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Editorial

Biodiversity and Ecosystem Services in Rivers

Alla Khosrovyan

Laboratory of Environmental Toxicology, National Institute of Chemical Physics and Biophysics, 23 Akadeemia tee, 12618 Tallinn, Estonia; alla.khosrovyan@kbfi.ee

1. Introduction

Rivers are complex networks of aquatic–terrestrial interactions where changes in one part (e.g., land use or pollution in the watershed) will soon or even immediately be reflected elsewhere (e.g., deterioration of riverine water quality). It has long been understood that to maintain good river water quality and quantity, an integrated approach involving planning and management of the whole river basin is needed [1]. Even in highly regulated rivers, continuous or even seasonal environmental flow releases can substantially improve or maintain biodiversity [2]. On the contrary, the mere declaration of a national park status for biodiversity conservation without recognizing the livelihoods and well-being of local communities depending on the area may not enable a well-meaning conservation effort to achieve its desired objective [3].

Rivers provide multiple ecosystem services such as drinking water, recreational activities, irrigation, and fisheries, and the role of rivers in supporting human activities is invaluable. However, anthropogenic pressure on rivers (such as channelizing rivers to divert water for human use) and the damming of rivers (for hydroelectric power generation) have already impacted river morphology and ecological integrity [4], destroying various habitats and reducing aquatic biodiversity. In addition, pollutant inflow from the watersheds, especially discharges from big cities or agricultural areas, substantially influences the chemical content of water and suspended sediments in given localities [5], inevitably affecting some of the river ecosystem services. More than half of the world's river basins, representing 40% of the world's continental surface and 37% of the world's river length, have experienced deep anthropogenic changes impacting fish biodiversity [6]. Meanwhile, biodiversity supports all types of ecosystem services, as it underpins all ecosystem processes [7,8].

Measures for the restoration of natural diversity in rivers have been actively explored and implemented in many countries. However, most river restoration projects have had limited success [9], and there is a need to consider the current state of a target river system to choose the right approach rather than developing solutions based on its historical state [4].

Water is the foundation of life. The categorization of water as a public, private, merit, or economic good undervalues the numerous services it provides [10]. A diverse (multidisciplinary), broad (inclusive for all stakeholders), responsive (addressing current situation and future trends) and scientific assessment of surface water quality with clear recommendations for practitioners, governmental agencies, and policy makers is perhaps imperative for preserving and improving riverine ecosystems and their services.

2. Main Messages of the Special Issue

Six articles were published in this collection addressing different aspects and means for the improvement of riverine ecosystem services.

Vardanyan et al. [11] investigated the possibility of fish egg incubation in a spawning river to increase the success of a trout restocking effort in Armenia. While millions of farm-raised smolts of trout are released into a lake, natural reproduction does not occur there. The authors investigated the success of incubating eggs (at different stages of development)

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in a selected spawning river, instead of releasing smolts into the lake. For comparison, a mesocosm experiment was conducted in fish farm conditions. The hatching rate of just-fertilized eggs was extremely low in the river's stretches (<10%), in contrast to the mesocosm condition (57%). The hatching of eyed eggs (black spot of the embryo eyes visible) varied from 5 to 80% in the river vs. 93% in the mesocosm. According to the authors, the incubation of eyed eggs in the spawning rivers can be a cheaper alternative to releasing the smolts into a lake; however, its effectiveness depends on the environmental conditions of the rivers. For example, in the middle and upper stretches of the study river, water temperature is very low or can even be frozen from mid-November. Apparently, this would make the natural reproduction of trout impossible.

Indeed, worldwide fish restocking is implemented as a means of fishery management. However, its effectiveness is difficult to assess [12]. Perhaps, for salmonids, which undertake home migration for spawning [13], egg transplantation in home rivers may be a prerequisite for successful reproduction in the future. However, the condition of spawning rivers (e.g., substrate availability, lack of contaminants, appropriate river flow) is another important factor influencing the success of restocking efforts. Further, poaching in the spawning rivers during spawning seriously undermines efforts to restock the lake [14]. Obviously, ecosystem management and conservation plans should carefully address the characteristics and limitations of a target area to successfully fulfill set objectives.

