Report for 2005GU54B: Heavy Metals in Biotic and Abiotic Components of a Guam Reef Flat Impacted by Leachate from a Municipal Dump

Publications

- Water Resources Research Institute Reports:
  - Denton, Gary, R.W., Walter C. Kelly, H. Rick Wood and Yuming Wen. 2006. Impact of Metal Enriched leachate from Ordot Dump on the Heavy Metal Status of Biotic and Abiotic Components of Pago Bay. Water and Environmental Research Institute (WERI) Technical Report No. 113, University of Guam, Mangilao, Guam, 63 pp.

Report Follows

PROJECT SYNOPSIS REPORT

Project Title: Heavy Metals in Biotic and Abiotic Components of a Guam Reef Flat Impacted by Leachate from a Municipal Dump

Problem and Research Objectives

Pago Bay is a windward fringing reef flat on the eastern shore of central Guam. It is approximately 3 km long, 0.75 km at its widest point, and covers an area of around 1.5km^2. The bay harbors a relatively rich diversity of marine life and supports a variety of scientific, commercial and recreational activities. Additionally, local residents traditionally harvest many of its fisheries resources for food.

The bay receives continuous drainage from the Pago River system, a complex of three rivers that drains a catchment area of approximately 27 square kilometers inland. One of these rivers, the Lonfit River, receives leachate from the island's only municipal dump located just outside the village of Ordot, about two miles upstream of Pago Bay. The dump, which has been in continuous use for over 50 years, is unlined and does not have a leachate retention system in place. As a consequence, leachate emerging from it flows down gradient into the Lonfit River and out into Pago Bay. Over the years, local residents have voiced some considerable concern over the potential impact of contaminants in the leachate on the fisheries resources of the river, estuary and bay.

Chemical characterization of the leachate has identified heavy metals as the contaminants of primary concern, both from an ecological and human health perspective. Specific elements that exceed USEPA toxicity reference values included copper, chromium, iron, lead, manganese, mercury, nickel, and zinc (USEPA 2002, Denton *et al.* 2005). These metals tend to accumulate in sediments of the leachate streams under low stream flow conditions and are periodically swept downstream into Pago Bay during major storm events (Olsen and Denton in prep.). The biological effects of such episodic inputs into the bay are currently unknown. The study outlined here provides a necessary first step towards addressing these deficiencies by evaluating the degree of heavy metal enrichment in biotic and abiotic components of the bay.

Methodology

Surface sediments were collected from 44 sites in Pago Bay in January 2005. Sampling sites were located at ~100-m intervals along the beach and at ~100-m to 200-m intervals along five transect lines running perpendicular to the shore (Fig. 1). The precise location of each sampling station was recorded using GPS. Samples (~100 g) were gently scooped up in acid washed plastic containers so as not to disturb surface layers. Three separate samples were taken within a 3-m diameter circle at each site. In the laboratory, all samples for mercury analysis were dried at ~30^{o}C to minimize losses associated with volatilization. They were then sieved through a 1-mm Teflon screen in preparation for analysis. Samples analyzed for all other metals were dried at ~60^{o}C prior to sieving.

Biota samples were collected at low tide between June and September 2005 from 48 sites in the bay (Fig. 2). Emphasis was placed on collecting species with established or potential bioindicator capability as well as those traditionally harvested by local residents for food (e.g., algae, seacucumbers, bivalve mollusks). A complete list of the organisms taken for analysis, together with their respective collection sites, is shown in Table 2. It can be seen that not all species were available at all sites.

All specimens were handpicked from the reef flat and transported to the lab in clean polyethylene bags. Gross particulate material was rinsed from the algae beforehand by vigorously shaking the samples back and forth in clean seawater; the holdfasts and older, more encrusted portions of the plants were discarded. Blades of seagrass were carefully removed as close to the plant root as possible. The proximal 12 inches of each blade was found to be relatively free of epiphytic growth and was the only portion of the plant taken for analysis. Bivalves were scrubbed clean of adhering particulates and purged of their gut contents in clean seawater for 48 h prior to storage at -20^{o}C. Subsequently, the entire soft parts of thawed specimens were taken for analysis. In contrast, seacucumbers were dissected live to prevent tissue fluid cross-contamination that can occur during the thawing of frozen specimens. Dorsal sections of the body wall and the portions of the hemal system were separated out for analysis in these organisms.

