Impact of a coastal dump in a tropical lagoon on trace metal concentrations in surrounding marine biota: A case study from Saipan, Commonwealth of the Northern Mariana Islands (CNMI)

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Solid waste disposal facilities (dumps/landfills) have long been known as sites of potential environmental problems, unless they are very well managed (Lisk, 1991). This is particularly true if such facilities are located near water bodies. In the Pacific Islands, many past urban solid waste disposal sites were situated on the coast and, in most cases, were little more than open dumps (Morrison and Munro, 1999). These operations usually were ineffectively managed, with minimal control on the materials dumped and no impervious lining or leachate control (SPREP, 2006). The Puerto Rico Dump in Saipan, CNMI, is one such example and served as the island’s primary waste disposal site for over 50 years before its closure in February, 2003. This 8 ha site sits directly on the coast at the southern end of Tanapag Lagoon, a typical high-island barrier reef lagoon bordering the western shore of Saipan (Fig. 1) and is rumoured to contain a plethora of toxic chemicals of both military and civilian origin (Ogden Environmental and Energy Services, 1994). Trace metal enrichment of subtidal sediments from around the base of the dump has previously been identified (Denton et al., 2001, 2006). The preliminary study described herein examines the metal status of dominant ecological representatives collected close to the dump and other known or suspected sources of trace element contamination in the lagoon including two marinas, a sea port (Port of Saipan) and dry dock area, and a power plant.

Biota and surface sediments were collected from 12 intertidal sites in Tanapag Lagoon (Fig. 1) over a two week period in June 2003. Site details and sediment characteristics are summarized in Table 1. Biota samples were collected on either low or falling tides. Preference was given to species with known or suspected bioindictor potential as well as those traditionally harvested for food by local residents. Any size effects were minimized by selecting similar sized representatives for analysis from each site. A complete list of organisms taken for analysis, together with their respective collection sites are shown in Table 2. Not all species were available at all sites. Juvenile fish were captured in shallow water (<1 m depth) using a cast net and immediately placed in chilled containers. In the laboratory, axial muscle was taken for analysis from pooled samples of from one to six fish depending upon the species and size of individuals caught. All other biotic representatives and surface sediments were collected and processed as previously described along with all analytical methods and QA/QC protocols (Denton and Morrison, 2008). Metal recoveries from standard reference materials (soil, orchard leaves and albacore tuna) were within satisfactory limits.

The sediment metals concentrations are summarized in Table 3. Levels of copper, lead, and zinc in sediment from the base of the dump (Site 2) were at least two orders of magnitude higher than the lowest values determined elsewhere in the lagoon, while values for silver, cadmium, chromium, mercury and nickel were at least one order of magnitude higher. Relatively high concentrations of copper, zinc and lead were determined in sediment from Seaplane Ramps (Site 4) and lead enrichment was apparent at CUC Beach (Site 5). The generally lower metal concentrations in sediments from the northern half of the lagoon reflect less extensive
anthropogenic activity in this area. The comparatively high mercury value found in sediment from the mouth of Saddok Dogas (Site 8), a small stream that feeds into a relatively remote part of the lagoon, was unexpected. A possible connection with past military activities further upstream remains to be examined. Sedimentary arsenic concentrations were low throughout the study area with most samples yielding values of <3 μg/g. Such low levels are typical of uncontaminated marine sediments in this part of the world (Denton et al., 2005a, 2006; Denton and Morrison, 2008). Significant positive correlations (coefficients all >0.8) were found between sediment concentrations of most metals with the notable exception of arsenic which showed no strong relationship to any other element studied. Particularly strong relationships (coefficients all >0.9) were found between cadmium, chromium, copper, nickel, lead and zinc, while mercury was less well correlated with these elements.

The biota data are presented in Tables 4–8 and were evaluated by comparative assessments with similar and related species from elsewhere. Of particular importance here was the information available for identical species of algae, seagrass, seacucumbers and bivalves from a relatively clean bay off the eastern coast of central Guam, ~120 nautical miles SSW of Saipan (Denton and Morrison, 2008).

