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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 bioindicator 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

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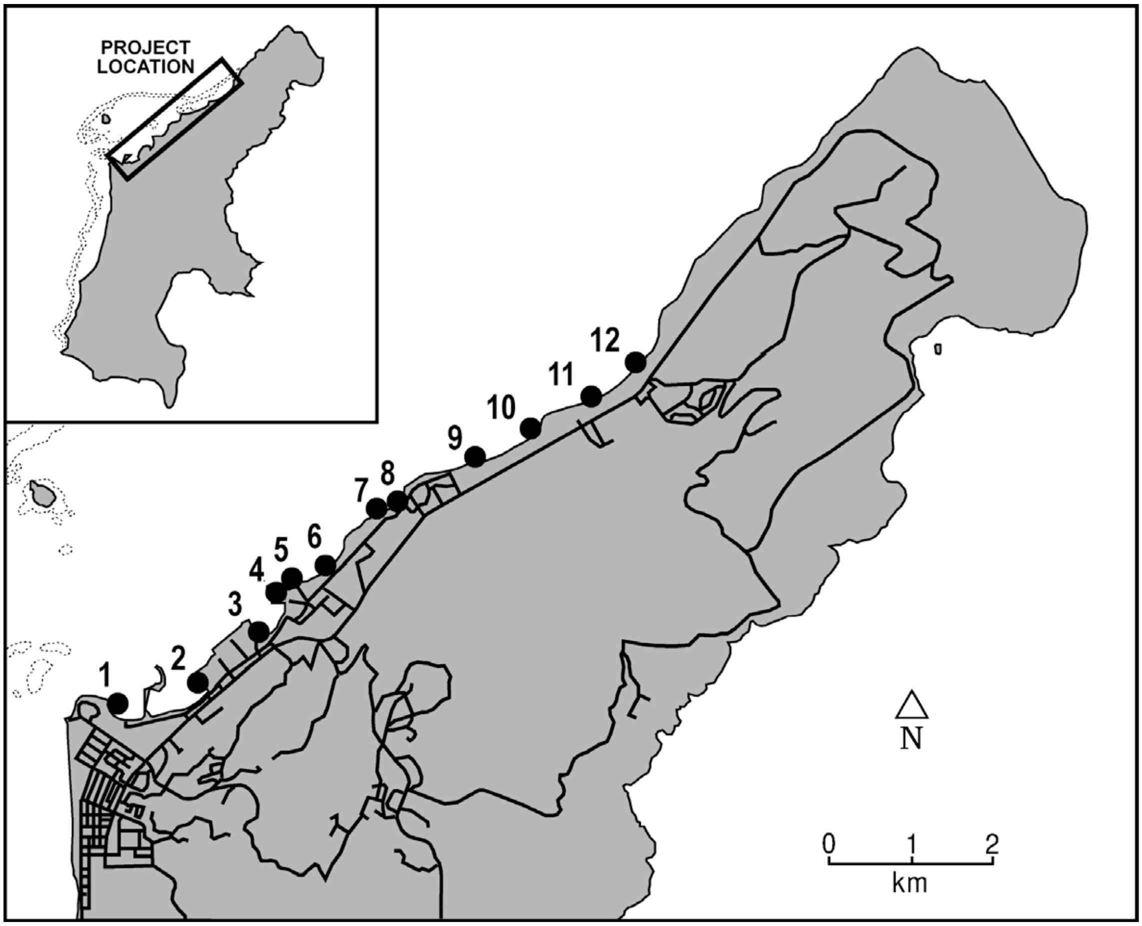

Fig. 1. Biota and sediment sampling site locations in Tanapag Lagoon, Saipan.

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

Table 1
Information on the Tanapag Lagoon sites visited in this study.

