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Trace metal content in sediments and autochthonous intertidal organisms from two adjacent bays near Ushuaia, Beagle Channel (Argentina)

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ABSTRACT

The aim of this work was to monitor levels of Cd, Cu, Pb, Zn and Fe in sediments, mussels (*Mytilus edulis chilensis*) and limpets (*Nacella magellanica*) from the Industrial zone (IZ); fuel dock (FD) and Ushuaia Peninsula (UP) on the Beagle Channel. In sediments, seasonal variations showed high values of Cu and Pb in spring and Zn in autumn. Comparing among sites, Cd concentration was superior in UP (2.07 μg/g); while Pb was maximum in FD (41.00 μg/g). In mussels, a higher bioaccumulation in winter was found. Mussels from UP showed the highest bioaccumulation of Cu (5.95 μg/g) and those from FD presented the highest of Zn (170.15 μg/g). A seasonal trend was not found for limpets, while differences among sites were observed for Cd being the highest at IZ (3.02 μg/g). Although pollution level found was low, anthropic activities at the studied sites could result in deterioration, further monitoring is recommended.

1. Introduction

The coastal areas adjacent to human and industrial settlements are influenced by direct anthropogenic activities allowing more accurate data about the impacts that such activities produce (Valdés and Sifeddine, 2009). Marine sediments are the ultimate repository of many substances and therefore have been recognized as indicators of pollution levels (Botello et al., 1997; Förstner and Salomons, 1980).

Trace metals such as cadmium, copper, lead, zinc and iron are considered among the most important pollutants. The natural concentrations of these elements in an ecosystem can vary by natural or anthropogenic mobilization. These compounds, widely distributed in the environment, are used in industries and are present in most wastewaters discharged into the sea, even from domestic sources (Páez Osuna, 2005).

The levels of trace metals in environments under constant human pressure could be of concern due to their toxicity and their ability to accumulate in the biota (Islam and Tanaka, 2004). Several studies have been conducted to analyze the influence and effect of pollutants, using autochthonous organisms to quantify the presence of some elements in particular (Szefer et al., 2004). Marine organisms, especially mollusks, are considered important tools in monitoring programs because they are able to accumulate trace metals in their tissues from the environment through filtering water and food (Cravo and Bebianno, 2005; Giarratano and Amin, 2010; Hamed and Emara, 2006; Usero et al., 2005).

Ushuaia city is located on the coast of the Beagle Channel (54° 48′S, 68° 190′W) and its urban development is extended approximately along 20 km. The coastal system is subjected to the contribution of several substances from different sources, mainly through natural water courses that flow through the city and are loaded with wastes; storm waters; untreated sewage and industrial wastewaters (Amin et al., 2011; Duarte et al., 2011; Esteves et al., 2006; Giarratano et al., 2010; Gil et al., 2011; Torres et al., 2009). Additionally, in the area there are very large peatlands that produce big loads of organic matter (Roig, 2004) and have been considered as potential sources of nitrogen (Amin et al., 2011).

The fast and unplanned urban growth and the tourist activities are other key factors to be considered. The constant population growth and industrial production, mainly electronic articles, could also be an important source of trace metals for the system.

The presence of trace metals in adjacent areas to Ushuaia city using transplanted mussels (Giarratano et al., 2010, 2011) and native organisms have been reported (Comoglio et al., 2011; Duarte

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et al., 2011), but none of them considered the seasonal variation during four consecutive seasons using two different species of mollusks.

The aim of this work was to monitor spatial and seasonal patterns of accumulation of Cd, Cu, Pb, Zn and Fe in intertidal sediments and in autochthonous organisms from coastal environments surrounding Ushuaia city. Two species of mollusks were used, the mussel *Mytilus edulis chilensis* (filter feeder) and the limpet *Nacella magellanica* (scraper organism), which are among the most conspicuous species in the Beagle Channel. We also evaluated physical and chemical parameters that characterize the studied sites. An attempt also has been made to understand the possible influence of physical and chemical parameters of the water and sediments from the studied sites on the observed patterns of trace metals.

2. Materials and methods

2.1. Sampling

Three sites were selected on the coastal zone of Ushuaia city according to the kind of anthropogenic influence: industrial zone (IZ) and fuel dock (FD) within Ushuaia bay and the third one located at the outflow of the sewage pipeline in the occidental coast of Ushuaia Peninsula (UP) within Golondrina bay (Fig. 1). Samples of water, sediment and organisms were collected at each site in winter and spring of 2006 and summer and autumn of 2007 as described in the following paragraphs.

