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Natural and Geomorphological Response of the Small Lowland River Valley for Anthropogenic Transformation

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Abstract: The regulation of small rivers and the consequent maintenance works are common in the Central European Lowlands. This article attempts to determine the relationship between the invertebrate fauna (and consequently the biocenosis) of the small lowland river valley and its landforms (morphodynamics) under the conditions of very large and rapid changes caused by river regulation and maintenance. On this basis, an attempt to analyze the response of the ecosystem to rapid transformations associated with engineering works was made. The study covered Kraska, a small river typical for Polish Lowlands, which has been regulated along almost the entire length. The results showed that, in the regulated sections, where the natural forms of the relief were destroyed, there were significantly fewer taxa and significantly smaller numbers of the specimen. Despite the clear negative impact of the regulatory work on the ecosystem, the river in some sections showed the ability to spontaneously restore certain geomorphic features.

Keywords: river valley; biological diversity; ecological status; macroinvertebrates; landforms; fluvial geomorphology

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1. Introduction

According to the Annex II of the Water Framework Directive (Directive 2000/60/EC, 2000) [1], a small lowland river is considered to be one whose catchment area covers between 100 and 1000 km^2 and is located at an altitude not exceeding 200 m above the sea level. Small river valleys are typical elements of the lowlands of Central Poland—the part of vast Central European Lowlands. They play important roles as free migration corridors for biota, as well as refuges and breeding grounds for fish, amphibians, birds and invertebrates [2]. They also increase biological diversity and contribute to the ecological balance of valuable nature areas at a regional scale [3,4].

One of the most important threats to environmental values of small lowland rivers is the human activity, especially technical river regulation and maintenance works, both in the riverbed and in the riparian zone [5,6]. Such impacts may significantly reduce faunistic diversity, causing disturbances in the functioning of trophic networks and loss of ecological stability of the entire system [7].

Many authors [8,9] emphasize that anthropogenic transformation of rivers and their surroundings threat the ecological safety of aquatic ecosystems. They also state that the results of such transformation may be difficult to foreseen ex ante. Thus, the investors and designers deal with the constantly changing and diverse hydromorphological and biological scheme. Proper evaluation of the ecological and geomorphological features of particular areas (the river and its valley) may be therefore very helpful for the creation of the most effective design of regulatory works in the aspect of sustainable development.

The diversity of relief and related habitats in the riverbed zone is an important factor affecting the richness and abundance of protozoans and invertebrate fauna—one of the most important elements of the riverine environment and the entire biocenosis of the valley [10]. The natural relief of the channel and floodplain of the Polish Lowlands is characterized by the occurrence of a large number of landforms occurring in results of balanced erosion and accumulation [11–14]. They function as habitats for many plant and animal species, creating a complex ecosystem functioning in specific hydrological and climatic conditions. In such conditions, we deal with a large number of invertebrate fauna and its vast diversity [15,16]. The protozoans and macroinvertebrates-based indicators, therefore, play a key role in the assessment of status of water bodies [17] and remain a very important element in the decision making when managing free migration corridors [18,19].

Polish river valleys reflect the superimposition of many natural and anthropogenic conditions [20]. There are areas of the biggest intensity of the morphodynamical processes in Polish Lowlands, which results from reciprocal impacts of hydrological and geological factors [14,20–22]. The relief of river bottoms and their bank zones (the proximal part of the floodplain) is constantly changing, causing the disappearance of some habitats and the development of new ones, so the valley biotopes are at different stages of succession and sometimes undergo partial or total degradation. In the case of intentional engineering activities, the changes are rapid and often permanent, which makes it impossible for the invertebrates and fish to react/adjust to the new conditions, resulting in increasing in biological diversity and the deterioration of ecological status of the river [7]. The basic destructive factor in this case is the regulation or periodical maintenance of rivers such as dredging, reinforcing banks and bottom and straightening of the channel [23]. Restoration of such rivers is difficult, expensive and demands the extensive support of local communities [24–27]. Both biologists and landscape ecologists for a long time have stressed the fact that—especially according to the current concept of sustainable development—technical activities should take into account the interests of nature without adversely affecting the condition of ecosystems, especially biological diversity [28].

The river valley morphodynamics seems to be one of the most important factors influencing the nature of the biotopes and, consequently, the diversity of invertebrate fauna and the level of ecological balance and resilience. The model of this dependence can be presented in the following way: channel flows and cyclic floods (the valley floor is remodeled during the floodplains)—the relief of the floodplain, especially the proximal part (the coastal zone) and in consequence the diversity of habitats which increases the diversity/enrichment of invertebrate fauna and, in consequence, the level of ecological sustainability. It is very important—in terms of the overall assessment of the environmental value of the valley and its sections—to preserve such landforms as side arms, crevasses or oxbow lakes (and the associated clumps of trees and shrubs), which are valuable ecosystems used by fish and amphibians as breeding sites and by water birds as breeding grounds.

The basic aim of this work was to determine the relationship between the invertebrate fauna (and consequently the biocenosis) of the valley of a small lowland river and its relief (morphodynamics) under conditions of very large and rapid changes caused by the human activity. On this basis, an attempt was made to analyse the response of the ecosystem to rapid transformations associated with engineering works. To establish as precisely as possible the relationships between the structure of the riverbed—also changed as a result of maintenance and regulation works—and the invertebrate fauna and other elements of the biocenosis seem to be crucial for the preservation of good ecological status of small rivers.

2. Study Area

The Kraska River is a small lowland river that is located in the Central Poland Lowlands, persisting under very strong anthropogenic pressure. The river and its valley were chosen as the research area, as they are the focus of the majority of the management issues that are present in small European lowland rivers. The river itself is a right tributary of Jeziorka (Figure 1). The Kraska Valley is located in Mazovian Province, within the communes of Belsk Duży, Jasieniec, Grójec and Chynów. The total length of the river is 28.8 km, while the catchment area is 213.6 km^2 [29]. The width of the river bed ranges from 2 to 9 m, and the average annual momentary discharge is about 0.1 m^3/s. The river has been regulated along almost the entire length. The only section remaining in a near-natural ecological status is the downstream-most fragment of about 200 m (later marked as I). Upstream—as a result of the regulation, the riverbed is straightened and strengthened with a fascine. The maintenance work carried out on the existing canal structures was and is connected with various forms of action, such as destruction of natural shore and bottom structures; removal of beaver dams and accumulated wood debris, as well as macrophytes covering the riverbed; extraction of fallen trees; cutting down smaller trees and shrubs; removal of sludge; and introduction of fascine protection. The Kraska catchment area is under the risk of eutrophication due to surface runoff from settlements and cultivated areas. Around 90% of the catchment area is covered with orchards, crops, gardens, meadows or pastures, forests and fields. The Kraska is fed by three right-bank and nine left-bank tributaries. The water quality in the river was classified as very bad [30].

