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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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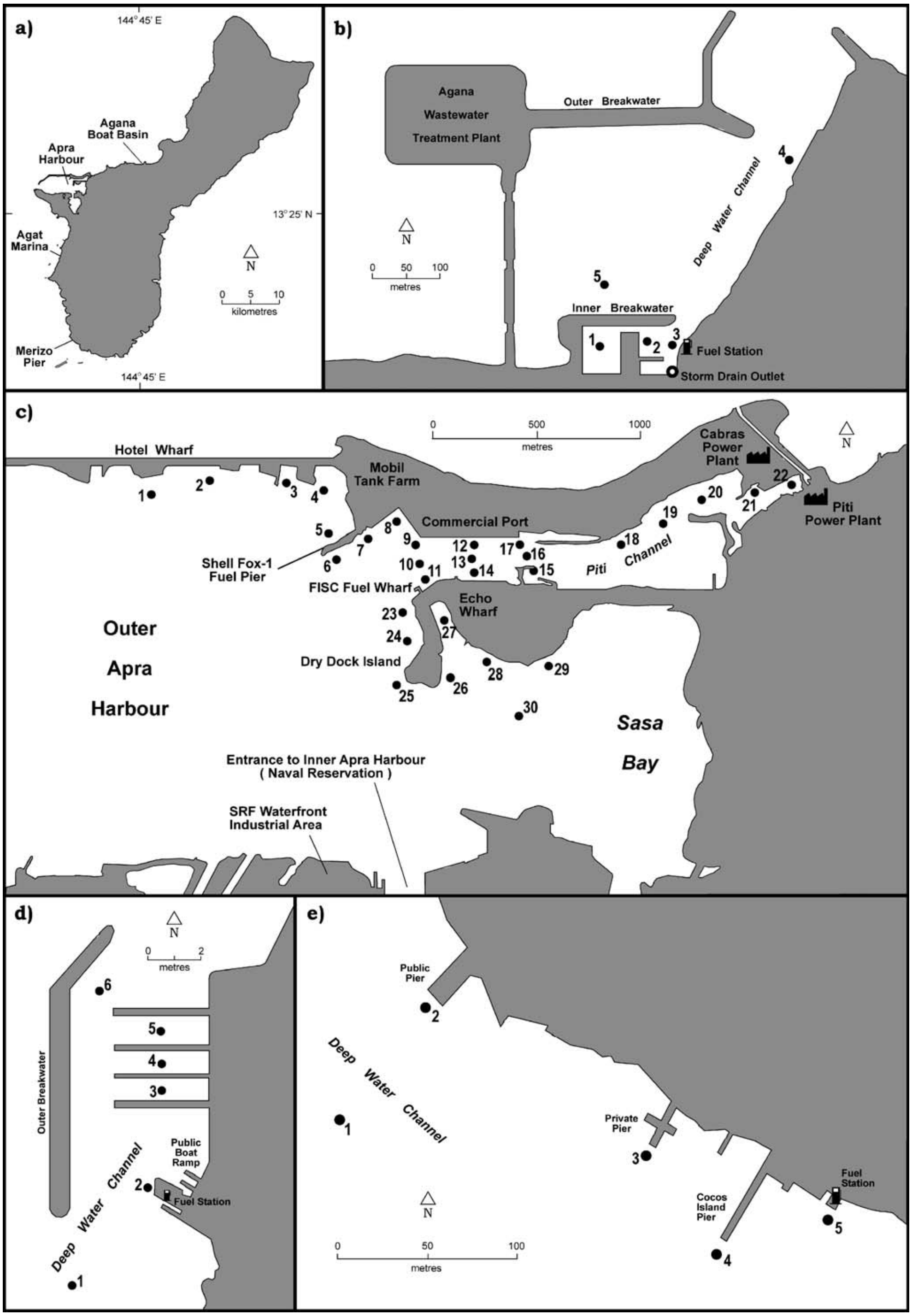

Fig. 1. (a) Locations of harbours studied on Guam and sediment sampling sites at (b) Agana Boat Basin, (c) Outer Apra Harbour, (d) Agat Marina and (e) Merizo Pier.

many organisms often reaching alarming concentrations in predatory species at the head of food chains (Wasserman et al., 1979). Concern over the immunosuppressive and endocrine disruptor effects of PCBs has promoted widespread interest in the extent of pollution caused by this group of compounds.

