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# Comparison of phytoremediation potential capacity of *Spartina densiflora* and *Sarcocornia perennis* for metal polluted soils

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A B S T R A C T

Phytoremediation is considered the most appropriate technique to restore metal polluted soil, given its low cost, high efficiency and low environmental impact. *Spartina densiflora* and *Sarcocornia perennis* are perennial halophytes growing under similar environmental conditions in San Antonio marsh (Patagonia Argentina), therefore it is interesting to compare their phytoremediation potential capacity. To this end, we compared concentrations of Pb, Zn, Cu, and Fe in soils and in below- and above-ground structures of *S. perennis* and *S. densiflora*. It was concluded that both species are able to inhabit Pb, Zn, and Cu polluted soils. Although *Sarcocornia* translocated more metals to the aerial structures than *Spartina*, both species translocated only when they were growing in soils with low metal concentrations. It seems that the plants translocate only a certain proportion of the metal contained in the soil. These results suggest that both species could be considered candidates to phytostabilize these metals in polluted soils.



## 1. Introduction

During the last decades, anthropogenic activities (e.g., agricultural practices and industrial activities) have been increasingly associated with the accumulation of trace metals in the environment. As intertidal environments, salt marshes can receive trace metals from the ocean or the inland zone, which can be immobilized in the soil as biologically unusable forms (Botté et al., 2010; Hung and Chmura, 2007) or be absorbed by plants (Almeida et al., 2011; Caçador et al., 2009; Duarte et al., 2010; Hempel et al., 2008; Redondo-Gómez et al., 2009). While some plant species are sensitive to the harmful effects of trace metals, others are able to grow on contaminated soils excluding or accumulating these elements. Thereby, when trace metals enter plants, they could either be retained in their underground structures or translocated to their aerial ones (Weis and Weis, 2004).

There are several techniques to remediate soils that contain high levels of trace metals, but currently the phytoremediation techniques are considered the most appropriate, given their low cost, high efficiency and low environmental impact (Ashraf et al., 2010). Some of these techniques are: (1) phytostabilization: use of pollutant tolerant plants to reduce the bioavailability and immobilize pollutants in the rhizosphere; and (2) phytoextraction: direct removal of pollutants by the uptake into plants and their translocation and accumulation in above-ground tissues (Alkorta et al., 2004; Wenzel et al., 2004). Thus, it is essential to perceive that the technique selection has crucial ecological implications, given that the use of each technique leads to differences in the fate of the metals, which may be retained in the soil, accumulated in the plants (roots and aerial tissues) or excreted by the leaves. In this regard, it is important to study the influence of different plant species on soil metals, as well as their capacity to grow in polluted environments and the way that they accumulate or distribute these metals.

In a previous study we investigated the concentration of iron and some trace metals in soils and *Spartina densiflora*'s (Poaceae) tissues in the salt marsh surrounding San Antonio Bay (Río Negro, Argentina, Idaszkin et al., 2015). We found that soil metal concentrations follow a decreasing concentration gradient toward the sea. Potentially, this is due to the fact that the open-air dump is the main source of metals in the salt marsh, and it is located inland near the head of this channel. Also, the results of this research showed moderate pollution and a potentially negative biological effect.

Like *Spartina* spp., *Sarcocornia perennis* (Amaranthaceae) inhabits the salt marsh surrounding the San Antonio Bay. There the pickleweed *S. perennis* and the austral cordgrass *Spartina densiflora* are common perennial species of high marsh levels (Bortolus et al., 2009). *Spartina densiflora* is a $C_4$ cordgrass species, native of South America coastal marshes, and is invading successfully salt marshes of North America,

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Spain, Portugal and North Africa (Bortolus, 2006). On the other hand, *S. perennis* is a $C_3$ shrub species found in salt marshes of Europe, Southern Africa and the Atlantic coast of southern South America (Davy et al., 2006). Both are widespread species whose distribution range includes very different climate conditions and environmental scenarios (Bortolus, 2006; Davy et al., 2006; Idaszkin et al., 2011, 2014a), including polluted salt marshes, where they grow in soils with high concentrations of trace metals (Curado et al., 2014; Redondo-Gómez, 2013). Although both species inhabit the same salt marsh level (Bortolus et al., 2009) and are able to grow under similar environmental conditions, they have different life or growth form, therefore, it is interesting to compare their phytoremediation potential capacity. In addition, this comparison could provide valuable information for the studied region that could also be generalizable to other similar environments worldwide. Even though previous studies have shown the phytoremediation capacity of each of these species (or similar ones) (Cambrollé et al., 2008, 2011; Curado et al., 2014; Duarte et al., 2010; Idaszkin et al., 2014a, 2014b, 2015), there is a lack of studies concerning a system in which both species interact and co-exist in the same salt marsh level, thus providing a very complete and complex natural image. So, and for the first time, concentrations of Pb, Zn, Cu, and Fe were determined in soils and in below- and above-ground structures of *S. perennis* to combine with results about *S. densiflora* of a previous study in the San Antonio salt marsh (Idaszkin et al., 2015)), considering the potential interactions they can present in between. Thereby, we compared the capacity of *S. perennis* and *S. densiflora*, the dominant halophytes co-existing in this salt marsh, to absorb and accumulate metals from the soil, as well as their capability to immobilize metals in the rhizosphere soil.

## 2. Material and methods

### 2.1. Study area

The sampled salt marsh is located surrounding the San Antonio Bay (40°44′S, 54°68′W), in a Natural Protected Area (Río Negro, Argentina; Fig. 1). Samples were collected at three sites within the salt marsh adjacent to the main tidal channel (sites called "A", "B" and "C") and a fourth site (called "D") outside the channel (Fig. 1). All sampling sites were within the high salt marsh level inhabited by *Spartina densiflora* and *Sarcocornia perennis*, accompanied by other shrubs such as *Limonium brasiliense* and *Atriplex* spp.

