IMPACT OF METAL ENRICHED LEACHATE FROM ORDOT DUMP ON THE HEAVY METAL STATUS OF BIOTIC AND ABIOTIC COMPONENTS IN PAGO BAY

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OF THE WESTERN PACIFIC
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Plate 1: Pago Bay, looking northwards during dry weather conditions. Note the Pago River mouth and the conspicuous channel that bisects the reef flat (aerial photograph courtesy of John Jocson, WERI)

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ABSTRACT

Pago Bay was suspected of being the final resting place for heavy metal contaminants discharged into the Lonfit River from the Ordot Dump. To test this hypothesis, surface sediments (top 1-3 cm) were collected from 44 sites within the bay in January 2005. Thirty-two of these sites were located intertidally at ~100-m intervals along the beach. The remaining sites were positioned at ~100-200-m intervals along five transect lines running perpendicular to the shore. Later in the year, (June-September 2005), dominant biotic representatives (algae, seagrass, seacucumbers and bivalves) were taken for analysis from 48 sites within the bay in order to identify any metal uptake abnormalities that might be occurring in the resident fisheries resources. Biota collection sites were largely confined to the inner moat and outer reef flat. The organisms selected for study were chosen because of their known or suspected bioindicator potential and their ability to reflect biologically available metal fractions in specific segments of the environment. Algae, for example, only respond to the soluble metal fraction in the water column, whereas seagrasses derive their metal load mainly from sediment pore waters via their root systems. Seacumbers are sediment ingesters, while bivalves obtain their trace metal load from both suspended particulates and the soluble fraction in the surrounding water. Data from such a suite of organisms thus provides the investigator with a means of differentiating between sediment-bound and soluble metal fractions and rating the relative importance of each.

The findings of the study are discussed with reference to heavy metal levels previously determined in water and sediments from the Lonfit River and in leachate from the Ordot Dump. They are also compared with values for clean and polluted coastal sediments and biota from tropical environments elsewhere. It was concluded that metal concentrations in the biotic and abiotic components of Pago Bay are generally low by world standards and largely reflect natural contributions associated with the alluvial discharges from the Pago River (volcanic detrital material), and groundwater intrusion. Localized areas of light enrichment were noted for lead, mercury and zinc in shoreline sediments at the northern end of the bay and are likely associated with the type of wastewater disposal systems currently servicing the Marine Lab and WERI. A highly localized area of moderate lead enrichment was noted at the southern end of the bay away from any obvious signs of illegal dumping or other potential source of lead contamination. Metal levels in biotic representatives from these sites, though marginally elevated in some species, remained well within the ranges typical of relatively clean environments.

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.

INTRODUCTION

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. A narrow, shallow-water moat extends along the inner edge of the bay, adjacent to the coastline. This gives way to an extensive reef flat, and a reef margin characterized by a well-developed spur and grove formation (Randall and Holloman 1974). Bottom substrates within the bay range from soft alluvial mud at the southern end, to coarse carbonate sands and coral rubble further north. 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 Ordot Dump, as it is locally referred to, has been in continuous use for over 50 years and receives about 2,500 cubic feet of solid waste per day (GEPA 1995). It occupies an area of almost 60 acres and towers to ~90m at its mid-point (Smit 2001). Unlike modern sanitary landfills, Ordot Dump is not lined with an impervious material and does not have a leachate retention system in place. As a consequence, seasonally dependant streams of brown, foul smelling liquid emerge at a number of points along the western edge and southern toe of the dump. These flow down gradient into the Lonfit River and eventually make there way out into Pago Bay.

Chemical characterization of the leachate streams and the receiving waters of the Lonfit River have been attempted on at least four occasions since 1982 (USEPA 2002). In each case, heavy metals have been identified as the contaminants of primary concern both from an ecological and human health perspective. Specific elements flagged as exceeding toxicity thresholds included arsenic, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, silver and zinc. 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. Given the time period over which they have occurred, there seems little doubt that subtle changes in sediment and water chemistry have taken place throughout the bay over the last few decades. However, to what extent such changes have altered the delicate balance of this environmentally sensitive area, or imparted unfavorable characteristics to its edible resources remains to be investigated.

As a first step towards addressing these deficiencies in our level of understanding, the following study examined levels of the above elements in biotic and abiotic components of Pago Bay. Such a database is vital for the protection and sustainable development of fisheries resources in the area. The investigation was conducted in two discrete phases. Phase I focused on surface sediments from the outer perimeter of the bay and reef flat in order to identify distribution and abundance profiles for each element. Phase II examined dominant ecosystem representatives for the purpose of identifying any metal accumulation abnormalities that might be occurring in the biota. The metals considered here have a diversity of industrial uses (Table 1) and rank among the more common global contaminants. All are essential for life with the exceptions of cadmium, lead, mercury and silver, which have no known biological function and are highly toxic, accumulative poisons.

Table 1: Past and Present Industrial Uses of the Heavy Metals Examined[a]

Metal	Uses of Metals and Compounds[b]
Arsenic:	Component of pesticides; wood preservative; alloys; semi-conductors; medicines; glass and enamels.
Cadmium:	Electroplating (anticorrosion coatings); thermoplastic stabilizers, e.g. in PVC; Ni-Cd batteries; alloys; solders; catalysts; engraving; semi-conductors; TV tube phosphors; pigments in paints and plastics; glass ceramics; biocides
Chromium:	Metallurgy - ferrochromium alloys; refractory bricks; electroplating; industrial dyes; ink; tanning; paint; wood preservative; glass making; cement production.
Copper:	Electrical industry; alloys; e.g. brass; chemical catalyst; anti-fouling paint; algaecide; wood preservative.
Iron:	Iron and steel industry
Lead:	Storage batteries; leaded gasoline; pigments; red lead paint; ammunition; solder; cable covering; anti-fouling paint; glazing; PVC stabilizers.
Manganese:	Metallurgy – largely steel alloys; dry batteries; chemical industry, e.g. permanganate; glass; ceramic coloring
Mercury:	Chlorine production; electrical apparatus; anti-mildew paint; instruments; catalyst e.g. for PVC and acetaldehyde production; pesticides; preservatives; pharmaceuticals; dentistry; anti-fouling paint.
Nickel:	Metallurgy - steel and other alloys; electroplating; catalyst; rechargeable Ni-Cd batteries.
Silver	Photography; electric conductors; sterling ware; solders; coinage; electroplating; catalyst; batteries; food and beverage processing.
Zinc	Zinc based alloys; brass and bronze; galvanizing; rolled zinc; paints; batteries; rubber; sacrificial anodes on marine watercraft.

[a] from Bryan (1976), Förstner and Wittmann (1981), Moore (1991), Bryan and Langston (1992)
[b] importance generally decreasing from left to right.

MATERIALS AND METHODS

GENERAL DESCRIPTION OF PAGO BAY

Pago Bay is one of several prominent bays along the southeastern coastline of Guam. Exposed to the easterly trade winds, the fringing reefs along this part of the island show prominent spurs and groove formation, algal margins and broad reef flats (Randall and Holloman 1974). Pago Bay itself is approximately 2 km in length along the reef front and covers an area of approximately 1 sq km. Limestone cliffs at the northern and southern ends of the bay give way to low lying terraces of the same material in between. The Pago River drains into the southern half of the bay and is highly seasonal. Over the years, the river has formed a channel that cuts completely though the reef flat and drains much of the water coming over the reef margin at high tide back into the ocean (Plate 1).

Sedimentary deposits within the bay are largely confined to the moat and intertidal zone and are virtually absent on much of the reef flat. The geochemistry of these deposits varies appreciably from one end of Pago Bay to the other. For example, at the northeastern end of the bay, surface sediments are composed largely of bioclastic (biogenic) carbonates (e.g., foraminifera, coral, shells, *Halimeda* debris and calcareous red algae) while volcanic detrital material predominates at the southeastern end, adjacent to the river mouth (Randall and Holloman 1974). A mixture of the two sediment types occurs to varying degrees in between. Currently, conspicuous banks of silt and clay have accumulated in the intertidal zone on both sides of the river mouth as a result of soil erosion processes further upstream. The extent of deposition of this material is controlled largely by rain events, which also play a significant role in purging the bay of accumulated sediments when major storms (typhoons) come in from the east (Plate 2).

Groundwater seepage occurs at various points along the beach north of the river mouth for ~1.5 km and a major spring discharges into the bay ~200 m to the south (Plate 3). During the wet season, the central part of the bay is heavily inundated with urban runoff from a nearby residential area (Pago Bay Estate). The northern part of the bay also receives stormwater runoff from the University of Guam campus as well as wastewaters (septic tank) from WERI and the Marine Lab.

Biotic representation is unevenly distributed throughout the bay. At the time of this study, conspicuous patches of seagrass (*Enhalus acoroides*) occurred in the muddy moat sediments on both sides of the river channel in the southern half of the bay and provided a suitable habitat for several species of bivalves (e.g., *Ctena bella*, *Gafrarium pectinatum*, and *Quidnipagus palatum*). Of the common brown algae encountered, *Sargassum cristafolium* dominated the outer reef flat along the entire length of the reef margin while *Padina boryana* was the most abundant species in the moat area. Seacucumbers (*Holothuria atra*) were also reasonably well represented in this region of the bay (see Plates 4-6).

SAMPLE COLLECTION AND PREPARATION

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 were dried at either ~30^{o}C (for mercury analysis) or ~60^{o}C (for all other metals) and sieved through a 1-mm Teflon screen in preparation for analysis.

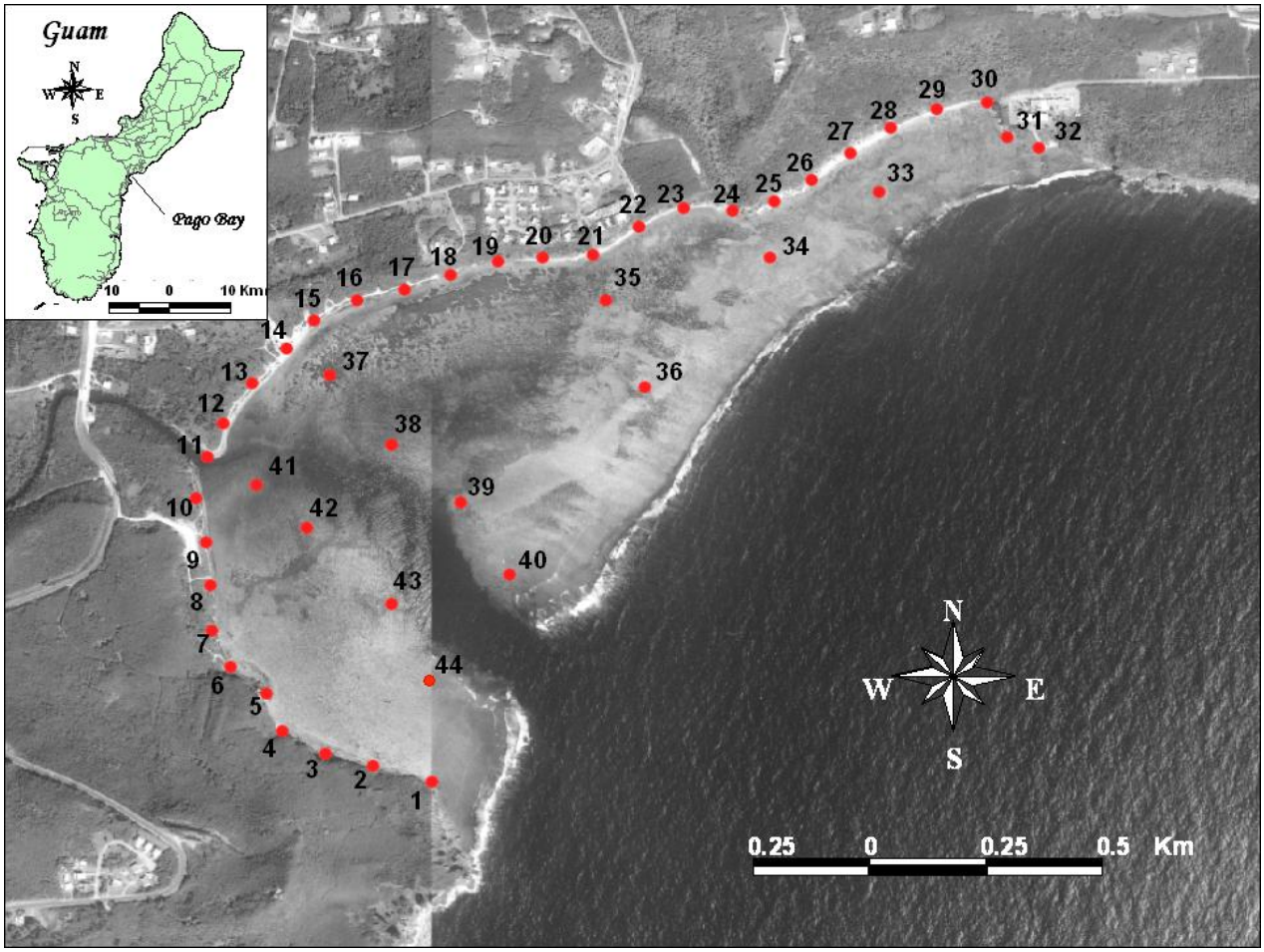

Figure 1: Panchromatic stereophoto composite of Pago Bay showing sediment sampling sites

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. 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 relatively free of epiphytic growth and 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 from these organisms.

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°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.

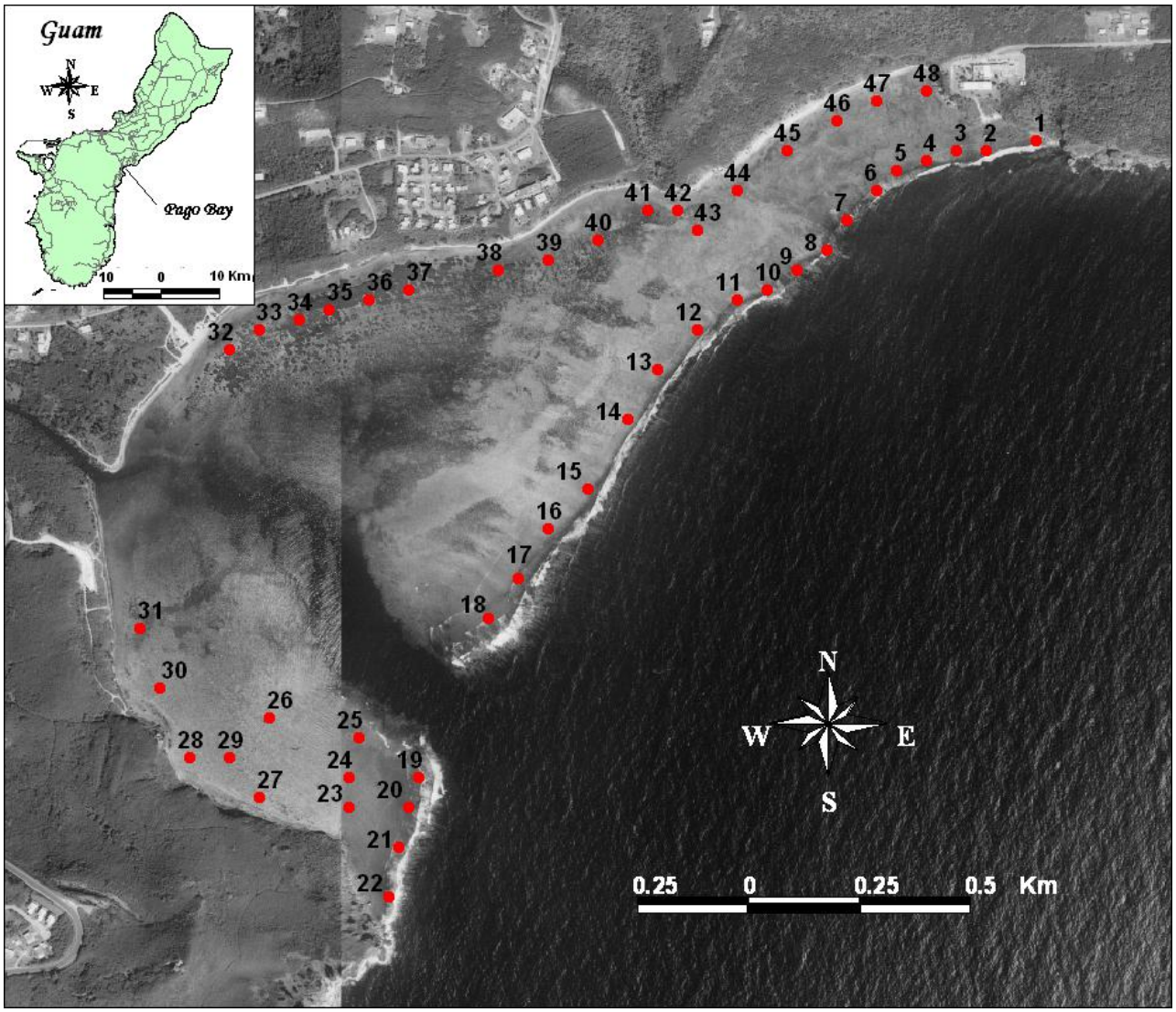

Figure 2: Panchromatic stereophoto composite of Pago Bay showing biota sampling sites.

SEDIMENT ANALYSES:

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 as outlined below. It is designed specifically to release weakly to strongly bound metals in the sample without completely destroying the non-carbonate, mineral matrix of the sample and is particularly useful for identifying metal enrichment as a result of anthropogenic activities.

Table 2: Flora & Fauna Sampled 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

Mercury:

Approximately 2 g of sieved sediment samples were weighed into 80-ml polypropylene digestion tubes specifically made for a MOD BLOCK digestion block (CPI International). The tubes were loosely capped with Teflon stoppers and refluxed with 15 ml of concentrated nitric acid at 100^{o}C for 3 hours. Upon cooling the digests were topped up to 30 ml with distilled water and analyzed by flameless (cold vapor) atomic absorption spectrophotometry (AAS). This involved the generation of metallic mercury vapor (Hg^{o}) following reduction with 2% stannous chloride (Hatch and Ott 1968). The process was facilitated using the syringe technique described by Stainton (1971). Calibration standards (5-20 ng/l) were made up in 10% nitric acid containing 0.05% potassium dichromate as a preservative (Feldman 1974).

Arsenic:

The digestion procedure was identical to that described above for mercury. However, analysis utilized the hydride generation technique whereby inorganic arsenic is converted to arsine gas (AsH_3) by reduction with 3% sodium borohydride in 1% sodium hydroxide. All calibration standards (1-10 μg/l) and sample dilutions were made up in 10% nitric acid.

Other Metals:

Approximately 2 g of the dried sediment samples were weighed into 80 ml glass tubes and digested with approximately 15 ml of concentrated nitric acid at 110-135^{o}C for 3 hours in the apparatus described above. The digests were then evaporated to dryness and redissolved in 20 ml of 10% nitric acid with gentle warming. The contents of each flask was thoroughly mixed, allowed to stand for several minutes to permit settlement of residual particulates, and then decanted into clean polypropylene vials ready for analysis. Analysis was performed by flame AAS, the contents of each vial being aspirated directly into the instrument. Simultaneous corrections for non-atomic absorption were made by the instrument (deuterium lamp). All calibration standards (0.2-10 mg/l) were made up in 10% nitric acid from a commercial mixed stock solution (100 mg/l of each metal).

BIOTA ANALYSIS:

The procedures for biota analyses were essentially the same as described for sediments with three notable exceptions. First, all samples were cold digested overnight to minimize frothing during the initial warming phase. Second, samples for mercury analysis were digested in 2:1 nitric and sulfuric acids rather than nitric acid alone. The more powerful oxidizing mixture was required for the complete destruction of organic matter in the wet tissues. Finally, samples for all other metals were subjected to two 3-hour digestion/drying cycles with hot nitric acid prior to topping up to final volume with 10% nitric acid.