Biotic silver concentrations were close to or below analytical detection limits in most species with the notable exception of *Quidnipagus palatum* from Site 2 (Table 7). This species appears to be particularly sensitive to changes in the ambient availability of silver and clearly highlights the mild enrichment noted in the surrounding sediment. No unusual arsenic concentrations were found in any of the organisms analysed in this study. There was also no compelling evidence to suggest a significant net increase in cadmium concentrations had occurred in biotic components near the dump despite the significant enrichment noted in sediment at the base of this facility.

Chromium levels in algae and seagrass from uncontaminated waters usually range between 1 and 3 μg/g (Denton et al., 1980; Denton and Burdon-Jones, 1986) and concentrations found in specimens from Tanapag Lagoon are in agreement with this (Tables 4 and 5). While seacucumbers clearly compartmentalized chromium in their hemal tissue (Table 6), there was no obvious relationship between levels accumulated and those in surrounding sediments. Chromium concentrations in marine molluscs normally lie between 0.5 and 3.0 μg/g (Eisler, 1981). Values recorded in Tanapag Lagoon (Table 7) ranged from less than 1 μg/g in *Ctenna bella* from Micro Beach (Site 1), to over 10 μg/g in *Asaphia violascens* and *Q. palatum* near the dump (Site 2). Levels in the latter species were at least an order of magnitude higher than in their Guam counterparts (Denton and Morrison, 2008). These data provide additional evidence of light to moderate chromium enrichment near the dump and highlight the bioindicator potential of both species for this element.

Marine plants normally contain copper levels of less than 10 μg/g except near polluting sources where values in excess of 50 μg/g are not uncommon (Moore, 1991). Copper concentrations recorded in seaweeds and seagrass during the present investigation were almost always less than 10 μg/g. The notable exceptions were at Seaplane Ramps (Site 4) were levels ranged from 25 to 30 μg/g in algae and approached 50 μg/g in seagrass (Tables 4 and 5). These data infer elevated levels of dissolved copper exist in the water column.

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**Fig. 1.** Biota and sediment sampling site locations in Tanapag Lagoon, Saipan.
Information on the Tanapag Lagoon sites visited in this study.

