Evaluation of the Potential of Salt Marsh Plants for Metal Phytoremediation in Estuarine Environment

C. Marisa R. Almeida, A. Cristina Rocha, Ana P. Mucha and M. Teresa S. D. Vasconcelos

Abstract Constant discharge of pollutants into the environment, namely at salt marshes, poses a serious problem. Hence, remediation of these ecosystems is crucial not only for their conservation, but also to prevent the propagation of pollutants into the food web. Salt marsh plants have been suggested as suitable alternatives for soil/sediment remediation, having shown potential for the phytoremediation of metal-polluted media. However, more studies in conditions as close as possible to those found in the environment are needed to really confirm this potential; this is the aim of the two studies reported in this chapter. The first study results showed the capability of the salt marsh plant *Halimione portulacoides* for accumulating high metal levels from metal-polluted in its tissues, indicating, however, that a high plant biomass will be required for phytoremediating metal-affected areas. The second study results indicate that both *Juncus maritimus* and *Phragmites australis* have the capacity to be Cd phytostabilizers indicating that these plants can contribute to the recovery of impacted estuarine areas. More experiments should now be carried out to confirm the phytoremediation applicability in the estuarine environment and to assess ways to improve the capability shown by these plants for phytostabilization of metals.

Keywords Phytoremediation · Estuaries · Marsh plants · Metals

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C. M. R. Almeida (✉) · A. C. Rocha · A. P. Mucha · M. T. S. D. Vasconcelos
CIMAR/CIIMAR–Centro Interdisciplinar de Investigação Marinha e Ambiental, Universidade do Porto, Rua dos Bragas, 289 4050-123 Porto, Portugal
e-mail: calmeida@ciimar.up.pt

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1 Introduction

Salt marshes are ecosystems located between land and coastal environments. They are normally settled on intertidal areas of mud and sand flats, which were stabilized by vegetation, and which are submerged, during a certain period by daily tidal flow (Valiela et al. 2002). Being regarded in the past as "intertidal wastelands of little benefit to anyone" (Boorman 1999), the remarkable importance of salt marshes is nowadays widely recognized. Salt marshes present a relevant role in coastal defense and on wildlife conservation and are recognized as high productivity areas.

Salt marshes have been exploited by humans for centuries. However, the intensive and non-sustainable exploitation of these ecosystems, their conversion to cattle grazing, transportation routes, or for agricultural purposes, the construction of sea walls and, more recently, the rise in sea level are stress factors threatening the health of these ecosystems. Salt marshes provide a dynamic linkage between terrestrial and marine ecosystems, presenting the ability to change the nature of the adjoining ecosystems (Boorman 1999; Valiela et al. 2002). As a result, apart from wildlife conservation, biodiversity maintenance, and stabilization of shoreline, the protection of salt marshes is also crucial for the preservation of other ecosystems dependent on these intertidal areas with a view to maintain the environmental equilibrium.

In addition to being both sources and sinks of organic matter and nutrients, salt marshes also function as filters for land- and sea-derived pollutants, retaining them within their sediments (Carvalho et al. 2010; Almeida et al. 2011). Estuaries, especially those verging on urban centers, are transitory areas between land and sea environments, presenting a very exposed geographical position, and are frequently subjected to important loads of land- and sea-derived pollutants. Therefore, salt marshes accumulate pollutants in their sediments, a fact supported by an immense literature reporting the levels of different pollutants found on various salt marsh sediments. Studies have shown that, worldwide, salt marsh sediments are contaminated by metals such as Co, Cu, Cd, Zn, Ni, Pb, Cr, Fe, Mn, and As (Löser and Zehnsdorf 2002; Otero and Macías 2002; Fitzgerald et al. 2003; Weis and Weis 2004; Aksoy et al. 2005, Cambrollé et al. 2011). Portugal has evidence of the presence of varying concentrations of different metals in estuarine sediments of the Douro (Almeida et al. 2004; 2006a, b), Tagus (Caetano and Vale 2002; França et al. 2005; Caetano et al. 2007; Reboreda et al. 2008), Guadiana (Caetano et al. 2007, 2008), Lima (Almeida et al. 2011), Cávado, and Sado (Almeida et al. 2008a) Rivers have also been reported of having metal contamination, in most cases, attributed to anthropogenic pollution sources. Almeida and co-workers (2008a) reported levels of Cu, Zn, and Pb in Sado and Cávado estuaries above the ERL (effect range-low, that is the chemical concentration below which adverse effects would be rarely observed (MacDonald et al. 2000) which may pose a risk for the living organisms of the polluted ecosystem.