Site no.	Location	Sediment type	Comments
1	Micro Beach – northern end	Very coarse carbonate sand intertidal sediments giving way to finer material immediately offshore	Net southerly movement of surface water transports contaminants from the Port, the Puerto Rico Dump and two small boat marinas into the general area
2	Puerto Rico Dump – south-western edge	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	Aqueous contaminants impacting this site are principally derived from the dump itself (in leachate streams), the Port, and road surface water drainage
3	Echo Bay – western side	Poorly sorted medium to coarse carbonate sands of biogenic origin	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
4	Seaplane Ramps - centrally located on the inner side of the eastern ramp	Intertidal zone sediments are typically very course, gravelly sand, while finer deposits occur in deeper waters alongside the ramps themselves	Primary sources of metal contamination in this area are almost exclusively confined to shipping and ship repair activities
5	CUC Beach	Fine to medium biogenic sands interspersed with muddy fines of mixed origin	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 are of land previously used as a dumpsite for old car batteries and other assorted automobile hardware
6	Lower Base Channel	Fine to medium muddy sands	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
7	Saddok As Agatan	Relatively course sand in the upper intertidal zone to finer, muddier material at the mouth and further offshore	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
8	Saddok Dogas	Relatively course sand in the upper intertidal zone to finer, muddier material at the mouth and further offshore	Saddok Dogas, the second stream in this area, empties onto the beach approximately 150 m from the southern boarder 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 in the area
9	Bobo Achgao	Medium to fine sand. predominated throughout the intertidal and sub tidal regions	Bobo Achagao is the smallest of the three streams that discharge into this area of coastline and is the first to stop flowing during prolonged periods of dry weather
10	Plumeria Hotel Beach	Clean, coarse sands characterized the intertidal zone of this relatively pristine, shallow water embayment. Somewhat finer deposits of clean sand were found sub tidally	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 in the area
11	San Roque Cemetery Beach	Clean, coarse sands characterized the intertidal zone of this relatively pristine, shallow water embayment. Somewhat finer deposits of clean sand were found sub tidally	Site receives effluent from a nearby reverse osmosis desalination plant at the Nikko hotel. No other obvious sources of metal contamination in the area
12	Pau Pau Beach	Clean coarse to very coarse sediments with little terrigenous material present	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

Table 2
Biota sampled from Tanapag Lagoon, Saipan.

Species	Sites											
	1	2	3	4	5	6	7	8	9	10	11	12
Algae												
Acanthophora spicifera	x			x			x	x	x	x		
Dictyota bartayresiana											x	
Gracilaria salicornia		x	x		x	x			x			
Laurencia sp.		x	x									
Padina sp.		x	x	x			x		x	x	x	x
Sargassum polycystum											x	
Seagrass												
Enhalus acaroides	x	x		x	x	x	x	x	x			
Halodule uninervis					x				x	x	x	
Seacucumbers												
Bohadschia argus								x				
Bohadschia mormorata			x	x	x	x						
Holothuria atra	x	x	x	x	x	x	x	x	x	x	x	x
Bivalves												
Asaphia violascens		x										
Atactodea striata	x							x	x	x	x	x
Ctena bella	x											
Gafrarium pectinatum		x	x		x	x						
Pinna fragilis						x						
Quidnipagus palatum		x	x		x	x						
Juvenile fish												
Caranx sexfasciatus	x	x		x		x	x					
Gerres argyreus	x	x	x	x	x	x	x	x				
Mulloides vanicolensis	x	x	x	x		x	x	x	x	x	x	x
Valamugil engeli	x	x	x	x	x	x						

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

Site	Location	Sediment type[a]	Ag	As	Cd	Cr	Cu	Hg[b]	Ni	Pb	Zn
1	Micro Beach	Clean coarse sand	<0.20	0.62	<0.20	3.27	0.50	3.70	<0.20	0.65	2.42
2	Puerto Rico Dump	Medium to coarse muddy sand	0.75	2.56	1.69	17.5	102	74.7	11.9	158	358
3	Echo Bay	Medium to coarse sand	<0.21	3.55	0.31	2.56	6.76	18.1	<0.20	3.19	7.39
4	Sea Plane Ramps	Muddy sand	<0.15	5.68	0.23	2.83	39.8	23.0	0.89	17.7	84.0
5	CUC Beach	Muddy sand	<0.16	2.14	0.32	4.61	5.34	24.2	0.94	21.3	26.4
6	Lower Base Channel	Muddy sand	<0.10	2.52	0.24	2.43	1.34	10.9	0.46	1.78	6.00
7	Saddok As Agatan	Fine to coarse muddy sand	<0.17	7.79	<0.17	3.08	4.70	6.90	0.85	0.84	15.1
8	Saddok Dogas	Fine muddy sand	<0.18	2.50	<0.18	3.67	5.79	50.2	1.16	1.33	18.5
9	Bobo Achugao	Fine to medium sand	<0.17	0.28	<0.17	1.42	4.80	3.28	0.25	4.07	12.1
10	Plumaria Hotel Beach	Clean coarse sand	<0.18	1.19	<0.18	2.78	2.53	4.37	0.26	2.19	12.0
11	San Roque Cemetery	Clean coarse sand	<0.15	0.33	0.22	1.71	0.60	2.38	0.22	1.08	3.73
12	Pau Pau Beach	Clean coarse sand	<0.18	0.74	0.27	1.52	2.70	3.31	0.44	1.16	4.49

Data are single replicates of bulk sample homogenates.
[a] All sediments were dried at either 30 °C (arsenic and mercury) or 60 °C (all other metals) and sieved through a 1 mm Teflon screen prior to analysis.
[b] Mercury concentrations expressed as ng/g dry wt.