QUALITY ASSURANCE AND QUALITY CONTROL (QA/QC):

All reagents used were analytical grade and all plastic and glassware were acid-washed and deionized water rinsed prior to use. Standard stock solutions were purchased from a commercial supplier. All analyses were performed in duplicate and were accompanied by appropriate method blanks and matrix spikes. Heavy metal recoveries from certified standard reference materials (one soil and four biota) were within acceptable limits for all elements examined (Tables 3-4).

PRESENTATION OF DATA:

The tabulated data are preceded by notes that compare and contrast the current findings with the work of others on a metal-by-metal basis. Reference to comparable investigations recently carried out in the Lonfit-Pago river system, upstream and downstream of the Ordot Dump, and in clean and polluted coastal sites in Guam and Saipan, are also included where appropriate. Much of this data has been tabulated in Tables 5 and 6 at the end of the current section to facilitate ease of reference. Isoconcentration contour maps for each metal in surface sediments within Pago Bay are appended at the end of the report. The maps provide an immediate visual assessment of the abundance and distribution of each element within the study area and highlight concentration gradients and any areas of enrichment.

Table 3: Recovery of Heavy Metals (µg/g dry wt.) from a Soil Standard Reference Material

Metal	This Study		Certified Values	
	Mean	Range	Mean	Range
	PriorityPollutnT ^{TM} ***/CLP Inorganic Soils*** **[Catalog N^{o} PPS-46; Lot N^{o} 242]**			
Arsenic	57.5	51.3 – 63.8	58.6	41.1 – 76.1
Cadmium	195	183 – 208	185	143 – 228
Chromium	41.3	38.1 – 44.6	50.7	35.7 – 65.7
Copper	61.9	55.9 – 67.9	63.6	52.1 – 75.1
Lead	53.2	46.4 – 60.0	56.6	43.1 – 70.1
Mercury	1.19	0.96 – 1.42	1.29	0.83 – 1.74
Nickel	72.9	62.7 – 83.2	75.4	59.0 – 91.7
Silver	155	145 – 165	149	110 – 188
Tin	76.5	64.3 – 88.6	73.1	52.7 – 93.4
Zinc	64.8	58.2 – 71.4	69.6	51.1 – 88.1

Table 4: Recovery of Heavy Metals (µg/g dry wt.) from Biota Standard Reference Materials

Metal	**Mean ± 95% Confidence Limits**		**Mean ± 95% Confidence Limits**	
	This Study	**Certified Values**	**This Study**	**Certified Values**
	Apple Leaves (SRM 1515)		**Bovine Liver (SRM 1577b)**	
Cadmium	0.03 ± 0.005	0.013 ± 0.002	0.45 ± 0.01	0.50 ± 0.03
Copper	5.17 ± 0.26	5.64 ± 0.24	133 ± 2.64	160 ± 8
Chromium	0.36 ± 0.084	0.3[a]	0.91 ± 0.14	-
Iron	61.9 ± 2.10	83 ± 5	165 ± 3.41	184 ± 15
Manganese	47.0 ± 2.15	54 ± 3	8.75 ± 0.21	10.5 ± 1.7
Nickel	0.95 ±0.08	0.91 ± 0.12	0.64 ± 0.16	-
Lead	0.32 ± 0.002	0.47 ± 0.02	0.16 ± 0.001	0.129 ± 0.004
Silver	0.05 ± 0.006	-	0.06 ± 0.01	0.039 ± 0.007
Zinc	12.1 ± 0.50	12.5 ± 0.03	106 ± 4.28	127 ± 16
	Marine Mussels (SRM 2974)		**Albacore Tuna (RM 50)**	
Arsenic	3.3 ± 0.4	7.4 ± 1.1	2.47 ± 0.07	3.3 ± 0.4
Mercury	0.145 ± 0.01	0.176 ± 0.013	1.04 ± 0.04	0.95 ± 0.1

[a]unconfirmed reference value only; dashes indicate no data

Table 5: Heavy Metals in Surface Sediments from Guam and Saipan

	Site (dominant sediment type[a])	Depth	Fraction	Metal (µg/g dry wt.)											Reference
				Ag	As	Cd	Cr	Cu	Fe	Hg[b]	Mn	Ni	Pb	Zn	
GUAM:															
Pago Bay	beach and moat (BC)	surface	<1 mm	all <0.15	0.16-0.39	all <0.15	1.96-4.44	0.60-1.78	203-1,055	1.67-11.9	10.9-73.3	<0.15-2.41	<0.26-3.19	0.77-12.4	This Study
Pago Bay	beach and moat (BC-WV mix)	surface	<1 mm	all <0.15	0.14-1.60	all <0.15	3.59-21.1	1.41-19.9	861-41,743	1.55-13.6	39.9-453	1.63-25.4	<0.26-14.4	1.46-65.4	This Study
Pago Bay	river mouth-channel and adjacent reef flat (WV)	surface	<1 mm	all <0.10	-	0.01-0.05	49.1-102	47.4-67.1	37,500-50,080	18-26	258-651	52.2-63.7	0.80-0.96	53.9-67.1	Tsuda *et al.*, 2004
Pago River	below route four bridge (WV)	surface	<1 mm	all <0.10	-	all <0.10	13.4-74.6	15.8-66.6	21,015-54,998	7.9-44.4	533-1,423	23.5-66.9	<0.3- 13.9	23.4-84.6	Olsen and Denton, in prep.
Pago River	~1.5 km downstream of Ordot Dump (WV)	surface	<1 mm	all <0.10	-	all <0.10	50.2-67.2	74.3-76.1	56,800-63,416	20.2-20.8	1,125-1,223	77.5-89.3	all <1.00	68.1-84.5	Olsen and Denton, in prep.
Lonfit-Pago River	500-700 m downstream of Ordot Dump (WV)	surface	<1 mm	all <0.10	-	all <0.10	59.2-77.5	61.5-70.4	46,131-66,381	23.0-61.2	1,062-1,178	68.4-92.1	<1.00-1.38	62.0-64.3	Olsen and Denton, in prep.
Lonfit River	downstream of Ordot Dump (WV)	surface	bulk sediment	nd	0.9	0.05	24.1	28.9	20,800	1100	402	37	11	27	Black and Veatch, 1983
Lonfit River	adjacent to Ordot Dump (WV)	surface	<1 mm	all <0.10	-	all <0.10	51.7-74.1	64.3-96.3	46,914-63,061	25.1-30.8	988-1,312	95.7-107	all <1.00	55.7-68.5	Olsen and Denton, in prep.
Unnamed Stream	contaminated with leachate from Ordot Dump (WV)	surface	<1 mm	all <0.10	-	all <0.10	57.9-82.9	57.5-251	75,825-76,007	56.7-61.7	1,747-1,875	44.3-46.4	34.7-90.2	178-258	Olsen and Denton, in prep.
Leachate Streams/Pond	south, southeast and western face of Ordot Dump	surface	bulk sediment	nd	0.5-1.1	<0.05-0.2	16.4-46.1	23.7-30.5	13,000-36,600	2,200-4,400	360-2,350	17.2-26.4	6.8-32	35.5-108	Black and Veatch, 1983
Lonfit River	confluence point with unnamed leachate streams (VC)	surface	<1 mm	all <0.10	-	all <0.10	46.7-81.0	56.4-76.4	48,063-70,791	40.5-50.9	970-2,592	81.2-107	1.08-12.0	53.1-145	Olsen and Denton, in prep.
Lonfit River	200-500 m upstream of Ordot Dump (WV)	surface	<1 mm	all <0.10	-	all <0.10	58.0-75.9	63.7-68.1	53,280-57,040	22.7-26.0	1,120-1,525	67.9-112	all <1.00	53.8-59.0	Olsen and Denton, in prep.
Lonfit River	upstream of Ordot Dump (WV)	surface	bulk sediment	nd	0.9	0.05	30.8	33.7	19,400	3200	1,370	52.3	12	26.2	Black and Veatch, 1983
Agana Boat Basin:	Inner marina: (TC-BC mix)	0-30	<1 mm	all <0.20	1.35-6.00	all <0.20	3.99-28.8	1.91-74.7	-	9.16-107	-	1.54-19.9	11.1-70.7	4.45-104	Denton *et al.*, 1997
Agana Boat Basin:	Outer marina: (BC)	0-30	<1 mm	all <0.20	1.00-1.03	all <0.20	3.61-4.25	0.56-3.01	-	4.59-4.77	-	1.01-1.48	1.99-3.46	3.44-4.57	Denton *et al.*, 1997
Agat Marina	(BC)	0-30	<1 mm	all <0.20	5.31-9.78	all <0.20	9.85-30.7	2.63-10.3	-	4-6	-	12.3-30.2	all <0.6	4.42-11.2	Denton *et al.*, 1997
Merizo Pier	(BC)	0-30	<1 mm	all <0.20	2.87-5.19	all <0.20	13.5-39.5	4.34-123	-	8-32	-	14.0-71.0	<1.00-27.1	9.58-130	Denton *et al.*, 1997
Apra Harbor	outer harbor: (TC-BC mix)	0-30	<1 mm	all <0.20	1.16-10.7	0.27-2.18	3.59-17.1	1.00-142	-	11-403	-	<0.2-14.0	<1.00-96.3	2.3-461	Denton *et al.*, 1997
Apra Harbor	Echo Wharf: outer harbor (TC-BC mix)	surface	bulk sediment	<0.23	<0.99	<0.17	16-18	-	-	-	-	-	17	-	US Navy (PWC) 1997, unpublished
Apra Harbor	SRF Industrial: outer harbor (TC-BC mix)	surface	>65µm	-	-	2.0-4.3	-	30-123	-	ND-430	-	9.3-21.5	53-129	82-3548	Belt Collins Hawaii, 1994
Apra Harbor	SRF Industrial: outer harbor (TC-BC mix)	surface	<65µm	-	-	3.5-6.0	-	320-1435	-	80-4600	-	22.6-51.2	142-395	234-856	Belt Collins Hawaii, 1994
Apra Harbor	outer harbor (TC-BC mix)	0-10	bulk sediment	-	-	1.88-3.12	62.0-113	30.1-211	-	ND-999	-	10.3-21.4	50.5-132	34.1-223	Belt Collins Hawaii, 1993
Apra Harbor	outer harbor (TC-BC mix)	70-80	bulk sediment	-	-	2.02-2.88	59.8-126	21.6-238	-	ND-1740	-	8.8-190	45.9-138	16.2-236	Belt Collins Hawaii, 1993
Apra Harbor	inner harbor (TC-BC mix)	0-10	bulk sediment	-	-	1.93-3.44	64.0-129	41.0-255	-	140-1700	-	7.6-36.9	42.8-139	51.9-279	Belt Collins Hawaii, 1993
Apra Harbor	inner harbor (TC-BC mix)	70-80	bulk sediment	-	-	2.59-3.76	99.4-112	32.2-176	-	79-2400	-	24.1-40.6	54.3-123	29.5-208	Belt Collins Hawaii, 1993
Apra Harbor	Inner harbor: USS Proteus Site (TC-BC mix)	surface	bulk sediment	-	6.0c	-	34.0c	26.0c	-	360	-	7.35c	132c	72.2c	Ogden, 1996
SAIPAN:															
Tanapag Lagoon	intertidal (TC-BC mix)	surface	<1 mm	<0.15-0.75	2.14-5.68	0.18-1.69	2.43-17.5	1.34-102	-	10.9-74.7	-	0.46-11.9	1.33-158	6.00-358	Denton *et al.* in prep.
Tanapag Lagoon	intertidal (BC)	surface	<1 mm	all <0.21	0.28-7.79	0.17-0.31	1.42-3.27	0.50-6.76		2.38-18.1		<0.20-0.85	0.65-4.07	2.42-15.1	Denton *et al.* in prep.
Tanapag Lagoon	subtidal-nearshore (TC-BC mix)	0-15	<1 mm	<0.10-0.28	1.33-10.4	<0.10-0.58	1.40-9.67	0.22-27.8	-	12-101	-	<0.20-5.06	<0.4-40.6	1.63-127	Denton *et al.* in prep.
Tanapag Lagoon	subtidal-offshore (BC)	0-15	<1 mm	all <0.10	0.69-1.57	all <0.10	1.06-2.43	<0.10-2.43	-	3-16	-	<0.20-0.36	<0.4-1.2	<0.02-2.09	Denton *et al.* in prep.

[a] BC = biogenic carbonates, TC = terrigenous clays, WV = weathered volcanics; [b] mercury as ng/g dry weight; [c] only maximum concentration reported; ND = not detectable; dashes indicate no data

Table 6: 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 6 (cont.): 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	
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

Plate 2: Pago Bay after a period of prolonged, heavy rain. Note the sediment plume extending along both sides of the Pago River mouth and into the reef channel. During major storms that approach from the east, alluvial deposits in the bay are resuspended and exported offshore. The reef channel facilitates this natural cleansing process, acting as a conduit through which sediments are transported into deeper waters. The relatively high frequency of storms in the region thus ensures the periodic removal of contaminated sediments that might otherwise build-up in the watershed and in the bay.

Plate 3: Groundwater intrusion: Spring located approximately 200 m south of Pago River mouth

Plate 4: Bioindicator: *Sargassum cristafolium* along the outer reef flat of Pago Bay

Plate 5: Bioindicators: the seacucumber, *Holothuria atra* and the brown seaweed, *Padina boryana*

Plate 6: Bioindicators: Seagrass, *Enhalis acoroides*, at southern end of Pago Bay and (inset) two resident bivalves, *Gafrarium pectinatum* (top) and *Quidnipagus palatum* (bottom)

RESULTS AND DISCUSSION

The data for all metals considered during this study are summarized in Table 7 for surface sediments and Tables 8-11 for the biota. The tables are located at the end of this section. The isoconcentration contour maps for each metal are appended at the end of the report. The findings of the survey are briefly evaluated here with reference to levels found in sediments and similar or related biota from clean and polluted environments from elsewhere. Reference to levels previously recorded in river water and sediments upstream and downstream of the Ordot Dump are also made where appropriate. For convenience, these discussions are organized on a metal-by-metal basis and are presented in alphabetical order of each element's chemical symbol identity. All referenced data are expressed on a dry weight basis, unless stated otherwise.

SILVER (Ag):

Silver ranks among the most toxic of heavy metals to marine organisms (Moore 1991). Levels in abiotic components of aquatic environments are usually low. Total silver concentrations in uncontaminated river waters, for example, range from 0.01-1 µg/l and average 0.1 µg/l (Wilson 1979). Levels determined in the Lonfit River between 1990-1994 were consistently below an analytical detection limit of 0.2 µg/l ~100 m upstream and downstream of the Ordot Dump. Silver was also undetectable in surface waters from a leachate stream downgradient of the dump over the same time period (Denton *et al.* 2005). More recent investigations failed to detect this metal in raw leachate emanating from two sites along the western and southern edges of the dump (Denton et al. 2005). An earlier claim that silver levels in leachate and the receiving waters of the Lonfit River posed potential health risks to humans and the environment (USEPA 2002) is, therefore, unsubstantiated.

Silver concentrations in uncontaminated sediments are around 0.1 µg/g (Bryan and Langston 1992) while concentrations in highly polluted environments can exceed 100 µg/g (Skei *et al.* 1976). Levels found in sediments during the current work were consistently below an analytical detection limit of 0.15 µg/g indicating that silver is not an element of environmental concern in Pago Bay (Table 7). Such findings were consistent with those previously reported for other coastal sediments in Guam and Saipan (Denton *et al.* 1997, 2001). Silver has never been detected in stream sediments of the Lonfit-Pago river system (USEPA 2002, Olsen and Denton, in prep., Table 5). The relatively low levels encountered in biota during the present work are, therefore, not surprising (Table 6).

Marine algae and macrophytes generally do not concentrate silver to levels above 0.4 µg/g in clean waters (Preston *et al.* 1972, Bryan and Uysal 1978, Burdon-Jones *et al.* 1975, Denton *et al.* 1980). In metal enriched environments, however, levels may be substantially higher. For example, Bryan and Hummerstone (1977) reported a maximum value of 2.42 µg/g for *Fucus* spp. (brown algae) collected from the metal enriched Looe River estuary in Cornwall, UK. In the current study, silver concentrations were consistently below an analytical detection limit of ~0.2 µg/g in all algae and seagrass examined (Tables 8-9).

Silver levels in almost all species of echinoderms examined by others are either non-detectable, or near the limits of analytical detection (Eisler 1981). The results of the present study are in line with these findings (Table 10). In a previous investigation, a relatively high silver concentration of 4.9 µg/g was found in hemal tissue of a single specimen of *Holothuria atra* from the Port Authority

Beach area in Apra Harbor, suggesting it may have indicator capability for this particular element. Silver was not detected in any hemal tissue of any specimen analyzed during the present study.

Mollusks show considerable inter- and intra-specific variations in silver concentrations with levels reported in the literature ranging from <0.1-185 µg/g. In most cases, the highest values are from samples taken from polluted environments (Eisler 1981). Specimens examined during the present work contained levels below, or close to, the limits of analytical detection (Table 11). Appreciably higher values were found in similar species removed from metal enriched sediment near the Puerto Rico Dump in Tanapag Lagoon, Saipan (Table 6).

Clearly, none of the organisms examined here were excessively enriched with silver. This is to be expected in view of the absence of detectable levels of this element in sediments from within the study area.

ARSENIC (As):

Although arsenic has several oxidation states, the chemical form normally encountered in the environment is not particularly toxic to aquatic organisms (Moore 1991). Wilson (1979) gives average arsenic concentrations in river water of 0.4 µg/l. Lonfit River water samples, taken upstream and downstream of the Ordot Dump over 20 years ago, yielded measurable arsenic concentrations of ~0.1 µg/l. A single leachate stream sample collected at the same time produced a value of 0.2 µg/l (Camp Dresser and McKee 1985). Sediment concentrations of arsenic, measured two years earlier in samples from all three locations, gave identical values of 0.9 µg/g (Black and Veatch 1983). The great majority of sediment samples analyzed during the present investigation revealed similarly low arsenic concentrations implying no significant change over time (see Table 7 and Appendix 1). Arsenic levels of 1-3 µg/g are considered to be fairly typical of clean coastal sediments on Guam and Saipan (Denton *et al.* 1997, 2001). In highly contaminated environments, concentrations of this element can exceed 1,000 µg/g (Langston 1984, 1985).

Appreciable and often highly variable amounts of arsenic are found in most marine organisms. Levels in algae, for example, are typically around 20 µg/g (Bryan 1976) with normal ranges between 2-60 µg/g (Eisler 1981). Most specimens analyzed from Pago Bay during the present study yielded values within this range, although concentrations in *Sargassum cristafolium* from the reef front averaged 33 µg/g and ranged from 12-117 µg/g (Table 8). Interestingly, arsenic concentrations in seagrass were considerably lower than those found in algae and rarely exceeded 1 µg/g (Table 9). No comparable data was found in the literature for this group.

Arsenic levels in the seacucumber, *Holothuria atra*, were in line with the 5 µg/g average suggested by Bryan (1976) for echinoderms generally. Bivalves from uncontaminated sites usually contain arsenic concentrations between 1-15 µg/g (Eisler 1981) and specimens analyzed during the present study were mostly within this range. Data from these organisms confirm that arsenic is not a problem element in Pago Bay (Tables 10-11).

CADMIUM (Cd):

Cadmium, particularly as the free cadmium ion, is highly toxic to most plant and animal species. Fortunately, levels found in uncontaminated aquatic environments are normally well below 1 µg/l (Moore 1991). Cadmium levels monitored in surface waters of the Lonfit River, upstream and downstream of the Ordot Dump, between 1990 and 1994, were consistently below an analytical

detection limit of 0.2 µg/l (Denton *et al.* 2005). Cadmium concentrations in leachate samples taken over the same time were also undetectable. More recent analyses of leachate and surface water samples from this area indicate the situation has not changed over time (Denton *et al* 2005).

Non-polluted sediments normally contain less than 0.2 µg/g cadmium, while levels may exceed 100 µg/g at heavily contaminated sites (Naidu and Morrison 1994). Previously reported cadmium concentrations in sediments from the Lonfit River were all <0.2 µg/g (Black and Veatch 1983, Olsen and Denton, in prep., see also Table 5). Levels found in Pago Bay during the current study were similarly low (Table 7). Clearly, cadmium is not an element of concern here. The absence of detectable cadmium levels in the great majority of biotic representatives analyzed from these waters supports this conclusion (Tables 8-11).