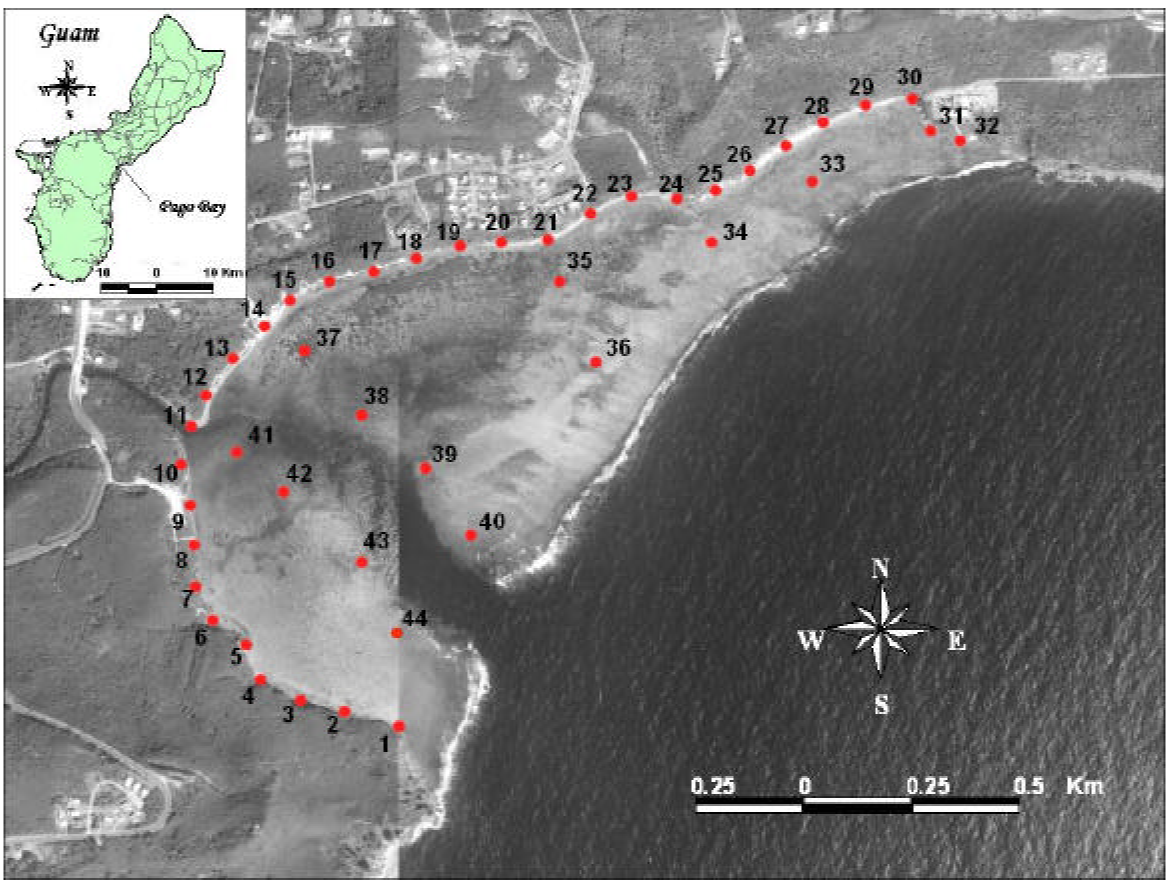

Figure 1: Sediment sampling sites within Pago Bay

All cleaned and separated samples were placed in acid-washed, polypropylene vials (80 ml). The analyses were performed on samples dried to constant weight at 60^{o}C for all metals except mercury. Owing to the relatively high volatility of this element the analysis was conducted on wet rather than dried tissues.

All samples were analyzed for heavy metals by atomic absorption spectroscopy (AAS) following conventional wet oxidation in hot mineral acids. This digestion procedure is essentially similar to EPA method 3050A, SW-846 (USEPA 1995) with minor modifications. Mercury was determined by flameless (cold vapor) AAS using the syringe method described by Stainton (1971). Arsenic determinations utilized the hydride generation technique.

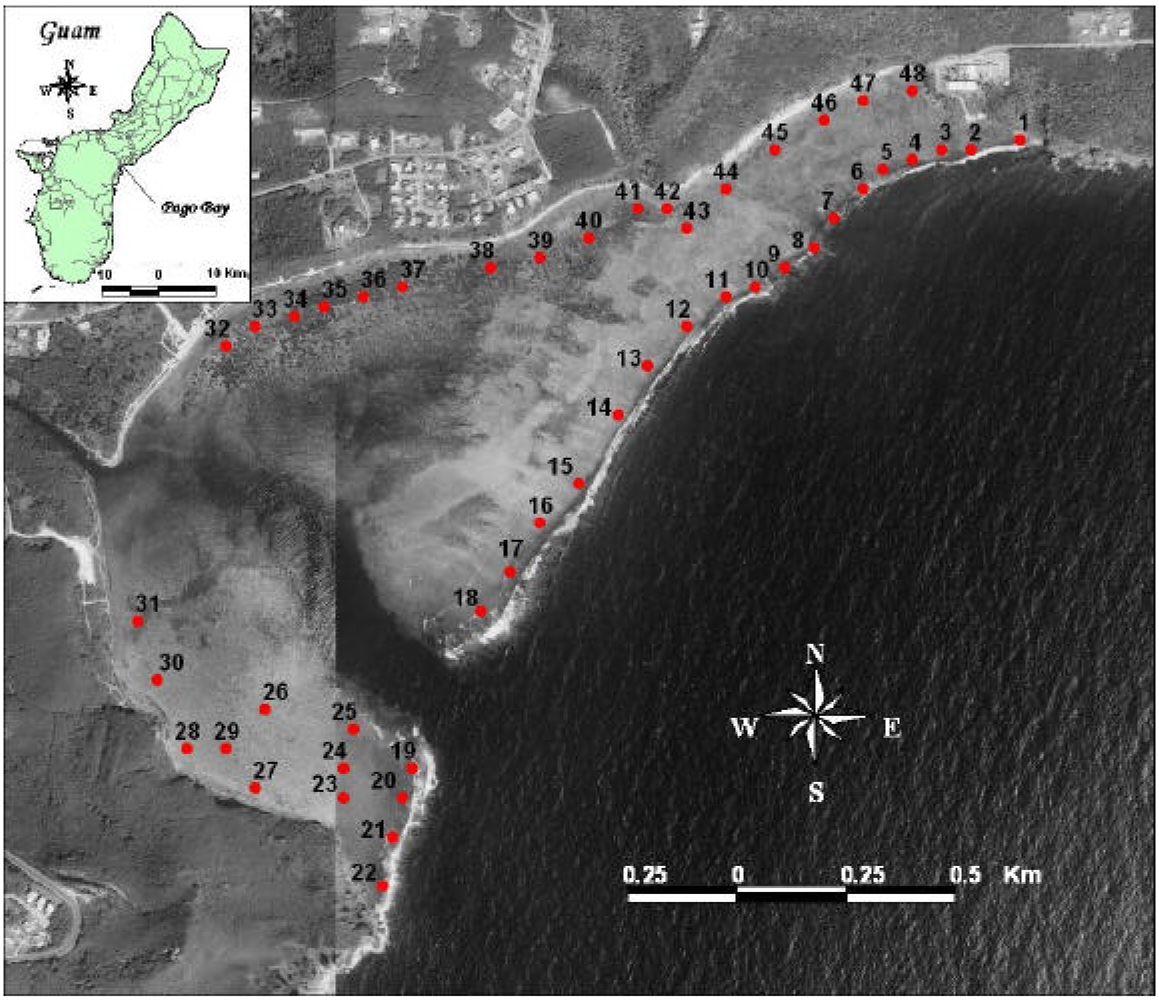

Figure 2: Biota sampling sites within Pago Bay

Appropriate quality control and quality assurance procedures, including full procedural blanks, matrix spikes and certified reference materials, were built into the analytical protocols. All reagents used were analytical grade and all glassware was acid-washed and deionized water rinsed prior to use. Standard stock solutions were purchased from a commercial supplier. Heavy metal recoveries from a biotic standard reference material were within acceptable limits for all elements examined.

