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Trace metals in marine organisms from four harbours in Guam

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Historically, marine resources have provided a major protein source for the people of Guam, and fishing is still and important commercial and recreational activity. Local inhabitants commonly harvest a variety of algae, molluscs, crustaceans, sea cucumbers and fish for sale and home consumption (Amesbury et al., 1986). These resources have been relatively protected from the adverse effects of pollution generated by the industrial nations of the world due to Guam's geographic isolation (13°48′N, 144°80′E). However, the island has supported a sizable military presence since WWII and has undergone tremendous commercial growth (especially in the tourism and hospitality industry) and urban expansion over the last 20 years. Such developments have greatly contributed to the waste disposal, pollution and environmental management problems confronting the island today.

Prior to the mid-1990s, very little was known about the degree of chemical contamination in Guam's coastal waters. Management strategies are currently being developed for the sustainable development of resources within this ecologically sensitive area. These include the identification and evaluation of major coastal pollution sources and the health risks to consumers of contaminated fisheries, through the establishment of a major monitoring program. This paper reports on the baseline study of trace metals in marine organisms from four harbours (Fig. 1) where contaminated and clean sites had been identified in an earlier sediment study (Denton et al., 2005). Species selected for study were from various trophic levels, in addition to those frequently harvested for human consumption. Attention was also paid to biotic groups popularly used as bioindicators of trace metal pollution.

Biota sampling sites were selected on the basis of sediment contamination profiles identified by Denton et al. (1997) and preliminary biodiversity assessments. Full details are given in Denton et al. (1999), and are summarised in Table 1. A full list of species sampled at each site is given in Table 2. Not all species were available at all the sites studied. Biota were collected between June 1998 and January 1999. In most cases, sampling was by scuba diving, handpicking off the reef, ocean floor or from the sides of submerged structures. Shellfish were removed from their point of attachment using a hammer and chisel. Fish were captured by spear gun and hook and line. All samples, except bivalves were immediately wrapped in aluminium foil and placed on ice. The bivalves were held in clean seawater for approximately 6 h to facilitate depuration.

In the laboratory, all organisms were thoroughly cleaned of epiphytic growth and/or adhering particulate material before sub-sampling for analysis. With algae, the holdfasts and older, more encrusted portions of the plant were discarded and only the fronds were taken for analysis. With the sponges, it was necessary to carefully pare away sediment laden portions of the exterior and interior surfaces prior to sub-sampling. The sponges and ascidians were analysed whole, and the entire soft parts of the bivalves were taken for analysis. In contrast, specific tissues were removed from the sea cucumbers (dorsal body wall

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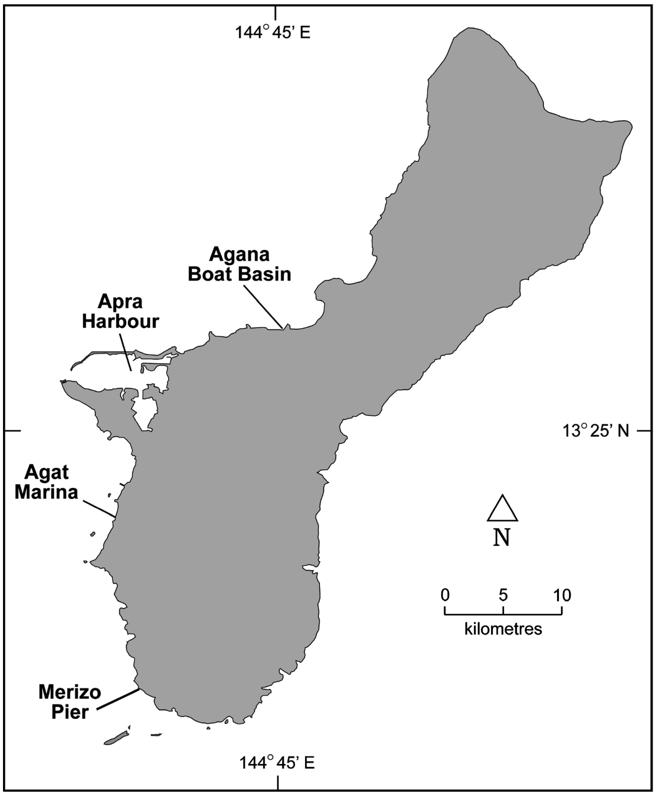

Fig. 1. Locations of harbours studied on Guam.

and hemal system), octopus (tentacles and liver), mantis shrimp (tail muscle and gonad) and fish (axial muscle and liver). With fish, muscle samples were taken immediately below and parallel to the dorsal fin on the left-hand side of the body. Samples for all metals, except mercury, were dried to constant weight, in an oven at 60 °C, and stored in acid-cleaned, polypropylene vials. Owing to the relatively high volatility of mercury, analyses were conducted on wet rather than dry tissues.

All tissue samples were analysed for trace metals following conventional wet oxidation procedures in hot mineral acids. The digestion procedures were essentially similar to USEPA method 3050A, SW-846 (USEPA, 1996) with minor modifications as outlined below. Appropriate quality control and quality assurance procedures including full procedural blanks, matrix spikes, and certified reference materials were built into the analytical protocols.

For mercury, approximately 1 g of wet tissue was accurately weighed into a 125 mL Erlenmeyer flask and allowed to stand overnight in 10 mL of a 2:1 mixture of concentrated nitric and sulfuric acids. Several bivalve samples that were too big to analyse individually were split into two or more portions and digested separately. The following day the cold digests were heated to 100 °C in a boiling water bath for 3 h. Each flask was loosely capped with a Teflon stopper to facilitate good refluxing and exclude extraneous contaminants. After cooling, the digests were made up to volume with deionized water (75 mL), and analysed by flameless atomic absorption spectroscopy (AAS) 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).

For all other metals, between 1 and 3 g of dried tissue were accurately weighed into the digestion flasks described above. Approximately 10 mL of concentrated nitric acid were added to each flask and allowed to stand at room temperature overnight. The following day the digests were gradually heated to 100 ± 5 °C and allowed to reflux for 2–3 days. The solutions were then evaporated to dryness and further additions of acid were made as necessary to complete digestion. Finally, digests were made up to volume with 10% nitric acid (10 mL/g tissue weight) and analysed by AAS within five working days. Blanks (two per batch of 40 digests) were treated similarly. Corrections for non-atomic absorption were made simultaneously by the instrument.

Table 1
Biota sampling sites in Guam harbours

Harbour	Geographic details	Sampling locations[a]	Comments[b]
Agana Boat Basin	13°28′N, 144°45′E	Inner Boat Basin	Sediments highly contaminated with Cu, Pb, Zn, moderately with Cr, Hg, Sn
Apra Harbour	13°27′N, 144°40′E	Site a: W end of Hotel Wharf	Sediments highly contaminated with Cu, Pb, Hg, Sn, Zn
		Site b: Central Hotel Wharf	Sediments highly contaminated with Cu, Pb, Hg, Sn, Zn
		Site c: Shell Fox-1 Fuel Pier	Sediments highly contaminated with Cu, Pb, Hg, Zn
		Site d: W end of Commercial Port	Sediments highly contaminated with Cu, Pb, Hg, Zn
		Site e: S end of Dry Dock Island	Sediments highly contaminated with Cu, Pb, Hg, Zn
		Site f: E end of Echo Wharf	Control clean site
		Site g: Off Port Authority Beach	Control clean site
Agat Marina	13°22′N, 144°39′E	Mooring sites and adjacent to fuel station	Relatively new small boat harbour; sediments show Cr contamination
Merizo Pier	13°16′N, 144°40′E	Along entire length of small boat impacted shoreline	Deep water sediments clean; nearshore sediments showed Cu, Pb, Sn and Zn contamination

[a] Map of sampling sites available in Denton et al. (2006).

[b] Data from Denton et al. (1997).

Table 2
Flora and fauna samples used in this study

Species collected for analysis	Agana Boat Basin	Apra Harbour							Agat Marina	Merizo Pier
		Site a	Site b	Site c	Site d	Site e	Site f	Site g		
Brown alga										
Padina sp.	×	×		×	×	×	×		×	×
Sponges										
Callyspongia diffusa									×	
Cinachyra sp.	×									×
Clathria vulpina ?									×	×
Dysidea sp.				×	×		×		×	
Liosina cf. *granularis*						×				
Stylotella aurantium			×			×				×
Yellow bread sponge									×	
Yellow sponge (red outside)				×						
Brown wart sponge			×			×	×			
Orange brown wart sponge						×				
Hard corals										
Acropora formosa						×				
Fungia concinna				×						
Fungia echidata						×				
Herpolitha limax				×		×				
Pocilopora damicornis	×			×	×		×		×	×
Soft corals										
Sinularia sp.	×			×		×				×
Sea cucumbers										
Bohadschia argus	×		×	×		×			×	×
Holothuria atra	×					×		×	×	×
Bivalve mollusks										
Chama lazarus			×	×	×	×	×			×
Chama brassica					×					
Saccostrea cuccullata				×						×
Spondylus? *multimuricatus*	×								×	
Striostrea cf. *mytiloides*	×	×				×	×		×	×
Cephalopod mollusk										
Octopus cyanea				×						
Stomatopod crustacean										
Gonodactylus sp. (mantis shrimp)						×				
Tunicates										
Ascidia sp.			×			×				
Rhopalaea				×	×	×				
Fish										
Acanthurus xanthopterus	×			×			×			
Balistoides viridescens										×
Bolbometopon muricatum				×						
Caranx ignobilis	×									
Caranx melampygus			×			×				
Caranx sexfasciatus	×			×	×					
Cephalopholis sonnerati										×
Cheilinus chlorounus									×	
Cheilinus fasciatus				×						
Cheilinus trilobatus										×
Ctenochaetus binotatus					×					
Ctenochaetus striatus						×	×		×	
Epibulus insidiator				×		×				
Epinephelus merra										×
Gerres argyreus	×				×					
Gymnothorax javanicus			×							
Leiognathus equulus									×	
Lethrinus rubrioperculatus									×	×
Lutjanus kasmira										×
Monodactylus argenteus	×				×					

Table 2 (*continued*)

Species collected for analysis	Agana Boat Basin	Apra Harbour							Agat Marina	Merizo Pier
		Site a	Site b	Site c	Site d	Site e	Site f	Site g		
Naso annulatus						×				
Naso unicornis		×	×							
Odenus niger									×	
Parupeneus barberinus										×
Parupeneus cyclostomus										×
Parupeneus multifasciatus										×
Saurida gracilis	×								×	
Saurida nebulosa			×							×
Scarus sordidus						×				
Siganus spinus	×									
Sufflamen chrysoptera						×				
Valamugil engeli				×						

Key to Apra Harbour sites:
Apra Harbour (site a) = Western end of Hotel Wharf.
Apra Harbour (site b) = Central Hotel Wharf.
Apra Harbour (site c) = Shell Fox-1 Fuel Pier.
Apra Harbour (site d) = Western end of Commercial Port.
Apra Harbour (site e) = Southern end of Dry Dock Island.
Apra Harbour (site f) = Eastern end of Echo Wharf.
Apra Harbour (site g) = Off Port Authority Beach.

