THE EFFECT OF MAINTENANCE WORKS TO PHYSICAL AND CHEMICAL CONDITIONS OF SMALL RIVERS IN AGRICULTURAL AREAS

Abstract: Abiotic and biotic bounty of riparian waters may be affected by inadequate maintenance works. Improper planning and execution of maintenance works cause changes to hydrological and hydrochemical condition of water in small rivers, affecting biocenose of riverbeds by modifying the taxonomic composition of organisms inhabiting the regulated river section. Five (5) rivers were subject to studies - Plonia, Mysla, Tywa, Rurzyca, and Wardynka (Odra river basin), which were monitored before and after maintenance works consisting in desilting, mowing and removal of aquatic plants. This study examined hydrological (mean depth and width of small rivers, speed and flow), physical and chemical parameter of water (temperature, pH, O₂, N-NO₃, N-NH₄, P-PO₄) before and after dredging of selected rivers. Obtained results and resulting statistical analysis demonstrated increase in hydrological indices - depth, width, speed and flow. Among other physical and chemical properties that significantly increased following completion of maintenance works, were O₂ and NH₄. NO₃ concentration and temperature dropped, but not statistically significant. Changes in hydrological and hydrochemical properties of waters caused by maintenance works may affect biodiversity of the regulated river sections, including changes in composition of ichthyofauna species.

Keywords: desilting, small rivers, water quality, biogenes

Introduction

Rivers are subjected to anthropogenic impact [1, 2], mainly because they are the lowest part of landscape, accumulating all kinds of run-offs from the whole river basin [3-5]. They are often a source of drinking water for residents, especially in agricultural areas [6]. It seems that not only large rivers are impacted, but also small rivers that are considered as regional reserves of biodiversity [1, 7, 8]. Due to significant sedimentation of benthic deposits in small rivers, paired with total biomass of macrophytes (which might lead to slowing water flow, and flooding of the adjacent land), maintenance works are routinely performed on them [9, 10].

Small rivers are characterised with diversity of morphologic features, such as riparian habitats and species of aquatic animals [11]. Human impact such as channel maintenance
works imposes pressure on hydrological systems and causes imminent response in the river ecosystems [12, 13]. Regulation and conservation works have direct and indirect impact on biocenoses of river beds [8, 14, 15], due to direct reduction in numbers of aquatic organisms caused by maintenance [16, 17], but also indirectly - due to modifications to hydromorphological conditions of their habitats [18, 19]. The latter may result in changes to taxonomic composition of the water course section, and in some cases, creating habitats for new species of animals [20, 21].

Sustainable management of waters should provide for such execution of works that do not cause changes to aquatic environment, in particular to physical and chemical properties of waters that are critical to survival of aquatic organisms [22-24], and some living organisms (e.g. algae) may be a biosorbert of toxic compounds or heavy metals [25]. Various river regulation methods are adopted that fully comply with engineering standards, while ensuring protection of aquatic ecosystems [15]. This process should probably also consider changes to physical and chemical properties of water during completion such works, since the majority of aquatic organisms is extremely susceptible to any changes in the environment [24, 26]. Haidekker and Hering [23] state that altered physical and chemical parameters of river habitats may interfere with reproduction, development of embryos, and metamorphosis, leading to eradication of multiple aquatic organisms.

This study focused on the assessment of hydrological, physical and chemical properties of small rivers subject to maintenance works in the context of potential impact of such works on aquatic organisms.

**Material and methods**

Studies were performed on 5 small rivers located within Odra river basin in north-western Poland (Fig. 1). In years 2017 and 2018, 100 m long sections were isolated on each river (Plonia, Mysla, Tywa, Rurzyca, and Wardynka) - 1 section on one river, where the monitoring was maintained throughout the vegetation season (spring, summer and autumn). After sampling performed in autumn 2018, maintenance works were conducted over the entire study sections in each river, involving silt removal from the water course, and mowing and removing of aquatic plants. Physical and chemical analyses at pre-determined stations in rivers were continued also in vegetation season 2019 (spring, summer, autumn). Hydrological parameters, such as mean depth at individual stations, width of water course, speed and flow were determined during field studies. Hydrological and physicochemical analyses at each station were performed during specific seasons, every 7 days. In 2017-2018 (before maintenance works), during spring, summer and autumn, monitoring was performed 24 times at each research station in each of the above seasons, while in 2019 (after maintenance works), 12 times. Samples for physicochemical analyses were collected from each station at 3 sites (in the upper, middle and lower section of the research station with the length of 100 m), while hydrological analyses were conducted at 5 sites in each of the stations.

