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Heavy metals dynamics in seaweeds and seagrasses in Bahía Magdalena, B.C.S., México

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Abstract The process of metal bioaccumulation in marine food chains is poorly understood because very little data is available on metal concentration at different trophic levels and their temporal or spatial variation. Because of that, we were interested to (1) determine the concentration range of heavy metals in seaweed and seagrasses species in Magdalena Bay; (2) describe the spatial and temporal variation of heavy metal concentrations in the seaweeds and seagrasses. Seasonal collections were done at Estero Banderitas in November 2004, February, and April 2005 wherein we divided the estuary into three major areas (upper, middle, and lower), and within each area, two sites were selected. Our results showed that iron, copper, and magnesium were the most significant metals found in seagrasses, red, and green algae. We found significant more variation in temporal heavy metal concentrations in relation to the maximum abundance in the samples and spatial variation in relation to the studied taxa suggesting that hervibores have a differential intake of the metals. Also, our results suggest that heavy metals might be incorporated regularly in the diet of many herbivorous animals with severe consequences to their health. Management strategies for these species should consider monitoring the levels of metals.

Keywords Bioaccumulation · Turtles · Health · Heavy metals · Seaweed · Seagrass · Mexico

Introduction

Heavy metals occur naturally in the environment (Sparling et al. 2000) as part of the biogeochemical cycles (Sánchez-Rodríguez et al. 2001), and it is often difficult to differentiate between natural and anthropogenic sources (Kieffer 1991; Moreno 2003). In marine systems, natural processes (e.g., upwelling, river runoff) can redistribute and concentrate heavy metals in the environment, occasionally reaching toxic levels (Sparling et al. 2000; Machado et al. 2002). The effects of these processes may vary over seasonal and spatial scales (Sawidis et al. 2001). An understanding of temporal and spatial changes in metal concentrations in the environment can aid in determining the sources as biomonitors (Szefer et al. 1998; Páez-Osuna et al. 2000), and ultimately their effects on wild life (Sparling et al. 2000; Talavera-Saenz et al. 2007). Also, they can be used for biosorption in contaminated waters (Kumar and Kaladharan 2006). Caliceti et al. (2002) found a decrease in Zn and Cd concentrations from the center of a lagoon, close to an industrial district, towards the Venice lagoon (Italy) openings to the sea, suggesting anthropogenic sources, while Villares et al. (2002) found that seasonal and special variation in metals was related to algal growth cycles and river runoff.

The process of metal bioaccumulation in marine food chains is poorly understood because very little data is available on metal concentration at different trophic levels

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(de la Lanza et al. 1989; Talavera-Saenz et al. 2007) or their temporal (Abdallah et al. 2006; Rodriguez-Castañeda et al. 2006) or spatial variation (Kalesh and Nair 2006) and their effects on the photosynthetic process (Catriona et al. 2002). Previous studies in Magdalena Bay, Mexico (Méndez et al. 2002; Gardner et al. 2006) have found high concentrations of metals in marine vertebrates, despite the lack of obvious anthropogenic sources. For example, Cd, Zn, and Fe concentrations in the herbivorous green turtle, *Chelonia mydas*, were the highest ever reported in sea turtles globally (Gardner et al. 2006). Rodríguez-Meza et al. (2008) developed an extensive evaluation of the heavy metals in sediments and seaweeds along ten sites in the bay. They suggested that the high levels of some heavy metals are related to terrigenous input from the arroyos and biogenic origin by the upwelling. In order to better understand the sources of heavy metals to marine species, more information is needed on metal concentrations in primary producers that make up the base of the food chain. However, few papers have approached the study of natural levels of heavy metals in seaweed communities and their temporal and spatial variation.

The aims of the present paper are to: (1) determine the concentration range of heavy metals in seaweed and seagrass species in Magdalena Bay; (2) describe the spatial and temporal variation of heavy metal concentrations in the seaweeds and seagrasses.

Methods

Magdalena Bay is located on the Pacific coast of the Baja California Peninsula between 24° 15′ N and 25° 20′ N and 111° 30′ W and 112° 15′ W. It is a shallow lagoon protected from the Pacific by barrier islands with high productivity resulting from seasonal marine upwelling. Diverse marine habitats within the bay include sandy bottoms and rocky margins, extensive beds of the seagrass, *Zostera marina*, and a diverse assemblage of macroalgae (Riosmena-Rodríguez unpublished data). A sea turtle refuge area known as Estero Banderitas is a mangrove channel located in the northwest region of the Bay (Fig. 1). Rodríguez-Meza et al. (2008) has found that the presence of heavy metals in the bay is heavily influenced by sediment type, organic material, and carbonates and concluded that there was no evidence of human impacts.

