Contaminant assessment of surface sediments from Tanapag Lagoon, Saipan, Commonwealth of the Northern Mariana Islands

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Tanapag Lagoon is a typical high-island barrier reef bordering the western shore of central Saipan in the western Pacific Ocean, and adjacent to the main port area on that island (Fig. 1a). It is about 9 km long and 3 km at its widest point, and covers an area of about 13 km^2. Large expanses of patch reef, interspersed with sand and rubble, provide for a diversity of shallow water habitats and harbour rich assemblages of flora and fauna (Doty and Marsh, 1977; Amesbury et al., 1979). In addition to its ecological significance, the Lagoon supports a variety of recreational activities, and local people traditionally harvest many of its fisheries resources for food.

Saipan (15°12′N, 145°43′E) is the major population centre of the Commonwealth of the Northern Mariana Islands. The island was ruled by Spanish, German, Japanese and USA administrations, prior to becoming a Commonwealth of the USA in 1986. The resident population is nearing 70,000 and there is a substantial influx of tourists, mainly from SE Asia and Japan. Saipan has been a shipping centre in Micronesia for about 400 years, but major increases in shipping activity have taken place since the 1940s during and following World War II. Over the last quarter century, the southern, nearshore section of Tanapag Lagoon has become heavily impacted by human activities. Primary sources of anthropogenic disturbances between Muchot Point and Flores Point, a distance of approximately 3 km, include a commercial port (Saipan Harbour) and bulk fuel facility, a sewer outfall, a recently closed municipal dump, and two small-boat marinas. The area is also heavily inundated by stormwater runoff during prolonged periods of wet weather.

The municipal dump is of particular concern to the local community, and is perhaps the greatest environmental problem facing Saipan today. It is located at the edge of Saipan Harbour, within the district of Puerto Rico, and covers an area of around 8 ha. Records indicate that the dump was first established shortly after World War II for the disposal of military heavy scrap metal (e.g., junk tanks and vehicles) and unexploded ordnance devices (Ogden, 1994). From that time until its closure in February, 2003, it served as a repository for every type of waste generated on island, including toxic chemicals of both military and civilian origin (Ogden, 1994). As the Puerto Rico dump was never designed for the safe disposal of hazardous wastes, and remediation strategies for the closed facility have yet to be implemented, local concerns over the mobilization of such chemicals into the abutting waters of Tanapag Lagoon are understandable.

The effects of the Puerto Rico dump and other anthropogenic perturbations on the indigenous biota within the Lagoon are largely unknown. In addition, basic data describing the abundance and distribution of persistent and potentially toxic pollutants within the system are also lacking. A preliminary contaminant assessment of surface sediments within the Lagoon was, therefore, undertaken and is reported herein. The study is seen as an important first step towards achieving sustainable development of the resources within this environmentally sensitive area.

Sediments were the focus of this investigation because they act as major sinks for many of the more persistent and potentially toxic organic and inorganic chemicals introduced into the aquatic environment (Ingersoll, 1995). Common examples include trace metals, polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs). The partitioning behaviour of these contaminants is such that they tend to accumulate in sediments to levels that are several orders of magnitude higher than in the surrounding water, and their deposition rates are generally related to their rates of input into the immediate area (Förstner, 1990). The chemical analysis of sediments can, therefore, provide a useful and convenient initial measure of environmental quality. In this study, surficial sediments from 41 sites within Tanapag Lagoon were analyzed for the three groups of pollutants noted above.

Sediment samples were collected in June 1999 from 32 nearshore stations along transect lines running approximately parallel to the coast, between Flores Point and Muchot Point (Fig. 1b). Sites were ~300 m–500 m apart, reducing to ~100 m, or less, in the vicinity of known or suspected point sources of contamination. Sediments from nine outer Lagoon sites were collected along three equally spaced transect lines (~1400 m apart) running seaward toward the barrier reef, between the same geographical boundaries (Fig. 1c). These sites were located approximately 500 m, 1250 m and 2250 m from the shore, or closest nearshore station, along each transect line. All sites