Depth and width of small rivers were measured using scalable depth gauge and measuring tape, whereas the speed of flow was measured using the electromagnetic meter SENSA RC2 fitted with RV2 probe (Quantum Dynamics Ltd. Aqua Data Services Division). In addition, water temperature, electrical conductivity (EC) and pH, as well as the dissolved oxygen content and oxygen saturation of water were determined using multiple-parameter mobile meter HACH; also 3 samples of water were taken from each station...
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station for subsequent laboratory tests. Concentrations of N-NO₃, N-NH₄, and P-PO₄ were determined by the Environmental Chemistry Research Laboratory of ITP-PIB in Falenty by colorimetric method, using automatic flow analyser manufactured by Skalar. The study presents mean values of individual features, with standard deviations, for all small rivers - before and after the maintenance works.

![Map](image)

**Fig. 1.** Locations of research stations on small rivers within Odra river basin, selected for maintenance works

Statistical analysis were performed using Statistica 13.3 PL software in the R development environment (cran.r-project.org). Shapiro-Wilk test was conducted to verify normal distributions of examined parameters. Wilcoxon test [27] was conducted to compare parameter values before and after maintenance works. Statistical significance of correlations between parameters were was determined using correlation matrix. Principal Component Analysis (PCA) [28] was used to demonstrate dependencies between observed correlated variables. In addition, discrimination analysis was used to determine features that most diversify data sets for physical and chemical conditions before and after the maintenance works [28]. Correlations between the study parameters were assessed with the use of the Pearson correlation coefficient.

**Study findings**

Mean values of hydrological and hydrochemical features, before and after the maintenance works in specific seasons of study, are shown in Table 1. Despite clear and apparent variability of some parameters throughout the study NO₃, NH₄, and PO₄, statistically significant differences were observed in oxygen content (O₂ [mg/dm³]) and
saturation [%] in spring and autumn, and electrical conductivity (EC) and PO₄ in spring were noted before and after maintenance works.

Table 1

| Parameters | Season | Before | After | T | Z | P |
|------------|--------|--------|-------|---|---|---|
| Speed [cm/s] | Spring | 0.38 ±0.24 | 0.45 ±0.34 | 20 | 0.76 | 0.45 |
|           | Summer | 0.32 ±0.21 | 0.44 ±0.31 | 12 | 1.58 | 0.11 |
|           | Autumn | 0.32 ±0.27 | 0.47 ±0.30 | 0  | 2.80 | 0.01* |
| Flow [cm³/s] | Spring | 0.45 ±0.58 | 1.5 ±2.3 | 11 | 1.68 | 0.09 |
|            | Summer | 0.30 ±0.36 | 1.8 ±2.3 | 10 | 1.78 | 0.07 |
|            | Autumn | 0.26 ±0.23 | 1.5 ±2.2 | 10 | 1.78 | 0.07 |
| Width [m] | Spring | 2.8 ±1.4 | 3.5 ±2.5 | 11 | 1.68 | 0.09 |
|           | Summer | 2.6 ±1.3 | 3.4 ±2.4 | 11 | 1.68 | 0.09 |
|           | Autumn | 3.1 ±1.2 | 3.5 ±2.5 | 25 | 0.25 | 0.80 |
| Depth [m] | Spring | 0.29 ±0.18 | 0.39 ±0.29 | 15 | 1.27 | 0.20 |
|           | Summer | 0.26 ±0.13 | 0.49 ±0.44 | 12 | 1.58 | 0.11 |
|           | Autumn | 0.24 ±0.19 | 0.39 ±0.30 | 14 | 1.37 | 0.17 |
| Temp. [°C] | Spring | 15.3 ±3.3 | 13.2 ±1.9 | 17 | 1.08 | 0.29 |
|           | Summer | 20.0 ±1.3 | 19.9 ±2.2 | 22 | 0.06 | 0.95 |
|           | Autumn | 14.1 ±3.5 | 11.2 ±1.7 | 12 | 1.58 | 0.11 |
| pH [-] | Spring | 7.64 ±0.16 | 7.79 ±0.29 | 14 | 1.38 | 0.17 |
|           | Summer | 7.50 ±0.20 | 7.56 ±0.28 | 17 | 0.65 | 0.52 |
|           | Autumn | 7.51 ±0.11 | 7.39 ±0.20 | 13 | 1.48 | 0.14 |
| EC [μS/cm] | Spring | 703 ±108 | 814 ±85 | 3  | 2.50 | 0.01* |
|           | Summer | 746 ±166 | 842 ±367 | 18 | 0.97 | 0.33 |
|           | Autumn | 791 ±264 | 782 ±301 | 26 | 0.15 | 0.88 |
| O₂ [mg] | Spring | 3.33 ±1.16 | 5.4 ±1.4 | 0  | 2.80 | 0.01* |
|           | Summer | 2.7 ±1.0 | 4.1 ±2.6 | 10 | 1.78 | 0.07 |
|           | Autumn | 2.9 ±1.2 | 4.82 ±0.85 | 3  | 2.50 | 0.01* |
| O₂ [%] | Spring | 33 ±11 | 53 ±12 | 1  | 2.70 | 0.01* |
|           | Summer | 26 ±11 | 43 ±29 | 10 | 1.78 | 0.07 |
|           | Autumn | 29 ±12 | 45.6 ±8.4 | 5  | 2.29* | 0.02* |
| NO₃ [mg/dm³] | Spring | 7.1 ±6.0 | 4.0 ±1.9 | 26 | 0.15 | 0.88 |
|           | Summer | 3.6 ±1.3 | 5.1 ±3.7 | 21 | 0.66 | 0.51 |
|           | Autumn | 3.7 ±1.8 | 4.1 ±1.7 | 21 | 0.66 | 0.51 |
| NH₄ [mg/dm³] | Spring | 0.12 ±0.06 | 0.41 ±0.38 | 10 | 1.78 | 0.07 |
|           | Summer | 0.41 ±0.42 | 0.53 ±0.68 | 15 | 1.27 | 0.20 |
|           | Autumn | 0.7 ±1.4 | 2.1 ±1.1 | 11 | 1.68 | 0.09 |
| PO₄ [mg/dm³] | Spring | 0.76 ±0.25 | 1.10 ±0.46 | 3  | 2.50 | 0.01* |
|           | Summer | 1.14 ±0.32 | 1.5 ±1.0 | 21 | 0.66 | 0.51 |
|           | Autumn | 0.70 ±0.56 | 0.8 ±1.1 | 24 | 0.36 | 0.72 |

