Cd, Cu, Pb and Zn in clams and sediments from an impacted estuary by the oil industry in the southwestern Gulf of Mexico: Concentrations and bioaccumulation factors

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With the objective of estimating the temporal variation and bioavailability of Cd, Cu, Pb and Zn in Coatzacoalcos estuary, the biota-sediment accumulation factors (BSAF) were calculated. For this purpose, surficial sediments and clams from 14 selected sites were collected during three climatic seasons. In surficial sediments, highest levels of Cd and Cu were measured during the rainy season near to the industrial area of Minatitlán, while highest concentrations of Pb and Zn were registered during the windy season in sediments collected near to the industrial area of Coatzacoalcos. Considering all the sampling seasons and bivalve species, average metal concentrations followed the order Zn > Cu > Cd > Pb. BSAF ranged from 0.01 (Pb) in Corbicula fluminea during the hot season to 25.1 (Cd) in Polymesoda caroliniana during the windy season. BSAF of Cd, Cu and Zn were higher during the windy season; in the case of Pb, the dry season was the time when such figure was more elevated. It can be stated that Polymesoda caroliniana is a net accumulator of Cd and Zn and a weak accumulator of Pb for the studied estuary.

Keywords: Trace metals, surficial sediments, bivalves, Coatzacoalcos estuary, biota-sediment accumulation factor.

Introduction

Recently, population growth in coastal areas has increased in comparison with inland areas; as a consequence, a range of environmental impacts have occurred. Coastal lagoons and estuaries are natural systems of great ecological concern, because of their elevated productivity and biodiversity. Limited water turnover strongly reduces the dilution potential when contaminants are released into such environments. Coastal lagoons, wetlands and estuaries are being exposed to human pressure; as natural resources are overexploited and urban, industrial and agricultural pollution increase.[1] Considering the dynamics and importance of coastal ecosystems, it is necessary to monitor trace metal pollution through the use of sediments and organisms; for this reason, most of the national programmes for monitoring the coastal aquatic environments involve the use of sediments and sessile organisms, typically filter-feeding bivalves.[2] Bivalve species including oysters, mussels and clams are utilized as the biomonitor for the evaluation of heavy metal pollution in coastal waters.[3] In Coatzacoalcos estuary (Gulf of Mexico), a major petrochemical production center is located.

Considering that facilities related to petrochemical manufacture may cause significant inputs of heavy metals due to effluent discharges,[4] the area has been regarded as the most polluted coastal area in Mexico; the present study was designed in order to assess metal availability from surficial sediments to biota. The knowledge of concentration factors of metals in marine organisms is useful for recognizing the relative ability of organisms to bioaccumulate selected metals from their environment.[5] In this sense, an investigation related to the quantitative estimation of temporal variation of trace metal (Cd, Cu, Pb and Zn) bioavailability through the biota-sediment accumulation factors (BSAF) was carried out. For this purpose, surficial sediments and clams from fourteen selected sites were collected during three defined climatic seasons in the region.

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**Materials and Methods**

**Study area**

The portion of the Coatzacoalcos estuary where surficial sediments and clams were collected is located at 17° 46' and 18° 10' N, and 94° 25' and 94° 31' W (Fig. 1). The Coatzacoalcos estuary has an estimated length of 40 km. In the upper estuary, width and depth reach 213 and 18 m, respectively; in the river mouth, width and depth reach 530 and 11 m, respectively. In the course of the main water body, several rivers and streams discharge their waters, contributing to the load of contaminants to the estuary: Coachapa river, Uxpanapa river, San Francisco stream, Calzada river, and Teapa stream. The weather of the area is hot and humid with summer rains, with an average temperature of 24°C. Three defined seasons are encountered in the region: from June to September heavy rains occur in the catchment area; from October to February strong winds from the north (“Nortes”) are frequent; the dry season ranges from March to May and saline waters can be detected 40 km upstream.

Because of the proximity of the study area to the major oil resources in the Gulf of Mexico, industrial development has occurred in the past 40 years. Currently, it is considered that the most important industrial centers in Mexico are located in this area. As a major petrochemical production center, it is regarded as the most polluted coastal area in Mexico; other authors consider that the area is affected by anthropogenic discharges of major and minor chemical components in water and air.

**Field work**

Sampling was carried out between May 2005 and January 2006. The sites where bivalve specimens and surficial...
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### Table 1. Sampling sites for surficial sediments and clams in Coatzacoalcos estuary.