<table>
<thead>
<tr>
<th>Site no.</th>
<th>Location</th>
<th>Sediment type</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Micro Beach – northern end</td>
<td>Very coarse carbonate sand intertidal sediments giving way to finer material immediately offshore</td>
<td>Net southerly movement of surface water transports contaminants from the Port, the Puerto Rico Dump and two small boat marinas into the general area.</td>
</tr>
<tr>
<td>2</td>
<td>Puerto Rico Dump – south-western edge</td>
<td>Poorly sorted, gravelly coarse sand interspersed with muddy fines of marine and terrestrial origin, metal fragments, glass, wood, plastic, cloth fibres, bituminous asphalt, rubber and tar balls</td>
<td>Aqueous contaminants impacting this site are principally derived from the dump itself (in leachate streams), the Port, and road surface water drainage.</td>
</tr>
<tr>
<td>3</td>
<td>Echo Bay – western side</td>
<td>Poorly sorted medium to coarse carbonate sands of biogenic origin</td>
<td>The bay separates the main Port on the western side from Echo Docks on the east. Primary sources of contamination in this area are associated with shipping activities, including boat repair and maintenance. Site 3 located near a small stream (Saddok Tasi) that drains a nearby wetland.</td>
</tr>
<tr>
<td>4</td>
<td>Seaplane Ramps - centrally located on the inner side of the eastern ramp</td>
<td>Intertidal zone sediments are typically very course, gravelly sand, while finer deposits occur in deeper waters alongside the ramps themselves</td>
<td>Primary sources of contamination in this area are almost exclusively confined to shipping and ship repair activities.</td>
</tr>
<tr>
<td>5</td>
<td>CUC Beach</td>
<td>Fine to medium biogenic sands interspersed with muddy fines of mixed origin</td>
<td>Lies immediately to the east of the Lower Base power station. The site borders a Department of Public Works vehicle maintenance yard and an open area of land previously used as a dumpsite for old car batteries and other assorted automobile hardware.</td>
</tr>
<tr>
<td>6</td>
<td>Lower Base Channel</td>
<td>Fine to medium muddy sands</td>
<td>Site receives discharge from a small creek that drains the Lower Base area. Urban runoff and industrial activities along the Lower Base Drive are the primary sources of metal contamination in this area.</td>
</tr>
<tr>
<td>7</td>
<td>Saddok As Agatan</td>
<td>Relatively course sand in the upper intertidal zone to finer, muddier material at the mouth and further offshore</td>
<td>Saddok As Agatan is the largest of three streams that drain watersheds of the hilly interior in this part of the island, and discharges continuously onto a relatively flat beach approximately 300 m southwest of Tanapag village. No obvious sources of metal contamination were evident in the area.</td>
</tr>
<tr>
<td>8</td>
<td>Saddok Dogas</td>
<td>Relatively course sand in the upper intertidal zone to finer, muddier material at the mouth and further offshore</td>
<td>Saddok Dogas, the second stream in this area, empties onto the beach approximately 150 m from the southern border of Tanapag village. The stream drains an upland area of land that was once used as a military dumpsite and an array of military junk can still be found in one of the headwater tributaries. No other obvious sources of metal contamination.</td>
</tr>
<tr>
<td>9</td>
<td>Bobo Achgao</td>
<td>Medium to fine sand, predominated throughout the intertidal and subtidal regions</td>