* statistically significant differences (p < 0.05)

Statistically significant differences in physical and chemical properties were noted only in O₂ content and saturation, and in NH₄ concentration.

Maintenance works caused small decrease (p > 0.05) in water temperature and NO₃ content (Table 2). Maintenance works, however, slightly increased EC, PO₄, NH₄, and O₂ content and O₂ saturation (p > 0.05).

Discrimination analysis demonstrated that O₂, PO₄, and NH₄ content are major contributors to discrimination of groups between before and after maintenance works.
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With these parameters, the classification matrix of discrimination analysis demonstrated that 100% cases were well assigned to the pre maintenance works group, and 93.3% cases were correctly classified in post maintenance works group.

Table 2

| Parameters       | Before (±SD) | After (±SD) | T     | Z     | p-value |
|------------------|-------------|-------------|-------|-------|---------|
| Speed [cm/s]     | 0.34±0.23   | 0.45±0.30   | 84    | 3.05* | 0.00    |
| Flow [cm/s]      | 0.34±0.41   | 1.6±2.2     | 82    | 3.10* | 0.00    |
| Width [m]        | 2.8±1.3     | 3.5±2.4     | 143   | 1.84  | 0.07    |
| Depth [m]        | 0.26±0.16   | 0.42±0.34   | 113   | 2.46* | 0.01    |
| Temp. [°C]       | 16.5±3.8    | 14.8±4.3    | 137   | 1.74  | 0.08    |
| pH [-]           | 7.55±0.17   | 7.58±0.30   | 198   | 0.42  | 0.67    |
| EC [μS/cm]       | 750±190     | 813±270     | 140   | 1.90  | 0.06    |
| O₂ [mg]          | 3.0±1.1     | 4.8±1.8     | 34    | 4.08* | 0.00    |
| O₂ [%]           | 30±11       | 47±18       | 42    | 3.92* | 0.00    |
| NO₃ [mg/dm³]     | 4.8±3.9     | 4.7±2.7     | 219   | 0.28  | 0.78    |
| NH₄ [mg/dm³]     | 0.42±0.83   | 1.0±1.3     | 108   | 2.56  | 0.01    |
| PO₄ [mg/dm³]     | 0.87±0.43   | 1.15±0.93   | 173   | 1.22  | 0.22    |

* statistically significant differences (p < 0.05)