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

Sample	Site	Location	Ag	As[a]	Cd	Cr	Cu	Hg[b]	Ni	Pb	Zn
Acanthophora spicifera	1	Micro Beach	<0.08	0.76	0.23	0.51	5.04	1.86	2.07	0.64	57.4
	4	Sea Plane Ramps	0.51	0.53	0.13	1.29	30.5	4.39	1.87	8.14	130
	7	Saddok As Agatan	0.23	1.13	0.70	1.16	4.41	2.25	1.94	0.97	17.6
	8	Saddok Dogas	0.15	0.77	0.58	0.97	2.88	6.26	1.90	0.49	22.2
	9	Bobo Achugao	0.23	0.93	0.69	1.54	4.17	4.69	2.52	0.96	22.6
	10	Plumaria Hotel Beach	<0.08	0.79	0.62	<0.26	4.40	10.2	1.78	0.65	21.1
Dictyota bartayresiana	11	San Roque Cemetery Beach	<0.16	4.50	0.47	0.56	1.87	3.54	1.28	0.63	29.6
Gracilaria salicornia	2	Puerto Rico Dump	<0.07	2.62	<0.07	<0.23	1.22	4.38	0.22	1.04	11.6
	3	Echo Bay	<0.09	2.40	<0.09	<0.31	2.28	4.26	<0.19	<0.31	17.1
	5	CUC Beach	<0.07	2.19	<0.07	<0.23	1.71	2.43	0.22	<0.23	14.2
	6	Lower Base Channel	<0.11	2.49	<0.11	0.93	2.63	2.42	0.46	<0.37	14.5
	9	Bobo Achugao	<0.10	2.82	0.20	0.83	2.90	2.76	0.52	1.17	24.8
Laurencia sp.	2	Puerto Rico Dump	0.24	0.18	0.78	1.12	4.15	2.91	2.66	3.16	39.4
	3	Echo Bay	0.18	3.24	0.44	1.62	11.3	6.18	2.39	4.27	54.6
Padina sp.	2	Puerto Rico Dump	0.21	7.53	<0.11	0.53	2.80	6.33	0.88	5.47	17.5
	3	Echo Bay	0.29	5.98	0.29	0.84	8.44	3.99	1.05	3.12	60.1
	4	Sea Plane Ramps	0.11	3.56	0.22	1.43	25.3	3.10	1.12	14.7	107
	7	Saddok As Agatan	0.26	4.16	1.72	0.88	2.01	6.02	1.65	1.76	10.6
	8	Saddok Dogas	0.16	7.60	0.97	0.67	1.98	2.65	1.52	<0.27	12.1
	10	Plumaria Hotel Beach	<0.10	5.32	0.58	<0.32	1.30	3.69	1.11	<0.32	5.32
	11	San Roque Cemetery Beach	<0.09	12.3	0.64	0.46	2.02	1.74	1.42	1.06	18.5
	12	Pau Pau Beach	<0.09	7.03	0.63	<0.30	2.02	3.91	1.41	<0.30	7.76
Sargassum polycystum	11	San Roque Cemetery	<0.16	22.9	0.40	0.57	1.27	0.45	1.08	0.51	15.9

Data are single replicates of bulk sample homogenates.
[a] Arsenic concentrations as μg/g wet wt.
[b] Mercury concentrations as ng/g wet wt.

(Phillips, 1980). Copper based antifouling paints were considered to be the most probable source of enrichment at this site in view of the ongoing dry dock activities in the area. The relatively low copper levels in macrophytes collected near the dump (Site 2) were of interest considering the marked enrichment noted in sediment. Clearly, processes are at work here that maintain the soluble copper fraction close to baseline.

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 ~3 and 6 μg/g in specimens from clean environments (Denton et al., 2005a; Denton and Morrison, 2008). Levels determined in individuals from Sites 2 and 4 (Table 6) therefore suggest at best only limited bioindicator capability for this element. The bivalve, *Q. palatum*, on the other hand, is clearly a very sensitive indicator of ambient copper availability with levels approaching 2000 μg/g in representatives from Site 2 (Table 7). Baseline levels for this species normally hover around 5 μg/g (Denton and Morrison, 2008).