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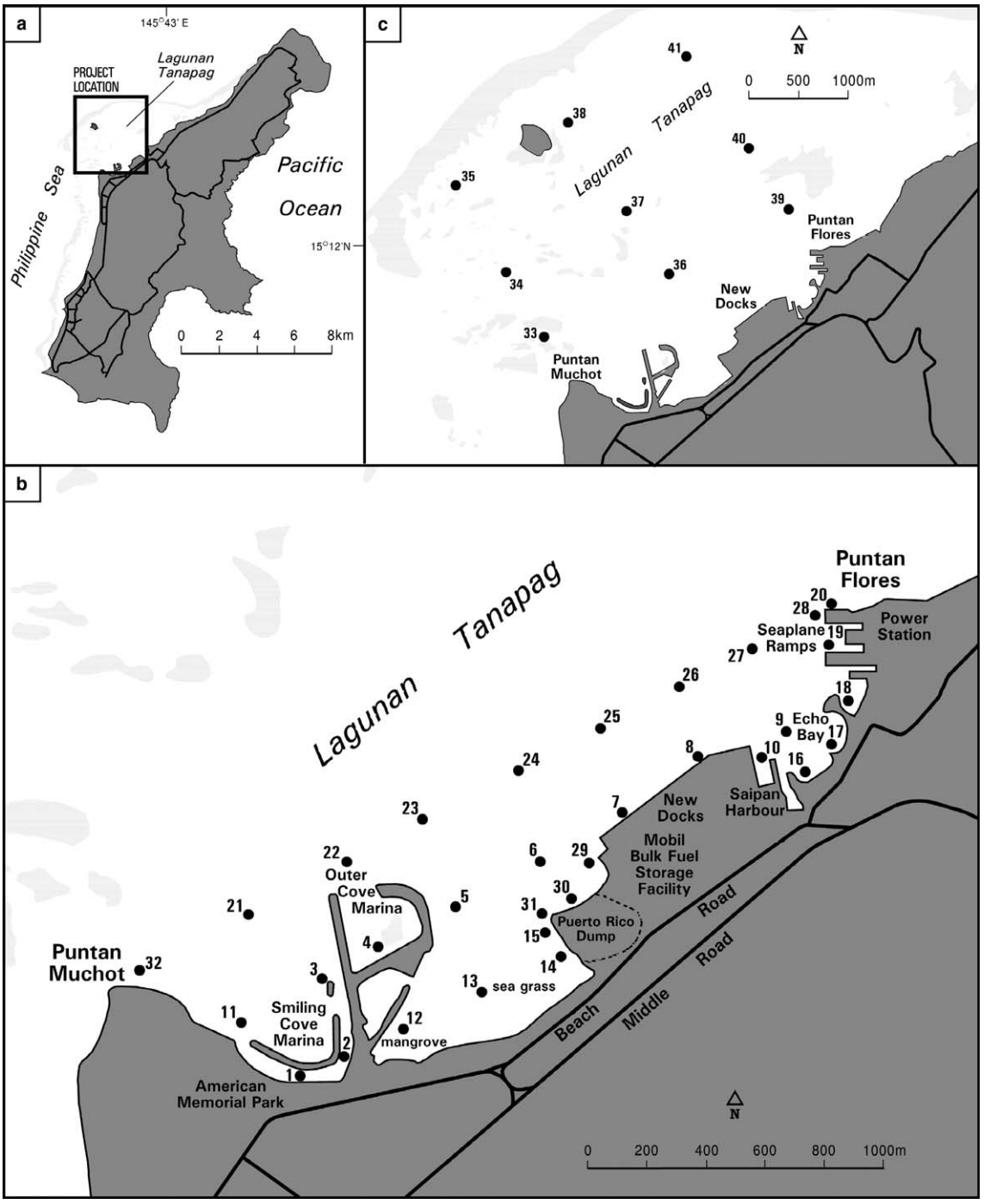

Fig. 1. Locations of (a) study area in Saipan, CNMI, (b) nearshore sampling sites and (c) offshore sampling sites in Tanapag Lagoon.

were located using digital-orthophoto-imagery maps with reference to prominent landmarks, compass bearings on fixed points of reference, and GPS.

Sediment sampling (15 cm cores), handling and storage procedures were as described in Denton et al. (2005), except that the samples were deep frozen after collection for air transport to Guam where the analyses were carried out. The sediments were analysed for particle size distribution, petrographic composition and total organic carbon (Denton et al., 2001) in addition to the chemical contaminants reported here. Samples for trace metal analyses were placed in acid cleaned, polyethylene vials and dried to constant weight at 60 °C while those for PCB and PAH analyses were air dried, in the dark, in shallow aluminium pans. Upon drying, sediments were disaggregated in non-contaminating containers with a heavy Teflon rod.

Samples for metal analyses were sieved through a 1 mm nylon sieve and stored in polyethylene vials at room temperature until analysis. Samples for PCB and PAH analyses were sieved through a 1 mm stainless steel screen into clean glass vials and stored at −20°C. Analytical methods for the above contaminants were adapted from the USEPA SW-846 protocols (1996) and the NOAA National Status and Trends Program for Marine Environmental Quality (NOAA, 1993). Appropriate quality control and quality assurance procedures including full procedural blanks, matrix spikes, and certified reference materials were built into the analytical protocols. Full details on procedures are given in Denton et al. (2005, in press-a, in press-b). A summary of the data obtained for standard reference materials is given in Table 1.

The results of the trace metal, PCB and PAH analyses are given in Tables 2–4. The trace metals data indicated that there are no major contamination issues. The offshore sites showed very low concentrations of all metals with a few exceptions at site 36, near a recently constructed sewage outfall, where several values above background were determined. In the nearshore areas, concentrations were generally higher, particularly adjacent to the dump (sites 14 and 15), the new docks (site 7), the port (site 10) and small-boat marinas (sites 1, 2, and 12). The only concentrations of real concern, however, were those of mercury at site 7 (near old sewage outfall) and arsenic, copper, lead, mercury and zinc at site 14, which were high enough to indicate possible biological effects (MacDonald et al., 1996). In general, trace metal concentrations decreased on moving away from the shore and from the previously identified likely anthropogenic sources.

The PCB data are presented in Table 3 as total PCB concentrations (sum of detectable congeners from the 20 congener standard) and rank order of abundance of PCB homologues in sediment samples from each site. All offshore sites in Tanapag Lagoon were relatively free of contamination, with total PCB concentrations consistently below 1 ng/g. Somewhat higher values were observed closer to the shore with a maximum mean value of 16.6 ng/g