Seasonal collections were done at Estero Banderitas in November 2004, February, and April 2005. We visited the site on July 2004 but no plant species were present in the visited sites. To collect our samples, we divided the estuary into three major areas (upper, middle, and lower) and within each area, two sites were selected. Seaweed samples were collected along the length of the channel using 16 transects of 30 m length. Every 6 m along the transects, algae was manually collected within a 25-cm^2 to 1-m^2 area, depending on the density of the algae at that location, for a

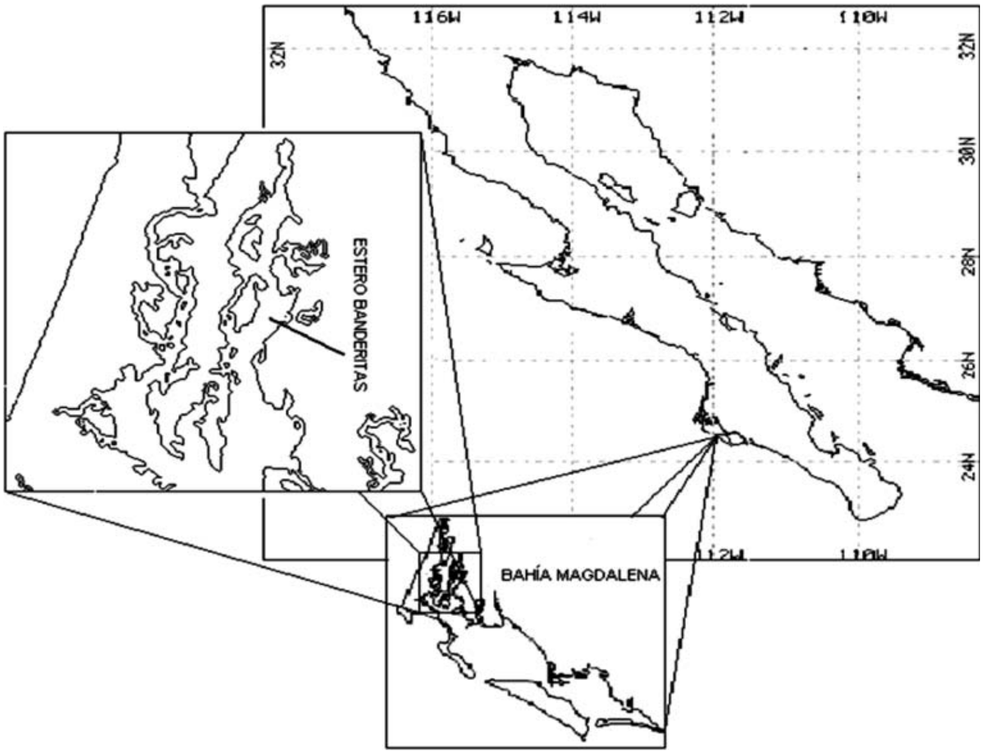

Fig. 1 Study area in Estero Banderitas (24° 50′–25° 00′ N and 112°08′ W) located in Bahía Magdalena, Baja California Sur, Mexico

total of 80 samples per trip. We collected the most common species in the area (Riosmena-Rodríguez, unpublished data). The samples were stored in labeled plastic bags and contents were separated by species using keys provided by Riosmena-Rodríguez (1999). Samples were sun-dried in the field, and in the laboratory, they were pressed to further remove moisture.

Laboratory analyses

Tissue samples (0.5 g) were dried in an oven at 70°C until a dry weight was obtained and then digested in acid-washed Teflon tubes with concentrated nitric acid in a microwave oven. Samples were analyzed by atomic absorption (GBC Scientific equipment, model AVANTA, Australia) using an air–acetylene flame. The certified standard reference material TORT-2 (National Research Council of Canada, Ottawa) was used to verify accuracy, and the analytical values were within the range of certified values. The percentage of recovery was greater than 15% for all metals analyzed. All recoveries of metals analyzed were over 95%. Detection limits were: Zn=0.0910 μg g^{-1}, Cd=0.0390 μg g^{-1}, Mn=0.0680 μg g^{-1}, Cu=0.043 μg g^{-1}, Ni=0.0400 μg g^{-1}, Fe=0.0190 μg g^{-1}, Pb=0.049 μg g^{-1}.

Quantitative analyses

We analyzed the data based on taxonomic group (red algae, green algae, and seagrass), season, spatial area, and dominant species. Reported statistics are medians ($n>2$) and ranges in μg g^{-1} on a dry weight basis. The Kruskal–Wallis test was used to compare the median metal concentration across all floral species. The null hypothesis was rejected if $P \leq 0.05$. Additionally, factorial analysis was used to determine trends in the presence of heavy metals and the relative spatial and/or temporal variation.