### 2.2. Sampling

At each site in spring 2013, five core samples were collected from *Spartina densiflora* (hereafter called '*Spartina*') stands (Idaszkin et al., 2015) and five from *Sarcocornia perennis* (hereafter called '*Sarcocornia*') stands, all with a distance of 1 m from each other obtained at low tide. Each core sample (15-cm-diameter and 15-cm-depth) consisted of plants (below- and above-ground structures) and surrounding soils of below-ground plant tissues (hereafter called '*Spartina* soil' and '*Sarcocornia* soil' respectively). Five samples of non-vegetated soil in each site were also collected. Samples were kept in polyethylene bags, immediately carried to the laboratory stored, and there were stored in a freezer at −20 °C until they could be analyzed.

### 2.3. Soil samples

All soil samples, either surrounding below-ground plant structures or from non-vegetated areas, were dried at 80 °C until constant weight and sieved through a 2 mm mesh to remove large stones and dead plant material. In all soil samples the redox potential (Eh), pH, electrical conductivity (EC), organic matter (OM) and percentages of sand, silt, and clay were measured as described in Idaszkin et al. (2015).

### 2.4. Plant samples

Plants were carefully washed with tri-distilled water and separated into below-ground tissues (roots and rhizomes) and above-ground tissues (stems and leaves). All plant samples were dried at 80 °C until constant weight and pulverized in a mill until the powder was fine enough to pass through a 1-mm sieve.

### 2.5. Analysis of metals

For the analysis of metals, 1 g of dried and sieved soil or 0.5 g of dried plant material was digested in 2 ml of $HNO_3$ (Merck) ultrapure using microwave oven MARS-5, CEM Corporation, USA (2011) and was then diluted to a final volume of 15 ml with $HNO_3$ (EPA, 2000). Lead (Pb),

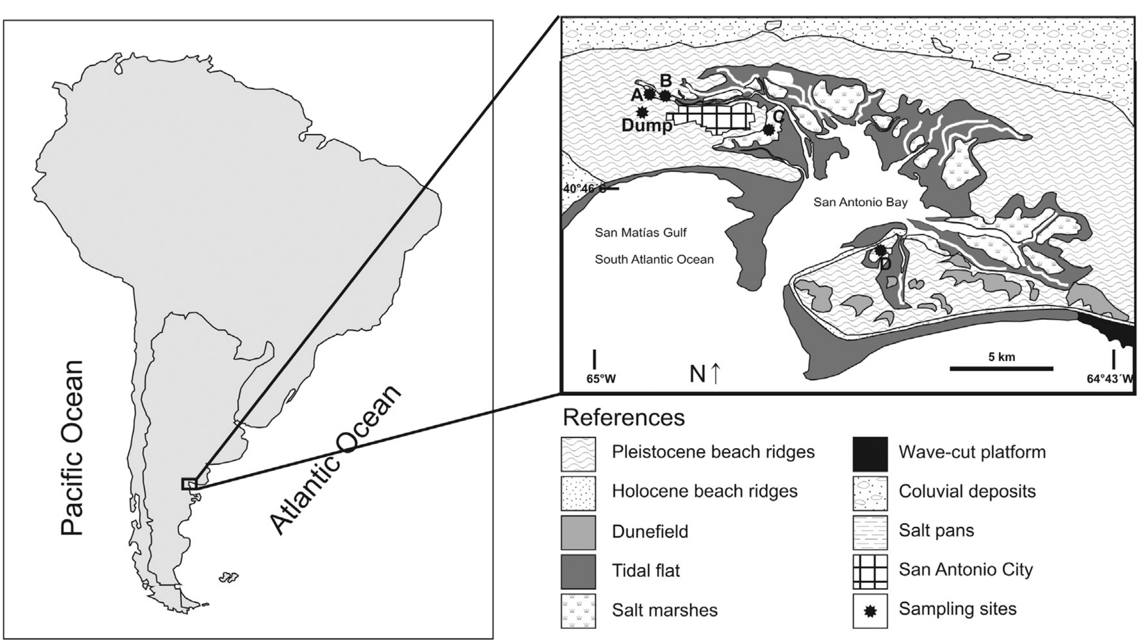


**Fig. 1.** Location of the sampling sites in the San Antonio salt marsh.

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zinc (Zn), copper (Cu), and iron (Fe), in both matrixes were then measured by inductively coupled plasma (ICP-AES) spectroscopy (Shimadzu 9000) ($n = 5$). In all cases, the average uncertainty of metal ion determination was <2%. All extractions were carried out in duplicate and blanks were processed as the samples. Results are reported on a dry weight. Reagents of analytical grade were used for the blanks and for calibration curves. Quality assurance of soils and plants was done through analysis of standard reference freshwater sediment CNS392-050 and BCR-060 aquatic plant (*Lagarosiphon major*), respectively. The recovery in soil sample varied between 87% for Zn to 98% for Fe, while in plant tissues it was >96% for all metals.

### 2.6. Data analysis

We calculated the soil-bioaccumulation factor (SBAF: [metal in below-ground structure]/[metal in soils]) as a value of the capability of *Sarcocornia* plants to take up and accumulate metals present in the soil in its underground tissues (Mason, 2013).

To evaluate the potential of *Spartina* and *Sarcocornia* plants to be used with phytoremediation purpose, we calculated the bioconcentration factor (BCF: [metal in above-ground structure] / [metal in soils]) and the translocation factor (TF: [metal in above-ground structure] / [metal in below-ground structure)] for both species (Fitz and Wenzel, 2002).

Confidence intervals were generated for the average value of each of the measurements made by site, soil type (*Spartina* soil, *Sarcocornia* soil, and non-vegetated soil), plant structure (below- and above-ground), and factors (SBAF, BCF, and TF). The intervals were generated by taking random samples with replacement n = sample size (e. g., faith to site A, above-ground) and calculating the average value of the sample obtained. This step was repeated 3000 times, and a confidence interval was generated based on the resulting 3000 estimations of the average values. The differences between sites, soil types, plant structures, or factors were evaluated by comparing the confident intervals at $\alpha = 0.05$ level with Student's *t*-test.