The constant discharge of pollutants into the environment, as a result of world industrialization and development, leads to anthropogenic contamination of salt marshes, thus posing serious threats to the ecological equilibrium and the surrounding media, and affecting the maintenance of such environments with its inhabiting fauna and flora. As consequence of the entry of pollutants into the food web, the deleterious effects of pollution may also affect the human population. Therefore, remediation of salt marsh sediments is crucial, not only for their conservation, but also to prevent the propagation of pollutants into the food web.

Inhabiting waterlogged, anoxic, and reduced environments as salt marsh sediments, salt marsh plants face serious challenges to cope with the environmental stresses to which they are exposed. For this purpose, salt marsh plant roots stimulate several biogeochemical changes on the surrounding sediment (rhizosediment) which is imperative for plant survival in such media and may represent pivotal features, among others, that make salt marsh plants a possible and efficient resource for phytoremediation purposes. Halophytes seem to present advantages over non-halophytic plants (Manousaki and Kalogerakis 2011) because they are able to survive and reproduce in salt-rich environments (owing to plants internal biophysicochemical mechanisms), a feature that may ensure their tolerance to other environmental stresses as metal contamination. For these reasons, halophytes represent a better choice over salt-sensitive plants when dealing with soil/sediment remediation.

As regards pollution by metals, the rates of metal uptake, allocation, and excretion are both plant species and metal-dependent. Salt marsh plants, in general, have been suggested as suitable alternatives for soil/sediment remediation, especially when considering harsh environments as contaminated sediments with high salinity (Manousaki and Kalogerakis 2011). The ability of salt marsh plants to take up and accumulate metals in their tissues as well as the specificities of different plants for this purpose is supported by a vast literature. For instance, *Spartina alterniflora* and *Phragmites australis* have been shown to present different patterns of metal allocation (Windham et al. 2003). Duman et al. (2007) reported that *Phragmites australis* and *Schoenoplectus lacustris* were both metal accumulators, concentrating metals mainly in their roots, but *Phragmites australis* presented higher ratios of root accumulation. Almeida and co-workers (2006b) reported that both *Juncus maritimus* and *Scirpus maritimus* were suitable Cd-phytostabilizers and the latter presented also a potential for Pb phytostabilization. Moreover, *Halimione portulacoides* has been emphasized as a more efficient metal accumulator than *Spartina maritima* since the former concentrated higher contents of metals in its roots and in its rhizosediments (Caçador et al. 2000). However, the same authors observed, in another study, that *Spartina maritima* was more efficient in stabilizing Cu and Cd than *Halimione portulacoides*, while the latter presented a higher potential to accumulate metals in the aboveground biomass, being more suitable for phytoextraction purposes (Reboreda and Caçador 2007). Considering the high root turnovers and cycling coefficients, *Spartina maritima* was also suggested as a phytostabilizer species for several metals by Duarte and co-workers (2010) and by Cambrollé et al. (2008, 2011). Despite being bioaccumulators of metals, *Spartina alterniflora* have shown to translocate metals more efficiently to the aboveground biomass while in *Phragmites australis*, metals were mainly concentrated in the roots and rhizomes (Weis and Weis 2004). Anjun and co-workers (2012) report that *P. australis* has enough potential to be used for mercury stabilization due to the high accumulation of this metal in its roots. On the other hand, Almeida et al. (2011) reported that, considering the biomass of each plant in a given salt marsh, significant metal burden can be observed not only in the belowground structures but also in the aboveground structures despite the low metal translocation observed in these plants.