Results

Based on our analysis, we found temporal and spatial variations in the concentration in several of heavy metals (Tables 1 and 2). Analyzing all of the species (all sites combined), we found significant seasonal differences in the heavy metal concentrations with the exception of Zn ($P=0.53$). Samples collected in April had a higher concentration of Cd ($P<0.001$) and Fe ($P=0.002$) and a lower concentration of Pb ($P<0.001$) and Ni ($P=0.002$) than the other months. Mn was highest in November ($P=0.049$) and Cu was higher in November compared to February ($P=0.01$). In comparisons between the profiles of heavy metals in major plant groups, we found that Ni differed significantly between the major groups ($P=0.01$), wherein seagrasses had lower concentrations. In the case of the analysis of green algae using all species combined, we found temporal significant differences of Cd in April ($P=0.01$). When comparisons between the five most relevant red algae (*Halophila johnstonii*, *Gracilaria vermiculophylla*, *G. textorii*, *Gracilariopsis andersonii*, and *Laurencia pacifica*) are done, significant differences between seasons can be detected (Tables 1 and 2).

However, spatial differences in Pb concentration was significantly different in *G. vermiculophylla* ($P=0.02$) in November but this species also had the highest concentration of Ni ($P=0.03$) in relation to the other four species. Also, there were significant differences in the concentrations of Cd ($P=0.001$), Fe ($P=0.01$), and Ni ($P=0.002$), while Pb ($P<0.001$) and Cu ($P=0.03$) were significantly different than the same metals in November. In the same month, highest Ni concentrations were recorded in *Codium amplivesiculatum* both from the middle zone. While in April, *C. amplivesiculatum*, *Codium cuneatum*, and *Caulerpa sertularoides* from the middle region had the highest concentrations of Cu (7.3 μg g^{-1} dw), Ni (11 μg g^{-1} dw), and Mn (61.4 μg g^{-1} dw), respectively.

In February, like November, we had the highest Fe concentration and several species were responsible for this difference (in *H. johnstonii*; 567.5 μg g^{-1} dw) and Zn concentration (in *G. textorii*; 46.8 μg g^{-1} dw). However, the lower zone had the highest concentrations of Cd (in *G. textorii*; 4.4 μg g^{-1} dw) and Ni (*L. pacifica* and *Chondria nidifica*; 13.3 and 13.3 μg g^{-1} dw). Cu (in *L. pacifica*; 2.9 μg g^{-1} dw) and Pb concentrations were highest in *G. andersonii* from the middle zone (3.8 μg g^{-1} dw).

Spatial differences in metal concentrations were dependent on the major taxa. In the case of seagrasses, we found a high concentration of Fe (Fig. 2) who was significant different from Mn (in *Z. marina*; 78.6 μg g^{-1} dw) concentrations were highest in the upper zone ($P=0.01$) because their uneven distribution in the area. Consistent with the above analysis were the multifactorial analysis (Fig. 3) wherein the extreme values are represented by Fe and Mn with no association among seasons or areas.

In the green algae (Figs. 4 and 5), we were able to find many metals in the entire area, but the significant difference was found in Cd in April ($P=0.01$), when all species combined, because the low value in relation to other metals are highly concentrated. There is no consistent pattern in relation to the area of the highest concentration of any metal, they tend to present a group lower (Fig. 4) in relation to higher concentration in different areas or times (Fig 5). This is well supported by the multivariate analysis (Fig. 6) wherein most of the observed metals show a combination among them and the areas of sampling.

We found an extremely high variability in the median content in the red algae (Figs. 7 and 8) but there were no

Table 1 Heavy metal concentrations µg g^{-1} dry weight in seaweeds and seagrasses colected in the three seasons at the Estero Banderitas. Values are expressed as medians and ranges given in parenthesis