Table 3
Recovery of trace metals from standard reference materials (data in μg/g dry wt. are mean ± 95% confidence limits)

Metal	Apple leaves (SRM 1515)		Bovine liver (SRM 1577b)	
	This study	Certified value	This study	Certified value
Arsenic	0.032 ± 0.026	0.038 ± 0.007	0.060 ± 0.026	0.05[a]
Cadmium	<0.04–0.07	0.013 ± 0.002	0.58 ± 0.17	0.50 ± 0.03
Copper	5.02 ± 0.18	5.64 ± 0.24	152 ± 31	160 ± 8
Chromium	0.82 ± 0.57	0.3[a]	1.05 ±1.04	–
Mercury	0.057 ± 0.012	0.044 ± 0.004	0.005 ± 0.011	0.003[a]
Nickel	0.66 ± 0.20	0.91 ± 0.12	<0.18–0.2	–
Lead	0.47 ± 0.32	0.470 ± 0.024	<0.30 to <0.38	0.129 ± 0.004
Silver	<0.09 to <0.11	–	<0.10 to <0.13	0.039 ± 0.007
Tin	0.003–0.03	<0.2[a]	<0.004–0.07	–
Zinc	11.2 ± 3.28	12.5 ± 0.3	110 ± 16.9	127 ± 16

[a] Certified value not available. Dashes indicate no data.

For metals other than arsenic and tin, analyses were by conventional flame AAS. All methods were validated using the standard reference materials shown in Table 3.

Arsenic and tin were analysed by cold vapour AAS using the hydride generation technique. For arsenic, between 50 and 1000 μL of sample were accurately dispensed into a polypropylene reaction vessel containing 4 mL of 1.5% HCl. The total volume was adjusted to 5 mL with 10% nitric acid. Arsine gas was generated by reduction of the sample 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. For tin, 1 mL of sample was added to 5 mL of saturated boric acid (50 g/L). For smaller sample volumes, adjustments to a 6-mL total volume were made using 10% nitric acid in order to minimize changes in pH. Stannane gas was generated with 3% sodium borohydride in 0.5% sodium hydroxide. Calibration standards (5–20 μg/L) were made up in saturated boric acid solution on a daily basis. Concentrations of both metals were calculated by standard additions to compensate for matrix interferences.

The trace metal data obtained are summarised in Tables 4–11. Some data from other Pacific locations are summarised in Table 12 for comparison purposes. Only data where concentrations were of interest or concern are discussed below; further discussion is available in Denton et al. (1999). In addition to comments on information about specific metal concentrations, the bioindicator potential of each group of organisms is discussed where appropriate.

Silver concentrations in Guam sediments were consistently below an analytical detection limit of ~0.2 μg/g indicating that this is not an element of environmental concern locally (Denton et al., 2005). Silver concentrations in the brown alga, *Padina* sp., were below the limits of analytical detection except at Agana Boat Basin where the pooled

Table 4
Trace metals in seaweed from Guam harbour waters (μg/g dry wt.)

Species	Location (site)	Date	Statistic	Ag	As	Cd	Cr	Cu	Hg[a]	Ni	Pb	Sn	Zn	% H_2O
Padina sp.	Agana Boat Basin	18 December 1998	Mean	0.89	32.2	0.26	0.68	1.53	<0.002	1.18	0.46	<0.01	11.0	86
			Range	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	
			n	1	1	1	1	1	1	1	1	1	1	
Padina sp.	Apra Harbour (a)	5 June 1998	Mean	nc	6.38	0.17	0.62	2.66	0.007	2.55	1.84	nc	45.8	83
			Range	<0.11	5.79–7.09	0.15–0.18	0.57–0.67	2.59–2.71	nd	2.45–2.74	1.76–1.93	all <0.01	45.1–46.8	
			n	3	3	3	3	3	1	3	3	3	3	
Padina sp.	Apra Harbour (c)	3 June 1998	Mean	nc	7.34	0.17	1.36	5.42	0.009	1.09	6.04	nc	66.9	85
			Range	<0.11	7.06–7.58	0.15–0.19	1.31–1.39	5.35–5.46	nd	1.01–1.16	5.59–6.48	all <0.01	65.0–68.4	
			n	3	3	3	3	3	1	3	3	3	3	
Padina sp.	Apra Harbour (d)	9 June 1998	Mean	nc	33.2	0.18	2.05	33.9	0.026	1.63	4.96	nc	182	81
			Range	<0.12	30.0–38.1	0.15–0.21	1.97–2.10	29.8–36.6	nd	1.46–1.76	4.67–5.34	all <0.01	176–192	
			n	3	3	3	3	3	1	3	3	3	3	
Padina sp.	Apra Harbour (e)	9 June 1998	Mean	nc	27.5	0.49	2.9	14.5	0.014	3.0	5.1	nc	119	86
			Range	<0.12	24.0–35.9	0.49–0.49	2.84–2.98	13.9–15.1	nd	2.89–3.17	4.03–5.82	all <0.01	114–122	
			n	3	3	3	3	3	1	3	3	3	3	
Padina sp.	Apra Harbour (f)	12 June 1998	Mean	nc	18.3	0.2	2.8	6.3	0.007	1.8	2.6	nc	73.6	90
			Range	<0.10	17.7–18.8	0.20–0.22	2.80–2.86	6.21–6.36	nd	1.68–1.86	2.58–2.66	all <0.01	72.3–74.9	
			n	2	2	2	2	2	1	2	2	2	2	
Padina sp.	Agat Marina	21 December 1998	Mean	<0.08	20.5	0.09	2.67	4.07	<0.002	2.85	<0.25	<0.01	18.7	81
			Range	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	
			n	1	1	1	1	1	1	1	1	1	1	
Padina sp.	Merizo Pier	22 December 1998	Mean	<0.08	17.4	0.07	14.1	27.7	0.003	2.28	8.07	<0.01	78.3	83
			Range	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	
			n	1	1	1	1	1	1	1	1	1	1	

Mean = geometric mean.
n = number of replicates analysed.
nc = not calculable.
nd = no data.
[a] Hg concentrations as μg/g wet wt.

Table 5
Trace metals in sponges from Guam harbour waters (μg/g dry wt.)

Species	Location (site)	Date	Ag	As	Cd	Cr	Cu	Hg[a]	Ni	Pb	Sn	Zn	% H_2O
Sponges													
Callyspongia diffusa	Agat Marina	21 December 1998	<0.11	<0.01	0.86	9.72	40.4	0.014	6.04	0.45	23.6	62.5	86
Cinachyra sp.	Agana Boat Basin	18 December 1998	0.39	<0.01	0.26	0.98	46.2	0.027	0.40	1.46	5.73	26.4	64
Cinachyra sp.	Merizo Pier	22 December 1998	0.11	0.01	0.20	1.11	15.0	0.023	0.87	<0.72	10.9	22.2	71
Clathria vulpina?	Agat Marina	21 December 1998	<0.08	<0.01	0.46	2.02	30.3	0.005	5.37	<0.25	13.5	200	85
Clathria vulpina?	Merizo Pier	22 December 1998	<0.11	<0.01	0.33	0.45	15.6	0.007	0.70	<0.34	17.0	178	86
Dysidea sp.	Apra Harbour (c)	3 June 1998	0.47	6.39	0.23	2.20	72.9	0.015	1.65	2.58	0.03	62.7	71
Dysidea sp.	Apra Harbour (d)	9 June 1998	0.33	10.5	0.28	2.24	73.1	0.059	0.62	4.37	0.04	75.6	75
Dysidea sp.	Apra Harbour (f)	12 June 1998	<0.11	6.90	0.15	1.70	21.3	0.010	1.61	2.50	<0.01	25.8	65
Dysidea sp.	Agat Marina	21 December 1998	<0.10	<0.01	0.20	4.29	20.2	0.007	3.81	<0.30	17.7	47.5	84
Liosina cf. *granularis*	Apra Harbour (b)	5 June 1998	0.15	39.7	0.50	24.9	72.4	0.008	9.04	68.3	<0.01	275	76
Liosina cf. *granularis*	Apra Harbour (e)	9 June 1998	<0.10	47.7	0.18	15.1	40.3	0.051	8.93	52.0	<0.01	232	80
Stylotella aurantium	Apra Harbour (b)	5 June 1998	<0.09	6.25	0.33	1.90	23.5	0.021	0.79	2.70	<0.01	61.2	83
Stylotella aurantium	Apra Harbour (e)	9 June 1998	<0.12	5.96	0.22	2.60	21.0	0.043	1.71	3.02	<0.01	53.3	84
Stylotella aurantium	Apra Harbour (e)	9 June 1998	<0.10	6.42	0.11	2.43	17.7	0.053	1.15	2.92	<0.01	70.8	84
Stylotella aurantium	Merizo Pier	22 December 1998	<0.11	<0.01	0.20	1.33	19.4	0.027	2.01	<0.33	16.1	83.5	82
Unidentified sponges													
Brown wart Sponge	Apra Harbour (e)	9 June 1998	0.14	19.8	0.23	17.3	34.9	0.012	10.6	20.3	<0.01	131	78
Brown wart Sponge	Apra Harbour (f)	12 June 1998	0.24	5.91	0.21	13.5	31.5	0.005	7.04	23.7	<0.01	144	73
Orange wart sponge	Apra Harbour (e)	9 June 1998	<0.10	37.9	0.24	2.27	7.86	0.031	12.6	7.24	<0.01	34.5	83
Yellow bread sponge	Agat Marina	21 December 1998	<0.08	<0.01	0.14	1.10	6.2	0.004	0.66	<0.26	6.45	102	86
Yellow bread sponge (red outside)	Apra Harbour (c)	3 June 1998	<0.10	43.1	0.14	0.45	17.0	0.087	35.0	1.20	0.01	47.4	84

[a] Hg concentrations as μg/g wet wt.

Table 6
Trace metals in corals from Guam harbour waters (µg/g dry wt.)

Species	Location (site)	Date	Ag	As	Cd	Cr	Cu	Hg[a]	Ni	Pb	Sn	Zn	% H_2O
Soft corals													
Sinularia sp.	Apra Harbour (c)	3 June 1998	<0.11	2.33	0.13	0.31	0.89	0.007	0.53	<0.34	0.13	143	72
Sinularia sp.	Apra Harbour (e)	9 June 1998	<0.12	1.60	0.16	0.27	0.44	0.013	0.70	<0.37	0.24	76.3	60
Sinularia sp.	Agana Boat Basin	18 December 1998	2.69	0.01	0.10	<0.15	0.98	0.004	0.80	<0.28	10.5	74.5	84
Sinularia sp.	Merizo Pier	22 December 1998	<0.10	<0.01	<0.05	<0.16	0.60	0.022	0.24	<0.30	7.12	38.9	65
Hard corals													
Acropora formosa	Apra Harbour (e)	6 June 1998	<0.11	0.14	0.09	0.27	<0.10	0.017	2.12	<0.32	<0.01	1.69	16
Fungia concinna	Apra Harbour (c)	3 June 1998	0.24	0.25	0.08	0.34	1.06	<0.011	<0.17	<0.34	0.06	3.14	16
Fungia echidata	Apra Harbour (e)	6 June 1998	0.14	0.19	0.10	0.24	0.49	0.007	0.27	<0.31	<0.01	1.76	18
Herpolitha limax	Apra Harbour (c)	3 June 1998	<0.12	0.17	0.09	0.29	0.85	<0.005	<0.18	<0.36	<0.01	2.21	14
Herpolitha limax	Apra Harbour (e)	6 June 1998	1.17	0.20	0.08	0.25	1.52	0.015	<0.15	<0.30	<0.01	4.14	16
Pocilopora damicornis	Agana Boat Basin	18 December 1998	<0.10	<0.01	<0.06	<0.17	<0.11	0.006	<0.16	<0.32	0.16	1.29	10
Pocilopora damicornis	Apra Harbour (c)	3 June 1998	0.18	67.1	0.07	<0.12	0.11	<0.006	0.29	<0.33	<0.01	7.16	21
Pocilopora damicornis	Apra Harbour (d)	6 June 1998	0.26	0.84	0.24	0.33	<0.10	<0.007	0.24	<0.31	<0.01	7.66	29
Pocilopora damicornis	Apra Harbour (f)	12 June 1998	<0.11	0.41	0.09	0.14	0.15	<0.005	0.21	<0.34	<0.01	6.97	17
Pocilopora damicornis	Agat Marina	21 December 1998	<0.07	<0.01	<0.04	<0.12	0.24	0.005	<0.11	<0.23	0.63	3.26	12
Pocilopora damicornis	Merizo Pier	22 December 1998	<0.12	<0.01	<0.06	<0.19	<0.13	0.004	<0.18	<0.36	0.37	3.81	14