## 3. Results and discussion

### 3.1. Soil characteristics

We focused on potential differences among soil types (i.e., non-vegetated soil, *Spartina* soil, and *Sarcocornia* soil) within each site. Although we are aware of the existence of some differences among sites (Idaszkin et al., 2015), in this study we are interested mainly in differences in soil metal concentration due to the plant species linked to characteristic properties of the soil (Table 1). In this regard, both the OM content and the EC were different among all soil types in site C. Also, the OM differed between the soils associated to each plant species in site A and the EC in site D. Similarly, the Eh showed differences in site C, but only between the soils associated to each plant species and between non-vegetated soils and *Sarcocornia* soils. Even so, the Eh was oxidized in all cases. Although the pH was statistically different among all soil types in all sites, it was slightly basic in all cases. Regarding the textures, there were scarce differences; the sand content, the silt content and the fine fraction (clay + silt) content only showed differences between non-vegetated soils and *Spartina* soils in site C and between non-vegetated soils and *Sarcocornia* soils in site D. In general terms, within sites, the edaphic conditions were homogeneous among types of soils, the plant presence effect being relative. This is in agreement with the fact that both species are in the same salt marsh level, therefore, under the same tidal influence, the main conditional abiotic factor in intertidal environments (Bockelmann et al., 2002; Idaszkin et al., 2011).

Metal concentration in *Sarcocornia* soils were higher at site A from where they decreased toward sites C and D, in accordance with the distance from the open-air dump, the main source of metals (Fig. 2). The highest value was measured for Fe, followed by Zn, Pb, and Cu. These

**Table 1**
Physicochemical properties of soils in the San Antonio salt marsh (mean ± S.E, n = 5).

| Soil parameters | Site A | | | Site B | | | Site C | | | Site D | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Non-vegetated soil | *Spartina* soil | *Sarcocornia* soil | Non-vegetated soil | *Spartina* soil | *Sarcocornia* soil | Non-vegetated soil | *Spartina* soil | *Sarcocornia* soil | Non-vegetated soil | *Spartina* soil | *Sarcocornia* soil |
| OM % | (5.84 ± 0.41) | (6.46 ± 0.26)* | (5.79 ± 0.23)* | (4.49 ± 0.34) | (5.69 ± 0.64) | (4.76 ± 0.39) | (3.08 ± 0.09)* | (2.93 ± 0.13)* | (2.53 ± 0.07)* | (2.45 ± 0.26) | (2.55 ± 0.29) | (2.39 ± 0.24) |
| EC (mmhos $cm^{-1}$) | (7.68 ± 0.76) | (9.2 ± 1.15) | (7.25 ± 0.67) | (7.27 ± 0.37) | (6.57 ± 0.45) | (6.93 ± 0.49) | (3.97 ± 0.1)* | (3.75 ± 0.06)* | (3.69 ± 0.09)* | (3.55 ± 0.52) | (3.41 ± 0.31)* | (2.78 ± 0.15)* |
| pH | (7.66 ± 0.05)* | (7.61 ± 0.02)* | (7.64 ± 0.04)* | (7.51 ± 0.01)* | (7.68 ± 0.05)* | (7.66 ± 0.05)* | (7.65 ± 0.04)* | (7.54 ± 0.05)* | (7.42 ± 0.02)* | (7.74 ± 0.06)* | (7.63 ± 0.05)* | (7.88 ± 0.03)* |
| Eh (mV) | (142.8 ± 7.36) | (139.6 ± 7) | (140.8 ± 7.2) | (143.75 ± 15.1) | (163.2 ± 11.59) | (123.4 ± 29.44) | (167 ± 4.01)* | (147.2 ± 10.64)* | (121.4 ± 6.34)* | (162.75 ± 5.92) | (189.6 ± 13.87) | (164.8 ± 4.61) |
| Clay (%) | (18.86 ± 4.09) | (22.63 ± 3.81) | (25.13 ± 3.81) | (20.04 ± 2.38)* | (14.97 ± 1.03)* | (15.36 ± 1.84) | (3.85 ± 0.59) | (3.87 ± 0.33) | (3.43 ± 0.32) | (4.91 ± 0.89) | (6.1 ± 0.48) | (4.77 ± 0.57) |
| Silt (%) | (52.04 ± 6.49) | (55.57 ± 3.29) | (54.39 ± 3.99) | (50.51 ± 4.13) | (52.54 ± 5.48) | (48 ± 4.98) | (27.41 ± 0.66)* | (30.26 ± 1.2)* | (26.74 ± 2.23) | (26.56 ± 1.73)* | (23.75 ± 3.33) | (20.35 ± 2)* |
| Fine fraction (%) (clay + silt) | (70.9 ± 5.42) | (78.2 ± 2.07) | (79.53 ± 0.4) | (70.55 ± 6.18) | (67.5 ± 6.28) | (63.37 ± 6.59) | (31.26 ± 1)* | (34.13 ± 1.02)* | (30.17 ± 2.35) | (31.48 ± 1.28)* | (29.85 ± 3.68) | (25.12 ± 1.96)* |
| Sand (%) | (29.09 ± 5.42) | (21.79 ± 2.07) | (20.46 ± 0.4) | (29.45 ± 6.18) | (32.5 ± 6.28) | (36.63 ± 6.59) | (68.74 ± 1)* | (65.87 ± 1.02)* | (69.83 ± 2.35) | (68.52 ± 1.28)* | (70.15 ± 3.68) | (74.88 ± 1.96)* |

"*" indicate significant differences ($p < 0.05$) between soil type in *t*-test.