Season	Species	Cd	Pb	Ni	Mn	Fe	Zn	Cu
November	*Codium amplivesiculatum*	0.2 (nd–0.5)	1.8 (1.3–2.3)	8 (6–9.9)	52.9 (42.2–63.5)	362.2 (349.8–374.7)	7 (5.2–8.8)	0.9 (0.7–1.2)
	Gracilaria textorii	1.5 (nd–3.9)	1.4 (nd–1.9)	4.8 (3–5.1)	48.5 (45.3–51.1)	325 (100.9–1231.2)	14.4 (6–58.8)	1.6 (0.7–4.8)
	Gracilaria vermiculophylla	0.6 (0.5–1.4)	2.7 (1–3.3)	5.3 (4.9–5.5)	22.4 (13–23.9)	302.7 (185.9–372.2)	7.3 (5.7–9.6)	1.3 (1–1.6)
	Gracilariopsis andersonii[a]	0.5 –	2 –	5.7 –	28.5 –	195.2 –	11 –	–
	Hypnea johnstonii	0.4 (0.3–1.5)	1.8 (1.1–8.5)	6.7 (6–6.9)	26.7 (23.7–282.5)	263.9 (227.8–1424.1)	4.1 (3.6–17.2)	1.8 (0.9–4.4)
February	*Codium amplivesiculatum*	nd	0.8 (0–2.3)	6.6 (6.2–7.3)	12.6 (12.1–20.4)	190.2 (189.5–522.7)	15 (2.2–18.2)	0.8 (nd–1.3)
	Codium cuneatum[a]	nd –	1.6 –	5.9 –	17.2 –	241.7 –	4.7 –	–
	Chondria nidifica	1 (nd–1.7)	1.6 (1.5–1.6)	9.3 (5.1–13.3)	15.6 (14.40–21)	291.5 (88.8–557.8)	9.1 (8.8–10.6)	1.3 (0.2–1.4)
	Gracilaria textorii	3.4 (2.7–4.4)	1 (0.7–2)	6 (4.5–6.2)	49.1 (43.5–54.8)	139.9 (81.8–476.3)	10.7 (8.5–46.8)	0.5 (0.4–1.2)
	Gracilaria vermiculophylla	1.1 (1.1–1.6)	0.8 (0.7–0.9)	4.3 (3.6–5.1)	19.3 (14.4–19.5)	206.2 (139.4–269.9)	9.7 (9.6–10.9)	0.6 (0.3–1.6)
	Gracilariopsis andersonii[a]	1.6 –	3.8 –	4.5 –	23.5 –	160.4 –	8.7 –	2.1 –
	Hypnea johnstonii[a]	nd –	nd –	11.3 –	20.6 –	567.5 –	2 –	nd –
	Laurencia pacifica[a]	3 –	1.7 –	13.3 –	25.2 –	195.8 –	14.9 –	2.9 –
	Sarcodiotheca gaudichaudii[a]	0.9 –	1 –	5.4 –	17.2 –	121.8 –	5.3 –	0.1 –
	Zostera marina[a]	nd –	2.5 –	3.1 –	78.6 –	51.1 –	13.5 –	0.4 –
April	*Codium amplivesiculatum*	1.6 (1.2–1.9)	0.5 (0.4–0.7)	7.8 (7.6–7.9)	18.7 (15.3–22.1)	399.2 (298.1–500.4)	9.7 (5.7–14.2)	4.1 (1–7.3)
	Codium cuneatum	2.1 (1.9–2.2)	0.3 (0.1–0.5)	7.1 (3.2–11)	16.7 (10.5–23)	284.3 (141.5–427.1)	7.3 (6.4–8.1)	1.2 (0.5–1.8)
	Caulerpa sertularoides	2.1 (1.8–2.3)	0.2 (nd–0.4)	2.6 (1.8–3.4)	34.3 (7.3–61.4)	374 (223.9–524.1)	8.3 (6.6–10.1)	1.8 (1.1–2.6)
	Gracilaria crispata[a]	4.6 –	nd –	3.9 –	40.3 –	576.8 –	11.6 –	1.6 –
	Gracilaria textorii	4.5 (4.3–4.8)	0.4 (0.1–0.6)	5.3 (3–7.6)	41.5 (37.6–45.4)	579.5 (578.4–580.6)	12.3 (11.5–13.1)	1.7 (1.5–1.8)
	Gracilaria vermiculophylla	2.9 (2.7–2.9)	0.2 (nd–0.6)	2.9 (1.1–2.9)	18.1 (14.7–23.6)	236.2 (214.4–771.5)	10.6 (7.5–11.7)	0.9 (0.9–1.6)
	Gracilariopsis andersonii[a]	3.8 –	0.1 –	2.3 –	25.5 –	322.3 –	13.4 –	1.5 –
	Hypnea johnstonii[a]	2.7 –	0.6 –	1.8 –	41.9 –	774.5 –	8.8 –	2.1 –
	Laurencia pacifica[a]	4.6 –	nd –	1.9 –	22.9 –	497.6 –	10.2 –	1.8 –
	Ruppia maritima	4.5 (2.1–7)	2.1 (0.5–3.8)	2.3 (1.7–2.9)	30.6 (28.6–32. 6)	1230.2 (1017.4–1443)	16.9 (8.9–24.9)	0.5 (nd–0.9)
	Zostera marina[a]	2.2 –	nd –	2.8 –	33.9 –	630.3 –	16.5 –	1.6 –

nd not detected

[a] The values are referred to one specimen

Table 2 Heavy metal concentrations (μg g^{-1} dry weight) in seaweeds and seagrasses collected in the three sites. Values are expressed as medians and ranges given in parenthesis