[a] Hg concentrations as µg/g wet wt.

tissue composite yielded a value of 0.89 µg/g, while the range for sponges was <0.11–0.47 µg/g, with the highest concentrations found in Apra Harbour and Agana Boat Basin. For corals, concentrations rarely exceed 0.1 µg/g (Veek and Turekian, 1968; Riley and Segar, 1970; Burdon-Jones and Klumpp, 1979), so the relatively high level of 2.7 µg/g recorded in the soft coral, *Sinularia* sp., from Agana Boat Basin was of interest because it supports the mild enrichment demonstrated by *Padina* sp. collected from this area. In sea cucumbers, only one relatively high concentration (4.9 µg/g) was determined in the hemal system of a specimen of *Holothuria atra* from Apra Harbour (site g). Like most other metals, silver tends to be more concentrated in the liver rather than the axial muscle of fish (Eisler, 1981) although levels rarely exceed 1 µg/g wet wt. During the present work, higher levels were found in less than 3% of liver samples analysed.

Arsenic concentrations previously reported by us for Guam harbour sediments ranged from <1.0 to 17.0 µg/g, with the highest levels occurring in samples from biota site b in Apra Harbour (Denton et al., 2005). Arsenic concentrations in *Padina* sp. in this study fell within the normal range of 2–60 µg/g (Eisler, 1981). Relatively high arsenic concentrations (5.96–47.7 µg/g) were measured in the majority of sponges collected from Apra Harbour, but values were at or below detection in specimens from all other sites. Corals from Apra Harbour generally contained the highest arsenic concentrations, although values in this group were generally lower than found in neighbouring algae and sponges. *Pocilopora damicornis* from beneath the Shell Fox-1 Fuel Pier (site c) yielded an arsenic concentration of 67.1 µg/g and was the only exception found. This value is substantially higher than Bryan's (1976) estimate of average arsenic concentrations for coelenterates (~20 µg/g).

Oysters normally contain around 10 µg/g arsenic (Förstner, 1980) although the natural range can extend from 1 to 15 µg/g (Eisler, 1981). Oyster arsenic concentrations measured here frequently exceeded 20 µg/g and peaked at 38.4 µg/g in one specimen from Agat Marina. In most bivalves, the paired kidneys are anatomically inconspicuous but in spondylids and chamids they are enlarged. This could account for the relatively high arsenic concentrations observed in representatives from both groups in this study. Cephalopod molluscs show a similar affinity for arsenic as their bivalve relatives, and according to Bryan (1976), contain average concentrations of around 40 µg/g. Thus, the relatively high arsenic values determined in the liver (44.3 µg/g) and tentacles (96 µg/g) of the octopus captured in Apra Harbour during the present study are to be expected. For comparative purposes, we note that Leatherland and Burton (1974) reported arsenic concentrations of 73 µg/g in the mantle of the cuttlefish, *Sepia officianalis*, from temperate waters.

Arsenic concentrations in edible fish tissues are generally lower than those for edible portions of algae, crustaceans, and bivalve molluscs (Lunde, 1977). Eisler (1981)

Table 7
Trace metals in sea cucumbers from Guam harbour waters (μg/g dry wt.)

Species	Location (site)	Date	Tissue	Ag	As	Cd	Cr	Cu	Hg[a]	Ni	Pb	Sn	Zn	% H_2O
Bohadschia argus	Agana Boat Basin	18 December 1998	M	<0.10	<0.01	0.08	<0.13	0.89	0.007	0.28	<0.37	14.5	12.5	86
			H	<0.12	<0.01	0.18	7.55	2.25	0.096	0.39	<0.33	40.3	58.3	83
Bohadschia argus	Apra Harbour (b)	5 June 1998	M	<0.13	14.7	0.12	<0.17	0.63	0.005	1.38	<0.33	0.26	13.8	87
			H	<0.13	32.6	0.33	7.28	2.84	0.221	0.43	0.58	3.27	374	78
Bohadschia argus	Apra Harbour (c)	12 June 1998	M	<0.12	17.7	0.11	0.43	0.63	0.005	1.04	<0.31	0.11	18.0	87
			H	<0.14	42.8	0.39	31.9	4.15	0.459	1.21	<0.38	5.25	206	87
Bohadschia argus	Apra Harbour (e)	9-June 1998	M	<0.09	7.81	0.11	0.23	2.26	0.005	1.07	0.56	0.12	13.8	87
			H	<0.11	16.6	0.32	8.28	39.1	0.301	0.48	0.88	1.72	41.4	80
Bohadschia argus	Agat Marina	21 December 1998	M	<0.09	<0.01	0.08	<0.13	0.66	0.001	1.01	<0.36	7.25	8.33	86
			H	<0.14	0.15	0.28	12.6	3.15	0.006	0.90	<0.37	45.9	76.3	85
Bohadschia argus	Agat Marina	21 December 1998	M	<0.09	<0.01	0.06	<0.12	0.69	0.003	0.70	<0.35	19.3	16.6	87
			H	<0.12	0.20	0.24	6.27	3.45	0.070	0.50	<0.32	51.9	96.8	84
Bohadschia argus	Merizo Pier	22 December 1998	M	<0.10	<0.01	0.09	<0.14	0.59	0.003	1.12	<0.39	14.8	11.0	88
			H	<0.09	<0.01	0.20	10.1	3.47	0.058	0.62	<0.26	38.5	40.6	84
Holothuria atra	Agana Boat Basin	18 December 1998	M	0.24	<0.01	0.06	<0.13	1.40	0.008	<0.19	<0.36	10.6	12.6	87
			H	0.72	<0.01	0.12	3.14	6.37	0.091	<0.43	<0.72	18.3	117	88
Holothuria atra	Apra Harbour (e)	9 June 1998	M	<0.12	13.6	0.07	0.25	0.71	0.008	<0.19	<0.32	0.11	15.5	89
			H	<0.35	7.24	0.25	2.21	4.70	0.049	<0.54	<0.92	1.63	120	91
Holothuria atra	Apra Harbour (g)	12 June 1998	M	<0.10	23.2	0.04	<0.13	1.18	0.007	<0.15	<0.26	0.16	17.9	89
			H	4.90	28.3	0.26	8.58	5.19	0.088	<0.49	<0.84	6.54	180	85
Holothuria atra	Agat Marina	21 December 1998	M	<0.10	<0.01	0.07	<0.14	1.71	0.014	<0.22	<0.40	21.5	17.0	90
			H	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Holothuria atra	Agat Marina	21 December 1998	M	<0.16	<0.01	<0.07	<0.23	1.27	0.022	<0.34	<0.63	9.76	15.4	90
			H	<0.17	0.18	0.09	0.88	3.69	0.072	<0.28	<0.47	11.9	141	93
Holothuria atra	Merizo Pier	22 December 1998	M	<0.11	<0.01	0.07	<0.16	2.51	0.008	<0.23	<0.43	10.7	21.2	86
			H	<0.11	0.03	0.10	2.85	3.81	0.016	<0.18	<0.30	17.8	253	85

M = body wall muscle tissue.
H = hemal system.
nd = no data.
[a] Hg concentrations as μg/g wet wt.

Table 8
Trace metals in oysters from Guam harbour waters (μg/g dry wt.)

Species	Location (site)	Date	Statistic	Ag	As	Cd	Cr	Cu	Hg[a]	Ni	Pb	Sn	Zn	% H_2O
Saccostrea cucullata	Apra Harbour (c)	5 June 1998	Mean	nc	12.4	0.56	nc	916	0.056	0.65	0.60	0.43	2933	86
			Range	<0.14–0.61	8.33–21.8	0.51–0.69	<0.28–<0.49	661–1911	0.043–0.078	<0.36–1.21	<0.33–1.14	0.24–0.70	2262–4722	78–90
			*n**	5	5	5	5	5	4	5	5	5	5	5
Saccostrea cucullata (Juveniles)	Merizo Pier	22 December 1998	Mean	4.48	26.5	0.69	1.12	654	0.02	1.37	nc	nc	1153	86
			Range	4.09–4.91	21.3–32.9	0.61–0.77	1.03–1.21	598–715	nd	1.25–1.50	<0.31–0.38	<0.01–<0.01	1086–1225	85–87
			*n**	2	2	2	2	2	1	2	2	2	2	2
Striostrea cf. *mytiloides*	Agana Boat Basin	30 January 1999	Mean	0.56	21.1	0.58	1.81	1968	0.092	1.28	2.79	nc	5130	82
			Range	0.13–2.96	16.5–35.5	0.36–0.78	0.84–9.04	500–3047	0.080–0.149	0.37–3.60	0.72–12.2	<0.01–0.09	2002–8375	79–86
			n	13	13	13	13	13	4	13	13	13	13	13
Striostrea cf. *mytiloides*	Apra Harbour (a)	5 June 1998	Mean	0.14	19.3	0.73	nc	1381	0.039	0.65	0.57	0.34	6367	81
			Range	<0.09–0.47	13.6–25.1	0.51–0.99	<0.19–0.71	878–2076	0.031–0.053	0.45–0.91	<0.27–0.93	0.23–0.57	4014–9789	71–83
			n	8	8	8	8	8	6	8	8	8	8	8
Striostrea cf. *mytiloides*	Apra Harbour (e)	9 June 1998	Mean	0.17	12.2	0.31	nc	777	0.033	0.73	nc	0.04	3931	84
			Range	<0.08–0.30	9.48–15.0	0.23–0.37	<0.15–0.49	496–1483	0.022–0.043	0.43–2.56	<0.17–<0.24	<0.01–0.08	2148–5643	78–83
			n	10	10	10	10	10	9	10	10	10	10	10
Striostrea cf. *mytiloides*	Apra Harbour (f)	12 June 1998	Mean	0.37	14.1	0.43	0.24	1071	0.037	1.03	nc	0.18	4225	84
			Range	<0.11–1.34	12.2–18.9	0.39–0.60	<0.18–0.89	629–2971	0.031–0.048	0.68–1.43	<0.21–0.62	0.11–0.27	2800–6280	81–88
			n	10	10	10	10	10	9	10	10	10	10	10
Striostrea cf. *mytiloides*	Agat Marina	21 December 1998	Mean	0.13	33.2	0.70	1.74	795	0.017	2.01	nc	0.02	3944	81
			Range	<0.10–0.20	28.7–38.4	0.56–1.04	1.54–2.01	689–962	0.016–0.022	1.64–2.67	<0.30–<0.70	0.01–0.05	2492–5393	79–84
			n	4	4	4	4	4	3	4	4	4	4	4
Striostrea cf. *mytiloides*	Merizo Pier	22 December 1998	Mean	<0.09	27.7	0.60	2.17	815	nd	2.73	6.48	<0.02	3571	84
			n	1	1	1	1	1	nd	1	1	1	1	1

Mean = geometric mean.
n = no. of individuals.
*n** = number of pooled samples analysed (5 oysters per pool).
nc = not calculable.
nd = no data.