Table 1
Analytical data for standard reference materials

Analyte	Certified value (μg/g dry wt.)		This study (μg/g dry wt.)		*n*
	Mean	Range	Mean	Range	
Metals (PriorityPollutnT™/CLP inorganic soils [Catalog No. PPS-46; Lot No. 242]*)*					
Arsenic	58.6	41.1–76.1	57.5	51.3–63.8	5
Cadmium	185	143–228	195	183–208	5
Chromium	50.7	35.7–65.7	41.3	38.1–44.6	5
Copper	63.6	52.1–75.1	61.9	55.9–67.9	5
Lead	56.6	43.1–70.1	53.2	46.4–60.0	5
Mercury	1.29	0.83–1.74	1.19	0.96–1.42	5
Nickel	75.4	59.0–91.7	72.9	62.7–83.2	5
Silver	149	110–188	155	145–165	5
Tin	73.1	52.7–93.4	76.5	64.3–88.6	5
Zinc	69.6	51.1–88.1	64.8	58.2–71.4	5
PCBs (RTC PCB in soil [Catalog No. CRM911-050; Lot No. J911])					
Aroclor 1254	1.34	0.61–2.07[a]	1.13	0.57–1.69	15
PAHs (RTC PAH contaminated soil/sediment [Catalog No. CRM104-100; Lot No. CR12]*)*					
Naphthalene	0.77	0.0–1.57[a]	NC	0.0–0.48	10
Acenaphthylene	1.21	0.0–2.98	0.05	0.0–0.13	10
Acenaphthene	0.77	0.27–1.28	0.38	0.0–1.48	10
Fluorene	0.65	0.25–1.05	1.37	0.0–4.07	10
Phenanthrene	5.79	2.11–9.48	3.90	1.74–6.05	10
Anthracene	1.44	0.08–2.80	2.26	0.33–4.18	10
Fluoranthene	24.6	4.53–44.6	16.3	10.7–21.8	10
Pyrene	15.0	0.0–30.7	9.32	2.50–16.2	10
Benzo(*a*)anthracene	7.98	2.09–13.9	3.48	2.31–4.64	10
Chrysene	8.60	3.39–13.8	6.59	0.64–12.5	10
Benzo(*b*)fluoranthene	(9.69)	None given	4.87	3.52–6.23	10
Benzo(*k*)fluoranthene	(5.10)	None given	2.62	1.90–3.35	10
Benzo(*a*)pyrene	5.09	1.56–8.63	3.42	1.13–5.71	10
Benzo(*ghi*)perylene	3.58	0.0–8.08	3.89	2.10–5.68	10
Indeno(1,2,3,-*cd*)pyrene	4.46	0.0–9.09	2.00	1.24–2.77	10
Dibenzo(*a,h*)anthracene	(1.55)	None given	5.77	3.42–8.12	10

PAH values listed in parentheses are not certified and are listed for information only. NC = not calculable.
[a] Certificate of analysis for PCB and PAH standard reference materials gives only the 95% prediction interval about the certified mean.

Table 2
Trace metal concentrations in sediments from Tanapag Lagoon, Saipan (μg/g dry wt.)

