Study of the Ecotoxicological Effects of Metals from Scrubber Washwaters on Aquatic Biota

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Abstract. The maritime transport sector predominantly relies on fuel oil as the energy source for ships, leading to the emission of exhaust gases that comprise harmful substances, which could cause chronic toxicity (polycyclic aromatic hydrocarbons) and inherently persistent (heavy metals), posing substantial short and long-term risks to marine ecosystems. Exhaust Gas Cleaning Systems (EGCS), commonly referred to as scrubbers, play a crucial role in compliance with international maritime emissions regulations. While this technology effectively lowers SO_2 emissions, the environmental challenges related to the subsequent discharge of scrubber water containing the aforementioned harmful substances remain. This study investigates the toxicity of the most prevalent heavy metals in scrubber effluents: iron, vanadium, nickel, and zinc, using two key marine model organisms widely used in toxicity bioassays: *Artemia franciscana* and *Brachionus plicatilis*. The results indicate a marked sensitivity of these organisms to the evaluated metals, particularly in early developmental stages of *A. franciscana* (nauplii). The study reveals that vanadium and iron were the most toxic metals. Furthermore, the metal mixture showed higher toxicity than any individual metal, indicating significant effects and representing a potentially underestimated environmental risk.

Keywords: ecotoxicology, metals, environmental risk, scrubber washwater, EGCS.

1. Introduction

Emissions derived from the use of heavy fuels in maritime transport, such as fuel oil, can release sulfur oxides (SOx), nitrogen oxides (NOx), particulate matter, and black carbon into the atmosphere, causing negative effects on the environment, in addition to posing a risk to human health, especially in coastal communities (Lack & Corbett, 2012; Viana et al., 2014). The most widely implemented alternative by shipping companies to comply with the new limits enforced by the International Maritime Organization (IMO) under Annex VI of the MARPOL Convention has been the installation of exhaust gas cleaning systems, commonly known as scrubbers.

However, this technology introduces a new problem: the generation of effluents containing pollutants, which are discharged into the marine environment, especially in the case of open-loop systems (Turner et al., 2017). After washing exhaust gases, the washwaters generated by scrubbers contain residues of the contaminants present in these gases. These contaminants include heavy metals such as vanadium (V), nickel (Ni), zinc (Zn), iron (Fe), and copper (Cu), as well as polycyclic aromatic hydrocarbons (PAHs) (Turner et al., 2017).

Unlike many organic pollutants, metals do not easily degrade or transform, which allows them to bioaccumulate and biomagnify over time in benthic compartments and throughout the food chain (El-Sharkawy et al., 2025).

These metals not only pose a direct risk to marine biota but can also introduce structural and functional alterations in marine ecosystems, especially in port areas, where their dispersion is limited and their accumulation intensifies. Furthermore, the simultaneous combination of various metals, as occurs in scrubber washwaters, further complicates the prediction of toxic effects, as synergistic, antagonistic, or additive interactions can occur.

2. Material and methods

For the toxicity test, two widely used marine organisms were utilized: *Artemia franciscana* and *Brachionus plicatilis*. For *A. franciscana*, organisms at three developmental stages were used: nauplii, juveniles, and adults. The metals studied were vanadium (V), nickel (Ni), iron (Fe), and zinc (Zn), and a mixture of these four elements in different proportions, based on concentrations found in real scrubber washwaters. Mortality was measured after 48 hours of exposure, in order to calculate the LC50 for each metal and organism.

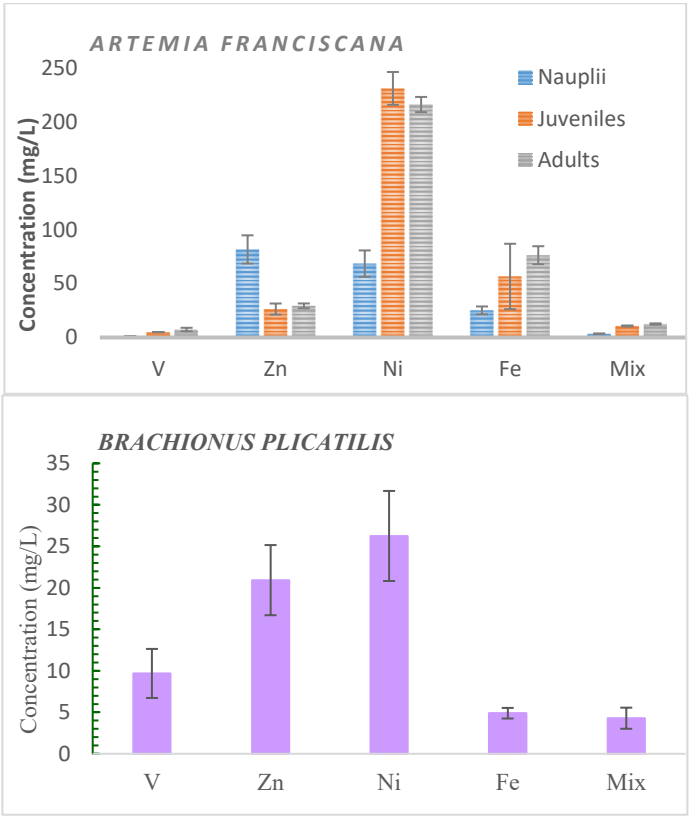

Figure 1. Graphical representation of LC50 results with their respective error bars for A) the three developmental stages of *A. franciscana* B) *B. plicatilis*.

3. Results and discussion

For *A. franciscana*, vanadium is confirmed as the most toxic metal in all cases, with very low LC_{50} values: 1.02 mg/L in nauplii, 4.94 mg/L in juveniles, and 7.38 mg/L in adults, demonstrating its high toxicity even at minimal concentrations. In contrast, nickel and zinc show notably lower toxicities. The metal mixture also shows high toxicity, with LC_{50} values of 3.43 mg/L in nauplii, 10.70 mg/L in juveniles, and 12.47 mg/L in adults, being more toxic than nickel, zinc, and iron individually. For *B. plicatilis*, the results for the four metals analyzed individually, as well as for their mixture, reveal differentiated toxicity. Nickel and zinc are the least toxic in this organism, with LC_{50} values of 26.25 mg/L and 20.93 mg/L, respectively. Conversely, iron presents the highest individual toxicity, with an LC_{50} of 4.89 mg/L, followed by vanadium, with 9.68 mg/L. However, the most significant result is that of the metal mixture, whose LC_{50} is 4.29 mg/L, even lower than that of iron alone, positioning it as the most toxic agent in this species.

4. Conclusion

This study demonstrates that the metal mixture generates greater toxicity than that of the individual metals. This is particularly relevant in the real environmental context, where organisms are exposed to combined, not isolated, contaminants. This phenomenon amplifies the ecological risk beyond what might be expected from the isolated behavior of the metals. The results of this research are expected to advance the knowledge regarding the ecotoxicological hazards of metals present in scrubber washwaters on marine organisms.

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