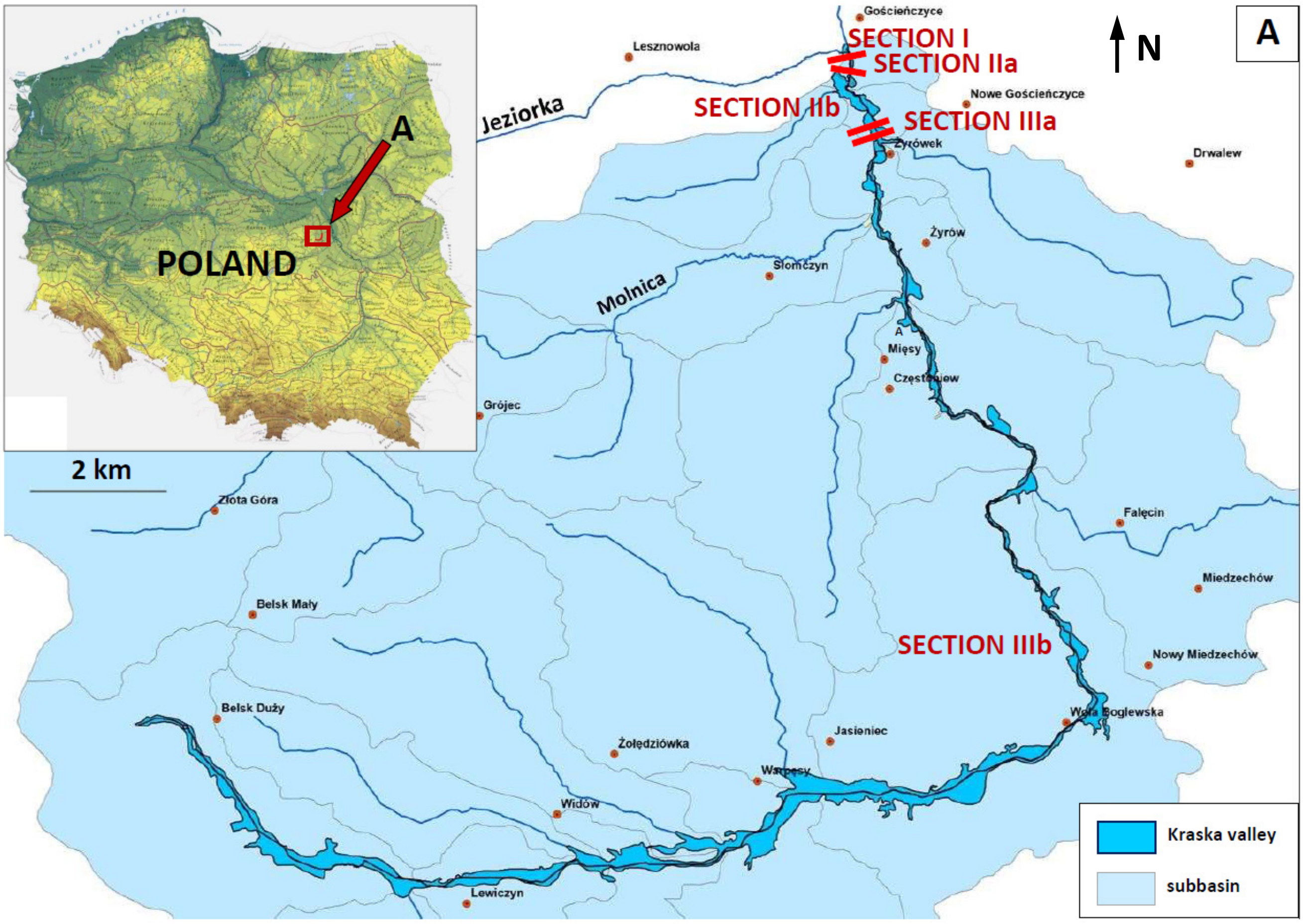


Figure 1. Location of the study reach.

3. Methods

3.1. Division of the Valley into Research Sections

The first stage of the work was preliminary analysis of the physiocenosis of the valley floor on the basis of available remote sensing materials and field surveys of the biologist/geomorphologist team in order to divide it into research sections and determine the sampling points of invertebrate fauna. The basic criterion for the division was geomorphological differentiation and the degree of anthropogenic transformation of the channel and proximal part of the floodplain. On this basis, the river was divided into five research sections of different lengths and geomorphological features (Figure 2 and Table 1), where the trapping points were selected. This division was the basis for further analyses. Within Sections I and II, the locations of six geomorphological cross-sections, marked with symbols from CS1 to CS6, were also determined (Figures 2 and 3). The authors would like to emphasize that, according to both geomorphologists and biologists, the channel is the most important part of the valley floor relief.

Table 1. Basic characteristics of the study reach.

Sections	The Length (km)	The Section Characteristics	The Scope of Conservation Works	The Amount/Number of the Invertebrate Sampling Points
I	0.2	close to natural; narrow floodplain approximately 40 m wide; large number of natural elements in the channel zone	unregulated	5/1–5
IIa	0.2	transitional; narrow floodplain zone approximately 40 m wide; large number of natural elements in the channel zone	regulated in the years 2002/2003	3/6–8
IIb	0.9	transitional; wide floodplain zone up to 300 m wide with traces of meandering (paleomeanders, oxbow lakes)		4/10–13
IIIa	0.2	channelized; floodplain zone up to 200 m wide; the channel with few natural elements	regulated in the years 2014–2019	4/14–17
IIIb	27.3	completely channelized, without any natural structures, the only elements differentiating the channel are of anthropogenic origin		14/18–31

3.2. Studies on Invertebrate Riverbed Fauna

Sampling of riverbed invertebrates was carried out between 2018 and 2020 (namely 07.07.2018, 29.09.2018, 05.04.2019, 27.05.2019. 14.10.2019 and 12.02.2020. A total of 107 samples were taken at 31 points (selected points were tested only at some dates).

Protozoa and invertebrates were sampled at 31 points. Sampling areas were equal to 1 m^2 of the bottom, the entire water column, as well as bottom sediment, debris and macrophyte parts (if macrophytes were present in a selected area). A bottom scoop, a Birge-Ekman box-corer and a 55 mm mesh diameter net were used for collection, while invertebrates visible to the naked eye were removed from the mesh with forceps and transferred to plastic bottles. The collected material was determined within 48 h under laboratory conditions, using a binocular, magnifying glass or microscope. The samples were then fixed in 70% ethanol and reviewed again after one week. Specialized keys and guides [31,32] were used to determine protozoa and invertebrates, with accuracy to species or genus, and in one case—Nematoda—to the family.

3.3. Analysis of the River Valley Bottom Relief

The analysis of the Kraska River valley bottom spanned the field surveys and remote sensing activities. In the case of river valleys, the identification of the landforms and morphodynamics of the bottom of the valley requires a joint geospatial analysis of different types of remote sensing materials [33,34]. Therefore, in the case of the Kraska River, three types of data from the State Surveying and Cartographic Resource of the Central Office of Surveying and Cartography were used. There were as follows: the orthophotomap of spatial resolution equal to 0.25 m based on aerial images taken on 27 May 2017, dynamic Digital Terrain Model (DTM) and Digital Elevation Model (DEM) of spatial resolution equal to 1 m based on ALS (Airborne Laser Scanning) taken on 23 August 2017.

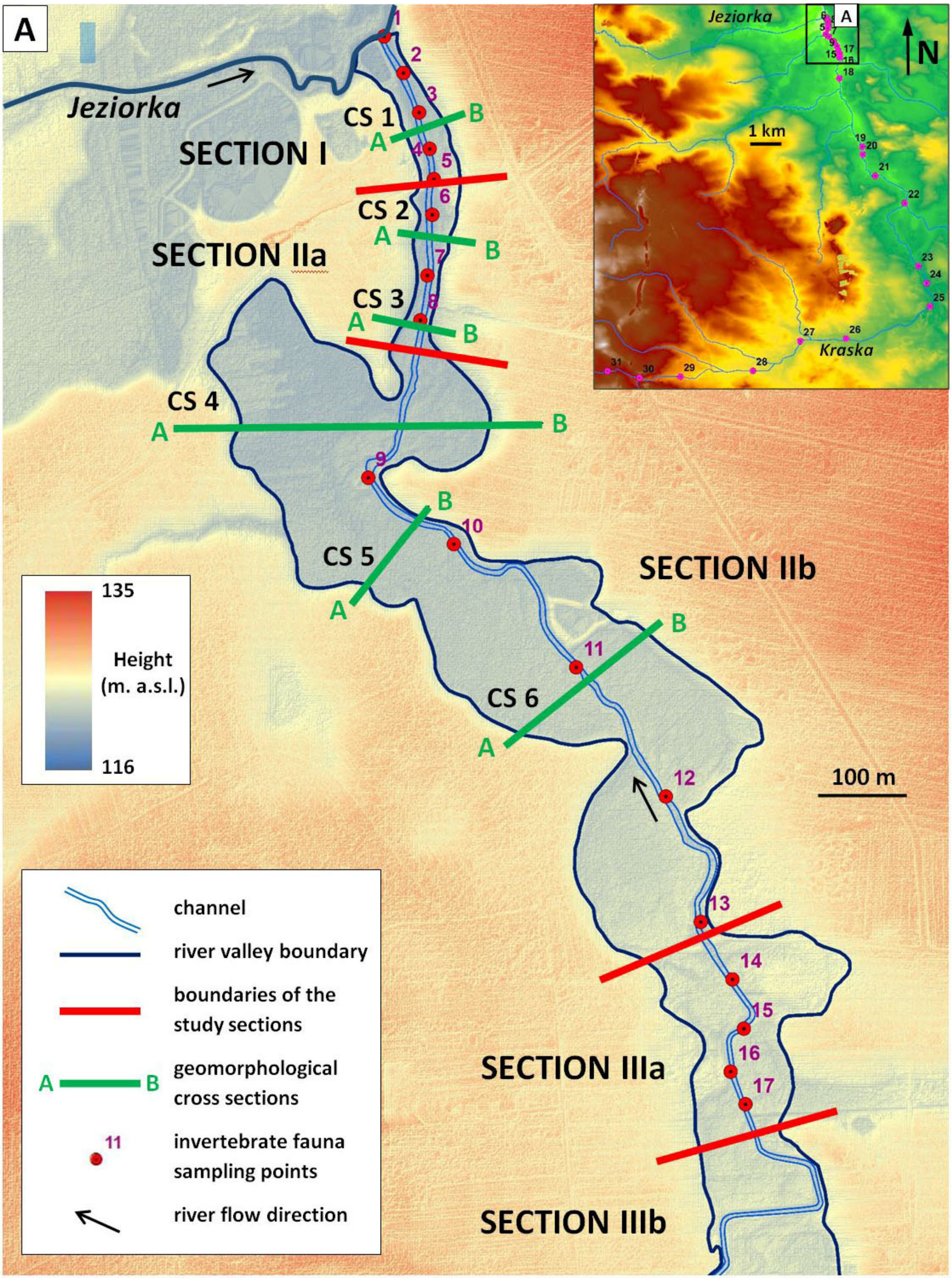


Figure 2. Location of research sections and geomorphological cross-section against a digital terrain model (DTM) based on LIDAR (ALS).