CHROMIUM (Cr):

Chromium is only moderately toxic to aquatic organisms (Moore 1991). Dissolved levels in river water can range from 0.2-20 µg/l according to Wilson (1979), although average concentrations lie somewhere close to 1.0 µg/l. Historic values for this element in the Lonfit River, upstream and downstream of Ordot Dump, range from 0.06-0.9 µg/l and 0.01-0.9 µg/l respectively (USEPA 2002). In the early 90s, Denton and Wood detected concentrations of 1.1-5.0 µg/l (average 2.0 µg/l) in water from a small, leachate-contaminated spring draining into the Lonfit River. A more recent analysis of raw leachate, taken directly from the dump face, revealed substantial chromium enrichment with maximum dissolved and total concentrations of 19.6 µg/l and 210 µg/l respectively (Denton *et al.* 2005). In spite of this, there is no clear evidence to indicate sedimentary levels of chromium have increased significantly in leachate streams or the Lonfit River. On the contrary, sediments recently collected from river sites upstream and downstream of the dump yielded almost identical concentration ranges of 58.0-75.9 µg/g and 59.2-77.5 µg/g respectively, while those taken from two major leachate streams ranged from 46.7-82.9 µg/g (Olsen and Denton, in prep.).

Although chromium levels in uncontaminated sediments of lithogenic origin vary according to their mineralogical characteristics, levels generally lie between 10-100 µg/g (Turekian and Wedepole 1961). Thus, there is nothing unusual about the concentrations noted above for Lonfit River sediments, as they fit well within this range. It is noteworthy that chromium concentrations in excess of 2,000 µg/g can occur in sediments from severely contaminated areas (Young and Means 1987).

Clean, bioclastic sediments contain considerably lower chromium concentrations than their lithogenic counterparts. Those from coastal waters of Guam and Saipan, for example, yielded values mostly between 3-5 µg/g (Denton *et al.* 1997, 2001). Levels encountered sediments from Pago Bay during the present study ranged from 1.76-25.6 µg/g (Table 7), with the highest values occurring near the river mouth and in areas affected by groundwater intrusion (see Appendix 2).

Chromium levels in algae and seagrasses from clean waters usually range between 1-3 µg/g although lower values have been reported (Table 6). Levels found in specimens from Pago Bay are in agreement with this (Tables 8-9). In contaminated environments, concentrations may be an order of magnitude higher or more. For example, Burdon-Jones *et al.* (1975, 1982) reported a high of 31.5 µg/g in *Padina* sp. from the upper reaches of Townsville Harbor in north Queensland, Australia, while Gryzhanková *et al.* (1973) recorded a high of 140 µg/g in algae from polluted coastal waters in Japan.

Chromium is clearly compartmentalized in seacumbers with higher levels occurring in the hemal tissue compared with the body wall musculature. These organisms may have some bioindicator capacity for chromium as implied by the work of Thompson and Patton (1978), who found 2.2 µg/g in the body wall of *Molpadia intermedia* from a contaminated sediment disposal site in Georgia Strait, Vancouver, Canada. Levels determined in this tissue during the present study were all less than 0.3 µg/g (Table 10).

Chromium concentrations in the edible tissues of uncontaminated marine mollusks usually lie between 0.5-3.0 µg/g (Eisler 1981). Levels recorded here ranged from a low 0.14 µg/g in *Ctenna bella* to a high of 0.46 µg/g in *Quidnipagus palatum* (Table 11). Interestingly, a maximum value of 10.6 µg/g was found in the latter species from chromium-enriched sediments adjacent to the Puerto Rico Dump in Saipan (Denton *et al.* in prep). This clearly highlights the sensitivity of *Q. palatum* to changes in the ambient availability of this element, and provides additional evidence for low levels of biologically available chromium in the Pago Bay area.

From the forgoing data, it is clear that chromium levels in sediments and biota from Pago Bay reflect natural background concentrations only.

COPPER (Cu):

Copper is particularly noxious to plants and invertebrates (Brown and Ahsanulla 1971, Denton and Burdon-Jones 1982), and ranks among the more toxic heavy metals to fish (Denton and Burdon-Jones 1986b, Moore 1991). Dissolved copper levels in unpolluted rivers are generally less than 10 µg/l (Wilson 1979). Denton and Wood recorded levels ranging from 0.3-4.1 µg/l in the Lonfit River between 1990 and 1994. These researchers also noted elevated copper levels of up to 31 µg/l in the small, leachate-contaminated stream that coursed its way along the western edge of the dump into the Lonfit River (Denton *et al.* 2005). Based on these and other findings, copper has been identified as an element of potential concern in the area with respect to human and environmental health risks (USEPA 2002).

Copper levels in clean, non-geochemically enriched coastal sediments rarely exceed 10 µg/g whereas values in excess of 2,000 µg/g can occur in severely polluted environments (Legoburu and Canton 1991, Bryan and Langston 1992). Clean bioclastic sediments typically contain 1-3 µg/g copper nearshore, whereas levels of 0.1 µg/g, or less, are frequently encountered offshore (Denton *et al.* 1997, 2001). In the current study, sedimentary copper levels ranged from less than 1µg/g in predominantly bioclastic material at the northern end of the bay to ~20 µg/g in alluvial deposits around the Pago River mouth further south (see Table 7 and Appendix 3).

A recent study by Olsen and Denton (in prep) established baseline copper levels in Lonfit River sediments as 50-70 µg/g. Adjacent to the dump, maximum levels approached 100 µg/g and exceeded 250 µg/g in sediment from one leachate stream examined (Table 5). This said, there is no evidence to suggest this potentially toxic element is accumulating downstream in the watershed, and levels currently encountered in Pago Bay sediments and biota certainly show no cause for concern. In fact, copper levels found in all organisms analyzed rank among the lowest values ever reported for similar and related species from elsewhere (Table 6).

According to Moore (1991), total copper levels in marine plants are normally less than 10 µg/g, except near polluting sources where values upwards of 50 µg/g are not uncommon (Bryan and Hummerstone 1973, Burdon-Jones *et al.* 1975). Levels recorded in seaweeds and seagrass during the present investigation ranged from 0.30-4.65 µg/g and 0.74-5.73 µg/g respectively, with the great majority of samples yielding values below 3 µg/g. Denton and Burdon-Jones (1986a) analyzed several species of algae from near pristine sites along the entire length of the Australian Great Barrier Reef and reported values ranging from 0.74-7.2 µg/g, most of which fell between 1-4 µg/g. Clearly, no signs of copper enrichment are indicated in the current work (Table 8).

Seacucumbers concentrate copper more so in hemal tissue than body wall muscle and there are indications from the literature that these organisms have bioindicator capability for this element. For example, Thompson and Paton (1978) reported values of 26 µg/g in the body wall of *Molpadia intermedia* from a contaminated sediment disposal site in the Georgia Strait, Vancouver, whereas Burdon-Jones and Denton (1984) found much lower levels of 1.5-2.1 µg/g in the same tissue of *Stichopus variagatus* from near pristine waters within the Australian Great Barrier Reef. The latter values compare well with those found in *Holothuria atra* during the current study (0.98-1.54 µg/g).

Bivalve mollusks have been used extensively to monitor copper in the marine environment, although some species are far more sensitive to ambient changes in the biological availability of this element than others. Not much is known about the bioindicator potential of the bivalve species examined during the present study although what little information there is suggests *Quidnipagus palatum* is a promising candidate. In Saipan, for example, *Q. palatum* from the Puerto Rico Dump area in Tanapag Lagoon, yielded copper concentrations of 324-1027 µg/g compared with 4.26-68.9 µg/g in specimens from Pago Bay. A similar data-set comparison for *Gafrarium pectinatum* also highlights the copper enrichment around the Saipan dump but not with the same degree of sensitivity as that demonstrated by *Q. palatum*.

The above data clearly demonstrates that copper is not a problem metal in the Pago Bay area.

IRON (Fe):

Iron is the fourth most abundant element in the earth's crust and of little toxicological significance. (Moore 1991). Levels of dissolved iron in river water can range from 3-300 µg/l but are usually less than 50 µg/l (Wilson 1979). Mean values recorded in the Lonfit River in the early 90s were 7.7 µg/l and 16.5 µg/l upstream and downstream of the dump respectively (Denton *et al.* 2005). Levels detected in a major leachate stream over the same time period averaged 87 µg/l with a high of 646 µg/l. This degree of enrichment could well account for the marginally higher downstream values referred to above.

Iron levels in uncontaminated sediments can vary enormously depending upon background mineral content. Bioclastic reef sediments are generally iron depleted with levels seldom exceeding 200 µg/g (Denton unpublished data). In sharp contrast, sediments of the Pago-Lonfit-Sigua River systems are predominantly derived from ferruginous latisols. Thus, they are iron enriched with baseline levels typically in the range of 50,000-60,000 µg/g (Table 4). Bed sediments from leachate streams emanating from the dump, though generally higher in iron (70,000-80,000 µg/g), appear to have little, if any, impact on sedimentary levels of iron further downstream (Olsen and Denton, in prep.). The levels found in Pago Bay during the present investigation (200-53,000 µg/g) were thus considered to be representative of natural weathering and mixing processes operating within the

system; the high variability reflecting the proportions of bioclastic and alluvial materials present in samples from each site (see Table 7 and Appendix 4).

Iron is a redox sensitive element, a characteristic that greatly influences its biological availability. In aerobic environments, inorganic iron exists primarily in the insoluble, particulate form and is of limited availability, whereas under anaerobic conditions, the reverse is true. Levels in biota are, therefore, conditional upon the redox status of the environment in which they live, in addition to the overall abundance of iron in their immediate surroundings. For this reason, organisms inhabiting hypoxic sediments may well have higher tissue burdens of iron than their counterparts living under well-oxygenated conditions. Salinity is also another important variable that needs to be taken into account, when interpreting the data, because inorganic iron is markedly more soluble in freshwater than ocean water.

Marine algae are effective accumulators of iron, concentrating it in their tissues to levels several orders of magnitude above ambient (Eisler 1981). Levels reported in the literature range from less than 10 µg/g in clean environments, to more than 10,000 µg/g in polluted waters (Eisler 1981). Levels encountered during the current study were relatively low by comparison and ranged from ~20-1,800 µg/g. As expected, the highest levels were found in specimens closest to the river channel and shoreline sites impacted by groundwater intrusion (Table 8). Levels found in seagrass were similarly low when compared with related species from tropical waters elsewhere in the world (Table 6).

No comparative iron data was found for seacucumber tissues, although two independent studies considered whole body analysis of *Holothuria* sp., and reported values ranging from 74-200 µg/g in specimens from the Sea of Japan (Matsumoto *et al.* 1964) and the Mediterranean (Papadopoulu *et al.* 1976). These values were generally higher than those found in *H. atra* during the present study. The bivalves examined here all have hemoglobin as their respiratory blood pigment and, therefore, probably exercise some metabolic control over their iron uptake. They are, therefore, considered unsuitable for monitoring the distribution and abundance of this element in the marine environment. In summary, the biota generally indicates moderate to low levels of available iron in the Pago Bay area.

MERCURY (Hg):

Mercury is highly toxic to aquatic organisms, particularly in the organic form, and methyl mercury can account for close to 40% of total mercury concentrations in surface waters (Schintu *et al.* 1989). Concentrations of dissolved mercury in freshwaters typically range from 10-100 ng/l (Moore 1991). Levels previously reported for the Lonfit River range from a low of 1.8 ng/l approximately 100m downstream of the dump (Camp Dresser and McKee 1985) to a massive high of 77 µg/l about the same distance upstream (Black and Veatch 1983). The earlier of these two works also reported very high upstream and downstream sediment concentrations of mercury of 3.1µg/g and 1.1 µg/g respectively.

In 1993, the USEPA declared mercury an element of potential concern in the Lonfit River based largely on the above findings (USEPA 1993). More recent studies suggest, however, that such concerns are unwarranted. For example, a study conducted by Denton and Wood in the early 90s failed to detect mercury in water from the Lonfit River, or a major leachate stream draining into it. The analytical detection limit in this particular instance was 0.3 µg/l (Denton *et al.* 2005). A decade

later, Denton *et al.* (2005) collected raw leachate directly from the face of the dump and screened it for a range of priority pollutants. Once again, mercury levels were below the limits of analytical detection (~0.2 µg/l). In a companion study, Olson and Denton (in prep.) screened sediments from the Lonfit River and the same leachate stream. They reported mean mercury levels in the river immediately above and below the dump of 23-26 ng/g and 23-61 ng/g respectively. Sediments from the leachate stream yielded values of 57-62 ng/g. These data are considerably lower than the earlier findings of Black and Veatch (1983) and suggest only mild enrichment occurs in the river, and only close to points of confluence with leachate streams.

Sediment concentrations of mercury in unpolluted, non-geochemically enriched areas, usually do not exceed 30 ng/g (Knauer 1976, Bryan and Langston 1992, Benoit *et al.* 1994), and may be as low as 2 ng/g in clean bioclastic sediments (Denton *et al.* 1997, 2001). Estuarine sediments adjacent to heavy industrialized areas or mercury mining activities can be three to five orders of magnitude higher than this (Langston 1985, Benoit *et al.* 1994). Mean levels found in Pago Bay sediments during the present study ranged from 1.55-13.6 ng/g with the highest levels generally occurring in alluvial deposits and nearshore sediments directly impacted by groundwater intrusion (Table 7, Appendix 5). The mild enrichment noted in shoreline sediments from site 31 (10.1-15.7 ng/g) at the northern end of the bay near the UOG Marine Laboratory and WERI is of interest and suggests a localized point source, possibly leachate from the wastewater disposal system (septic tanks) currently in place there.

Mercury is the only metal that tends to become more concentrated at higher trophic levels, a process known as biomagnification. Levels in marine algae from clean environments are generally less than 20 ng/g wet weight and may be as low as 1 ng/g or less (Denton and Burdon Jones 1986a). In the present study, mean values for all species of algae analyzed ranged from 1.02-6.6 ng/g wet weight and rank among the lowest ever recorded. Levels of the same order were found in seagrass and the body wall of the seacucumber, *Holothuria atra*, while marginally higher values of up to 52.3 ng/g wet weight were found in the hemal system of the latter species. In his review of the literature, Eisler (1981) concluded that mercury levels in echinoderms from non-polluted environments never exceed 400 ng/g wet weight, which is well above the highest levels encountered here for *H. atra.*

Although bivalve mollusks are excellent accumulators of mercury, tissue concentrations in specimens from clean environments rarely exceed 100 ng/g wet weight. Levels found in the bivalves analyzed during the present work ranged from 5.63-62.4 ng/g wet weight, providing further evidence that Pago Bay does not have a mercury contamination problem.

MANGANESE (Mn):

Manganese, like iron, is of little toxicological significance and can influence levels of other heavy metals in surface waters (Moore 1991). Dissolved manganese concentrations in river water lie mostly between 1-100 µg/l and are usually around 5 µg/l (Wilson 1979). Some geological formations on Guam are manganese bearing, and streams draining such areas are enriched with this element. Values of up to 710 µg/l were found in the Taelayag River on the western side of central Guam, for example (Siegrist *et al.* 1997). Levels found in the Lonfit River in the early 90s, while appreciably lower than this, were generally well above 5 µg/l. Values recorded upstream and downstream of the dump ranged from 3.8-132 µg/l (mean: 18.8 µg/l) and 8.3-52.3 µg/l (mean: 21.4 µg/l) respectively (Denton *et al.* 2005). These relatively high concentrations reflect the mineral composition of local sediments that typically contain 1,000-1,500 µg/g manganese (Olsen and

Denton, in prep). The dump contributes some manganese to the watershed and levels approaching 3,000 µg/g have been found in bottom deposits of leachate streams that drain the facility (Olsen and Denton in prep.). However, the overall impact of this on the manganese content of river sediments is marginal in view of the naturally high background levels present.

In light of the above, manganese concentrations determined in Pago Bay sediments during the present study are unremarkable with values ranging between 10-20 µg/g in bioclastic material from the northern end of the bay, to a high of 533 µg/g alluvial deposits at the river mouth (Table 7, Appendix 6). Levels showed a very strong positive correlation with those of iron ($P<0.001$), which suggests that both metals were predominantly derived from common natural sources.

Comparative manganese data for similar species of biota from elsewhere is limited. Algae are thought to possess some regulatory capability for this element and therefore may not be the best indicators of ambient availability in the water column (Morris and Bale 1975). Whether seagrasses are similarly affected is unknown. This notwithstanding, levels recorded in both groups were lower than those reported in the literature for related species from elsewhere (Table 6).

No manganese data exists for seacucumbers, although levels of this element have been determined in other types of echinoderms. Reported levels for starfish, for example, range from 6.5-43.0 µg/g (Riley and Segar 1970) and Bryan (1976) estimated an average value of 40 µg/g for echinoderms generally. Seacucumbers analyzed during the current work yielded values that were considerably lower than this (Table 10).

Manganese concentrations are known to vary substantially in certain bivalves depending upon their size, sex and reproductive state (Galtsoff 1942). This suggests that the group as a whole may exert some metabolic control over this element, at least in some tissues. Certainly, there is considerable interspecific variability in whole flesh concentrations of manganese, that is not readily explained in terms of biological availability differences (Eisler 1981). Manganese levels found in bivalves analyzed during the current study, ranged from 1.63-23.9 µg/g (Table 11), approaching the average value of 25 µg/g given by Bryan (1976) for bivalves generally.

NICKEL (Ni):

Nickel is only moderately toxic to most species of aquatic plants and is one of the least toxic heavy metals to invertebrates and fish (Denton and Burdon-Jones 1982, 1986b, Moore 1991). Dissolved levels of this element in freshwater typically range from 1-3 µg/l in uncontaminated settings (Scoullos and Hatzianestis 1989) up to 30 µg/l, or higher, in polluted environments (Moore 1991). Concentrations previously reported for a leachate contaminated stream down gradient of Ordot Dump ranged from 3.3-27.3 µg/l, while dissolved levels measured in leachate taken directly from the dump face were ~70 µg/l (Denton *et al.* 2005). Despite this obvious enrichment, nickel has never been detected above 1 µg/l anywhere in the Lonfit River (USEPA 2002, Denton *et al.* 2005).

Mean sedimentary nickel concentrations determined in Pago Bay during the present study ranged from a low of <0.21 µg/g in predominantly bioclastic deposits, at the northern end of the bay, to a high of 25.4 µg/g in alluvium around the river mouth (Table 7, Appendix 7). Clean bioclastic sediments from Guam and Saipan coastal waters typically contain nickel concentrations of less than 1 µg/g (Denton *et al.* 1997, 2002). Concentrations in lithogenic deposits generally range between 10-20 µg/g (Bryan and Langston 1992), but can exceed 200 µg/g in contaminated regions (Fowler

*et al.*1993). Baseline values for nickel in Lonfit River sediments generally lie between 70-110 µg/g (Olsen and Denton in prep.). Thus, there is nothing unusual about the levels encountered in Pago Bay during the present investigation. Nickel concentrations in the biota examined tend to support this conclusion (Tables 8-11).

Brown algae rarely concentrate nickel above 3 µg/g in uncontaminated environments (Denton and Burdon Jones 1986a), whereas levels in excess of 30 µg/g have been recorded in specimens from nickel-enriched waters (Stevenson and Ufret 1966). The highest mean value recorded during the present work was 6.37 µg/g in *Sargassum cristafolium* from the outer reef flat. The great majority of other samples analyzed yielded values below 3 µg/g.

Seacucumbers do not appear to be particularly sensitive indicators of nickel pollution (Denton *et al.* 1999), although one study reported whole body levels of 38 µg/g in *Stichopus tremulus* from an unspecified location (Noddack and Noddack 1939). All other studies suggest that levels in the body wall and hemal tissue do not deviate much beyond 1-2 µg/g regardless of ambient nickel concentrations (Table 6). Levels determined in the body wall of *Holothuria atra* during the current study ranged from <0.1-0.32 µg/g.