<table>
<thead>
<tr>
<th>Site</th>
<th>Name</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Allende</td>
<td>SS</td>
</tr>
<tr>
<td>2</td>
<td>Main Harbor</td>
<td>SS</td>
</tr>
<tr>
<td>3</td>
<td>Coatzacoalcos river</td>
<td>SS</td>
</tr>
<tr>
<td>4</td>
<td>Calzada/Coatzacoalcos Joint</td>
<td>BI, SS</td>
</tr>
<tr>
<td>5</td>
<td>Calzadas river</td>
<td>SS</td>
</tr>
<tr>
<td>6</td>
<td>Calzadas river</td>
<td>SS</td>
</tr>
<tr>
<td>7</td>
<td>Nanchital</td>
<td>SS</td>
</tr>
<tr>
<td>8</td>
<td>San Francisco stream</td>
<td>SS</td>
</tr>
<tr>
<td>9</td>
<td>Guerrero island</td>
<td>SS</td>
</tr>
<tr>
<td>10</td>
<td>Uxpanapa river</td>
<td>SS</td>
</tr>
<tr>
<td>11</td>
<td>Santa Alejandrina</td>
<td>SS</td>
</tr>
<tr>
<td>12</td>
<td>Capoacán</td>
<td>SS</td>
</tr>
<tr>
<td>13</td>
<td>Ixhuatepec</td>
<td>SS</td>
</tr>
<tr>
<td>14</td>
<td>Hidalgotitlán*</td>
<td>BI, SS</td>
</tr>
</tbody>
</table>

SS, surficial sediment; BI, clams; *, control site.

Sediments were collected covered 14 selected stations along the Coatzacoalcos estuary, from the mouth and up to the cities of Coatzacoalcos (pop. 267,000) and Minatitlán (pop. 153,000); in order to contrast results, biota and surficial sediments, while silt (from 2 to 62 µm) was separated from the fine-grained sediments, while silt (from 2 to 62 µm) was separated from clay (<2 µm) by the pipette analysis and the relative percentage corresponding to each fraction was calculated. After taxonomic identification of organisms, soft tissue of bivalves was separated from shells for the analyses.

### Analytical procedure

Sediment and biota samples were freeze-dried for 72 hours (−49°C and 133 × 10⁻³ mBar) then ground in an agate mortar. Before the sediment was ground, about 30 g were used for the granulometric analysis. The sandy fraction (>62 µm) was separated by wet sieving from the fine-grained sediments, while silt (from 2 to 62 µm) was separated from clay (<2 µm) by the pipette analysis and the relative percentage corresponding to each fraction was calculated.

Total organic carbon (TOC) content in sediments was performed by oxidizing the organic carbon with potassium dichromate.

Powdered and homogenized samples of sediments and biota were acid digested using teflon vials with caps (Savillex). In the case of biota samples, digestion was achieved by using 5 mL of quartz distilled concentrated nitric acid at 120°C for 3 h; for sediments, an acid mixture (nitric, hydrochloric and hydrofluoric acids) was used according to Shumilin et al. and Soto-Jiménez et al. Dried samples were stored in polyethylene containers for further analysis. Duplicated samples were analyzed. Analyses of Cd and Pb were made by graphite-furnace atomic absorption spectrophotometry (GFAAS); regarding Cu and Zn, analyses were performed by flame atomic absorption spectrophotometry (FAAS).

All determinations were made in a Varian SpectrAA220 equipment. Blanks were run with every batch of samples. Precision and accuracy of the analytical methods were assessed by using reference materials: sediment SDN-1/2, with recoveries between 87 and 116% and fish muscle MAB-3/TM, with recoveries between 85 and 114%.

In order to estimate the degree of anthropogenic input of metals to the estuary, the enrichment factor (EF) was calculated according to the equation:

\[
EF = \frac{(M/Al)_{sample}}{(M/Al)_{crust}} \times \frac{Al}{3} \times \frac{1}{P}
\]

Baseline values corresponded to average composition of surface rocks that are exposed to weathering:

\[
\begin{align*}
Al & \quad 6.9\% \\
Cd & \quad 0.2 \mu g \ g^{-1} \\
Cu & \quad 32 \mu g \ g^{-1} \\
Pb & \quad 16 \mu g \ g^{-1} \\
Zn & \quad 127 \mu g \ g^{-1}
\end{align*}
\]

