Water **2015**, *7*, 4511-4522; doi:10.3390/w7084511

OPEN ACCESS

water

ISSN 2073-4441

www.mdpi.com/journal/water

Communication

Agricultural Rivers at Risk: Dredging Results in a Loss of Macroinvertebrates. Preliminary Observations from the Narew Catchment, Poland

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Academic Editor: Young-Seuk Park

Received: 25 June 2015 / Accepted: 5 August 2015 / Published: 17 August 2015

Abstract: Ecosystem deterioration in small lowland agricultural rivers that results from river dredging entails a significant threat to the appropriate ecohydrological conditions of these water bodies, expressed as homogenization of habitats and loss of biodiversity. Our study was aimed at a comparison of abundance and taxonomic structure of bottom-dwelling macroinvertebrates in dredged and non-dredged stretches of small lowland rivers and tributaries of the middle Narew River, namely: Czaplinianka, Turośnianka, Dąb, and Ślina. The experimental setup was (1) to collect samples of the bottom material from the river stretches that either persisted in a non-modified state (dredging was not done there in the last few years) or had been subjected to river dredging in the year of sampling; and (2) to analyze the abundance and taxonomic structure of macroinvertebrates in the collected samples. The study revealed that at the high level of statistical significance (from $p = 0.025$ to $p = 0.001$), the total abundance of riverbed macroinvertebrates in the dredged stretches of the rivers analyzed was approximately 70% lower than in non-dredged areas. We state that the dredging of small rivers in agricultural landscapes seriously affects their ecological status by negatively influencing the concentrations and species richness of benthic macroinvertebrates.

Keywords: macroinvertebrates; aquatic ecosystems; river regulation; dredging; river; Narew

1. Introduction

Although modified water bodies in agricultural landscapes may potentially play an important role as refuges for freshwater biodiversity [1–4], inappropriate management of these ecosystems vastly decreases the aquatic ecosystems' health [5–7]. Particularly, mechanic dredging of the river bed degrades the structure and composition of riverbanks and bottoms and negatively affects macroinvertebrate communities [6,8–12]. Considering the scale of river dredging in Poland in recent years, reported as critically affecting ecohydrological features of small and medium lowland rivers [13,14], and wishing to follow the Water Framework Directive's (WFD) call for European Union member states to conserve the status of their waters, we believed that technical measures applied in a country-wide manner for the "reduction of flood risk in agricultural areas" had to be revisited to assess their compliance with the requirements of environmental conservation and to protect rivers. As the first step towards revealing the responses of aquatic ecosystems to bottom dredging, we intended to undertake comparative research on the bottom macroinvertebrates of selected dredged and non-dredged stretches of small lowland rivers. Due to the fact that a high diversity of bottom macroinvertebrates reflects the appropriate ecohydrological status of rivers (resulting from feedbacks of ecological, hydrological, and micro-habitat processes [15]), we focused on differences in the abundance and taxonomic composition of macroinvertebrates. Our research was performed in small lowland rivers located in northeastern Poland, known for its unique environmental features. The preliminary results, despite being based upon a small sample of collected data, indicate that the responses of the examined aquatic ecosystems to dredging tend to be critically negative and demand re-consideration in terms of fulfilling the requirements of the WFD in any similar cases on the European scale.

2. Materials and Methods

We investigated four rivers of which certain sections were subjected to dredging. These sandy lowland rivers and streams (Czaplinianka, Dąb, Ślina, and Turośnianka) are tributaries of the middle Narew, northeast Poland (Figure 1). The lowermost stretches of the Czaplinianka and Turośnianka rivers are located within the Natura 2000 sites, and the remaining rivers are situated within a few kilometers of the protected areas. The rivers sampled flow through the agricultural landscapes (hay meadows, pastures), and due to their morphological and hydrological features, they can be classified as small lowland rivers (Table 1). Catchments of the rivers analyzed are located in a temperate climate with strong continental influences. The average air temperature in the region is 7 °C, and the average annual precipitation equals 580 mm [16].

The shares of the analyzed river catchments covered with forests range from 19% to 36% for the catchments of Dąb and Czaplinianka, respectively, and the areas of agricultural lands range from 61%

to 78% for the catchments of Czaplinianka and Dąb, respectively [17]. The research was conducted in September and October 2013 when, in summer and autumn, river dredging was implemented to keep the geometric shape of the river channel's cross-sections and to remove 0.3 m of the bottom sediments. This action is expected to eventually mitigate the flood risk. However, the probable influence of these actions on reduction of the floodwave was never examined nor proven by the river management authority and river dredging is being implemented with no particular pre-assessment of its probable efficiency.