[a] Hg concentrations as μg/g wet wt.

Table 9
Trace metals in other bivalve molluscs from Guam harbour waters (μg/g dry wt.)

Species	Location (site)	Date	Statistic	Ag	As	Cd	Cr	Cu	Hg[a]	Ni	Pb	Sn	Zn	% H_2O
Chamids														
Chama brassica	Apra Harbour (d)	9 June 1998	Mean	0.25	35.3	0.41	5.09	8.76	0.10	18.9	0.71	0.09	141	86
			Range	<0.12–0.58	23.6–51.6	0.23–0.68	3.97–6.22	6.84–11.2	0.033–0.312	14.9–25.1	<0.30–2.03	0.03–0.23	79.4–387	85–87
			n	3	3	3	3	3	2	3	3	3	3	3
Chama lazarus	Apra Harbour (b)	5 June 1998	Mean	nc	54.1	0.13	1.04	5.95	0.054	2.79	nc	0.03	97	84
			Range	<0.12	43.0–61.9	0.09–0.16	0.55–2.51	4.42–6.94	0.053–0.055	2.44–3.58	<0.28–<0.35	0.01–0.05	62.7–202	83–86
			n	3	3	3	3	3	2	3	3	3	3	3
Chama lazarus	Apra Harbour (c)	3 June 1998	Mean	nc	29.2	0.21	1.3	7.3	0.3	2.2	nc	0.010	78.3	80–85
			Range	<0.10–<0.10	28.4–30.0	0.21–0.21	1.13–1.42	6.99–7.57	0.064–1.041	1.98–2.53	<0.29–<0.30	<0.01–0.03	50.1–122	83
			n	2	2	2	2	2	2	2	2	2	2	2
Chama lazarus	Apra Harbour (d)	9 June 1998	Mean	nc	131	0.30	2.77	13.4	0.076	2.52	0.64	0.05	103	86
			Range	<0.10–0.23	73.6–331	0.18–0.75	1.94–2.90	8.55–129	0.036–0.193	1.49–7.81	<0.31–0.94	<0.01–0.37	70.1–161	84–87
			n	5	5	5	5	5	4	5	5	5	5	5
Chama lazarus	Apra Harbour (e)	9 June 1998	Mean	nc	31.9	0.11	1.04	6.57	0.037	1.67	nc	nc	82.2	83
			Range	<0.11	21.6–66.8	0.09–0.15	0.60–1.36	5.35–8.14	0.020–0.229	1.30–3.19	<0.31	<0.01	46.2–137	82–84
			n	4	4	4	4	4	4	4	4	4	4	4
Chama lazarus	Apra Harbour (f)	12 June 1998	Mean	nc	70	0.19	1.91	5.83	0.058	2.48	nc	0.01	102	84
			Range	<0.10–<0.12	67.5–104	0.11–0.35	1.38–2.78	5.17–6.52	0.030–0.150	1.78–3.85	<0.30–<0.34	<0.01–0.03	61.8–197	82–86
			n	5	5	5	5	5	4	5	5	5	5	5
Chama lazarus	Merizo Pier	22 December 1998	Mean	0.11	152	0.18	0.57	7.19	0.018	2.59	nc	0.02	170	81
			Range	<0.11–0.22	103–225	0.18–0.19	0.48–0.67	5.35–9.67	nd	1.90–3.53	<0.35–<0.67	<0.02–0.05	127–227	77–84
			n	2	2	2	2	2	1	2	2	2	2	2
Spondylids														
Spondylus? *multimuricatus*	Agana Boat Basin	18 December 1998	Mean	1.01	44.4	5.95	6.34	331	0.001	15.1	79.5	0.31	492	82
			Range	0.41–1.73	33.0–52.3	5.30–6.89	2.93–9.55	271–432	0.001–0.001	13.7–18.0	72.8–88.6	0.28–0.33	404–730	79–85
			n	3	3	3	3	3	2	3	3	3	3	3
Spondylus? *multimuricatus*	Agat Marina	21 December 1998	Mean	nc	88.0	5.64	3.27	153	0.003	33.8	2.88	0.11	448	86
			Range	<0.10–0.26	46.7–195	3.92–6.76	0.56–6.07	52.5–328	0.002–0.004	23.0–65.2	1.76–6.32	0.07–0.19	213–858	83–88
			n	10	10	10	10	10	5	10	10	10	10	10

Mean = geometric mean.
n = number of individuals analysed.
nc = not calculable.
nd = no data.
[a] Hg concentrations as μg/g wet wt.

Table 10
Trace metals in octopus, mantis shrimp and ascidians from Guam harbour waters (μg/g dry wt.)

Species	Location (site)	Date	Tissue	Ag	As	Cd	Cr	Cu	Hg[a]	Ni	Pb	Sn	Zn	% H_2O
Octopus														
Octopus cyanea	Apra Harbour (c)	6 June 1998	T	<0.12	96.4	0.06	<0.16	12.1	0.047	<0.18	<0.31	0.17	69.5	80
			L	4.40	44.3	7.82	1.87	5680	0.242	4.70	24.8	0.77	573	68
Mantis shrimp														
Gonodactylus sp.	Apra Harbour (e)	9 June 1998	M	0.27	5.06	0.36	0.57	11.0	0.075	<0.23	<0.39	0.09	125	81
			G	1.43	4.58	9.11	0.91	3195	0.085	<0.81	<1.38	0.25	148	75
Ascidians														
Ascidia sp.	Apra Harbour (b)	5 June 1998	W	0.33	3.92	0.23	1.03	5.58	0.013	0.60	0.54	0.01	22.8	95
Ascidia sp.	Apra Harbour (e)	9 June 1998	W	<0.49	3.05	0.36	5.08	3.48	0.038	<0.71	<1.47	0.13	95.8	93
Ascidia sp.	Apra Harbour (e)	9 June 1998	W	<0.13	2.74	0.08	1.41	3.10	0.011	0.84	0.64	<0.01	15.2	95
Rhopalaea sp.	Apra Harbour (b)	9 June 1998	W	<0.81	3.59	0.44	9.65	9.87	0.011	2.95	2.21	<0.01	34.1	95
Rhopalaea sp.	Apra Harbour (c)	3 June 1998	W	<0.27	2.31	0.20	3.08	8.57	0.009	0.89	2.91	<0.01	21.6	95
Rhopalaea sp.	Apra Harbour (d)	9 June 1998	W	0.27	2.85	0.13	1.82	6.66	0.007	1.64	1.94	<0.01	27.6	95
Rhopalaea sp.	Apra Harbour (e)	9 June 1998	W	<0.28	2.84	0.28	3.35	6.46	0.017	1.52	1.06	0.01	20.7	95

T = tentacle.
L = liver.
M = tail muscle.
G = gonad.
W = whole.

[a] Hg concentrations as μg/g wet wt.

conducted an extensive review of arsenic in fish tissue and concluded that while levels in muscle and liver tissues varied widely, most fell between 2 and 5 μg/g wet wt. The results of our study confirm this. However, Eisler also noted that hepatic arsenic values were usually higher than those found in muscle tissue, which is contrary to what we observed in the species analysed here.

Cadmium concentrations in Guam sediments ranged from less than 0.1μg/g, in the great majority of samples to 2.18 μg/g at Hotel Warf (close to biota sites a and b) in Apra Harbour (Denton et al., 2005). Cadmium concentrations in *Padina* sp. during the present study ranged from <0.1 μg/g, in samples from Agat Marina and Merizo Pier, to 0.5 μg/g in algae from Apra Harbour. These values compare well with levels found in related species from Singapore coastal waters (Bok and Keong, 1976) and the Australian Great Barrier Reef (Denton and Burdon-Jones, 1986a), but they are somewhat lower than those found in *Padina* sp. from elsewhere (Table 5). For example, Burdon-Jones et al. (1982) determined a maximum mean value of 1.4 μg/g in *Padina tenuis* from Townsville, Australia, while Sivalingam (1978) reported a high of 7.1 μg/g for the same species from Penang, Malaysia.

While algae are generally considered to be useful biological indicators of dissolved cadmium, the presence of elevated levels of iron and/or manganese in the water can significantly reduce cadmium uptake (Moore, 1991). This is thought to occur as a result of competition between the metals for cellular binding sites. Since harbours are typically enriched with both metals, some caution is required in interpreting cadmium contamination profiles in such areas from the analysis of algae alone. The work of Burdon-Jones et al. (1982) clearly demonstrated this problem. These researchers collected *Padina tetrostromatica* from Townsville Harbour, an area enriched with all three metals. Cadmium levels in algae, collected monthly for one year from this location, ranged from 0.2 to 0.6 μg/g compared with 0.2 to 1.2 μg/g at a control site.

Chromium concentrations in Guam harbour sediments ranged from 3.1 to 52.7 μg/g, and were indicative of fairly clean conditions overall with light to moderate enrichment in places (Denton et al., 2005). Surprisingly, the Merizo Pier area in the vicinity of the Cocos Island ferry terminal contained the highest values of sedimentary chromium. *Padina* from this site was also chromium enriched, 14 μg/g being recorded, compared with 0.57–2.98 μg/g in specimens from all other sites.

Chromium in sea cucumbers collected during the current investigation was largely confined to the hemal system. Concentrations ranged from 6.27 to 31.9 μg/g in *Bohadschia argus* and 0.88 to 8.58 μg/g in *H. atra*. Chromium concentrations in the muscle tissue of both species were mostly below a detection limit of ~0.2 μg/g. Fukai (1965) recorded a chromium concentration of 0.28 μg/g in muscle tissue of *Holothuria forksalli*, while Thompson and Paton (1978) reported a relatively high value of 2.2 μg/g in the body wall of *Molpadia intermedia* collected from a sediment disposal

Table 11
Trace metals in fish from Guam harbour waters (μg/g dry wt.)