Site	Statistic	Ag	As	Cd	Cr	Cu	Hg[a]	Ni	Pb	Sn	Zn
1 (a–c)	Mean[b]	NC	6.71	NC	6.55	16.7	47.4	1.38	7.50	1.51	25.7
	Range	<0.11–<0.12	6.08–7.50	<0.04–0.06	5.30–8.01	13.6–19.6	40.5–53.1	1.13–1.58	5.77–8.99	1.27–1.69	22.0–29.6
2 (a–c)	Mean	NC	6.20	NC	5.65	9.44	33.0	0.85	4.79	1.15	16.4
	Range	<0.10–<0.12	5.53–6.67	<0.03–0.11	5.25–6.08	8.18–10.8	30.4–36.5	0.67–1.16	4.08–5.43	0.89–1.64	15.0–17.2
3 (a–c)	Mean	NC	2.49	NC	3.58	4.13	25.4	NC	2.08	0.76	8.93
	Range	<0.11–<0.12	2.10–3.29	<0.04–<0.04	2.82–4.31	2.72–6.46	23.6–28.8	<0.20–0.62	1.09–3.15	0.59–0.98	5.89–11.0
4 (a–c)	Mean	NC	5.79	NC	6.71	12.2	85.2	1.60	13.6	3.45	34.6
	Range	<0.09–<0.11	4.64–6.94	<0.03–0.15	5.70–8.27	8.73–14.5	82.1–87.4	1.15–2.03	8.73–18.0	2.68–4.40	25.6–42.3
5 (a–c)	Mean	NC	3.95	NC	1.66	0.75	35.6	NC	1.09	0.35	5.37
	Range	<0.08–<0.12	3.40–4.61	<0.03–<0.04	1.00–5.47	0.40–1.25	29.3–40.3	<0.15–<0.21	0.34–2.40	0.31–0.40	3.68–12.0
6 (a–c)	Mean	NC	6.81	NC	5.94	6.09	100	1.64	26.2	36.1	40.5
	Range	<0.10–<0.23	3.95–9.78	<0.03–0.30	3.65–9.93	4.18–10.1	86.0–127	0.61–4.89	6.61–121	1.53–209	19.7–186
7 (a–c)	Mean	NC	4.11	0.08	3.25	7.87	347	1.58	6.49	1.27	19.8
	Range	<0.10–<0.12	3.65–4.82	0.04–0.13	2.86–3.81	5.97–11.5	113–862	1.24–2.05	4.97–8.49	1.22–1.31	15.3–41.6
8 (a–c)	Mean	NC	3.28	0.12	4.61	7.44	85.3	2.06	7.53	3.88	21.5
	Range	<0.10–<0.12	2.67–3.83	0.07–0.28	4.19–5.46	6.25–9.46	73.9–111	1.97–2.16	5.67–11.4	3.34–4.68	17.4–26.9
9 (a–c)	Mean	NC	3.76	0.08	3.53	5.40	83.8	1.27	4.14	1.22	15.4
	Range	<0.10–<0.11	3.25–4.37	0.07–0.11	3.19–3.68	4.39–6.38	78.7–87.0	1.07–1.48	3.93–4.60	1.11–1.37	14.3–15.9
10 (a–c)	Mean	NC	3.65	0.10	5.90	12.8	109	2.07	9.47	2.95	26.2
	Range	<0.09–<0.12	3.50–3.86	0.08–0.11	5.56–6.33	11.8–13.8	98.8–119	1.91–2.20	8.72–10.5	2.44–3.30	23.9–29.4
11 (a–c)	Mean	NC	1.59	0.06	3.35	2.27	21.3	0.88	0.86	0.55	5.28
	Range	<0.09–<0.12	1.34–2.17	0.03–0.09	2.95–3.60	1.70–3.09	17.1–25.5	0.77–1.07	0.45–1.34	0.47–0.65	3.46–6.99
12 (a–c)	Mean	NC	2.46	0.21	9.01	8.94	67.7	2.13	7.36	1.90	22.7
	Range	<0.10–<0.12	2.07–2.81	0.19–0.26	7.42–10.2	6.76–11.4	55.5–83.3	1.74–2.83	6.13–8.28	1.45–2.29	17.9–25.8
13 (a–c)	Mean	NC	4.37	0.13	4.02	2.43	33.8	0.85	3.85	0.90	13.8
	Range	<0.10–<0.12	4.28–4.51	0.08–0.20	3.54–4.71	1.97–3.31	29.7–39.8	0.72–0.96	2.89–5.04	0.80–1.07	11.6–16.0
14 (a–c)	Mean	NC	10.0	0.58	9.67	27.8	101	5.06	40.6	3.54	127
	Range	<0.10–<0.11	9.56–10.8	0.54–0.61	8.84–11.0	25.6–32.5	97.7–106	4.74–5.23	36.1–43.4	3.34–3.94	119–134
15 (a–c)	Mean	NC	5.73	0.24	5.03	8.87	52.7	1.52	12.0	2.15	38.6
	Range	<0.09–<0.12	3.98–7.49	0.21–0.31	3.67–9.44	6.77–11.9	41.8–60.4	1.11–1.80	9.47–15.1	1.98–2.47	31.0–46.5
16 (a–c)	Mean	NC	1.46	0.10	1.40	1.42	21.0	0.33	1.29	0.62	3.24
	Range	<0.09–<0.12	1.05–2.11	0.09–0.12	0.91–1.71	0.74–1.99	14.7–27.7	0.22–0.49	0.70–1.79	0.58–0.68	1.84–4.51
17 (a–c)	Mean	NC	1.78	0.14	1.48	1.19	21.8	NC	1.94	0.63	5.01
	Range	<0.09–<0.12	1.72–1.85	0.11–0.18	1.18–1.91	0.98–1.54	17.6–25.6	<0.16–0.37	1.53–2.27	0.59–0.71	4.38–6.38
18 (a–c)	Mean	NC	1.91	0.12	1.54	0.92	18.4	NC	0.90	0.69	5.27
	Range	<0.10–<0.12	1.63–2.20	0.09–0.14	1.30–1.68	0.70–1.01	13.4–25.4	<0.17–0.25	0.64–1.52	0.63–0.72	3.76–9.20
19 (a–c)	Mean	NC	2.81	NC	2.24	6.95	22.6	NC	2.92	1.00	11.3
	Range	<0.10–<0.11	2.25–3.30	<0.03–<0.04	1.86–2.47	5.03–14.4	18.0–25.3	<0.21–0.41	2.49–3.42	0.91–1.07	10.2–12.9
20 (a–c)	Mean	NC	3.36	NC	3.05	4.67	23.7	0.65	7.84	1.35	17.7
	Range	<0.10–<0.12	2.87–4.25	<0.03–0.11	2.73–3.63	2.82–7.60	16.8–31.6	0.46–1.02	5.32–12.9	1.11–1.52	12.2–25.6
21 (a–c)	Mean	NC	1.33	NC	2.85	0.22	10.9	0.28	NC	0.30	1.63
	Range	<0.09–<0.12	1.12–1.85	<0.03–<0.04	2.37–3.74	0.14–0.27	9.46–12.2	0.16–0.40	<0.32–<0.42	0.23–0.48	1.20–2.72
22 (a–c)	Mean	NC	1.66	NC	2.12	0.30	9.73	0.31	NC	0.32	2.84
	Range	<0.10–<0.12	1.45–1.86	<0.03–0.08	1.82–2.36	0.13–0.52	6.34–13.1	<0.20–0.53	<0.36–1.95	0.22–0.47	1.60–21.0
23 (a–c)	Mean	NC	1.76	NC	2.13	0.35	18.1	0.29	NC	0.36	2.63
	Range	<0.09–<0.11	1.71–1.86	<0.03–<0.04	2.02–2.35	0.29–0.45	17.0–19.7	0.20–0.46	<0.32–<0.40	0.29–0.41	2.21–3.13
24 (a–c)	Mean	NC	2.56	NC	2.67	1.90	39.5	0.57	1.33	0.85	6.53
	Range	<0.10–0.33	2.32–2.70	<0.03–<0.04	2.36–2.89	1.46–2.22	37.0–45.1	0.39–0.76	0.94–1.67	0.76–1.00	5.39–7.17
25 (a–c)	Mean	0.28	2.86	0.06	3.18	3.61	52.7	0.88	1.29	0.72	8.99
	Range	0.23–0.32	2.32–3.20	0.05–0.07	2.94–3.53	3.29–3.91	47.7–56.5	0.67–1.06	0.93–1.65	0.50–1.19	8.12–9.94
26 (a–c)	Mean	0.17	3.95	NC	3.18	3.46	60.3	1.35	2.06	0.67	8.86
	Range	0.07–0.31	3.25–4.63	<0.03–0.08	3.04–3.36	2.88–4.06	43.5–86.3	1.13–1.70	1.82–2.28	0.49–0.81	7.98–10.3
27 (a–c)	Mean	0.27	3.88	NC	3.73	4.69	44.4	1.42	2.12	0.78	11.6
	Range	0.22–0.30	3.38–4.36	<0.04–0.12	3.42–4.11	4.03–5.19	40.3–47.6	1.12–1.84	1.56–2.52	0.55–0.98	10.1–13.6
28 (a–c)	Mean	NC	1.99	NC	2.27	1.02	12.1	0.35	NC	0.18	2.42
	Range	<0.08–<0.10	1.87–2.09	<0.03–<0.04	2.14–2.52	0.85–1.20	11.6–12.4	0.23–0.47	<0.28–<0.35	0.15–0.22	2.18–2.75
29 (a–c)	Mean	0.16	3.14	NC	2.71	5.13	55.0	0.78	3.55	1.22	15.2
	Range	0.10–0.24	2.41–2.59	<0.03–<0.04	2.38–2.91	3.94–6.94	41.4–85.2	0.72–0.86	2.44–5.20	0.86–1.78	12.3–21.9
30 (a–c)	Mean	0.17	4.52	0.06	3.12	8.31	64.6	1.16	6.90	1.93	25.8
	Range	0.12–0.26	4.05–5.60	0.05–0.10	2.64–3.72	5.97–12.6	55.1–82.3	0.84–1.80	4.36–9.48	1.45–2.30	20.8–31.4
31 (a–c)	Mean	NC	2.91	NC	2.74	2.02	30.7	NC	6.68	7.05	13.4
	Range	<0.08–<0.12	2.64–3.29	<0.03–0.08	2.13–3.38	1.36–2.49	22.9–41.7	<0.16–0.31	3.56–23.7	1.45–68.1	7.90–31.9