Bivalves are generally more affective accumulators of nickel than seacucumbers, although their bioindicator capacity for this element also remains in question. Certainly the similarity between Pago Bay and Saipan data sets for *Gafrarium pectinatum* and *Quidnipagus palatum* (Table 6) suggests both species exert some metabolic control over tissue levels of this element, especially as the latter environment was shown to be nickel enriched (Denton *et al.* in prep.).

LEAD (Pb):

Although inorganic lead is only moderately toxic to aquatic plants and animals, organolead compounds, particularly those used as antiknock agents in gasoline, are highly toxic to all forms of life (Moore 1991). Dissolved lead concentrations in freshwater are normally less than 5 µg/l (Wilson 1979). Levels determined in the Lonfit River by Denton and Wood in the early 90s were almost always below an analytical detection limit of ~0.6 µg/l. Leachate samples recently collected from the dump face were enriched with particulate lead (4.7-45 µg/l) while dissolved levels were less than 0.5 µg/l (Denton *et al.* 2005). Not surprisingly, then, bottom deposits of leachate streams around the dump act as major repositories for this element. Olsen and Denton (in prep.) recorded concentrations close to 100 µg/g in the bed sediments of one stream recently examined. While these researchers found no evidence of lead enrichment above background (~1 µg/g) in Lonfit River sediments, downstream of the dump, they did identify major difference in the seasonal deposition rates of this element in the Pago River estuary. Sediments from this section of the watershed were taken from a site just seaward of the Route 4 Bridge in August 2003 and again in March 2004, during wet season and dry season conditions respectively. Recorded lead values were 13.3-14.5 µg/g in August and 1.64-4.66 µg/g in March. Their data is thought to reflect the seasonal flushing of contaminated sediments from further upstream, although contributions from automobile emissions in highway runoff cannot be discounted. During the 2004 wet season, Tsuda *et al.* (2004) reported lead levels of ~3 µg/g in sediments from the Pago River mouth and channel. These findings highlight the mechanism by which contaminated sediment are exported from the river into deeper waters offshore.

Lead concentrations in clean, non-geochemically enriched, lithogenic sediments generally do not exceed 25 µg/g (Bryan and Langston 1992), while levels in clean bioclastic deposits rarely exceed 1.0 µg/g (Denton *et al.* 2001). In severely polluted locations, near mining activities, or industrial processes that utilize lead, sedimentary lead concentrations may exceed 2,000 µg/g (Jones 1986, Bryan and Langston 1992). The highest level reported to date is 266,000 µg/g in sediments adjacent to a battery factory in Suva Harbor, Fiji (Naidu and Morrison 1994).

Mean lead levels recorded in sediments during the present investigation ranged from <0.26 µg/g, in predominantly bioclastic material to 14.4 µg/g in river alluvium (Table 7). The distribution and abundance profiles for lead throughout the study area are shown in Appendix 8. A fairly extensive area of light to moderate enrichment is clearly identified at the southern end of the bay. Whether this enrichment is of fluvial or terrestrial origin is not clear at the present time. Certainly, circulatory gyres do exist in this part of the bay (Marsh *et al.* 1981), which could enhance alluvial deposition rates along the adjacent shoreline.

A localized area of light enrichment was also identified at the northern end of the bay, near the Marine Laboratory and WERI (sites 30 and 31). This could possible reflect the type of wastewater systems serving these buildings as discussed earlier. However, a circulatory gyre that also exists in this part of the bay, could conceivably increase residence times of lead enriched fluvial deposits reaching the area by long-shore drift (see Marsh *et al.* 1981).

Lead concentrations in biota analyzed from Pago Bay generally mirrored the distribution and abundance profiles identified in the sediments. In algae, for example, the highest lead concentrations in *Sargassum cristafolium* from the outer reef flat were found in specimens from sites 2-7 at the northern end of the bay (Table 8). Relatively high levels of lead were also seen in *Padina boryana* from the inner moat area in this region (site 47) as well as in samples from the lead enriched zone at the southern end of the bay (site 28).

Algae, unlike seagrass, have a high affinity for lead and levels in excess of 100 µg/g have been reported in tropical species from relatively contaminated waters (Burdon-Jones *et al.* 1975, Agadi *et al.* 1978). The highest level reported to date is 1,200 µg/g in the green alga, *Enteromorpha*, from a severely polluted fjord on the West Coast of Norway (Stenner and Nickless 1974). Thus, the highest levels reported here (max: 13.9 µg/g) are no cause for concern.

From the literature, it would seem that echinoderms are unable to regulate lead levels in their tissues and, therefore, may serve as potentially useful indicators of environmental contamination by this metal. Stenner and Nickless (1974) reported lead levels of up to 460 µg/g in various echinoderms from the West Coast of Norway. Matsumoto (1964) gave values of up to 14.4 µg/g wet weight in *Holothuria* sp. from lead-contaminated coastal waters of Japan, while Denton (unpublished data) found 3.8 µg/g in the same genera from a residential beach in Townsville, Australia. In contrast, specimens of *Stichopus variagatus*, from pristine waters of the Great Barrier Reef, contained <1.0 µg/g of lead in their body wall muscle (Burdon-Jones and Denton 1984). Similarly low concentrations were found in seacucumbers from Pago Bay during the present study (Table 10).

Lead levels in the bivalve, *Quidnipagus palatum*, were marginally higher in specimens from seagrass beds at the southern end of the bay compared with specimens collected north of the river (Table 11). This species appears to be particularly sensitive to lead, and levels approaching 200

µg/g have been recorded in samples collected near the Puerto Rico Dump, in Saipan (Denton *et al*. in prep.). Values recorded during the present study (<0.2-0.62 µg/g) are, therefore, indicative of a comparatively clean coastal habitat by local standards.

ZINC (Zn):

Although zinc is not appreciably toxic, it is a ubiquitous contaminant and is sometimes released into the aquatic environment in substantial quantities (Bryan and Langston 1992). Dissolved zinc levels in freshwaters typically range from 1-50 µg/l (Moore 1991). Levels found in the Lonfit River from 1990-94 ranged from <0.1-10.0 µg/l with most readings below 1.0 µg/l (USEPA 2002). Leachate from the Ordot Dump is relatively enriched with particulate zinc although soluble levels are considerably lower. Maximum values recently recorded for each fraction were 12,000 µg/l and 61 µg/l respectively (Denton *et al.* 2005). Sediments therefore act as a major sink for this element and levels exceeding 250 µg/g can occur in bottom deposits of leachate streams entering the Lonfit River (Olsen and Denton in prep.). Sedimentary zinc levels elsewhere in the watershed typically range between 50-70 µg/g, and may exceed 100 µg/g around confluence points with leachate streams from the dump. Some minor zinc enrichment also occurs in surface sediments of the Pago River estuary during wet season conditions (Olsen and Denton in prep.), which presumably can be traced back to the dump. Highway runoff may also be a contributing source of zinc in this region.

Lithogenic sediments from uncontaminated waters typically contain zinc levels of 5-50 µg/g depending upon local geology (Moore 1991). Residues in excess of 3,000 µg/g are frequently found in the vicinity of mines and smelters (Bryan *et al.* 1985) and in contaminated harbor environments (Poulton 1987, Legorburu and Canton 1991). Levels in nearshore bioclastic deposits are normally within 3-5 µg/g, and may drop below 1 µg/g in clean coral sands (Denton *et al.* 1997, 2002).

Sedimentary zinc concentrations found in the present study ranged from 0.6-89.5 µg/g, and were highest in alluvial deposits around the river mouth, at the southern end of the bay (Table 7). Minor enrichment was also noted at shoreline sites impacted by groundwater intrusion in the middle reaches of the bay, and near the Marine Laboratory and WERI further north (Appendix 9).

Marine algae are commonly used as bioindicators of heavy metal pollution and readily concentrate zinc (Phillips 1980). Levels ranging from several hundred to several thousand parts per million (µg/g) have been recorded in certain species from severely polluted environments (Bryan and Hummerstone 1973, Fuge and James 1973, Haug *et al.* 1974, Stenner and Nickless 1974, Melhuus *et al.* 1978). According to Denton and Burdon-Jones (1986a), algae from clean environments usually contain zinc concentrations below 10 µg/g. These authors analyzed algae from the Australian Great Barrier Reef and reported mean zinc concentrations of 2.0, 2.7, and 2.2 µg/g in brown, red, and green representatives respectively. Mean values recorded here for all species taken from Pago Bay ranged from a low of 1.01 µg/g in *Sargasum cristafolim,* from site 9 on the outer reef flat, to a high of 8.40 µg/g in *Gracilaria salicornia,* from site 48 near the Marine Lab (Table 8).

Mean zinc concentrations in seagrass from Pago Bay ranged from 5.25-15.5 µg/g, considerably lower than those found in the same species (*Enhalus acoroides*) from Tanapag Lagoon, in Saipan (Table 6). Levels generally mirrored the distribution profile that emerged from the sediment survey, with the highest values confined to specimens closest to the Pago River mouth and along the southern shoreline (Table 9).

Whether seacucumbers are capable of regulating zinc concentrations in their tissues is a matter of some debate. Recent evidence suggests they can, which means that they have limited bioindicator potential for this element. Zinc concentrations in the body wall of *Holothuria atra* from clean and contaminated sites in Saipan, for example, yielded similar ranges of 15.2-22.6 µg/g and 13.1-24.1 µg/g respectively. Likewise, hemal tissue concentrations of this element, though higher, were not significantly different between the two sample groups (Denton *et al*. in prep). In the current study, we found zinc levels of 12.8-17.8 µg/g in the body wall of *H. atra* and 56.9-301 µg/g in the hemal tissue (Table 10). Values determined in the latter tissue of specimens from clean and contaminated sites in Saipan were highly comparable at 40.0-201 µg/g and 33.5-287 µg/g respectively.

Bivalves are frequently used to monitor zinc levels in the marine environment although, little data exists for the species examined during the present study. Based on data-set comparisons with specimens collected from contaminated sites in Saipan, *Quidnipagus palatum* obviously possesses some bioindicator potential for zinc, whereas *Gafrarium pectinatum* clearly does not (Table 6). Levels recorded in the former species from Pago Bay ranged from 93.6-341 µg/g (mean 222 µg/g) compared with 305-1,027 µg/g (mean: 622 µg/g) in specimens from Saipan.

In summary, the above data demonstrates some light zinc enrichment in sediments impacted by fluvial discharges and groundwater intrusion. However, background levels are generally low and anthropogenic contributions minimal. Biotic levels of this element are plainly within the ranges expected of relatively clean coastal environments. Clearly then, zinc is not a problem element in these waters.

Table 7: Heavy Metals in Surface Sediments from Pago Bay, Guam

Site	Statistic[a]	Heavy Metals (µg/g dry wt.)										
		Ag	As	Cd	Cr	Cu	Fe	Hg[b]	Mn	Ni	Pb	Zn
4 (a-c)	mean	nc	0.86	nc	7.39	10.1	3,848	6.26	140	4.46	14.4	8.18
	range	all <0.15	0.74 - 1.01	all <0.15	6.71 - 7.87	8.19 - 12.0	3,603 - 4,203	5.85 - 6.67	128 - 153	4.28 - 4.80	14.2 - 14.6	8.04 - 8.29
5 (a-c)	mean	nc	1.28	nc	9.61	13.2	6,138	9.30	144	8.48	7.65	11.3
	range	all <0.15	0.81 - 2.39	all <0.15	7.08 - 12.8	10.2 - 15.3	5,417 - 6,627	8.53 - 10.4	135 - 158	7.61 - 9.66	4.68 -10.3	10.3 - 12.5
6 (a-c)	mean	nc	1.43	nc	6.44	5.76	3,990	6.39	131	4.98	3.71	9.24
	range	all <0.15	1.04 - 1.77	all <0.15	5.39 - 8.39	4.16 - 8.53	2,762 - 6,737	4.96 - 7.80	124 - 145	2.81 - 8.82	3.40 - 4.37	6.98 - 14.8
7 (a-c)	mean	nc	1.60	nc	14.1	17.5	20,533	12.4	453	21.7	1.85	28.0
	range	all <0.15	0.91 - 2.15	all <0.15	13.6 - 14.9	17.1 - 18.1	19,394 - 22,119	10.8 - 15.0	431 - 498	17.7 - 24.2	1.56 - 2.17	25.7 - 30 7
8 (a-c)	mean	nc	1.56	nc	14.4	14.9	17,330	13.6	421	22.1	1.60	28.4
	range	all <0.15	1.40 - 1.82	all <0.15	13.2 - 16.9	14.4 - 15.3	16,818 - 17,958	10.6 - 18.0	386 - 457	21.2 - 22.7	0.94 -4.67	27.7 - 29.6
9 (a-c)	mean	nc	0.98	nc	9.64	7.76	9,938	7.97	293	13.3	nc	14.0
	range	all <0.15	0.81 - 1.10	all <0.15	8.21 - 11.0	6.3 - 9.0	8,098 - 11,874	7.08 - 9.16	280 - 316	11.1 - 15.6	all <0.31	10.8 - 17.5
10 (a-c)	mean	nc	0.14	nc	21.1	6.45	41,743	4.34	430	15.0	4.41	65.3
	range	all <0.15	0.07 - 0.33	all <0.15	15.9 - 25.6	5.7 - 7.2	27,504 - 52,278	3.28 - 7.46	319 - 533	13.1 - 17.0	1.25 - 20.5	36.6 - 89.5
11 (a-c)	mean	nc	0.78	nc	10.9	9.51	12,184	7.37	265	14.8	1.10	19.0
	range	all <0.15	0.68 - 0.95	all <0.15	10.5 - 11.2	8.29 - 10.5	11,276 - 12,834	7.00 - 8.08	225 - 296	13.0 - 16.1	0.93 - 1.54	17.6 - 19.8
12 (a-c)	mean	nc	0.53	nc	7.70	6.73	8,653	4.64	216	10.4	nc	11.3
	range	all <0.15	0.34 - 0.76	all <0.15	7.49 - 7.88	6.58 - 6.80	8,434 - 8,992	3.27 - 6.25	197 - 229	9.65 - 11.1	all <0.27	10.7 - 11.9
13 (a-c)	mean	nc	0.56	nc	7.78	8.04	9,119	5.70	211	11.2	nc	13.0
	range	all <0.15	0.50 - 0.66	all <0.15	7.37 - 8.62	7.12 - 9.40	7,873 - 10,986	4.48 - 7.15	193 - 223	10.0 - 13.4	<0.25 - 0.88	12.2 - 14.3

[a] mean = geometric mean; [b] mercury data expressed as ng/g dry wt.; nc = not calculable; no sediment available at sites 1-3

Table 7 (cont.): Heavy Metals in Surface Sediments from Pago Bay, Guam

Site	Statistic[a]	Heavy Metals (µg/g dry wt.)										
		Ag	As	Cd	Cr	Cu	Fe	Hg[b]	Mn	Ni	Pb	Zn
14 (a-c)	mean	nc	1.17	nc	5.67	6.15	6,333	4.32	117	7.66	nc	10.2
	range	all <0.15	0.86 - 1.36	all <0.15	5.52 - 5.95	5.58 - 6.63	6,273 - 6,392	4.10 - 4.64	109 - 129	6.37 - 9.88	<0.26 - 0.53	9.96 - 10.4
15 (a-c)	mean	nc	1.14	nc	3.71	3.01	2,400	3.95	64.5	2.46	nc	5.61
	range	all <0.15	0.91 - 1.36	all <0.15	3.38 - 4.07	2.37 - 3.45	1,923 - 2,733	3.56 - 4.66	55.2 - 70.0	1.70 - 3.20	<0.24 - 0.76	4.60 - 6.21
16 (a-c)	mean	nc	0.57	nc	4.10	1.90	2,026	5.27	82.4	2.07	nc	4.13
	range	all <0.15	0.49 - 0.72	all <0.15	3.35 - 4.78	1.58 - 2.33	1,643 - 2,276	3.65 - 8.78	62.7 - 118	1.58 - 2.89	<0.25 - 0.48	3.70 - 4.80
17 (a-c)	mean	nc	0.51	nc	3.59	1.82	1,373	3.79	102	1.63	nc	4.41
	range	all <0.15	0.47 - 0.57	all <0.15	3.27 - 3.90	1.42 - 2.39	1,191 - 1,735	3.53 - 4.20	98.4 - 109	1.58 - 1.66	all <0.26	3.69 - 5.98
18 (a-c)	mean	nc	0.50	nc	4.28	1.96	1,871	3.07	134	2.01	nc	3.44
	range	all <0.15	0.41 - 0.74	all <0.15	3.57 - 5.34	1.83 - 2.18	1,604 - 2,197	2.48 - 3.47	111 - 169	1.29 - 3.39	all <0.25	3.24 - 3.77
19 (a-c)	mean	nc	0.54	nc	7.97	4.60	4297	3.45	221	4.85	0.63	6.99
	range	all <0.15	0.42 - 0.74	all <0.15	5.9 - 10.4	2.77 - 8.53	3,766 - 4,728	2.87 - 3.84	136 - 340	3.00 - 8.94	0.47 - 0.75	3.74 - 17.2
20 (a-c)	mean	nc	0.82	nc	15.8	7.83	9,115	6.59	244	7.25	nc	8.33
	range	all <0.15	0.66 - 0.92	all <0.15	15.4 - 16.1	5.48 - 9.86	7,560 - 10,393	5.86 - 7.92	159 - 382	4.58 - 9.88	<0.25 - 0.48	7.11 - 9.30
21 (a-c)	mean	nc	0.68	nc	12.0	5.13	6,444	6.11	218	6.84	0.88	6.77
	range	all <0.15	0.54 - 0.81	all <0.15	11.1 - 12.9	4.89 - 5.25	6,197 - 6,576	5.21 - 7.18	178 - 304	5.04 - 11.1	<0.24 - 4.06	6.00 - 7.95
22 (a-c)	mean	nc	0.67	nc	7.37	3.73	3,353	6.56	144	4.01	0.76	4.35
	range	all <0.15	0.55 - 0.87	all <0.15	5.95 - 8.41	3.33 - 4.37	2,518 - 4,160	5.23 - 8.91	120 - 203	3.10 - 5.59	0.46 - 1.02	4.02 - 4.67
23 (a-c)	mean	nc	0.79	nc	12.1	8.37	6,901	7.78	434	10.1	0.70	11.6
	range	all <0.15	0.68 - 0.97	all <0.15	11.3 - 13.3	7.30 - 9.64	6,340 - 8,064	6.94 - 8.43	369 - 474	9.00 - 12.2	0.50 -0.93	8.30 - 20.3

[a] mean = geometric mean; [b] mercury data expressed as ng/g dry wt.; nc = not calculable