Most marine organisms appear to be responsive to changes in 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 for all groups considered. Those for juvenile fish were of special interest given that all four species are popularly consumed by many Saipan residents. Their poorly defined foraging ranges, however, limit their utility as site-specific bioindicators for mercury. The data sets for each were thus combined to provide an overall picture of mercury availability within the lagoon (Table 8) and perhaps a better estimate of levels reaching the consumer given the fact that local fishermen tend to move along the shore in search of schooling fish rather than stay in any one place. Needless to say, the data did not raise any significant public health concerns when evaluated against the risk-based consumption limit health

Table 5
Trace metals (μg/g dry wt.) in seagrass from Tanapag Lagoon, Saipan.

Species	Site	Location	Statistic[a]	Ag	As[b]	Cd	Cr	Cu	Hg[c]	Ni	Pb	Zn
Enhalus acaroides												
	1	Micro Beach	Mean	<0.1 5	0.03	0.15	0.32	7.19	3.38	0.95	0.24	24.1
			Range	–	–	–	–	–	–	–	–	–
	2	Puerto Rico Dump	Mean	nc	0.07	0.30	0.44	7.77	3.82	2 24	0.69	32.7
			Range	all <0.20	–	0.29–0.32	0.33–0.60	7.66–7.88	–	2.14–2.34	0.68–0.71	32.6–33.0
	4	Sea Plane Ramps	Mean	nc	0.07	0.20	0.44	47.9	3.83	0.76	2.05	29.0
			Range	all <0.20	–	–	–	–	–	–	–	–
	5	CUC Beach	Mean	nc	0.13	0.54	0.34	6.57	9.01	0.76	0.23	22.8
			Range	all <0.20	–	0.48–0.60	0.30–0.34	5.66–7.63	–	0.60–0.95	0.22–0.24	20.3–25.7
	6	Lower Base Channel	Mean	<0.17	0.14	0.33	0.87	5.31	0.85	1.85	0.40	25.0
			Range	–	–	–	–	–	–	–	–	–
	7	Saddok As Agatan	Mean	nc	0.08	0.22	0.33	2.09	1.74	1.42	0.24	21.0
			Range	all <0.17	0.03–0.24	0.20–0.25	0.35–0.35	2.03–2.15	1.72–1.77	1.25–1.61	0.22–0.27	20.1–21.9
	8	Saddok Dogas	Mean	nc	0.19	0.31	0.56	2.38	1.44	1.03	0.41	22.3
			Range	all <0.20	–	0.24–0.41	0.35–0.87	2.24–2.53	–	0.99–1.08	0.26–0.66	20.8–23.8
	9	Bobo Achugao	Mean	<0.16	0.09	0.39	0.33	2.64	1.14	1.51	0.25	20.6
			Range	–	–	–	–	–	–	–	–	–
Halodule uninervis												
	5	CUC Beach	Mean	nc	0.11	0.66	0.47	6.46	1.8	0.85	0.53	27.6
			Range	all <0.20	–	0.64–0.66	0.47–0.69	6.00–6.46	–	0.70–0.85	0.52–0.53	25.7–27.6
	9	Bobo Achugao	Mean	<0.20	0.15	0.30	0.42	4.15	2.34	1.25	0.32	35.8
			Range	–	–	–	–	–	–	–	–	–
	10	Plumaria Hotel Beach	Mean	nc	0.13	0.47	0.46	4.90	2.67	1.15	1.01	31.6
			Range	all <0.20	0.03–0.54	0.38–0.56	0.41–0.50	4.62–5.20	2.25–3.18	1.09–1.21	0.93–1.09	30.4–32.7
	11	San Roque Cemetery Beach	Mean	<0.20	0.12	0.29	0.42	2.45	3.53	1.05	0.32	21.1
			Range	–	–	–	–	–	–	–	–	–

Dashes indicate not data; nc = not calculable.
[a] Mean as geometric mean (n = 1–3 replicate samples per site).
[b] Arsenic concentrations as μg/g wet wt.
[c] Mercury concentrations as ng/g wet wt.