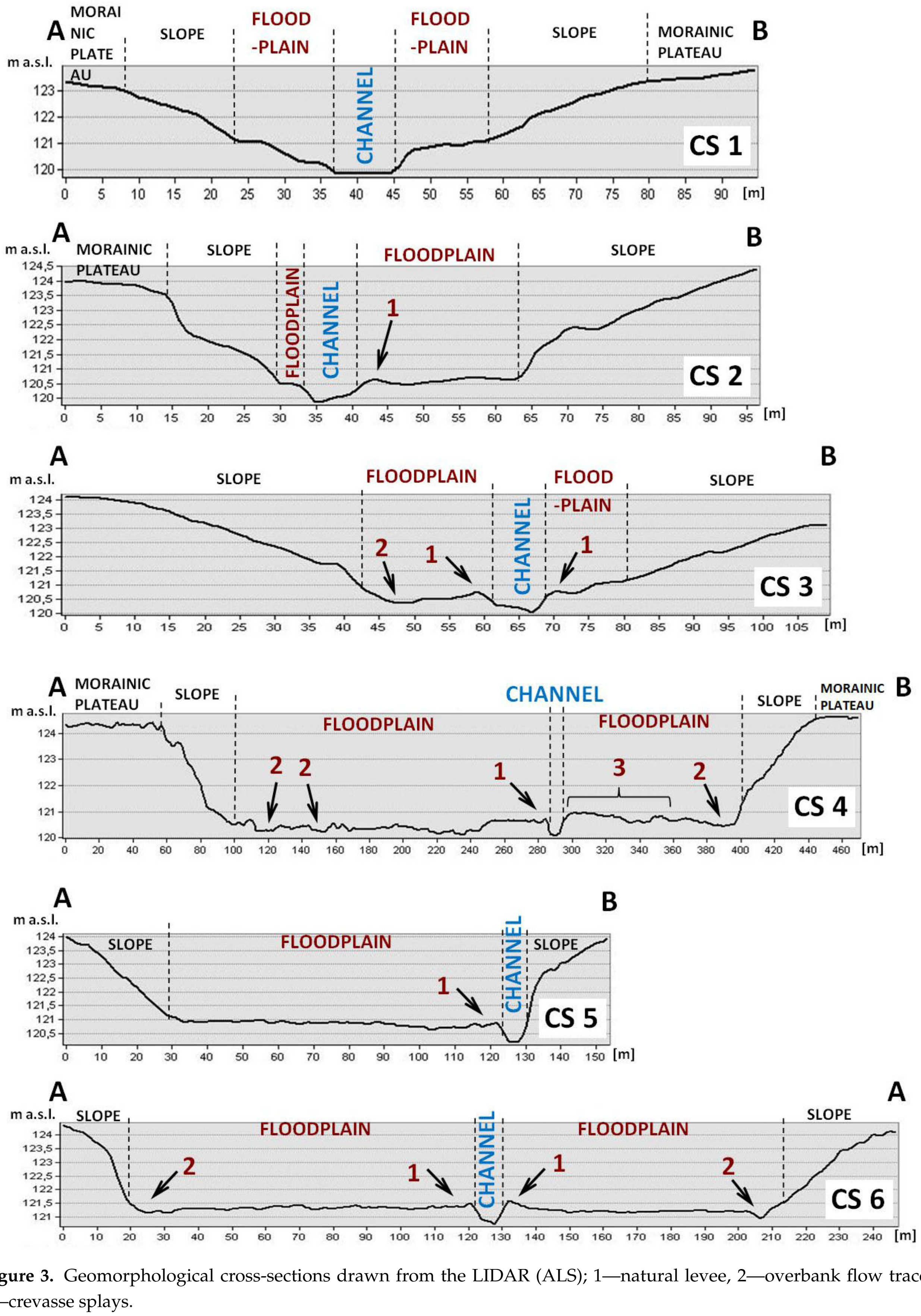


Figure 3. Geomorphological cross-sections drawn from the LIDAR (ALS); 1—natural levee, 2—overbank flow traces, 3—crevasse splays.

The orthophoto and dynamic Digital Terrain Model, designed on the base of ALS (Airborne Laser Scanning) from the resources of the national geo-portal [35] were the basic remote sensing materials, used for the selection of the investigated reaches. For an integrated analysis, those materials, with the use of WMS technology, were placed in the GIS database. The borders of the basic relief forms—the valley and the riverbed, as well as the valley division into the reaches—were designated on that base. The identification of chosen relief forms and their basic morphometric measurements was performed as well. The preliminary analysis of the valley bottom relief allows the selection of the sampling sites for invertebrate fauna identification.

The geomorphological mapping of the valley bottom, with the emphasis on the reach of the least anthropogenic transformations, was the second stage of the works. Geomorphological mapping due to the readability of the riparian zone relief and the riparian zone occurrence and status was made under low water conditions. Such conditions concern the description of the relief presented in Section 4.1. The identification of the landforms and verification of the results of preliminary remote sensing works were made at this stage. The invertebrate-sampling sites' positioning was detailed as well. The photographic documentation of the riverbed/riverbed forms and the valley bottom was prepared as well. The mentioned works were realized during the low water levels because of better floodplain accessibility and relief recognition. The results of the field works were implemented to the GIS database in the form of vector information primers.

The next stage embraced the remote-sensing analysis of the valley bottom relief on the base of the digital elevation model (DEM). The files in ASCII XYZ GRID format containing the coordinates (X, Y and Z) of the points in regular net of 1-m grid squares were the reference data. The points were interpolated on the base of the point-cloud from the air-scanning in the framework of ISOK project. The standard errors of the RMS values were equal to 0.5 m for the XY (XY_{RMS}) coordinates and 0.15 m for the height measurement Z (Z_{RMS}), respectively. For the relief identification purposes, the particular height classes DEM were assigned by colors. The color-scale was selected in the manner allowing for emphasizing the height differences in the ranges responding the minimal and maximal coordinates of the valley bottom. On the base of DEM the morphometric measurements of the chosen landforms and the terrain profiles in the zones of their occurrence were carried out. The measurements were essential to analyze the floodplain morphodynamics and were performed with the help of 3DAnalyst software from the ArcGIS ESRII pocket.

Using the GIS database, the geospatial, quantitative and qualitative relationships between the phytocoenosis elements under surveys were determined. The focus was on determining the relationship between the relief and related morphodynamic processes taking place at the bottom of the valley with the occurrence of invertebrate fauna at individual study sections. The work was complemented by simple statistical analyses, including indicators such as Pearson's linear correlation coefficient for individual sections.

Data processing and calculations, apart from statistical analyses, were performed by using the ESRI ArcGIS 10.5 software.

4. Results

4.1. The Valley Floor Relief

The width of the valley bottom, which is also an area of the floodplain, varies from 40 to 470 m. One can distinguish sections of visible narrowings of about 50 to 100 m wide, intersected by broader sections (200 to 350 m in width). The along valley on the unregulated reach of the river (I) has a parallel course and its width does not exceed 40 m (Figures 2, 3 and 4A). The bottom of the valley is limited by clearly marked slopes with a height of 2 to 2.5 m with a relatively small slope (Figure 3). The width of the riverbed under medium water conditions is on average 8 m, reaching a maximum of 12 m. In the immediate vicinity of the channel, there is a natural connecting shaft. Despite its small width, it is characterized by a fairly rich relief. There are both vegetation-perpetuated islands of up to 4 m length and unvegetated sandy dumps. A large amount of organic deposits deposited both in the bottom of the riverbed and on the surface of the trough forms can also be found.