Table 7 (cont.): Heavy Metals in Surface Sediments from Pago Bay, Guam

Site	Statistic[a]	Heavy Metals (µg/g dry wt.)										
		Ag	As	Cd	Cr	Cu	Fe	Hg[b]	Mn	Ni	Pb	Zn
24 (a-c)	mean	nc	0.26	nc	4.03	1.34	932	4.33	36.7	1.23	0.62	1.54
	range	all <0.15	0.25 - 0.28	all <0.15	3.29 - 4.61	1.19 - 1.53	893 - 973	3.43 - 5.39	33.1 - 40.1	0.77 - 1.68	0.47 - 1.01	1.34 - 1.77
25 (a-c)	mean	nc	0.29	nc	2.33	0.85	228	3.21	15.2	0.45	0.65	0.95
	range	all <0.15	0.24 - 0.35	all <0.15	2.06 - 2.52	0.72 - 1.15	206 - 256	2.72 - 3.54	14.8 - 15.9	0.45 - 0.46	0.51 - 0.73	0.75 - 1.15
26 (a-c)	mean	nc	0.20	nc	2.22	0.84	388	4.45	13.4	0.79	0.40	0.77
	range	all <0.15	0.12 - 0.39	all <0.15	1.94 - 2.64	0.73 - 0.90	279 - 600	3.45 - 7.08	12.2 - 14.7	0.60 - 1.08	0.25 - 0.51	0.60 - 1.05
27(a-c)	mean	nc	0.16	nc	2.13	0.72	231	2.98	12.0	nc	nc	0.77
	range	all <0.15	0.09 - 0.44	all <0.15	2.07 - 2.22	0.59 - 0.86	200 - 261	2.63 - 3.60	11.6 - 12.4	<0.16 - 0.32	all <0.25	0.71 - 0.88
28 (a-c)	mean	nc	0.25	nc	1.96	0.68	275	3.88	11.4	0.59	0.50	0.93
	range	all <0.15	0.22 - 0.27	all <0.15	1.76 - 2.21	0.57 - 0.75	238 - 298	3.52 - 4.45	10.9 - 11.8	0.31 - 0.82	0.48 - 0.51	0.85 - 1.05
29 (a-c)	mean	nc	0.38	nc	1.97	1.16	315	3.28	10.9	nc	0.70	1.34
	range	all <0.15	0.23 - 0.51	all <0.15	1.86 - 2.09	0.72 - 2.64	278 - 337	2.70 - 3.62	10.3 - 11.4	<0.15 - 0.31	0.50 - 0.94	1.15 - 1.79
30 (a-c)	mean	nc	0.27	nc	2.68	1.32	579	8.52	30.2	0.82	3.19	6.89
	range	all <0.15	0.23 - 0.36	all <0.15	2.48 - 2.92	1.23 - 1.47	379 - 1,125	7.78 - 8.97	29.4 - 30.9	0.75 - 0.92	1.90 - 5.23	4.35 - 12.2
31 (a-c)	mean	nc	0.26	nc	3.36	1.78	1,055	11.9	31.7	1.30	2.48	12.4
	range	all <0.15	0.25 - 0.27	all <0.15	2.84 - 3.93	1.59 - 2.21	993 - 1,148	10.1 - 15.7	31.1 - 32.3	1.10 - 1.80	2.20 - 2.96	7.57 - 16.6
33 (a-c)	mean	nc	0.36	nc	4.03	0.69	277	3.22	13.7	1.68	nc	0.96
	range	all <0.15	0.18 - 0.55	all <0.15	3.61 - 4.32	0.61 - 0.85	243 - 310	1.66 - 6.14	12.4 - 15.5	1.46 - 1.83	<0.25 - 0.99	0.85 - 1.13
34 (a-c)	mean	nc	0.25	nc	3.76	0.60	203	1.74	18.7	1.65	0.47	0.76
	range	all <0.15	0.10 - 0.56	all <0.15	3.63 - 4.00	0.56 - 0.64	148 - 311	1.65 - 1.79	13.3 - 22.8	1.57 - 1.73	<0.26 - 0.74	0.62 - 1.14

[a] mean = geometric mean; [b] mercury data expressed as ng/g dry wt.; nc = not calculable; no sediment available at site 32

Table 7 (cont.): Heavy Metals in Surface Sediments from Pago Bay, Guam

Site	Statistic	Heavy Metals (µg/g dry wt.)										
		Ag	As	Cd	Cr	Cu	Fe	Hg[a]	Mn	Ni	Pb	Zn
35 (a-c)	mean	nc	0.26	nc	4.44	0.86	410	1.56	18.1	1.95	nc	0.86
	range	all <0.15	0.24 - 0.30	all <0.15	4.18 - 4.91	0.83 - 0.90	309 -510	0.83 - 2.62	16.5 - 19.2	1.83 - 2.08	all <0.26	0.80 - 0.92
36 (a-c)	mean	nc	0.25	nc	3.80	0.97	464	3.67	21.7	1.92	nc	0.94
	range	all <0.15	0.16 - 0.47	all <0.15	3.60 - 3.96	0.82 - 1.08	360 - 593	3.28 - 4.17	19.6 - 23.1	1.75 - 2.12	<0.26 - 0.53	0.79 - 1.10
37 (a-c)	mean	nc	0.21	nc	5.94	1.58	861	2.39	39.9	2.24	0.36	1.46
	range	all <0.15	0.13-0.31	all <0.15	4.28 - 9.05	1.24 - 2.33	551 - 1,947	1.76 - 2.85	37.8 - 42.5	1.93 - 2.97	0.25 - 0.73	1.06 - 2.58
38 (a-c)	mean	nc	0.35	nc	4.57	1.61	914	1.55	46.1	2.29	nc	1.64
	range	all <0.15	0.25 - 0.44	all <0.15	4.37 - 4.87	1.43 - 1.98	731 - 1,232	0.81 - 2.67	40.0 - 49.6	2.01 -2.54	all <0.26	1.27 - 2.66
39 (a-c)	mean	nc	0.35	nc	3.76	1.06	522	1.67	41.9	2.03	nc	1.32
	range	all <0.15	0.26 - 0.50	all <0.15	3.60 - 3.92	0.96 - 1.20	397 - 671	1.62 - 1.71	40.3 - 43.0	1.98 - 2.11	<0.25 - 0.52	1.09 - 1.72
40 (a-c)	mean	nc	0.39	nc	4.05	1.23	790	1.92	73.3	2.41	nc	1.50
	range	all <0.15	0.34 - 0.43	all <0.15	3.85 - 4.16	1.09 - 1.44	642 - 998	1.63 - 2.55	70.6 - 77.4	2.18 - 2.67	<0.26 - 0.50	1.27 - 1.83
41 (a-c)	mean	nc	0.46	nc	14.5	19.9	24,316	12.4	441	25.4	nc	25.43
	range	all <0.15	0.37-0.58	all <0.15	13.3 - 15.4	19.6 - 20.3	23,465 - 25,014	11.5 - 13.4	418 - 464	24.9 - 26.0	all <0.26	25.0 - 26.2
42 (a-c)	mean	nc	0.61	nc	6.75	7.88	5,637	9.70	243	9.61	nc	9.65
	range	all <0.15	0.50-0.85	all <0.15	5.10 - 10.9	2.99 - 14.2	3,376 - 12,730	6.52 - 14.7	175 - 427	4.63 - 15.0	<0.24 - 0.79	4.02 - 15.8
43 (a-c)	mean	nc	0.40	nc	4.78	2.20	2,237	4.14	183	3.50	nc	3.10
	range	all <0.15	0.37-0.43	all <0.15	4.24 - 5.17	2.14 - 2.31	2,100 - 2,481	3.55 - 5.17	163 - 208	3.15 - 3.75	all <0.26	3.03 - 3.22
44 (a-c)	mean	nc	0.50	nc	4.58	1.41	1162	2.01	107	2.75	0.39	2.61
	range	all <0.15	0.38-0.65	all <0.15	4.43 - 4.70	1.25 - 1.61	912 - 1,947	1.75 - 2.61	103 - 113	2.59 - 2.89	<0.24 - 0.50	2.21 - 3.38

[a] mercury data expressed as ng/g dry wt.; [b] mean = geometric mean; nc = not calculable

Table 8: Heavy Metals in Algae from Pago Bay, Guam

Species	Site	Date	Statisitic[a]	Metals (µg/g dry wt)										
				Ag	As	Cd	Cr	Cu	Fe	Hg[b]	Mn	Ni	Pb	Zn
Acanthopora spicifera	39	28-Jul-05	mean	nc	0.73	0.30	1.07	2.57	689	2.13	18.2	4.33	nc	3.32
			range	all <0.15	0.39 - 1.11	0.3 - 0.3	0.80 - 1.57	2.42 - 2.71	588 - 801	1.72 - 2.37	15.5 - 21.6	3.97 - 5.20	all <0.32	3.14 - 3.61
	41	28-Jul-05	mean	nc	1.31	0.30	1.21	2.69	754	1.72	13.3	3.81	nc	4.70
			range	all <0.15	0.84 - 1.72	0.29 - 0.30	0.98 - 1.40	2.24 - 3.03	609 - 877	1.68 - 1.76	12.7 - 14.6	3.20 - 4.15	<0.3 0 - 0.62	4.33 - 5.00
	42	15-Aug-05	mean	nc	0.21	0.34	1.49	2.87	580	1.52	13.7	3.91	nc	7.35
			range	all <0.15	0.20 - 0.22	0.30 - 0.47	1.03 - 1.88	2.77 - 3.15	516 - 679	1.17 - 1.74	12.6 - 14.3	3.82 - 4.03	<0.34 - 0.70	6.96 - 8.04
	46	5-Jul-05	mean	nc	0.61	nc	nc	1.55	314	1.29	7.01	3.35	nc	3.49
			range	all <0.15	0.48 - 0.92	all <0.18	all <0.27	1.49 - 1.58	275 - 351	1.09 - 1.72	6.86 - 7.17	3.05 - 3.54	all <0.41	3.36 - 3.83
	47	5-Jul-05	mean	nc	0.45	nc	nc	1.26	208	2.00	6.75	3.27	0.89	3.85
			range	all <0.15	0.21 - 1.09	all <0.27	all <0.39	1.22 - 1.31	192 - 227	1.67 - 2.83	6.38 - 7.04	3.24 - 3.35	<0.42 - 1.36	3.88 - 4.08
Gracilaria salicornia	42	5-Jul-05	mean	nc	1.53	nc	0.76	0.61	104	2.55	15.0	0.29	nc	3.18
			range	all <0.16	1.44 - 1.67	all <0.16	0.58 - 1.15	0.47 - 0.72	83.4 - 145	2.35 - 2.99	13.8 - 17.5	<0.16 - 0.64	all <0.35	2.92 - 3.60
	48	15-Aug-05	mean	nc	1.57	nc	0.41	1.06	38.5	2.40	7.89	0.52	nc	8.40
			range	all < 0. 26	1.43 - 1.67	all < 0. 26	<0.25 - 0.75	0.98 - 1.17	35.2 - 40.1	1.74 - 3.48	7.60 - 8.37	<0.22 - 1.07	all <0.58	8.12 - 8.71
Caulerpa rasemosa	10	15-Aug-05	mean	nc	1.19	nc	0.44	0.98	436	1.18	10.3	1.40	nc	2.16
			range	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
Caulerpa serrulata	44	5-Jul-05	mean	nc	1.82	nc	nc	0.83	470	3.14	12.1	1.92	nc	1.98
			range	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
Caulerpa sertalarioides	48	5-Jul-05	mean	nc	2.82	nc	0.50	1.41	65.5	3.94	14.5	1.58	nc	4.37
			range	all <0.21	2.19 - 3.48	all <0.21	<0.3 - 1.09	1.31 - 1.49	62.0 - 69.5	3.50 - 4.19	13.6 - 15.4	1.51 - 1.65	all <0.46	4.13 - 4.52
Chlorodesmis fastigiata	21	19-Aug-05	mean	nc	9.55	nc	2.14	2.34	696	6.63	23.9	1.06	nc	4.61
			range	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 - 1.17	all <0.34	4.51 - 4.72

[a] mean as geometric mean; [b] mercury concentrations as ng/g wet weight; nc = not calculable

Table 8 (cont.): Heavy Metals in Algae from Pago Bay, Guam

Species	Site	Date	Statisitic[a]	Metals (µg/g dry wt)										
				Ag	As	Cd	Cr	Cu	Fe	Hg[b]	Mn	Ni	Pb	Zn
Padina boryana	27	19-Aug-05	mean	nc	3.11	nc	1.45	3.00	1310	2.52	102	3.20	nc	3.12
			range	all <0.15	2.86 - 3.33	all <0.15	1.25 - 1.47	2.88 - 3.09	1208 - 1516	2.27 - 2.97	91.4 - 108	2.97 - 3.36	<0.31 - 0.63	3.07 - 3.20
	28	19-Aug-05	mean	nc	2.29	nc	2.03	4.26	1585	1.75	91.3	2.99	1.79	4.48
			range	all <0.15	1.96 - 2.78	all <0.15	1.86 - 2.14	4.13 - 4.65	1451 - 1828	1.70 - 1.78	88.4 - 94.9	2.70 - 3.30	1.58 - 1.88	4.37 - 4.65
	42	15-Aug-05	mean	nc	3.36	0.29	1.29	1.10	530	1.91	48.6	1.80	nc	3.84
			range	all <0.16	2.95 - 3.60	0.23 - 0.32	0.94 - 1.68	0.87 - 1.26	440 - 590	1.74 - 2.29	42.1 - 52.4	1.56 - 2.15	0.27 - 0.66	3.65 - 4.16
	44	5-Jul-05	mean	nc	2.49	nc	nc	0.91	458	1.75	24.4	2.19	nc	2.28
			range	all <0.16	2.34 - 2.69	all <0.16	all <0.23	0.82 - 1.06	403 - 501	1.72 - 1.81	22.2 - 27.0	2.03 - 2.39	all <0.35	2.03 - 2.50
	45	5-Jul-05	mean	nc	3.16	nc	nc	1.01	437	1.82	23.2	2.05	nc	7.49
			range	all <0.16	2.52 - 3.71	all <0.16	all <0.23	0.96 - 1.07	408 - 458	1.12 - 2.34	21.5 - 25.9	1.98 - 2.14	all <0.35	6.14 - 8.27
	47	5-Jul-05	mean	nc	10.6	nc	nc	0.88	304	1.02	22.1	1.69	7.58	3.11
			range	all <0.18	10.3 - 11.0	all <0.18	all <0.26	0.74 - 0.94	262 - 358	0.59 - 1.62	19.0 - 24.0	1.59 - 1.85	4.24 - 13.9	2.75 - 3.36
Turbinaria ornata	26	19-Aug-05	mean	nc	8.80	nc	0.44	1.03	333	2.34	6.97	1.31	nc	1.73
			range	all <0.16	8.58 - 9.22	all <0.16	<0.16 - 0.83	0.90 - 1.25	209 - 573	2.32 - 2.36	5.76 - 8.14	1.11 - 1.69	all <0.32	1.51 - 2.14
	40	28-Jul-05	mean	nc	34.1	0.23	nc	0.88	348	4.82	9.37	1.47	nc	2.20
			range	all <0.16	32.0 - 36.9	<0.15 - 0.30	all <0.21	0.73 - 1.19	247 - 485	4.62 - 5.20	7.62 - 11.3	1.27 - 1.77	all <0.33	1.68 - 2.83
	41	28-Jul-05	mean	nc	21.0	nc	1.14	1.51	921	2.11	15.26	2.59	nc	3.81
			range	all <0.15	18.5 - 23.2	<0.15 - 0.29	0.96 - 1.38	3.58 - 4.37	731 - 1207	1.75 - 2.35	12.9 - 18.2	2.22 - 3.22	<0.31 - 0.61	3.58 - 4.37
	43	15-Aug-05	mean	nc	28.4	nc	0.43	0.66	260	4.11	6.54	1.24	nc	1.89
			range	all <0.16	27.4 - 30.4	<0.14 - 0.30	0.38 - 0.63	0.60 - 0.79	178 - 419	4.07 - 4.16	5.43 - 8.36	0.84 - 1.58	all <0.36	1.73 - 2.06
	44	5-Jul-05	mean	nc	18.3	nc	nc	0.35	144	3.45	4.16	0.66	nc	1.77
			range	all <0.24	15.7 - 21.1	all <0.24	all <0.35	0.30 - 0.43	123 - 177	3.40 - 3.50	3.96 - 4.35	0.58 - 0.74	all <0.53	1.62 - 1.91
	45	5-Jul-05	mean	nc	21.0	nc	nc	0.38	114	3.82	3.92	0.80	nc	2.51
			range	all <0.16	18.5 - 22.8	all <0.16	all <0.24	0.34 - 0.43	106 - 134	3.35 - 4.13	3.74 - 4.23	0.75 - 0.90	all <0.36	2.44 - 2.55
	47	5-Jul-05	mean	nc	22.2	nc	nc	0.46	55.3	2.86	2.96	0.61	nc	2.01
			range	all <0.26	21.4 - 23.0	all <0.26	all <0.37	0.41 - 0.53	48.7 - 69.2	2.77 - 2.94	2.88 - 3.09	0.49 - 0.75	<0.45 - 1.62	1.80 - 2.21

[a] mean as geometric mean; [b] mercury concentrations as ng/g wet weight; nc = not calculable

Table 8 (cont.): Heavy Metals in Algae from Pago Bay, Guam

Species	Site	Date	Statisitic[a]	Metals (µg/g dry wt)										
				Ag	As	Cd	Cr	Cu	Fe	Hg[b]	Mn	Ni	Pb	Zn
Sargassum cristafolium	1	16-Sep-05	mean	nc	39.3	0.21	nc	1.23	80.0	2.33	13.1	3.33	nc	2.41
			range	all <0.10	36.0 - 45.6	0.20 - 0.29	<0.14 - 0.44	0.98 - 1.49	69.7 - 105	2.29 - 2.39	5.6 - 19.0	2.22 - 4.15	all <0.19	2.06 - 2.58
	2	5-Jul-05	mean	nc	38.3	nc	nc	1.10	20.3	2.85	4.44	1.04	2.31	4.63
			range	all <0.19	36.1 - 40.5	all <0.19	all <0.28	0.94 - 1.25	17.3 - 21.7	2.32 - 3.46	4.36 - 4.67	0.68 - 1.19	1.80 - 2.99	4.28 - 4.83
	3	5-Jul-05	mean	nc	13.5	nc	nc	0.78	68.7	2.54	5.11	1.24	2.28	3.02
			range	all <0.17	12.0 - 15.8	all <0.17	all <0.25	0.73 - 0.84	59.3 - 76.8	2.31 - 2.99	4.86 - 5.43	0.99 - 1.39	1.69 - 2.99	2.85 - 3.21
	4	5-Jul-05	mean	nc	32.2	nc	nc	0.64	31.4	2.10	5.12	1.45	0.67	2.55
			range	all <0.16	30.1 - 35.0	all <0.16	all <0.22	0.59 - 0.69	21.3 - 58.5	1.72 - 2.40	4.89 - 5.32	1.13 - 2.01	0.65 - 0.69	2.27 - 2.81
	5	5-Jul-05	mean	nc	36.7	nc	nc	0.92	63.2	2.71	4.68	2.44	0.59	2.25
			range	all <0.16	32.3 - 39.9	all <0.16	all <0.23	0.77 - 1.09	48.2 - 79.9	2.41 - 2.99	3.71 - 5.69	2.01 - 2.88	<0.35 - 0.71	1.82 - 3.76
	6	5-Jul-05	mean	nc	57.1	nc	nc	0.71	40.7	3.78	2.84	2.47	2.72	1.37
			range	all <0.16	53.5 - 61.9	all <0.15	all <0.23	0.59 - 0.82	35.8 - 45.8	3.40 - 4.06	2.61 - 3.07	2.33 - 2.75	1.96 - 5.22	1.17 - 1.62
	7	5-Jul-05	mean	nc	41.9	nc	nc	0.74	50.8	3.44	3.36	2.94	0.52	1.07
			range	all <0.16	40.8 - 44.2	all <0.16	<0.21 - 0.44	0.58 - 0.86	30.4 - 65.3	3.42 - 3.46	3.09 - 3.63	2.81 - 3.14	<0.33 - 0.73	0.76 - 1.88
	8	5-Jul-05	mean	nc	61.9	nc	nc	0.58	41.2	2.81	3.12	2.75	nc	1.06
			range	all <0.16	50.9 - 70.5	all <0.16	all <0.23	0.53 - 0.77	22.3 - 64.0	2.32 - 3.35	2.76 - 3.77	2.15 - 3.40	all <0.36	0.76 - 1.35
	9	5-Jul-05	mean	nc	83.8	nc	nc	0.83	88.1	2.86	8.06	4.55	nc	1.01
			range	all <0.16	70.9 - 97.3	all <0.16	<0.21 - 0.42	0.78 - 0.88	66.7 - 142	2.39-3.40	3.29 - 16.9	3.36-6.29	<0.32 - 0.69	0.86 - 1.33
	10	15-Aug-05	mean	nc	23.6	nc	nc	0.73	103	2.14	7.27	1.66	nc	2.04
			range	all <0.16	21.9 - 24.9	<0.15 - 0.31	all <0.21	0.61 - 0.78	85.2 - 110	1.79 - 2.35	6.27 - 7.90	1.33 - 2.19	all <0.35	1.83 - 2.24
	11	19-Jul-05	mean	nc	21.0	0.23	nc	0.95	109	1.75	7.53	3.07	nc	3.38
			range	all <0.15	19.4 - 22.2	<0.15 - 0.30	all <0.20	0.76 - 1.06	79.5 - 147	1.73 - 1.78	6.72 - 8.74	2.18 - 3.77	<0.30 - 0.63	2.84 - 3.88