Site	Species	Cd	Pb	Ni	Mn	Fe	Zn	Cu
Head	*Codium amplivesiculatum*[a]	nd –	2.3 –	6.6 –	20.4 –	522.7 –	18.2 –	0.8 –
	Chondria nidifica[a]	nd –	1.5 –	5.1 –	14.4 –	88.8 –	8.8 –	0.2 –
	Gracilaria textorii	1.3 (nd–2.7)	1 (nd–2)	4.5 (3 – 6)	50.1 (45.3–54.8)	853.7 (476.3–1231.2)	52.8 (46.8–58.8)	3 (1.2–4.8)
	Gracilaria vermiculophylla	1.1 (0.6–2.9)	0.7 (0.2–3.3)	5 (1.1–5.1)	22.4 (19.5–23.6)	236.2 (206.2–372.2)	9.6 (7.5–10.9)	0.8 (0.3–1.6)
	Gracilariopsis andersonii[a]	0.5 –	2 –	5.7 –	28.5 –	195.2 –	11 –	2.5 –
	Hypnea johnstonii	0.7 (nd–1.5)	4.3 (0–8.5)	9.1 (6.9–11.4)	151.6 (20.6–282.5)	995.8 (567.5–1424.1)	9.6 (2–17.2)	(nd–4.4)
	Ruppia maritima[a]	6.9 –	3.8 –	2.9 –	32.6 –	1017.4 –	24.9 –	nd –
Medium	*Codium amplivesiculatum*	0.5 (nd–1.2)	0.7 (nd–1.3)	7.9 (7.3–10)	22.1 (12.1–63.5)	349.8 (190.2–500.4)	5.2 (2.2–14.2)	1.2 (nd–7.3)
	Codium cuneatum	0.9 (nd–2.3)	1 (0.5–1.6)	8.4 (5.9–11)	20.1 (17.2–22.9)	334.4 (241.7–427.1)	6.4 (4.7–8.1)	1.1 (0.4–1.8)
	Caulerpa sertularoides[a]	2.3 –	0.4 –	3.4 –	61.4 –	524.1 –	10.1 –	2.5 –
	Chondria nidifica[a]	1 –	1.6 –	9.3 –	20.9 –	557.8 –	10.6 –	1.4 –
	Gracilaria textorii	3.9 (3.4–4.8)	1 (0.6–1.4)	4.8 (4.5–7.6)	45.4 (43.5–51.2)	325 (139.9–580.6)	8.5 (6–13.1)	0.7 (0.4–1.8)
	Gracilaria vermiculophylla	1.4 (1.1–1.6)	0.9 (0.6–1)	3.5 (2.9–5.5)	18.1 (13–19.3)	302.7 (269.9–771.5)	9.7 (7.3–10.6)	1.4 (1–1.6)
	Gracilariopsis andersonii[a]	1.6 –	3.8 –	4.5 –	23.5 –	160.4 –	8.7 –	2.1 –
	Hypnea johnstonii[a]	0.3 –	1.1 –	6.7 –	26.7 –	263.9 –	4.1 –	1 –
	Ruppia maritima[a]	2.1 –	0.5 –	1.7 –	28.6 –	1443 –	8.9 –	0.9 –
	Sarcodiotheca gaudichaudii[a]	0.9 –	1 –	5.4 –	17.2 –	121.8 –	5.3 –	0.1 –
Mouth	*Codium amplivesiculatum*	nd (nd–1.9)	0.8 (0.4–2.3)	6.2 (6–7.6)	15.3 (12.6–42.2)	298.1 (189.5–374.7)	8.8 (5.2–15)	1 (0.7–1.3)
	Codium cuneatum[a]	2.2 –	0.1 –	3.2 –	10.5 –	141.5 –	6.4 –	0.5 –
	Caulerpa sertularoides[a]	1.8 –	nd –	1.8 –	7.3 –	223.9 –	6.6 –	1.1 –
	Chondria nidifica[a]	1.7 –	1.6 –	13.3 –	15.6 –	291.5 –	9.1 –	1.3 –
	Gracilaria crispata[a]	4.6 –	nd –	3.9 –	40.3 –	576.8 –	11.6 –	1.6 –
	Gracilaria textorii	4.3 (1.5–4.4)	0.7 (0.1–1.9)	5.1 (3–6.2)	48.5 (37.6–49.1)	100.9 (81.8–578.4)	11.5 (10.7–14.4)	1.5 (0.5–1.6)
	Gracilaria vermiculophylla	1.6 (0.5–2.9)	0.8 (0–2.7)	4.3 (2.9–5.3)	14.7 (14.4–23.9)	186 (139.4–214.4)	9.6 (5.7–11.7)	0.9 (0.6–1.3)
	Gracilariopsis andersonii[a]	3.8 –	0.1 –	2.3 –	25.5 –	322.3 –	13.4 –	1.5 –
	Hypnea johnstonii	1.6 (0.4–2.7)	1.2 (0.6–1.8)	3.9 (1.8–6)	32.8 (23.7–41.9)	501.1 (227.8–774.5)	6.2 (3.6–8.8)	1.9 (1.8–2.1)
	Laurencia pacifica	3.8 (3–4.6)	0.8 (nd–1.7)	7.6 (1.9–13.3)	24 (22.9–25.2)	346.7 (195.8–497.6)	12.6 (10.2–14.9)	2.3 (1.8–2.6)
	Zostera marina[a]	2.2 –	nd –	2.8 –	33.9 –	630.3 –	16.5 –	1.6 –