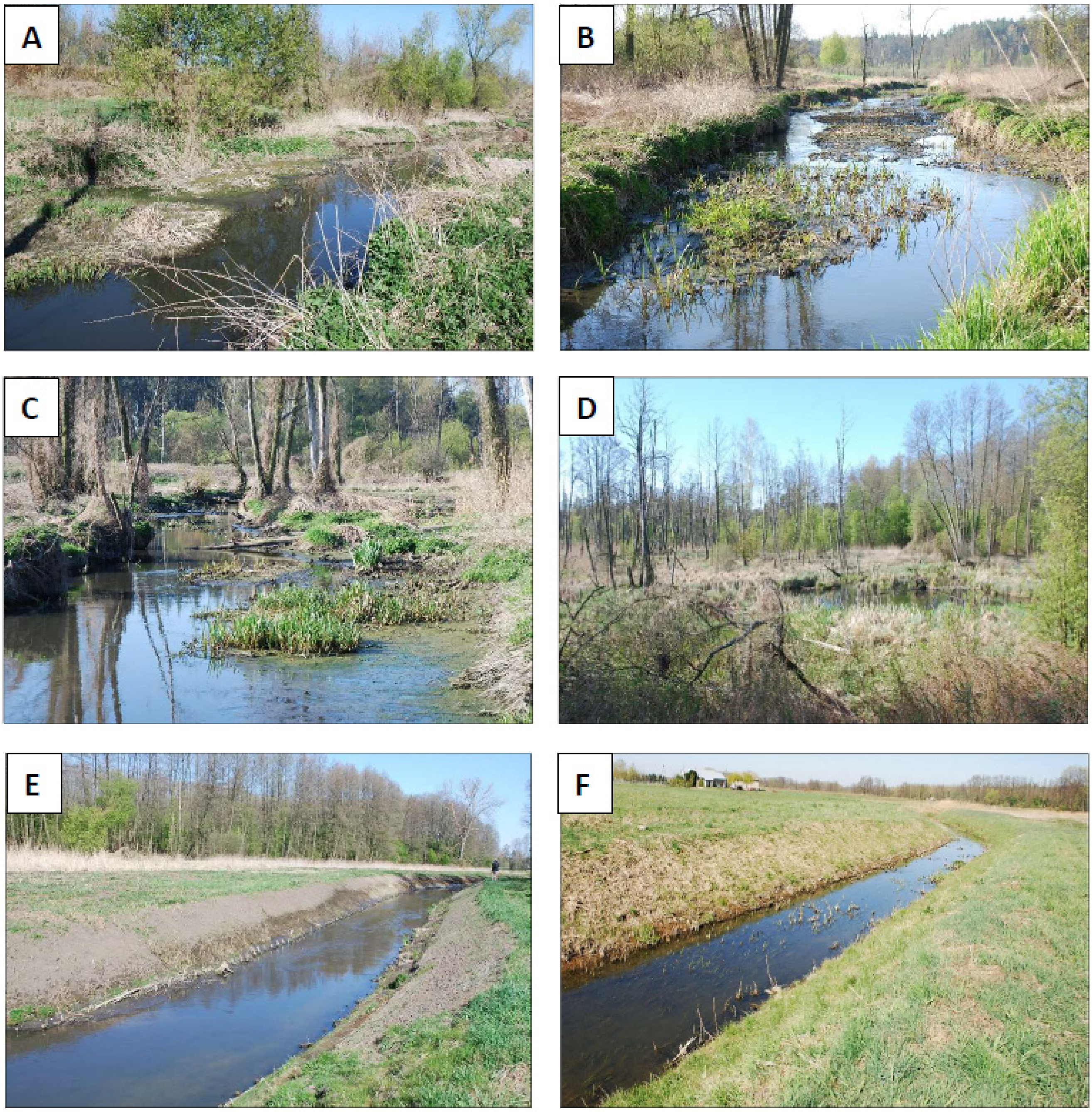


Figure 4. Kraska valley: (**A**) unregulated reach (Section I); (**B**) transition reach (Section IIa); (**C**) transition reach (Section IIb)—the riverbed zone; (**D**) transition reach (Section IIb)—distal part of the basin section floodplain; (**E**,**F**) regulated reach (Section III).

On the transition reach (II), the valley has a variable width. On this basis, it was divided into Sections IIa and IIb. Section IIa adjoins the unregulated section and is geomorphologically very similar to it, which is confirmed by comparison of Sections CS1, CS2 and CS3 (Figures 3 and 4A,B). Both the trough and the floodplain have a similar width, and in many sites the natural cover dike is well visible.

The Section IIb characterizes itself with a completely different relief. The floodplain, which is the bottom of the valley, is much wider here. Its maximum width in the geomorphological cross-section CS 4 is 320 m (Figures 2, 3, 4C,D and 5). The valley on that reach has the characteristics of relief seized of larger rivers. The adhesive shaft, cut in many places by narrow crevasses reductions, is clearly visible. In the distal part of the floodplain, especially in the left bank part of the valley, there are reductions acting as flood pools overgrown with reeds and oxbow lake and paleomeanders (Figures 3, 4D and 5). At the edge of the terrace, the reduction strings connecting in some places to the main riverbed that are privileged routes of the flow of intake water can be identified. In the valley expansion zone, there are crevasse splays of significant size compared to the main channel of size but a small flesh (Figure 5). Complex relief can also be found in a riverbed zone (Figure 4C). There are numerous islands and few sandy dumps in the shadow of obstacles to the flow (e.g., wood debris).

On the regulated Section III (IIIa and IIIb), the Kraska riverbed is a canal. It was straightened, narrowed to a fixed width of 5 m and reinforced with a fascine (Figure 4E,F). As a result of the regulation works, the natural bedding shaft was destroyed and the blood cutting it. The edges of the trough were levelled and slightly raised in relation to the surface of the floodplain. The few natural elements in the bottom of the trough (e.g., wood debris) occur only in a short Section IIIa.

4.2. The Invertebrate Fauna of the Riverbed

Fifty-seven protozoan and invertebrate taxa (in the range of species or genus) were found total in the Kraska River which is significantly lower in the comparisons with other small Polish Lowland rivers, investigated by the authors. For example, in the Jeziorka River, the tributary of the Kraska, seventy-four invertebrate taxa were found [36].

The taxonomic profile of the protozoan and invertebrate fauna in the Kraska looks as follow: Protozoa—three taxa, Spongiaria—two taxa, Hydrozoa—one taxa, Turbellaria—three taxa, Nematoda—one taxa, Oligochaeta—two taxa, Hirudinea—five taxa, Crustacea—four taxa, Odonata—three taxa, Ephemeroptera—two taxa, Coleoptera—five taxa, Trichoptera—three taxa, Hemiptera—five taxa, Diptera—seven taxa, Arachnida—one taxa, Gastropoda—seven taxa and Bivalvia—three taxa. The list of the taxa noticed in peculiar catching sites is presented in Table 2.

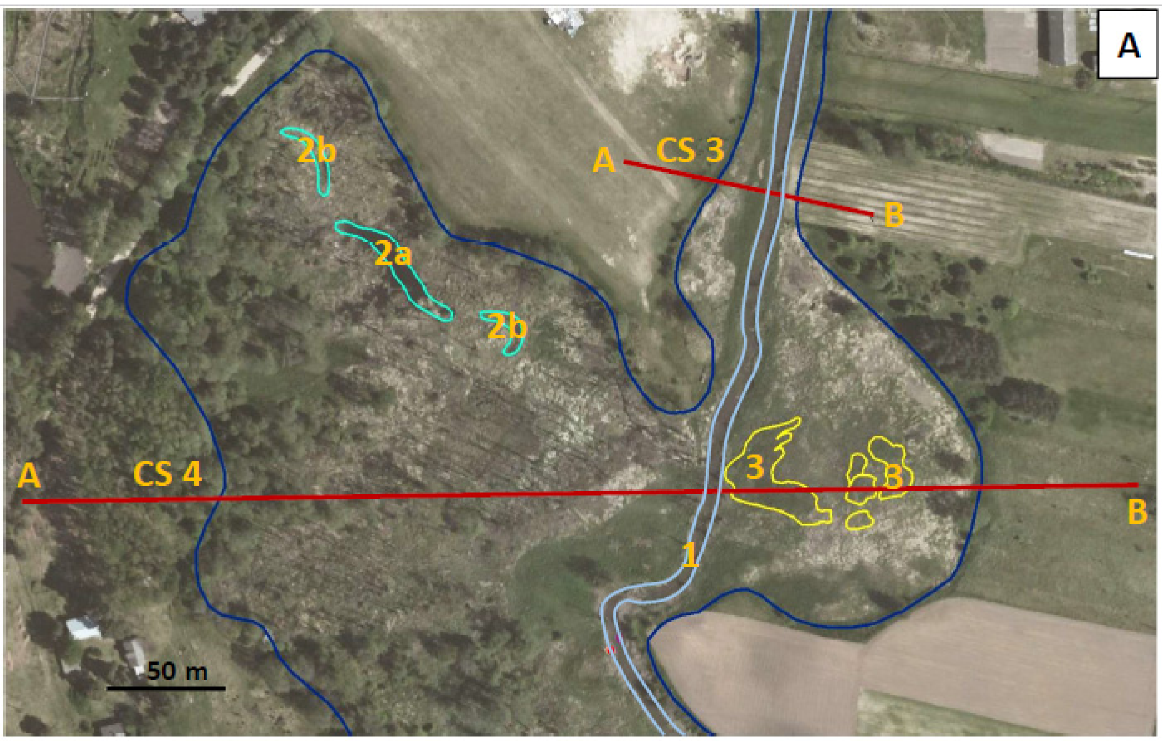
Fifty-five invertebrate taxa were found on the unmanaged reach, Section I (Sites 1–5); 44 taxa were found on the Section II, (Sites 6–13) of anthropogenic character, but with the environmental "enclaves", such as wood debris, the differentiated bottom structure, etc.; and 41 taxa were found on the upper reach, Section III, of the typical channel character (Sites 14–31).

In the case of Reaches II and III, the differences between the distinguished sections (a and b) were also stated. Thirty-eight taxa were found in Section IIa, and 34 were found in Section IIb; on Reach III, 37 taxa were found on Section IIIa, and 33 taxa were found on Section IIIb, respectively (Tables 2 and 3).

The average number of taxa per sampling point and a given section exceeded 25 taxa in Section I, reached 18 taxa for Section II and reached 12 taxa for Section III (Table 3). The representatives of 17 higher taxa (e.g., family, order or phylum) were identified. The following numbers of higher taxa were represented on the particular reaches: I—17, II—16 and III—14, but in the last case, there were often the very rare catches of one species (refer to Table 2).