The above-mentioned studies were carried out in the field and conclusions were drawn by analyzing exclusively natural metal burdens on both salt marsh plant tissues and sediments, in different environments with varied pollutant loads, which significantly influenced the obtained results. Studies in controlled laboratory conditions have also been conducted to ascertain the capability of salt marsh plants to uptake metals and contribute for their phytoremediation in estuarine areas. However, most of these studies were carried out in non-natural media, like in hydroponics (Reboredo 1991, 2001), perlite (Cambrollé et al. 2012a, b), or in a more natural but simplified medium like elutriate solutions (e.g., Almeida et al. 2008b). Therefore, additional studies in the natural environment or in controlled conditions that simulate the natural environment in the best way possible are needed to consolidate the knowledge on salt marsh potential to remediate metals in estuarine areas, either through phytostabilization or phytoextraction.

In this chapter are reported two studies that were carried out to ascertain the phytoremediation potential of salt marsh plants in natural or near-natural controlled conditions. The first study reports an ex situ experiment with *Halimione portulacoides*, in which the plant was transplanted into cylinder litterbags, with a sleeve form, filled with metal-polluted estuarine sediment and left in a cleaner estuarine area for a 9-month period. In the second study is reported a microcosm experiment with *Juncus maritimus* and *Phragmites australis* in which the plants together with the sediment surrounding their roots were collected, put in vessels, and subjected to Cd contamination. The vessels were subjected to natural light conditions, alternating between flooded and dry, similar to the tides in an estuary.

2 Phytoremediation Potential of *Halimione portulacoides*

Metals distribution within salt marsh sediments is dependent upon several factors as sediment type, the hydrological regime, the presence of vegetation, redox potential, and organic matter content. Changes in physicochemical properties (redox potential, salinity, pH, etc.) may influence metal mobility, speciation, and consequent biological availability (Weis and Weis 2004). In addition, in most cases, environmental ecosystems are polluted not by a single chemical, but by a mixture of pollutants. Therefore, the antagonistic and synergetic effects between pollutants should be taken into consideration when studying the remediation potential of plants. The literature on this matter is scarce but includes interesting findings. For instance, Reboredo (1994) observed that the uptake and accumulation of Cu by *Halimione portulacoides* were not affected by the levels of Zn. However, Fe concentrations in leaves of the same plant decreased under high Zn exposure, indicating that competition between Fe and Zn may have occurred. In addition, relatively high Cu contamination induced a decrease in Fe and Zn levels in *Halimione portulacoides* tissues. In an in vitro study carried out by Almeida and co-workers (2008b) it was observed that Cu accumulation by *Halimione portulacoides* increased when the solution where the roots were immersed was amended with polycyclic aromatic hydrocarbons (PAHs). However, the same authors observed, in other studies, negligible effects of DDE and monobutyltin (MBT) on Cu accumulation by *Halimione portulacoides*, whereas anionic surfactants enhanced Cu accumulation but not the metal translocation to aboveground plant tissues. This fact indicates that these chemicals may favor Cu adsorption to roots (Almeida et al. 2009a, b). Nonetheless, all the chemicals mentioned could improve Cu solubility in the medium where the experiment was performed (Almeida et al. 2009a, b), indicating that the composition of pollutants in a given medium may be different from that expected considering only the effect of each individual pollutant.

Therefore, studies in conditions as close to the natural ones as possible are needed to test the effective capability of plants for remediation of contaminated environments. This work aimed at evaluating, in natural conditions, *Halimione portulacoides* capability for metal phytoremediation in a salt marsh area. For this purpose, an ex situ experiment was carried out in which *Halimione portulacoides* specimens were transplanted into plastic sleeves filled with metal-polluted estuarine sediment (see below). The metal-polluted sediment was collected in an estuary, in, an area where the levels of Cu, Zn, and Pb were above the ERL value (Almeida et al. 2008a), which may pose a risk for the living organisms of the polluted ecosystem. In addition, the content of tributyltin (Carvalho et al. 2010) was also above the maximum established as provisional ecotoxicological assessment criteria. Sediments from this area have also shown to contain organochlorine pesticides (Carvalho et al. 2011) and PAHs (unpublished results). Therefore, the selected sediment simulated the multi-contaminated natural sediment.