[a] mean as geometric mean; [b] mercury concentrations as ng/g wet weight; nc = not calculable

Table 8 (cont.): Heavy Metals in Algae from Pago Bay, Guam

Species	Site	Date	Statisitic[a]	Metals (µg/g dry wt)										
				Ag	As	Cd	Cr	Cu	Fe	Hg[b]	Mn	Ni	Pb	Zn
Sargassum cristafolium	12	19-Jul-05	mean	nc	23.0	0.30	nc	1.01	131	1.90	11.1	4.25	nc	2.56
			range	all <0.15	22.1 - 23.9	0.29 - 0.30	<0.19 - 0.39	0.91 - 1.05	122 - 147	1.73 - 2.27	10.0 - 13.7	3.94 - 4.80	all <0.32	2.19 - 2.59
	13	19-Jul-05	mean	nc	16.9	0.30	nc	0.97	140	1.91	9.21	4.03	nc	2.44
			range	all <0.16	13.5 - 20.1	0.29 - 0.31	<0.20 - 0.38	0.89 - 1.05	121 - 156	1.75 - 2.23	7.36 - 11.3	3.78 - 4.42	<0.30 - 0.63	2.20 - 2.66
	14	19-Jul-05	mean	nc	30.6	nc	nc	0.62	59.1	1.50	9.55	4.20	0.73	2.10
			range	all <0.16	30.2 - 30.9	all <0.16	all <0.21	0.59 - 0.74	44.1 - 73.3	1.17 - 1.72	8.44 - 10.8	3.84 - 4.67	0.61 - 0.98	1.74 - 2.95
	15	19-Jul-05	mean	nc	24.0	nc	nc	0.51	56.2	1.52	6.02	2.32	nc	1.58
			range	all <0.16	22.4 - 27.1	all <0.16	all <0.21	0.46 - 0.60	44.2 - 70.5	1.17 - 1.75	5.56 - 6.63	2.20 - 2.47	<0.31 - 0.62	1.49 - 1.70
	16	19-Jul-05	mean	nc	16.0	0.30	nc	0.80	154	1.48	8.02	2.60	nc	2.11
			range	all <0.16	15.1 - 17.0	0.29 - 0.31	all <0.20	0.74 - 1.07	97.7 - 250	1.12 - 1.71	7.48 - 8.12	2.18 - 3.15	<0.32 - 0.65	1.68 - 2.60
	17	19-Jul-05	mean	nc	26.5	nc	nc	1.00	267	2.61	20.7	6.37	0.37	1.84
			range	all <0.16	20.9 - 30.5	all <0.16	<0.20 - 0.41	0.79 - 1.22	184 - 307	2.21 - 2.86	16.9 - 27.8	5.07 - 8.00	<0.30 - 0.64	1.68 - 2.00
	18	19-Jul-05	mean	nc	48.1	nc	nc	1.38	418	2.43	8.32	3.47	nc	2.58
			range	all <0.15	42.2 - 51.5	all <0.15	<0.19 - 0.40	1.22 - 1.53	373 - 490	2.22 - 2.82	6.98 - 9.36	3.24 - 3.84	all <0.32	2.32 - 2.76
	19	19-Aug-05	mean	nc	19.1	nc	0.85	1.39	534	1.55	17.2	2.48	nc	3.93
			range	all <0.15	16.6 - 22.0	all <0.15	0.60 - 1.20	1.20 - 1.63	470 - 653	1.20 - 1.77	15.0 - 18.7	2.15 - 2.67	all <0.34	3.76 - 4.29
	20	19-Aug-05	mean	nc	57.8	nc	0.48	1.07	204	2.12	18.5	2.69	nc	3.14
			range	all <0.16	50.6 - 72.7	all <0.16	<0.20 - 0.83	0.91 - 1.25	154 - 281	1.76 - 2.34	12.8 - 28.3	2.37 - 2.79	all <0.36	2.83 - 3.60
	21	19-Aug-05	mean	nc	112	0.26	nc	0.90	85.9	2.16	29.5	3.89	nc	2.56
			range	all <0.16	108 - 117	<0.16 - 0.31	<0.20 - 0.39	0.78 - 1.09	71.8 - 97.8	1.80 - 2.39	24.0 - 36.7	3.66 - 4.49	all <0.36	2.19 - 2.93
	22	19-Aug-05	mean	nc	44.6	nc	0.43	1.07	242	2.56	33.9	4.68	nc	2.30
			range	all <0.15	37.8 - 49.9	all <0.15	<0.21 - 0.79	0.92 - 1.33	136 - 508	2.38 - 2.93	27.7 - 40.7	4.38 - 5.13	all <0.35	2.16 - 2.52

[a] mean as geometric mean; [b] mercury concentrations as ng/g wet weight; nc = not calculable

Table 8 (cont.): Heavy Metals in Algae from Pago Bay, Guam

Species	Site	Date	Statisitic[a]	Metals (µg/g dry wt)										
				Ag	As	Cd	Cr	Cu	Fe	Hg[b]	Mn	Ni	Pb	Zn
Sargassum polycystum	23	19-Aug-05	mean	nc	13.4	nc	1.06	1.69	854	1.91	89.7	3.16	nc	2.69
			range	all <0.15	12.9 - 13.8	all <0.15	0.93 - 1.29	1.60 - 1.82	787 - 1067	1.72 - 2.36	81.2 - 96.5	3.04 - 3.48	<0.30 - 0.63	2.56 - 2.88
	24	19-Aug-05	mean	nc	21.4	nc	1.82	2.38	1300	2.37	91.3	3.88	nc	3.54
			range	all <0.16	20.4 - 22.4	<0.15 - 0.29	1.40 - 2.20	2.35 - 2.44	1196 - 1497	2.35 - 2.39	84.0 - 101	3.77 - 4.07	<0.30 - 1.51	3.36 - 3.85
	25	19-Aug-05	mean	nc	20.0	nc	2.00	2.67	1594	2.26	89.7	3.88	nc	4.26
			range	all <0.16	19.1 - 21.4	all <0.15	1.60 - 2.31	2.55 - 2.79	1341 - 1765	1.75 - 2.91	81.1 - 101	3.59 - 4.13	<0.31 - 1.48	4.06 - 4.36
	37	12-Aug-05	mean	nc	15.8	nc	0.74	1.01	285	2.11	33.9	1.62	nc	3.78
			range	all <0.15	15.4 - 16.5	all <0.15	0.60 n- 0.96	0.92 - 1.05	236 - 347	1.73 - 2.33	29.4 - 42.0	1.48 - 1.77	all <0.35	3.32 - 4.16
	39	28-Jul-05	mean	nc	19.4	nc	1.09	1.73	1000	2.65	60.2	3.84	nc	3.35
			range	all <0.16	18.7 - 19.8	all <0.16	0.82 - 1.63	1.55 - 2.10	816 - 1277	2.32 - 2.87	53.1 - 68.7	3.50 - 4.28	all <0.33	3.09 - 3.60
	40	28-Jul-05	mean	nc	12.3	nc	2.07	2.40	1461	3.16	55.6	4.26	nc	5.08
			range	all <0.16	10.7 - 13.8	all <0.16	1.81 - 2.66	2.20 - 2.65	1330 - 1576	2.87 - 3.61	52.6 - 59.6	4.01 - 5.01	<0.31 - 0.64	4.54 - 7.01
	41	15-Aug-05	mean	nc	16.3	nc	2.18	2.50	1456	2.37	56.3	4.26	nc	4.07
			range	all <0.16	14.2 - 18.0	all <0.15	1.96 - 2.50	2.24 - 2.63	1254 - 1681	2.34 - 2.42	53.5 - 61.3	3.91 - 4.52	all <0.31	3.73 - 4.32
	42	15-Aug-05	mean	nc	11.2	nc	1.00	1.06	442	1.77	40.7	1.81	nc	3.20
			range	all <0.15	9.61 - 12.2	all <0.16	0.79 - 1.26	1.03 - 1.10	405 - 499	1.73 - 1.82	37.1 - 42.9	1.80 - 1.90	all <0.36	3.11 - 3.40

[a] mean as geometric mean; [b] mercury concentrations as ng/g wet weight; nc = not calculable

Table 9: Heavy Metals in the Seagrass, *Enhalus acoroides,* from Pago Bay, Guam

Site	Date	Statisitic[a]	Metal (µg/g dry wt.)										
			Ag	As	Cd	Cr	Cu	Fe	Hg[b]	Mn	Ni	Pb	Zn
29	29-Aug-05	mean	nc	0.25	nc	nc	2.92	115	1.83	12.4	1.85	nc	12.9
		range	all <0.15	0.20 - 0.28	all <0.15	<0.16 - 0.16	2.75 - 3.22	97.4 - 147	1.82 - 1.85	10.7 - 14.1	1.26 - 2.39	all <0.31	11.3 - 15.32
30	29-Aug-05	mean	nc	0.14	nc	0.35	4.76	139	1.80	15.3	1.96	nc	15.5
		range	all <0.16	0.10 - 0.17	all <0.15	<0.16 - 0.64	4.39 - 5.19	113 - 165	1.79 - 1.82	14.0 - 17.5	1.50 - 2.28	all <0.32	13.4 - 16.6
31	29-Aug-05	mean	nc	0.12	nc	0.41	5.18	224	3.19	32.3	3.36	nc	9.56
		range	all <0.16	0.10 - 0.20	all <0.16	0.32 - 0.49	4.83 - 5.73	189 - 273	3.00 - 3.56	30.1 - 36.4	2.61 - 4.26	all <0.32	8.52 - 10.2
32	30-Aug-05	mean	nc	0.16	nc	0.28	2.40	108	2.00	13.0	2.13	nc	11.1
		range	all <0.15	0.10 - 0.20	all <0.15	<0.15 - 0.48	2.32 - 2.58	81.5 - 130	1.78 - 2.43	11.4 - 14.3	1.39 - 2.93	all <0.31	9.42 - 12.8
33	12-Aug-05	mean	nc	0.23	nc	nc	1.84	138	1.78	11.7	1.87	0.74	8.78
		range	all <0.16	0.22 - 0.24	all <0.16	all <0.21	1.66 - 1.95	128 - 162	1.75 - 1.84	11.2 - 12.0	1.67 - 2.15	0.68 - 1.02	8.62 - 8.94
34	12-Aug-05	mean	nc	0.32	nc	0.27	1.45	89.3	1.54	8.35	1.91	nc	8.16
		range	all <0.16	0.21 - 0.42	all <0.16	<0.20 - 0.42	1.32 - 1.56	69.2 - 120	1.20 - 1.81	8.06 - 8.72	1.79 - 2.19	all <0.35	7.43 - 9.03
35	12-Aug-05	mean	nc	0.20	nc	nc	1.65	78.3	1.33	8.30	1.90	nc	7.88
		range	all <0.16	0.20 - 0.21	all <0.16	all <0.21	1.38 - 1.79	68.0 - 102	1.14 - 1.81	7.78 - 8.89	1.66 - 2.21	<0.34 - 0.70	7.17 - 9.03
36	12-Aug-05	mean	nc	0.26	nc	nc	1.45	69.4	1.51	8.20	1.95	nc	8.76
		range	all <0.16	0.20 - 0.41	all <0.16	all <0.21	1.41 - 1.57	61.7 - 83.1	1.16 - 1.72	7.99 - 8.50	1.57 - 2.73	<0.34 - 0.71	6.81 - 10.0
37	12-Aug-05	mean	nc	0.50	nc	nc	1.40	81.7	1.69	8.69	2.76	0.81	7.41
		range	all <0.16	0.21 - 0.90	all <0.16	<0.20 - 0.63	1.33 - 1.57	75.6 - 90.0	1.21 - 2.31	8.10 - 9.10	2.44 - 2.95	0.67 - 1.07	6.78 - 7.84
38	28-Jul-05	mean	nc	0.78	nc	nc	0.85	111	1.36	10.9	2.87	nc	5.25
		range	all <0.16	0.51 - 1.04	all <0.16	all <0.21	0.74 - 0.92	87.7 - 167	1.14 - 1.79	10.4 - 11.5	2.69 - 3.30	all <0.32	4.96 - 5.50
41	28-Jul-05	mean	nc	0.75	nc	nc	1.21	88.1	1.52	7.15	2.18	0.53	6.40
		range	all <0.16	0.59 - 1.22	all <0.16	all <0.21	0.98 - 1.40	59.1 - 109	1.13 - 1.77	4.61 - 8.10	1.37 - 2.77	<0.30 - 0.95	5.91 - 7.02

[a] mean as geometric mean; [b] mercury concentrations as ng/g wet weight; nc = not calculable

Table 10: Heavy Metals in the Seacumber, *Holothuria atra*, from Pago Bay, Guam

Site	Date	Tissue[a]	Statistic[b]	Metals (µg/g dry wt.)										
				Ag	As	Cd	Cr	Cu	Fe	Hg[c]	Mn	Ni	Pb	Zn
4	17-Aug-05	M	mean	<0.09	3.06	<0.09	0.30	1.23	19.7	2.01	0.28	<0.09	<0.19	14.3
			range	-	3.02 - 3.13	-	-	-	-	1.75 - 2.48	-	-	-	-
4	17-Aug-05	H	mean	<0.63	10.5	<0.63	0.67	5.69	80.9	17.9	1.90	1.16	<1.29	56.9
			range	-	9.54 - 11.2	-	-	-	-	16.1 - 20.0	-	-	-	-
6	17-Aug-05	M	mean	<0.10	3.82	<0.10	0.21	1.01	22.8	1.90	0.40	0.19	<0.21	13.5
			range	-	3.76 - 3.90	-	-	-	-	1.73 - 2.25	-	-	-	-
6	17-Aug-05	H	mean	<0.54	6.39	0.54	1.14	3.76	65.0	15.0	1.07	<0.49	<1.10	66.6
			range	-	6.00 - 7.08	-	-	-	-	14.5 - 15.5	-	-	-	-
12	17-Aug-05	M	mean	<0.09	2.84	<0.09	0.18	1.08	26.8	1.93	0.43	0.16	<0.18	13.1
			range	-	2.54 - 3.10	-	-	-	-	1.77 - 2.28	-	-	-	-
12	17-Aug-05	H	mean	<0.19	4.78	<0.19	1.80	6.14	54.4	12.8	2.82	0.34	<0.38	67.5
			range	-	4.48 - 5.26	-	-	-	-	11.1 - 14.4	-	-	-	-
13	17-Aug-05	M	mean	<0.09	5.35	<0.09	<0.10	1.62	30.8	2.30	0.82	0.17	<0.18	16.2
			range	-	4.80 - 5.83	-	-	-	-	1.78 - 2.82	-	-	-	-
13	17-Aug-05	H	mean	<0.53	1.42	<0.53	13.6	6.27	292	3.55	3.19	0.97	<1.08	301
			range	-	1.29 - 1.56	-	-	-	-	3.16 - 4.00	-	-	-	-
16	17-Aug-05	M	mean	<0.10	2.98	<0.10	0.32	1.04	19.1	1.54	0.40	0.27	<0.20	12.8
			range	-	2.67 - 3.35	-	-	-	-	1.13 - 1.85	-	-	-	-
16	17-Aug-05	H	mean	<0.20	4.09	<0.20	3.85	6.27	84.4	17.4	1.00	0.37	<0.41	74.5
			range	-	3.78 - 4.39	-	-	-	-	9.35 - 45.31	-	-	-	-
17	18-Aug-05	M	mean	<0.09	2.49	<0.09	<0.09	0.89	39.5	1.77	0.61	0.24	<0.18	13.3
			range	-	2.41 - 2.64	-	-	-	-	1.65 - 1.87	-	-	-	-
17	18-Aug-05	H	mean	<0.27	-	<0.27	4.24	3.82	144	-	1.59	0.49	<0.54	125
			range		-	-	-	-	-	-	-	-	-	-
19	18-Aug-05	M	mean	<0.14	1.96	<0.14	<0.14	1.40	17.5	1.78	0.54	<0.12	<0.28	17.8
			range	-	1.77 - 2.13	-	-	-	-	1.74 - 1.84	-	-	-	-
19	18-Aug-05	H	mean	<0.77	4.27	<0.77	4.08	5.05	81.3	11.2	3.07	<0.70	<1.57	157
			range	-	4.24 - 4.30	-	-	-	-	9.32 - 13.3	-	-	-	-
20	18-Aug-05	M	mean	<0.13	4.37	<0.13	0.29	1.30	20.5	2.62	0.54	0.37	<0.28	15.5
			range	-	3.98 - 4.95	-	-	-	-	2.37 - 3.07	-	-	-	-
20	18-Aug-05	H	mean	<0.63	6.72	<0.63	2.00	3.75	63.9	45.1	1.88	<0.58	<1.28	80.7
			range	-	6.61 - 6.91	-	-	-	-	35.8 - 52.3	-	-	-	-
22	18-Aug-05	M	mean	<0.13	4.88	<0.13	0.28	1.54	21.9	2.65	0.78	<0.12	<0.26	16.7
			range	-	4.32 - 5.61	-	-	-	-	1.71 - 4.48	-	-	-	-
22	18-Aug-05	H	mean	<0.78	4.85	<0.78	5.00	6.37	91.7	31.7	3.92	<0.72	<1.60	154
			range		4.69 - 5.02	-	-	-	-	24.2 - 41. 4	-	-	-	-

[a] Tissues: M = body wall muscle (one replicate per site), H = hemal system (3-5 replicates per site); [b] mean as geometric mean; [c] mercury concentrations as ng/g wet weight; dashes indicate no data

Table 11: Heavy Metals in Bivalves from Pago Bay, Guam

Species	Site	Date	Statisitic[a]	Metals (µg/g dry wt)										
				Ag	As	Cd	Cr	Cu	Fe	Hg[b]	Mn	Ni	Pb	Zn
Asaphia violascens	48	23-Jun-05	mean	0.11	-	0.11	0.16	7.61	971	-	15.2	5.87	0.81	72.9
			range	-	-	-	-	-	-	-	-	-	-	-
Ctena bella	31	29-Aug-05	mean	0.09	-	0.66	0.14	20.9	74.0	-	3.03	7.83	0.54	205
			range	-	-	-	-	-	-	-	-	-	-	-
	34	13-Aug-05	mean	nc	4.68	1.86	nc	6.24	68.5	11.6	2.18	14.6	0.55	191
			range	all <0.13	4.61 - 4.74	1.29 - 1.86	all <0.20	5.84 - 6.67	63.2 - 74.3	11.5 - 11.8	2.00 - 2.39	10.1 - 21.2	<0.20 - 1.00	126 - 289
	36	30-Aug-05	mean	nc	4.59	1.60	nc	7.7	62.9	5.63	1.88	14.6	0.72	167
			range	all <0.18	-	1.02 - 2.51	all <0.27	7.54 - 7.96	55.1 - 71.8	-	1.63 - 2.15	10.7 - 19.8	0.39 - 1.35	112 - 248
	37	23-Jun-05	mean	0.12	6.89	0.72	0.18	5.79	65.1	17.4	2.53	9.75	0.45	164
			range	-	-	-	-	-	-	-	-	-	-	-
Gafrarium pectinatum	34	13-Aug-05	mean	0.14	-	1.14	0.21	17.0	386	-	22.9	16.4	0.27	59.6
			range	-	-	-	-	-	-	-	-	-	-	-
Quidnipagus palatum	29	29-Aug-05	mean	0.10	20.5	nc	0.25	30.1	791	32.7	4.46	12.4	0.62	188
			range	0.09	15.3 - 27.2	all <0.10	<0.13 - 0.46	24.6 - 36.9	726 - 862	25.84 - 38.3	3.49 - 5.72	12.1 - 12.6	0.50 - 0.77	157 - 226
	31	29-Aug-05	mean	0.13	19.7	nc	0.19	66.8	1253	58.4	20.8	24.1	0.65	279
			range	<0.13 - 0.13	19.6 - 19.8	all <0.30	<0.19 - 0.20	65.1 - 68.5	1214 - 1292	54.6 - 62.4	18.6 - 23.1	23.5 - 24.7	0.47 - 0.89	268 - 290
	36	30-Aug-05	mean	0.10	-	0.10	0.16	6.03	601	-	5.10	10.4	<0.20	93.6
			range	-	-	-	-	-	-	-	-	-	-	-
	48	23-Jun-05	mean	nc	11.3	nc	nc	4.52	724	26.2	3.95	15.7	0.29	323
			range	all <0.08	9.71 - 14.0	all <0.08	all <0.20	4.26 - 4.80	677 - 775	21.9 - 25.0	2.92 - 5.34	15.4 - 16.0	0.29 - 0.30	306 - 341
Scutarcopajia scobinata	36	30-Aug-05	mean	0.34	-	0.34	1.01	6.07	2178	-	6.07	9.09	0.64	50.6
			range	-	-	-	-	-	-	-	-	-	-	-

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

CONCLUSIONS AND RECOMMENDATIONS

The Ordot Dump has been in continuous use for over 60 years. During much of that time, metal enriched leachate emanating from the facility has flowed unabated into the nearby Lonfit River. Over the years, local residents have voiced some considerable concern over the potential impact of these contaminants on the fisheries resources of the river, the river estuary and the bay into which they are finally discharged. Such concerns have been fuelled by speculative supposition from various sections of the community in the complete absence, or near absence, of defensible data. The study presented in this document is therefore of special significance and is the first of its kind to address such concerns.