Table 2 (*continued*)

Site	Statistic	Ag	As	Cd	Cr	Cu	Hg[a]	Ni	Pb	Sn	Zn
32 (a–c)	Mean	NC	1.38	NC	2.65	0.62	12.1	NC	NC	0.08	1.76
	Range	<0.08–<0.11	1.14–1.58	<0.03–<0.04	2.29–2.98	0.48–0.75	9.28–14.0	<0.13–<0.17	<0.04–0.88	0.03–0.29	1.55–2.06
33 (a–c)	Mean	NC	0.82	NC	2.43	NC	5.37	NC	NC	NC	0.53
	Range	<0.07–<0.11	0.73–0.89	<0.03–<0.04	2.11–3.44	<0.07–0.11	3.46–7.01	<0.12–<0.18	<0.26–<0.37	<0.02–0.08	0.41–0.58
34 (a–c)	Mean	NC	0.69	NC	1.51	NC	3.95	NC	NC	0.10	0.15
	Range	<0.09–<0.11	0.62–0.74	<0.03–<0.04	1.40–1.64	<0.08–<0.11	2.78–5.21	<0.14–<0.17	<0.29–<0.37	0.07–0.14	0.09–0.45
35 (a–c)	Mean	NC	0.90	NC	1.11	NC	3.57	NC	NC	0.08	0.10
	Range	<0.08–<0.11	0.62–1.09	< 0.03–<0.04	0.96–1.17	<0.08–<0.11	3.21–4.25	<0.13–<0.17	<0.27–<0.37	0.04–0.14	0.05–0.27
36 (a–c)	Mean	NC	1.53	NC	2.20	0.78	16.2	0.36	NC	0.24	2.09
	Range	<0.08–<0.10	1.44–1.59	< 0.03–<0.04	2.03–2.44	0.68–0.86	13.4–20.9	0.26–0.61	<0.28–<0.35	0.15–0.34	1.68–2.96
37 (a–c)	Mean	NC	1.87	NC	1.43	NC	5.89	NC	1.20	NC	0.78
	Range	<0.08–<0.11	1.72–2.04	<0.06–0.13	1.30–2.25	<0.08–0.28	5.25–6.98	<0.14–<0.18	1.03–1.35	<0.02–0.22	0.39–3.74
38 (a–c)	Mean	NC	0.99	NC	2.07	NC	3.54	NC	NC	NC	NC
	Range	<0.08–<0.10	0.89–1.13	<0.05–<0.06	1.83–2.32	<0.07–<0.10	2.84–4.08	<0.13–<0.17	<0.55–0.75	<0.02–0.03	<0.03–<0.04
39 (a–c)	Mean	NC	1.57	NC	2.38	NC	4.54	NC	NC	0.05	NC
	Range	<0.08–<0.10	1.53–1.63	<0.05–<0.06	2.26–2.60	<0.08–<0.10	4.02–5.16	<0.14–<0.16	<0.45–0.88	0.04–0.06	<0.03–0.10
40 (a–c)	Mean	NC	1.15	NC	1.62	NC	2.88	NC	NC	NC	NC
	Range	<0.06–<0.09	0.97–1.35	<0.04–<0.06	1.45–1.76	<0.06–<0.09	2.14–4.46	<0.11–<0.16	<0.36–<0.53	<0.02–0.08	<0.02–<0.03
41 (a–c)	Mean	NC	0.76	NC	1.06	NC	5.16	NC	NC	NC	NC
	Range	<0.07–<0.11	0.56–1.05	<0.05–<0.07	0.96–1.17	<0.07–<0.11	4.76–5.39	<0.13–<0.19	<0.42–<0.62	<0.02–0.15	<0.03–<0.04

NC = not calculable.