The following species may be treated as valuable in the scale of the region or even the country: *Haemopis sanguisuga*, *Argyroneta aquatica* and *Unio pictorium*—all found only on the lower reach (in one, the same catching site).

Five taxa (*Codonella cratera*, *Haemopis sanguisuga*, *Orconectes limosus*, *Argyroneta aquatica* and *Unio pictorum*) were recorded only in the Section I.



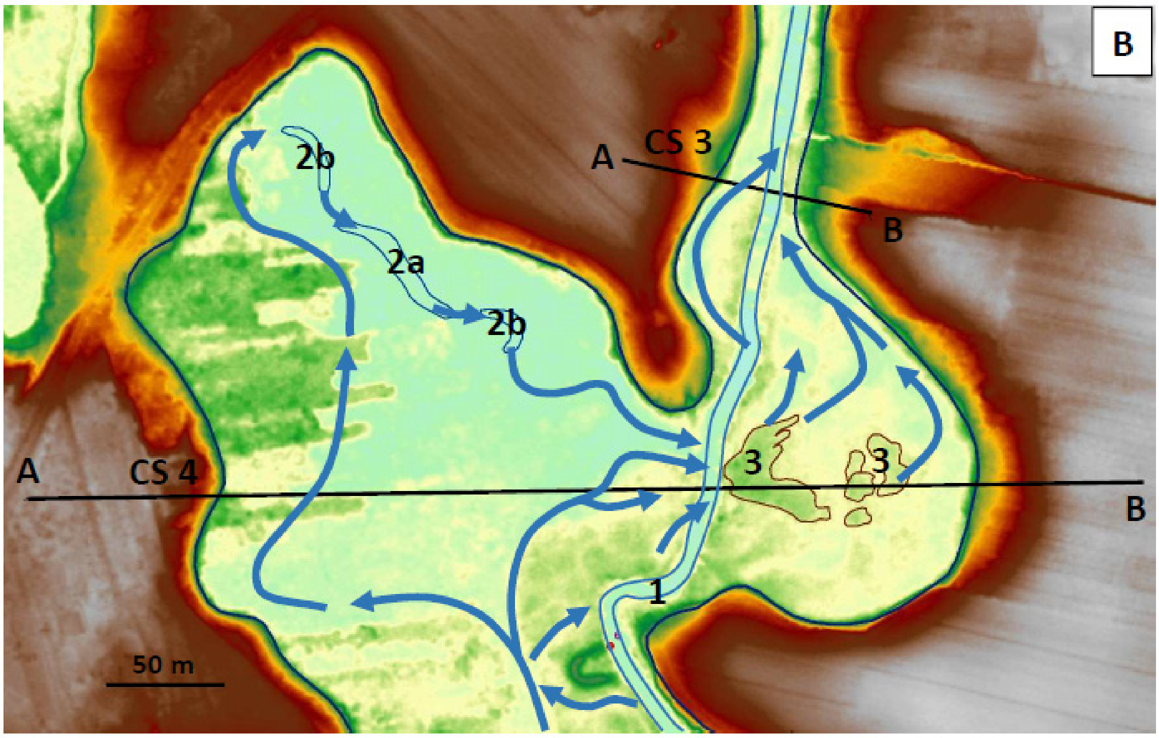


Figure 5. Extension of the valley floor within Section IIb against the background of the orthophotomap (**A**) and the digital terrain model (DTM) (**B**); 1—main channel, 2a—oxbow lakes, 2b—paleomeanders, 3—crevasse splays; the arrows mark the main flood flows direction.

Table 2. The invertebrate taxa identified in particular sampling points on the Kraska.

Taxa	Section I					Section II A			Section IIb					Section IIIa		Section IIIb															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Protozoa																															
Amoeba proteus	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Codonella cratera	+			+																											
Stentor sp.	+	+			+		+			+				+		+	+			+			+								
Spongiaria																															
Euspongilla lacustris	+				+	+				+			+	+			+					+									
Ephydatia fluviatilis				+	+																	+	+								
Hydrozoa																															
Hydra sp.	+	+	+	+	+	+	+		+	+		+		+	+	+		+		+		+	+		+		+		+	+	
Turbellaria																															
Dendrocoelum lacteum			+			+		+				+	+																		
Dugesia sp.		+		+	+		+	+	+		+				+					+			+			+	+		+		
Planaria torva	+		+	+		+	+	+		+																					
Nematoda	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+		+	+		+	+	+	+	+
Oligochaeta																															
Lumbricus sp.	+		+	+						+	+					+		+	+			+		+		+	+			+	
Tubifex sp.	+	+								+	+		+				+			+		+			+	+					
Hirudinea																															
Erpobdella nigricollis			+					+				+	+	+																	
Erpobdella octooculata	+			+		+													+												
Glossiphonia complanata			+					+				+	+																		
Haemopis sanguisuga		+																													
Piscicola geometra	+	+	+	+	+	+	+	+					+	+	+									+	+				+		
Crustacea																															
Asellus aquaticus		+				+		+																							
Orconectes limosus			+																												
Daphnia sp.	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+		+	+		+		+	+	+
Gammarus sp.			+					+																							
Odonata																															
Aeschna grandis	+	+				+	+			+					+																
Anax imperator					+		+																	+							
Agrion sp.																	+							+	+						
Ephemeroptera																															
Ephemera vulgata			+	+				+				+	+	+																	
Leptophlebia marginata					+									+					+					+	+				+		
Coleoptera																															
Dytiscus marginalis	+		+			+									+									+							
Hydrobius fuscipes	+	+	+			+	+	+				+					+														
Hydrophillus caraboides			+														+														
Gyrinus sp.	+			+	+	+		+		+			+	+		+	+												+		
Donacia crassipes		+					+																								
Trichopetra																															
Hydropsyche lepida	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+		+	+		+			+			+	
Polycentropus flavomaculatus		+					+	+																							
Anabolia nervosa		+	+									+		+		+															
Hemiptera																															
Gerris sp.	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+		+	+	+	+	+	+	+	+	+	+	+
Microvelia sp.		+			+																		+								
Nepa cinerea			+																										+		

Table 2. *Cont.*

Taxa	Section I					Section II A			Section IIb					Section IIIa			Section IIIb														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**
Ranatra linearis																														+	
Velia sp.	+			+		+											+														
Diptera																															
Culex sp.		+		+	+		+			+	+		+	+		+	+	+		+				+	+	+					+
Dixa amphibia	+				+	+				+			+	+																	
Chironomus sp.	+	+				+			+		+		+		+		+				+					+	+			+	
Simulium sp.			+							+		+	+				+														
Pericoma sp.	+	+		+			+				+		+		+		+		+							+	+				
Tipula sp.			+	+												+										+	+				
Tabanus sp.	+	+	+	+	+	+		+		+	+	+	+	+	+	+	+	+	+	+		+	+		+		+	+	+	+	+
Arachnida																															
Argyroneta aquatica		+																													
Gastropoda																															
Bithynia tentaculata	+	+		+		+	+			+	+		+			+	+										+				
Lymnaea stagnalis	+	+	+	+	+		+	+						+		+				+					+	+			+	+	+
Physa fontinalis		+					+																								

Table 3. Total numbers of taxa in individual research sections and average numbers of taxa at sampling points.

Section	I	IIa	IIb	IIa + IIb	IIIa	IIIb	IIIa + IIIb
Total number of taxa	55	38	34	44	37	33	41
Average number of taxa at sampling point	25.4	21.3	16.4	18.25	18.5	9.8	11.7

When analyzing the obtained results, it can be seen that the relation between the number of observed taxa and the distance from the confluence of the Kraska River to the Jeziorka River is quite visible (Figures 6 and 7). Despite the small number of sampling points, which made statistical analyses difficult, a correlation coefficient (r) equaling 0.63 was obtained for all analyzed points, which can be considered satisfactory, even though the probability of error does exist [37]. However, in the case of joint analysis of Sections I and IIa, the value of the r coefficient increases up to 0.87. The analysis of the scanned section of the river itself (IIIa and IIIb) showed the lack of any statistical significance (the obtained coefficient values were close to zero).

In case of the box diagram (Figure 7), due to the small number of measurement results, it was not decided to separate extreme and outlier observations. For Sections I and II the graph looks roughly symmetrical. Section IIa is characterized by the smallest scattering of results but one should keep in mind that it is the shortest section among the analyzed sections of the Kraska. Section IIb is the most diverse in this respect, which indicates a large variation in the number of taxa observed at individual measurement points. In the case of the whole Section III, a clear left-handed asymmetry can be observed—in this case, there were single points with a very small number of observed taxa. The high difference between the mean value and the median can also be noticed for Section IIIb.