2.2. Physical and chemical parameters in water samples

Salinity, temperature, pH and dissolved oxygen were registered *in situ* during low tide, using a multiparameter device HORIBA U-10. At the same time, two water samples were collected by hand using plastic bottles according to the analytical specifications and were transported to the laboratory to be analyzed. A volume of 1000–1250 ml was filtered by GF/C filter to determine the concentration of chlorophyll-*a* using a Sequoia Turner (model 450) fluorometer (Holm-Hansen et al., 1965). Another aliquot of 1000 ml was filtered by GF/C membrane to determine particulate organic matter (POM) in the retained material and dissolved inorganic nutrients in the filtrate. POM was analyzed following the method described by Strickland and Parsons (1972). Ammonia, nitrate, nitrite, phosphate and silicate were determined according to Strickland and Parsons (1972), Treguer and Le Corre (1975), Grashoff et al. (1983), Eberlein and Kattner (1987) and Technicon® (1973), respectively. A Perkin Elmer UV–Vis lambda 25 spectrophotometer was used to perform the corresponding POM and ammonia determinations. A four-channel automatic Technicon® AA-II autoanalyzer was used for the other nutrients. The results of all parameters were reported as the arithmetic mean.

2.3. Trace metals in sediments

Intertidal surface samples (~5 cm depth; $N = 12$) were obtained to evaluate total concentration of Cd, Pb, Cu, Zn and Fe. A composited sample of 10 subsamples of sediment (about 1 kg) was taken at each site and at each season using a plastic spoon and was stored in a polyethylene bag. At the laboratory, composite samples were dried out in an oven until constant weight at 60 ± 5 °C and then sieved in order to obtain the smallest fraction (<62 μm). Subsamples (about 0.5 g) were taken to determine total metal concentrations following the method described by Marcovecchio et al. (1988). This technique includes a mineralization with a strong acid mixture ($HClO_4$:HNO_3, 1:3 v/v) under a controlled temperature glycerin bath (110 ± 5 °C). The extracts were diluted in 0.7% (v/v) HNO_3 up to 10 ml and metal concentrations were measured using a Perkin Elmer 2380 AAS with air-acetylene flame.

In an attempt to compensate the natural variability, total trace elements in sediments were normalized to Fe, so any anthropogenic contribution could be detected and quantified. An enrichment factor (EF) was calculated for each metal by dividing its ratio to the normalizing element by the same ratio found in Earth crust. Factors were calculated from the formula:

$$EF = (Me/Fe)\ sample/(Me/Fe)\ crust$$

where (Me/Fe) sample is the ratio of metal concentration (μg/g dw) to Fe concentration (% dw) in the sediment sample and (Me/Fe)

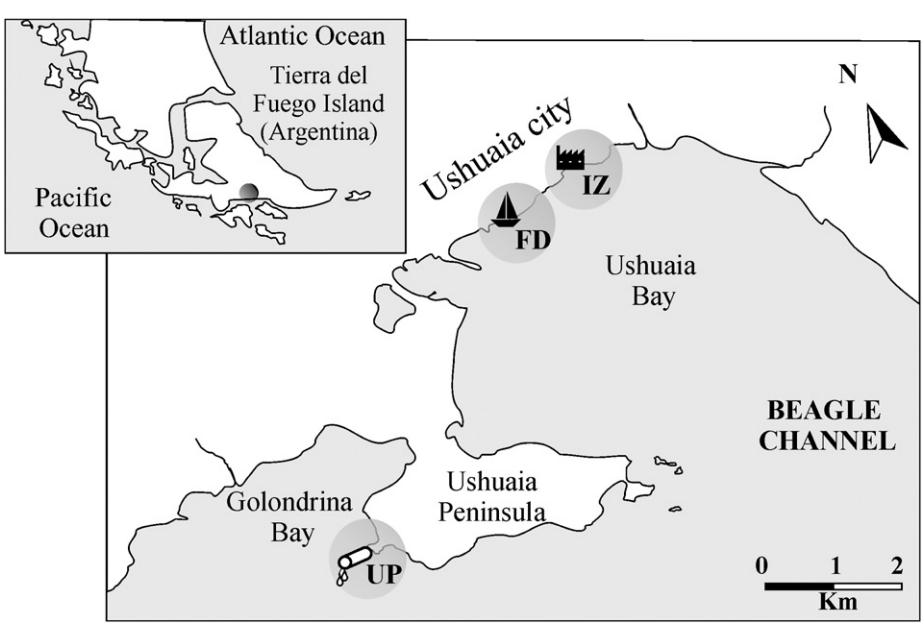

Fig. 1. Location of sampling sites: Industrial zone (IZ), fuel dock (FD) and Ushuaia peninsula (UP).

crust is the corresponding ratio in Earth crust. The values for the Earth crust are from Martin and Maybeck (1979) and represent the average composition of the surficial rocks exposed to weathering. These values are: Fe 4.1%, Cd 0.2, Pb 16, Cu 32 and Zn 127 μg/g. EF around 10 indicates that the element in the sediment is of lithogenic origin, whereas EF much greater than 10 indicates that the element is of anthropogenic origin (Szefer et al., 1996).