Table 1: Flora & Fauna Sampled in Pago Bay During the Present Study

Species	Biota Sites
Algae:	
Acanthophora spicifera	39, 41, 42, 46, 47
Gracilaria salicornia	42, 48
Caulerpa racemosa	10
Caulerpa serrulata	44
Caulerpa sertularioides	48
Chlorodesmis fastigiata	21
Padina boryana	27, 28, 42, 44, 45, 47
Turbinaria ornata	26, 40, 41, 43, 45, 47
Sargassum cristafolium	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22
Sargassum polycystum	23, 24, 25, 37, 39, 40, 41, 42
Seagrass:	
Enhalus acoroides	29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 41
Seacucumber:	
Holothuria atra	4, 6, 12, 13, 16, 17, 19, 20, 22,
Bivalves:	
Asaphia violascens	48
Ctena bella	31, 34, 36, 37
Gafrarium pectinatum	34
Quidnipagus palatum	29, 31, 36, 48,
Scutarcopajia scobinata	36

Principal Findings and Significance

Sediment characteristics varied appreciably from one end of Pago Bay to the other and largely controlled the elemental composition of sediments at each site. At the northern end of the bay, surface sediments were composed largely of bioclastic carbonates (e.g., foraminifera, coral, shells, *Halimeda* debris and calcareous red algae), while volcanic detrital material predominated at the southern end, adjacent to the river mouth (Randall and Holloman 1974). A mixture of the two sediment types occurred to varying degrees in between.

Bioclastic sediments are typically lower in most heavy metals compared with their volcaniclastic counterparts. As a consequence, metal levels determined in sediments from Pago Bay during the current investigation were generally higher in the alluvial deposits around the river mouth and southern shoreline. Certain elements (e.g., arsenic, chromium, copper, iron, manganese) were also marginally elevated at sites impacted by groundwater intrusion. A highly localized zone of mild mercury, lead and zinc enrichment was identified at the northern end of the bay, near the University of Guam Marine Laboratory and WERI. This was thought to reflect the wastewater disposal systems (septic tanks) currently in place there.

The sedimentary data is summarized in Table 2, together with background heavy metal levels normally encountered in coral reef deposits and sediments from the Lonfit River.

The vast majority of data gathered during this investigation fell within the combined natural ranges for these two sediment types. Heavy metal levels found in the biota examined are summarized in Table 3. The data were compared with levels encountered in similar and related species from clean and polluted environments elsewhere (Table 4). It was concluded that metal concentrations in biotic and abiotic components of Pago Bay are generally low by world standards and largely reflect natural contributions associated with alluvial discharges and groundwater intrusion. A more detailed evaluation of the data along is available in Denton *et al.* (2006)

The study clearly demonstrates that Pago Bay is not a permanent sink for sediment bound metal contaminants mobilized downstream from the Ordot Dump. We therefore conclude that any contaminated sediments deposited in and around the river mouth, the reef channel and the southern half of the bay during a normal wet season, are re-suspended and flushed from the system by major storms (typhoons) that approach the eastern side of the island. Under such conditions, the reef channel serves as a conduit for their transportation and dispersion into offshore waters beyond the reef margin. Thus, the climatic and topographic characteristics of the area combine to provide an effective means of periodically flushing out pockets of contaminated sediments from the entire watershed into the ocean. Past concerns of heavy metal accumulation in fisheries recourses in this region are therefore unwarranted.

.

Table 2: Baseline Heavy Levels (µg/g dry wt.) in Lonfit River & Coral Reef Sediments Compared with Sediments from Pago Bay

Metal	Lonfit River[a] (lithogenic: volcanics)	Coral Reef[b] (biogenic: carbonates)	Pago Bay[c] (lithogenic/biogenic mix)	Degree of Enrichment in Pago Bay: Location
Ag	<0.1	<0.1	<0.2	None
As	<0.1	0.5-3	<0.2-1.6	None
Cd	<0.2	<0.1	<0.2	None
Cr	50-80	1-5	2-21	None
Cu	50-70	<0.1-3	<0.1-20	None
Fe	50,000-60,000	50-500	203-41,743	None
Hg[d]	20-30	2-10	1-15	V. Mild: N. end
Mn	1,000-1,500	10-50	11-453	None
Ni	60-120	<0.2-3	<0.2-25	None
Pb	<1-2	<1	<0.3-14	Mild: S. end; N. end
Zn	50-70	<1-5	<1-90	Mild: river mouth; N. end

[a] Olsen and Denton in prep; [b] Denton *et al.* 1997, 2001; [c] This study; [d] Mercury concentrations as ng/g dry weight

Table 2: Heavy Metals Levels in Dominant Biotic Representatives from Pago Bay, Guam

