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Editorial: Biotechnological solutions to assess, monitor and remediate metal pollution in the marine environment

Sílvia C. Gonçalves[1*], Zhisong Cui[2] and K. Suresh Kumar[3]

[1]MARE – Marine and Environmental Sciences Centre, ESTM, Polytechnic Institute of Leiria, Peniche, Portugal, [2]Marine Bioresource and Environment Research Center, Key Laboratory of Marine Eco-Environmental Science and Technology, First Institute of Oceanography, Ministry of Natural Resources of China, Qingdao, China, [3]Department of Botany, University of Allahabad, Allahabad (Prayagraj), Uttar Pradesh, India

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EDITED AND REVIEWED BY
Wei Zhang,
Marine Bioproducts Cooperative Research Centre, Australia

*CORRESPONDENCE
Sílvia C. Gonçalves
scgoncalves@ipleiria.pt

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Editorial on the Research Topic
Biotechnological solutions to assess, monitor and remediate metal pollution in the marine environment

Colossal rise in human populations, industrialization and, increased human activities along coastal regions, have cumulatively caused an escalation in the presence of metals in marine environments. Although metals are naturally released in the oceans through weathering and leaching processes, their discharge has drastically increased due to anthropogenic activities (*e.g.* industrial discharge, wastewaters, agricultural effluents and fossil fuel combustion) making them pollutants of concern (Masindi and Muedi, 2018).

Metal toxicity has become an issue of great environmental concern since they are highly toxic (even at low concentrations) and persistent (Ali et al., 2021); they have an accumulative behaviour, especially in sediments, and a long-range transport via suspended particles. They either remain dissolved or suspended in the water column, and become bioavailable to be incorporated by organisms, thereby entering the food chains. Despite the several attempts to circumscribe and contain metal contamination studied and suggested so far, the enormity of this issue seems to outrun the remediation measures. There is an imperative need to restore the ecological balance of ecosystems, by providing effective counter measures for remediation of metals in the marine environment.

Environmental biotechnology provides pivotal tools for assessing, monitoring, remediating, and mitigating the adverse effects of metal pollution in the marine domain (Mishra et al., 2023). Several marine organisms, ranging from algae to plants and invertebrates to vertebrates, have metal sorption or metal accumulation abilities. They provide valuable information on the temporal and spatial variations of bioavailable metals within the marine environment. In fact, marine bacteria and fungi are considered suitable biosensors for metal toxicity measurements, for monitoring metal and for bioremediation processes; they often serve as metal detoxification agents. Bioremediation processes involving marine bacteria, fungi, algae and plants are efficient, eco-friendly and less expensive options of containing metal pollution as compared to conventional (chemical and physical) methods (Ojuederie and Babalola, 2017).

Marine biotechnological techniques addressing metal pollution have been developing over the course of time. Today, researchers have created several environmental applications-oriented processes that help combat metal pollution in the marine environment (Selvi et al., 2019). However, there is a restraint in applicability of certain processes and others are not widely popularized. In this context, our Research Topic aimed to bring together the most recent biotechnological approaches, tools and solutions that may assist in the assessment, monitoring, detoxification and remediation of metals in marine environments.

Liang et al. assessed the distribution of several trace metals (Zn, Cd, Co, Pb and Cr) in seawater at the NE coast of China for two consecutive summer seasons, also performing an ecological health risk assessment. The authors found that the spatial distribution of the trace metals was influenced by the combined influences of physical, chemical and biological processes, at the regional and local scales. Local sources such as aquacultures, riverine inputs and the Lubei coastal current had a significant influence. In their region of study, the major contaminating metals were Zn and Pb.