<td>Bobo Achgao is the smallest of the three streams that discharge into the general area of coastline and is the first to stop flowing during prolonged periods of dry weather. Urban runoff and industrial activities along the Lower Base Drive are the primary sources of metal contamination in this area.</td>
</tr>
<tr>
<td>10</td>
<td>Plumeria Hotel Beach</td>
<td>Clean, coarse sands characterized the intertidal zone of this relatively pristine, shallow water embayment. Somewhat finer deposits of clean sand were found subtidally</td>
<td>Other than the hotel, there were no obvious potential sources of metal contamination in the area considered to be representative of a relatively pristine stretch of coastline. No other obvious sources of metal contamination.</td>
</tr>
<tr>
<td>11</td>
<td>San Roque Cemetery Beach</td>
<td>Clean, coarse sands characterized the intertidal zone of this relatively pristine, shallow water embayment. Somewhat finer deposits of clean sand were found subtidally</td>
<td>Site receives effluent from a nearby reverse osmosis desalination plant at the Nikko hotel. No other obvious sources of metal contamination.</td>
</tr>
<tr>
<td>12</td>
<td>Pau Pau Beach</td>
<td>Clean coarse to very coarse sediments with little terrigenous material present</td>
<td>Relatively high energy conditions prevail along this narrow stretch of Tanapag Lagoon. Sources of metal contamination restricted to storm water drainage from the main highway and septic tank seepage from beach park facilities.</td>
</tr>
</tbody>
</table>

Biota sampled from Tanapag Lagoon, Saipan.

<table>
<thead>
<tr>
<th>Species</th>
<th>Sites</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Algae</td>
<td></td>
</tr>
<tr>
<td>Acanthophora spicifera</td>
<td>X</td>
</tr>
<tr>
<td>Dictyota bartysrensis</td>
<td>X</td>
</tr>
<tr>
<td>Gracilaria salicornia</td>
<td>X</td>
</tr>
<tr>
<td>Laurencia sp.</td>
<td>X</td>
</tr>
<tr>
<td>Padina sp.</td>
<td>X</td>
</tr>
<tr>
<td>Sargassum polycystum</td>
<td>X</td>
</tr>
<tr>
<td>Seagrass</td>
<td></td>
</tr>
<tr>
<td>Enhalus acoroides</td>
<td>X</td>
</tr>
<tr>
<td>Halodule uninervis</td>
<td>X</td>
</tr>
<tr>
<td>Seacucumbers</td>
<td></td>
</tr>
<tr>
<td>Bohadschia argus</td>
<td>X</td>
</tr>
<tr>
<td>Bohadschia marmorata</td>
<td>X</td>
</tr>
<tr>
<td>Holothuria atra</td>
<td>X</td>
</tr>
<tr>
<td>Bivalves</td>
<td></td>
</tr>
<tr>
<td>Asaphia violascens</td>
<td>X</td>
</tr>
<tr>
<td>Atactodea striata</td>
<td>X</td>
</tr>
<tr>
<td>Clona bella</td>
<td>X</td>
</tr>
<tr>
<td>Gafarium pectinatum</td>
<td>X</td>
</tr>
<tr>
<td>Pinna fragilis</td>
<td>X</td>
</tr>
<tr>
<td>Quidnipagus palatum</td>
<td>X</td>
</tr>
<tr>
<td>Juvenile fish</td>
<td></td>
</tr>
<tr>
<td>Coraxus sesilis</td>
<td>X</td>
</tr>
<tr>
<td>Coraxus argenteus</td>
<td>X</td>
</tr>
<tr>
<td>Mullideres vanicolensis</td>
<td>X</td>
</tr>
<tr>
<td>Vulturugil engeli</td>
<td>X</td>
</tr>
</tbody>
</table>
suggest at best only limited bioindicator capability for this element. Levels in the former tissue typically range between 0.08 and 0.18 g/g in specimens from clean environments. Values recorded during the current study rank among the lowest reported ambient mercury availability and the literature is replete with examples, both from clean and polluted environments. Values recorded during the current study rank among the lowest reported ambient mercury availability and the literature is replete with examples, both from clean and polluted environments.