In order to estimate the ability of bivalves to accumulate the metals of interest from the associated sediment, the biota-sediment accumulation factor (BSAF) was calculated according to the formula given by:

\[
BSAF = \frac{[M]}{[M]_{crust}}
\]

Results and discussion

### Surficial sediments

Grain size of surficial sediments along the studied estuary was variable depending on the season and the site. From Figure 2, it can be seen that sediments from the mouth

### Table 2. Biometric information of collected clams from Coatzacoalcos estuary.

<table>
<thead>
<tr>
<th>Common name</th>
<th>Species</th>
<th>Habitat</th>
<th>Site (N)</th>
<th>Date (season)</th>
<th>Weight ± SD (g)</th>
<th>Length ± SD (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asiatic Clam</td>
<td>Corbicula fluminea</td>
<td>F</td>
<td>14* (6)</td>
<td>05/2005 (D)</td>
<td>3 ± 2</td>
<td>2.0 ± 0.3</td>
</tr>
<tr>
<td>Carolina Marsh Clam</td>
<td>Polymesoda caroliniana</td>
<td>F</td>
<td>4(7)</td>
<td>05/2005 (D)</td>
<td>19 ± 5</td>
<td>4.1 ± 0.3</td>
</tr>
<tr>
<td>Carolina Marsh Clam</td>
<td>Polymesoda caroliniana</td>
<td>F</td>
<td>4(7)</td>
<td>09/2005 (R)</td>
<td>47 ± 16</td>
<td>4.9 ± 0.5</td>
</tr>
<tr>
<td>Carolina Marsh Clam</td>
<td>Polymesoda caroliniana</td>
<td>F</td>
<td>4(7)</td>
<td>01/2006 (W)</td>
<td>47 ± 20</td>
<td>4.0 ± 0.8</td>
</tr>
</tbody>
</table>

F, freshwater; N, number of pooled samples; *, control site; D, dry; R, rainy; W, windy.
of the estuary were mostly composed of sands (from 83 to 100%) all over the study; nevertheless, the extension of the area covered by sandy sediments varied according to the season: during the dry season, sediments that were predominantly sandy were located in the mouth of the estuary while during the rainy and windy seasons, the sandy fraction was predominant in more number of sites in the estuary. Mud sediments occurred in high percentages in sampling stations located mainly upstream; during the dry season, stations 9 and 12 had 68 and 63% of mud respectively, clearly in concordance to a previous study in the same estuary \cite{22} where finer fractions of sediments occurred in stations located upstream (stations 9 and 12). The rainy season was the time when more sampling stations upstream had surficial sediments with elevated amounts of mud (from 68 to 94%), in a similar study carried out in the same estuary, elevated clay concentrations were present in surficial sediments collected during the rainy season.\cite{23} During the windy season only stations 8 and 11 had elevated amounts (> 68%) of mud in surficial sediments.

Total organic carbon (TOC) percentages were also variable depending on the season and site. During the dry season, two peaks were observed at stations 5 (3.0%) and 10 (2.4%). The rainy season had a top value (2.01%) at

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**Fig. 2.** Variation of percentages of sand, mud and total organic carbon (TOC) in surficial sediments collected along Coatzacoalcos estuary during three climatic conditions.
station 3 and the windy season showed the highest percentage (1.8%) at station 9. In general, highest levels of TOC were recorded between sites of high industrial activity and urban development.

Variations of metal levels in surficial sediments from Coatzacoalcos estuary are shown in Figure 3. No significant ($P > 0.05$) differences were defined after the statistical analyses comparing metal levels (considering all the sampling sites) among sampling seasons.

If metal concentrations for the different sites are compared, it can be seen that highest levels of Cd and Cu were measured during the rainy season in sites located near to the industrial area of Minatitlán (around sites 10 to 12), while highest concentrations of Pb and Zn were registered during the windy season in sediments collected near to the industrial area of Coatzacoalcos (site 2). In a previous study within the same estuary, Cd, Cu, Pb and Zn showed the highest average values in surficial sediments from the same industrialized site; in relation to the seasonal variation, it was reported that average levels of Cd and Zn were higher during the dry season, while Cu and Pb concentrations were more elevated during the windy season.[23] From the preceding information, it can be seen that Coatzacoalcos estuary is a highly variable area from the temporal point of

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**Fig. 3.** Concentrations ($\mu$g g$^{-1}$ dry weight) of Cd, Cu, Pb and Zn in surficial sediments from Coatzacoalcos estuary during three sampling seasons.
Fig. 4. Fluctuation of enrichment factors (EF) of Cd, Cu, Pb and Zn in surficial sediments from Coatzacoalcos estuary during three sampling seasons.

view, whereas spatial variation is less noticeable, being industrialized areas the most impacted sites by the analyzed metals.