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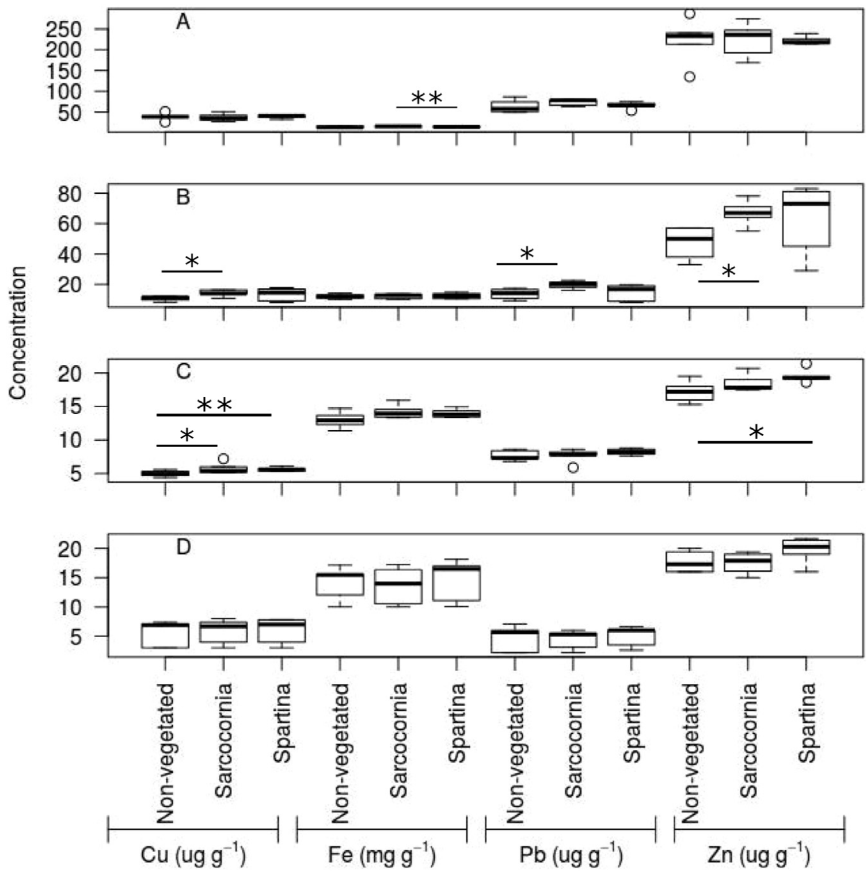


**Fig. 2.** Pseudototal concentration of studied metals in the different types of soils, from sites A to D (upper to lower panels) in the San Antonio salt marsh. The horizontal line in boxes indicates the median value. The lower and upper hinges represent respectively the 25% and 75% percentile (n = 5). Horizontal bars show significant differences between types of soils (* < 0.05, ** < 0.01). Comparisons were conducted by re-sampling, based on *t*-test.

same patterns were observed in non-vegetated soils and in *Spartina* soils (Idaszkin et al., 2015). The levels of Cu were lower and the levels of the other measured metals were higher in *Sarcocornia* soils in San Antonio salt marsh than in *Sarcocornia* soils in the polluted Odiel marsh (southwest of Spain; Curado et al., 2014). Moreover, Pb, Zn, and Cu reached higher concentrations in San Antonio salt marsh soils than in other Argentinian salt marshes where the same plant species are present (Idaszkin et al., 2014b; Negrin et al., 2016). This is denoting a major impact of the human intervention in the San Antonio marsh than in the other salt marshes.

Comparison of soil metal concentrations within each site in the San Antonio salt marsh helps us to understand the role of the plants in the metal concentrations (Fig. 2). In this regard, in site A Fe was higher in *Sarcocornia* soils than in *Spartina* soils and in site B Pb was higher in *Sarcocornia* soils than in *Spartina* soils (Fig. 2). Also, in site B Pb, Cu and Zn were higher in *Sarcocornia* soils than in non-vegetated soils. In site C Cu was higher in *Sarcocornia* soils, followed by *Spartina* soils, and non-vegetated soils (Fig. 2). On the other hand, Zn was higher in *Spartina* soils than in non-vegetated soils (Fig. 2). Although there were few differences in metal concentrations among types of soils, when they were significant, non-vegetated soils showed lower metal concentrations than vegetated soils which is in agreement with studies in other salt marshes (Almeida et al., 2006a, 2006b, 2011; Moreira da Silva et al., 2015). Likewise, *Sarcocornia* soils showed the highest metal concentrations, suggesting a tendency of *Sarcocornia* to immobilize the metals in its rhizosphere in the San Antonio salt marsh. The same tendency was reported for *Sarcocornia* as *Spartina alterniflora* in salt marshes from the Bahía Blanca Estuary (Buenos Aires, Argentina; Negrin et al., 2016).

### 3.2. Trace metals concentrations in Sarcocornia perennis

In all sites, *Sarcocornia* concentrated statistically more Cu and Fe in below- than in above-ground structures (Fig. 3a). At the same time, it concentrated more Zn in the below-ground part at sites A and B, but more Pb in the above-ground structures in site C (Fig. 3a). Regarding statistic differences in trace metal concentrations in below-ground parts among sites, the results were very similar to those found for *Spartina* (Idaszkin et al., 2015). *Sarcocornia* concentrated significantly more Cu in below-ground structures in site A, followed by plants from sites B, D and then C; more Pb in below-ground structures of plants from site A than in the other sites; and more Zn in below-ground structures of plants from site A, followed by plants form site B, C and then D (Fig. 3b). However, Fe concentration in below-ground structures did not show significant differences among sites (Fig. 3b). On the other hand, concerning differences in trace metal concentrations in above-ground parts among sites, *Sarcocornia* concentrated significantly more Cu in above-ground structures in sites A than in C and D; more Pb in site B

**Fig. 3.** Trace metal concentrations in below- and above-ground structures of *Sarcocornia perennis* (a) into each site and (b) for all sites in the San Antonio salt marsh. The horizontal line in boxes indicates the median value. The lower and upper hinges represent respectively the 25% and 75% percentile (n = 5). (a) "*" indicate significant differences (p < 0.05) between structures in aech site; (b) Different letters indicate significant differences (p < 0.05) among sites for aech structure. Comparisons were conducted by re-sampling, based on *t*-test.