Species	Statistic	Metal (µg/g dry wt.)									
		Ag	**As**	**Cd**	**Cu**	**Cr**	**Fe**	**Hg**[a]	**Mn**	**Ni**	**Pb**
ALGAE:											
Acanthophora spicifera	Mean[b]	nc	0.56	0.2	2.13	0.56	470	1.7	11.3	3.75	nc
	Range	all <0.15	0.20-1.72	<0.07-0.47	1.22-3.15	<0.11-1.98	192-877	1.09-2.83	6.38-21.6	3.05-5.20	<0.30-1.36
Gracilaria salicornia	Mean	nc	1.55	nc	0.78	0.54	66.9	2.48	11.3	0.3	nc
	Range	all <0.26	1.43-1.67	all <0.26	0.47-1.17	0.26-1.15	35.2-145	1.74-3.48	7.6-17.5	<0.16-1.07	all <0.58
Caulerpa rasemosa	Mean	nc	1.19	nc	0.98	0.44	436	1.18	10.3	1.4	nc
	Range	all <0.15	1.04-1.53	all <0.15	0.77-1.19	0.39-0.60	345-527	1.17-1.20	8.89-11.7	0.39-0.60	all <0.46
Caulerpa serrulata	Mean	nc	1.82	nc	0.83	nc	470	3.14	12.1	1.92	nc
	Range	all <0.22	1.63-2.22	all <0.22	0.67-0.90	all <0.31	448-517	2.83-3.66	11.2-13.1	1.65-2.16	all <0.48
Caulerpa sertalarioides	Mean	nc	2.88	nc	1.41	0.5	65.5	3.94	14.5	1.58	nc
	Range	all <0.21	2.19-3.48	all <0.21	1.31-1.49	0.30-1.09	62.0-69.5	3.50-4.19	13.6-15.4	1.51-1.65	all <0.46
Chlorodesmis fastigiata	Mean	nc	9.55	nc	2.34	2.14	696	6.63	23.9	1.06	nc
	Range	all <0.15	9.24-9.90	all <0.15	2.29-2.40	1.91-2.40	617-784	6.52-6.81	21.3-26.7	0.95-1.17	all <0.34
Padina boryana	Mean	nc	3.54	nc	1.58	0.48	672	1.73	45.1	2.29	nc
	Range	all <0.18	1.96-11.0	<0.14-0.32	0.74-4.65	<0.21-2.14	262-1828	0.59-2.97	19.0-108	1.56-3.36	<0.27-13.8
Turbinaria ornata	Mean	nc	20.4	nc	0.7	nc	238	3.25	6.4	1.15	nc
	Range	all <0.26	8.58-36.9	<0.14-0.30	0.30-1.95	<0.16-1.83	48.7-1207	1.75-5.20	2.88-18.2	0.49-3.22	<0.30-1.62
Sargassum cristafolium	Mean	nc	85.4	nc	0.88	nc	96.4	2.21	8.45	2.82	nc
	Range	all <0.19	70.9-97.3	<0.14-0.31	0.46-1.63	<0.14-1.20	17.3-653	1.12-3.40	2.61-40.7	0.68-8.00	<0.18-5.22
Sargassum polycystum	Mean	nc	15.8	nc	1.82	1.39	911	2.29	61	3.15	nc
	Range	all <0.26	9.61-22.4	<0.14-0.29	0.92-2.79	0.60-2.66	236-1820	1.72-3.61	29.4-101	1.48-5.01	<0.3-1.51
SEAGRASS:											
Enhalus acoroides	Mean	nc	0.28	nc	1.95	nc	107	1.73	11.2	2.2	nc
	Range	all <0.19	0.10-1.2	all <0.19	0.74-5.7	<0.15-0.60	59.1-273	1.13-3.6	4.61-36.4	1.26-4.30	<0.29-1.10
SEACUCUMBERS:											
Holothuria atra (body wall)	Mean	nc	3.36	nc	1.21	0.19	23.5	2.02	0.51	0.17	nc
	Range	all <0.14	1.77-5.83	all <0.14	0.89-1.62	<0.09-0.32	17.5-39.5	1.13-4.48	0.28-0.82	<0.09-0.37	all <0.28
Holothuria atra (Hemal tissue)	Mean	nc	4.93	nc	5.11	2.85	92.2	16.2	2.06	0.6	0.91
	Range	all <0.8	1.29-11.2	all <0.8	3.75-6.37	0.67-13.6	54.4-292	1.75-52.3	1.00-3.92	0.34-1.16	0.38-<1.10
BIVALVES:											
Asaphia violascens	Mean	0.11	-	0.11	0.16	7.61	971	-	15.2	5.87	0.81
	Range	-	-	-	-	-	-	-	-	-	-
Ctena bella	Mean	nc	5.13	1.2	8.1	nc	66.9	10.7	2.25	12.3	0.55
	Range	all <0.18	4.59-6.89	0.66-2.51	5.79-20.9	all <0.27	55.1-74.3	5.63-17.4	1.63-3.30	7.83-21.2	0.22-1.35
Gafrarium pectinatum	Mean	0.14	-	1.14	0.21	17.0	386	-	22.9	16.4	0.27
	Range	-	-	-	-	-	-	-	-	-	-
Quidnipagus palatum	Mean	nc	16.8	nc	17.5	nc	846	36.9	6.81	nc	0.43
	Range	all <0.13	9.71-27.2	all <0.13	4.26-68.5	<0.12-0.46	601-1292	21.9-62.4	2.92-23.1	<0.12-0.46	<0.20-0.89
Scutarcopajia scobinata	Mean	0.34	-	0.34	1.01	6.07	2178	-	6.07	9.09	0.64
	Range	-	-	-	-	-	-	-	-	-	-

[a] mercury concentrations expressed as ng/g wet weight; [b] mean = geometric mean; nc = not calculable; dashes indicate no data

Table 4: Heavy Metals in Similar and Related Species of Marine Organisms from Guam and Elsewhere