The metal-polluted sediment was filled into four 750 mL plastic sleeves, open at both extremes, and placed into holes opened in the ground after cleaning the site to avoid mixture between native and transplanted *Halimione portulacoides* (Fig. 1), in a cleaner area of the estuary (Almeida et al. 2008a). The plastic sleeves allowed vertical water flow and prevented roots from being mixed between the native and the transplanted specimens. Five individual *Halimione portulacoides* plants, raised in hydroponic conditions to obtain a homogeneous sample of plants grown in similar conditions, were transplanted into plastic sleeves. Another four

Fig. 1 Transplantation of *Halimione portulacoides* into metal-polluted estuarine sediment. Transplants were placed in a cleaner area of the estuary

plastic sleeves filled with polluted sediment but without plants were used as controls. After 9 months all the plastic sleeves were removed and dismantled. Nearby native *Halimione portulacoides* and respective rhizosediments (sediment in contact with plant roots) were also collected for a parallel study (Duarte et al. 2012).

Figure 2 shows the metal levels observed in the different plant tissues before transplantation and after 9 months of exposure in each one of the four plastic sleeves. High variability in the metal content in the different plant tissues was observed among the different plastic sleeves. A parallel study indicated that the transplanted plants were still adjusting to the new surroundings after the 9-month period, showing stress indices and reduced adaptation to the environment (Duarte et al. 2012). In that study it was also observed that most of the transplants did not exhibit patterns of microbial activity similar to those assessed for the sediments vegetated by native plants, which suggest that the period of revegetation was not sufficient for plant acclimation and for the establishment of a normal microflora in the roots (Duarte et al. 2012). Moreover, the variability observed, in terms of microbial activity, among the rhizosediments of the transplants showed that the process of establishment was also still in progress (Duarte et al. 2012). These results justify the high variability among the metals accumulated by the plants in each plastic sleeve.

Despite this high variability it can be observed that, in general, all plants in all plastic sleeves accumulated metals, particularly in their roots, and that all metals were translocated to the aboveground structures (stems and leaves). Not only elements considered essential to plants, like Cu and Zn, but also elements not recognized as essential ones, like Pb and Cd, were accumulated and translocated within the plant. Due to medium oxidation and acidification, metals become more bioavailable, being mobilized from reduced sediments toward the oxidizing sediments around roots. For this reason, several studies have reported higher concentrations around roots than in bulk sediments (Almeida et al. 2004; Reboreda et al. 2008). Furthermore, the formation of metals concretions around roots, due to precipitation of iron and other metal oxides has also been reported (Weis and Weis 2004). Sundby et al. (1998) observed an enrichment of Cd, Cu, Pb, and Zn, in sediments around *Spartina maritima* roots, 5–10 times higher compared to the