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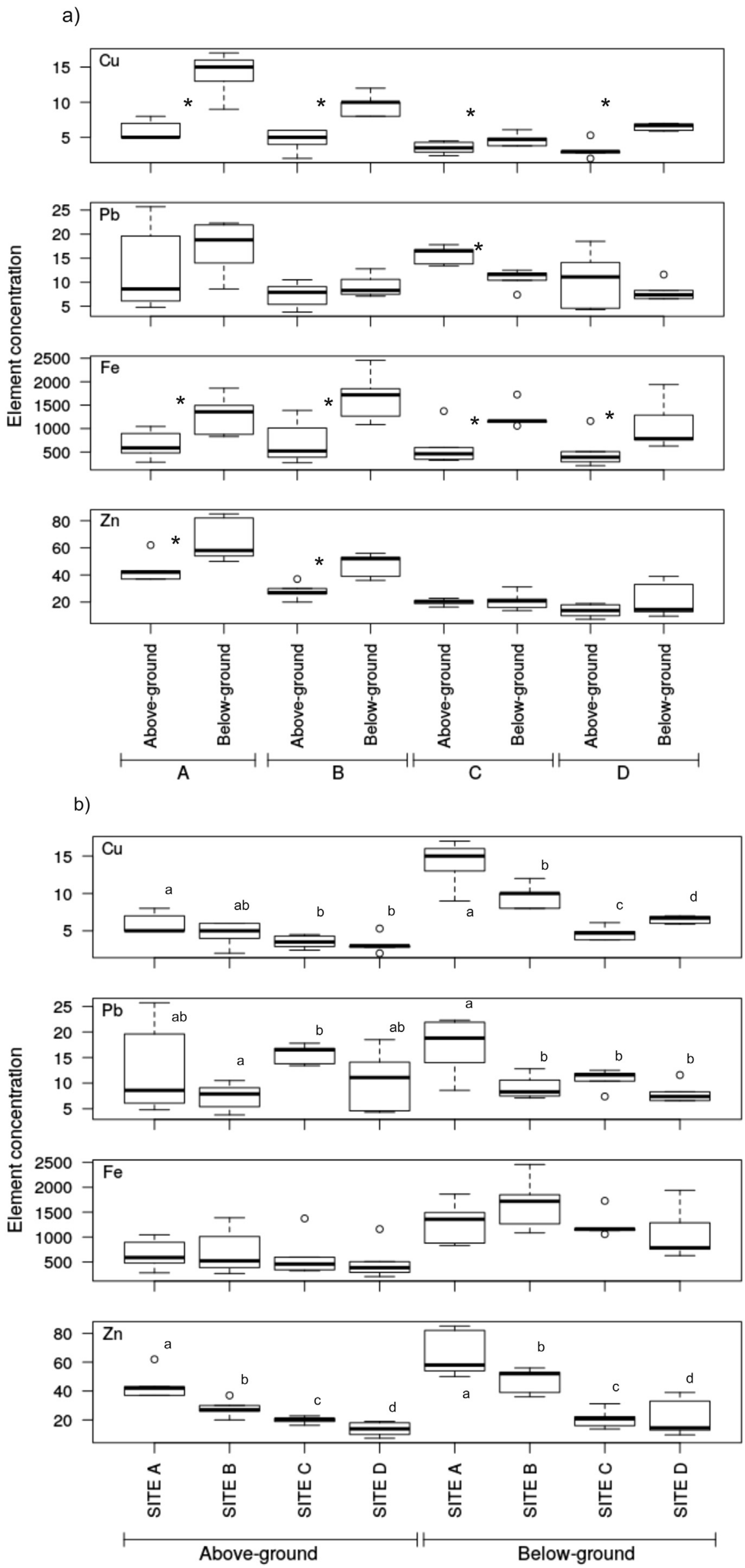


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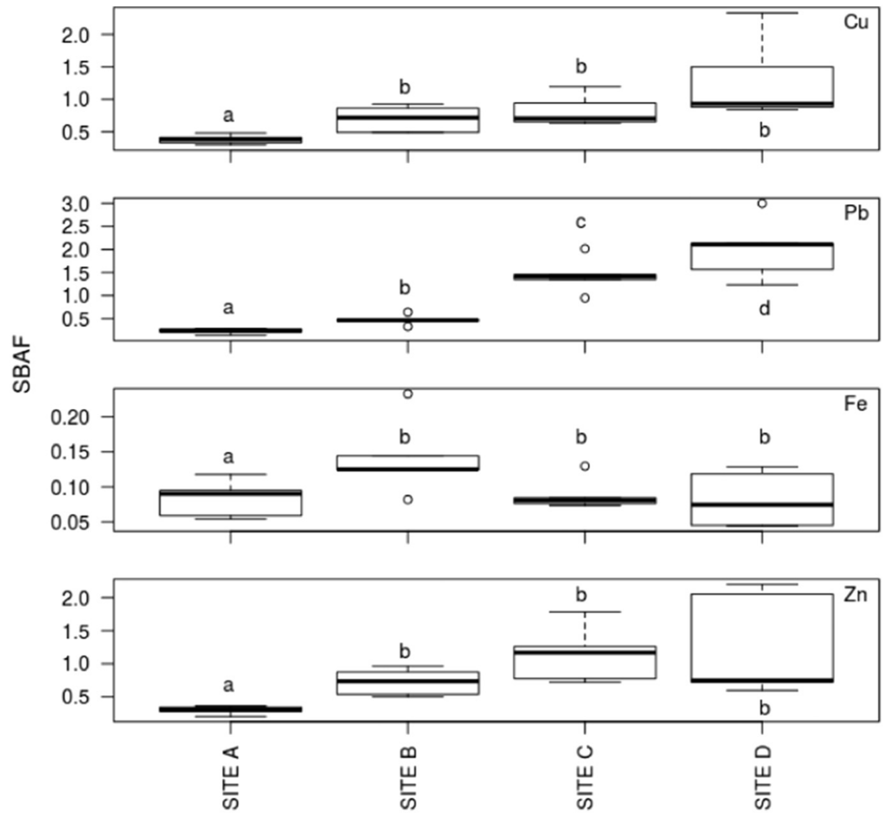