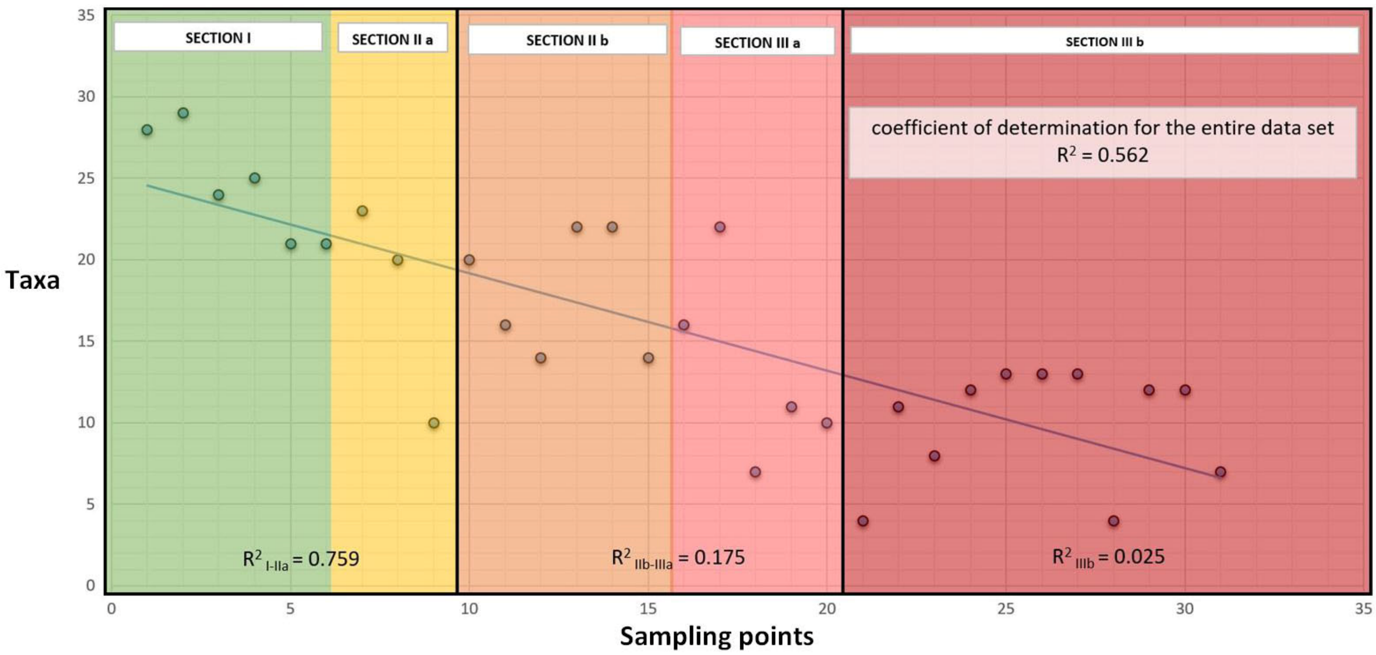


Figure 6. Graph of the dependence of the number of taxis on the distance from the mouth of the river, divided into distinguished sections.

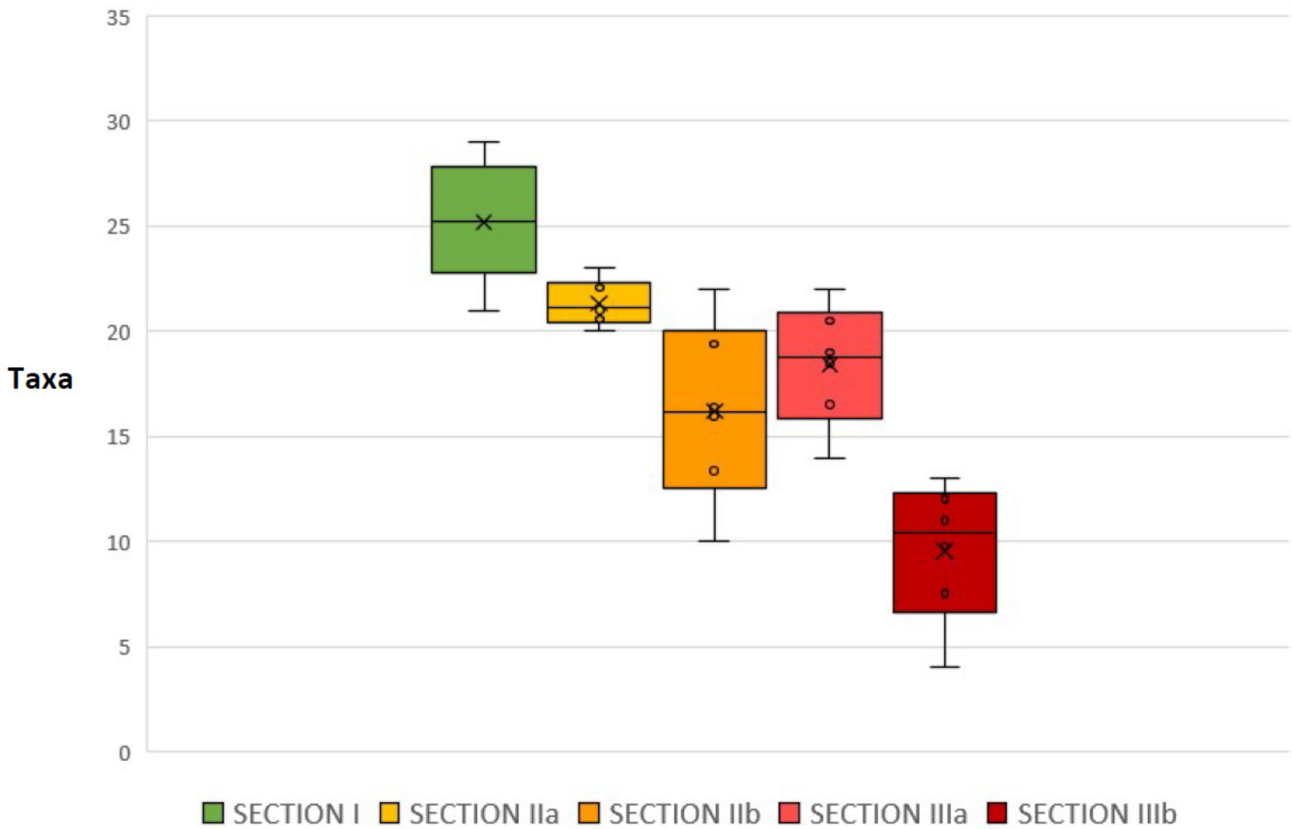


Figure 7. Box chart of the relationship between the numbers of existing taxa by section.

5. Discussion

River valleys, especially the small ones, are particularly important because of their number and local functions, especially as free migration corridors for the biota. Due to objective research difficulties, there is no sufficient database on the structure of functioning of such river valley's mosaic of the ecosystems [38].

The proper studying of the processes connecting with the river training works would be the very helpful tool for achieving both technical goals and environmental protection of the watercourse and its surroundings [8].

As highlighted in the Introduction, the protozoan and the invertebrate fauna are the extremely important elements of river communities and, at the same time, may be indicators of the direction and intensity of the changes [39,40]. Research on this group of organisms in the Kraska, which is an example of a lowland one, combined with careful geomorphological analysis, will, according to the authors, contribute to a better understanding of the relationship between both, extremely important elements of the river valley environment. Many authors [41] argue that maintaining (ensuring) the proper structure of the invertebrate fauna—as a result of the morphological diversity of the channel—is a key element for maintaining the good ecological status of rivers and their valleys. This is because invertebrates are food for fish and other vertebrates (amphibians, birds), determining their ability to survive in a particular environment.

The greatest threat to biological diversity—and consequently to ecological balance—in those ecosystems is considered to be regulation and, to a lesser extent, periodic maintenance [3,42]. Representatives of the institutions responsible for these activities explain the need for flood protection, although it is known from many sources that the most serious floods have occurred and are occurring on regulated rivers [43,44].

An example of the mentioned actions is the Kraska, which has been regulated or actually transformed into an artificial canal along almost the entire length (Figure 4E,F). As a result of the regulation and maintenance works, the natural landforms of the riverbed and adjacent zone were destroyed, and the natural morphogenetic processes leading to their formation were disturbed/interrupted. This impoverishment/destruction of most forms of landforms is associated with the destruction of most habitats, which results in low biological diversity.

A model example of biological and geomorphological effects of regulation of a small stream is the longest of the studied sections, i.e., Section IIIb, covering 95 percent of the river length. It is characterized by the lowest species richness and the number of taxa at the individual sampling points. The reason for this state of affairs is that the riverbed has been straightened and straightened and all natural elements removed from it, which limits the differentiation into erosion and deposition zones, giving it a transit character. This results in a lack of bottom vegetation, which is the habitat or food base (e.g., for *Donacia crassipes* and representatives of the Hydrophilidae family), muddy bottoms (no suitable substrate for crisps and bivalve molluscs) or the absence of organisms which are the food base of a particular taxon (e.g., *Asellus aquaticus*, which is fed by *Planaria torva*). Even the taxa without high requirements for the water quality, such as *Dixa amphibia* or *Simulium* sp., prefer overgrown and adequately oxygenated habitats, which the freshly regulated sections are not able to provide.