Enrichment factors of analyzed elements in surficial sediments collected along Coatzacoalcos estuary are presented in Figure 4. It can be noted that near to the mouth of the estuary and around 30 km away from the mouth, where urban and industrial centers are located, EF values were highly variable. Highest EF values of Cd were found during the rainy season; in the case of Cu, top levels corresponded to the dry and rainy season; for Pb, highest EF values were observed during the windy and rainy season in the industrialized area of Coatzacoalcos (site 2) near to the mouth of the estuary, whereas for Zn, the dry season was the time when EF were highest. Considering EFs around 1 as indicative of elements in sediments originating from lithogenous material, Coatzacoalcos estuary has metals (particularly Cu, Zn and Pb) that are naturally supplied, specially in areas located upstream (control site) far from the main industrialized areas. All the analyzed elements had EFs > 1 for a certain season and zone of the estuary: EF for Cd were around 4 during the windy season in a site located between the main two industrialized areas and upstream; EF for Cu were above the unit along the industrialized portion of the estuary during the dry and rainy seasons; in the case of Zn only a site near to the mouth of the estuary showed a value
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The other sampling times and *C. fluminea* and *P. caroliniana* were significantly (P < 0.05) higher in *Polymesoda caroliniana* collected during the dry season (control site). Levels of Zn were significantly (P < 0.05) higher in *Polymesoda caroliniana* collected during the windy season (site 4) than in *C. fluminea* collected during the dry season (control site).

To have a comparative view of metal levels in clam species, levels of Cd, Cu Pb and Zn in soft tissue of clams are presented in Table 4. Elevated concentration of the compared metals occurred in clams from the United Kingdom; it is worth mentioning that such specimens were collected in estuarine areas with a high degree of impact from mining activities. Interspecific comparisons of metal concentrations in analyzed clam species in the present study shows that Cu and Zn in soft tissue of *Corbicula fluminea* (control site, present study) were an order of magnitude lower than levels reported in *C. fluminea* from Mexicali valley. In relation to *Polymesoda caroliniana*, values of Cu reported in the present study were bivariate view of metal levels in clam species, levels of Cd, Cu Pb and Zn in soft tissue of clams are presented in Table 4. Elevated concentration of the compared metals occurred in clams from the United Kingdom; it is worth mentioning that such specimens were collected in estuarine areas with a high degree of impact from mining activities. Interspecific comparisons of metal concentrations in analyzed clam species in the present study shows that Cu and Zn in soft tissue of *Corbicula fluminea* (control site, present study) were an order of magnitude lower than levels reported in *C. fluminea* from Mexicali valley. In relation to *Polymesoda caroliniana*, values of Cu reported in the present study were comparable to concentrations published in the same area by Villanueva et al. [25]; in the case of Zn, concentration were two times more concentrated in the present study.

**BSAF** ranged from 0.01 (Pb) in *Corbicula fluminea* during the hot season to 25.1 (Cd) in *Polymesoda caroliniana* during the windy season (Table 3). Averaged BSAF for the whole study followed the order Cd > Zn > Cu > Pb. Seasonally (considering only *Polymesoda caroliniana*, that occurred in all the sampling times), BSAF of Cd, Cu and Zn were higher during the windy season; in the case of Pb,

### Table 3. Average metal concentrations (µg g⁻¹) and biota-sediment accumulation factor (BSAF) in clams from Coatzacoalcos estuary during the sampling seasons.