[a] Mercury data expressed as ng/g dry wt.

[b] Mean = geometric mean.

at site 14, adjacent to the dump. Relatively high mean values were also found at site 9 (11.1 ng/g) and site 10 (8.53 ng/g). The PCB profile from site 9 resembled the technical PCB mixture Aroclor 1260, whereas the profile from site 14 was more like a combination of Aroclor 1260 and possibly Aroclor 1254, both commercial preparations commonly used in electrical transformers. Sediments previously analysed from an area that now corresponds to the new docks, contained total PCB concentrations (as Aroclor 1254) of 14–24 ng/g (Unitek, 1993), which is close to levels found at nearby sites 9 and 10 during the current work. However, the data from around the dump do not support earlier findings of up to 1528 ng/g (as Aroclor 1260) in sediments bordering this facility (DEQ, 1987), but this may be a consequence of discrete and highly localised sources of contamination and/or burial of enriched sediments under more recent deposits. In any event, there does not appear to be a major PCB threat in surface sediments to benthic communities in this area at the present time.

In the Tanapag sediments, almost all of the samples with detectable concentrations of PCBs were dominated by Cl_5–Cl_7 homologues. This may reflect the natural aging of PCBs in the environment, indicating that no new discharges of PCBs have occurred in the area in recent times. Alternatively, most of the PCB contamination in Tanapag may be associated with Aroclor 1260, which contains almost no congeners with less than 4 Cl atoms per molecule. The relatively high abundance of the Cl_8–Cl_{10} homologues in a number of samples lends weight to this hypothesis (Ballschmiter et al., 1989; De Voogt et al., 1990).

PCB profiles in Tanapag Lagoon sediments varied considerably between stations, but certain trends were apparent. The two most frequently encountered congeners were PCBs 101 and 153, which were found in 57% and 59% of the sediment cores respectively. These were followed in decreasing order by PCB 180 (53%) > PCB 187 (49%) > PCB 209 (40%) > PCB 170 (37%) > PCB 206 (31%) > PCB 138 (21%) > PCB 8 (13%) > PCB 195 (10%) > PCB 128 (9%) > PCB 118 (6%) > PCB 18 (2%). A similar ranking occurred when these congeners were placed in order of overall abundance for those sites yielding quantifiable levels of PCBs.

In their review of the literature, McFarland and Clarke (1989) listed all the above congeners in environmental samples from elsewhere and also noted that PCBs 101 and 153 were the most commonly encountered. A notable differences between the global data and that presented here was that PCBs 18 and 118 were rarely encountered in the Tanapag samples although frequently found elsewhere, while the reverse was true for PCB 209. Such differences further suggest that Aroclor 1260 is the major PCB source in Tanapag Lagoon.

The PAH data for the Tanapag Lagoon samples is summarised in Table 4. PAHs were detected in 33% of the offshore sites and 81% of the nearshore sites. The Σ_{16}PAH concentrations in the offshore samples were very low (<0.5 μg/g), but closer to the shore, concentrations were appreciably higher rising to 2.44 μg/g near the docks (site 7) and 3.23 μg/g near the dump (site 30). The PAH profiles were dominated by higher molar mass compounds, but whether these were predominantly derived from combustion or aged petrochemical spills could not be determined. The most frequently encountered PAHs were the 4-ringed members (chrysene, benzene(*a*)anthracene and pyrene), which occurred in 60–70% of the samples. The frequent

Table 3
PCB concentrations in sediments from Tanapag Lagoon, Saipan (ng/g dry wt.)