Table 3

| Parameters | Wilks’ Lambda | Partial Wilks’ Lambda | F to Remove (1.51) | p     |
|------------|---------------|-----------------------|--------------------|-------|
| O₂         | 0.56*         | 0.46*                 | 59.1*              | 0.00* |
| PO₄        | 0.52*         | 0.50*                 | 50.8*              | 0.00* |
| NH₄        | 0.36*         | 0.72*                 | 19.5*              | 0.00* |
| Depth      | 0.28*         | 0.91*                 | 4.74*              | 0.03* |
| pH         | 0.29*         | 0.91*                 | 4.94*              | 0.03* |
| NO₃        | 0.28*         | 0.92*                 | 4.40*              | 0.04* |
| Width      | 0.28          | 0.94                  | 3.42               | 0.07  |
| Flow       | 0.27          | 0.97                  | 1.44               | 0.24  |

* statistically significant differences (p < 0.05)

Analysis of the 25 pairs of properties correlation matrix indicated statistically significant dependencies (Table 4). Among hydrological features, the most significant correlations (correlation coefficient R > 0.80) were observed between speed and width (0.83), flow and width (0.88), flow and depth (0.84), and width and depth (0.82). In the case of physical and chemical properties, statistically significant negative correlation was determined for 7 pairs of properties, and positive correlation also for 7 pairs of properties. The highest correlation was observed between oxygen content and saturation in water (0.98) followed by pH and NH₄ (−0.57), EC and PO₄ (0.50), pH and EC (−0.47), EC and oxygen saturation (−0.42), and EC and NH₄ (0.49).

PCA analysis (Fig. 2) demonstrated positive correlation between oxygen content and saturation in water and NO₃ as well as weaker positive correlation of parameters with water pH. Also, strong negative correlation between oxygen content and saturation in water and PO₄ was observed, as well as weaker negative correlation with temperature, EC, and NH₄.
Correlation between hydrological, physical and chemical properties (Pearson correlation coefficient), at research stations within Odra River basin

| Parameters | Flow [m/s] | Width [cm] | Depth [cm] | Temp. [°C] | pH [-] | EC [μS·cm⁻¹] | O₂ [mg/L] | O₂ [%] | NO₃ [mg·dm⁻³] | NH₄ [mg·dm⁻³] | PO₄ [mg·dm⁻³] |
|------------|------------|------------|------------|------------|-------|--------------|-----------|-------|----------------|----------------|----------------|
| Speed [m/s]| 0.760*     | 0.83*      | 0.63*      | 0.17       | 0.40* | -0.63*       | 0.08      | 0.09  | -0.02          | -0.44*         | -0.07          |
| Flow [m/s] | 0.88*      | 0.84*      | 0.18       | 0.11       | -0.21 | -0.20        | -0.18     | 0.02  | -0.26*         | 0.11           |                |
| Width [cm] | 0.82*      | 0.11       | 0.21       | -0.38*     | 0.01  | 0.02         | 0.03      | -0.15 | -0.02          |                |                |
| Depth [cm] | 0.27*      | 0.16       | -0.24      | -0.04      | -0.02 | -0.04        | -0.21     | 0.04  |                |                |                |
| Temp. [°C] | -0.04      | -0.13      | -0.22      | -0.14      | -0.19 | -0.31*       | 0.33*     |       |                |                |                |
| pH [-]     | -0.47*     | 0.38*      | 0.38*      | 0.30*      | -0.57*| -0.21        |           |       |                |                |                |
| EC [μS·cm⁻¹]| -0.39*     | -0.42*     | 0.08       | 0.49*      | 0.50* |                |           |       |                |                |                |
| O₂ [mg/L]  | 0.98*      | 0.10       | -0.19      | -0.39*     |       |              |           |       |                |                |                |
| O₂ [%]     | 0.07       | -0.23      | -0.39*     |           |       |              |           |       |                |                |                |
| NO₃ [mg·dm⁻³]| -0.06     | 0.04       |            |           |       |              |           |       |                |                |                |
| NH₄ [mg·dm⁻³]| 0.00       |            |            |           |       |              |           |       |                |                |                |

* statistically significant differences (p < 0.05)

Fig. 2. Results of PCA analysis on hydrological and physical and chemical parameters at individual stations (numbers in the current study)
Discussion

Maintenance works completed on selected rivers demonstrated changes to both hydrological parameters of rivers and in the content of biogenic compounds. The impact of dredging and removal of river substrate, combined with mowing of aquatic plants, contributed to the increase in depth and width as well as the increase in speed and flow.