The A reach of Kraska, close to nature, is very short in relation to the total length of the river, but it is characterized by the largest number of taxa. Its species richness is associated with a variety of forms, especially in the riverbeds zone, i.e., habitats where representatives of various invertebrate species can find convenient sites. In spite of the small width of the valley, the course of natural morphogenetic processes occurring with the highest intensity during the cyclic invasions is crucial here [13,14,45–48]. The large habitat diversity in the estuarial section is the reason why the taxa absent in the sections upstream are found there. Apart from the *Codonella cratera* protozoan, which is not very important for the functioning of the river biocenosis, the remaining species were found only at one sampling point. Therefore, it is not possible to speak of their stable populations, but only of the use of favorable habitat conditions, provided by a section close to nature, by individual specimens.

It seems almost certain that the estuary section of Kraska is the reproduction ground for invertebrates from Jeziorka during the breeding period. Its role in this aspect is all the more important as it “has” suitable habitats for high water-dependent organisms. A similar role is played by the adjacent Section IIb for the sewerage section (Sections IIIa and IIIb). This is evidenced by the higher number of taxa present in Section IIIa than in Section IIIb and almost twice as high as the average number of taxa per harvesting point (Table 3). Hence, there is a very important aspect concerning regulation/maintenance of rivers: if it is necessary to interfere in the riverbed zone, the lower-most, confluence sections of small lowland rivers should not be regulated and care should be taken to keep it as accessible as possible for invertebrates (and also fish). It is also important that when regulating longer stretches of watercourses, they should be separated by even short unregulated stretches. At the same time, it is worth pointing out that, after the possible restoration of a part of the river, they could be inhabited relatively quickly by taxis with greater habitat requirements, which already have their “bridgeheads” in unregulated sections. The largest species variability in the unregulated section (Section I) and the smallest in the canalized section (Section III) should be considered to be in line with expectations, although the possibility of determining the scale of this phenomenon in the case of small lowland rivers seems important here (Figures 6 and 7; Tables 2 and 3).

However, the most interesting results were obtained for the transitional Sections IIa and IIb, which was regulated in 2002/2003. From the geomorphological point of view, it did not differ significantly from Section I and contained many elements characteristic for watercourses with a high degree of naturalness (Figures 3, 4B,C and 5). In only about 18 years, the morphogenetic processes conditioned by natural factors led to the restoration of the original relief and thus the habitats in the riverbed and floodplain (Figures 8 and 9). In this case, the most important factor should be considered the cyclic congestion and related to it long-lasting extra-riverbed flows [13], usually determining the relief of the trough and floodplain. The surprisingly fast rate of renaturation in the case of Kraska was possible, as it seems, thanks to the technology used in the regulation, which was not very durable (earthworks secured only with fascia fortifications). Such tendencies to the natural course of morphodynamic processes, often resulting in the destruction of regulation devices, are also quite commonly observed on large rivers of the Polish Lowlands, such as the Vistula [22,47,48]. The geomorphological changes in Section II have also confirmed the results of trapping invertebrate fauna (Figure 6 and Tables 2 and 3), i.e., slightly lower number of taxa present than in Section I. A comparison of Sections I and IIa, which are characterized by the same valley bottom morphology, seems particularly interesting here (Figures 2 and 3). If it had not been made 18 years ago, the adjustment of the channel could have been treated as one section. The number of registered taxa in Sections I and IIa is similar (Figure 6 and Table 2). It is connected with their differentiated and very similar sculpture of the channel zone influencing the habitat richness. The similarity of these sections is also confirmed by the high value of the coefficient of determination (0.76).

Undoubtedly, the species richness of invertebrate fauna is a factor that helps to maintain an ecological balance, as it determines the complexity of the food network and the ecosystem’s resistance to adverse external factors. Therefore, such large differences between sections close to nature (Section I) and regulated (Section III) in the case of Kraska should raise justified concerns about the ecological condition of the whole river and its valley. The example of the Kraska shows how big is the potential of even a small stream in the case of preserving natural structures, and how strong is the degradation in the case of their removal. The trend towards the natural course of morphogenetic processes within the valley floor, despite the regulatory work carried out, should be another argument taken into account in the discussion on the advisability of river regulation.

Figure 8. Relief differentiation (habitat richness) of the Kraska riverbed zone in Sections IIa (**A**) and IIb (**B**); traces of the regulation of the riverbed made in 2002/2003 are difficult to notice.

Figure 9. Features of natural morphodynamics/relief in the Kraska riverbed zone visible 18 years after the regulation (Section IIb); 1—reconstructed natural levee, 2—levee destruction site, 3—organic silt deposition zone and 4—erosion zone in the channel.

The current state of the Kraska River and its valley reflects the rapid changes occurring in the valleys of small lowland rivers in Poland and the Central European Lowlands. Failure to understand the principles of rational flood protection is the reason for the devastation of exceptionally valuable natural areas, interruption of local ecological corridors and changes in the landscape that are difficult to reverse.

6. Conclusions

1. In the regulated sections of Kraska, natural forms of relief in the channel zone and the proximal part of the floodplain were destroyed, which caused the destruction of most of the habitats. The samplings of protozoan and invertebrate fauna confirmed that these sections significantly reduced their biological diversity. The regulation not only

significantly worsened the ecological condition of the river but made it practically impossible for it to act as a corridor for free migration.
2. The results of the investigations gained in some sections of the river showed the ability for spontaneous self-recovery of the aquatic ecosystem about 18 years from the completion of the regulatory work. The reason for this is probably the cyclical congestion characteristic of the Polish Lowland rivers and the associated long-lasting extra-corridor flows.
3. The studies of the Kraska River point out the mass regulation of small watercourses in the Central European Lowlands that may lead to drastic biological impoverishment of these areas.
4. The analysis of relief changes in the Kraska River valley indicates that the regulation of small watercourses, especially in the case of less expensive technologies, is not able to counteract the natural morphodynamics of the valley floor. This makes costly maintenance work necessary. This factor should be taken into account when assessing the advisability of carrying out the river regulation and planning of maintenance works, versus possible, wise restoration and management of aquatic ecosystems.

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References

1. Council of the European Communities. 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. *Off. J.* **2000**, *327*, 1–72.
2. Rinaldo, A.; Gatto, M.; Rodriguez-Iturbe, I. River networks as ecological corridors: A coherent ecohydrological perspective. *Adv. Water Resour.* **2018**, *112*, 27–58. [CrossRef]
3. Beisel, J.N.; Usseglio-Polatera, P.; Thomas, P.S.; Moreteau, J.-C. Stream community structure in relation to spatial variation: The influence of mesohabitat characteristics. *Hydrobiologia* **1998**, *389*, 73–88. [CrossRef]
4. Sender, J.; Maślanka, W. Natural Values of the Urban River Valley and the Possibilities of its Development – Bystrzyca River Valley Study Case (Poland). *J. Lucian Braga Univ. Sibiu* **2018**, *20*, 85–102. [CrossRef]
5. Callow, P.; Petts, G. *The Rivers Handobook*; Blackwell Scientific Publications: Oxford, UK, 1992; Volume 1.
6. Paisley, M.F.; Walley, W.J.; Trigg, D.J. Identification of macro-invertebrate taxa as indicators of nutrient enrichment in rivers. *Ecol. Inform.* **2011**, *6*, 399–406. [CrossRef]
7. Bączyk, A.; Wagner, M.; Okruszko, T.; Grygoruk, M. Influence of technical maintenance measures on ecological status of agricultural lowland rivers—Systematic review and implications for the river management. *Sci. Total Environ.* **2018**, *627*, 189–199. [CrossRef]
8. Hachol, J.; Hämmerling, M.; Bondar-Nowakowska, E. Applying the Analytical Hierarchy Process (AHP) into the effects assessment of river training works. *J. Water Land Dev.* **2017**, 35. [CrossRef]
9. Hachol, J.; Bodnar-Nowakowska, E.; Hachaj, P.S. Application of Game Theory against Nature in the Assessment of Technical Solutions Used in River Regulation in the Context of Aquatic Plant Protection. *Sustainability* **2019**, *11*, 1260. [CrossRef]
10. Beisel, J.N.; Usseglio-Polatera, P.; Moreteau, J.C. The spatial heterogeneity of a river bottom: A key factor determining macroinvertebrate communities. *Hydrobiologia* **2000**, *422*, 163–171. [CrossRef]
11. Florek, W.; Zwoliński, Z.; Andrzejewski, L.; Kostrzewski, A.; Smolska, E.; Szmańda, J. Współczesne procesy kształtujące rzeźbę dolin rzecznych. In *Współczesne Przemiany Rzeźby Polski*; Starkel, L., Kostrzewski, A., Kotarba, A., Krzemień, K., Eds.; IGiGP UJ: Kraków, Poland, 2008; pp. 292–305.
12. Falkowski, T.; Ostrowski, P. Relief of the Pilica river valley between Inowłódz and Domaniewice and its relationship with the geological structure of alluvia basement. In *Infrastruktura i Ekologia Terenów Wiejskich*; Polska Akademia Nauk: Kraków, Poland, 2010; pp. 53–63.