Guam (13°28′N, 144°45′E) has been the major shipping centre in Micronesia for about 400 years, but there have been few studies of the impacts on the coastal environment of such activities. This paper reports on the first major study of PCBs in the sediments in four harbours in Guam. The four harbours (Fig. 1a) were selected on the following

Table 1
PCBs in sediments from Apra Harbour (ng/g dry weight)

Congener IUPAC no.[a]	Site									
	1	2	3	4	5	6	7	8	9	10
8/5	–	–	0.13	0.17 (0.15–0.26)	0.18	0.94	–	2.02	0.38	0.14 (0.13–0.15)
18/15	–	0.58	0.84	0.22	0.19	0.44	2.42	0.33	–	0.15
28/31	–	–	0.31	0.18 (0.14–0.30)	0.19	0.57	3.25	0.71	1.16 (0.61–2.35)	0.14
37	–	–	0.85	–	–	–	–	0.36	3.10	–
44	5.37	0.11	0.11 (0.09–0.24)	0.17 (0.11–0.28)	0.21	0.45	5.92 (5.07–7.01)	0.96 (0.39–1.83)	1.06	0.10
49	3.13 (1.67–6.18)	–	0.10 (0.08–0.13)	0.15 (0.13–0.18)	0.11 (0.11–0.12)	1.07 (0.73–1.48)	9.82 (8.80–10.5)	1.74 (1.07–2.25)	1.07	0.12 (0.12–0.12)
52	6.80 (4.15–13.8)	0.50	0.65	1.45 (1.03–1.74)	1.43	3.64 (2.55–4.64)	19.5 (18.0–20.8)	4.56 (2.71–5.91)	2.87	0.33 (0.09–0.65)
60/56	3.74	–	–	–	–	–	5.17 (4.70–5.81)	1.99	1.34	–
66/80/95	–	–	–	0.30	–	–	13.8 (12.7–15.0)	–	–	–
70/76	9.88	–	–	0.09	–	0.39	10.9 (9.77–11.9)	–	1.45	–
74/94	3.02	–	–	–	–	0.20	4.19 (3.72–4.64)	–	0.16	–
77	–	–	–	–	–	–	–	–	–	–
82	2.36 (1.33–5.05)	–	–	0.12 (0.11–0.12)	0.06 (0.06–0.07)	2.31 (0.69–13.8)	7.39 (6.89–8.35)	1.19 (0.68–3.00)	1.43 (0.55–2.48)	–
87	2.97 (1.16–10.5)	0.05 (0.05–0.05)	–	0.10	0.06 (0.06–0.06)	0.74 (0.44–0.96)	14.8 (13.7–17.0)	1.21 (0.43–5.11)	3.02	–
99/113	5.21 (3.36–11.2)	0.08 (0.08–0.08)	0.11 (0.09–0.13)	0.27 (0.23–0.35)	0.20 (0.18–0.22)	1.83 (1.11–2.57)	16.2 (14.6–17.7)	2.29 (1.26–5.12)	1.55 (0.8–3.26)	0.17 (0.15–0.19)
101/90	8.26 (5.24–19.6)	0.22	0.28	0.37 (0.28–0.43)	0.32	2.62 (1.75–3.36)	26.1 (23.7–28.6)	3.68 (1.77–9.95)	2.53 (1.35–6.41)	0.18 (0.07–0.28)
105	2.53 (1.03–7.82)	–	0.14	0.22	0.15	0.69 (0.52–0.80)	10.8 (9.13–12.7)	1.14 (0.52–3.15)	1.97	–
114	–	–	–	–	–	–	1.29 (1.06–1.67)	0.37	–	–
118	7.8 (4.09–21.4)	0.06	0.15	0.21 (0.13–0.30)	0.15 (0.09–0.17)	2.05 (1.43–2.52)	28.5 (25.3–33.2)	3.11 (1.44–9.07)	1.85 (0.92–6.00)	0.07 (0.04–0.10)
126	–	–	0.13	0.24	0.15	0.29	–	–	1.29	–
128	3.25	0.05	0.13	0.18	0.14	0.97	5.12 (4.30–6.15)	2.08	1.60	0.06