Further differences were observed in water quality, as some parameters improved after silt removal - e.g. oxygen saturation. In the course of our study, we noted a slight reduction in NO$_3^-$ concentration, decrease in temperature, and increase in PO$_4^{3-}$ concentration (no statistically significant differences) and NH$_4^+$ concentration (statistically significant differences). Negative correlations between oxygen content and saturation and PO$_4^{3-}$ may be the evidence of the latter release from the river bottom as a result consequence of maintenance works. Ammonium (NH$_4^+$) originating in part from biochemical decomposition of organic nitrogen compounds release from plants, or from sewage, may accumulate in near-bottom layers of rivers. Increase in this parameter may be the evidence of excess dead plants left after completion of maintenance works, or additional influx from the river basin area.

As demonstrated by previous studies of water quality in the Odra river basin rivers that were conducted during the 2018 vegetation season, 4 water quality indicator out of 7 (N-NO$_3^-$, and P-PO$_4^{3-}$ concentration), were elevated [29]. This indicates that availability of N and P in rivers promoted macrophyte growth and increase in primary production, causing the need for mowing large stands of vegetation. Dredging and removal of silt were followed by reduction in the content of biogenes, with simultaneous increase in oxygen content. However, three-fold increase in N-NH$_4^+$ concentration, due to maintenance works, was also observed.

Positive correlation between water oxygen content and saturation and NO$_3^-$ concentration demonstrated by PCA analysis, can be explained by (i) regulation of rivers, and (ii) high fertility of aquatic ecosystems (such as rivers discussed in this study) [26]. Specifically, nutrient fluctuations in the direction of affect rates of ammonification, nitrification, and denitrification processes may be observed [30, 31]. In the summer, autotrophs intensely assimilate nitrates and therefore the content of this biogen in water should decrease. In the summer season post maintenance works, increase NO$_3^-$ was most likely released, as a consequence off increased nitrification processes at higher temperatures.

Obolewski et al. [32] conducted studies on river Kwacza, one year before and one year after maintenance works. After comparing results from pre and post silt removal form river bottoms, the quantity of NO$_3^-$, PO$_4^{3-}$, and total phosphorus was higher pre works (except for the quantity of NO$_3^-$ in spring, phosphates PO$_4^{3-}$ in autumn and total phosphorus in spring) than post works. The content of nitrates in ours studies was different - only in spring when nitrates were observed in more quantities than before the dredging: in summer and autumn nitrates were higher post works than pre works. Phosphates were reduced in our study post maintenance works. Similar results were found in other studies [33], where the concentration of phosphorus in deposits after dredging of water course decreased by 33-66 %. The opposite was observed in Smith et al. [34] studies, where the content of phosphorus increased after completion of dredging works.

Oxygen content in studies of Obolewski et al. [32] was higher post maintenance works than pre maintenance works, which was also confirmed by our studies. Similar increase in
oxygen saturation of water were also observed in studies on recultivation of ponds. After the dredging, oxygen content increased, which corresponded with an increase in the number of fish. Study results indicated that recultivation works may change the structure of fish communities as a result of changes in dissolved oxygen content, affected by changes in macrophyte cover [35].

Removal of bottom substrate (silt removal) mostly affects river habitats, as it is the substrate for a series of biological processes. It is also the substrate for plant roots and the habitat of multiple organisms, including fish [8]. Dredging of river bottom may cause the addition of particulate and sand suspensions deposited, in the lower course of the river.

Dredging works are controversial and their impact on living organisms is huge. In studies by Dabkowski et al. [36], once the river was dredged the population and species diversity of beetles were significantly reduced. In addition, the composition and structure were strongly affected. However, the number and diversity of species quickly increased and restored within a half a year. Water flow had a very strong effect on restoration of beetle population [36]. In other studies, some species of caddis fly (Brachycentrus subnubilus and Lepidostoma hirtum) disappeared form dredged sections of the river, replaced by significantly more new species, of typically riparian nature. Such substitution of species may be connected with changes in habitats and uncovering larges areas of sandy bottom once the silt was removed [37]. Also in studies of macroinvertebrates, groups of dragonflies were destroyed after dredging works, but began to restore quickly. Multiple biocenotic indices reached high values as soon as six months after the dredging [38].

In the case of fish dredging of river bottom caused movement of fish due to noise emitted by dredging machine, also increasing the mortality rate among young fish. Contamination effect of removed silt had, however, higher impact than noise form dredging works. Studies demonstrated that the most exposed were early development forms of fish, such as eggs and larvae [39]. Studies by Brysiewicz and Czerniejewski [8] also demonstrated that the impact of maintenance works on changes to composition of ichthyofauna is huge. It is probably due to movements of fish in the river in the course of dredging works and avoidance of resulting adverse conditions, and their gradual return to previously occupied habitats [8]. Rivers subjected to maintenance works in forests also showed degraded fish habitats as compared to new ecosystems [40].