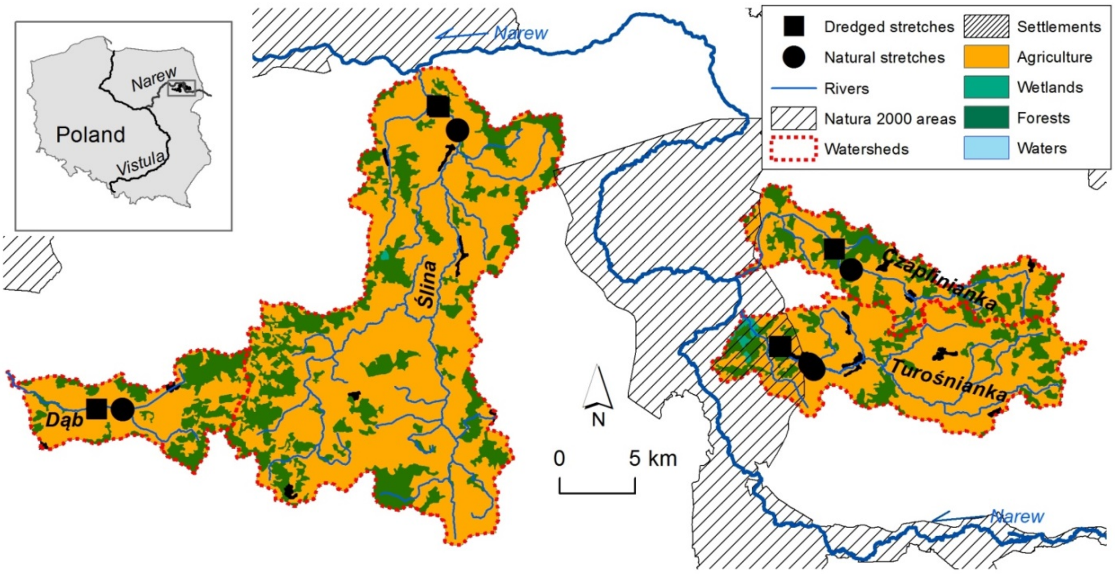

Figure 1. Study area—catchments of tributaries of the middle Narew river: Dąb, Czaplinianka, Ślina, and Turośnianka. Location of selected sampling stretches, land use, hydrography, and boundaries of protected areas (Natura 2000 and Narew National Park).

Table 1. Hydrological features of sampled rivers.

River	Ślina	Dąb	Czaplinianka	Turośnianka
Length [km]	39.3	16.5	31.3	31.4
Catchment area [km^2]	359.29	66.79	77.95	137.73
Average width in sampling locations [m]	7	2	3	4
Average depth in sampling locations [m]	1.2	0.3	0.8	0.8
Average flow velocity in sampling locations [m/s]	0.15	0.11	0.09	0.10
Average discharge in the confluence [m^3/s]	1.5	0.3	1.1	1.2
X Coordinate of the centroid of the non-dredged stretch of the river (GPS)	22.67306	22.32890	23.05540	22.98110
Y Coordinate of the centroid of the non-dredged stretch of the river (GPS)	53.16604	53.00912	53.07010	53.02692
X Coordinate of the centroid of the dredged stretch of the river (GPS)	22.65379	22.30228	23.03923	23.00352
Y Coordinate of the centroid of the dredged stretch of the river (GPS)	53.18109	53.01021	53.08307	53.01727

Macroinvertebrate sampling was done as follows: in each of the four rivers we selected two sampling stretches of 100 m; one stretch was located within the fragment of the river recently subjected to dredging, and the other was a reference stretch, where dredging had not been implemented recently. Dredged and non-dredged sampling stretches were located between 1.7 and 2.5 km from one another (Figure 1). Dredged stretches of the rivers sampled were cleared with an excavator, so the riparian vegetation was very poor. Non-dredged river stretches were vegetated. In Ślina and Czaplinianka, the dominant macrophytes were *Nuphar lutea* and *Saggittaria* sp., while the macrophytes in the sampled stretches of Dąb and Czaplinianka were poorly developed due to river size and shading from adjacent trees and shrubs. All of the rivers sampled have sandy banks. Water levels during the sampling were below the average annual water level and oscillated around the median of the lowest annual water levels recorded in the most recent multi-year period.