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

Species	Site	Location	Tissue[a]	Statistic[b]	Ag	As[c]	Cd	Cr	Cu	Hg[d]	Ni	Pb	Zn
Bohadschia argus													
	8	Saddok Dogas	M	Mean	<0.09	7.45	<0.09	<0.37	0.86	3.42	0.30	<0.14	15.9
				Range	–	–	–	–	–	–	–	–	–
			H	Mean	<0.11	0.59	0.32	4.27	2.48	36.3	0.44	<0.36	44.2
				Range	–	–	–	–	–	–	–	–	–
B. mormorata													
	3	Echo Bay	M	Mean	nc	1.46	nc	0.34	0.47	2.00	0.76	nc	12.6
				Range	all <0.12	1.34–1.58	all <0.12	<0.32–0.71	0.45–0.50	1.31–3.04	0.66–0.87	all <0.20	12.3–12.8
			H	Mean	nc	1.53	0.12	4.91	2.76	83.9	0.70	0.91	152
				Range	all <0.11	0.73–3.20	<0.11–0.27	3.68–6.54	2.71–2.82	59.5–118	0.66–0.74	0.59–1.40	102–227
	4	Sea Plane Ramps	M	Mean	nc	2.18	nc	nc	1.13	0.82	0.82	0.65	10.7
				Range	all <0.08	1.71–2.78	all <0.08	all <0.34	0.63–2.01	0.54–1.25	0.80–0.85	0.64–0.67	10.2–11.3
			H	Mean	nc	0.91	0.38	6.71	5.22	79.1	0.80	3.25	161
				Range	all <0.13	0.60–1.39	0.36–0.39	4.83–9.31	4.83–5.63	76.0–82.4	0.68–0.94	2.87–3.68	118–221
	5	CUC Beach	M	Mean	<0.08	10.1	<0.08	0.56	1.50	2.89	1.11	0.88	41.5
				Range	–	–	–	–	–	–	–	–	–
			H	Mean	<0.12	12.1	3.72	29.7	5.23	321	3.39	10.3	503
				Range	–	–	–	–	–	–	–	–	–
	6	Lower Base Channel	M	Mean	<0.11	1.03	<0.11	0.74	0.53	1.58	0.65	<0.17	9.92
				Range	–	–	–	–	–	–	–	–	–
			H	Mean	<0.09	1.46	0.36	3.14	2.34	39.0	0.47	<0.30	93.4
				Range	–	–	–	–	–	–	–	–	–
Holothuria atra													
	1	Micro Beach	M	Mean	nc	7.30	nc	nc	1.90	2.61	nc	0.19	18.7
				Range	all <0.13	5.32–10.3	all <0.13	all <0.56	1.58–2.29	1.50–4.54	all <0.23	<0.21–0.36	18.3–19.0
			H	Mean	nc	0.51	0.10	nc	3.13	8.62	nc	0.28	44.5
				Range	all <0.12	0.50–0.53	<0.08–0.25	<0.41	3.11–3.16	5.53–13.4	all <0.26	<0.41–0.39	40.0–49.5
	2	Puerto Rico Dump	M	Mean	nc	1.38	nc	0.37	1.27	1.83	0.19	1.79	13.8
				Range	all <0.09	0.75–2.53	all <0.09	<0.41–0.66	1.25–1.29	1.65–2.02	<0.16–0.45	1.53–2.09	13.1–14.5
			H	Mean	nc	1.56	0.70	2.33	8.18	30.8	nc	4.33	153
				Range	all <0.07	1.19–2.04	0.56–0.86	1.91–2.83	7.76–8.63	19.8–47.9	all <0.14	2.96–6.33	95.2–246
	3	Echo Bay	M	Mean	nc	0.44	nc	nc	1.30	3.39	nc	nc	15.9
				Range	all <0.12	0.40–0.49	all <0.12	all <0.54	1.30–1.77	2.99–3.5	all <0.21	all <0.45	13.1–19.2
			H	Mean	nc	0.49	0.25	0.66	3.91	53.6	nc	0.29	42.8
				Range	all <0.12	0.21–1.15	0.17–0.37	0.49–0.89	3.33–4.60	45.5–63.2	all <0.22	0.20–0.41	31.7–57.8

Table 6 (*continued*)