Species	Location (site)	Date	Fork length (cm)	Tissue	Ag	As	Cd	Cr	Cu	Hg[a]	Ni	Pb	Sn	Zn	% H_2O
Acanthurus xanthopterus	Agana Boat Basin	18 December 1998	36.0	M	<0.10	8.17	<0.04	<0.13	0.30	0.165	<0.20	<0.37	<0.01	8.41	69
				L	<0.10	12.1	0.72	<0.15	20.4	1.028	<0.16	0.50	0.13	426	56
Acanthurus xanthopterus	Agana Boat Basin	31 December 1998	22.0	M	<0.09	9.08	<0.04	<0.13	0.39	0.024	<0.20	<0.36	<0.01	12.1	77
				L	<0.20	2.29	1.44	<0.31	17.4	0.180	<0.33	10.8	0.14	485	73
Acanthurus xanthopterus	Agana Boat Basin	30 December 1998	18.0	M	<0.08	7.61	<0.03	<0.11	0.42	0.017	<0.17	<0.32	0.02	8.76	78
				L	<0.30	1.49	0.21	<0.46	17.2	0.169	<0.48	1.32	0.07	290	74
Acanthurus xanthopterus	Agana Boat Basin	31 December 1998	14.5	M	<0.13	10.1	0.06	0.32	0.40	0.065	<0.27	<0.50	<0.01	10.9	78
				L	<0.90	0.54	<0.46	<1.39	10.4	0.333	<1.39	<2.70	nd	49.3	Wet
Acanthurus xanthopterus	Apra Harbour (c)	3 June 1998	38.0	M	<0.07	2.24	<0.04	<0.17	0.62	0.265	<0.16	<0.35	0.06	8.31	71
				L	<0.10	2.77	0.18	<0.14	5.33	1.060	<0.16	<0.27	0.28	394	50
Acanthurus xanthopterus	Apra Harbour (c)	3 June 1998	30.5	M	<0.06	3.78	<0.03	<0.15	3.28	0.067	<0.15	<0.32	0.11	12.7	76
				L	0.45	2.37	0.32	<0.19	97.2	0.356	<0.22	<0.38	0.63	435	63
Acanthurus xanthopterus	Apra Harbour (c)	3 June 1998	29.0	M	<0.08	6.38	<0.04	<0.18	0.51	0.060	<0.17	<0.37	0.13	12.4	76
				L	<0.09	1.25	0.16	<0.13	7.01	0.123	<0.15	0.32	0.21	277	58
Acanthurus xanthopterus	Apra Harbour (f)	12 June 1998	16.5	M	<0.09	9.00	<0.05	<0.22	1.72	0.018	<0.21	<0.45	0.20	13.5	81
				L	<0.53	3.38	0.48	<0.73	319	0.111	<0.82	<1.40	1.91	407	80
Acanthurus xanthopterus	Apra Harbour (f)	12 June 1998	15.5	M	<0.09	3.42	<0.05	<0.22	2.86	0.014	<0.21	<0.45	0.09	11.5	80
				L	<1.74	0.31	<0.69	<2.43	42.9	0.092	<3.65	<6.78	nd	47.9	Wet
Acanthurus xanthopterus	Apra Harbour (f)	12 June 1998	12.8	M	<0.12	2.56	<0.06	<0.30	4.00	0.037	<0.28	<0.61	0.22	17.7	81
				L	<0.87	4.31	0.71	<1.19	9.90	0.053	<1.35	<2.30	1.84	214	83
Acanthurus xanthopterus	Apra Harbour (f)	12 June 1998	11.0	M	<0.17	6.30	<0.09	<0.41	5.03	0.035	<0.39	<0.84	0.40	14.5	80
				L	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Balistoides viridescens	Merizo Pier	22 December 1998	18.5	M	0.28	52.4	0.07	<0.17	0.79	0.048	<0.26	<0.48	<0.01	24.3	82
				L	<0.18	8.88	0.71	<0.27	3.43	0.053	<0.29	<0.48	<0.01	392	53
Bolbometopon muricatum	Apra Harbour (c)	3 June 1998	52.0	M	<0.08	4.81	<0.04	<0.18	2.08	0.022	<0.17	<0.37	0.05	20.6	77
				L	<0.12	5.12	0.06	<0.16	5.39	0.020	<0.18	<0.31	0.18	28.9	30
Caranx ignobilis	Agana Boat Basin	30 December 1998	26.5	M	<0.09	1.60	<0.04	<0.13	0.60	0.068	<0.19	<0.36	<0.01	13	78
				L	<0.57	3.04	0.31	<0.87	12.2	0.112	<0.92	<1.54	0.07	89.9	67
Caranx melampygus	Apra Harbour (b)	5 June 1998	26.5	M	<0.07	0.90	<0.03	<0.16	1.42	0.660	<0.15	<0.33	0.10	14.0	74
				L	<0.25	2.35	0.54	<0.34	13.6	0.553	<0.38	<0.66	1.18	102	63
Caranx melampygus	Apra Harbour (e)	9 June 1998	33.0	M	<0.07	0.95	<0.03	<0.15	1.22	0.385	<0.15	<0.32	0.13	17.6	76
				L	<0.31	3.21	0.53	<0.42	25.2	0.557	<0.48	<0.81	0.43	154	71
Caranx sexfasciatus	Agana Boat Basin	30 December 1998	25.0	M	<0.09	3.02	<0.04	<0.12	0.64	0.062	<0.19	<0.35	<0.01	13.5	77
				L	<0.13	7.15	0.48	<0.20	11.6	0.158	<0.21	<0.36	0.01	92.7	68
Caranx sexfasciatus	Agana Boat Basin	30 December 1998	23.0	M	<0.09	1.58	<0.04	<0.13	0.67	0.151	<0.19	<0.36	<0.01	11.7	78
				L	<0.29	2.81	1.80	<0.45	10.6	0.227	<0.48	<0.79	0.29	112	77
Caranx sexfasciatus	Apra Harbour (c)	3 June 1998	22.0	M	<0.07	4.93	<0.03	<0.17	3.24	0.069	<0.16	<0.34	0.13	10.8	76
				L	<0.71	1.78	<0.29	<1.00	3.42	0.069	<1.50	<2.78	nd	25.4	Wet

(*continued on next page*)

Table 11 (*continued*)

Species	Location (site)	Date	Fork length (cm)	Tissue	Ag	As	Cd	Cr	Cu	Hg[a]	Ni	Pb	Sn	Zn	% H_2O
Caranx sexfasciatus	Apra Harbour (d)	9 June 1998	17.0	M	<0.09	24.2	<0.05	<0.22	3.42	0.137	<0.21	<0.45	0.09	13.6	77
				L	<0.47	2.69	4.76	<0.64	16.1	0.089	<0.72	<1.23	9.67	136	66
Cephalopholis sonnerati	Merizo Pier	22 January 1999	16.5	M	<0.15	2.98	<0.06	<0.20	0.45	0.026	<0.31	<0.57	<0.01	12.4	74
				L	<1.56	0.46	<0.65	<1.95	3.32	0.010	<1.95	<3.78	nd	23.7	Wet
Cheilinus chlorounus	Agat Marina	22 January 1999	22.5	M	<0.09	2.48	<0.05	<0.14	0.51	0.033	<0.13	<0.26	0.01	12.0	77
				L	<2.80	0.79	<1.44	<4.33	8.66	0.182	<4.33	<8.41	nd	27.8	Wet
Cheilinus fasciatus	Apra Harbour (c)	3 June 1998	24.5	M	<0.08	4.92	<0.04	<0.20	1.85	0.140	<0.19	<0.41	0.01	13.4	80
				L	<0.16	5.41	0.31	<0.22	5.40	2.197	<0.25	<0.42	0.38	83.4	59
Cheilinus fasciatus	Apra Harbour (c)	3 June 1998	24.5	M	<0.10	6.52	<0.05	<0.23	0.64	0.244	<0.22	<0.47	0.04	12.5	80
				L	0.31	4.06	0.35	<0.35	35.9	1.405	<0.40	<0.68	0.69	202	54
Cheilinus fasciatus	Apra Harbour (c)	3 June 1998	19.0	M	<0.08	18.7	<0.04	<0.20	0.62	0.152	<0.19	<0.40	0.01	10.1	77
				L	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Cheilinus trilobatus	Merizo Pier	22 December 1998	19.5	M	<0.08	1.65	<0.03	<0.11	0.32	0.021	<0.17	<0.32	<0.01	11.0	76
				L	<0.29	3.81	1.51	<0.45	9.86	0.060	<0.48	<0.80	<0.01	76.4	51
Cheilinus trilobatus	Merizo Pier	22 December 1998	19.0	M	0.10	2.48	<0.03	<0.12	0.31	0.023	<0.18	<0.33	<0.01	11.9	76
				L	<0.18	1.87	0.83	<0.28	3.78	0.051	<0.30	<0.50	<0.01	31.8	41
Ctenochaetus binotatus	Apra Harbour (d)	9 June 1998	21.0	M	<0.07	24.1	<0.03	<0.16	0.72	0.101	<0.15	<0.32	0.10	9.21	76
				L	<0.23	13.0	0.35	<0.31	61.8	0.672	<0.35	1.66	1.70	466	71
Ctenochaetus striatus	Apra Harbour (e)	9 June 1998	12.5	M	<0.16	0.63	<0.08	<0.37	1.71	0.013	<0.35	<0.76	0.16	10.0	80
				L	<0.49	1.42	0.66	<0.66	30.3	0.050	<0.75	2.08	0.74	540	77
Ctenochaetus striatus	Apra Harbour (f)	12 June 1998	13.0	M	<0.12	1.62	<0.06	<0.28	2.40	0.018	<0.26	<0.57	0.19	11.3	75
				L	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Ctenochaetus striatus	Agat Marina	22 January 1999	12.5	M	<0.21	5.17	<0.11	<0.34	0.51	0.003	<0.32	<0.65	0.07	11.8	75
				L	<1.41	0.15	1.67	<2.19	7.07	0.478	<2.19	<4.24	nd	192	Wet
Epibulus insidiator	Apra Harbour (c)	3 June 1998	24.5	M	<0.07	5.13	<0.04	<0.17	2.97	0.361	<0.16	<0.36	0.10	14.2	77
				L	<0.28	3.10	0.20	<0.38	7.97	0.758	<0.43	<0.73	1.39	42.9	52
Epibulus insidiator	Apra Harbour (e)	12 June 1998	16.0	M	<0.08	5.38	<0.04	<0.20	2.67	0.177	<0.19	<0.41	0.06	11.2	78
				L	<0.38	1.66	0.21	<0.52	11.6	0.308	<0.59	<1.01	0.83	73.3	57
Epinephelus merra	Merizo Pier	22 December 1998	24.0	M	<0.09	4.03	<0.04	<0.13	0.37	0.116	<0.19	<0.35	<0.01	13.8	76
				L	<1.04	0.93	2.74	<1.61	5.96	0.761	<1.61	<3.12	nd	53.3	Wet
Gerres argyreus	Agana Boat Basin	30 December 1998	24.0	M	<0.11	7.30	<0.04	0.58	0.33	0.116	<0.22	<0.41	<0.01	34.9	74
				L	<0.40	2.03	0.66	<0.62	5.42	0.110	<0.66	<1.10	0.21	52.8	75
Gerres argyreus	Agana Boat Basin	30 December 1998	15.5	M	<0.18	5.68	<0.07	<0.25	0.52	0.082	<0.38	<0.70	<0.01	48.9	79
				L	<3.67	2.74	<1.88	<5.66	3.00	0.119	<5.66	<11.0	nd	73.0	Wet
Gerres argyreus	Apra Harbour (d)	9 June 1998	16.5	M	<0.11	15.9	<0.06	<0.26	1.48	0.154	<0.25	<0.54	0.17	34.2	77
				L	4.09	3.35	1.00	<1.36	8.27	0.105	<1.54	<2.63	2.20	127	57
Gerres argyreus	Apra Harbour (d)	9 June 1998	15.0	M	<0.15	8.00	<0.07	<0.35	1.74	0.056	<0.33	<0.71	0.11	31.8	80
				L	<3.26	0.99	<1.30	<4.56	<3.59	0.101	<6.84	<12.7	nd	52.5	Wet