**Fig. 4.** Soil Bioaccumulation Factor (SBAF) of *Sarcocornia perennis* from each sample site in the San Antonio salt marsh. The horizontal line in boxes indicates the median value. The lower and upper hinges represent respectively the 25% and 75% percentile ($n = 5$). Different letters indicate significant differences ($p < 0.05$) among sites. Comparisons were conducted by re-sampling, based on *t*-test.

than in site C; and more Zn in site A, followed by sites B, C and then D (Fig. 3b). Fe concentration in above-ground structures did not show significant differences among sites either. This pattern is in accordance with the soil metal concentration which is higher closer to the dump for all matrices. In both the below- and above-ground structures of *Sarcocornia*, the reached concentrations of Cu, Fe, Pb and Zn were lower in the San Antonio salt marsh plants than in the Odiel marsh *Sarcocornia* plants (Curado et al., 2014). However, Cu, Pb and Zn were higher in below-ground structures and lower in above-ground structures of *Sarcocornia* plants from the San Antonio salt marsh than in *Sarcocornia* plants from the Bahía Blanca Estuary (southeast of Buenos Aires province, Argentina; Negrin et al., 2016).

Considering the soil-bioaccumulation factors (SBAF), Cu- and Zn-SBAF were significantly lower in plants from site A than in plants from the other sites (Fig. 4). The Pb-SBAF was lower in site A, followed by sites B, C, and then D. On the other hand, Fe-SBAF was higher for plants from site B than for plants from the other sites (Fig. 4). In addition, *Sarcocornia* plants accumulated soil Zn and Pb in their below-ground structures (SBAF > 1) in sites C and D, and Cu only in site D (Fig. 4). This same pattern was found for *Spartina* plants in the studied salt marsh, which also accumulated Zn in their roots in site B (SBAF > 1; Idaszkin et al., 2015). Instead, in the Bahía Blanca Estuary the SBAF appears to be <1 for all metals measured (Cr, Cd, Pb, Ni, Cu, and, Zn; Negrin et al., 2016), suggesting that there the plants tend to immobilize these metals in soils, more than to accumulate them in their below-ground tissues. That could be related with the fact that Zn and Pb bioavailabilities are higher in the San Antonio salt marsh, which may be related to the fact that the soil chemical features differ (e. g., Eh, pH, OM, clay content), causing metals to be more retained in the soils of the northern estuary (Reboredo, 1993). Also, the high translocation of these metals to the aerial tissues in the Bahía Blanca Estuary plants could be influencing (Negrin et al., 2016) the differences with our results.

### 3.3. *Spartina* vs. *Sarcocornia*

Given that different plant species could have different allocation patterns of metals and that each plant species has a particular role on salt marsh ecosystems, we compared the concentration of each trace metal in each structure between species (Fig. 5). In below-ground structures, *Spartina* concentrated significantly more Fe only in site A; while it concentrated more Zn in all sites. However, *Sarcocornia* concentrated more Cu in site C in below-ground tissues (Fig. 5). Regarding above-ground structures, in general, *Sarcocornia* concentrated more metals than *Spartina* (Fig. 5). In this sense, *Sarcocornia* concentrated more Cu than *Spartina* in sites A, B, and D. However, Pb and Zn were significantly higher in *Sarcocornia* than in *Spartina* in site C (Fig. 5). Even though both are halophyte species, *Sarcocornia* is a succulent, which could be sequestering the metals in vacuoles in aerial tissues and in this way minimize the toxic effect of the accumulation of metals (Lokhande and Suprasanna, 2012). On the other hand, *Spartina* species have salt glands, through which they can also excrete the excess of metals in the above-ground structures (Redondo-Gómez, 2013). There exist other examples of different plant species coexisting in a metal-polluted field displaying comparable results (Bidar et al., 2007; Cambrollé et al., 2008, 2011; Reboreda et al., 2008) which show us how different species may have different behaviour under the same stressful situation. These could be

**Fig. 5.** Trace metal concentrations (a) in below- and (b) in above-ground structures of *Spartina densiflora* and *Sarcocornia perennis* for each sample site in the San Antonio salt marsh. The horizontal line in boxes indicates the median value. The lower and upper hinges represent respectively the 25% and 75% percentile ($n = 5$). "*" indicates significant differences ($p < 0.05$) between species. Comparisons were conducted by re-sampling, based on *t*-test.