Species	Site	Location	Tissue[a]	Statistic[b]	Ag	As[c]	Cd	Cr	Cu	Hg[d]	Ni	Pb	Zn
	4	Sea Plane Ramps	M	Mean	nc	1.51	nc	0.32	1.59	1.83	0.12	1.84	22.7
				Range	all <0.08	0.82–2.77	all <0.08	<0.33–0.62	1.50–1.69	1.46–2.31	<0.13–0.22	1.77–1.91	21.4–24.1
			H	Mean	nc	0.48	0.95	3.39	9.41	12.0	0.34	3.92	276
				Range	all <0.11	0.24–0.99	0.95–1.05	2.94–3.90	7.88–11.2	8.14–17.5	0.25–0.46	3.62–4.24	266–287
	5	CUC Beach	M	Mean	nc	1.44	nc	nc	1.42	2.33	nc	1.83	19.9
				Range	all<0.12	1.39– 1.49	all <0.12	all <0.56	1.24–1.62	2.09–2.60	all <0.22	1.62–2.07	17.0–23.3
			H	Mean	nc	0.75	0.74	0.74	4.74	32.8	0.34	1.61	168
				Range	all <0.12	0.73–0.77	0.56–0.98	<0.53–2.04	2.83–7.95	29.3–36.7	0.32–0.35	1.19–2.18	100–281
	6	Lower Base Channel	M	Mean	<0.08	1.92	<0.08	0.69	1.94	2.66	0.20	0.26	17.2
				Range	–	–	–	–	–	–	–	–	–
			H	Mean	<0.11	1.65	<0.11	0.95	3.79	19.7	0.49	0.54	33.5
				Range	–	–	–	–	–	–	–	–	–
	7	Saddok As Agatan	M	Mean	nc	0.37	nc	nc	1.56	2.42	nc	0.63	18.7
				Range	all <0.10	0.35–0.38	all <0.10	all <0.43	1.48–1.64	1.90–3.07	all <0.18	0.58–0.68	18.4–19.0
			H	Mean	nc	0.82	0.10	0.84	5.26	11.0	nc	0.97	40.6
				Range	all <0.09	0.56–1.20	<0.09–0.24	0.60–1.20	3.55–7.79	7.82–15.4	all <0.16	1.03–0.92	29.8–55.4
	8	Saddok Dogas	M	Mean	nc	0.75	nc	nc	1.60	2.37	nc	nc	17.9
				Range	all <0.12	0.71–0.80	all <0.12	all <0.51	1.56–1.64	1.97–2.85	all <0.21	all <0.20	16.6–19.4
			H	Mean	nc	0.18	0.09	1.61	6.23	24.7	nc	nc	164
				Range	all <0.12	0.12–0.27	<0.12–0.14	0.95–2.74	5.57–6.96	13.4–45.6	all <0.20	all <0.19	129–210
	9	Bobo Achugao	M	Mean	nc	0.72	nc	nc	1.43	2.47	nc	0.17	18.3
				Range	all <0.12	0.38–1.36	all <0.12	all <0.50	1.07–1.90	2.46–2.47	all <0.21	<0.19–0.32	16.9–19.9
			H	Mean	nc	0.54	0.28	2.35	5.68	12.7	0.24	nc	39.7
				Range	all <0.23	–	0.23–0.34	1.70–3.25	4.36–7.39	6.14–26.3	<0.24–0.48	all <0.38	37.4–42.2
	10	Plumaria Hotel Beach	M	Mean	nc	2.33	nc	nc	1.82	3.94	nc	1.19	21.2
				Range	all <0.13	1.04–5.23	all <0.13	all <0.53	1.51–2.19	3.43–4.52	all <0.22	1.01–1.40	20.4–22.1
			H	Mean	nc	0.75	0.35	3.17	4.15	17.8	0.46	1.70	95
				Range	all <0.13	0.46–1.23	0.34–0.36	2.02–4.98	3.84–4.50	12.6–25.2	0.43–0.51	1.21–2.38	61.1–147
	11	San Roque Cemetery Beach	M	Mean	nc	14.8	nc	nc	1.41	nc	nc	0.62	20.0
				Range	all <0.11	14.3–15.4	all <0.11	all <0.45	1.33–1.50	all <0.48	all <0.19	0.44–0.85	18.2–22.6
			H	Mean	nc	1.27	0.09	1.56	4.99	25.3	nc	0.96	129
				Range	<0.10	0.99–1.63	<0.08–0.20	1.37–1.77	4.55–5.46	20.2–31.5	all <0 .21	0.85–1.09	80.2–206
	12	Pau Pau Beach	M	Mean	nc	2.59	nc	nc	1.88	2.15	nc	0.34	16.1
				Range	all <0.08	2.22–3.02	all <0.08	all <0.44	1.4–3.10	2.13–2.18	all <0.18	0.33–0.36	15.2–17.0
			H	Mean	nc	0.62	nc	0.46	3.49	19.5	0.25	nc	48.5
				Range	all <0.25	0.53–0.73	all <0.12	<0.41–1.05	3.23–3.76	12.7–29.9	<0.16–0.77	all <0.41	41.6–56.4

Dashes indicate no data; nc = not calculable.
[a] Tissues: M, body wall; H, hemal system.
[b] Mean as geometric mean (n = 1–2 replicate samples per site).
[c] Arsenic concentrations as μg/g wet wt.
[d] Mercury concentrations as ng/g wet wt.