Seacucumbers derive their metal load primarily via the ingestion of surface sediments and concentrate copper more so in hemal tissue than body wall muscle. Levels in the former tissue typically range between 0.08 and 0.18 g/g in specimens from clean environments. Values recorded during the current study rank among the lowest reported ambient mercury availability and the literature is replete with examples, both from clean and polluted environments. Values recorded during the current study rank among the lowest reported ambient mercury availability and the literature is replete with examples, both from clean and polluted environments.

Data are single replicates of bulk sample homogenates.

Table 3
Strong acid extractable trace metals (μg/g dry wt.) in intertidal sediments from Tanapag Lagoon, Saipan.

<table>
<thead>
<tr>
<th>Site Location</th>
<th>Sediment type</th>
<th>Ag</th>
<th>As</th>
<th>Cd</th>
<th>Cr</th>
<th>Cu</th>
<th>Hg</th>
<th>Ni</th>
<th>Pb</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Micro Beach</td>
<td>Clean coarse sand</td>
<td>&lt;0.20</td>
<td>0.62</td>
<td>&lt;0.20</td>
<td>3.27</td>
<td>0.50</td>
<td>3.70</td>
<td>&lt;0.20</td>
<td>0.65</td>
<td>2.42</td>
</tr>
<tr>
<td>2 Puerto Rico Dump</td>
<td>Medium to coarse muddy sand</td>
<td>0.75</td>
<td>2.56</td>
<td>1.69</td>
<td>17.5</td>
<td>102</td>
<td>74.7</td>
<td>11.9</td>
<td>158</td>
<td>358</td>
</tr>
<tr>
<td>3 Echo Bay</td>
<td>Medium to coarse sand</td>
<td>&lt;0.21</td>
<td>3.55</td>
<td>0.31</td>
<td>2.56</td>
<td>6.76</td>
<td>18.1</td>
<td>&lt;0.20</td>
<td>3.19</td>
<td>7.39</td>
</tr>
<tr>
<td>4 Sea Plane Ramps</td>
<td>Muddy sand</td>
<td>&lt;0.15</td>
<td>5.68</td>
<td>0.23</td>
<td>2.83</td>
<td>39.8</td>
<td>23.0</td>
<td>0.89</td>
<td>17.7</td>
<td>84.0</td>
</tr>
<tr>
<td>5 CUC Beach</td>
<td>Muddy sand</td>
<td>&lt;0.16</td>
<td>2.14</td>
<td>0.32</td>
<td>4.61</td>
<td>5.34</td>
<td>24.2</td>
<td>0.94</td>
<td>21.3</td>
<td>26.4</td>
</tr>
<tr>
<td>6 Lower Base Channel</td>
<td>Muddy sand</td>
<td>&lt;0.10</td>
<td>2.52</td>
<td>0.24</td>
<td>2.43</td>
<td>1.34</td>
<td>10.9</td>
<td>0.46</td>
<td>1.78</td>
<td>6.00</td>
</tr>
<tr>
<td>7 Saddock As Agatan</td>
<td>Fine to coarse muddy sand</td>
<td>&lt;0.17</td>
<td>7.79</td>
<td>&lt;0.17</td>
<td>3.08</td>
<td>4.70</td>
<td>6.90</td>
<td>0.85</td>
<td>0.84</td>
<td>15.1</td>
</tr>
<tr>
<td>8 Saddock Dogas</td>
<td>Fine muddy sand</td>
<td>&lt;0.18</td>
<td>2.50</td>
<td>&lt;0.18</td>
<td>3.67</td>
<td>5.79</td>
<td>50.2</td>
<td>1.16</td>
<td>1.33</td>
<td>18.5</td>
</tr>
<tr>
<td>9 Bobo Achugao</td>
<td>Fine to medium sand</td>
<td>&lt;0.17</td>
<td>0.28</td>
<td>&lt;0.17</td>
<td>1.42</td>
<td>4.80</td>
<td>3.28</td>
<td>0.25</td>
<td>4.07</td>
<td>12.1</td>
</tr>
<tr>
<td>10 Plumaria Hotel Beach</td>
<td>Clean coarse sand</td>
<td>&lt;0.18</td>
<td>1.19</td>
<td>&lt;0.18</td>
<td>2.78</td>
<td>5.23</td>
<td>4.37</td>
<td>0.26</td>
<td>2.19</td>
<td>12.0</td>
</tr>
<tr>
<td>11 San Roque Cemetery</td>
<td>Clean coarse sand</td>
<td>&lt;0.15</td>
<td>0.33</td>
<td>0.22</td>
<td>1.71</td>
<td>0.60</td>
<td>2.38</td>
<td>0.22</td>
<td>1.08</td>
<td>3.73</td>
</tr>
<tr>
<td>12 Pau Pau Beach</td>
<td>Clean coarse sand</td>
<td>&lt;0.18</td>
<td>0.74</td>
<td>0.27</td>
<td>1.52</td>
<td>2.70</td>
<td>3.31</td>
<td>0.44</td>
<td>1.16</td>
<td>4.49</td>
</tr>
</tbody>
</table>