2.4. Trace metals in organisms

Adult native mussels *M. edulis chilensis* and limpets *N. magellanica* (5.0 ± 0.5 cm shell length) were collected by hand ($N = 20$ for each species) during low tide on the intertidal area and were transported to the laboratory in plastic buckets containing seawater from the corresponding sampling site. At the laboratory, whole soft tissues of each species were processed in pooled samples ($N = 5$), freeze-dried, homogenized in porcelain mortar and stored in polyethylene bags until analysis. From each composite sample, aliquots of about 0.5 g were taken and digested according to Marcovecchio et al. (1988).

All sediment and organism samples were run by duplicate. Results were averaged and expressed as micrograms (except for Fe in sediment which was expressed as milligrams) per gram of dry basis, Analytical quality (AQ) was checked against certified reference materials from National Institute for Environmental Studies (NIES), Tsukuba (Japan). The percentage of recovery for all metals ranged between 91% and 103%. The detection limit for each metal was: Cu 0.77, Zn 0.88, Fe 2.73, Cd 0.27 and Pb 2.15 (μg/g dw).

2.5. Statistical analysis

Trace metal concentration in sediments and tissues were reported as mean ± standard deviation for each site (mean values from the 4 seasons) and for each season (mean values from the 3 sites).

Variations were tested by two-way ANOVA with sites and seasons as factors. When a significant difference was observed in the ANOVA, *a posteriori* Tukey's test was used to check differences among groups. Logarithmic transformations of the data were performed when necessary to fulfill the conditions of the parametric analysis of variance. Statistical significance was accepted at $p < 0.05$.

3. Results

3.1. Physical and chemical parameters in water samples

Temperature showed typical seasonal variations, with the lowest averages in winter (4.88 °C) and the highest in summer (8.80 °C). Average value of pH in spring (8.14) was higher than in other seasons. Dissolved oxygen was minimum in winter (8.96 mg/L), being in the rest of the year close or above saturation. The highest salinity values were measured in winter (30.23‰) and a decreasing tendency was observed in the following seasons. The lowest values were measured at UP in summer (19.85%) and autumn (20.85%).

Chlorophyll *a* concentrations were maximum in spring (0.58 μg/L) and minimum in winter (0.06 μg/L). Nitrates were the highest in winter (12.26 μmol/L). The rest of the inorganic nutrients did not show clear seasonal patterns. In summer and autumn, water samples from UP showed the highest values of all nutrients, being the only exception the silicates measured at IZ in autumn (21.98 μmol/L). The uppermost values of particulate organic matter were recorded in summer at IZ (1.86 mg C/L) and at FD (2.34 mg C/L) and in autumn at UP (3.06 mg C/L) (Table 1).

Table 1
Mean and standard deviation values of physical and chemical parameters measured in water samples.

Season	Site	Temp (°C)	pH	DO (mg/L)	Salinity ‰	Chl. *a* (μg/L)	POM (mg C/L)	Ammonia (μmol/L)	Nitrite (μmol/L)	Nitrate (μmol/L)	Phosphate (μmol/L)	Slicate (μmol/L)
Winter	IZ	5.10 ± 0.28	7.76 ± 0.04	8.48 ± 0.10	30.10 ± 0.42	0.09 ± 0.10	0.31 ± 0.31	5.81 ± 5.91	0.40 ± 0.00	12.77 ± 0.41	4.56 ± 4.23	6.27 ± 0.27
	FD	4.95 ± 0.49	7.69 ± 0.05	8.77 ± 0.52	30.20 ± 0.57	0.02 ± 0.01	0.17 ± 0.17	0.55 ± 0.00	0.36 ± 0.02	13.39 ± 0.54	1.41 ± 0.20	6.84 ± 0.00
	UP	4.60 ± 0.71	7.78 ± 0.01	9.63 ± 0.68	30.40 ± 0.42	0.07 ± 0.01	0.25 ± 0.25	0.91 ± 0.46	0.27 ± 0.01	10.61 ± 0.60	1.00 ± 0.11	4.01 ± 0.00
Spring	IZ	8.15 ± 1.63	8.16 ± 0.00	13.90 ± 4.81	25.35 ± 3.18	0.44 ± 0.48	0.26 ± 0.26	19.62 ± 26.72	0.11 ± 0.06	1.61 ± 0.31	0.90 ± 0.82	5.52 ± 2.84
	FD	8.00 ± 1.84	7.94 ± 0.30	10.99 ± 0.25	26.25 ± 4.74	0.77 ± 0.59	0.85 ± 0.85	1.33 ± 0.60	1.07 ± 1.38	3.66 ± 3.31	0.84 ± 0.09	2.39 ± 0.16
	UP	8.15 ± 1.48	8.33 ± 0.05	14.43 ± 3.85	25.75 ± 6.01	0.54 ± 0.29	1.03 ± 1.03	0.44 ± 0.11	0.38 ± 0.40	1.43 ± 1.34	0.54 ± 0.04	2.26 ± 1.05
Summer	IZ	8.60 ± 0.85	7.78 ± 0.11	10.73 ± 0.33	24.05 ± 0.21	0.20 ± 0.03	1.86 ± 1.86	3.12 ± 1.22	0.26 ± 0.20	1.53 ± 1.15	0.73 ± 0.29	5.26 ± 3.77
	FD	8.50 ± 0.71	7.69 ± 0.05	10.29 ± 0.05	24.05 ± 0.07	0.38 ± 0.39	2.34 ± 2.34	1.00 ± 0.29	0.24 ± 0.08	2.07 ± 1.21	0.75 ± 0.20	3.84 ± 0.85
	UP	9.30 ± 1.70	7.64 ± 0.02	9.33 ± 1.73	19.85 ± 0.49	0.18 ± 0.05	1.89 ± 1.89	141.34 ± 31.94	1.26 ± 0.24	7.17 ± 0.46	14.40 ± 8.78	20.90 ± 1.02
Autumn	IZ	6.40 ± 0.00	7.66 ± 0.11	9.86 ± 0.83	22.30 ± 1.84	0.23 ± 0.11	0.90 ± 0.90	2.41 ± 0.22	0.51 ± 0.29	6.35 ± 0.18	2.45 ± 0.58	21.98 ± 0.51
	FD	6.15 ± 0.07	7.60 ± 0.09	9.66 ± 0.58	23.00 ± 0.42	0.29 ± 0.25	1.44 ± 1.44	1.80 ± 0.83	0.32 ± 0.27	2.95 ± 2.71	1.01 ± 0.23	5.59 ± 3.31
	UP	6.65 ± 0.07	7.65 ± 0.05	10.22 ± 0.40	20.85 ± 2.47	0.11 ± 0.02	3.06 ± 3.06	112.12 ± 9.38	0.96 ± 0.73	7.51 ± 4.82	10.75 ± 13.94	16.58 ± 17.33