<table>
<thead>
<tr>
<th>Species</th>
<th>Site</th>
<th>Season</th>
<th>Cd</th>
<th>BSAF</th>
<th>Cu</th>
<th>BSAF</th>
<th>Pb</th>
<th>BSAF</th>
<th>Zn</th>
<th>BSAF</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Corbicula fluminea</em></td>
<td>14</td>
<td>D</td>
<td>0.45 ± 0.11a</td>
<td>6.8</td>
<td>9.0 ± 6.4</td>
<td>0.49</td>
<td>0.090 ± 0.003b</td>
<td>0.01</td>
<td>65.9 ± 10.0b</td>
<td>1.21</td>
</tr>
<tr>
<td><em>P. caroliniana</em></td>
<td>4</td>
<td>D</td>
<td>1.05 ± 0.11b</td>
<td>23.9</td>
<td>8.7 ± 1.1</td>
<td>1.78</td>
<td>1.5 ± 0.5c</td>
<td>0.37</td>
<td>119.8 ± 48.5</td>
<td>3.37</td>
</tr>
<tr>
<td><em>P. caroliniana</em></td>
<td>4</td>
<td>R</td>
<td>0.85 ± 0.44</td>
<td>14.9</td>
<td>7.9 ± 2.2</td>
<td>0.96</td>
<td>0.6 ± 0.3b</td>
<td>0.14</td>
<td>91.4 ± 37.4</td>
<td>2.99</td>
</tr>
<tr>
<td><em>P. caroliniana</em></td>
<td>4</td>
<td>W</td>
<td>0.95 ± 0.36</td>
<td>25.1</td>
<td>11.1 ± 2.8</td>
<td>2.26</td>
<td>0.6 ± 0.1b</td>
<td>0.19</td>
<td>126.7 ± 46.5b</td>
<td>4.13</td>
</tr>
<tr>
<td>Average (±SD)</td>
<td></td>
<td></td>
<td>0.82</td>
<td>9.2</td>
<td>0.11</td>
<td>0.44</td>
<td>0.11</td>
<td>0.5</td>
<td>0.11</td>
<td>0.003</td>
</tr>
</tbody>
</table>

D, dry season (May, 2005); R, rainy season (September, 2005); W, windy season (January, 2006); for a given element, different superscript letters denote significant differences (p < 0.05).

### Table 4. Levels of Cd, Cu, Pb and Zn (in µg g⁻¹ dry weight) in the soft tissue of some clam species from diverse sites.

<table>
<thead>
<tr>
<th>Species</th>
<th>Site</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Mya arenaria</em></td>
<td>Gdańsk bay, Poland</td>
<td>[27]</td>
</tr>
<tr>
<td><em>Scrobia laricina</em></td>
<td>Peel estuary, United Kingdom</td>
<td>[28]</td>
</tr>
<tr>
<td><em>Macoma balthica</em></td>
<td>Severn estuary, United Kingdom</td>
<td>[29]</td>
</tr>
<tr>
<td><em>Corbicula fluminea</em></td>
<td>Mexicali valley, Mexico</td>
<td>[30]</td>
</tr>
<tr>
<td><em>Chione californiens</em></td>
<td>Gulf of California</td>
<td>[30]</td>
</tr>
<tr>
<td><em>Chione californiens</em></td>
<td>Altata-Ensenada del Pabellón lagoon, Mexico</td>
<td>[31]</td>
</tr>
<tr>
<td><em>Chione subrugosa</em></td>
<td>Altata-Ensenada del Pabellón lagoon, Mexico</td>
<td>[31]</td>
</tr>
<tr>
<td><em>Polymesoda caroliniana</em></td>
<td>Coatzacoalcos river, Mexico</td>
<td>[25]</td>
</tr>
<tr>
<td><em>Polymesoda caroliniana</em></td>
<td>Coatzacoalcos river, Mexico</td>
<td>[25]</td>
</tr>
<tr>
<td><em>Corbicula fluminea</em></td>
<td>This study</td>
<td>This study</td>
</tr>
</tbody>
</table>

Interspecific comparisons of metal concentrations in *Corbicula fluminea* during the dry season (control site). Levels of Zn were significantly (P < 0.05) higher in *Polymesoda caroliniana* collected during the windy season (site 4) than in *C. fluminea* collected during the dry season (control site).

Bivalves

Average metal concentrations and BSAF in collected clams are presented in Table 3. Considering all the sampling seasons and bivalve species, average metal concentrations followed the order Zn > Cu > Cd > Pb. The bivalve species that occurred during the three sampling seasons was *Polymesoda caroliniana*; this clam showed the highest levels of Cd and Pb during the dry season, in the case of Cu and Zn, the highest concentrations were measured in specimens collected during the windy season. Statistical differences were found for Cd, Pb and Zn; in the case of Cd, levels were significantly (P < 0.05) higher in *P. caroliniana* from site 4 during the dry season than in *C. fluminea* (control site) during the dry season. Pb concentrations were significantly (P < 0.05) higher in *Polymesoda caroliniana* collected during the dry season than in *P. caroliniana* collected during the other sampling times and *C. fluminea* collected during the dry season (control site). Levels of Zn were significantly (P < 0.05) higher in *Polymesoda caroliniana* collected during the windy season (site 4) than in *C. fluminea* collected during the dry season (control site).