nd not detected

[a] The values are referred to one specimen

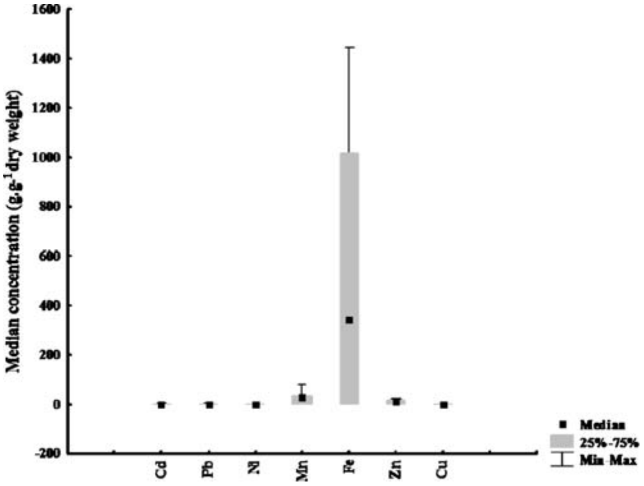

Fig. 2 Spatial comparison of the heavy metal median concentration among seagrasses (species combined in all following graphs, *Cd* cadmium, *Pb* lead, *Ni* nickel, *Fe* iron, *Zn* zinc, *Cu* copper, *Al* aluminum)

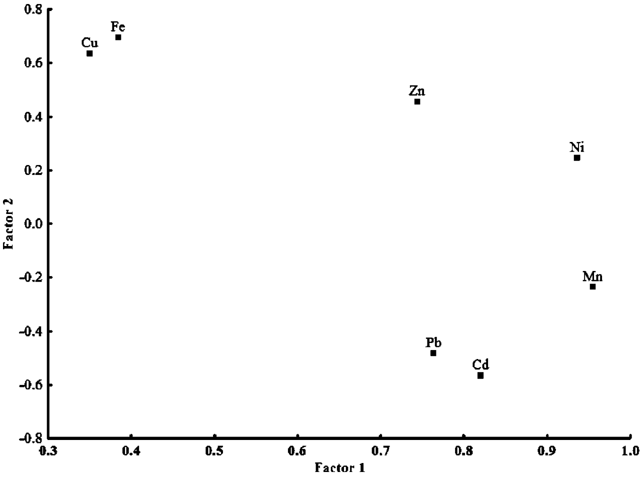

Fig. 3 Multivariate analysis of heavy metal contents in seagrasses

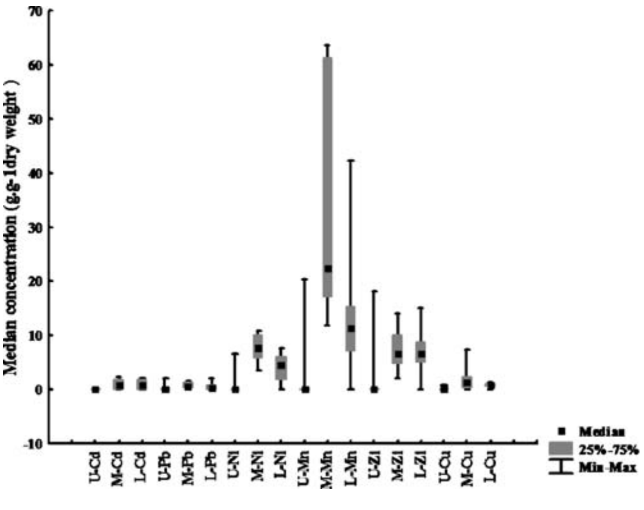

Fig. 4 Spatial comparison of heavy metal in green algae wherein the lower median values of concentration is present (for all the following graphs terminology is the same, *U* upper, *M* median, and *L* lower)

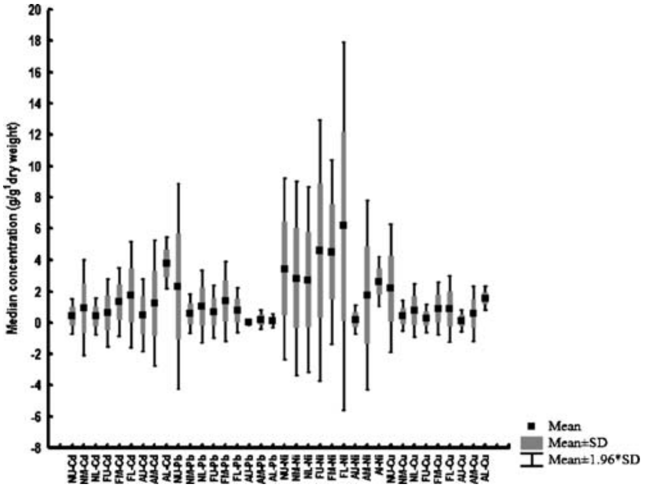

Fig. 5 Spatial comparison of heavy metal in green algae wherein the higher median values of concentration is present

