New Insights into Impacts of Toxic Metals in Aquatic Environments

Elise David, Claudia Cosio

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Editorial

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Elise David * and **Claudia Cosio**

Université Reims Champagne Ardenne, UMR-I 02 SEBIO, 51100 Reims, France; claudia.cosio@univ-reims.fr
* Correspondence: elise.david@univ-reims.fr

Chemical contamination of the aquatic environment, as a consequence of anthropogenic activities, remains of major worldwide concern. Among the most ubiquitous environmental contaminants, metals have been historically and widely studied. Numerous studies documented their discharge, concentration, speciation, bioavailability, and their interactions with biota including exposure, bioaccumulation, and toxicity. Despite regulatory initiatives, toxic metals still represent an important threat to aquatic ecosystems. The development of new technologies created new sources of metals, such as those emerging from the use of metallic nanoparticles or tetravalent metals, for instance. If extensive literature on metal effects on the environment is available, knowledge acquisition is still required to efficiently face these concerns, considering effects of metals at different levels of organization, from cellular targets to ecosystems. The aims of those further investigations are to develop scientific and operational tools to better monitor the quality of aquatic environment, and assess environmental risk.

This Special Issue provides new perspective on the toxicity of metals to aquatic organisms, from freshwater and marine environments. Five papers were selected as highly relevant studies addressing important questions in metal ecotoxicology and environmental biomonitoring. Beyond the summary of new insights on toxicity mechanisms of metals, these papers share some new ideas relative to cocktail effects of metal-containing mixtures, toxicity of metals on communities, and effect threshold definitions as tools for environmental risk assessment.

Metal impacts on aquatic organisms have been documented for years at different levels of biological organization. Here, Le Saux et al. [1] present a review of the cellular responses to toxic metals in freshwater and marine animals. Common cellular and molecular responses involving reactive oxygen species (ROS) production are identified. Then authors present a summary of the literature information concerning metal effects on different biomarkers of stress response, with a particular focus on stress proteins, redox homeostasis, cytoskeleton rearrangement, metabolism reshuffle, cellular energy and mitochondrial metabolism, and immunity [1]. This review highlights promising endpoints, that contribute to specifying molecular and cellular toxicity pathways, identifying early and sensitive tools of detection, and anticipating the impact of environmental metal pollution, notably when used in multi-biomarker approaches [1].

A second review by Li et al. [2] describes published data on effects of metallic pollutants in mixtures with engineered nanoparticles (ENP) on aquatic biota, from microorganisms to fish. New contaminants, that are increasingly released in environment due to new technologies, may interact with metals and subsequently modify their toxicity mechanisms on aquatic organisms. In this context, metal-containing ENP and their interaction with metal pollutants are of particular relevance. These interactions may have consequences on organisms' exposure, metal bioavailability, bioaccumulation, and toxicity [2].

In their review, Li et al. [2] highlight the importance of cocktail effects in risk assessment of metal toxicity. ENP affect exposure to metals when metallic pollutants are adsorbed

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Citation: David, E.; Cosio, C. New Insights into Impacts of Toxic Metals in Aquatic Environments. *Environments* **2021**, *8*, 1. https://doi.org/environments8010001

Received: 15 December 2020
Accepted: 24 December 2020
Published: 30 December 2020

on them. Toxicity of mixtures of ENP and metallic pollutants is also discussed, and a comparison is made between ENP that have no effect, an enhancing effect, or a reducing effect on metal toxicity. To summarize, ENP may affect the entry of pollutants, bioavailability, bioaccumulation, and injury caused by pollutant if membrane integrity, cell permeability, subcellular metal distribution, or metabolism is modified. Finally, Li et al. [2] propose different scenarios of bioaccumulation and toxicity outcomes in ENP-metals co-exposed "particle-proof" and "particle-ingestive" organisms [2].

Cocktail effects are also considered by Vivien et al. [3] who used oligochaete metrics to propose relevant tools to assess sediment quality. They integrated a large in situ data set of eight metallic pollutants in sediment and oligochaete metrics. They showed that individual pollutant concentrations may fail in explaining oligochaete community alterations, and that sediment quality monitoring must consider interactions between contaminants and with environmental factors that modify their bioavailability and toxicity (depending on speciation, synergism, antagonism) [3].

If effects of many toxic metals have been documented at individual and sub-individual levels, data concerning higher scales such as community level remains less frequent. In their study, Vivien et al. [3] address this topic, considering oligochaete indices to evaluate toxicity of stream sediments. An important data set, based on ten years of investigation on dozens of stream sites, allows confirming the relevance of oligochaete community indices as tools for sediment quality assessment. Such in situ studies present some limitations due to both multi-stress conditions and interactions between contaminants. Nonetheless, oligochaete index metrics, percentage of tubificids without hair setae, and oligochaete density were highly correlated with the level of metal contaminants in sediment [3]. Authors emphasized the importance of considering a wide range of species with different levels of sensitivity to define relevant sediment quality standards.

Doose et al. [4] also dealt with effects of metals at the community level. They focused on periphyton algae and micromeiofauna to assess the toxicity of a tetravalent metal, zirconium (Zr), on freshwater organisms. Very few ecotoxicological studies report Zr effect on aquatic organisms, although Zr concentrations in environment may increase due to its industrial application. Here, authors exposed glass slides previously colonized with periphytic biofilm to environmental concentrations of Zr. They analyzed algal growth and micromeiofauna biodiversity and revealed that taxonomic structure of biofilms was altered by Zr exposure, through direct or indirect effects of the metal [4]. These results on biofilm community level suggest that the whole aquatic ecosystem structure and function may be affected [4].

Environmental risk assessment approaches require effect threshold definition. In their study of oligochaete indices to evaluate in situ stream sediments, Vivien et al. [3] updated previous data to propose effect thresholds for eight metal alone and in combination with other metals. Three thresholds were proposed as promising to define sediment quality: a threshold effect level (TEL: concentration below which the incidence effect was $\leq$10%), a probable effect level (PEL: concentration above which the percentage of samples with a biological impact on the oligochaete community was $\geq$90%), and a probable effect for the combined metals (sum of the ratios between the concentration of each metal and its corresponding PEL divided by the number of metals considered). Authors propose these thresholds to screen alteration of in situ communities [3].

Eventually, Belamy et al. [5] performed acute toxicity tests of cadmium (Cd), arsenic (As), aluminum (Al), but also sodium chloride, nitrates and orthophosphates in juveniles of the endangered species *Margaritifera margaritifera*, a freshwater pearl mussel. They applied modified standardized protocol to define toxicity thresholds (effective concentrations) for a watercourse, the Dronne River, where *M. margaritifera* population is known to be the largest in France. In this river, sediments contain As and Al, and pearl mussels are impacted by Cd. To preserve the Dronne population of *M. margaritifera*, juveniles are produced in rearing facilities and reintroduced in the field. Here, 16 to 22-month-old juveniles were exposed to metals in the laboratory for 96 h. Results allowed to determine toxicity thresholds that appeared higher than metal concentrations measured in the Dronne River. For instance, the ratio of toxicity threshold of as (96 h EC50) to its measured concentrations was greater than 3.6 for 17 month old juveniles. Tolerance was age-dependent with a higher sensitivity in younger juveniles. This study emphasizes the relevance of such an approach in risk assessment for sensitive species in the context of conservation.

Acknowledgments: The editors would like to thank all authors who participated in the Special Issue.

Conflicts of Interest: The authors declare no conflict of interest.

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