Data are single replicates of bulk sample homogenates.

a Arsenic concentrations as μg/g wet wt.
b Mercury concentrations as ng/g wet wt.

Table 4
Trace metals (μg/g dry wt.) in algae from Tanapag Lagoon, Saipan.

<table>
<thead>
<tr>
<th>Sample Site Location</th>
<th>Site Location</th>
<th>Sediment type</th>
<th>Ag</th>
<th>As</th>
<th>Cd</th>
<th>Cr</th>
<th>Cu</th>
<th>Hg</th>
<th>Ni</th>
<th>Pb</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acanthophora spicifera</td>
<td>Micro Beach</td>
<td>Clean coarse sand</td>
<td>&lt;0.08</td>
<td>0.76</td>
<td>0.23</td>
<td>0.51</td>
<td>5.04</td>
<td>1.86</td>
<td>2.97</td>
<td>0.64</td>
<td>57.4</td>
</tr>
<tr>
<td>2 Sea Plane Ramps</td>
<td>Muddy sand</td>
<td>0.51</td>
<td>0.53</td>
<td>0.13</td>
<td>1.29</td>
<td>30.5</td>
<td>4.39</td>
<td>1.87</td>
<td>8.14</td>
<td>13.0</td>
<td></td>
</tr>
<tr>
<td>3 Saddock As Agatan</td>
<td>Muddy sand</td>
<td>0.23</td>
<td>1.13</td>
<td>0.70</td>
<td>1.16</td>
<td>4.41</td>
<td>2.25</td>
<td>1.94</td>
<td>0.97</td>
<td>17.6</td>
<td></td>
</tr>
<tr>
<td>4 Saddock Dogas</td>
<td>Muddy sand</td>
<td>0.15</td>
<td>0.77</td>
<td>0.58</td>
<td>0.97</td>
<td>2.88</td>
<td>6.26</td>
<td>1.90</td>
<td>0.49</td>
<td>22.2</td>
<td></td>
</tr>
<tr>
<td>5 Bobo Achugao</td>
<td>Fine to medium sand</td>
<td>0.23</td>
<td>0.93</td>
<td>0.69</td>
<td>1.54</td>
<td>4.17</td>
<td>4.69</td>
<td>2.52</td>
<td>0.96</td>
<td>22.6</td>
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</tr>
<tr>
<td>6 Plumaria Hotel Beach</td>
<td>Clean coarse sand</td>
<td>&lt;0.08</td>
<td>0.79</td>
<td>0.62</td>
<td>&lt;0.26</td>
<td>4.40</td>
<td>10.2</td>
<td>1.78</td>
<td>0.65</td>
<td>21.1</td>
<td></td>
</tr>
<tr>
<td>Dicryota bartayresiana</td>
<td>San Roque Cemetery Beach</td>
<td>&lt;0.16</td>
<td>4.50</td>
<td>0.47</td>
<td>0.56</td>
<td>1.87</td>
<td>3.54</td>
<td>1.28</td>
<td>0.63</td>
<td>29.6</td>
<td></td>
</tr>
<tr>
<td>Gracilaria salicornia</td>
<td>Puerto Rico Dump</td>
<td>&lt;0.07</td>
<td>2.62</td>
<td>0.07</td>
<td>&lt;0.23</td>
<td>1.22</td>
<td>4.38</td>
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<td>&lt;0.09</td>
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<td>2.28</td>
<td>4.26</td>
<td>&lt;0.19</td>
<td>0.31</td>
<td>17.1</td>
<td></td>
</tr>
<tr>
<td>4 Sea Plane Ramps</td>
<td>CUC Beach</td>
<td>&lt;0.07</td>
<td>2.19</td>
<td>&lt;0.07</td>
<td>&lt;0.23</td>
<td>1.71</td>
<td>2.43</td>
<td>0.22</td>
<td>&lt;0.23</td>
<td>14.2</td>
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</tr>
<tr>
<td>5 Lower Base Channel</td>
<td>0.11</td>
<td>2.49</td>
<td>0.11</td>
<td>0.93</td>
<td>2.63</td>
<td>2.42</td>
<td>0.46</td>
<td>&lt;0.37</td>
<td>14.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 Bobo Achugao</td>
<td>&lt;0.10</td>
<td>2.82</td>
<td>0.20</td>
<td>0.83</td>
<td>2.90</td>
<td>2.76</td>
<td>0.52</td>
<td>1.17</td>
<td>24.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Laurencia sp.</td>
<td>Puerto Rico Dump</td>
<td>0.24</td>
<td>0.18</td>
<td>0.78</td>
<td>1.12</td>
<td>4.15</td>
<td>2.91</td>
<td>2.66</td>
<td>3.16</td>
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Data are single replicates of bulk sample homogenates.

a Arsenic concentrations as μg/g wet wt.
b Mercury concentrations as ng/g wet wt.
## Table 5
Trace metals (µg/g dry wt.) in seagrass from Tanapag Lagoon, Saipan.

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<th>Hg</th>
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Halodule uninervis

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Dashes indicate not data; nc = not calculable.

* Ag concentrations as µg/g dry wt.
* Cd concentrations as µg/g wet wt.

### Table 6
Trace metals (µg/g dry wt.) in seacucumbers from Tanapag Lagoon, Saipan.

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*Holothuria atra*

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</table>

advisories for methylmercury recommended by the US EPA (USEPA, 1986).