According to Smith et al. [34], despite increase in phosphorus concentration in water, dredging is a necessary management tool to ensure adequate drainage of water from adjacent fields. On the other hand, regulation may cause multiple, larger or smaller, adverse effects to river and river valley environment. Thorough determination of specific river morphology and condition in its natural environment should be the starting point for implementation of adequate regulation works. Rivers are characterised by high variability and dynamics of river bed and transport processes. Misguided maintenance works may cause adverse hydraulic effects (e.g. lowering of water level), morphological effects (e.g. river bed erosion), ecological effects (e.g. degradation of river bed biotopes, changes in vegetation) in regulated sections [41].

As stated by Baczyk et al. [41] the analysis of 203 cases of maintenance work on river ecosystems demonstrated that in 96 % cases the observed effects of silt removal, plant removal or other works performed in river beds, adversely impacted species composition of fish, macrophytes, macrozoobenthos and water quality were adverse. Mowing and removal of vegetation, as a maintenance measure, directly affects the functioning of buffer, while
indirectly affecting hydrochemical parameters of water (increased eutrophication) and habitats of invertebrates and fish in the water course [42, 43].

However, also the positive effects of regulation works have to be mentioned. Mowing off of vegetation during a year may be a form of control over the invasive species of plants. In times of draught, removal of plants from extremely transformed small rivers may be temporarily necessary (especially in lowlands) to maintain the level and flow of water, while keeping unregulated sections to promote periodic retention of water and reduction in water flow to the sea.

**Conclusion**

Our study demonstrates that maintenance works performed on small rivers affect hydrological and hydrochemical properties of waters. On one hand, the increase in oxygen content in water improved environmental conditions, providing better oxygen conditions for heterotrophic organisms inhabiting these river sections. On the other hand, the increase in biogenic content, probably released from the bottom during regulation works, interfered with ammonification, nitrification and denitrification processes in water. It is assumed that aforementioned changes shall affect aquatic animal and plant species composition inhabiting these river sections. However, maintenance works are often necessary in degraded and strongly eutrophic sections of rivers. As confirmed by studies, their effect to water quality, and thus to habitat conditions of plants and animals, is significant, and therefore any decision on silt removal should be taken on reasonable grounds and supported by findings from prior environmental monitoring.

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**References**

[1] Williams P, Whitfield M, Biggs J, Bray S, Fox G, Nicolet P, et al. Comparative biodiversity of rivers, streams, ditches and ponds in an agricultural landscape in Southern England. Biol Conserv. 2004;115:329-41. DOI: 10.1016/S0006-3207(03)00153-8.

[2] Bezuidenhout J, Nekhoroshkov P, Zinicovscaia I, Yushin N, Frontasyeva M. Accumulation features of micro and macroelements in indigenous and alien molluscs in Saldanha Bay, South Africa. Ecol Chem Eng S. 2021;27(4):495-508. DOI: 10.2478/eces-2020-0030.

[3] Nilsson C, Jansson R, Malmqvist B, Naiman R. Restoring riverine landscapes: the challenge of identifying priorities, reference states, and techniques. Ecol Society. 2007;12(1). Available from: http://www.jstor.org/stable/26267827.

[4] Oz N, Topal B, Uzun HI. Prediction of water quality in Riva River watershed. Ecol Chem Eng S. 2019;26(4):727-42. DOI: 10.1515/eces-2019-0051.

[5] Naiman RJ, Bunn SE, Nilsson C, Petts GE, Pinay G, Thompson LC. Legitimizing fluvial ecosystems as users of water: an overview. Environ Manage. 2002;30:455-67. DOI: 10.1007/s00267-002-2734-3.

[6] Oppeltová P, Boráková J. Monitoring of basic physicochemical parameters in the flow and their possible influence on the quality of the small water source. J Water Land Develop. 2020;44:106-17. DOI: 10.24425/jwld.2019.127051.

[7] Li S, Gu S, Liu W, Han H, Zhang Q. Water quality in relation to land use and land cover in the upper Han River Basin, China. Catena. 2014;75(2):216-22. DOI: 10.1016/j.catena.2008.06.005.
Brysiewicz A, Czerniejewski P. The effect of maintenance works on ichthyofauna in the context of hydrochemical conditions of small watercourses of central and north-western Poland. J Ecol Eng. 2019;20(8):82-9. DOI: 10.12911/22998993/110814.