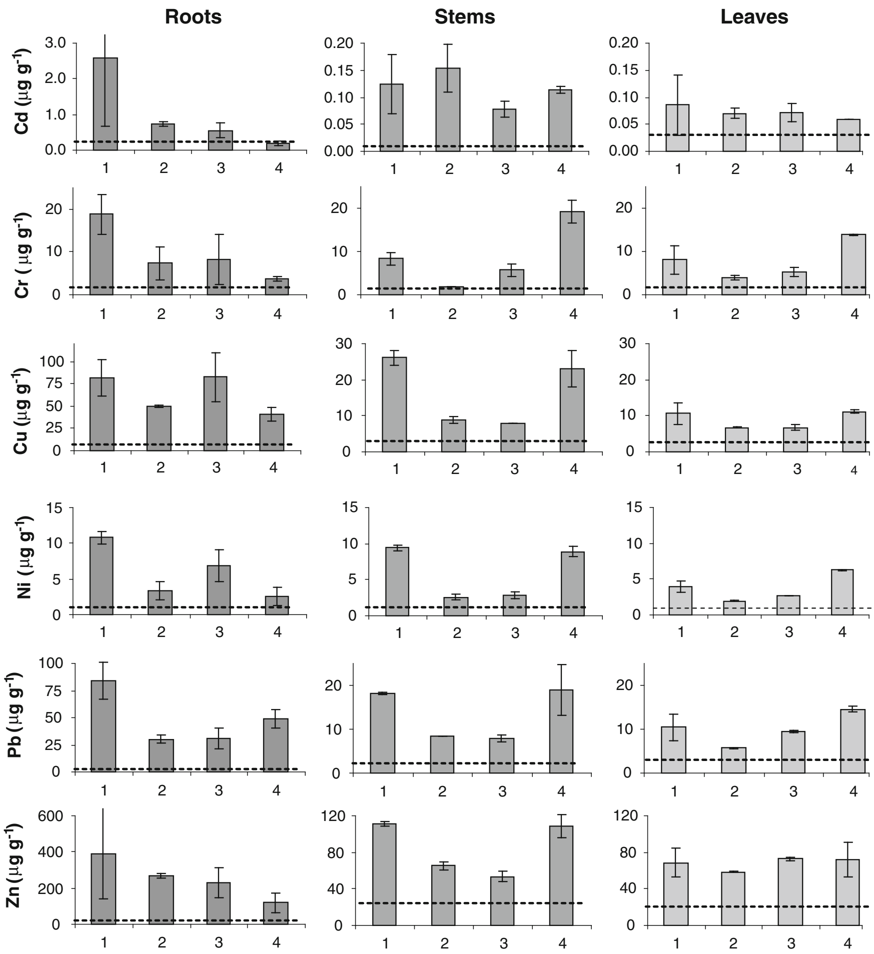

Fig. 2 Metals levels in *Halimione portulacoides* tissues (roots, stems, and leaves) observed after 9 months for each of the four cylinder litterbags (number from 1 to 4). *Dashed lines* show initial metal levels in plants used for transplantation

metals' contents observed in the surrounding sediment due to the formation of metals concretions, suggesting that the salt marsh plant presented an important role on metal mobilization. Caetano et al. (2002) also observed that metal concretions formed on *Halimione portulacoides* sediments presented high concentrations of Fe and As which decreased drastically when withdrawn from rhizosediment.

However, the plant's influence on the metal contents of the sediment was not clear in this study. In fact, despite the high metal accumulation observed in the transplanted plants, no significant differences were observed in the metal levels between vegetated and non-vegetated sediment after the 9-month period of transplantation (Fig. 3), although metal losses were observed for Cr, Cu, Ni, and

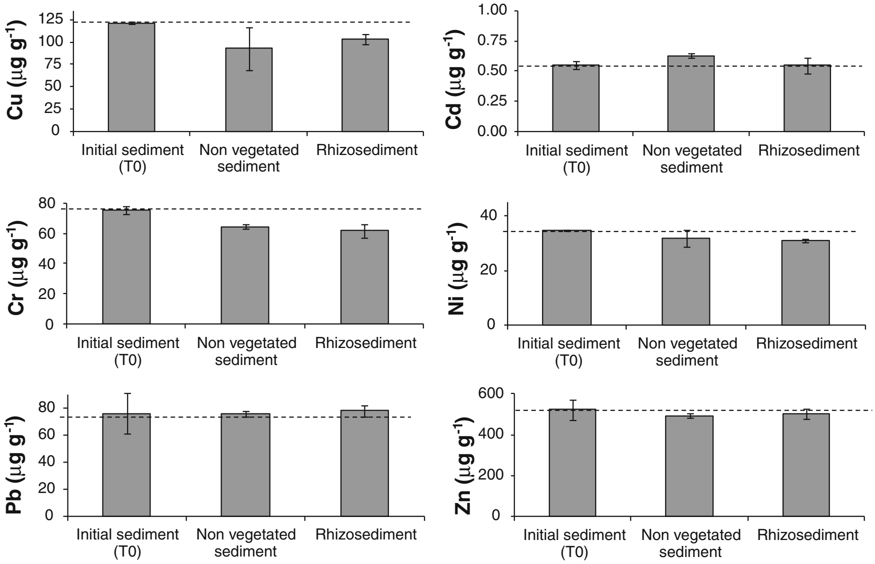

Fig. 3 Metal levels in non-vegetated sediments and in rhizosediments from the cylinder litterbags after 9 months (mean of four different cylinder litterbags). Metal levels in the initial sediment (T0) are also shown. *Dashed lines* indicate initial metal levels

Zn, both in vegetated and non-vegetated sediments. For Pb no losses were observed and for Cd an increase in non-vegetated sediment (although not significant) was observed.