To have a comparative view of metal levels in clam species, levels of Cd, Cu Pb and Zn in soft tissue of clams are presented in Table 4. Elevated concentration of the compared metals occurred in clams from the United Kingdom; it is worth mentioning that such specimens were collected in estuarine areas with a high degree of impact from mining activities. Interspecific comparisons of metal concentrations in analyzed clam species in the present study shows that Cu and Zn in soft tissue of *Corbicula fluminea* (control site, present study) were an order of magnitude lower than levels reported in *C. fluminea* from Mexicali valley. In relation to *Polymesoda caroliniana*, values of Cu reported in the present study were comparable to concentrations published in the same area by Villanueva et al. [25]; in the case of Zn, concentration were two times more concentrated in the present study.

BSAF ranged from 0.01 (Pb) in *Corbicula fluminea* during the hot season to 25.1 (Cd) in *Polymesoda caroliniana* during the windy season (Table 3). Averaged BSAF for the whole study followed the order Cd > Zn > Cu > Pb. Seasonally (considering only *Polymesoda caroliniana*, that occurred in all the sampling times), BSAF of Cd, Cu and Zn were higher during the windy season; in the case of Pb,
the dry season was the time when such figure was more elevated. Variability of BSAF values agrees with changing conditions in the estuary, perhaps during the windy season sediment resuspension in shallow areas contribute to a higher load and availability of metals in filter-feeder organisms.\textsuperscript{[26]}

Results of BSAF higher than 1 were detected for Cd and Zn during all the seasons and in two out of four cases for Cu. Values of BSAF for all the elements were lower in clams from control site (station 14) than in clams from site 4 located near to the industrialized area of Coatzacoalcos where such organisms were available.

Values of BSAF less than one reveal that the capacity of clams to accumulate metals is low in relation to the existent level in the associated sediments. BSAF higher than one indicate that bivalves are able to accumulate metals from the surrounding sediments. Cd and Zn figures of BSAF in both clams were above the unit for all the sampling seasons and sites, it can be evidenced that Polymesoda caroliniana is a net accumulator of Cd and Zn and a weak accumulator of Pb for the studied estuary. In a study with Ostrea cucullata from the Gulf of Aden, it was found that this species of oyster was also a good accumulator of Cd and Zn.\textsuperscript{[9]} In another study carried out in a discharge zone of a submarine outfall in the southeastern Gulf of California, Soto-Jiménez et al.\textsuperscript{[10]} concluded that the oyster Crassostrea tridescens was a strong net accumulator of Cu and Zn, moderate accumulator of Cd and a weak accumulator of Pb.

**Conclusion**

Size of surficial sediments and percentages of total organic carbon in Coatzacoalcos estuary were variable depending on the season and the site. In general, highest levels of TOC were recorded between sites of high industrial activity and urban development. Highest levels of Cd and Cu in surficial sediments were measured during the rainy season in sites located near to the industrial area of Minatitlán, while highest concentrations of Pb and Zn were registered during the windy season in sediments collected near to the industrial area of Coatzacoalcos. From EF values, it can be said that Coatzacoalcos estuary has metals (particularly Cu, Zn and Pb) that are naturally supplied, specially in areas located upstream (control site) far from the main industrialized areas. Analyzed elements had EFS > 1 in different sites and seasons: for Cd, EF around 4 was registered during the windy season in a site located between the main two industrialized areas; for Cu, EF above the unit were reported along the industrialized portion of the estuary during the dry and rainy seasons; in the case of Zn only a site near to the mouth of the estuary showed a value higher than one during the dry season; concerning Pb, EF higher than one was reported in the mouth of the estuary (close to an industrial area) during the three sampling seasons.

For the overall study, i.e. considering all the sampling seasons and clam species, average metal concentrations followed the order Zn>Cu>Cd>Pb. Polymesoda caroliniana showed the highest levels of Cd and Pb during the dry season; in the case of Cu and Zn, the highest concentrations were measured in specimens collected during the windy season. Averaged BSAF for the whole study followed the order Cd>Zn>Cu>Pb. Considering only Polymesoda caroliniana, BSAF of Cd, Cu and Zn were higher during the windy season; in the case of Pb, the dry season was the time when such figure was more elevated. It can be evidenced that Polymesoda caroliniana is a net accumulator of Cd and Zn.

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