Species	Location	Metal (µg/g dry wt.)											Reference
		Ag	As	Cd	Cr	Cu	Fe	Hg[a]	Mn	Ni	Pb	Zn	
ALGAE:													
Acanthophora spicifera	Pago Bay, Guam	all <0.27	0.20-1.55	<0.16-0.47	<0.21-1.88	1.22-3.03	192-877	1.09-2.83	6.38-21.6	3.05-5.20	0.31-1.36	3.36-8.04	This study
Acanthophora spicifera	Tanapag Lagoon, Saipan	<0.08-0.51	0.53-1.13	<0.13-0.70	<0.26-1.54	2.88-30.5	-	1.86-10.2	-	1.78-2.52	0.49-8.14	17.6-130	Denton *et al.*, in prep.
Gracilaria salicornia	Pago Bay, Guam	all <0.26	1.43-1.67	all <0.26	<0..25-1.15	0.98-1.17	35.2-145	1.74-3.48	7.60-17.5	<0.16-1.07	all <0.58	2.92-8.71	This study
Gracilaria salicornis	Tanapag Lagoon, Saipan	all <0.11	2.19-2.82	<0.07-0.20	<0.23-0.93	1.22-2.90	-	2.42-4.38	-	<0.19-0.52	<0.23-1.17	11.6-24.8	Denton *et al.*, in prep.
Gracilaria sp.	N. Queensland coastal wateres, Australia	all <0.2	-	<0.2-0.8	1.7-4.0	2.3-3.9	1250-2030	-	51.1-94.7	0.3-1.4	all <0.4	11.2-15.6	Burdon-Jones *et al.*, 1975
Caulerpa racemosa	Pago Bay, Guam	all <0.15	1.04-1.53	all <0.15	0.41-0.60	0.77-1.19	345-527	1.17-1.20	8.89-11.7	1.19-1.55	<0.34-1.05	1.86-2.39	This study
Caulerpa racemosa	Gt. Barrier Reef, Australia	-	-	0.17-0.48	-	1.4-2.6	-	22-246	-	0.82-1.6	<0.67-2.4	0.27-10.0	Denton & Burdon-Jones, 1986
Caulerpa serrulata	Pago Bay, Guam	all <0.22	1.66-2.22	all <0.22	all <0.31	0.67-0.90	448-517	3.01-3.66	11.2-13.1	1.65-2.16	all <0.48	1.73-2.12	This study
Caulerpa serrulata	Gt. Barrier Reef, Australia	-	-	0.20-0.49	-	1.0-2.4	-		-	0.78-2.4	all <0.93	1.7-5.2	Denton & Burdon-Jones, 1986
Chlorodesmis fastigiata	Pago Bay, Guam	all <0.15	9.24-9.90	all <0.15	1.91-2.40	2.29-2.40	617-784	6.52-6.81	21.3-26.7	0.95-1.1	all <0.34	4.51-4.72	This study
Chlorodesmis fastigiata	Gt. Barrier Reef, Australia	-	-	0.10-0.50	-	1.4-2.4	-	38-130	-	0.41-1.7	<0.57-2.1	1.3-12.1	Denton & Burdon-Jones, 1986
Padina australis	Gt. Barrier Reef, Australia	-	-	0.4-0.6	-	2.0-3.0	-	1-4	-	1.0-1.4	<0.9-5.0	3.8-9.5	Denton & Burdon-Jones, 1986
Padina boyana	Pago Bay, Guam	all <0.18	1.96-11.0	<0.15-0.32	<0.23-2.14	0.74-4.65	262-1516	0.59-2.97	19.0-108	1.56-3.36	0.27-13.9	2.75-8.27	This study
Padina commersonni	Singapore coastal waters	-	-	0.4-0.6	2.9-6.5	3.8-7.3	112-202	<10[b]	40.8-82.6	4.0-6.5	4.3-7.9	20.7-50.1	Bok & Keong, 1976
Padina gymnospora	Puerto Rico	-	-	-	-	nd	520-5700	-	80.0-150	23.0-32.0	-	-	Stevenson & Ufret, 1966
Padina tenuis	Penang Island, Malaysia	-	-	7.1	25.6	5.7	3328	1025[b]	2844	-	17.1	45.5	Sivalingam, 1978; 1980
Padina tenuis	Townsville coastal waters, Australia	<0.1-0.4	-	0.2-1.4	1.4-10.0	1.4-5.1	355-4037	-	37.8-496	0.7-8.4	<0.3-6.2	3.7-30	Burdon-Jones *et al.*, 1982
Padina tetrostromatica	Goa coastal waters, India	-	-	nd	-	3.2-7.9	389-1005	-	205-531	8.0-18.3	3.0-28.3	4.5-11.7	Agadi *et al.*, 1978
Padina tetrostromatica	Goa coastal waters, India	-	4.8-12.6	nd	-	8.7-20.1	-	-	233-456	nd	nd	20.2-31.5	Zingde *et al.*, 1976
Padina tetrostromatica	Townsville coastal waters, Australia	<0.1-0.4	-	0.2-1.2	1.6-9.9	2.0-11.1	606-8055	-	61.8-554	0.9-4.0	1.1-4.9	5.5-25.7	Burdon-Jones *et al.*, 1982
Padina tetrostromatica	Townsville Harbor (upper reaches)	<0.1	-	<0.4	31.5	58.9	6429	-	818	13.1	108	440	Burdon-Jones *et al.*, 1975
Padina tetrostromatica	Townsville Harbor (lower reaches)	<0.1-0.4	-	0.2-0.6	2.1-9.9	4.4-11.1	-	-	-	0.7-5.6	2.0-10.2	67.2-166	Burdon-Jones *et al.*, 1982
Padina sp.	Lizard Island, Great Barrier Reef	-	-	0.2	-	2.2	-	2	-	1.1	<0.74	5.9	Denton & Burdon-Jones, 1986
Padina sp.	Agana Boat Basin, Guam	0.89	32.2	0.3	0.68	1.53	-	<2	-	1.18	0.46	11	Denton *et al.*, 1999
Padina sp.	Apra Harbor, Guam	all <0.10	5.8-38.1	0.2-0.5	1.3-3.0	2.6-36.6	-	7-26	-	1.1-3.2	2.6-6.5	45.1-192	Denton *et al.*, 1999
Padina sp.	Agat Marina, Guam	<0.10	20.5	<0.1	2.7	4.1	-	<2	-	2.9	<0.25	18.7	Denton *et al.*, 1999
Padina sp.	Merizo Pier, Guam	<0.10	17.4	<0.1	14.1	27.2	-	3.00	-	2.28	8.07	78.3	Denton *et al.*, 1999
Padina sp.	Tanapag Lagoon, Saipan	<0.10-0.29	3.56-12.3	<0.11-1.72	<0.30-1.43	1.30-25.3	-	1.74-6.33	-	0.88-1.65	<0.27-14.7	5.3-107	Denton *et al.*, in prep.
Sargassum conusum	Korean waters	-	-	1.6	-	7	-	-	-	-	5.8	14	Pak *et al.*, 1977
Sargassum cristafolium	Pago Bay, Guam	all <0.16	2.39-117	<0.15-0.31	<0.20-1.20	0.46-1.63	17.3-653	1.12-4.06	2.61-40.7	0.68-5.13	<0.19-2.99	0.76-4.83	This study
Sargassum fulvellum	Korean waters	-	-	2.4-3.0	-	8-19	-	-	-	-	4.2-6.2	11-23	Pak *et al.*, 1977
Sargassum cgrevillei	Penang, Malaysia	-	-	6.4	-	5.2	-	-	-	-	5.2	15.5	Sivalingam, 1978
Sargassum horneri	Korean waters	-	-	1.7-2.7	-	9-25	-	-	-	-	6.7-8.9	28-61	Pak *et al.*, 1977
Sargassum pallidum	Vostok Bay, Sea of Japan	-	-	-	-	4.3	-	-	-	-	-	2.7	Saenko *et al.*, 1976
Sargassum pallidum	Pacific coastal waters	-	-	1.3-5.1	-	1.6-4.3	-	-	-	-	5.5-25.2	2.7-95.9	Khristoforova *et al.*, 1983
Sargassum polycystum	Pago Bay, Guam	all <0.16	9.61-22.4	<0.15-0.29	0.60-2.66	0.92-2.79	236-1765	1.72-3.61	52.6-101	1.48-5.01	<0.31-1.51	2.56-7.01	This study
Sargassum polycystum	Tanapag Lagoon, Saipan	all <0.16	15.6-22.9	0.28-0.40	<0.31-0.57	1.27-1.47	-	0.45-0.88	-	0.81-1.08	0.45-0.51	12.6-15.9	Denton *et al.*, in prep.
Sargassum sp.	N. Queensland coastal wateres, Australia	all <0.2	-	all <0.2	<0.4-3.1	2.2-3.1	1186-1398	-	29.7-48.8	<0.3-1.1	all <0.4	7.0-10.0	Burdon-Jones *et al.*, 1975