Temp. (Temperature); DO (dissolved oxygen); Chl. *a* (Chlorophyll *a*); POM (particulate organic matter).

Table 2
Results of ANOVA analysis for trace metal concentrations in sediment and organisms. Degrees of freedom: 3 for season and 2 for site. Values in bold indicate significant differences at $p < 0.05$.

	Cd		Pb		Cu		Zn		Fe	
	F	*p*	*F*	*p*	*F*	*p*	*F*	*p*	*F*	*p*
Sediment										
Season	2.65	0.08	27.17	**<0.01**	14.33	**<0.01**	17.57	**<0.01**	0.62	0.61
Site	6.64	**0.01**	16.20	**<0.01**	3.19	0.20	3.25	0.06	2.76	0.09
M. edulis chilensis										
Season	3.56	**0.04**	–	–	30.52	**<0.01**	32.38	**<0.01**	37.41	**<0.01**
Site	1.54	0.24	–	–	4.08	**0.04**	27.27	**<0.01**	1.54	0.25
N. magellanica										
Season	1.07	0.39	3.09	0.05	10.22	**0.02**	6.29	**<0.01**	2.21	0.53
Site	11.67	**<0.01**	1.63	0.22	1.52	0.47	0.65	0.54	2.44	0.29

3.2. Trace metals in sediments

Significant differences were found among sites in Cd and Pb concentrations (Table 2). The peak values of Cd were found at UP (2.07 μg/g) and the highest of Pb at FD (41.00 μg/g) (Fig. 2). The maximum concentrations of Pb (44.52 μg/g) and Cu (54.75 μg/g) were measured in spring, while for Zn an increasing tendency was measured from winter (88.88 μg/g) to autumn (168.14 μg/g) (Fig. 3).

