.J.; De Troyer, N.; Lock, K.; Witing, F.; Baert, L.; De Saeyer, N.; Rîşnoveanu, G.; Popescu, C.; Kupilas, B.A. Bayesian Belief Network learning tool integrates multi-scale effects of riparian buffers on stream invertebrates. *Sci. Total Environ.* **2022**, *810*, 152146. [CrossRef]
82. Ruiz, M.; Velasco, J. Nutrient Bioaccumulation in *Phragmites australis*: Management Tool for Reduction of Pollution in the Mar Menor. *Water Air Soil Pollut.* **2010**, *205*, 173–185. [CrossRef]
83. Kalengo, L.; Ge, H.; Liu, N.; Wang, Z. The Efficiency of Aquatic Macrophytes on the Nitrogen and Phosphorous Uptake from Pond Effluents in Different Seasons. *J. Ecol. Eng.* **2021**, *22*, 75–85. [CrossRef]