[a] mercury concentrations as ng/g wet weight; [b] mercury concentrations as ng/g dry weight; dashes indicate no data

Table 4 (cont.): Heavy Metals in Similar and Related Species of Marine Organisms from Guam and Elsewhere

Species	Location	Metal (µg/g dry wt.) Ag	As	Cd	Cr	Cu	Fe	Hg[a]	Mn	Ni	Pb	Zn	Reference
SEAGRASSES:													
Enhalus acoroides	Pago Bay, Guam	all <0.16	0.10-1.22	all <0.16	<0.15-0.64	0.74-5.73	59.1-273	1.13-3.56	4.61-36.4	1.26-4.26	<0.30-1.07	4.96-16.6	This study
Enhalus acoroides	Tanapag Lagoon, Saipan	all <0.20	0.03-0.19	0.15-0.60	<0.30-0.40	2.15-48.0	-	0.60-2.34	-	0.60-2.34	<0.22-2.05	20.0-33.0	Denton *et al.*, in prep.
Halodule uninervis	Tanapag Lagoon, Saipan	all <0.20	-	0.29-0.66	<0.32-1.09	2.45-6.46	-	0.70-1.25	-	0.70-1.25	<0.32-1.09	21.1-35.8	Denton *et al.*, in prep.
Halodule uninervis	Cleveland Bay, Townsville, Australia	<0.3	-	0.5	1.6	2.7	1995	-	96.0	0.7	7	11.0	Denton *et al.*, 1980
Halodule pinifolia	Lockhardt River, Cape York, Australia	0.1	-	1.1	2.3	7.7	2010	-	46.0	4.9	3.6	26.0	Denton *et al.*, 1980
Halophila ovalis	Lockhardt River, Cape York, Australia	<0.2	-	0.5	1.0	9.0	4418	-	68.0	1.7	1	67.0	Denton *et al.*, 1980
Zostera capricornia	Upstart Bay, N Queensland, Australia	<0.2	-	0.2	0.9	3.0	5250	-	70.0	0.6	0.4	18.0	Denton *et al.*, 1980
Zostera capricornia	Shoalwater Bay, N. Queensland, Australia	<0.2	-	0.2	1.9	2.8	3500	-	44.0	1.8	0.4	14.0	Denton *et al.*, 1980
SEACUCUMBERS:													
Bohadschia argus (muscle)	Apra Harbor, Guam	all <0.13	7.8-17.7	0.1-0.1	<0.2-0.4	0.6-2.3	-	5-5	-	1.0-1.4	<0.3-0.6	13.8-18.0	Denton *et al.*, 1999
Bohadschia argus (muscle)	Small boat marinas, Guam	all <0.10	all <0.01	0.10-0.10	<0.10-0.10	0.6-0.9	-	1-7	-	0.3-1.1	all <0.4	8.3-16.6	Denton *et al.*, 1999
Bohadschia argus (hemal system)	Apra Harbor, Guam	all <0.14	16.6-32.6	0.32-0.39	7.28-31.9	2.84-39.0	-	221-459	-	0.43-1.21	<0.33-0.88	41.4-374	Denton *et al.*, 1999
Bohadschia argus (hemal system)	Small boat marinas, Guam	all <0.14	<0.10-0.20	0.18-0.28	6.27-12.6	2.25-3.47	-	6-96	-	0.39-0.90	all <0.37	40.6-96.8	Denton *et al.*, 1999
Bohadschia argus (muscle)	Tanapag Lagoon, Saipan	<0.09	7.45	<0.09	<0.37	0.86	-	3.42	-	0.30	<0.14	15.9	Denton *et al.*, 1999
Bohadschia argus (hemal system)	Tanapag Lagoon, Saipan	<0.11	0.59	0.32	4.27	2.48	-	36.3	-	0.44	<0.36	44.2	Denton *et al.*, 1999
Bohadschia mormorata (muscle)	Tanapag Lagoon, Saipan	all <0.12	1.03-10.1	<0.3-0.74	<0.30-0.71	0.45-2.01	-	0.54-3.04	-	0.65-1.11	<0.12-0.88	9.92-41.5	Denton *et al.*, in prep.
Bohadschia mormorata (hemal system)	Tanapag Lagoon, Saipan	all <0.09	0.60-12.1	<0.11-3.72	3.14-29.7	2.34-5.63	-	39.0-321	-	0.47-3.39	<0.30-10.3	93.4-503	Denton *et al.*, in prep.
Holothuria atra (muscle)	Pago Bay, Guam	all <0.14	1.77-5.83	all <0.14	<0.09-0.30	0.89-1.62	17.5-39.5	1.13-4.48	0.28-0.82	<0.09-0.27	all <0.28	12.8-17.8	This study
Holothuria atra (hemal system)	Pago Bay, Guam	all <0.78	1.29-11.2	all <0.78	0.67-13.6	3.75-6.37	54.4-144	3.16-52.3	1.07-3.19	<0.49-1.16	all <1.57	56.9-301	This study