Obtained results indicate that abiotic environmental conditions, like water leaching, may have contributed to metal losses. Belowground biomass of the transplanted plants after the 9-month period, particularly root biomass, was still very low compared with the belowground biomass observed in the field for native plants. On average, belowground biomass in the plastic sleeves was ca. 30 g_{roots} per m^2, whereas in the field, in areas colonized by *Halimione portulacoides*, it can be ca. 4200 g_{roots} per m^2 (Caçador et al. 2009). Aboveground biomass in the plastic sleeves was also lower than in the field but only by a factor of 2–3 (Caçador et al. 2009). Thus, in the 9–month period plants were not able to significantly grow their belowground biomass, probably because the adaptation period was still not fulfilled. In addition, despite a previous study (Sousa et al. 2008) having shown that high metal levels in the sedimentary environment did not cause toxicity to *Halimione portulacoides*, because this plant immobilizes metals in different cell compartments (cell wall + proteic fraction + intracellular) outside the key metabolic sites, in the present study metal influence on plant establishment cannot be ruled out. Furthermore, the selected contaminated sediment was not only contaminated with metals but also with organic pollutants that may also negatively affect the plant.

Results confirm the capability of *Halimione portulacoides* for accumulating high metal levels from polluted sediments but a higher plant biomass will be required so that metal phytoextraction is sufficiently high for remediating polluted areas. On the other hand, a longer adaptation time (much higher than 1 year) should be considered when engaging a revegetation of estuarine metal-polluted sites with this plant.

3 Phytoremediation Potential of *Juncus maritimus* and *Phragmites australis*

Several previous studies carried out in the field in which the authors have been involved show that the salt marsh plants *Juncus maritimus* and *Phragmites* have potential for phytoremediating Cd and Cu polluted sediments. *Juncus maritimus* has shown enrichment factors for Cd higher than 1 ($[Cd]_{root}/[Cd]_{sediment} > 1$), this value depending on the sediment characteristics (Almeida et al. 2004, 2006a, 2011). In addition, sediment in contact with the plant roots had in general a higher metal content than non-vegetated sediment. Similar results were observed for *Phragmites australis* ($[Cd]_{belowground\ tissues}/[Cd]_{sediment} > 1$) (Almeida et al. 2011), indicating that both plants contributed to the retention of Cd in the area of influence of their roots, having therefore, potential for phytostabilization of this metal. The literature categorizes the ability of salt marsh plants for metal remediation in phytostabilization and in phytoextraction, depending on plant aptitude to immobilize metals in their roots or rhizosediment, preventing their migration in soil, groundwater and air, or to translocate and accumulate metals to aboveground biomass (Weis and Weis 2004).

Therefore, experiments in controlled conditions, simulating the natural conditions to which the system is subjected, are in need to accurately assess the usefulness or not of these plants for metal phytoremediation.

The aim of this study is to carry out a first set of experiments in controlled laboratory conditions, with *Juncus maritimus* and *Phragmites australis* for deepening the conviction that these plants are suitable for phytoremediation of Cd in estuarine areas.

Both halophytic plants are perennial, from different families, and have different physiological structures. *Phragmites australis* is a common reed from the family *Poaceae*. It is a rhizomatous perennial macrophyte found in wetlands in the temperate and tropical regions of the world. It has invaded many coastal salt marshes, excluding most other plant species (Haven et al. 1997). In North America it is considered an invasive species and its presence in Atlantic salt meadows is also considered an indication of habitat degradation. In Portugal it is distributed throughout the country, except at high altitudes. *Juncus maritimus*, is a sea rush from the family *Juncaceae*, an autochthonous monocotyledon widely spread in salt marshes in the Atlantic coast of Europe. In Portugal it grows on the intertidal zone.