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 in the overlying water column. At Seaplane Ramps (Site 4), the situation is somewhat different with both algae and seagrass indicating mild enrichment of the soluble lead fraction despite considerably lower levels in sediment (relative to Site 2). We presume this to reflect greater contributions from alternative lead sources such as boat fuels, antifouling and anticorrosive paints. Although there is no enforceable standard for lead in seafood in the USA., a non enforceable guideline of 1.7 μg/g wet wt. (∼10 μg/g dry wt.) is currently in place for bivalves (USFDA, 1998). All three species mentioned above are harvested for food by local residents and all three greatly exceed this advisory at Site 2. From the data, it would also appear that bivalve populations from Site 2 northwards to Site 6 are similarly impacted.

Marine algae are particularly good bioindicators of zinc contamination although levels rarely exceed 10 μg/g in specimens from clean waters (Denton and Burdon-Jones, 1986; Denton and Morrison, 2008). In Tanapag Lagoon, the highest concentrations were found in specimens from Micro Beach (Site 1) at the mouth of a small boat marina, Echo Bay adjacent to the Port (Site 3) and Seaplane Ramps (Site 4). This is hardly surprising considering that harbour waters and marinas are typically enriched with soluble zinc leached predominantly from boat paints, galvanized structures and sacrificial anodes. The relatively low zinc levels found in algae near the dump (Site 2) once again point to processes that keep the soluble metal fraction close to baseline. In sharp contrast, the bivalves, *A. violascens* and *Q. palatum*, clearly depict increased sedimentary levels of biologically available zinc at this site with maximum levels slightly in excess of 300 μg/g and 1000 μg/g in each species, respectively, compared with 70 μg/g and 350 μg/g in their Guam relatives (Denton and Morrison, 2008).

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 (Förstner and Wittmann, 1983) and undoubtedly of primary importance here considering

Table 7
Trace metals (µg/g dry wt.) in bivalve molluscs from Tanapag Lagoon, Saipan.