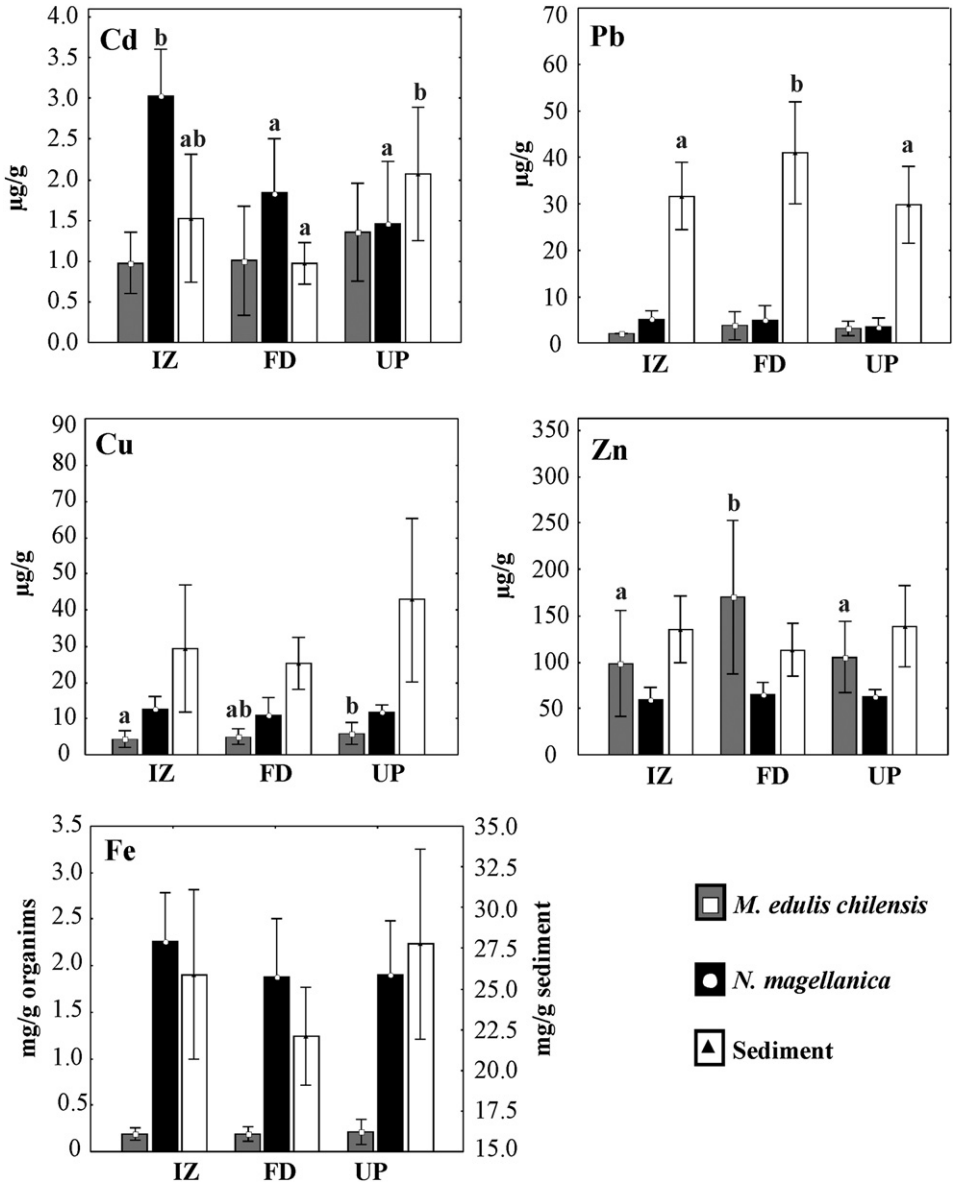

Fig. 2. Concentrations of Cd, Pb, Cu, Zn and Fe in *M. edulis chilensis*, *N. magellanica* and sediment (mean values ± standard deviations) at each sampling site. For each metal, different letters indicate that spatial variation is significant at $p < 0.05$.