Jędrzyk E. Needs of work management connected with conservation of surface water and water facilities at restoration areas. Infrastruktura Ekologia Terenów Wiejskich. 2006;4(2):43-50. Available from: http://www.infraeco.pl/pl/art/a_14991.htm.

Obeta MCh. Private for-profit rural water supply in Nigeria: Policy constraints and options for improved performance. J Water Land Develop. 2019;41:101-10. DOI: 10.2478/jwld-2019-0033.

Naiman RJ, Bechtold JS, Drake DC, Latterell JJ, O’Keefe TC, Balian EV. Origins, Patterns, and Importance of Heterogeneity in Riparian Systems. In: Lovett GM, Turner MG, Jones CG, Weathers KC. Editors. Ecosystem Function in Heterogeneous Landscapes. 2005;279-309. New York, NY: Springer; 2005. DOI: 10.1007/0-387-24091-8_14.

Downs PW, Dusterhoff SR, Sears WA. Reach-scale channel sensitivity to multiple human activities and natural events: Lower Santa Clara River, California, USA. Geomorphology. 2013;189:61-8. DOI: 10.1016/j.geomorph.2013.01.023.

Hachol J, Bondar-Nowakowska E. Tendencies in the development of hydromacrophytes after the completion of regulatory and maintenance works in a river bed. Ecol Chem Eng A. 2012;19(9):997-1013. DOI: 10.2428/ecea.2012.19(09)096.

Aldridge DC. The impacts of dredging and weed cutting on a population of freshwater mussels (Bivalvia: Unionidae). Biol Conserv. 2000;95:247-57. DOI: 10.1016/S0006-3207(00)00045-8.

Ochs K, Rivas RP, Ferreira T, Egge G. Flow management to control excessive growth of macrophytes - an assessment based on habitat suitability modeling. Front Plant Sci. 2018;9:356-67. DOI: 10.3389/fpls.2018.00356.

Bellezza M, Nasini L, Casadei S, Standardi A. Watercourse maintenance: a look at the plants and hydrology of a case study on the Tiber River. River Basin Management III. WIT Press. WIT Transactions on Ecology and the Environment. 2005;83:443-53. Available from: www.witpress.com.

Hachol J, Hämmerling M, Bondar-Nowakowska E. Applying the analytical hierarchy process (AHP) into the effects assessment of river training works. J Water Land Develop. 2017;35:63-72. DOI: 10.1515/jwld-2017-0069.

Petkovska V, Urbaniček G. Links between morphological parameters and benthic invertebrate assemblages, and general implications for hydromorphological river management. Ecolhydrology. 2015;8:67-82. DOI: 10.1002/eco.1489.

Vaughan IP, Diamond M, Gurnell AM, Hall KA, Jenkins A, Milner NJ, et al. Integrating ecology with hydromorphology: a priority for river science and management. Aquat Conserv: Marine Freshwater Ecosyst. 2009;19(1):113-25. DOI: 10.1002/aqc.895.

Mazerolle MJ. Drainage ditches facilitate frog movements in a hostile landscape. Landscape Ecol. 2006;20:579-90. DOI: 10.1007/s10980-004-3977-6.

Davies B, Biggs J, Williams P, Whitfield M, Nicolet P, Sear D, et al. Comparative biodiversity of aquatic habitats in the European agricultural landscape. Agric Ecosyst Environ. 2008;125:1-8. DOI: 10.1016/j.agee.2007.10.006.

Feld CL, De Bello F, Dolédec S. Biodiversity of traits and species both show weak responses to hydromorphological alteration in lowland river macroinvertebrates. Freshwater Biol. 2014;59:233-48. DOI: 10.1111/fwb.12260.

Haidekker A, Herding D. Relationship between benthic insects (Ephemeroptera, Plecoptera, Coleoptera, Trichoptera) and temperature in small and medium-sized streams in Germany: A multivariate study. Aquat Ecol. 2008;42:463-81. DOI: 10.1007/s1052-0-07-9097-z.

Dvurechenskaya SYa, Yermolaeva NL. Interrelations between chemical composition of water and characteristics of zooplankton in the Novosibirsk Reservoir. Contemp Probl Ecol. 2014;7:465-73. DOI: 10.1134/S1995425514040039.

Rajfur M. Algae - heavy metals biosorbent. Ecol Chem Eng S. 2013;20(1):23-40. DOI: 10.2478/ececs-2013-0002.

Barr etto MG, Uieda VS. Influence of the abiotic factors on the ichthyofauna composition in different orders stretches of Capivara River, São Paulo State, Brazil. Verh Internat Verein Limnol. 1998;26:2180-3. DOI: 10.1080/03680770.1995.11901132.