Holothuria atra (muscle)	Apra Harbor, Guam	all <0.12	13.6-23.2	<0.1-0.1	<0.1-0.3	0.7-1.2	-	7-8	-	<0.2	all <0.3	15.5-17.9	Denton *et al.*, 1999
Holothuria atra (hemal system)	Apra Harbor, Guam	<0.35-4.90	7.24-28.3	0.25-0.26	2.21-8.58	4.70-5.19	-	49-88	-	all <0.50	all <0.92	120-180	Denton *et al.*, 1999
Holothuria atra (muscle)	Small boat marinas, Guam	<0.01-0.24	all <0.01	<0.1-0.1	all <0.20	1.3-2.5	-	8-22	-	all <0.20	all <0.60	12.6-21.2	Denton *et al.*, 1999
Holothuria atra (hemal system)	Small boat marinas, Guam	<0.11-0.72	<0.01-0.18	0.09-0.12	0.08-3.14	3.69-6.37	-	16-91	-	all <0.43	all <0.72	117-253	Denton *et al.*, 1999
Holothuria atra (muscle)	Tanapag Lagoon, Saipan	all <0.13	0.61-15.4	all <0.13	<0.28-0.69	0.96-3.10	-	<0.48-4.55	-	<0.12-0.45	<0.15-2.09	13.1-24.1	Denton *et al.*, in prep.
Holothuria atra (hemal system)	Tanapag Lagoon, Saipan	<0.07-0.25	0.12-2.04	<0.08-0.25	<0.26-4.99	3.11-11.2	-	5.53-63.2	-	<0.12-0.77	<0.11-6.33	29.8-287	Denton *et al.*, in prep.
Holothuria sp. (whole)	Townsville coastal waters, Australia	all <0.2	nd	<0.2	<0.3-6.3	<0.3-3.5	-	-	-	all <0.5	<0.4-3.8	13.9-39.4	Denton, unpublished data
Molpadia intermedia (muscle)	Georgia Strait, Vancouver (dump site)	-	-	1.7	2.2	26	-	-	-	1.7	1.4	171	Thompson & Paton, 1978
Stichopus variagatus (muscle)	Gt. Barrier Reef, Australia	-	-	all <0.1	-	1.5-2.1	-	<1-3	-	all <0.5	all <0.90	1.9-13.9	Burdon-Jones & Denton, 1984
BIVALVES:													
Asaphia violascens	Pago Bay, Guam	0.11	-	0.11	0.16	7.61	971	-	15.2	5.87	0.81	72.9	This study
Asaphia violascens	Tanapag Lagoon, Saipan	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	Denton *et al.*, in prep.
Ctena bella	Pago Bay, Guam	0.09-0.12	4.59-6.89	0.11-2.51	0.14-0.18	5.79-20.9	55.1-74.3	5.63-17.4	1.63-3.03	7.83-21.2	<0.20-1.35	112-289	This study
Ctena bella	Tanapag Lagoon, Saipan	0.33-0.81	0.92	1.16-2.71	0.82-0.92	5.31-14.1	-	22.0	-	4.40-5.57	5.94-6.38	384-430	Denton *et al.*, in prep.
Gafrarium pectinatum	Pago Bay, Guam	0.14	-	1.14	0.21	17	386	-	22.9	16.4	0.27	59.6	This study
Gafrarium pectinatum	Tanapag Lagoon, Saipan	<0.14-0.62	2.64-4.42	0.78-1.79	0.58-1.31	6.69-35.3	-	9.91-23.3	-	10.6-14.1	7.97-46.9	42.3-62.6	Denton *et al.*, in prep.
Gafrarium tumidum	Magnetic Island, N. Queensland, Australia	5.7	-	0.3	1.6	7.1	1066	11.9	64.5	3.1	68.8	-	Burdon-Jones *et al.*, 1975
Gafrarium tumidum	Red Rock Bay, Townsville, Australia	5.3	-	0.3	0.6	7.7	787	14.5	145	5.1	26.3	-	Burdon-Jones *et al.*, 1975
Quidnipagus palatum	Pago Bay, Guam	<0.08-0.13	9.71-27.2	<0.08-0.10	<0.13-0.46	4.26-68.5	601-1292	21.9-62.4	2.92-23.1	10.4-24.7	0.20-0.89	93.6-341	This study
Quidnipagus palatum	Tanapag Lagoon, Saipan	0.32-24.1	1.67-3.24	0.16-1.40	4.46-10.6	14.7-1876	-	33.6-111	-	7.30-13.1	9.01-184	305-1027	Denton *et al.*, in prep.

[a] mercury concentrations as ng/g wet weight; dashes indicate no data

Literature Cited

Agadi, V.V., N.B. Bhosle and A.G. Untawale (1978). Metal Concentration in Some Seaweeds of Goa (India). *Botanica Marina*, XXI: 247-250.