Several attempts have been made to quantify aqueous contaminant levels in the Lonfit River, both upstream and downstream of the dump. Unfortunately, much of the early metal data are erroneously high as a result of contamination associated with poor sampling and/or inappropriate analytical techniques. As a consequence much of data collected prior to the early 90s is of limited value or of no value at all, at least for certain critical elements like cadmium, lead, mercury and silver (see USEPA 2002 for complete compilation of available metal data up to September 1998).

Despite these shortcomings, there is now unequivocal evidence of metal enrichment in leachate discharged from the dump, as well as in the bed sediments of leachate streams that empty into the Lonfit River (USEPA 2002, Denton *et al.* 2005, Olsen and Denton in prep.). Once again, however, the recent data do not support some of the earlier figures that indicated elevated levels of cadmium, mercury and silver occurred in the mix. Metals present in emergent leachate at levels that have clearly exceeded the appropriate USEPA toxicity reference values (TRVs)[1], on at least one occasion, include copper, chromium, iron, lead, manganese, nickel and zinc (USEPA 2002, Denton *et al.* 2005).

These potentially toxic metals ultimately make their way down gradient into the receiving waters of the Lonfit River but are never discharged in sufficient quantities to significantly elevate aqueous levels above baseline immediately downstream (Denton *et al.* 2005). This is because discharge rates from the dump are entirely rainfall dependant, as are stream flow conditions in the Lonfit River. As a result, stream flow is always sufficient for the degree of dilution necessary to keep contaminant levels in the water column close to baseline (Denton and Wood unpublished data, cited in Denton *et al.* 2005). Similarly, sediments in the Lonfit River seem only marginally impacted by heavy metals, and only in areas around confluence points with leachate streams (Olsen and Denton in prep.). Again, this is related to stream flow conditions although the natural process involved is also dependent upon local topography.

The Lonfit River, like most steep-banked streams that drain the volcanic uplands of Guam, is periodically subjected to flash flooding during the wet season. At such times, pockets of contaminated sediment that accumulate in the leachate streams, and at their points of confluence with the Lonfit River, are swept downstream into the Pago River estuary and out into the bay. This process naturally cleanses the Lonfit River of potentially persistent contaminants that might otherwise accumulate in bottom deposits and impact aquatic food chains in the neighborhood. At

[1] TRVs represent the most conservative of values listed in the Guam Numerical Criteria for Freshwater Organisms, the USEPA Ambient Water Quality Criteria for freshwater organism, and in peer reviewed publications (USEPA 2002).

greater risk of metal contamination, therefore, are the Pago River estuary and Pago Bay itself. Sediment deposition in these areas is much more pronounced, particularly in and around the river mouth. However, the absence of any significant heavy metal build-up in this region suggests the same natural cleansing principles operate, although the process may be restricted to major storms (typhoons) that approach from the eastern side of the island. We speculate that such storms are instrumental in purging the area of old alluvial deposits and any contaminants that have accumulated therein during the intervening period. Certainly, stream flow into the bay under such conditions is of sufficient volume and velocity to create an extensive sediment plume that is funneled into deeper waters via the reef channel (see Plate 2). Bottom deposits in this region could therefore be the ultimate sink for metal contaminants mobilized downstream from the dump. If such is the case, then resident demersal and benthic species could well be the most vulnerable biotic components in the area in terms of metal exposure. The analysis of sediments and biota from this region would therefore be of interest and is seen as a logical extension of the current work.

Surprisingly little effort has been directed towards establishing baseline levels of heavy metals in sediments of the Lonfit River. In fact only two investigations have been conducted to date. The first study was undertaken in the early 1980s (Black and Veatch 1983). It involved the analysis of single sediment samples upstream and downstream of the dump and from several leachate streams. The second study, conducted over 20 years later, took multiple sediment samples from sites over much the same area in an attempt to differentiate between levels of natural and anthropogenic origin (Olsen and Denton in prep.). The data from the two studies are summarized in Table 12. Typical values for coral reef sediments are also included for comparative purposes, in addition to the findings obtained here for sediments from Pago Bay.

The Black and Veatch data was recently reviewed by USEPA who compared the elemental levels present in these naturally enriched deposits with standard benchmarks for geologically dissimilar coastal sediments from elsewhere in the world (USEPA 2002). It was concluded that sediment TRVs were exceeded in the Lonfit River for copper, iron, manganese, mercury and nickel. Clearly, such conclusions are flawed as the more recent study demonstrates. In fact, the earlier reported data for copper, iron, manganese and nickel do not exceed the range of natural baseline values established for each element by Olsen and Denton. The high levels of mercury reported by Black and Veatch (1983) are now considered to be erroneous. Values reported for lead by these authors are also suspect.

And so it would appear that the Lonfit-Pago river system is in remarkably good shape considering that it has been inundated by vast quantities of metal enriched leachate over the past half-century or more. Climatic and topographic characteristics of the area have effectively conspired to produce natural cleansing processes that periodically scour the watershed of heavy metal contaminants and transport them out to sea. Climatic disturbance also prevent the long-term accumulation of contaminants in the Pago Bay area despite some seasonal deposition of lead and zinc in the estuary during the milder wet season conditions (Olsen and Denton in prep.) and chronic, low-level inputs of lead, mercury and zinc from septic systems at the northern end of the bay. Nevertheless, continued monitoring of the area is recommended at least once every 5 years until remediation strategies for the Ordot Dump are in place. It may also be worth expanding the contaminant database to include PCBs. Electrical transformers containing these compounds were apparently disposed of at the dump in the distant past (Black and Veatch 1983).

Table 12: Sedimentary Baseline Levels of Heavy Metals (µg/g) in the Lonfit River and Coral Reef Waters Compared with Pago Bay

Metal	Lonfit River[a,b] (lithogenic: volcanics)		Coral Reef[c] (biogenic: carbonates)	Pago Bay[d] (lithogenic/biogenic mix)	Degree of Enrichment in Pago Bay: Location
Ag	nd	<0.1	<0.1	<0.2	None
As	0.9	<0.1	0.5-3	<0.2-1.6	None
Cd	0.05	<0.2	<0.1	<0.2	None
Cr	24.1-30.8	50-80	1-5	2-21	None
Cu	28.9-33.7	50-70	<0.1-3	<0.1-20	None
Fe	19,400-20,800	50,000-60,000	50-500	203-41,743	None
Hg	1,100-3,200	0.020-0.030	0.002-0.010	0.001-0.015	V. Mild: N. end
Mn	402-1,370	1,000-1,500	10-50	11-453	None
Ni	37-52	60-120	<0.2-3	<0.2-25	None
Pb	11-12	<1-2	<1	<0.3-14	Moderate: S. end Mild: river mouth; N. end
Zn	26-27	50-70	<1-5	<1-90	Mild: river mouth; N. end

[a]Black and Veatch 1983 (column 1); [b]Olsen and Denton in prep (column 2); [c]Denton *et al.* 1997, 2001 (column 3); [d]This study (columns 4 and 5); nd = not determined

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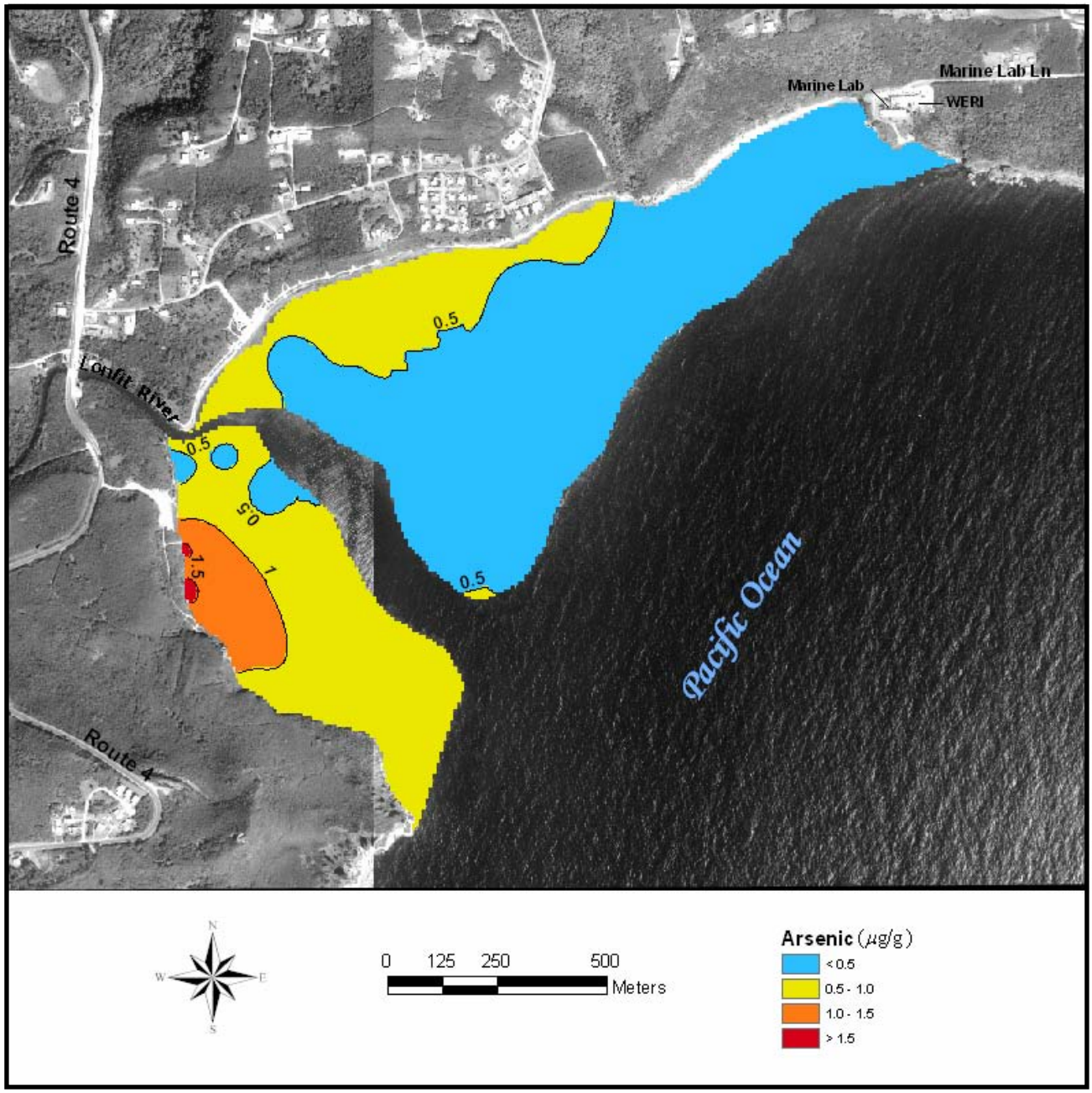
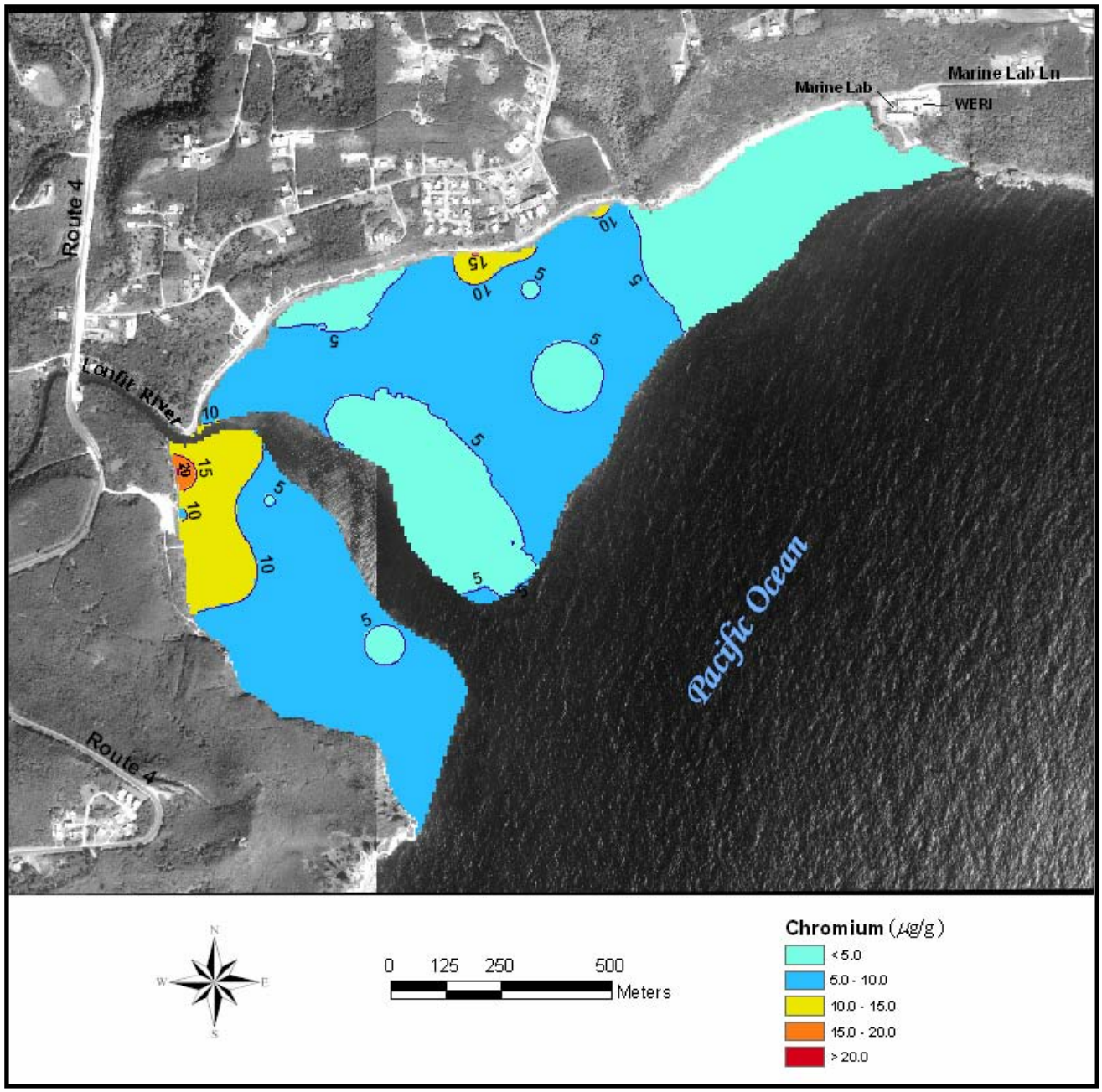
APPENDICES

Isoconcentration Contour Maps of Heavy Metals in Pago Bay Sediments

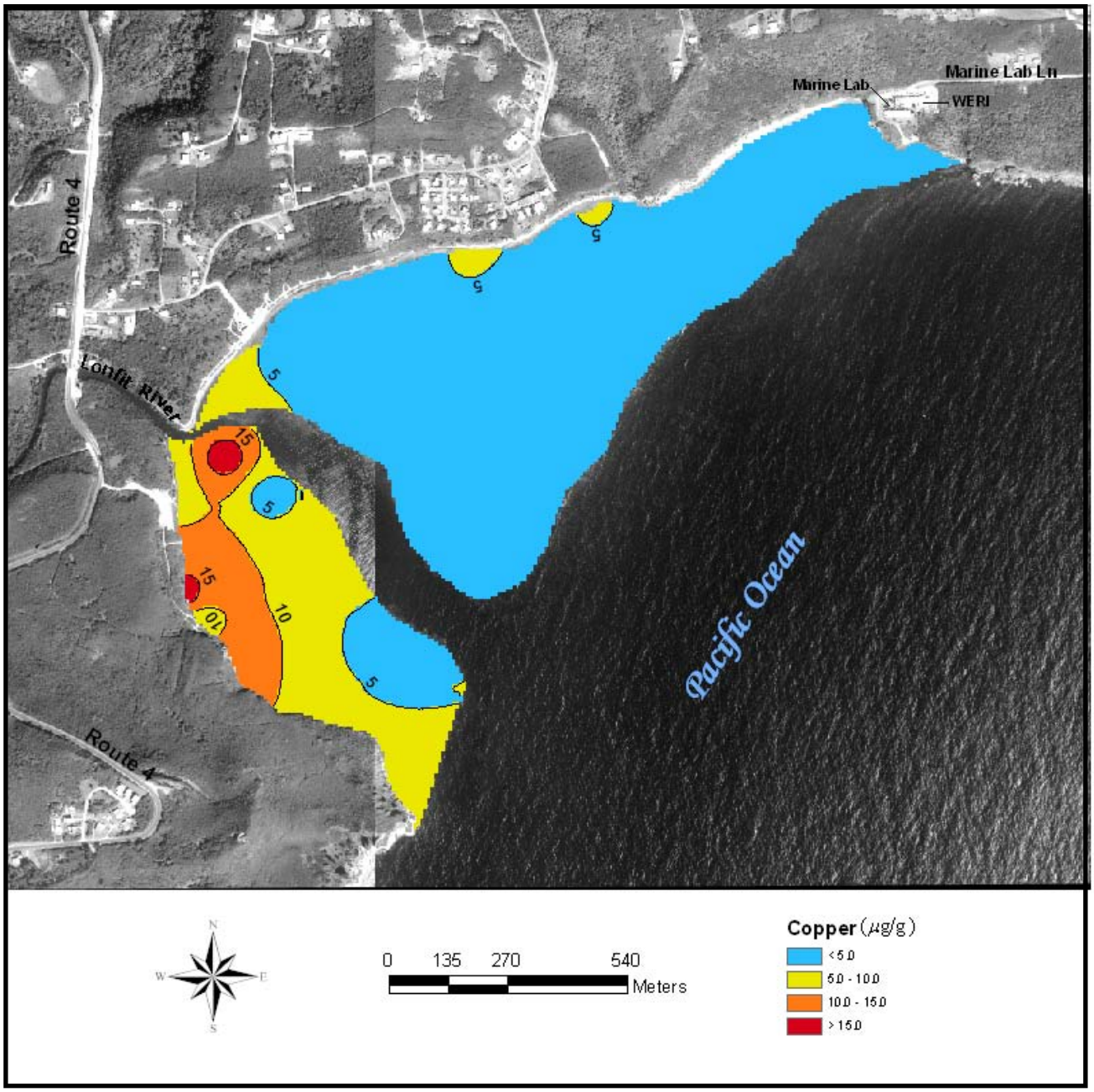
Appendix 1: Distribution & Abundance of Arsenic in Surface Sediments of Pago Bay