On each of the eight selected sampling stretches (Figure 1) we collected five samples of bottom sediments. Sampling locations were distributed every 20 m along the stretch. Samples were collected with the standard Eckman-Birge's bottom-sediment sampler that allows sampling of 225 cm^2 of the river bottom [18]. As the study was oriented at the analysis of bottom-dwelling macroinvertebrates, field research did not include drift measurements. Collection locations were selected to cover the most representative aquatic habitats of each stretch in various water depths, from an average distance of one-third of the river width. Samples were collected wading in the river. Forty samples of bottom sediments were examined in total (20 collected from dredged stretches of rivers and 20 collected from reference stretches that had not been dredged recently). Sampling was done from five days (Ślina river) to approximately one month after the river bed dredging (Turośnianka river). River flow velocities in the sampled stretches were approximated with surface flow measurements averaged to one value representative for the whole sampling stretch. Each sample was stored in a plastic bag immediately after collection and transferred to the laboratory where the abundance and species composition of macroinvertebrates were assessed. Macroinvertebrates were sorted after preservation in ethanol and counted by the naked eye. Obtained results of macroinvertebrate abundance and taxonomic composition were tested in order to reveal their statistical significance.

3. Results

Field research revealed the presence of 10 taxa of macroinvertebrates, namely *Amphipoda*, *Bivalia*, *Diptera*, *Ephemeroptera*, *Gastropoda*, *Hirudinea*, *Isopoda*, *Megaloptera*, *Oligochaeta*, and *Trichoptera*. It was generally observed that both the total abundance of macroinvertebrates and their taxonomic compositions were significantly higher in the natural stretches of rivers (Figure 2A) than in the freshly dredged ones (Figure 2B).

We tested the sampling results for statistical relevance. The Student's *t*-test for dependent variables (for n-2 degrees of freedom) and a Mann-Whitney-Wilcoxon test were applied in order to determine the statistical significance of observed differences in the abundance and species compositions of macroinvertebrates between the dredged and natural stretches of the rivers examined. The *t*-values for the total macroinvertebrates' abundance analysis reached 2.813; that gives a statistical significance at the level of $p = 0.023$. The *t*-values for the comparison of the taxonomic composition of macroinvertebrates of dredged and natural river stretches reached 4.420; that gives a statistical significance at the level of $p = 0.001$. The *U*-value of the Mann-Whitney-Wilcoxon test analyzing total macroinvertebrate abundance was 19 (giving $p = 0.025$), and for the taxonomic composition of macroinvertebrates of dredged and natural river stretches they were $U = 61$ and $p = 0.01$. The results of the statistical tests applied allow us to state that the recorded differences between the total abundances of macroinvertebrates and their taxonomic compositions are statistically significant (the lowest recorded level of statistical significance was 0.025, which we considered satisfactory).