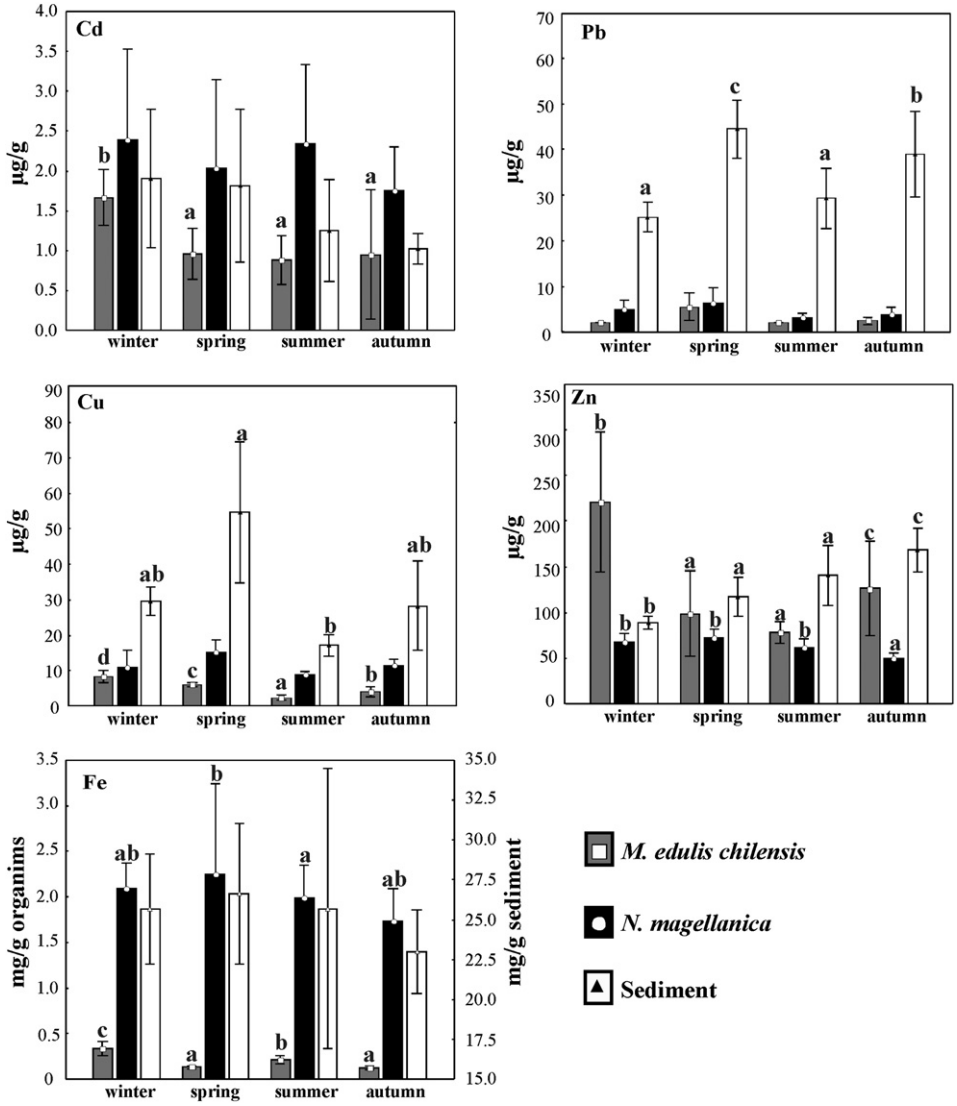

Fig. 3. Concentrations of Cd, Pb, Cu, Zn and Fe in *M. edulis chilensis*, *N. magellanica* and sediment (mean values ± standard deviations) at each sampling season. For each metal, different letters indicate that seasonal variation is significant at $p < 0.05$.

The Fe concentration in sediment showed no significant variations among sites or seasons.

The EF calculated in relation to Fe was greater than 10 only for Cd in 9 of the 12 composite samples. In the case of IZ, EF higher than 10 were observed in winter (11.52) and spring (16.06); at FD in winter (10.45), summer (10.44) and autumn (10.28); and at UP, in winter (24.26), spring (19.90) and summer (11.63) (Fig. 4).

3.3. Trace metals in organisms

In mussels *M. edulis chilensis* concentrations of Cu were higher in UP (5.95 µg/g) than in IZ (4.43 µg/g), while Zn concentration was the highest at FD (170.15 µg/g) (Fig. 3, Table 2). Significant differences among seasons were not found for Pb, meanwhile the other metals showed the highest values in winter (1.67 µg/g for Cd; 2.15 µg/g for Pb; 8.40 µg/g for Cu; 221.07 µg/g for Zn and 0.33 mg/g for Fe). Regarding Pb concentrations in mussels, values above the detection limit were only observed at FD (8.73 µg/g) and UP (5.66 µg/g) in spring and at UP (3.02 µg/g) in autumn (Fig. 3, Table 2).

For limpet *N. magellanica* significant differences among sites (Fig. 2) were found only for Cd showing the highest values at IZ (3.02 µg/g) (Table 2). Significant seasonal variations were recorded in Zn and Fe (Fig. 3). The lowest values of Zn were recorded in autumn (49.98 mg/g), while for Fe the minimum values recorded in summer (1.99 mg/g) were significantly lower than the highest values measured in spring (2.24 mg/g). No significant differences among sites or seasons were found for Cu and Pb concentrations.

4. Discussion

4.1. Trace metal concentrations in sediments

Trace metals enter into the aquatic environment from both natural and anthropogenic sources. The entry may be as a result of direct discharges into both freshwater and marine ecosystems or through indirect routes such as dry and wet deposition and land runoff (Hamed and Emara, 2006). Their ultimate repositories are the sediments, where they distribute according to different factors, mainly texture and anthropogenic influence. To minimize the effect of particle size in spatial differences in this study, metals were determined on the sediment fraction smaller than 62 µm.