Bonnail et al. [15] addressed the cleanliness of wastewater discharges from textile industries. The textile industry is one of the main polluting sources of rivers and it is mixed with domestic wastewater before being processed and discharged. The authors investigated the physico-chemical characteristics of the fluid and solid waste of the effluents from synthetic and natural fiber manufacturing facilities after the application of an innovative purification technology. This technology is based on evaporation and crystallization processes conducted in one step under adiabatic conditions (ASE&C) (World International Patent Organization EP3135635). After treatment, the fluid from several synthetic and natural fiber manufacturing facilities was similar to distilled water, with electrical conductivity < 20 μS cm^{-1} (vs. initial 2000–11,390 μS cm^{-1}) and total suspended solids <10 mg L^{-1} (vs. initial 2000–8950 mg L^{-1}). Metal concentration was also substantially reduced, or metals were completely removed from the fluid. From the solid waste after treatment, 71–99% of the content was sulfur and around 75% consisted of light elements (H, He, Li, Be, B, C, N, O, F, Na). The authors presented a waste revalorization analysis which compares the water use reduction after the ASE&C treatment, equivalent to 103 and 16 Olympic pools in the synthetic and natural fiber manufacturing facilities, respectively. For the same facilities, the value of recovered metals from the solid waste could amount to USD 62,000 and 275,000 annually, respectively. Another element of high commercial value in the solid waste is sulfur, which comprises 46–99% of the waste from synthetic fiber production. Indeed, waste reuse and the sustainable use of primary resources is at the heart of the European Union's circular economy strategy adopted in 2023. As such, the installation of promising cleaning technologies at highly or even low-polluting industrial facilities and further use of the produced waste, whenever possible, would perhaps better protect our environment by reducing the release of harmful waste at the source and allowing the reuse/recycling of the waste.

Dallakyan et al. [16] used the DNA barcoding method for the determination of the diversity of freshwater gammarids (amphipods). While the gammarids are one of the most important animals in temperate freshwater ecosystems, the taxonomic identification of the *Gammarus* spp. is difficult and so is the quantification of their diversity. According to the authors, four to six well-defined molecular operational taxonomic units within three distinct morphospecies clusters were identified in several rivers in Armenia. Five new unique Barcode Index Numbers were identified and included in the Barcode of Life Data Systems. Indeed, molecular techniques are used worldwide for monitoring, characterizing, and conserving biodiversity. Biodiversity is influenced by genetic diversity and the analysis of genetic diversity via marker genes helps us to understand species' adaptive potential [17]. Genetic information also demonstrates the history of populations and allows for estimating populations' structure [18] or identifying targets for biodiversity conservation planning, such as managing small populations or restoring genetic diversity in specific populations [19].

Blumfelde et al. [20] investigated the potential toxicity of landfill leachate in terms of the spread of antibiotic resistance genes (ARG). According to the authors, the pharmaceuticals ibuprofen and diclofenac were found in the highest concentrations in all Latvian study dumpsites: a mature dumpsite (operation closed for 13 years before the sampling time), a young dumpsite (in operation since 2015), and a leachate collection pond (from both dumpsites). While the number and composition of specific ARGs varied among the study sites, in total, 80 ARGs (known for resistance against 19 different classes of antibiotics) were found. If a sterile leachate was used for the exposure of the bacterium *Pseudomonas putida* MSCL650, a decrease in the minimum inhibitory concentrations or even total inhibition of cells for several antibiotics was found. Indeed, bacterial resistance to antibiotics increases as a consequence of natural selection and genetic mutation; when these mutations are passed transgenerationally, they confer resistance [21]. As leachate is a by-product of a dumpsite generated from rainwater percolation through the disposed solid waste [22], it represents a hazard for surface- and groundwater and may pose a risk of pollutant and ARG dissemination. As such, the European One Health Action Plan against antimicrobial resistance 2017 delineated support for both the development of new antimicrobials and alternative products and research into development of new economic models for ensuring the restricted (responsible) use of new products to minimize the risk of resistance development.