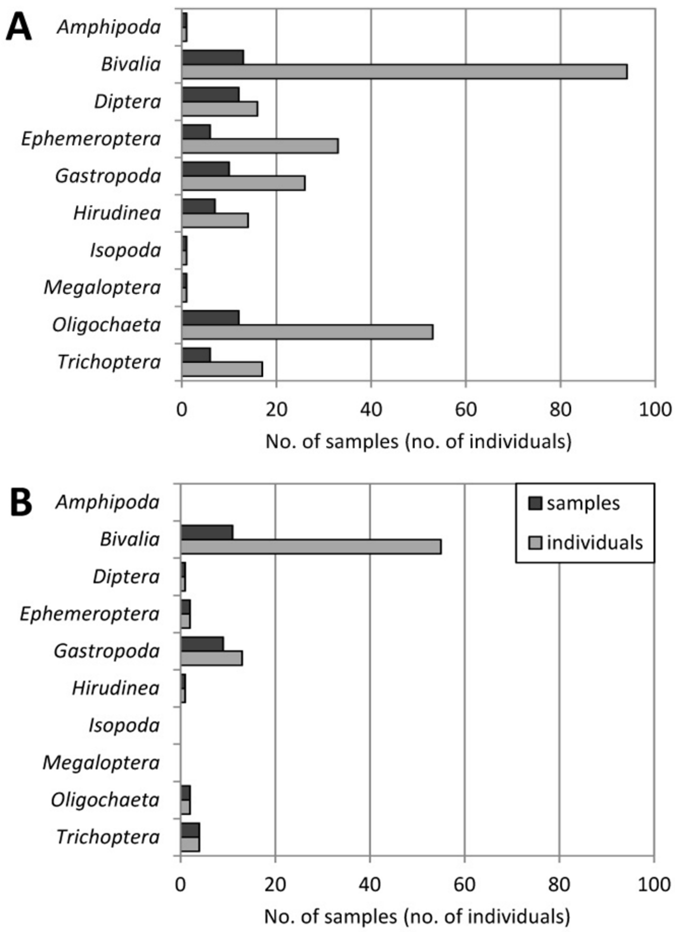

Figure 2. Comparison of the abundance of macroinvertebrate taxa *vs.* number of samples in which particular taxa were recorded in natural (**A**) and dredged (**B**) stretches of rivers.

Considering the total abundance of macroinvertebrates in all samples collected, we recorded approximately 70% lower concentrations of macroinvertebrates in the dredged stretches than in undredged ones (Figure 3A). The biggest differences between the total abundance of macroinvertebrates were found in the analyzed stretches of the Ślina and Dąb rivers (Figure 3B,C), which were nearly 91% and 98%, respectively. In the analyzed stretches of Czaplinianka and Turośnianka, differences in macroinvertebrate abundances were lower than in the cases of Ślina and Dąb, but still reached approximately 50% (Figure 3D,E). The most significant differences in the abundance of macroinvertebrate taxa were reported for the taxon of *Ephemeroptera*, whose numbers in dredged river segments were 83% to nearly 100% lower than in the undisturbed stretches of the rivers analyzed. Equally significant differences between dredged and non-dredged stretches were recorded for *Trichoptera*, *Gastropoda*, and *Diptera*. Differences in the abundance of *Amphipoda*, *Isopoda*, and *Megaloptera* between the dredged and non-dredged stretches of the rivers were insignificant. Of the rivers analyzed, the most critical disparities of macroinvertebrate abundance and composition were recorded in the smallest of the sampled rivers, the Dąb. Although individuals of *Amphipoda*, *Bivalia*, *Diptera*, *Ephemeroptera*, *Gastropoda*, *Hirudinea*, and *Oligochaeta* were recorded in the non-dredged stretch of this river, these taxa were not reported in dredged stretches. *Bivalia* was the taxon with the lowest disparities of abundance.