Plant species may considerably affect metal distribution and retention in the environment, which ultimately will affect phytoremediation processes. Therefore, differences between native and invasive species must be taken into consideration.

In this study, sediment cores with *Phragmites australis* and *Juncus maritimus* stands (separately) were used, so that interactions between salt marsh plants and the inhabiting microorganisms of marsh sediments would be considered. The literature on this matter shows that such interactions can induce biochemical changes in sediments. For instance, higher rates of extracellular enzymes were determined on vegetated sediments of *Spartina maritima* and *Halimione portulacoides* and only the upper sediment layer of both studied plants showed consistent differences with respect to the physiological profiles of microbial communities, suggesting that microbial colonization was influenced by salt marsh plants (Oliveira et al. 2010). Duarte and co-workers (2008) observed that extracellular enzymes activity varied seasonally in salt marsh sediments and influenced the metal fraction bound to organic matter, presenting therefore a major role on metal speciation. Ravit and co-workers (2005) demonstrated that *Spartina alterniflora* and *Phragmites australis* influenced the microbial community ability to dehalogenate tetrabromobisphenol-A (TBBPA), the dehalogenation of TBBPA being faster in *Spartina alterniflora* sediments than in *Phragmites australis* sediments or non-colonized sediments. Ribeiro and co-workers (2011) found that *Juncus maritimus*, *Triglochin striata,* and *Phragmites australis* exhibited consistent differences in the levels of hydrocarbon degraders. However, all the plants presented higher levels of those microorganisms in their rhizosediment than in the bulk sediment, confirming that microbial colonization of salt marsh sediments was promoted by salt marsh plants which, combined with plants' ability to accumulate hydrocarbons, can enhance the removal and degradation of those pollutants. Couto and co-workers (2011) reported an increase of hydrocarbon remediation at soil layer with higher root density when a non-ionic surfactant amendment and bioaugmentation were used together. On the other hand, lower toxicity of Cu to microorganisms was observed in the presence than in the absence of the plant *Halimione portulacoides,* by Mucha and co-workers (2011). It was inferred that the release of organic ligands by plant roots, which complex Cu into less toxic forms, was important for decreasing Cu toxicity. These studies clearly indicate that the rhizospheric microbial community is very important. Therefore, in this study the plant was collected together with the sediment surrounding their root to preserve the rhizosphere environment, being the sediment afterwards doped with Cd. Sediments were spiked because Cd levels in the field were low. The levels of metals determined in another study in Lima River estuary (Almeida et al. 2011) indicated that in general this was a non-polluted estuary, with metal loads lower than those observed in other Portuguese estuaries.

For the experiments, *Juncus maritimus* and *Phragmites australis* were collected in an estuary together with the sediment involving their roots and placed in vessels. A nutritive saline solution was added to the vessels to maintain the plant at their optimal state and to mimic the sea tides, i.e., the solution was added and kept in the vessels for 6 h (simulating the high tide), being afterwards drained and discarded.

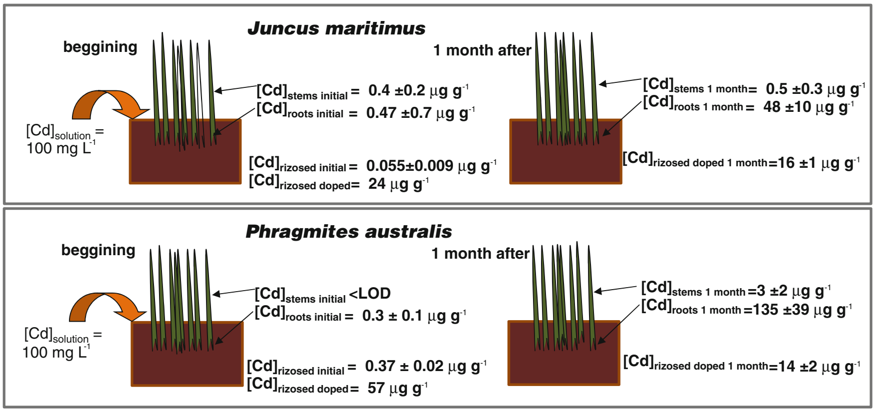

Fig. 4 Cd levels observed in *Juncus maritimus* and *Phragmites australis* tissues (roots and stems) at the beginning of the experiment (before the spiking of the medium) and after 1 month of exposure to medium contaminated with Cd. Cd levels in rhizosediment before and after spiking with Cd and after 1 month are also shown