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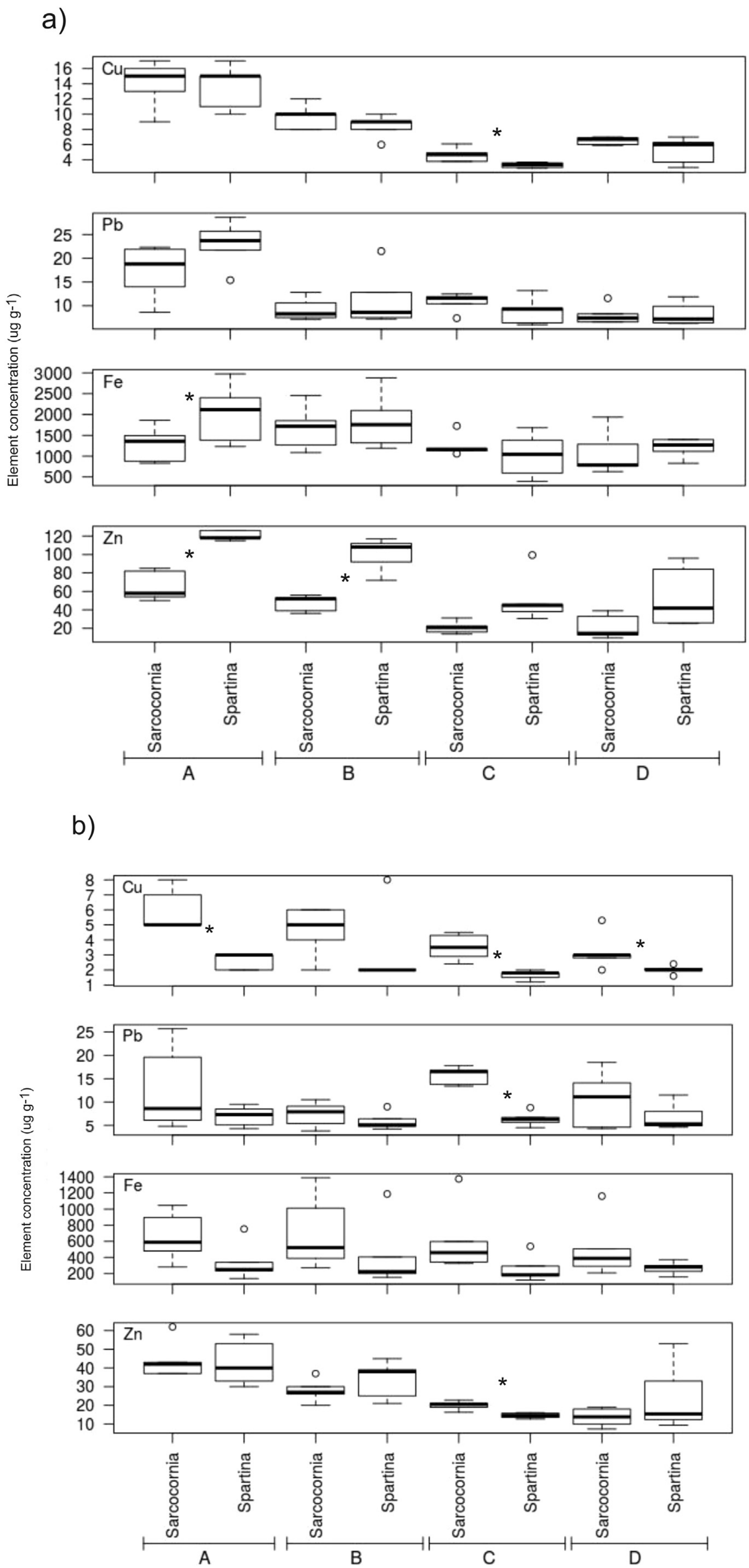


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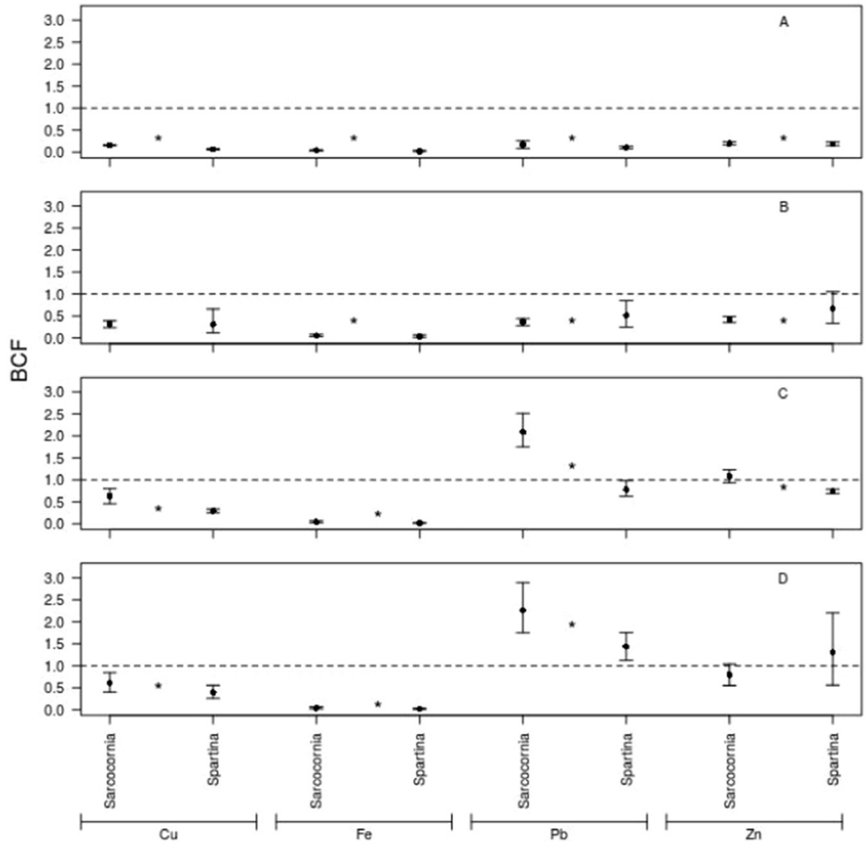


**Fig. 6.** Bioconcentration Factor (BCF) for *Spartina densiflora* and *Sarcocornia perennis* from each sample site in the San Antonio salt marsh. Data are means and the error bars mark the 95% confidence interval (n = 5). "*" indicates significant differences ($p < 0.05$) between species. Comparisons were conducted by re-sampling, based on *t*-test.

related both with differences between *Sarcocornia* and *Spartina* in processes related with the absorption of metals, or with the accumulation and the translocation.