While nickel concentrations were unremarkable in all biotic representatives examined, those for lead were indicative of source- and species-dependant differences in abundance and availability. For example, the lead enriched sediment at the base of the dump had little to no influence on levels in resident macrophytes but dramatically increased those in bivalves raising levels from baseline values of less than 1 μg/g (Denton and Morrison, 2008) to highs of 184, 102 and 54 μg/g in Q. palatum, A. violascens and G. pectinatum, respectively. These data imply that lead released into the lagoon from the dump is rapidly confined to the sediment compartment and has little impact on the soluble metal fraction close to baseline. In sharp contrast, the lead released into the lagoon from the dump is rapidly confined to the sediment compartment and has little impact on the soluble metal fraction close to baseline. In sharp contrast, the lead released into the lagoon from the dump is rapidly confined to the sediment compartment and has little impact on the soluble metal fraction close to baseline. In sharp contrast, the lead released into the lagoon from the dump is rapidly confined to the sediment compartment and has little impact on the soluble metal fraction close to baseline. In sharp contrast, the lead released into the lagoon from the dump is rapidly confined to the sediment compartment and has little impact on the soluble metal fraction close to baseline. In sharp contrast, the lead released into the lagoon from the dump is rapidly confined to the sediment compartment and has little impact on the soluble metal fraction close to baseline. In sharp contrast, the lead released into the lagoon from the dump is rapidly confined to the sediment compartment and has little impact on the soluble metal fraction close to baseline. In sharp contrast, the lead released into the lagoon from the dump is rapidly confined to the sediment compartment and has little impact on the soluble metal fraction close to baseline. In sharp contrast, the lead released into the lagoon from the dump is rapidly confined to the sediment compartment and has little impact on the soluble metal fraction close to baseline. In sharp contrast, the lead released into the lagoon from the dump is rapidly confined to the sediment compartment and has little impact on the soluble metal fraction close to baseline. In sharp contrast, the lead released into the lagoon from the dump is rapidly confined to the sediment compartment and has little impact on the soluble metal fraction close to baseline. In sharp contrast, the lead released into the lagoon from the dump is rapidly confined to the sediment compartment and has little impact on the soluble metal fraction close to baseline. In sharp contrast, the lead released into the lagoon from the dump is rapidly confined to the sediment compartment and has little impact on the soluble metal fraction close to baseline.

In summary, this preliminary investigation confirmed previous findings of trace element enrichment in surface sediments around the base of the Puerto Rico Dump. Evidence is also presented that clearly shows this enrichment is being transmitted to biotic components in the area although the implications from the data are that natural processes operating in the sediments and overlying water column place some constraints on rates of transfer. The role of iron and manganese in regulating metal recycling processes in aquatic environments is well known (Förster and Wittmann, 1983) and undoubtedly of primary importance here considering...
that both elements are typically high in leachate streams emerging from municipal dumps (Denton et al., 2005b, 2008). Additionally, the complexation of free metal ions with dissolved organic ligands released from decomposing organic wastes in the dump, coupled with continual tidal flushing in and out of the area, all serve to keep the biologically available dissolved metal fraction in the water column of this area close to baseline. Thus, metal contaminants released from the dump tend to accumulate in bottom deposits

<table>
<thead>
<tr>
<th>Species</th>
<th>Site Location</th>
<th>Statistic</th>
<th>Ag</th>
<th>As</th>
<th>Cd</th>
<th>Cr</th>
<th>Cu</th>
<th>Hg</th>
<th>Ni</th>
<th>Pb</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asaphia violascens</td>
<td>2 Puerto Rico Dump</td>
<td>Mean</td>
<td>1.15</td>
<td>–</td>
<td>0.66</td>
<td>12.0</td>
<td>44.1</td>
<td>–</td>
<td>6.10</td>
<td>83.5</td>
<td>270</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Range</td>
<td>0.99–1.32</td>
<td>–</td>
<td>0.62–0.70</td>
<td>11.9–12.2</td>
<td>26.5–73.3</td>
<td>–</td>
<td>5.07–7.35</td>
<td>68.1–102</td>
<td>220–332</td>
</tr>
</tbody>
</table>

