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# Levels of heavy metals in wetland and marine vascular plants and their biomonitoring potential: A comparative assessment

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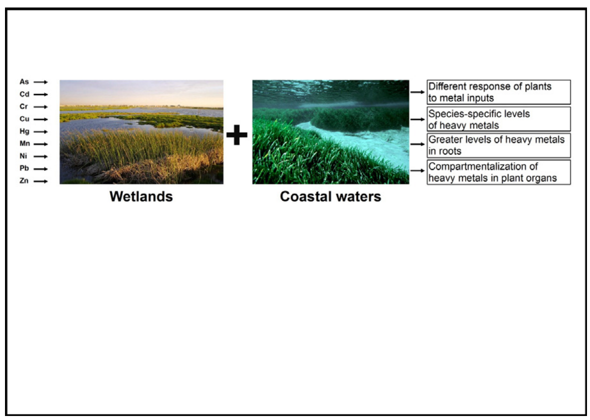
## HIGHLIGHTS

- Plants respond differently to metal inputs, despite similar ecology and anatomy.
- Bioaccumulation, internal translocation and bioindication are species-specific.
- Total metal concentrations are generally species-specific.
- Plants share high metal levels in roots and organ element compartmentalization.
- *P. australis* was the best bioaccumulator and bioindicator species.

## GRAPHICAL ABSTRACT

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## ABSTRACT

The present study investigated the levels of As, Cd, Cr, Cu, Hg, Mn, Ni, Pb and Zn in the seagrasses *Posidonia oceanica* and *Cymodocea nodosa*, and in the wetland macrophytes *Phragmites australis*, *Arundo donax*, *Typha domingensis*, *Apium nodiflorum*, and *Nasturtium officinale*. Results showed that the bioaccumulation capacity from sediments, translocation, total levels in plant tissues, and bioindication of metals in sediments, are generally species-specific. In particular, the patterns of metals in the aquatic plants studied were overall independent of ecology (coasts vs wetlands), biomass, anatomy (rhizomatous vs non rhizomatous plants), and life form (hemicrytophytes vs hydrophytes). However, marine phanerogams and wetland macrophytes shared some characteristics such as high levels of heavy metals in their below-ground organs, similar capacity of element translocation in the rhizosphere, compartmentalization of metals in the different plant organs, and potential as bioindicators of Cu, Mn and Zn levels in the substratum. In particular, the present findings indicate that, despite ecological and morphological similarities, different plant species tend to respond differently to exposure to heavy metals. Furthermore, this seems to result from the species individual ability to accumulate and detoxify the various metals rather than being attributed to differences in their ecological and morpho-anatomical characteristics.


## 1. Introduction

Heavy metals in air, soil and water have become a global issue as a consequence of the increasing human impact in the last few decades

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(Nriagu, 1996; Charlesworth et al., 2011). Because of their toxicity, accumulative and non-biodegradable nature, heavy metals are potentially hazardous to terrestrial and aquatic ecosystems, and thus to human and animal life (Tchounwou et al., 2012). Heavy metals are present in the environment as a result of natural sources and human activities (He et al., 2005; Li et al., 2009). In natural systems, heavy metals originate from rocks, ore minerals, volcanoes, and release of metals during weathering leading to soil formation (Szyczewski et al., 2009). On the other hand, anthropogenic causes of heavy metals are mostly related to urban development, generation of electricity, and the metal industry including mining, extraction, and refining processes (Alloway, 1995; Kabata-Pendias and Mukherjee, 2007; Norgate et al., 2007). Heavy metals are generally considered as inhibitors of life processes, although their inhibiting potential depends on several factors such as levels present, ability to form complexes, and degree of oxidation (Lin and Zhang, 1990; Szyczewski et al., 2009). Heavy metals fall within two basic categories: essential and non-essential. Essential metals or micronutrients, such as Cr, Co, Cu, Mn, Mo, Fe, Se and Zn, are necessary for the optimal functioning of biological and biochemical processes in organisms (including humans) that include redox reactions and formation of pigments and enzymes (Babula et al., 2008). In turn, non-essential metals, such as As (metalloid, strictly speaking), Cd, Hg, and Pb, have no known biological function and exert their toxicity by competing with essential elements for active enzyme or membrane protein sites (Torres et al., 2008). However, essential metals may also have detrimental effects to species and whole ecosystems when these are exposed to high levels (Nagajyoti et al., 2010).

Aquatic ecosystems, such as wetlands and coastal waters, are particularly vulnerable to heavy metal inputs (Mitsch and Gosselink, 2007; Halpern et al., 2008). The risks of heavy metal pollution are of great concern for the ecosystem services affected (Verhoeven et al., 2006), and also difficult to assess because of the elements complex behavior and interactions in aquatic ecosystems (Guilizzoni, 1991; Greger, 2004). Unlike most organic pollutants, indeed, heavy metals are typically not removed from aquatic ecosystems by natural processes (Bargagli, 1998). Once accumulated in bottom sediments, they begin to move up the food chain, often biomagnifying at higher trophic levels and ultimately causing potential disorders in humans and animals (Barwick and Maher, 2003; Roberts et al., 2008). Coastal ecosystems, in particular, are affected by a wide range of pollutants, among which heavy metals are particularly widespread and increasingly affecting marine habitats (Faganelli et al., 1997; Ralph et al., 2006; Boudouresque et al., 2009). Similarly, heavy metals may adversely affect the precarious stability of wetlands whose ecological importance for nutrient cycling and pollution control is widely recognized (Mitsch and Gosselink, 2007).