Along the same coastline of China, Wang et al. used 12 marine fish species collected on the Liaodong Bay, between 2015 and 2020, as potential bioindicators of contamination by metals (Cd, Cr, Cu, Ni, Pb and Zn). They evaluated the health risks of consumption of these fish by humans. In some of the studied species, Pb and Cd concentrations were high, exceeding the maximum permissible concentrations in edible fish. *Enedrias fangi*, *Cynoglossus robustus*, *Scomberomorus niphonius*, *Platycephalus indicus* and *Acanthogobius hasta*, which differed in their habitats and feeding strategies, were identified by the authors as good bioindicators of metal contamination.

The concentration, bioaccumulation and effects of the rare earth elements (REEs) or lanthanides in marine ecosystems was investigated by Neira et al. They studied a group of far less studied metals that are of increasing use in modern technologies. Higher concentrations were found in coastal waters as opposed to ocean waters, because of the continental origin of these elements. REEs are bioaccumulated in marine organisms but biomagnification along trophic levels has not yet been observed. The authors propose that future research should be focused on the individual fractionation of the different REEs, on the processes which transform these elements and render them bioavailable in marine environments, and on their possible detrimental effects to the marine organisms.

Under laboratory conditions, Cong et al. analysed the single and combined toxic and chronic effects of the exposure to different concentrations of Cd and polystyrene (PS) microspheres on the polychaete *Perinereis aibuhitensis*, as well as the bioaccumulation of Cd obtained after exposure. Their results demonstrated that the burrowing time of worms exposed to the lowest concentration of Cd decreased significantly and, when combined with exposure to PS, the endpoint response was prolonged. Cd body burdens were highest in the combined treatments at low and medium Cd concentrations. Epidermal and intestinal lesions were also observed for the single and combined exposures to both pollutants, highlighting the need to further explore the interactions and toxicities between metals and microplastics on marine benthic dwellers.

At the deep seafloor from the Arctic Ocean, Soltwedel et al. assessed the impact of local iron enrichment on the small benthic biota, due to the presence of corroding steel structures associated to a bottom-lander lying on the seabed. The authors found strong negative effects on the community's diversity, as well as on the bacterial and meiofaunal densities and biomasses at the iron-enriched sediments as compared to the unaffected sediments. They observed that specialized iron oxidizers and other chemolithoautotrophic bacteria were well established members of the community on the iron-enriched sediments, while rare or absent on the unaffected ones.

In sediment microcosms and transferred enrichment cultures, Wang et al. investigated the impact of heavy metal ions (Zn^{2+}, Cu^{2+}, Cd^{2+}) on microbial reductive dechlorination of 1,2-dichloroethane and tetrachloroethene, crucial for organohalide-contaminated site cleanup. Their findings revealed nuanced effects, with Cd^{2+} having minor impacts compared to Zn^{2+} and Cu^{2+}. Notably, Zn^{2+} exhibited the highest inhibitory effect, followed by Cu^{2+}. The study unveils the influence of contaminants on microbial community structure and highlights the resilience of specific organohalide-respiring bacteria (*Dehalococcoides*, *Dehalogenimonas*) to heavy metal exposure. These insights are vital for shaping effective bioremediation strategies in co-contaminated environments.

Common polluting metals that are reported to cause environment hazard include arsenic, cadmium, chromium, copper, nickel, lead and mercury. Apart from pollution, these metals are often accumulated in organisms and transferred up the food chain, thereby causing health hazards. Monitoring, managing and remediating metals with integrated approaches has become essential with growing urbanization, agriculture, and industrialization. Although it is rather difficult to encapsulate the prominent use of various metals and considering the fact that they also could be of natural origin, it becomes essential that sombre awareness regarding metal toxicity be created. Over the time, several techniques have been developed to combat heavy metal pollution; these include physical, chemical remediation and biological remediation processes. However, the best way out of this problem is lessening the utility of metals and pretreatment.

Author contributions

SG: Conceptualization, Writing – original draft, Writing – review & editing. ZC: Writing – original draft, Writing – review & editing. KK: Writing – review & editing, Writing – original draft.

Conflict of interest

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