Almost always, the bio-concentration factor (BCF) was significantly different between species (except for Cu in site B and Zn in site D), and in most of these cases, the BCF was higher for *Sarcocornia* than for *Spartina*, excepting Pb and Zn at site B (Fig. 6). Furthermore, BCF was greater or equal than 1 for Pb and for both species in sites C, and D, for Zn and for both species in site D, and for Zn only for *Spartina* in site B and only for *Sarcocornia* in site C (Fig. 6). Similarly, the translocation factor (TF) showed significant differences between plant species, levels being higher for *Sarcocornia* than for *Spartina* except for some cases (Fig. 7). Specifically, Cu is the metal most frequently translocated to aerial structures (TF ≥ 1), due to the fact that both species translocate it in all sites except for *Spartina* in site A (Fig. 7). Instead, Pb and Zn are only translocated by *Sarcocornia* in few sites (i.e., site C for Pb and site D for Zn; Fig. 7), while Fe is not translocated in any case. Unlike Cu and Zn, Pb is not an essential element for plants. Pb is considered a metal with low mobility within plants, which accumulates mainly in roots (binding to ion exchange sites and extracellular precipitation; Almeida et al., 2007; Bidar et al., 2007). However, in less contaminated sites, *Sarcocornia* translocated Pb to aerial parts, while *Spartina* retained and accumulated it more in its roots. This is in agreement with the fact that Pb seems to accumulate mainly in below-ground structures of monocots (as *Spartina*), and in the above-ground tissues of dicots (as *Sarcocornia*; Weis and Weis, 2004). Our results suggest that plants of both species translocate the studied metals when growing under less soil metal concentration. Bech et al. (2012) found similar results for *Bidens triplinervia* and *Senecio* sp. plants growing a in unpolluted and mine polluted soils in Peru.

When planning phytoremediation practices, it is important to consider the bioavailability of the target metals in soils as well as the edaphic properties, but the choice of the plant species (tolerant and/or accumulator or excluder) to use is crucial. As halophytes, both species could have particular features to cope with stressful environmental conditions. In this sense, both BCF and TF give interesting information related with the potential use of a plant species for phytoremediation purposes, being that they reflect the potential capacity of the plant to be used as a phytoextractor or phytostabilizer (Ali et al., 2013; Bech et al., 2012). In site A, where metal concentrations were higher, no one species showed BCF > 1 or TF > 1 of Pb and Zn. However, *Sarcocornia* had BCF > 1 and TF > 1 of Pb and Zn in sites with the lowest metal levels, while *Spartina* had BCF > 1 and TF < 1 of Pb and Zn in these sites in the San Antonio salt marsh (Figs. 6 and 7). Even though *Sarcocornia* translocates some metals to the aerial parts, it does not seem to be able to translocate when plants are growing in soils with high concentration of the target metals. This could indicate that both species could be considered to phytostabilize these metals when they are in high concentrations, restricting their accumulation on above-ground structures (Bech et al., 2012). However, further research manipulating the metal concentration is needed to evaluate in controlled-conditions the capability of each species to extract or to accumulate metals.

## 4. Conclusion

The present study indicates that metal pollution affects both *Sarcocornia perennis* and *Spartina densiflora* plants in San Antonio salt marsh (Río Negro, Argentina). Both species seem to be able to inhabit Pb, Zn, and Cu polluted soils. *Sarcocornia* seems to immobilize more metals in its rhizosphere than *Spartina*. In polluted soils *Spartina* concentrated more Zn and Fe in below-ground structures than *Sarcocornia*. However, *Sarcocornia* concentrated more Cu and Fe in above-ground structures. In addition, both species accumulated Zn and Pb in their below-ground structures. Nevertheless, *Sarcocornia* translocated more metals to the aerial structures than *Spartina*, but both species

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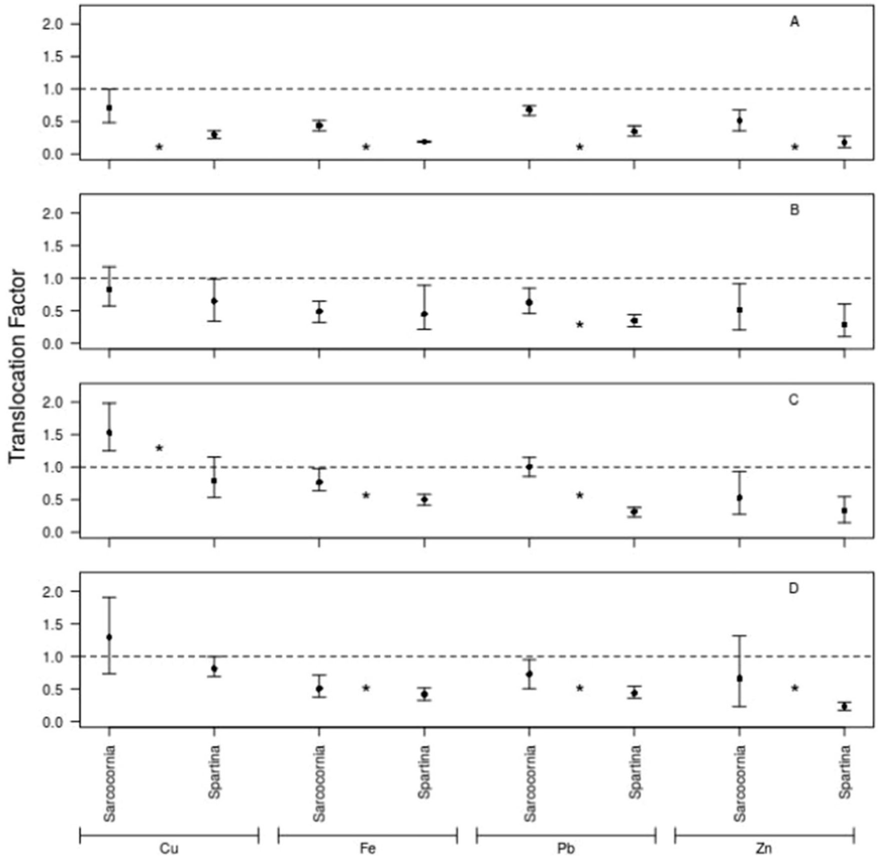


**Fig. 7.** Translocation Factor (TF) for *Spartina densiflora* and *Sarcocornia perennis* from each sample site in the San Antonio salt marsh. Data are means and the error bars mark the 95% confidence interval (n = 5). "*" indicates significant differences ($p < 0.05$) between species. Comparisons were conducted by re-sampling, based on *t*-test.

translocated only when they were growing in soils with low metal concentrations. It seems that the plants translocate only a certain proportion of the metals contained in the soil. These results suggest that both species could be considered candidates to phytostabilize these metals in polluted soils.

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