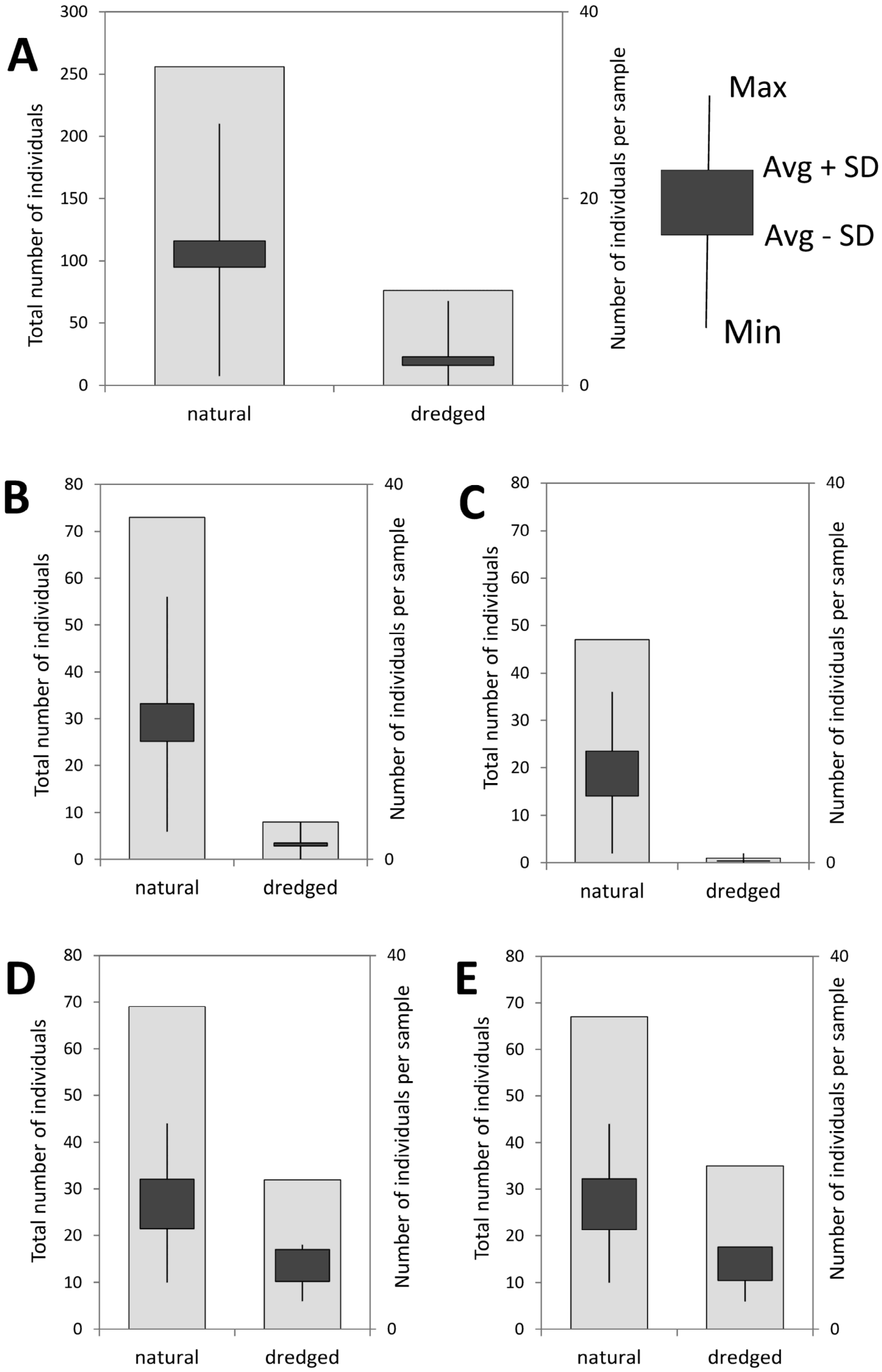

Figure 3. Comparison of abundance of macroinvertebrates between natural and dredged stretches: total number of sampled individuals and numbers of individuals per sample: (**A**) whole set of samples (*n* = 20 + 20); (**B**) Ślina river (*n* = 5 + 5); (**C**) Dąb river (*n* = 5 + 5); (**D**) Czaplinianka river (*n* = 5 + 5); and (**E**) Turośnianka river (*n* = 5 + 5).

4. Discussion

In subtle cases of river dredging where the response of macroinvertebrate communities (based on calculated macroinvertebrate indexes) to ecological disturbances might not be clearly linked to river regulation and maintenance works (dredging, macrophyte removal), additional mesohabitat assessments of river reaches or complex multivariate analyses may be required [8]. However, the strongly negative response of macroinvertebrate structure and abundance to river dredging found in our study tends to be clear and obvious. We see that, similarly to the studies of Armitage and Pardo [8], Bylak *et al.* [6], and Holmes *et al.* [15], the research we present should be extended to the other factors of the aquatic ecosystems examined (*i.e.*, the structure of bottom sediments, debris and microhabitat analysis, flow velocity distribution, and water quality assessment). However, in the cases of the Czaplinianka, Dąb, Ślina, and Turośnianka rivers, dredging to prevent floods involved mechanically removing (using excavators) some 0.3–0.5 m of the sediment material from the river bottom for the whole width of the river stretch and depositing the material on the river bank, causing the degradation of hydromorphology (Figure 4A). This type of river structure modification was proven as critically negative for freshwater mussels *Bivalvia* [9], but the negative impact of such river management measures can be extended to herein presented macroinvertebrates and other taxa (including amphibians, Figure 4B; Ukrainian brook lamprey *Eudontomyzon mariae*, Figure 4C; or numerous other taxa of macroinvertebrates, Figure 4D).