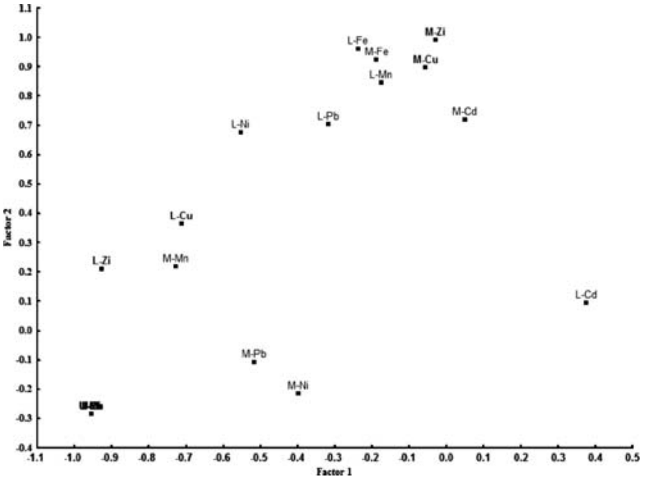

Fig. 6 Multivariate analysis of the spatial concentration of heavy metal in green algae

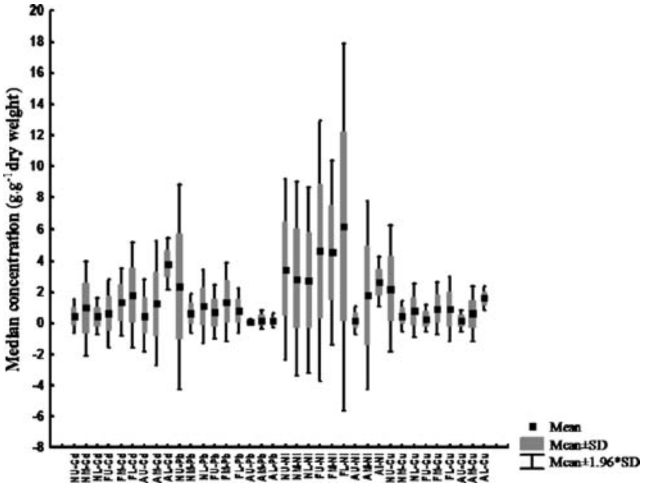

Fig. 7 Spatial comparison of heavy metal in red algae wherein the higher median values of concentration is present

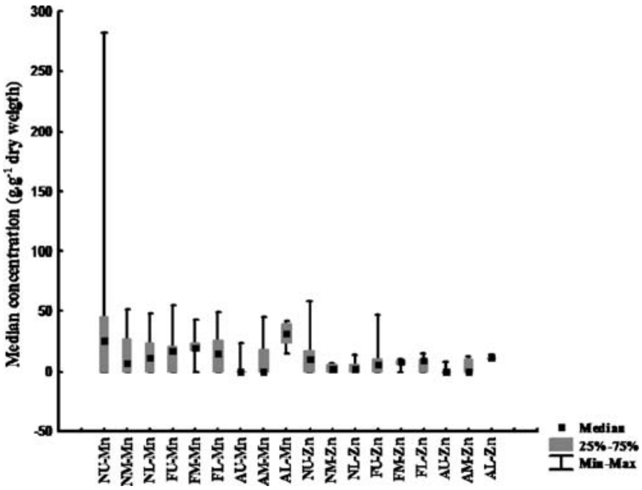

Fig. 8 Spatial comparison of heavy metal in red algae wherein the lower median values of concentration is present

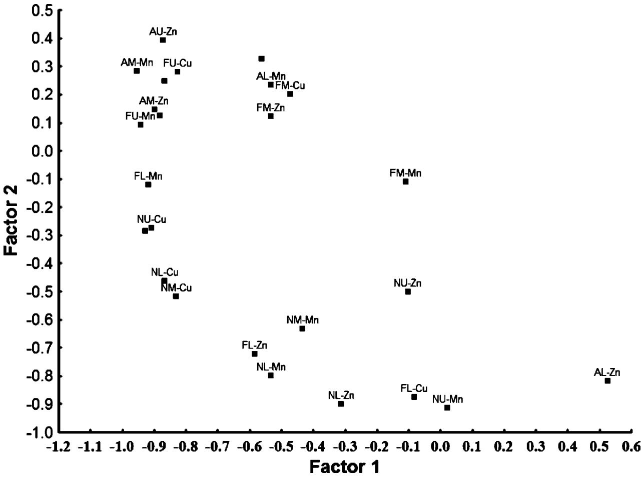

Fig. 10 Multivariate analysis of the spatial concentration of heavy metal in red algae

significant differences between sites, with the exception of Zn which was significantly higher in the upper zone (P=0.02). The highest concentration of any metal was Fe in *Hypnea johnstonii* from the upper zone (1,424.1 µg g^{-1} dw). The highest concentration of Mn (282.5 µg g^{-1} dw) and Pb (8.5) µg g^{-1} dw) were also detected in *H. johnstonii* from the upper zone. Similarly, Zn (58.8 µg g^{-1} dw) and Cu (4.8 µg g^{-1} dw) concentrations were highest in *G. textorii* in the same zone. The highest Cd concentrations were measured in *G. textorii* (4.8 µg g^{-1} dw; Figs. 6 and 7). Multivariate analyses show the same path (Figs. 9 and 10) with the clump of areas within metals and a group of metals with high concentration (Fig. 7) in relation to metals with low concentration (Fig. 8).