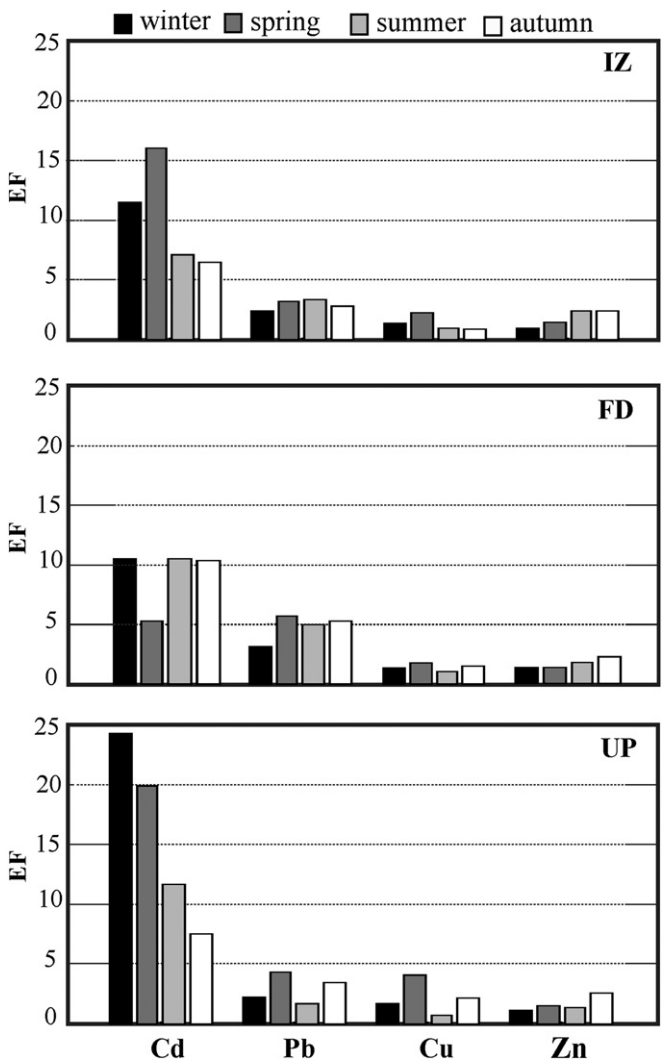

Fig. 4. Enrichment factor of trace metals in sediment from IZ, FD and UP.

In the case of IZ, the untreated industrial discharges and the lixiviates from solid wastes in the area could contribute to the levels of metals found in this work. Similar results have been found by Guzmán Amaya et al. (2005) in other areas located near industries.

Relative high concentrations of Pb in FD may be related to old fuel deposits which contained Pb. Nowadays most leaded fuels are not used in Argentina. This is confirmed by the lower values found in the present work than those reported for the same area by Amin et al. (1996).

In the case of Cd, higher levels at UP may be attributed to domestic wastewaters and storm waters which are discharged through untreated sewages (Esteves and Amin, 2004). Domestic wastewaters are considered an important source of trace metals into marine systems (Amat Infante et al., 2006; Förstner and Salomons, 1980). However, anaerobic conditions observed in sediments of this site, could have also contribute to the difference. Unlike the oxidized conditions of the sediments from FD and IZ, the strong smell and dark color observed in those from UP suggest that the metal would be mostly retained in the form of sulphides. Duarte et al. (2011) reported the highest level of particulate organic matter at UP, that contributes to the low oxygenation of the sediments. Organic enrichment of the benthic ecosystem may result in increased oxygen consumption by the sediment and formation of anoxic sediments (Kaiser et al., 1998). On the other hand, EF for Cd was higher than 10 in most of the samples of the 3 studied sites, indicating that levels are influenced by anthropogenic origin (Szefer et al., 1996) and/or by other external source. It is important to highlight that a percentage of that Cd would be of natural origin and could be linked to leaching from bedrock and upwelling phenomenon from marine sediment deposits (Sokolova et al., 2005). There is a previous research in a pristine area called Brown Bay, also on Beagle Channel, where the EF values were between 12 and 22 (Giarratano and Amin, 2010). In the same sense, Gil et al. (1999) found Cd in sediments from unpolluted Patagonian coastal areas and considered that it was of natural origin. Taking into account that upwelling phenomena and water circulation can play an important role in the distribution of such element, it would be necessary to quantify load inputs from residual waters entering the studied bays, in order to assess the actual human influence.

Trace metal concentrations found at the present work exceeded those recorded by Duarte et al. (2011) in a low impacted site located 5 km away from Ushuaia city and those reported by Bryan and Langston (1992) as unpolluted sediments (Cd 0.03 μg/g; Pb 25 μg/g; Cu 25 μg/g; Zn 100 μg/g). Additionally, our sediment data resulted similar to values of anthropic influenced coasts from Spain, Chile and Mexico reported by Ahumada (2006), Usero et al. (2005) and Guzmán Amaya et al. (2005), respectively. However, considering the concentrations that produce biological effect reported by Long et al. (1995) (Cd 1.2 μg/g; Pb 46 μg/g; Cu 34 μg/g; Zn 150 μg/g), only Cd and Cu from UP and Cd from IZ exceeded the limits.

4.2. Variations in trace metal concentrations in mussels and limpets

Temporal and spatial distributions of metals in organisms were not the same as in sediments. This could be indicative of different environmental bioavailability at each site and season. We found spatial variations in concentrations of Cd for *N. magellanica* (the highest at IZ) and Cu and Zn for *M. edulis chilensis* (the highest at UP and FD, respectively). In accordance with our results, several authors have found high metal bioaccumulation in mussels from industrial and harbor areas (Beldi et al., 2006; Hamed and Emara, 2006; Mora et al., 2004). Concentration of Cd in limpets from IZ could be related to discharges occurring at this site. Ansari et al. (2004) postulated that due to the association established between Cd and phosphates (considered one of the most important nutrients), Cd is incorporated into the phytoplankton. It is also possible a natural origin of Cd, as has been reported in worldwide environments (Ahumada and Vargas, 2005; Apeti et al., 2009; Bryan and Langston, 1992). Further studies are recommended in our study area to confirm this hypothesis. In the case of Zn, the highest concentration was found in mussels from FD, where its origin can be linked mainly to the intense port activities mentioned for this sector.