Plants have the ability to absorb all metals, especially those essential for their growth and development (Kabata-Pendias, 2011). Macrophytes, in particular, play a fundamental role in wetland geochemistry because they are the principal living accumulators of heavy metals through active and passive absorption (Vodyanitskii and Shoba, 2015). In terms of biomass, macrophytes are the predominant organisms in highly productive, littoral ecosystems, such as wetlands and shallow coastal areas (Brix and Schierup, 1989). Rooted macrophytes are also stationary and continuously exposed to contaminants such as metals (Jackson, 1998). Macrophytes, compared with other plant and animal species, have been reported to have a larger or similar capacity for metal accumulation (Jana, 1988; Albers and Camardese, 1993). Similarly, seagrasses have a high metal bioaccumulative capacity since they interact directly with both the water column (through the leaves) and the sediment pore water (through the roots), as both leaves and roots are sites of ionic uptake (Romero et al., 2006; Ralph et al., 2006). In particular, seagrasses contribute significantly to the primary production of aquatic ecosystems in the littoral zone, since they have a fundamental trophic role in aquatic ecosystems and an important link in the recycling of nutrients. Consequently, they can extract large amounts of metals from the environment (Kaldy, 2006).

Knowing patterns of metal levels in macrophytes, including seagrasses and wetland plants, and in sediments and soils, is important for ecological restoration, management and monitoring. In particular, knowing the relationship of a given plant species with specific heavy metals, may help implement tailored applications of ecological engineering aimed to regain the natural functions of impacted wetlands and coastal marine habitats. However, studies comparing the patterns of heavy metals between wetland and coastal marine vascular plants are generally lacking. For example, it is not clear yet whether wetland and marine ecosystems determine a different distribution of heavy metals in the respective primary producer species, and whether wetland and marine species have a similar capacity for heavy metals biomonitoring. The potential of metal uptake largely varies with plant species, and carrying out a comparative analysis between wetland and marine plant species may help identify general and specific patterns in species that differ ecologically and morphologically.

The marine phanerogam *Posidonia oceanica* (L.) Delile is an endemic Mediterranean species that forms dense communities (meadows), with bathymetric range of 0–40 m depth, widely distributed throughout the Mediterranean of which occupies c. 3% of its surface (c. 35,000 $km^2$) (IUCN, 2015). It is now well established that *P. oceanica* meadows hold a central position in the ecology of the Mediterranean being not only one of the most important contributors to coastal primary production but also acting as spawning areas, nurseries, and permanent habitats for numerous plant and animal species (Bay, 1984; Hemminga and Duarte, 2000). The marine phanerogam *Cymodocea nodosa* (Ucria) Asch., known as Lesser Neptune Grass, is a coastal seagrass of tropical origin, nowadays restricted to the Mediterranean Sea and some locations in the North Atlantic, from southern Portugal and Spain to Senegal, including the Canary Islands and Madeira (Green and Short, 2003; OSPAR, 2010). Generally, it forms monospecific meadows, and can be found in deep waters (40 m) (Mazzella et al., 1993). *C. nodosa* is considered a pioneer species that can quickly colonize bare areas of the sea floor, with its rhizomes growing several meters per years (Duarte and Sand-Jensen, 1990; Borum and Greve, 2004).

*Phragmites australis* (Cav.) Trin. ex Steud., *Arundo donax* L., and *Typha domingensis* Pers., are worldwide distributed emergent and partially submerged macrophytes. Such species are perennial herbaceous and rhizomatous plants that form dense monospecific stands in natural wetlands characterized by shallow and stagnant water, and muddy sediment (Pignatti, 1982). *P. australis* (common reed) is a large grass with stems up to 6 m, and can survive extreme environmental conditions, including high concentrations of toxic contaminants such as heavy metals (Batty and Younger, 2004; Bragato et al., 2009). *A. donax* (giant reed) is another perennial rhizomatous grass (Poaceae family), native to the freshwater regions of Eastern Asia but nowadays worldwide distributed (Quinn and Holt, 2008; Gordon et al., 2011). Able to reach the height of 8 m, *A. donax* is among the fastest growing terrestrial plants (Mirza et al., 2010). *T. domingensis* (southern cattail) is ecologically similar to *P. australis*, and can survive in highly contaminated sites (Maddison et al., 2009). *Apium nodiflorum* (L.) Lag. (fool's-watercress) and *Nasturtium officinale* W. T. Aiton (watercress) are two non-rhizomatous, herbaceous, and perennial plants, with a prostrate habitus (total height < 1 m), and preference for the stagnant waters of ponds, ditches and streams (Pignatti, 1982). Relatively few studies have focused on heavy metal concentrations in *A. nodiflorum* and *N. officinale* (Zurayk et al., 2001).

The main aim of the present work was to analyze the levels of As, Cd, Cr, Cu, Hg, Mn, Ni, Pb and Zn in sediments, in two Mediterranean seagrasses *P. oceanica* and *C. nodosa*, and in five common wetland plant species, *P. australis*, *A. donax*, *T. domingensis*, *A. nodiflorum* and *N. officinale*. The present study also aimed to shed further light on the role of ecology, biomass, anatomy and life form in influencing the levels of heavy metals in wetland and marine plants, and to assess the biomonitoring potential of the targeted species.