Cohen Y, Cohen JY. Statistics and Data with R. An Applied Approach Through Examples. The Atrium, Southern Gate, Chichester, West Sussex: Wiley; 2008. ISBN: 9780470758052.

Marques de Sa J, Joaquim P. Applied Statistics Using SPSS, STATISTICA, MATLAB and R. Berlin Heidelberg New York: Springer; 2007. ISBN: 9783540719717.
The effect of maintenance works to physical and chemical conditions of small rivers in agricultural areas

[29] Brysiewicz A, Bonisławka M, Czerniejewski P, Kierasiński B. Quality analysis of waters from selected small watercourses within the river basins of Odra river and Wisła river. Annual Set Environ Protection. 2019;21:1202-16. https://ros.edu.pl/images/roczniki/2019/072_ROS_V21_R2019.pdf.

[30] Meybeck M. The global change of continental aquatic systems: dominant impacts of human activities. Water Sci Technol. 2004;49(7):73-83. DOI:10.2166/wst.2004.0420.

[31] Rabalais NN. Nitrogen in aquatic ecosystems. Ambio: J Human Environment. 2002;31(2):102-112. DOI:10.1579/0044-7447-31.2.102.

[32] Obolowski K, Osadowski Z, Miler M. Sposoby renaturyzacji małych cieków na przykładzie rzeki Kwaczy [Dolina Slupi] (Renaturation methods for small river basins in the example of the Kwacza River [Slupia River basin]). Nauka Przyr Technol. 2009;3(3):1-11. http://www.npt.up-poznan.net/pub/art_3_95.pdf.

[33] Moore M, Locke MA, Jenkins M, Steinriede RW, McChesney DS. Dredging effects on selected nutrient concentrations and ecoenzymatic activity in two drainage ditch sediments in the lower Mississippi River Valley. Int Soil Water Conserv Res. 2017;5(3):190-5. DOI: 10.1016/j.iswcr.2017.06.004.

[34] Smith DR, Warnemuende EA, Haggard BE, Huang C. Dredging of drainage ditches increases short term transport of soluble phosphorus. J Environ Quality. 2006;35(2):611-6. DOI: 10.2134/jeq2005.0301.

[35] Mitsuo Y, Tsonodab H, Kozawac G, Yuma M. Response of the fish assemblage structure in a small farm pond to management dredging operations. Agric Ecosyst Environ. 2014;188:93-6. DOI: 10.1016/j.agee.2014.02.015.

[36] Dąbkowski P, Buczyński P, Zawal A, Stępień E, Buczyńska E, Stryjecki R, et al. The impact of dredging of a small lowland river on water beetle fauna (Coleoptera). J Limnol. 2016;75(3):472-87. DOI: 10.4081/jlimnol.2016.1270.

[37] Zawal A, Czachorowski S, Stępień E, Buczyńska E, Szlauer-Łukaszewska A, Buczyński P, et al. Early post-dredging recolonization of caddisflies (Insecta: Trichoptera) in a small lowland river (NW Poland). Limnologica. 2016;46:71-85. DOI: 10.1016/j.limno.2013.12.004.

[38] Buczyński P, Zawal A, Buczyńska E, Stępień E, Dąbkowski P, Michański G, et al. Early recolonization of a dredged lowland river by dragonflies (Insecta: Odonata). Knowl Manage Aquat Ecosyst. 2016;417(43):1-11. DOI: 10.1051/kmae/2016030.

[39] Wenger AS, Harvey E, Wilson S, Rawson C, Newman SJ, Clarke D, et al. A critical analysis of the direct effects of dredging on fish. Fish Fisheries. 2017;18:967-85. DOI: 10.1111/faf.12218.

[40] Rosenvald R, Järvekülg R, Lõhmus A. Fish assemblages in forest drainage ditches: Degraded small stream or novel habitats? Limnologica. 2014;46:37-44. DOI: 10.1016/j.limno.2013.12.004.

[41] 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 river management. Sci Tot Environ. 2018;627:189-99. DOI: 10.1016/j.scitotenv.2018.01.235.

[42] Bal KD, Meire P. The influence of macrophyte cutting on the hydraulic resistance of lowland rivers. J Aquat Plant Manage. 2009;47:65-68. Available from: https://www.apms.org/wp-content/uploads/japm-47-01-065.pdf.

[43] Clarke SJ. Conserving freshwater biodiversity: the value, status and management of high quality ditch systems. J Nature Conserv. 2015;224:93-100. DOI: 10.1016/j.jnc.2014.10.003.