Khosrovyan et al. [23] investigated the genotoxic potential of harmful algal blooms (HABs) using two *Tradescantia*-based tests-stamen hair mutation (Trad-SHM) and micronuclei (Trad-MN). Algal blooms can occur in standing and lotic water systems (lakes, slow-moving rivers) and can be triggered by both natural and anthropogenic factors. HABs are accompanied by the release of toxins which are harmful to humans and animals. According to the authors, in a HAB event in 2020 in Lake Sevan (Armenia), mutations in *Tradescantia* stamen hair, the presence of dwarf hair, and chromosomal aberrations during microsporogenesis (appearance of micronuclei) could be caused by several toxic algae such as green alga *Botryococcus braunii* and the cyanobacterial species Anabaena, *Oscillatoria, Phormidium* and *Aphanothece*. In contrast, the proliferation of diatom Bacillariophyta species in spring did not trigger genotoxic responses in the plant. Interestingly, the regularly monitored chemical parameters in the study area corresponded to the "good water" classification, according to the national norms of surface water quality. Indeed, ecotoxicological effects can be observed at levels far below those which were predicted to be safe by regulatory frameworks [24]. Further, a mixture of chemicals can be more toxic due to the synergistic effect of individual chemicals [25]. Finally, it is not possible to regulate all types of contaminants. Therefore, ecotoxicological assessment should apparently become a necessary component of the environmental assessment and monitoring as it improves the assessment of chemical risk when the chemicals are not regulated (e.g., emerging ones), not known, limited data are available on them (e.g., biotransformed chemical substances), or they occur at low concentrations (below instrumental detection limit). However, exposure assessments conducted in different environmental compartments (e.g., water, soil, air) may be costly [26]. Therefore, cheaper, more effective, and faster testing methods may come into play for environmental monitoring purposes such as Tradescantia-based test systems. Trad-MCN can effectively assess genotoxicity even at low concentrations of chemicals [27,28] and even when the concentrations of target elements are below regulatory norms [29].

Bonnail et al. [30] compared the effectiveness of two remediation technologies for the recovery of riverine water affected by mine drainage, a highly acidic lixiviate with metal, metalloid, and sulfate contents which occurs as a result of natural processes or mining activities. The effectiveness of the new disruptive technology (based on evaporation and crystallization under adiabatic conditions—ASE&C) was compared with that of passive remediation (dispersed alkaline substrate—DAS). Both technologies effectively removed contaminants (>90%) from the riverine water which was collected in different areas of the Iberian Pyrite Belt (Spain). However, the new technology is more efficient and convenient in terms of lower time and land use. In addition, while DAS technology produces recovered water that fulfills the international regulation guidelines to restore the impacted aquatic ecosystems, the ASE&C allows the recovery of water of distilled water grade. Indeed, aquatic and terrestrial pollution is a worldwide issue and the remediation of polluted ecosystems is continuously attracting the attention of scientists. While bioremediation strategies effectively remove contaminants [31], there exists a number of limitations to their use: space availability, increased toxicity due to unfavorable biochemical conversions in microorganisms, and regulatory factors related to the use of genetically engineered microorganisms [32]. The effectiveness of eco-engineered solutions such as constructed wetlands also often depend on local weather conditions and water composition [33]. In this regard, solutions based on physical processes (such as ASE&C), especially if they can be applied before the release of contaminants to natural systems, may provide certain advantages and ensure uninterrupted ecosystem services for humans.

3. Conclusions

This collection addressed different aspects of improvement of river ecosystem services, varying from risk assessment methods to the application of new purification technology. The biodiversity of a natural ecosystem is a mechanism by which the health of an ecosystem is sustained and the ecosystem delivers all expected benefits to humans. As such, biodiversity is a driver of ecosystem services. Obviously, for good ecosystem management, interdisciplinary approaches are needed to:

(i) understand the characteristics of the physical and biological processes occurring in the ecosystem;
(ii) have a means for the assessment of threats to an ecosystem's residents and to humans benefiting from it;
(iii) quantify and valuate natural resources;
(iv) incorporate the interests of all stakeholders into conservation planning;
(v) account for future trends (natural, e.g., climate warming or technological, e.g., innovations);
(vi) obtain support from appropriate authorities for the proper implementation of management objectives.

Although not without trade-offs among ecosystem services during decision making, concerns raised by specialists from various disciplines help to delineate safety boundaries for the implementation of any decisions and/or identify thresholds after which the future cost of the recovery of natural ecosystems may offset the benefits received today.

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