Bok, C.S. and Keong, W.M. (1976). Heavy Metals in Marine Biota from Coastal Waters around Singapore. Journal of Singapore Natural Academy of Science, 5: 47-53.

Burdon-Jones, C., G.R.W. Denton, G.B. Jones and K.A. McPhie (1975). Long-Term Sub-Lethal Effects of Metals on Marine Organism. Part I Baseline Survey. *Final Report to the Water Quality Council of Queensland, Australia*. 105 pp.

Burdon-Jones, C., G.R.W. Denton, G.B. Jones and K.A. McPhie (1982). Regional and Seasonal Variations of Trace Metals in Tropical Phaeophyceae from North Queensland. *Marine Environmental Research*, 7: 13-30.

Burdon-Jones and Denton (1984). Metals in Marine Organisms from the Great Barrier Reef Province. Part 1, Baseline Survey. *Final Report to the Australian Marine Science Technologies Committee, Canberra, Australia.* 155 pp.

Denton, G.R.W., H. Marsh, G.E. Heinsohn and C. Burdon-Jones (1980). The Unusual Metal Status of the Dugong *Dugong dugon*. *Marine Biology*, 52: 201-219.

Denton, G.R.W. and C. Burdon-Jones (1986). Trace Metals in Algae from the Great Barrier Reef. *Marine Pollution Bulletin*, 17: 98-107.

Denton G.R.W., H.R. Wood, L. P. Concepcion, H.G. Siegrist, V.S. Eflin, D.K. Narcis and G.T Pangelinan (1997). Analysis of In-Place Contaminants in Marine Sediments from Four Harbor Locations on Guam. A Pilot Study. *WERI Technical Report No. 81*, 120 pp. Available from: http://www.weriguam.org/reports/.

Denton, G.R.W., L.P. Concepcion, H.R. Wood, V.S. Eflin and G.T. Pangelinan (1999). Heavy Metals, PCBs and PAHs in Marine Organisms from Four Harbor Locations on Guam. A Pilot Study. *WERI Technical Report No. 87*, 154 pp. Available from: http://www.weriguam.org/reports/.

Denton G.R.W., B.G. Bearden, L. P. Concepcion, H. G. Siegrist, D.T. Vann and H.R. Wood (2001). Contaminant Assessment of Surface Sediments from Tanapag Lagoon, Saipan. *WERI Technical Report No. 93*, 110 pp. plus appendices. Available from: http://www.weriguam.org/reports/.

Denton G.R.W., M.H. Golabi, C. Iyekar, H.R. Wood, and Y. Wen (2005). Mobilization of Aqueous Contaminants Leached from Ordot Landfill in Surface and Subsurface Flows. *WERI Technical Report No. 108*, 34 pp. plus appendices. Available from: http://www.weriguam.org/reports/.

Denton, G.R.W., W.C. Kelly, H.R. Wood and Y. Wen (2006). Impact of Metal Enriched Leachate from Ordot Dump on the Heavy Metal Status of Biotic and Abiotic Components in Pago Bay. *WERI Technical Report No. 1113,* 52 pp. plus appendices. Available from: http://www.weriguam.org/reports/.

Denton G.R.W., B.G. Bearden and H.R. Wood. Heavy Metals in Biotic Representatives from Tanapag Lagoon Saipan. *WERI Technical Report.* (in prep.).

Khristoforova, N.K., N.N. Bogdanova and L.M. Tolstova (1983). Metals Present in *Sargassum* (Brown) Algae of the Pacific Ocean as Related to the Problem of Water Pollution Monitoring. *Oceanology,* 23: 200-2004

Pak, C.K., K.R. Yang and I.K. Lee (1977). Trace Metals in Several Edible Marine Algae of Korea. *Journal of the Oceanographic Society of Korea*, 12: 41-47.

Randall, R.H. and J, Holloman (1974). Coastal Survey of Guam. *University of Guam Marine Laboratory Technical Report No. 14,* 404 pp.

Saenko, G.N. M.D. Koryakova, V.F. Makienko and I.G. Dobrosmyslova (1976). Concentrations of Polyvalent Metals in by Seaweeds in Vostok Bay, Sea of Japan. *Marine Biology,* 34: 169-176.

Sivalingam, P.M. (1978). Biodeposited Trace Metals and Mineral Content Studies of Some Tropical Marine Algae. *Botanica Marina,* XXI: 327-330.

Sivalingam, P.M. (1980). Mercury Contamination in Tropical Algal Species of the Island of Penang, Malaysia. *Marine Pollution Bulletin,* 11: 106-107.

Stainton, M.P. (1971). Syringe Procedure for the Transfer of Nanogram Quantities of Mercury Vapor for Flameless Atomic Absorption Spectrophotometry. *Analytical Chemistry,* 43: 625-627.

Stevenson, R.A. and Ufret, S.L. (1966). Iron, Manganese and Nickel in Skeletons and Food of the Sea Urchins *Tripneustes esculentus* and *Echinometra lucunter*. *Limnology and Oceanography,* 11: 11-17.

Thompson, J.A.J. and D.W. Paton (1978). Heavy Metals in Benthic organisms from Point Grey Dumpsite – Vancouver, B.C. *A Preliminary Report, Institute of Oceanographic Sciences, Patricia Bay, Sidney, B.C., Canada,* PMCR 78-11: 18 pp.

USEPA (1995). SW-846 Test Methods for Evaluating Solid Waste Physical/Chemical Methods. Proposed Update III (January 1995). *Produced by the US Environmental Protection Agency, Office of Solid Waste.*

USEPA (2002). Ordot Landfill Site, Territory of Guam, Five-year Review Report, Second Five-Year Review. U.S. Environmental Protection Agency, Region IX. September 2002.

Zingde, M.D., S.Y.S. Singbal, C.F. Moraes and C.F.G. Reddy (1976). Arsenic, Copper, Zinc, and Manganese in the Marine Flora and Fauna of Coastal and Estuarine Waters around Goa. *Indian Journal of Marine Science*, 5: 212-217.