13. Ostrowski, P.; Utratna, M. The hydrological conditions of the morphogenesis in relation to the selected erosional landforms on the floodplain of the Bug river valley. *Sci. Rev.–Eng. Environ. Sci.* **2018**, *27*, 57–70. [CrossRef]
14. Ostrowski, P.; Falkowski, T.; Utratna-Żukowska, M. The Effect of Geological Channel Structures on Floodplain Morphodynamics of Lowland Rivers: A Case Study from the Bug River, Poland. *CATENA* **2021**, *202*, 105209, ISSN 0341-8162. [CrossRef]
15. Cogerino, L.; Cellot, B.; Bournard, M. Microhabitat diversity and associated macroinvertebrates in aquatic banks of a large European river. *Hydrobiologia* **1995**, *304*, 103–115. [CrossRef]
16. Oglęcki, P.; Pachuta, K. The effect of chosen riverbed parameters on different biological elements of lowland Wkra River Eco-systems. *Ann. Wars. Agric. Univ.—SGGW. Land Reclam.* **2005**, *36*, 47–53.
17. Verdonschot, P.F.M.; Nijboer, R.C. Testing the European stream typology of the Water Framework Directive for macroinvertebrates. *Hydrobiologia* **2004**, *516*, 35–54. [CrossRef]
18. Naiman, R.J.; Rogers, K.H. Large animals and system-level characteristics in river corridors. *BioScience* **1997**, *47*, 521–529. [CrossRef]
19. Rodriguez-Iturbe, I.; Muneepeerakul, R.; Bertuzzo, E.; Levin, S.; Rinaldo, A. River networks as ecological corridors: A complex systems perspective for integrating hydrologic, geomorphologic, and ecologic dynamics. *Water Resour. Res.* **2009**, *45*, 1–22. [CrossRef]
20. Andrzejewski, L.; Krzemień, K.; Zwoliński, Z. Zarys przyrodniczych i antropogenicznych uwarunkowań rozwoju systemów dolinnych i korytowych w Polsce. *Landf. Anal.* **2018**, *37*, 17–51. [CrossRef]
21. Kaszowski, L.; Krzemień, K. Classification systems of mountain river channels. In *River Channels Pattern, Structure and Dynamics*; Krzemień, K., Ed.; Prace Geograficzne Instytutu Geografii UJ; IGiGP UJ: Kraków, Poland, 1999; Volume 104, pp. 27–40.
22. Falkowski, T.; Ostrowski, P.; Bogucki, M.; Karczmarz, D. The trends in the main thalweg path of selected reaches of the Middle Vistula River, and their relationships to the geological structure of river channel zone. *Open Geosci.* **2018**, *10*, 554–564. [CrossRef]
23. Larsen, S.; Ormerod, S.J. Combined effects of habitat modification on trait composition and species nestedness in river invertebrates. *Biol. Conserv.* **2010**, *143*, 2638–2646. [CrossRef]
24. Romanowski, J.; Matuszkiewicz, J.; Kowalczyk, K.; Kowalska, A.; Kozłowska, A.; Solon, J.M.; Middendorp, H.; Reijnen, R.; Rozemeijer, R.; van der Slums, T. *Evaluation of Ecological Consequences of Development Scenarios for the Vistula River Valley*; Vistula Econet Development and Implementation VEDI: Warszawa/Wageningen/Utrecht, Poland, 2005.
25. Plit, J. Zarządzanie krajobrazem dolin rzecznych. In *Zarządzanie Krajobrazem Kulturowym*; Prace Komisji Krajobrazu Kulturowego Nr 10, 230–240; Komisja Krajobrazu Kulturowego PTG: Sosnowiec, Poland, 2008.
26. Żelazo, J.; Popek, Z. *Podstawy Renaturyzacji Rzek*; SGGW: Warszawa, Poland, 2002.
27. Szałkiewicz, E.; Sucholas, J.; Grygoruk, M. Feeding the Future with the Past: Incorporating Local Ecological Knowledge in River Restoration. *Resources* **2020**, *9*, 47. [CrossRef]
28. Gacka–Grzesikiewicz, E.; Cichocki, Z. *The Programme of the River Valleys Protection in Poland*; The Institute of Environmental Protection: Warsaw, Poland, 2001.
29. Orłow-Gozdowska, Ł. *Program for the Protection and Development of Water Resources in the Mazowieckie Voivodeship in the Field of Rivers Improvement for Bi-Environmental Fish—Project*; Department of Agriculture and Modernization of Rural Areas Office of the Marshal of the Mazowieckie Voivodeship: Warsaw, Poland, 2005.
30. Jagiełło, J. *The Jeziorka River, the Świder River, the Wilga River, the Okrzejka River and their Tributaries*; Wydawnictwo Ciekawe Miejsca: Warsaw, Poland, 2014.
31. McCafferty, W.P. *Aquatic Entomology: The Fisherman's and Ecologist's Illustrated Guide to Insects*; Jones and Bartlett Publishers: Boston, MA, USA, 1983; p. 448.
32. Kołodziejczyk, A.; Koperski, P. Bezkregowce Słodkowodne Polski. Klucz do oznaczania oraz podstawy biologii i ekologii. In *Freshwater Invertebrates in Poland: Key to the Identification and Principles of Biology and Ecology*; Warsaw University Press: Warsaw, Poland, 2000.
33. Ostrowski, P.; Falkowski, T. Application of Remote Sensing Methods to Study the Relief of Lowland River Valleys with a Complex Geological Structure—A Case Study of the Bug River. *Water* **2020**, *12*, 487. [CrossRef]
34. Bujakowski, F.; Falkowski, T.; Podlasek, A. Geomorphological immaturity as a factorconditioning the dynamics of channel processes in Rządza River. *Open Geosci.* **2021**, 27–38. [CrossRef]
35. National Geo-Portal. Digital Terrain Model, Information Layer Hypsometry (WMS). Available online: https://mapy.geoportal.gov.pl/imap/Imgp_2.html?locale=pl&gui=new&sessionID=566557 (accessed on 20 May 2021).
36. Oglęcki, P. Invertebrate and fish environment al preferences as the key factor for lowland riverbed biodiversity. *Ann. Wars. Univ. Life Sci.-SGGW Land Reclam.* **2008**, *40*, 125–130. [CrossRef]
37. Aczel, A.D.; Sounderpandian, J. *Complete Business Statistics*, 2nd ed.; Wydawnictwo Naukowe PWN: Warsaw, Poland, 2018.
38. Sheldon, F.; Boulton, A.J.; Puckridge, J.T. Conservation value of variable connectivity: Aquatic invertebrate assemblages of channel and floodplain habitats of a central Australian arid-zone river, Cooper Creek. *Biol. Conserv.* **2002**, *103*, 13–31. [CrossRef]
39. Cairns, J.; Pratt, J.R. A History of Biological Monitoring Using Benthic Macroinvertebrates. In *Freshwater Biomonitoring and Benthic Macroinvertebrates*; Rosenberg, D.M., Resh, V.H., Eds.; Chapman and Hall: New York, NY, USA, 1993.
40. Almeida, D.; Merino-Aguirre, R.; Angeler, D.G. Benthic invertebrate communities in regulated Mediterranean streams and least-impacted tributaries. *Limnol.—Ecol. Manag. Inland Waters* **2013**, *43*, 34–42. [CrossRef]

41. Strayer, D.L.; Dudgeon, D. Freshwater biodiversity conservation: Recent progress and future challenges. *J. N. Am. Benthol. Soc.* **2010**, *29*, 344–358. [CrossRef]
42. Bunn, S.E.; Arthington, A.H. Basic Principles and Ecological Consequences of Altered Flow Regimes for Aquatic Biodiversity. *Environ. Manag.* **2002**, *30*, 492–507. [CrossRef]
43. Finlayson, C.M. Wetland management and restoration: Summary. In *Proc. Workshop: Wetland Management and Restoration*; Finlayson, C.M., Larsson, T., Eds.; Report 3992; Swedish Environ. Protection Agency: Stockholm, Sweden, 1991; pp. 174–179.
44. Brookes, A. *Channelized Rivers: Perspectives for Environmental Management*; John Wiley & Sons, Chichester: Hoboken, NJ, USA, 1988.
45. Zwoliński, Z. Sedimentology and geomorphology of overbank flows on meandering river floodplains. *Geomorphology* **1992**, *4*, 367–379. [CrossRef]
46. Wierzbicki, G.; Ostrowski, P.; Mazgajski, M.; Bujakowski, F. Using VHR multispectral remote sensing and LIDAR data to determine the geomorphological effects of overbank flow on a floodplain (the Vistula River, Poland). *Geomorphology* **2013**, *183*, 73–81. [CrossRef]
47. Wierzbicki, G.; Ostrowski, P.; Falkowski, T.; Mazgajski, M. Geological setting control of flood dynamics in lowland rivers. *Sci. Total Environ.* **2018**, *636*, 367–382. [CrossRef]
48. Wierzbicki, G.; Ostrowski, P.; Falkowski, T. Applying floodplain geomorphology and flood management in the Lower Vistula River upstream from Plock. *Open Geosci.* **2020**, *12*, 1003–1016, ISSN 2391-5447. [CrossRef]