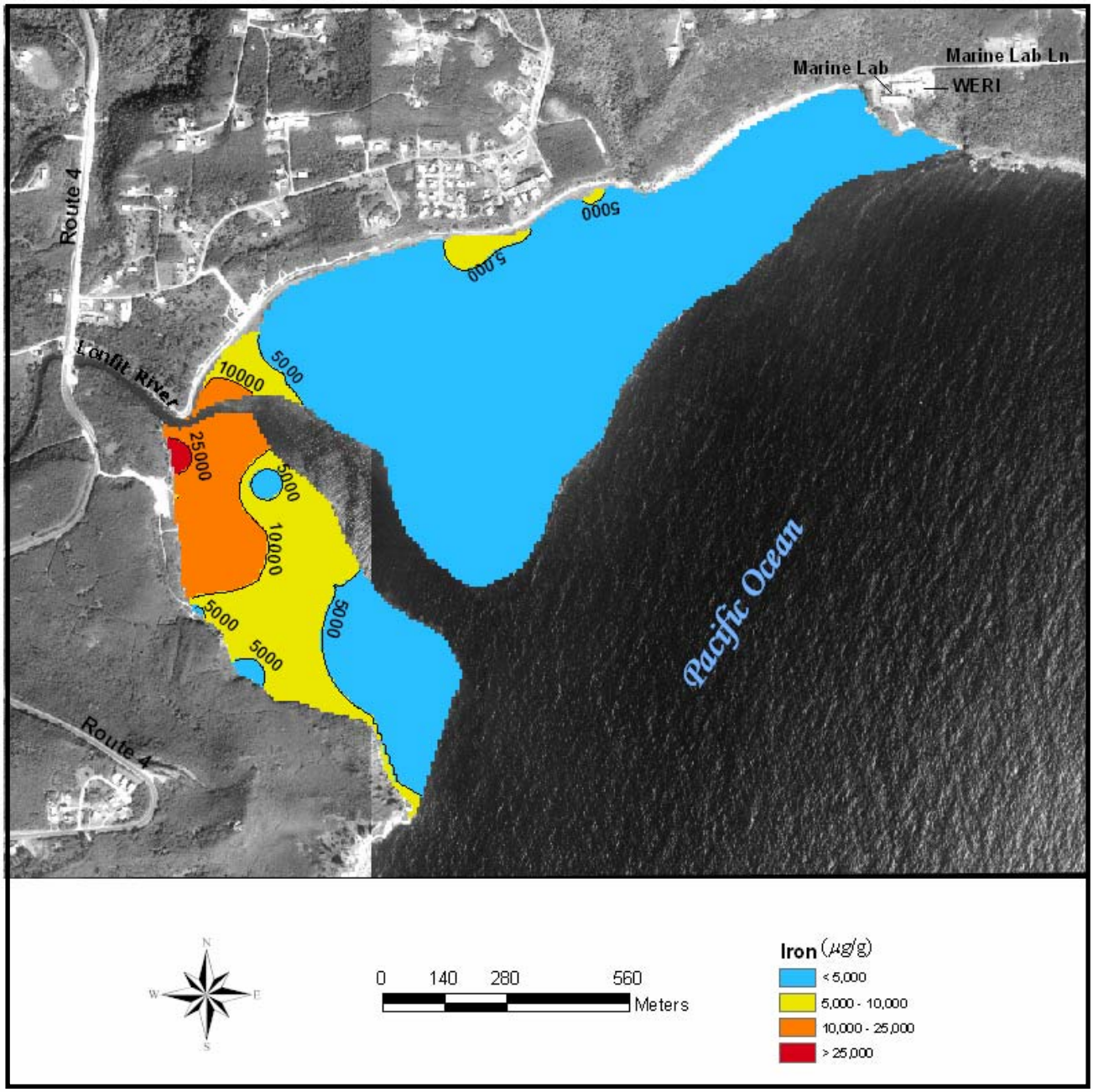
Appendix 2: Distribution & Abundance of Chromium in Surface Sediments of Pago Bay



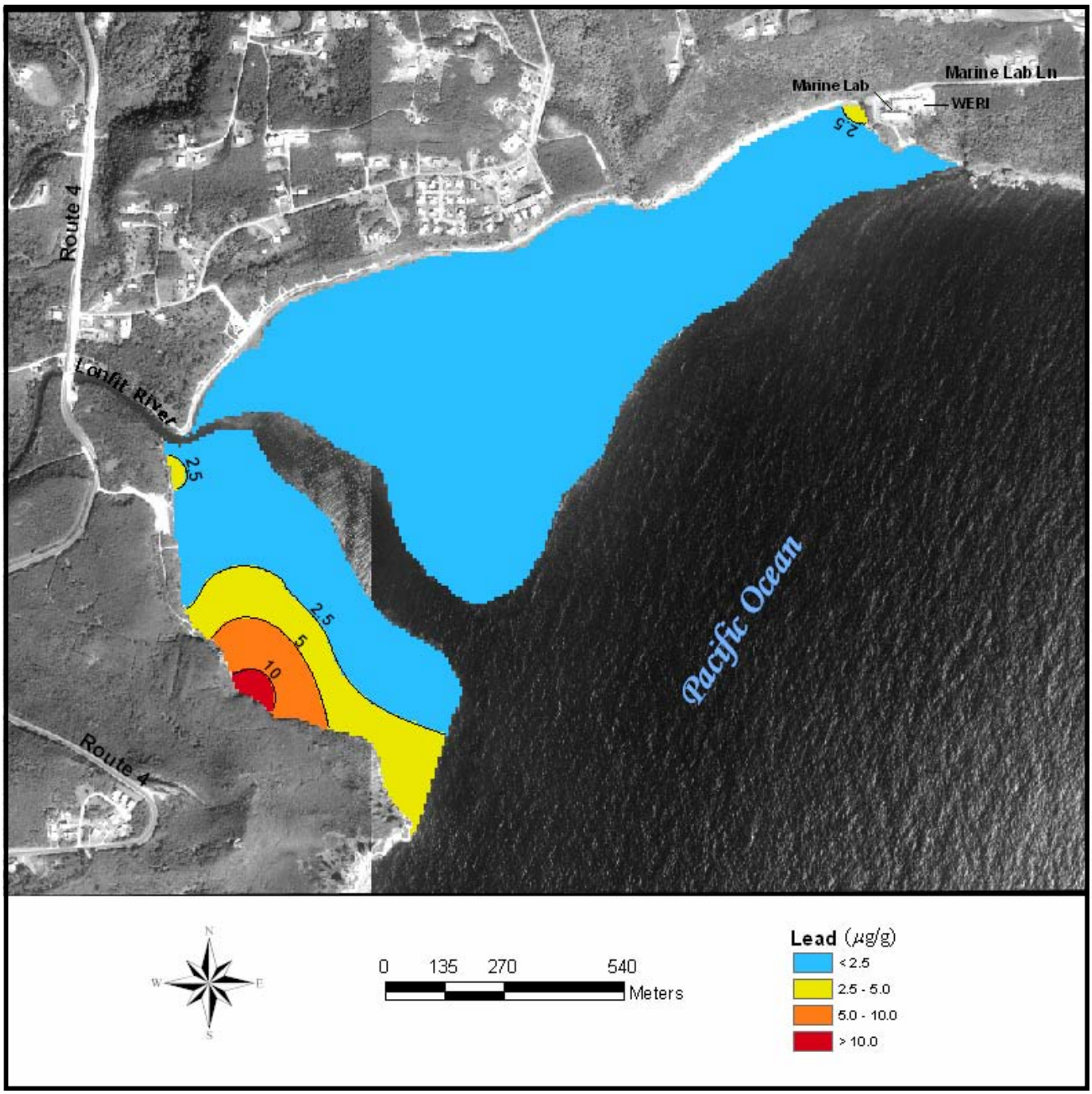
Appendix 3: Distribution & Abundance of Copper in Surface Sediments of Pago Bay



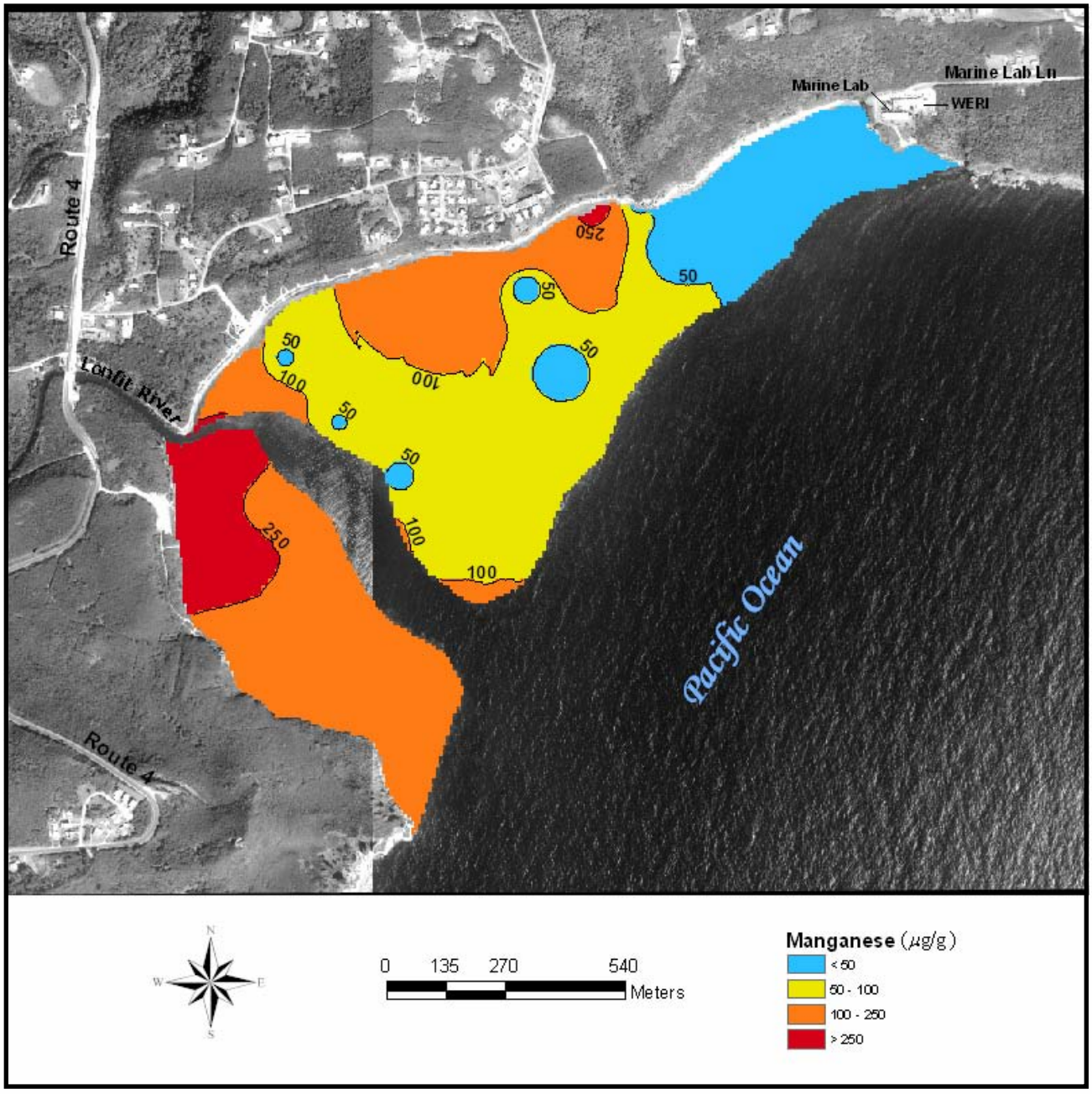
Appendix 4: Distribution & Abundance of Iron in Surface Sediments of Pago Bay



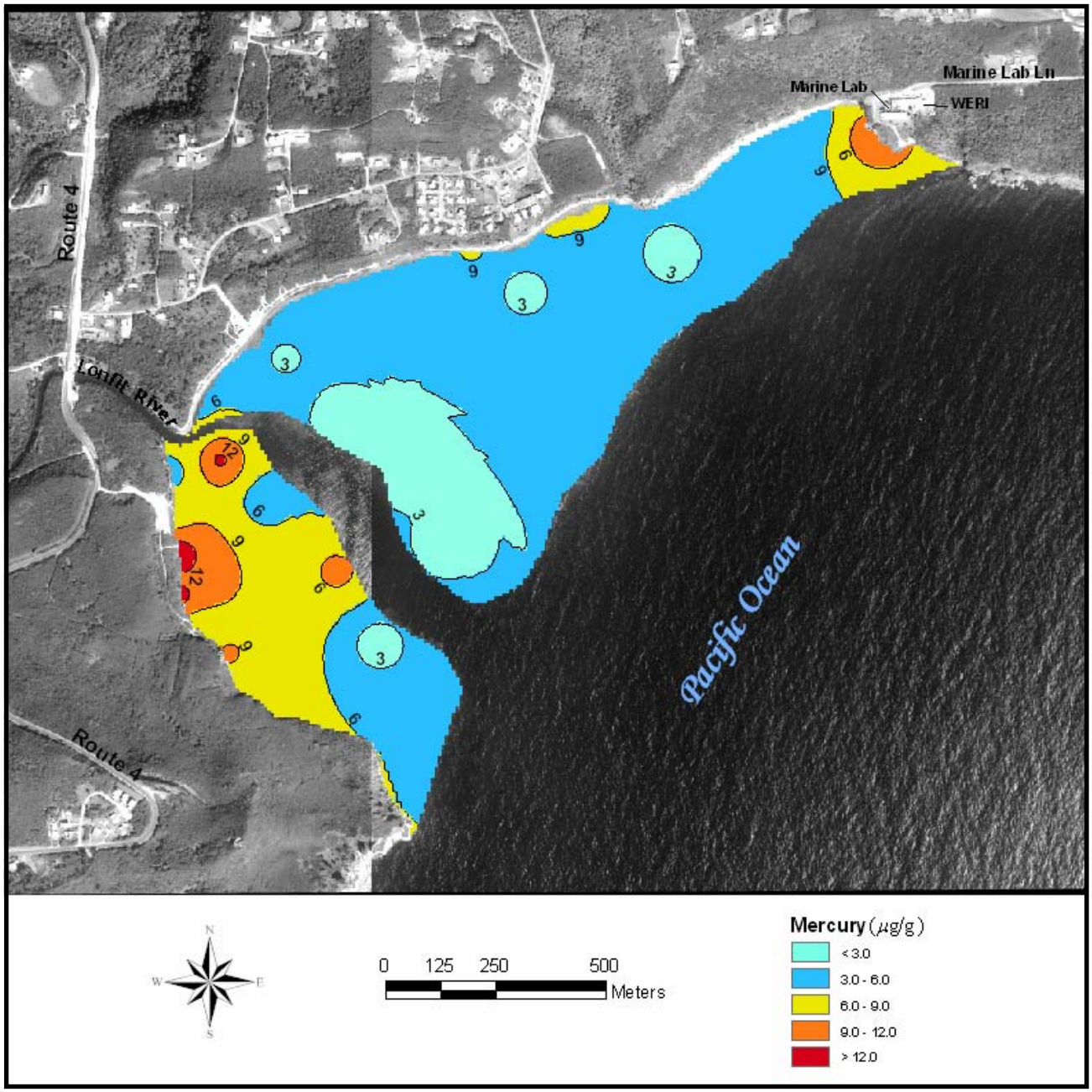
Appendix 5: Distribution & Abundance of Mercury in Surface Sediments of Pago Bay



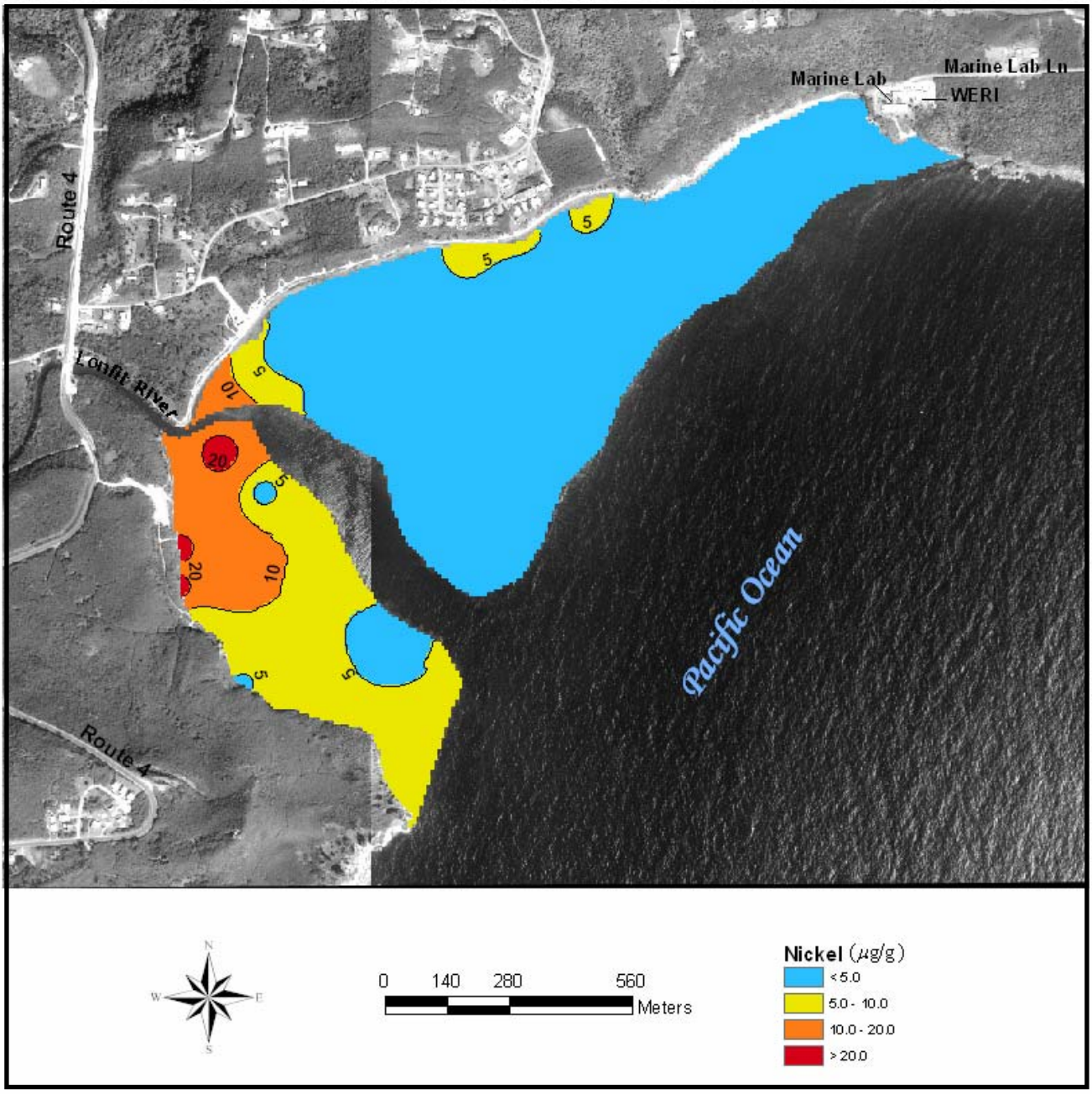
Appendix 6: Distribution & Abundance of Manganese in Surface Sediments of Pago Bay



Appendix 7: Distribution & Abundance of Nickel in Surface Sediments of Pago Bay



Appendix 8: Distribution & Abundance of Lead in Surface Sediments of Pago Bay



Appendix 9: Distribution & Abundance of Zinc in Surface Sediments of Pago Bay