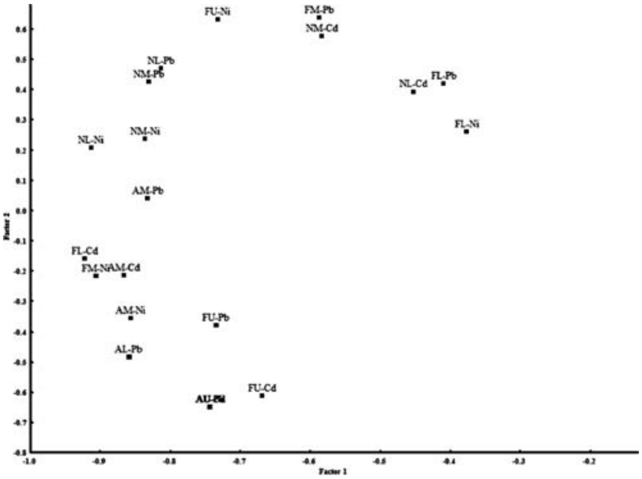

Fig. 9 Multivariate analysis of the spatial concentration of heavy metal in red algae

Discussion

We found significant spatial and temporal variations in heavy metal concentrations in marine plants as previous spatial studies has shown in the region (Páez-Osuna et al. 2000; Sánchez-Rodríguez et al. 2001; Rodriguez-Castañeda et al. 2006, Rodríguez-Meza et al. 2008). The high concentration of Zn and Fe in the upper region might be related to the isolation of the site (Rodríguez-Meza et al. 2008). Heavy metal concentration was, in some cases, in the levels of toxicity. Temporal variations in metal concentrations, such as high concentrations in Cd and other metals observed in April, may be related to local upwelling events. Surface water Cd concentrations have been strongly correlated with upwelling (Lares et al. 2002) which occurs during spring and early summer off the coast of Magdalena Bay (Zaytsev et al. 2003). These levels of Cd in seaweeds has not been observed in the Gulf of California studied populations but strong species and spatial variations where observed (Páez-Osuna et al. 2000; Sánchez-Rodríguez et al. 2001; Rodriguez-Castañeda et al. 2006).

The differences in heavy metal concentrations that we found in the seaweeds did not generally correspond with patterns of those elements previously observed in the sediment from the same region or seaweed species (Rodríguez-Meza et al. 2008), contrary to the studied sites in the Gulf of California near a mine (Rodriguez-Castañeda et al. 2006) or near industrial ports (Páez-Osuna et al. 2000; Sánchez-Rodríguez et al. 2001; Rodriguez-Castañeda et al. 2006). This finding, together with the observed species differences, suggests that the metabolic condition and life-cycle stage of the individual species might influence metal uptake and accumulation (Lobban and Wynne 1981). Similarly, Riget et al. (1995) found differences between seaweed species *Ascophyllum nodosum*, *Fucus vesiculosus*, and *Fucus distichus*. We found lower levels of Ni and Zn in *H. johnstonii* than in the environment as reported by Rodríguez-Meza et al. (2008). Based on our data, there are similarities between the composition and concentration of heavy metals between the plant species reviewed and the sediment; except in the case of Cu, Fe, and Mn (Rodríguez-Meza et al. 2008). All those elements are considered critical in the photosynthetic metabolism (Lobban and Wynne 1981). We might assume that those elements are more easily assimilated by the plants because of their use in photosynthesis.

The role of seaweeds and seagrasses in coastal lagoons (like Banderitas or any other along the Baja California Peninsula) are relevant because they are feeding grounds for black turtles (*C. mydas*), loggerhead turtles (*Caretta caretta*), olive Ridley turtles (*Lepidochelys olivacea*), and hawksbill turtles (*Eretmochelys imbricata*) and migratory birds like Brant geese (*Branta bernicla*; Seminoff 2000; Herzog and Sedinger 2004). All of the species are included in the Mexican endangered species list (NOM ECOL 059) and on the red list in the UICN endangered species (www.uicnredlist.org). They are high productivity areas for fishing all kind of products (CONABIO 2000; Carta Nacional 2005). The fact that we found more significant variation in the spatial than temporal heavy metal concentrations in most of the species show that they might be constantly incorporated in the diet of many herbivorous animals (Gardner et al. 2006) with severe consequences in their health. Management strategies for these species should consider monitoring the levels of metals.

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