Species	Site	Location	Statistic[a]	Ag	As[b]	Cd	Cr	Cu	Hg[c]	Ni	Pb	Zn
Asaphia violascens												
	2	Puerto Rico Dump	Mean	1.15	–	0.66	12.0	44.1	–	6.10	83.5	270
			Range	0.99–1.32	–	0.62–0.70	11.9–12.2	26.5–73.3	–	5.07–7.35	68.1–102	220–332
Atactodea striata												
	1	Micro Beach	Mean	nc	1.59	0.49	0.46	9.62	15.8	2.64	0.45	120
			Range	all <0.25	–	0.49–0.50	0.42–0.52	8.99–10.3	–	2.52–2.77	0.34–0.60	112–129
	8	Saddok Dogas	Mean	nc	1.41	1.14	0.69	7.69	15.3	1.91	0.61	105
			Range	all <0.23	–	1.14–1.15	0.58–0.81	7.35–8.04	–	1.81–2.01	0.51–0.74	105–106
	9	Bobo Achugao	Mean	nc	1.41	5.04	1.97	11.3	17.4	3.26	0.36	127
			Range	all <0.24	–	4.66–5.45	0.59–6.56	9.63–13.3	–	2.24–4.76	<0.39–0.68	109–147
	10	Plumaria Hotel Beach	Mean	nc	2.19	1.11	0.82	15.4	23.8	2.78	2.94	98.0
			Range	all <0.26	–	1.05–1.17	0.74–0.91	11.7–20.2	–	2.68–2.90	2.75–3.14	97.3–98.7
	11	San Roque Cemetery Beach	Mean	2.73	1.21	1.73	0.62	14.0	17.9	3.29	0.95	86.0
			Range	1.47–5.08	–	1.55–1.93	0.57–0.68	13.3–14.7	–	3.31–3.26	0.95–0.96	71.8–103
	12	Pau Pau Beach	Mean	nc	1.86	0.28	0.91	8.59	8.22	2.62	0.67	101
			Range	all <0.21	–	<0.08–0.93	0.71–1.16	7.95–9.29	–	2.61–2.63	0.55–0.83	92.2–110
Gafrarium pectinatum												
	2	Puerto Rico Dump	Mean	0.57	2.64	1.56	1.18	33.7	19.7	11.4	37.5	51.4
			Range	0.53–0.62	–	1.35–1.79	1.06–1.31	32.3–35.3	–	10.9–12.0	31.4–44.9	47.7–55.3
	3	Echo Bay	Mean	0.34	3.41	1.03	0.65	17.8	14.2	12.2	50.4	52.3
			Range	0.31–0.38	–	1.00–1.07	0.64–0.65	16.7–18.9	–	11.5–13.0	46.9–54.2	45.9–60.7
	5	CUC Beach	Mean	0.14	4.42	0.95	0.58	11.7	23.3	12.2	37.6	55.8
			Range	<0.14–0.28	–	0.69–1.31	0.58–0.59	8.34–16.3	–	10.6–14.1	30.2–46.7	49.7–62.6
	6	Lower Base Channel	Mean	nc	2.71	0.81	0.83	7.97	9.91	13.1	8.31	51.7
			Range	all <0.24	–	0.78–0.84	0.82–0.84	6.69–9.50	–	12.8–13.4	7.97–8.67	42.3–63.2
Ctena bella												
	1	Micro Beach	Mean	0.51	0.92	1.77	0.87	8.64	22.0	4.95	6.16	406
			Range	0.33–0.81	–	1.16–2.71	0.82–0.92	5.31–14.1	–	5.57–4.40	5.94–6.38	384–430
Quidnipagus palatum												
	2	Puerto Rico Dump	Mean	18.1	2.57	0.30	9.70	1389	111	10.1	172	720
			Range	10.9–24.1	–	0.28–0.37	7.38–10.6	866–1876	–	8.94–11.3	163–184	605–993
	3	Echo Bay	Mean	1.86	3.24	1.40	8.59	341	56.6	8.32	117	305
			Range	–	–	–	–	–	–	–	–	–
	5	CUC Beach	Mean	0.90	1.67	0.24	4.94	105	33.6	13.0	80.0	724
			Range	0.89–0.91	–	0.22–0.26	4.81–5.07	104–106	–	12.9–13.1	75.8–84.3	530–990
	6	Lower Base Channel	Mean	0.49	3.42	0.20	6.15	23.7	44.3	11.6	13.3	501
			Range	0.32–0.74	–	0.19–0.21	4.86–7.76	14.7–38.2	–	11.4–11.7	9.01–19.7	478–525
Pinna fragilis												
	8	Saddok Dogas	Mean	1.06	–	13.1	2.86	11.5	–	48.4	2.29	1051
			Range	–	–	–	–	–	–	–	–	–

Dashes indicate no data; nc = not calculable.
[a] Mean as geometric mean (*n* = 1–3 replicates per site, each replicate being a composite of 1–3 bivalves).
[b] Arsenic as µg/g wet wt.
[c] Mercury concentrations as ng/g wet wt. nc = not calculable.

Table 8
Trace metals (µg/g wet wt.) in axial muscle of juvenile fish from Tanapag Lagoon, Saipan.

Species	Sites	Total length (cm)		Statistic[a]	As	Hg[b]
		Average	Range			
Caranx sexfasciatus	1, 2, 4, 6, 7	13.1	11.5–17.0	Range	0.81–16.9	17.9–71.8
				Mean (±95% c.l.)	3.31 (1.40–7.86)	32.6 (22.4–47.5)
				n	6	6
Gerres argyreus	1–7	12.0	9.5–17.0	Range	2.14–37.9	6.56–97.4
				Mean (±95% c.l.)	13.1 (9.52–18.0)	23.0 (16.9–31.3)
				n	20	20
Mulloides vanicolensis	1–4, 6–12	12.3	8.5–17.5	Range	1.21–29.8	3.11–42.7
				Mean (±95% c.l.)	4.56 (3.72–5.56)	13.3 (10.8–16.3)
				n	45	47
Valamugil engeli	1–6	11.1	8.5–15.0	Range	0.29–23.3	8.74–74.8
				Mean (±95% c.l.)	1.83 (1.23–2.71)	20.3 (15.1–27.3)
				n	22	16

[a] Mean as geometric mean, *n* = number of replicates, each replicate being a tissue composite of from 1 to 6 fish.
[b] Mercury concentrations as ng/g wet wt.

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 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 excedences 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).

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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 proprieties, 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

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