Gerres argyreus	Apra Harbour (d)	9 June 1998	14.5	M	<0.14	4.17	<0.07	<0.32	0.93	0.104	<0.30	<0.66	0.11	25.1	80
				L	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Gymnothorax javanicus	Apra Harbour (b)	5 June 1998	60.0	M	<0.08	4.25	<0.04	<0.19	0.70	0.580	<0.18	<0.39	0.12	31.7	79
				L	<0.15	4.38	0.17	<0.21	16.9	0.426	<0.24	<0.41	0.71	88.7	74
Leiognathus equulus	Agat Marina	22 January 1999	14.0	M	<0.18	1.39	<0.10	<0.29	0.91	0.029	<0.27	<0.55	0.04	24.3	78
				L	<2.26	0.55	<1.16	<3.49	2.46	0.055	<3.49	<6.77	nd	30.0	Wet
Lethrinus rubrioperculatus	Agat Marina	21 December 1998	24.5	M	<0.12	1.25	<0.05	0.23	0.42	0.214	<0.25	<0.46	<0.01	11.7	74
				L	<0.28	1.41	1.90	<0.44	9.13	0.190	<0.46	<0.77	0.02	52.6	51
Lethrinus rubrioperculatus	Merizo Pier	22 December 1998	20.5	M	<0.10	16.8	<0.04	<0.15	0.50	0.042	<0.22	<0.41	<0.01	13.1	75
				L	<0.16	7.04	0.87	<0.25	71.7	0.086	<0.27	<0.45	<0.01	375	61
Lutjanus kasmira	Merizo Pier	22 December 1998	13.5	M	<0.08	6.98	<0.13	<0.47	0.77	0.025	<0.70	<1.30	<0.01	14.7	81
				L	2.32	18.2	0.83	<1.58	6.86	0.122	<1.67	<2.78	0.11	61.2	45
Monodactylus argenteus	Agana Boat Basin	18 December 1998	14.5	M	<0.13	5.83	<0.05	<0.18	0.80	0.042	<0.26	<0.49	<0.01	22.2	75
				L	<0.45	2.20	0.53	<0.69	8.29	0.196	<0.73	<1.22	0.09	69.8	32
Monodactylus argenteus	Apra Harbour (d)	9 June 1998	17.8	M	<0.09	7.21	<0.04	<0.21	1.55	0.253	<0.19	<0.42	0.16	18.9	76
				L	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Monodactylus argenteus	Apra Harbour (d)	9 June 1998	17.0	M	<0.07	17.7	<0.03	<0.16	1.77	0.195	<0.15	<0.32	0.07	24.7	77
				L	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Monodactylus argenteus	Apra Harbour (d)	9 June 1998	17.0	M	<0.09	21.3	<0.04	<0.21	1.09	0.284	<0.20	<0.42	0.03	24.8	70
				L	5.14	9.45	0.67	<0.15	2.57	0.123	<0.17	<0.29	0.60	28.2	41
Monodactylus argenteus	Apra Harbour (d)	9 June 1998	17.0	M	<0.07	5.10	<0.04	<0.17	1.63	0.265	<0.16	<0.35	0.20	16.4	74
				L	0.85	2.52	4.15	<0.75	6.05	0.084	<0.85	<1.45	2.37	75.0	49
Monodactylus argenteus	Apra Harbour (d)	9 June 1998	16.8	M	<0.11	13.7	<0.05	<0.25	2.72	0.180	<0.24	<0.52	0.11	25.0	74
				L	1.31	12.4	1.38	<0.28	3.28	0.097	<0.32	<0.55	0.38	39.8	53
Monodactylus argenteus	Apra Harbour (d)	9 June 1998	16.5	M	<0.07	10.9	<0.03	<0.17	0.93	0.135	<0.16	<0.34	0.13	16.1	74
				L	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Naso annulatus	Apra Harbour (e)	12 June 1998	13.5	M	<0.22	1.64	<0.11	<0.52	7.76	0.018	<0.49	<1.07	0.28	26.1	81
				L	<1.75	0.36	<0.70	<2.45	9.44	0.084	<3.67	<6.28	nd	35.8	Wet
Naso unicornis	Apra Harbour (a)	5 June 1998	18.5	M	<0.07	0.87	<0.04	<0.17	2.11	0.015	<0.16	<0.35	0.13	13.3	81
				L	2.16	3.89	0.89	<0.48	337	0.071	<0.54	<0.92	1.27	12.4	79
Naso unicornis	Apra Harbour (b)	5 June 1998	25.0	M	<0.07	2.50	<0.04	<0.17	1.33	0.012	<0.16	<0.34	0.26	20.6	79
				L	2.43	5.89	1.97	<0.26	1920	0.085	<0.29	<0.50	1.40	219	75
Odenus niger	Agat Marina	22 January 1999	17.0	M	<0.12	47.3	<0.07	<0.20	0.75	0.027	<0.19	<0.38	<0.01	15.7	78
				L	<0.23	26.4	60.4	<0.38	40.3	0.197	<0.36	<0.72	0.06	438	58
Parupeneus barberinus	Merizo Pier	22 December 1998	26.0	M	0.20	15.5	<0.04	<0.15	0.47	0.066	<0.22	<0.42	<0.01	10.1	76
				L	<0.23	18.4	2.87	<0.35	33.8	0.042	<0.37	3.85	<0.01	108	74
Parupeneus barberinus	Merizo Pier	22 December 1998	16.0	M	<0.16	33.9	<0.07	<0.23	0.41	0.062	<0.35	<0.64	<0.01	11.1	76
				L	<2.63	9.78	<1.35	<4.07	4.55	0.057	<4.07	<7.90	nd	25.2	Wet
Parupeneus cyclostomus	Merizo Pier	22 December 1998	25.0	M	<0.11	15.7	<0.04	<0.16	0.58	0.063	<0.23	<0.43	<0.01	9.55	77
				L	1.28	4.92	0.94	<0.42	17.4	0.068	<0.44	<0.74	<0.01	65.6	70

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Table 11 (*continued*)

Species	Location (site)	Date	Fork length (cm)	Tissue	Ag	As	Cd	Cr	Cu	Hg[a]	Ni	Pb	Sn	Zn	% H_2O
Parupeneus multifasciatus	Merizo Pier	22 December 1998	17.5	M	<0.11	77.6	<0.04	<0.15	0.65	0.061	<0.22	<0.42	<0.01	12.7	88
				L	<1.39	13.0	<0.71	<2.15	3.80	0.109	<2.15	<4.18	nd	24.8	Wet
Saurida gracilis	Agana Boat Basin	30 December 1998	23.0	M	<0.10	2.80	<0.04	0.24	0.43	0.099	<0.21	<0.39	<0.01	16.9	74
				L	1.00	0.69	0.22	<0.46	33.4	0.143	<0.49	<0.81	0.19	133	53
Saurida gracilis	Agana Boat Basin	30 December 1998	19.5	M	<0.14	10.8	<0.06	<0.19	0.47	0.025	<0.29	<0.54	<0.01	12.6	74
				L	<1.39	9.52	<0.71	<2.15	65.1	0.053	<2.15	<4.18	nd	116	Wet
Saurida gracilis	Agana Boat Basin	30 December 1998	16.5	M	<0.23	9.44	<0.09	<0.33	0.40	0.024	<0.49	<0.92	<0.01	13	79
				L	<2.21	9.14	<1.13	<3.41	41.7	0.048	<3.41	<6.62	nd	38.3	Wet
Saurida gracilis	Agana Boat Basin	30 December 1998	15.5	M	<0.21	8.23	<0.08	<0.29	0.33	0.034	<0.44	<0.81	<0.01	11.4	73
				L	<3.00	9.25	<1.54	<4.64	64.4	0.041	<4.64	<9.00	nd	57.5	Wet
Saurida gracilis	Agat Marina	31 December 1998	20.0	M	<0.11	10.3	<0.04	<0.15	0.40	0.027	<0.23	<0.42	<0.01	13.1	76
				L	<0.40	7.47	0.29	<0.61	89.8	0.637	<0.65	<1.08	0.55	212	50
Saurida gracilis	Agat Marina	31 December 1998	19.0	M	<0.11	14.2	0.05	<0.15	0.29	0.027	<0.23	<0.42	<0.01	11.5	76
				L	<1.48	11.7	0.94	<2.29	30.0	0.052	<2.29	<4.44	nd	43.0	Wet
Saurida gracilis	Agat Marina	31 December 1998	17.5	M	<0.19	12.0	<0.08	<0.27	0.47	0.017	<0.41	<0.76	<0.01	12.1	73
				L	<1.34	7.96	<0.69	<2.08	39.9	0.018	<2.08	<4.03	nd	39.2	Wet
Saurida nebulosa	Apra Harbour (b)	5 June 1998	21.5	M	<0.07	1.20	<0.04	<0.18	0.79	1.157	<0.17	<0.36	0.18	11.3	79
				L	<1.09	0.14	<0.43	2.50	67.5	0.556	<2.28	<4.23	nd	54.1	Wet
Saurida nebulosa	Merizo Pier	22 December 1998	16.5	M	<0.20	7.12	<0.08	0.48	0.54	0.011	<0.42	<0.78	<0.01	12.5	68
				L	<2.30	1.78	<1.18	<3.56	51.7	0.012	<3.56	<6.91	nd	43.9	Wet
Scarus sordidus	Apra Harbour (e)	12-June 1998	16.0	M	<0.11	0.80	<0.06	<0.27	4.89	0.021	<0.25	<0.55	0.14	10.4	78
				L	<0.38	1.34	0.21	<0.52	3.13	0.072	<0.58	<1.00	0.31	22.0	38
Scarus sordidus	Apra Harbour (e)	9 June 1998	15.0	M	<0.10	0.88	<0.05	<0.23	2.37	0.019	<0.22	<0.48	0.12	10.9	78
				L	0.51	1.53	0.13	<0.38	5.01	0.024	<0.43	<0.74	0.28	30.7	37
Scarus sordidus	Apra Harbour (e)	12 June 1998	14.0	M	<0.13	0.92	<0.07	<0.31	1.80	0.024	<0.29	<0.64	0.11	10.7	78
				L	<0.23	1.75	0.13	<0.31	3.56	0.036	<0.36	<0.61	0.18	29.3	38
Siganus spinus	Agana Boat Basin	18 December 1998	15.0	M	<0.14	1.37	<0.06	<0.20	0.32	0.009	<0.29	<0.55	<0.01	10.3	77
				L	1.70	0.41	0.28	<0.96	188	0.010	<1.02	<1.70	0.08	167	21
Sufflamen chrysoptera	Apra Harbour (e)	12 June 1998	17.0	M	<0.14	18.4	<0.07	<0.33	1.65	0.226	<0.31	<0.67	0.25	27.5	80
				L	<0.18	13.5	0.33	<0.24	1.61	0.227	<0.28	<0.47	0.23	78.2	37
Valamugil engeli	Apra Harbour (c)	3 June 1998	37.5	M	<0.08	1.45	<0.04	<0.18	1.35	0.027	<0.17	<0.37	0.15	10.5	77
				L	<0.20	5.97	0.34	<0.27	73.1	0.064	<0.30	<0.52	0.92	187	74

M = muscle tissue.
L = liver tissue.
nd = no data.
Wet = analysis performed on wet tissue.

[a] Hg concentrations as μg/g wet wt.