The vessels remained then dry (simulating low tide) until a new solution was added the following day. Plants were maintained in an open indoor space and subjected to natural day: night light regime. Temperature ranged from 16 (night) to 22 °C (day). After 1 week of acclimation, the vessels were spiked with Cd. Vessels were maintained for 1 month in the above-mentioned conditions, and later dismantled.

Metal levels in the sediments were significantly lower 1 month after spiking (Fig. 4). Some metal loss by lixiviation, caused by the tidal simulation, was observed. However, a part of the metal decrease on the sediment was a result of plant uptake. Results clearly showed that both plants were able to uptake significant amounts of Cd in their belowground tissues, confirming therefore, their uptake capacity for this metal. A significantly higher Cd uptake by *Phragmites australis* comparative to *Juncus maritimus* was observed, indicating different metal uptake capabilities between the two plants. The size and morphology of the root system are the sources of variation on the metal uptake between different plant species. In fact, differences in the root system promote the oxidation of the rhizosphere to different extents, and consequently, induce variations in the bioavailability of metals (Ravit et al. 2003). This makes the degree of metal uptake highly dependent on the plant species (Weis and Weis 2004). In the present case, the root system of the two plants was different. *Phragmites australis* has a fibrous and dense root system. *Juncus maritimus* has an appreciable rhizome structure, presenting adventitious roots born on the horizontal rhizome, generally, with thicker roots than *Phragmites australis*.

Despite the high metal uptake by plant roots, metal translocation was either inexistent, in the case of *Juncus maritimus*, or low, in the case of *Phragmites australis*. Plants have a wide range of mechanisms to protect themselves against the uptake of toxic metals and for restricting their transport within the plant. These mechanisms include subcellular compartmentalization of metals, especially in vacuoles, and the sequestration of the metal by specifically produced organic compounds, like phytochelatins, concentrating metal in the roots (Ross and Kaye 1994). *Juncus maritimus* and *Phragmites australis* may take advantage from these mechanisms, thus restricting the metal translocation to some of their tissues to prevent Cd toxicity. In fact, no visual toxicity signs due to the presence of the Cd contamination in the medium were observed, indicating that the plants were able to support the metal presence. Therefore, both *Juncus maritimus* and *Phragmites australis* have the capacity to be Cd phytostabilizers.

However, more research is needed to show that these two plants can effectively be useful for the phytoremediation of Cd in an estuarine area contributing to the recovery of the impacted areas. For instance, more microcosm experiments should be carried out in conditions as similar as possible to those occurring in a real estuarine environment, in the presence of different levels of Cd contamination. Assessment of the response of these plants to short-term and long term-contamination of the medium by Cd and/or other metals should also be done. Experiments should also highlight any advantages or disadvantages of using native and invasive plants. Moreover, studies should be carried out to assess ways to improve the potential shown by these plants for the phytostabilization of metals.

4 Conclusions

Several studies have indicated that salt marsh plants might have potential for metals phytoremediation. However, most studies were carried out in the field and conclusions were drawn by analyzing exclusively natural metal burdens on both salt marsh plant tissues and sediment, in different environments with varied pollutant loads, which can then significantly influence the obtained results. The two studies reported in this chapter were carried out to ascertain the phytoremediation potential of salt marsh plants in natural controlled conditions. Obtained results confirmed the potential usefulness of *Halimione portulacoides*, *Juncus maritimus,*, and *Phragmites australis* for metal phytoremediation, namely phytostabilization. This can be a low cost solution for remediating estuarine impacted areas in an attempt to recover these areas of high ecological value. The already obtained information requires further development in order to confirm the applicability of this technique in the field and to assess ways to improve the potential shown by these plants for the phytostabilization of metals.

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