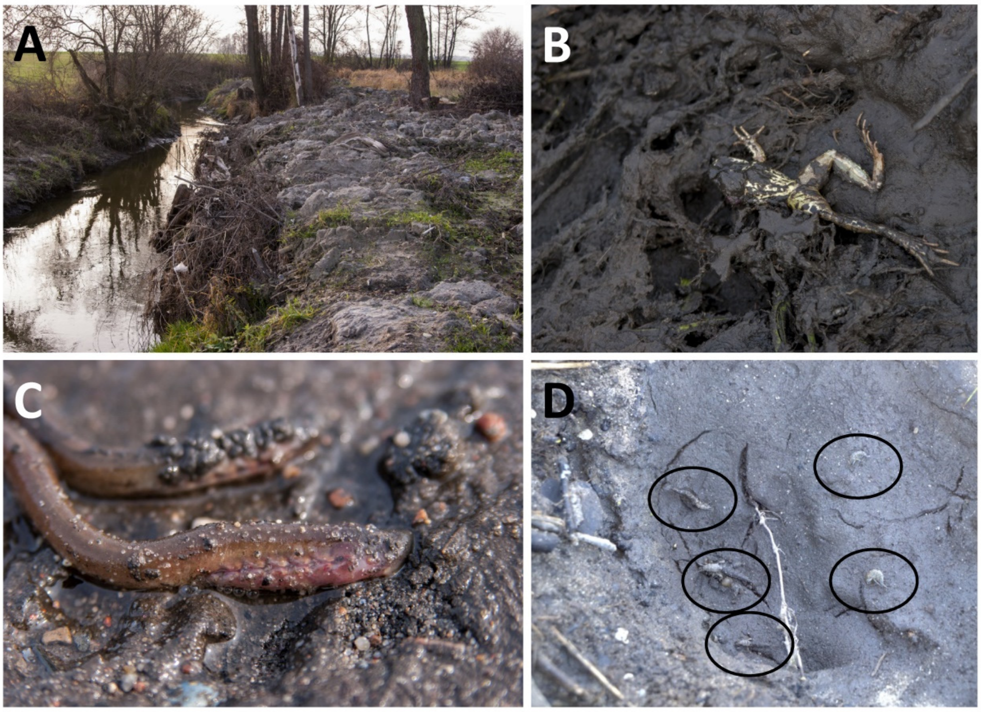

Figure 4. Environmental consequences of dredging agricultural rivers: (**A**) modified hydromorphology of the Czaplinianka River; (**B**) dead amphibians found in the excavated material (Ślina River); (**C**) dead Ukrainian brook lampreys *Eudontomyzon mariae* (Ślina River); (**D**) dead macroinvertebrates (*Gammaridae* and *Ephemeroptera*). Photos: courtesy of Paweł Fiedorczuk.

As the biggest differences in macroinvertebrate abundances between the dredged and non-dredged stretches were observed in the smallest river sampled (Dąb), we suspect that narrow and shallow (up to 2 m wide and up to 0.2 m deep) agricultural rivers may face the greatest risk of damage to their aquatic ecosystems as a result of inappropriate and devastating management.

It is likely that in the long run the self-restoration of the dredged river stretches analyzed may result in the re-establishment of hydromorphological conditions by allowing the re-development of macroinvertebrate abundance and species composition toward the reference values reported for non-dredged stretches [19,20]. However, if long headwater parts of these rivers remain under the pressure of dredging every 1–3 years (which is the case of analyzed and adjacent rivers), it is likely that the spontaneous restoration of macroinvertebrate populations of the whole river systems may be—if still possible—very slow. We rather expect the hydromorphological and ecological status of lowland agricultural rivers being dredged on up to 70% of their total length on an annual and bi-annual basis to deteriorate considerably. As it was observed that the structure of aquatic habitats and sediments, especially in the headwater streams (e.g., the small rivers examined in the presented research), promotes the abundance and taxonomic richness of bottom macroinvertebrates [15,21], it appears that once small lowland rivers' hydromorphology begins to suffer, the aquatic ecosystems subjected to dredging lose their resilience. Such speculation requires consideration in the catchment-scale river management. It should result in implementation of river dredging adaptation strategies by avoiding long stretches being dredged regularly and promoting dredging of selected short stretches only, if the flood risk was proven to be increasing due to the accumulation of sediments. This would require continuous monitoring of longitudinal profiles of the river bottom, which is predominantly not done in the case of small lowland agricultural rivers. As such actions are not anticipated in river management plans in northeastern Poland, we stress that only the reliable monitoring-based criteria of river dredging should be used to determine the relevance of this action for flood reduction.