Table 12
Trace metals in marine organisms (μg/g dry wt.) from other Pacific locations

Species	Location	Ag	As	Cd	Cr	Cu	Hg[a]	Ni	Pb	Sn	Zn	Reference
Brown algae												
Padina australis	Gt. Barrier Reef, Australia	nd	nd	0.4–0.6	nd	2.0–3.0	0.001–0.004	1.0–1.4	<0.9–5.0	nd	3.8–9.5	Denton and Burdon-Jones, 1986a
Padina commersonni	Singapore coastal waters	nd	nd	0.4–0.6	2.9–6.5	3.8–7.3	<0.01[b]	4.0–6.5	4.3–7.9	nd	20.7–50.1	Bok and Keong, 1976
Padina tenuis	Penang Island, Malaysia	nd	nd	7.1	25.6	5.7	1.025[b]	nd	17.1	nd	45.5	Sivalingam, 1978, 1980
Padina tetrostromatica	Townsville Harbour (lower reaches)	<0.1–0.4	nd	0.2–0.6	2.1–9.9	4.4–11.1	nd	0.7–5.6	2.0–10.2	nd	67.2–166	Burdon-Jones et al. 1982
Soft corals												
Gorgonian sp.	Gt. Barrier Reef, Australia	nd	nd	0.8–3.0	nd	2.8–4.3	all <0.003	all <0.3	all <0.7	nd	2.9–12.2	Denton and Burdon-Jones, 1986b
Sarcophyton acutangulum	Townsville coastal waters, Australia	<0.1	nd	1.6–9.7	nd	1.8–3.2	<0.06	0.13	0.8–1.5	nd	12.6–19.3	Burdon-Jones and Klumpp, 1979
Sinularia sp.	Gt. Barrier Reef, Australia	nd	nd	0.5–1.1	nd	2.3–3.2	all <0.002	all <0.4	all <0.8	nd	1.5–9.7	Denton and Burdon-Jones, 1986b
Hard corals												
Acropora formosa	Gt. Barrier Reef, Australia	nd	nd	0.02–0.2	nd	0.1–0.5	nd	0.1–0.8	all <0.4	nd	0.4–1.2	Denton and Burdon-Jones, 1986b
Fungia concinna	Gt. Barrier Reef, Australia	nd	nd	0.02–0.03	nd	0.3–0.5	nd	<0.1–0.3	all <0.3	nd	0.8–1.5	Denton and Burdon-Jones, 1986b
Fungia fungites	Gt. Barrier Reef, Australia	nd	nd	0.02–0.1	nd	0.2–0.4	nd	<0.1–0.2	<0.1–0.7	nd	0.6–1.1	Denton and Burdon-Jones, 1986b
Sea cucumbers												
Holothuria sp. (whole)	Townsville coastal waters, Australia	all <0.2	nd	all <0.2	<0.3–6.3	<0.3–3.5	nd	all <0.5	<0.4–3.8	nd	13.9–39.4	Denton, unpublished data
Molpadia intermedia (muscle)	Georgia Strait, Vancouver (dump site)	nd	nd	1.7	2.2	26	nd	1.7	1.4	nd	171	Thompson and Paton, 1978
Bivalves												
Crassostrea gigas	Hong Kong Waters	nd	nd	1.2[c]	nd	16.7[c]	0.06	nd	0.3[c]	nd	80.5[c]	Phillips et al., 1982
Saccostrea amasa	Townsville Harbour, Australia	<0.2–5.1	nd	0.9–3.9	<0.3–8.6	417–1775	nd	<0.2–1.8	<0.2–1.3	nd	1916–9073	Burdon-Jones et al., 1977
Chama iostoma	Townsville coastal waters, Australia	0.6–11.8	nd	2.3–12.1	nd	5.0–20.3	0.073–0.093	4.0–20.5	<0.5–10	nd	55.7–180	Burdon-Jones and Klumpp, 1979
Spondylus varians	Gt. Barrier Reef, Australia	nd	nd	7.5–9.2	nd	13.7–22.5	0.017	15.8–39.2	3.0–4.6	nd	34.7–72.6	Burdon-Jones and Denton, 1984
Cephalopods												
Sepia sp. (mantle)	Townsville Coastal Waters, Australia	<0.1	nd	0.1	0.9	0.7	0.15–0.25	<0.2	1.7	nd	4.1	Denton, unpublished data
Sepia sp. (liver)	Townsville Coastal Waters, Australia	1.8	nd	132	<0.3	660	0.19–0.39	3.8	<0.3	nd	331	Denton, unpublished data
Loligo formosana (tentacle)	Townsville Coastal Waters, Australia	0.1	nd	0.3	0.2	35.4	nd	<0.3	<0.2	nd	59.5	Denton, unpublished data
Loligo formosana (mantle)	Townsville Coastal Waters, Australia	<0.1	nd	0.1	<0.2	12.5	nd	<0.2	<0.2	nd	40.4	Denton, unpublished data
Loligo formosana (liver)	Townsville Coastal Waters, Australia	2.6	nd	8.5–27.5	<0.3	140–361	nd	<0.5	<0.4	nd	94.1–234	Denton, unpublished data
Octopus sp. (whole)	Japanese Waters	nd	nd	nd	nd	nd	nd	nd	1.0[c]	nd	106[c]	Matsumoto et al., 1964
Crustaceans (Shrimp)												
Penaeus merguiensis (whole)	Townsville Coastal Waters, Australia	0.9	nd	<0.1	<0.5	54.6	nd	<0.6	4.6	nd	59.1	Burdon-Jones et al., 1975
Penaeus merguiensis (muscle)	Townsville Coastal Waters, Australia	<0.4	nd	all <0.1	all <0.5	12.9–40.8	nd	all <0.4	all <0.6	nd	20.2–55.2	Denton, unpublished data

(*continued on next page*)

Table 12 (*continued*)

Species	Location	Ag	As	Cd	Cr	Cu	Hg[a]	Ni	Pb	Sn	Zn	Reference
Penaeus merguiensis (hepato)	Townsville Coastal Waters, Australia	3.9	nd	4.3	0.6	346	nd	11.7	<0.3	nd	138	Denton, unpublished data
Penaeus merguiensis (gonad)	Townsville Coastal Waters, Australia	0.5	nd	<0.2	<0.3	49.9	nd	0.7	2.5	nd	199	Denton, unpublished data
Fish (Muscle)												
8 spp.	Japan coastal waters	nd	nd	0.02–0.13	nd	nd	0.02–0.74[b]	nd	<0.1–0.6	nd	19.3–87.5	Einga, 1977
15 spp.	Townsville Coastal Waters, Australia	<0.1–0.2	nd	all <0.1	0.1–0.6	0.7–3.8	nd	<0.1–1.2	<0.2–1.0	nd	8.3–126	Burdon-Jones et al., 1975
50 spp.	Great Barrier Reef, Australia	nd	nd	all <0.1	nd	0.47–2.4	<0.002–1.9	all <0.5	all <0.7	nd	4.3–41.8	Denton and Burdon-Jones, 1986c
Fish (Liver)												
15 species	Townsville Coastal Waters, Australia	<0.2–3.0	nd	0.1–6.7	<0.6–2.8	5.7–540	nd	<0.2–7.4	<0.3–4.6	nd	49.6–588	Burdon-Jones et al., 1975
50 spp.	Great Barrier Reef, Australia	nd	nd	0.8–209	nd	1.1–1593	0.007–10.1	all <0.5	all <0.7	nd	62.9–2335	Denton and Burdon-Jones, 1986c

nd = no data.

[a] Hg determined as μg/g wet wt.

[b] Hg determined as μg/g dry weight.

[c] Metal determined on a wet weight basis.

site in Georgia Strait. These data imply that sea cucumbers are effective bioindicators of chromium contamination and that Guam harbour sediments are comparatively free of pollution by this element.

Copper concentrations in Guam harbour sediments ranged from 0.49 μg/g, in the outer Agana Boat Basin, to 181 μg/g at Hotel Wharf in Apra Harbour (Denton et al., 2005). Relatively high levels were also found at the western end of Commercial Port (72.7–127 μg/g) and off Dry Dock Island (35.7– 75.4 μg/g) in Apra Harbour (close to biota sites d and e, respectively), and adjacent to the Cocos Island ferry terminal at Merizo Pier (83.1–168 μg/g). Copper concentrations in *Padina* sp. from these locations were substantially above the 10 μg/g value suggested by Moore (1991) as typical of non-polluted waters. Elsewhere in this study copper concentrations in *Padina* sp. were low (0.57–2.98 μg/g).

Most of the sponges analysed during the current work contained reasonably high copper concentrations, but whether this was a reflection of elevated ambient copper availability, or the group's natural affinity for this element, is not entirely clear. The copper concentration profiles exhibited by *Dysidea* sp. appear to parallel those of *Padina* sp. insofar as identifying site d in Apra Harbour as the most copper enriched.

The highest copper concentration recorded in oysters during this study was 3047 μg/g, measured in a single specimen from the inner harbour area of Agana Boat Basin. The geometric mean copper concentration in 13 oysters analysed from this location was 1968 μg/g and is comparable with data from Townsville Harbour, Australia (Burdon-Jones et al., 1977). It also reflects the relatively high levels of copper in sediments (48–96 μg/g) from this location (Denton et al., 2005). Oysters from Apra Harbour were also copper enriched, with single specimen maxima ranging from 1483 μg/g at Dry Dock Island (site e) to 2971 μg/g at Echo Wharf (site f). In contrast, copper levels in oysters from Agat Marina and Merizo Pier were less than 1000 μg/g, suggesting lower copper availability in these areas. The copper concentration of 3195 μg/g found in the gonad of the stomatopod crustacean from Apra Harbour, ranks among the highest values ever recorded for this tissue.

Twenty nine of the 38 fish (76%) taken from Apra Harbour had muscle copper concentrations greater than 1 μg/g; values ranged from 0.51 to 7.76 μg/g with an overall geometric mean of 1.64 μg/g. Copper levels in fish flesh typically range between 0.5 and 2.0 μg/g in marine species (Denton and Burdon-Jones, 1986c) although values for fish from uncontaminated waters are usually less than 1.0 μg/g. Copper concentrations in fish muscle from all other Guam harbour sites were less than 1.0 μg/g.

Mercury concentrations in Guam harbour sediments ranged from 2.72 ng/g at Agat Marina, to 741 ng/g at Hotel Wharf in Apra Harbour. Moderate enrichment was also noted at or close to biota sites c (202–256 ng/g), d (107–264 ng/g), and e (160–428 ng/g) in Apra Harbour. It should be noted that all mercury data in Tables 4–11 and the ensuing discussions are expressed on a wet weight basis unless stated otherwise.

In this study, very low mercury concentrations were detected in *Padina* sp. (<0.002–0.026 μg/g), however, levels were consistently higher in specimens from Apra Harbour compared with those from elsewhere in the study area. A comparable range of values (<0.001–0.024 μg/g) was reported for 48 species of algae from relatively pristine sites along the Australian Great Barrier Reef (Denton and Burdon-Jones, 1986a). Sea cucumbers (*Stichopus variagatus*) from this location had mercury concentrations of <0.019–0.056 μg/g in their body wall muscle (Burdon-Jones and Denton, 1984). An almost identical range of 0.019–0.057 μg/g was determined in the same tissue of *B. argus* during the present study. A slightly higher range of 0.059–0.219 μg/g was noted for the same tissue of *H. atra*. In neither case did levels reflect those determined earlier in sediment samples. In contrast, mercury concentrations in the hemal tissue generally did, and were highest in both species from the Apra Harbour area. The utility of this tissue as an indicator of mercury contamination warrants further investigation.

Reported mercury concentrations in tropical oysters, from clean reef waters in northern Australia, ranged from 0.015 to 0.019 μg/g (Burdon-Jones and Denton, 1984). Similar values were found in oysters from Agat Marina and Merizo Pier during this study. Harbour environments typically contain a greater abundance of trace metals, including mercury, and a degree of elemental enrichment of the biota in such areas is to be expected. Concentrations found in oysters from Apra Harbour ranged from 0.022 to 0.078 μg/g and specimens from Agana Boat Basin contained marginally higher concentrations of 0.080–0.149 μg/g. Burdon-Jones and Denton (1984) reported that mercury in the chamid, *Chama iostoma*, from pristine, offshore areas of the Great Barrier Reef ranged from 0.006 to 0.032 μg/g. Nearer shore, the range widened from 0.018 to 0.326 μg/g. The authors concluded that chamids have potential as bioindicators of mercury pollution. Data from the current work tends to support their conclusion and infers enrichment in the Apra Harbour area when compared with previously reported data from elsewhere (Denton et al., 1999).