<p>| Table 7 | Trace metals (µg/g dry wt.) in bivalve molluscs from Tanapag Lagoon, Saipan. |</p>
<table>
<thead>
<tr>
<th>Species</th>
<th>Site Location</th>
<th>Average</th>
<th>Range</th>
<th>Statistical</th>
<th>Ag</th>
<th>As</th>
<th>Cd</th>
<th>Cr</th>
<th>Cu</th>
<th>Hg</th>
<th>Ni</th>
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<th>Zn</th>
</tr>
</thead>
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<td>2 Puerto Rico Dump</td>
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<td>6.10</td>
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<td>26.5–73.3</td>
<td>–</td>
<td>5.07–7.35</td>
<td>68.1–102</td>
<td>220–332</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<p>| Table 8 | Trace metals (µg/g wet wt.) in axial muscle of juvenile fish from Tanapag Lagoon, Saipan. |</p>
<table>
<thead>
<tr>
<th>Species</th>
<th>Sites</th>
<th>Total length (cm)</th>
<th>Average</th>
<th>Range</th>
<th>Statistical</th>
<th>As</th>
<th>Hg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caranx sexfasciatus</td>
<td>1, 2, 4, 6, 7</td>
<td>13.1</td>
<td>11.5–17.0</td>
<td>Range</td>
<td>0.81–16.9</td>
<td>17.9–71.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mean (±95% c.l.)</td>
<td></td>
<td></td>
<td>3.31 (1.40–7.86)</td>
<td>32.6 (22.4–47.5)</td>
<td></td>
</tr>
<tr>
<td>Gerres argyreus</td>
<td>1–7</td>
<td>12.0</td>
<td>9.5–17.0</td>
<td>Range</td>
<td>2.14–37.9</td>
<td>6.56–97.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mean (±95% c.l.)</td>
<td></td>
<td></td>
<td>13.1 (9.52–18.0)</td>
<td>23.0 (16.9–31.3)</td>
<td></td>
</tr>
<tr>
<td>Mullolobis vanicolensis</td>
<td>1–4, 6–12</td>
<td>12.3</td>
<td>8.5–17.5</td>
<td>Range</td>
<td>1.21–29.8</td>
<td>5.31–42.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mean (±95% c.l.)</td>
<td></td>
<td></td>
<td>4.56 (3.72–5.56)</td>
<td>13.3 (10.8–16.3)</td>
<td></td>
</tr>
<tr>
<td>Valamugil engeli</td>
<td>1–6</td>
<td>11.1</td>
<td>8.5–15.0</td>
<td>Range</td>
<td>0.29–23.3</td>
<td>8.74–74.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mean (±95% c.l.)</td>
<td></td>
<td></td>
<td>1.83 (1.23–2.71)</td>
<td>20.3 (15.1–27.3)</td>
<td></td>
</tr>
</tbody>
</table>
and are mobilized out of the area largely by forces that physically disturb them, e.g., typhoons, storm surges, dredging activities etc. Their movement into biotic communities within this area predominantly occurs via the sediment ingester-suspension feeder-carnivore route rather than through primary producers and secondary trophic level consumers. From a human health standpoint, lead was identified as the element of greatest concern with advisory exceedences noted in bivalves from the dump (Site 2) northwards to Lower Base Channel (Site 6). With the exception of copper in Q. palatum from Site 2, trace metal levels in all other biotic representatives were well below critical threshold levels of concern when weighed against existing USA advisories (USEPA, 1986; USFDA, 1998) and food standards of other countries (Nauen, 1983).

Acknowledgements

The authors thank Clarissa Bearden and her staff (DEQ, Saipan) for providing bench and freezer space for sample dissection, processing and storage; Melissa Schable, Nadia Wood and Kevin Cruz (Water and Environmental Research Institute, University of Guam) for analytical assistance and Mr. Richard Miller (School of Earth and Environmental Sciences, University of Wollongong) for preparing the site maps for this paper. The work was funded, in part, by the US Department of Interior via the Water Resources Research Institute Program of the US Geological Survey (Award No. 02HQGR0134).

References


Polychlorinated biphenyls in sediments of selected coastal environments in northern Morocco

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Morocco is presently experiencing a great deal of economic development, which often brings about the risk of pollution by toxic chemicals. Polychlorinated biphenyls (PCBs) are mixtures of synthetic organic chemicals that were used in hundreds of industrial and commercial applications, due to their flame retardant properties, chemical stability, high boiling point and insulating properties. Their production and use was severely regulated starting in the late 1970s but they are still used in electrical capacitors, electrical transformers, vacuum pumps and gas-transmission turbines. Furthermore, current evidence suggests that presently the major source of PCBs may be recycling through evaporation and redeposition of what has previously been introduced into the environment. This process of mobilisation from secondary sources may be further enhanced in tropical and sub-tropical regions due to the prevailing climatic conditions. Therefore, these regions are potential sources for persistent organic pollutants (POPs) (Iwata et al., 1994; Larsson et al., 1995). Currently, there is a scarcity of data...