Regarding seasonal variations, a trend in the accumulation of metals was not found in *N. magellanica*, while in *M. edulis chilensis* the pattern showed the highest concentrations of Cd, Cu, Zn and Fe in winter. Similar results were reported for *M. edulis chilensis* (Giarratano and Amin, 2010), *Mytilus galloprovincialis* (Szefer et al., 2004) and *Barbatus barbatus* (Hamed and Emara, 2006). Several studies that have reported higher levels of metals in winter (Avelar et al., 2000; Regoli, 1998; Soto et al., 1995) explained that could be related to the reproductive cycle stages that influence the incorporation, storage and/or excretion of metals and seasonal changes in fresh weight during the development of gonadal tissue.

The trace metal data obtained in the present study was comparable to those reported for other Patagonian coastal areas and lower than those reported for polluted areas (Table 3). It is important to note that concentrations measured in soft tissues

Table 3
Comparison of trace metal concentrations (expressed as μg/g, except for Fe mg/g) of soft tissues obtained in the present study with data from others regions.

Species	Reference	Degree of impact		Trace metals				
				Cd	Pb	Cu	Zn	Fe
N. magellanica	Present work	IZ	Mean	3.02	5.24	12.87	59.11	2.26
			SD	0.57	1.74	3.35	13.96	0.53
		FD	Mean	1.84	5.04	10.92	64.97	1.88
			SD	0.67	3.14	4.97	13.81	0.62
		UP	Mean	1.46	3.55	11.76	62.71	1.90
			SD	0.76	1.86	2.04	7.75	0.58
P. caerulea	Hamed & Emara (2006)	Gulf of Suez (Impacted area)	Min	0.23	2.16	1.02	12.62	0.46
			Max	3.74	147.55	18.64	408.50	6.14
N. concinna	Ahn et al. (2002)	Antártica (Impacted area)	Mean	5.04	1.42	27.60	69.90	3.13
			SD	1.56	0.39	5.40	7.70	0.66
Patinigera sp.	Gil et al. (2006)	Patagonian Coast (Low impacted area)	Mean value	3.33	6.17	13.03	73.86	s/d
P. aspera	Cravo & Bebianno (2005)	Portugal Coast (Unpolluted area)	Min	3.50	s/d	3.50	36.10	0.39
			Max	9.10		9.20	114.20	2.15
P. aspera	Cravo & Bebianno (2005)	Portugal Coast (Impacted area)	Min	1.00	s/d	4.20	73.40	0.39
			Max	2.60		15.20	172.00	3.10
M. edulis chilensis	Present work	IZ	Mean	0.98	2.15	4.43	98.14	0.19
			SD	0.38	0.01	2.25	56.89	0.07
		FD	Mean	1.00	3.80	5.03	170.15	0.19
			SD	0.67	3.10	2.20	82.73	0.08
		UP	Mean	1.36	3.25	5.95	105.39	0.21
			SD	0.60	1.61	3.01	38.36	0.13
B. barbatus	Hamed & Emara (2006)	Gulf of Suez (Impacted area)	Min	0.23	2.88	1.63	24.36	0.36
			Max	5.12	180.92	19.25	752.14	5.24
N. galloprovincialis	Nesto et al. (2007)	Venice (Impacted area)	Mean	2.57	2.64	7.10	215.13	0.16
			SD	1.87	1.11	2.68	85.48	0.11
M. edulis	Gil et al. (2006)	Patagonian Coasts (Low impacted area)	Min	1.12	1.82	4.37	48.51	s/d
			Max	3.89	8.07	13.03	214.33	
M. edulis	Ahumada et al. (2002)	Chilean-Austral Fiords (Unpolluted area)	Mean	0.90	0.70	5.70	83.10	s/d
			SD	0.30	0.80	3.00	34.70	s/d
M. edulis	Szefer et al. (1997, 1999)	Kyushu Islan, Japan (Polluted area)	Mean value	18.4	122.00	385.00	360.00	0.17
Bivalve mollusks	SENASA	Human intake	Limit value	5.00	7.50	s/d	s/d	s/d

were below the limit allowed by the National Safety and Quality Food Service (SENASA, 2008).

5. Conclusions

The trace metal concentrations recorded in the studied sediments showed signs of human impact. Particularly, Cd concentrations suggest a considerable contribution of this metal into the environment, but its natural or anthropogenic source has not been identified. Bioaccumulation levels in mussels and limpets were not correlated with sediment concentrations, indicating different bioavailability patterns. Both mussels and limpets meet the national standards set for trace metals for human consumption. Considering the constant increase in human activities within the studied area, monitoring studies are recommended, in order to control early environmental changes and related biological effects.

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