Mercury levels in fish form non-polluted areas are generally less than 0.2 μg/g (Denton and Burdon-Jones, 1986c), but it is now generally agreed that fish possess little ability to regulate tissue levels of mercury in the same way as they can essential elements like copper and zinc. Therefore, they serve as useful indicators of environmental contamination by this metal. In the present study, 11 out of 38 fish (29%) from Apra Harbour contained mercury in their axial muscle at concentrations above 0.2 μg/g. The highest value (1.157 μg/g) occurred in one specimen of lizardfish, *Saurida nebulosa*, from site b. Other species analysed from this site also contained relatively high mercury levels in their muscle tissue, including the conger eel, *Gymnothorax javanicus*, (0.58 μg/g) and the snapper, *Caranx malampygus* (0.66 μg/g). All three fish are predatory species and the latter two were among the largest specimens captured during the study.

Sedimentary nickel concentrations in Guam harbours ranged from <0.2 to 71.0 μg/g with areas of enrichment confined to Agat Marina and Merizo Pier. Baseline levels throughout the area were estimated at 1–3 μg/g (Denton et al., 1997). The data for nickel in organisms found in this study show that this element is of no environmental concern in Guam harbours.

Lead levels previously reported for Guam harbour sediments ranged from a low of <0.6 μg/g in all samples from Agat Marina to a high of 324 μg/g in sediments from the inner Agana Boat Basin, adjacent to a fuel station (Denton et al., 2005). Levels exceeding 100 μg/g were also found at Apra Harbour (close to biota sites b, d and f). Algae have a high affinity for lead and levels exceeding 100 μg/g have been reported in tropical species from relatively contaminated waters (Burdon-Jones et al., 1975; Agadi et al., 1978). Levels determined in *Padina* sp. from Guam harbours during the current work ranged from <0.25 to 8.07 μg/g and were relatively low by world standards. The highest levels were encountered in specimens taken in the commercial port area of Apra Harbour (sites c, d and e) and close to a fuel station at Merizo Pier. Some of the sponges exhibited relatively high lead concentrations, but no literature values were available for comparison.

Bivalves derive their metal loads primarily via the ingestion of food and suspended particulates, and are generally considered to be excellent indicators of trace metal pollution (Phillips, 1980). However, the utility of oysters as indicators of lead pollution is still a matter of some debate. The published data for lead in oyster tissues currently ranges from <0.1 to 84 μg/g, with the great majority of figures being less than 10 μg/g (Eisler, 1981), in keeping with the results found in the present study. Denton and Burdon-Jones (1982) examined the uptake and depuration kinetics of lead in the black-lip oyster, *Saccostrea echinata*. They found this bivalve's affinity for lead to be much lower than that shown for cadmium and mercury. Moreover, the biological half-life of lead in this species was relatively short, in the order of 30 days. It was concluded, therefore, that *S. echinata* was not a particularly sensitive indicator of lead, and that its usefulness as a long-term integrator of this element was questionable in areas where ambient levels fluctuated widely. This latter failing could certainly account for the high variability noted in specimens collected from Agana Boat Basin during the current study.

Spondylids are excellent indicator candidates and readily respond to changes in ambient lead availability. They also have a high affinity for this element, concentrating it almost exclusively in the enlarged kidney in much the same way as tridacnid clams (Denton and Heitz, 1991, 1993). Mean lead levels in whole soft tissue homogenates of *Spondylis ducalis* from remote locations of the Great

Barrier Reef ranged from 1.63 to 5.50 μg/g (Burdon-Jones and Denton, 1984). In this study, lead concentrations in whole soft tissues of *S. multimaricatus* from Agat Marina were of a similar order (1.8–6.3 μg/g), and suggest a relatively lead-free environment. Much higher concentrations were found in Agana Boat Basin (73–88 μg/g), clearly identifying this area as a zone of lead-enrichment. The hepatic lead value of 24.6 μg/g determined in an octopus specimen from Apra Harbour during the current work, is appreciably higher than those recorded in the same tissue of cuttlefish and squid from Townsville coastal waters (Denton et al., 1999).

Tin concentrations in Guam harbour sediments mostly ranged between 1 and 3 μg/g although values between 10 and 45 μg/g were occasionally observed (Denton et al., 2005). Levels of TBT and other organotin compounds in local harbour sediments, although currently unknown, are assumed to be extremely high in places, e.g., total tin concentrations of 148–1055 μg/g were found in sediments adjacent to a US naval ship repair and maintenance facility in the inner Apra Harbour area (Belt Collins Hawaii, 1993). These high values are probably related to the sandblasting and repainting of naval docks and vessels with organotin-based anti-fouling paints. The absence of comparative information for tin in many of the biotic groups studied in Guam harbours highlights the need for reliable baseline data for this element in tropical marine ecosystems.

Surprisingly high total tin concentrations were found in a number of sponges in this study, especially those taken from Agat Marina and Merizo Pier. The absence of any comparative data for sponges from elsewhere makes it difficult to draw any satisfactory conclusions from these observations. Nevertheless, some degree of tin-enrichment is indicated in both areas relative to the other harbour sites. Tin concentrations measured in soft and hard corals during the present study reinforce the harbour differences noted with sponges. The data also clearly show that soft corals have a greater affinity for this element than do their reef-building relatives. Data for both species of sea cucumber examined clearly indicate tin-enrichment at all sites other than those in Apra Harbour. Both muscle and hemal system portrayed similar distribution patterns for this element, although concentrations were generally much higher in the latter tissue. An exhaustive literature search failed to find any reference to tin in sea cucumbers from other areas of the world, but values found in this study are among the highest ever reported for invertebrates in general (Bryan, 1976; Eisler, 1981). They may reflect organotin uptake via ingestion of contaminated sediments.

Total tin concentrations in oysters from Guam harbours (<0.1–0.57 μg/g) are among the lowest reported for this group. Interestingly, the highest values encountered were in specimens collected from Apra Harbour in direct contrast to the pattern observed with the other invertebrate groups discussed above. Tin levels in all other bivalves examined were unremarkable.

Zinc concentrations in Guam harbour sediments ranged from baseline levels of 1–5 μg/g at uncontaminated sites, to 552 μg/g at Hotel Wharf in Apra Harbour. Values above 100 μg/g were also found in the inner Agana Boat Basin, close to biota sites c–e in Apra Harbour, and at adjacent to a fuel station at Merizo Pier (Denton et al., 2005). In the current study, clear evidence of zinc-enrichment was found in algae from Apra Harbour and at Merizo Pier. Within Apra Harbour, mean levels of zinc in *Padina* sp. ranged from 45.8 to 182 μg/g, peaking at site d at the western end of Commercial Port area. These values are very close to the range of means reported by Burdon-Jones et al. (1982) for *P. tetrstromatica* from the lower reaches of Townsville Harbour, and are much higher that the values found in Agana Boat Basin and Agat Marina (11–18.7 μg/g).

For corals, zinc concentrations of 38.9–143 μg/g were found in *Sinularia* sp. from Guam harbours. Mean values reported by Denton and Burdon-Jones (1986b) for this genus from the Great Barrier Reef ranged from 1.5 to 5.7 μg/g. Based on known inter-site difference in zinc availability, these authors concluded that soft corals show bioindicator potential for zinc, and the Guam data strongly support this conclusion. For hard corals, zinc concentrations ranged from a low of 1.29 μg/g in specimens from the outer Agana Boat Basin to a high of 7.66 μg/g in those from site d in Apra Harbour. The data therefore suggest that hard corals also have some bioindicator potential for this element.

The sea cucumbers examined during the present work revealed very little inter- and intra-site variability in body wall zinc concentrations. This finding suggests some metabolic regulation for zinc, at least in this tissue. Concentrations ranged from 8.33 to 18.0 μg/g in *B. argus,* and 12.6 to 21.2 μg/g in *H. atra*. Zinc concentrations in the hemal system were appreciably higher, particularly in specimens from sites b and d in Apra Harbour, where sedimentary zinc levels are known to be relatively high. These data imply that the hemal system of sea cucumbers is a better candidate tissue for determining zinc abundance in the marine environment.

Oysters rank amongst the greatest accumulators of zinc and reported concentrations range from <100 μg/g in clean waters to >100,000 μg/g in highly contaminated areas (Eisler, 1981). The high concentrations found in this study (up to 9789 μg/g) are typical of those for harbour locations where zinc contamination has been identified. Zinc concentrations in teleosts are generally lower than in most invertebrate groups and probably reflect their ability to regulate tissue levels of this metal within certain limits (Phillips, 1980). It is, therefore, not surprising that during the present investigation there was no consistent evidence to suggest zinc levels varied between trophic levels, or between harbour sites. The data did show, however, that inter-specific variations of zinc in liver tissue frequently span an order of magnitude or more. It was also evident that hepatic zinc concentrations generally bore no relationship to those in muscle tissue. Zinc concentrations in axial muscle showed relatively little inter- or intra-specific variation and ranged from 8.4 to 48.9 μg/g for all samples. Out of the 74 specimens analysed, only 15% had concentrations above 20 μg/g (mostly from Apra Harbour). The great majority of samples yielded values between 10 and 20 μg/g, a range similar to that found by Denton and Burdon-Jones (1986c) for fish from the Great Barrier Reef. On a fresh weight basis, the results of the current study also compare favourably with those reported by Powell et al. (1981) for eight tropical marine species from Bougainville Island, Papua New Guinea.

Overall, the results in this study indicate that Guam's harbours are relatively clean by world standards, although some enrichment of the biota with arsenic, copper, lead, mercury, tin and zinc was evident at certain sites. Oysters from Agana Boat Basin and Apra Harbour were contaminated with copper and zinc. Sea cucumbers and certain sponges from Apra Harbour contained relatively high concentrations of arsenic, probably resulting from fuel combustion and biocide use. Sea cucumbers and fish from Apra Harbour also contained higher mercury concentrations than specimens from the other harbours. For tin, concentrations were appreciably higher in sponges, soft corals and sea cucumbers from within the smaller boat harbours compared with those from Apra Harbour. These data are in line with findings elsewhere that marinas and small boat harbours are generally more prone to TBT pollution than larger ports.

None of the fish or shellfish showed metal concentrations that exceeded USFDA food standards or guidance limits (USFDA, 1998). The absence of an USFDA food standard for copper and zinc was noted in light of the high concentrations found in oysters from Agana Boat Basin and Apra Harbour. Concentrations in these bivalves frequently exceeded Australian food standards for both elements (ANZFA, 1999).

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Assessment of contamination by polychlorinated biphenyls and aliphatic and aromatic hydrocarbons in sediments of the Santos and São Vicente Estuary System, São Paulo, Brazil

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The Santos and São Vicente Estuary System is located in São Paulo State, the economic center of Brazil. The environmental problems of this area are most likely the result of intensive and continuous industrial and domestic effluent discharges (Lamparelli et al., 1993). The Cubatão industrial complex is situated in the Cubatão river basin, extends towards the estuary and is one of the most important petrochemical, chemical and metallurgical industrial poles of Brazil. It is composed of 23 large factories including a steel mill, an oil refinery, fertiliser, cement and chemical/petrochemical plants that sum up to 260 pollutant emission sources (CETESB, 1999). Around

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