Site	Σ_{20} PCB concentration			Overall order of abundance of detectable PCB homologues (Cl_2B–$Cl_{10}B$)
	Mean	Median	Range	
1 (a–c)	4.09	3.11	3.09–6.07	$Cl_7B > Cl_{10}B > Cl_6B > Cl_2B > Cl_9B > Cl_5B > Cl_8B$
2 (a–c)	2.35	1.83	1.78–3.45	$Cl_6B > Cl_7B > Cl_2B > Cl_5B$
3 (a–c)	NC	0.25	BDL–0.29	Cl_6B
4 (a–c)	4.87	4.93	3.55–6.12	$Cl_{10}B > Cl_7B > Cl_6B > Cl_9B > Cl_5B$
5 (a–c)	NC	BDL	BDL	
6 (a–c)	5.44	3.91	3.98–8.62	$Cl_7B > Cl_6B > Cl_5B > Cl_{10}B > Cl_2B > Cl_9B$
7 (a–c)	4.64	4.68	4.47–4.77	$Cl_5B > Cl_6B > Cl_7B > Cl_3B > Cl_{10}B > Cl_2B > Cl_9B$
8 (a–c)	4.86	3.92	3.52–7.13	$Cl_7B > Cl_6B > Cl_5B > Cl_{10}B > Cl_9B$
9 (a–c)	11.1	2.83	2.64–27.7	$Cl_7B > Cl_6B > Cl_5B > Cl_8B > Cl_9B > Cl_{10}B$
10 (a–c)	8.53	9.48	6.22–9.89	$Cl_7B > Cl_6B > Cl_{10}B > Cl_5B > Cl_9B > Cl_8B$
11 (a–c)	NC	BDL	BDL	
12 (a–c)	0.51	0.48	0.25–0.81	$Cl_6B > Cl_5B > Cl_7B$
13 (a–c)	0.59	0.40	0.38–1.00	$Cl_5B > Cl_7B > Cl_{10}B > Cl_6B$
14 (a–c)	16.6	15.9	14.9–18.8	$Cl_7B > Cl_6B > Cl_{10}B > Cl_5B > Cl_2B > Cl_9B > Cl_8B$
15 (a–c)	4.26	3.57	3.42–5.80	$Cl_7B > Cl_6B > Cl_{10}B > Cl_5B > Cl_8B$
16 (a–c)	NC	BDL	BDL–0.39	Cl_5B
17 (a–c)	1.58	1.32	1.08–2.34	$Cl_7B > Cl_6B > Cl_5B > Cl_{10}B$
18 (a–c)	NC	0.31	BDL–0.37	Cl_5B
19 (a–c)	NC	BDL	BDL–0.38	Cl_5B
20 (a–c)	2.80	2.61	0.83–4.97	$Cl_6B > Cl_7B > Cl_5B$
21 (a–c)	NC	BDL	BDL–0.45	Cl_5B
22 (a–c)	NC	BDL	BDL–0.34	Cl_5B
23 (a–c)	NC	BDL	BDL–0.37	Cl_5B
24 (a–c)	0.53	0.46	0.33–0.79	$Cl_5B > Cl_6B$
25 (a–c)	3.78	1.04	0.41–9.89	$Cl_{10}B > Cl_9B > Cl_5B > Cl_6B > Cl_7B$
26 (a–c)	2.00	1.91	1.52–1.91	$Cl_{10}B > Cl_9B > Cl_6B > Cl_7B > Cl_5B$
27 (a–c)	0.70	0.75	0.30–1.06	$Cl_6B > Cl_7B > Cl_5B > Cl_{10}B$
28 (a–c)	NC	BDL	BDL	
29 (a–c)	3.52	3.91	2.50–4.14	$Cl_7B > Cl_6B > Cl_{10}B > Cl_9B > Cl_5B > Cl_8B$
30 (a–c)	2.60	2.33	1.96–3.50	$Cl_7B > Cl_6B > Cl_5B > Cl_{10}B$
31 (a–c)	NC	0.19	BDL–0.34	Cl_6B
32 (a–c)	NC	BDL	BDL	
33 (a–c)	NC	BDL	BDL	
34 (a–c)	NC	BDL	BDL	
35 (a–c)	NC	BDL	BDL	
36 (a–c)	NC	BDL	BDL	
37 (a–c)	NC	BDL	BDL	
38 (a–c)	NC	BDL	BDL	
39 (a–c)	NC	BDL	BDL	
40 (a–c)	NC	BDL	BDL	
41 (a–c)	NC	BDL	BDL	

NC = not calculable; BDL = below detection limits (method detection limits for individual chlorobiphenyls ranged from 0.03 to 0.49 ng/g).

presence and relatively high abundance of pyrene supports the suggestion that combustion processes are a significant source of PAHs in Tanapag Lagoon (Fowler et al., 1993). Fluoranthene/pyrene and pyrene/benzene(*a*)pyrene ratios also suggest that hydrocarbon fuel spills contributed to the contamination of nearshore sediments (Neff, 1979).

Overall this study has shown that Tanapag Lagoon is relatively clean with only 2% of the results indicating significant contamination. The areas where problems were identified were sites close to the Puerto Rico dump (sites 6, 14, 29, 30), the boat marina (site 4), the new docks (site 7) and the port (sites 9, 10, 16). A major surprise in this study was the apparent improvement in sediment quality around the Puerto Rico dump compared to findings from the 1980s (DEQ, 1987). This could reflect the burial of previously contaminated sites under more recent sedimentary deposits associated with the port expansion activities that occurred in the mid-1990s, in addition to the erosion of offshore dredge material used to cover trash on the dump between 1997 and 1998. In any event, the analysis of deeper sediment cores in the vicinity of Saipan Harbour, the new docks and the Puerto Rico dump is warranted to assess the true nature of the underlying chemistry and the potential of residual contamination to impact resident biota as a result of bioturbation and climatic disturbances (e.g., typhoons). Such a survey could also include TBT, dioxins and persistent organochlorine pesticides. A data-

Table 4
PAH concentrations in sediments from Tanapag Lagoon, Saipan (μg/g dry wt.)