In light of our analysis, and emphasizing the results obtained by Bylak *et al.* [6], we state that technical measures referred to as "river regulation" have a critically negative influence on the ecological status of rivers. For small lowland agricultural rivers, it is regular dredging that poses an equally significant challenge to the ecological status by deterioration of river hydromorphology and populations of macroinvertebrates. Preliminary results presented in this paper require replication, especially in terms of additional sampling of the same river stretches over time (months or years after dredging was implemented), and extension to other elements of the riverine environment in order to provide a comprehensive analysis of rivers' responses to dredging [22]. Extension of the research to, for example, the response of fish communities to dredging-induced changes in mesohabitat structure and macroinvertebrate composition would allow results to reveal the relevance of the maintenance of agricultural rivers to fishery management [23,24]. Research on these aspects is now ongoing. However, we stress that despite the strength of the correlations and covariance between the abundance of benthic macroinvertebrates and other elements of the environment, the "everyday" management of small lowland agricultural rivers requires revision, detailed environmental impact assessment, and the analysis of trade-offs between the potential (not certain) reduction of flood risk and the loss of resilient aquatic ecosystems. In some specific cases, when dredging is oriented at the removal of contaminated sediments which pose a decent risk of losing river ecosystems' quality, one should consider if the probable negative response of benthic macroinvertebrates to mechanic sediment removal is of lower importance than preventing the deterioration of water and sediment quality.

Facing the above facts and the potential changes in environmental legislation in Poland to permit the standard "maintenance" of river channels (including dredging) without any environmental impact assessments, the scale of dredging is expected to become even greater than it is now. It is likely that small agricultural rivers that are "maintained" by regular dredging, contra the examples given by Chester and Robson [1] and supported with the observations of Tonkin *et al.* [20], will never again serve as a refuge for freshwater biodiversity. Avoiding this scenario will require management approaches, especially in cases of small agricultural rivers, to be individualized so each of the complex river ecosystems could retain its unique and specific environmental values [25]. It is intended that the preliminary observations presented in this paper will allow us to reveal the appropriate meaning of "river maintenance" which, in presented examples, underpinned the vast deterioration of the biodiversity of the agricultural rivers analyzed. We also hope that learning from river management mistakes will allow implementing efficient restoration and maintenance strategies for the recreation and sustainability of resilient aquatic ecosystems in the future [26], where flood protection does not contradict keeping the good ecological status of agricultural rivers.

5. Conclusions

This study revealed that the species composition and abundance of macroinvertebrates is much lower in dredged stretches of the rivers analyzed than in the stretches where river dredging was not done, leaving the structure and thickness of bottom sediments untouched. The most significant differences in the abundance of macroinvertebrates' taxa were reported for *Ephemeroptera*, which were 83% to nearly 100% less abundant in the dredged areas. We revealed that in dredged stretches of rivers, the quantitative loss of macroinvertebrate populations (numbers of individuals) was much more significant than the quantitative loss of taxonomic composition (decreasing number of taxa). Based on the examples analyzed, we conclude that river dredging entails a potential significant threat to species diversity and the abundance of bottom macroinvertebrates and, potentially, to the whole river ecosystem. We stress that more research directed at before-after control-impact studies of river dredging's influence on aquatic ecosystems (especially small rivers located within protected areas) is needed in order to reveal the full extent of river ecosystem degradation. Although one could argue that presented results could have been expected and the reported negative response of biota and hydromorphology to dredging small agricultural rivers is obvious, they highlight that regular actions oriented at the so-called "maintenance" of rivers by mechanic sediment removal are negative to the environment of riverscapes. Our preliminary study only underlines this issue, which should be considered in the everyday management of rivers. Finally, regardless of the probable self-restoration dynamics in agricultural rivers, we stress that the implementation of technical measures aimed at mud removal and shaping the river channel may lead to the deterioration of the ecological status of rivers by affecting their ecohydrological features. Such actions contradict national and international (EU Water Framework Directive) environmental legislation.

Acknowledgments

This study was funded by the Stefan Batory Foundation through a project implemented by Stowarzyszenie Niezależnych Inicjatyw Nasza Natura, aimed at the control of legal and environmental effects of the technical maintenance of rivers in NE Poland. Paweł Fiedorczuk, Jędrzej Grygoruk, and Zofia Namyślak are acknowledged for help in data collection. Reviewers are kindly acknowledged for valuable comments that allowed us to improve the manuscript.

Author Contributions

Mateusz Grygoruk developed the concept of the study, planned field research, and wrote the manuscript. Magdalena Frąk and Aron Chmielewski performed field research, laboratory analysis of macroinvertebrates, and assisted in manuscript preparation.

Conflicts of Interest

The authors declare no conflict of interest.

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