Site	Σ_{16} PAH concentration			Overall order of abundance of detectable PAH congeners
	Mean	Median	Range	
1 (a–c)	0.50	0.41	0.38–0.71	BPE > INP > BBF > BKF > BAP > CHR > PYR > BAA > ACE
2 (a–c)	0.42	0.29	0.25–0.71	BPE > DBA > BBF > BKF > INP > BAP > CHR > PYR > BAA > FLU > ACE
3 (a–c)	0.09	0.09	0.02–0.16	BAP > PYR > CHR > BBF > FLU > INP > BAA
4 (a–c)	1.22	1.31	0.94–1.42	BPE > BAP > BBF > INP > CHR > BKF > PYR > FLU > BAA > DBA > ANT
5 (a–c)	NC	BDL	BDL	
6 (a–c)	NC	0.13	BDL–1.23	BPE > BAP > PYR > BBF > INP > FLU > CHR > BKF > BAA > ANT
7 (a–c)	1.39	1.48	0.24–2.44	PYR > DBA > BAP > CHR > BBF > FLU > BPE > INP > BAA > BKF > ANT
8 (a–c)	0.43	0.50	0.28–0.50	BBF > CHR > BAP > PYR > INP > BPE > BKF > BAA > DBA > FLU
9 (a–c)	0.29	0.29	0.02–0.56	BPE > BAP > CHR > INP > FLU > BAA > BBF > PYR > BKF
10 (a–c)	0.97	1.03	0.85–1.04	BAP > PYR > CHR > BKF > BBF > FLU > INP > BAA > BPE > ANT
11 (a–c)	0.05	0.01	0.01–0.12	CHR > PYR
12 (a–c)	0.20	0.18	0.18–0.24	BKF > CHR > BBF > PYR > BAA
13 (a–c)	0.44	0.47	0.20–0.64	CHR > DBA > BBF > PYR
14 (a–c)	0.77	0.93	0.33–1.05	CHR > BAP > PYR > BKF > DBA > BBF > FLU > BAA > ANT
15 (a–c)	0.12	0.11	0.01–0.23	CHR > BAA > PYR
16 (a–c)	NC	BDL	BDL–0.01	BAA
17 (a–c)	NC	0.01	BDL–0.01	CHR > BAA
18 (a–c)	NC	BDL	BDL–0.004	BAA
19 (a–c)	NC	0.01	BDL–1.36	BAP > INP > BKF > BAA
20 (a–c)	0.03	0.02	0.01–0.06	BPE > CHR > DBA > BAA > PYR
21 (a–c)	NC	BDL	BDL–0.40	BPE
22 (a–c)	NC	BDL	BDL–0.07	BAP
23 (a–c)	NC	0.15	BDL–0.16	BPE > INP > BAA
24 (a–c)	0.03	0.01	0.01–0.08	INP > CHR > BAA > PYR
25 (a–c)	0.33	0.34	0.02–0.65	BPE > CHR > PYR > BAA
26 (a–c)	0.06	0.02	0.01–0.16	DBA > CHR > PYR > BAA
27 (a–c)	0.04	0.04	0.04–0.05	INP > CHR > BAA > PYR
28 (a–c)	NC	BDL	BDL	
29 (a–c)	0.78	0.68	0.35–1.29	BAP > DBA > CHR > PYR > INP > BBF > FLU > BAA > BPE > BKF > ANT
30 (a–c)	1.18	0.20	0.10–3.23	CHR > PYR > FLU > BAP > BBF > BAA > DBA > BPE > BKF > ANT > PHE > INP
31 (a–c)	0.06	0.01	0.01–0.15	BPE > CHR
32 (a–c)	NC	BDL	BDL	
33 (a–c)	NC	0.02	BDL–0.20	BPE > DBA > BAA
34 (a–c)	NC	BDL	BDL–0.03	DBA
35 (a–c)	NC	BDL	BDL	
36 (a–c)	0.05	0.04	0.01–0.10	INP > DBA > BAA > CHR > PYR
37 (a–c)	NC	BDL	BDL–0.004	BAA
38 (a–c)	NC	0.15	BDL–0.17	BPE
39 (a–c)	NC	BDL	BDL–0.44	BPE
40 (a–c)	NC	BDL	BDL–0.17	BPE
41 (a–c)	NC	BDL	BDL	

NC = not calculable; BDL = below detection limits (method detection limits for individual PAHs ranged from 1 to 20 ng/g); PAH Abbreviations (in order of molecular weight): NAP, Naphthalene; ACY, Acenaphthylene; ACE, Acenaphthene; FLR, Fluorene; PHE, Phenanthrene; ANT, Anthracene; FLU, Fluoranthene; PYR, Pyrene; BAA, Benzo(*a*)anthracene; CHR, Chrysene; BBF, Benzo(*b*)fluoranthene; BKF, Benzo(*k*)fluoranthene; BAP, Benzo(*a*)pyrene; BPE, Benzo(*ghi*)perylene; INP, Indenol(1,2,3-*cd*)pyrene; DBA, Dibenzo(*a,h*)anthracene.

base on contaminant concentrations in the biota of the region is currently under construction and will assist in determining the possible biological impacts of the observed sediment contamination noted during the present study.

Acknowledgements

Our thanks to Peter Barlas, former Acting Director of the Office of Coastal Resources, Saipan, for logistical support, and to Galt Siegrist (WERI), Clarence Igisiar, Carlos Ketebengang and Jessica Tomokane (DEQ) for assistance with the sediment sample collection. The figures were prepared by John Jocson (WERI) and Richard Miller (School of Earth and Environmental Sciences, University of Wollongong). This work was funded, in part, by the Department of Interior via the Water Resources Research Institute Program of the US Geological Survey (Section 104-B Award No. HQ-96-GR-02665).

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0025-326X/$ - see front matter
doi:10.1016/j.marpolbul.2006.02.019

Polychlorinated biphenyls (PCBs) in sediments of four harbours in Guam

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Although polychlorinated biphenyls (PCBs) were only commercially manufactured for about 50 years, their unusual versatility for certain purposes coupled with widespread use and improper disposal have resulted in global contamination (Hutzinger et al., 1974; Atlas et al., 1986). PCBs can enter the marine environment from leakages, urban runoff, dumped sewage sludge and industrial discharges (Connell and Miller, 1984). Once in the aquatic environment, PCBs, by virtue of their low water solubility, quickly become associated with particulate matter and ultimately end up in bottom sediments. PCBs, as hydrophobic compounds, are readily accumulated in the fatty tissues of

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