138/163/164	5.23 (2.72–9.79)	0.06	0.06 (0.02–0.15)	0.18 (0.13–0.25)	0.15 (0.09–0.20)	0.53	14.8 (11.9–18.3)	6.02	2.99 (1.33–5.24)	0.07 (0.01–0.27)
153/132	6.98 (4.79–10.7)	0.06 (0.02–0.12)	0.09 (0.02–0.23)	0.46 (0.41–0.48)	0.21 (0.07–0.39)	3.93 (2.63–5.05)	16.2 (14.5–18.8)	3.77	5.61 (2.80–9.37)	0.22 (0.05–0.48)
156/171	1.27 (0.55–2.35)	–	–	0.03	–	0.44 (0.38–0.50)	3.46 (2.60–4.38)	0.55 (0.30–1.52)	0.58 (0.26–1.14)	–
158	21.6 (11.2–40.1)	–	0.65	0.73 (0.52–0.98)	–	–	60.7 (48.6–61.5)	–	–	–
166	–	–	–	–	–	–	–	–	–	–
169	–	–	–	–	–	–	–	–	–	–
170/190	1.38 (0.99–1.93)	0.06	0.13	0.11 (0.07–0.17)	0.05 (0.02–0.15)	0.98 (0.76–1.12)	2.36 (1.74–2.51)	0.93 (0.64–1.45)	2.31 (1.45–5.69)	0.19
179/141	3.73 (1.97–6.22)	–	0.04	0.19 (0.16–0.24)	0.10 (0.10–0.10)	1.84 (1.36–2.24)	9.54 (8.54–11.1)	2.14 (1.37–4.96)	3.79 (1.64–7.93)	0.17 (0.14–0.20)
180	2.36 (1.93–2.17)	0.07 (0.03–0.11)	0.06 (0.02–0.16)	0.33 (0.31–0.34)	0.15 (0.08–0.26)	2.26 (1.76–2.59)	3.91 (3.14–4.63)	1.84 (1.35–2.40)	5.20 (2.66–15.2)	0.14 (0.02–0.43)
183	0.86 (0.70–1.13)	0.03 (0.03–0.04)	0.03 (0.03–0.03)	0.10 (0.08–0.10)	0.09 (0.08–0.11)	1.24 (1.09–1.39)	1.57 (1.35–1.82)	0.79 (0.55–1.00)	1.80 (1.07–4.69)	0.16 (0.15–0.16)
187/182/159	1.42 (1.26–1.77)	0.10 (0.07–0.12)	0.16	0.33 (0.30–0.37)	0.14 (0.08–0.24)	1.93 (1.40–2.43)	2.97 (2.65–3.43)	1.18 (0.97–1.51)	2.75 (1.33–8.90)	0.09 (0.02–0.23)
189	–	–	–	–	–	0.06	–	0.06	0.06	–
195	0.28	0.04	0.10	0.05 (0.03–0.11)	0.11	0.18	–	0.21	0.53 (0.23–1.76)	0.03 (0.02–0.05)
206	–	0.05 (0.04–0.06)	0.11	0.26 (0.21–0.33)	0.14	0.32 (0.27–0.38)	1.81	0.21	0.99	0.05 (0.05–0.05)
2.09	–	0.06	2.12	1.28 (0.38–14.2)	0.18	0.38	–	0.22	–	0.10 (0.07–0.25)
∑PCB congeners	92.4 (52.3–196)	1.21 (0.74–1.71)	2.27 (0.95–7.11)	9.7 (4.99–21.3)	2.15 (0.61–5.4)	32.2 (22.7–46.2)	298 (271–346)	38.7 (23.0–86.2)	49.3 (27.1–75.4)	2.26 (0.89–3.87)
Aroclor likeness	A-1254	None	None	None	None	A-1260	A-1254	A-1254	A-l254, A-1260	None
	11	12	13	14	15	16	17	18	19	20
8/5	0.19 (0.12–0.44)	0.46 (0.30–0.58)	1.37	0.20 (0.19–0.21)	0.08	0.30 (0.24–0.44)	0.36	0.14	0.20 (0.13–0.31)	0.14 (0.10–0.25)
18/15	0.40	0.53 (0.41–0.79)	0.33	0.13 (0.12–0.15)	0.06	0.17 (0.14–0.25)	0.27	0.08	0.14 (0.07–0.23)	–
28/31	0.40	0.60 (0.48–0.84)	0.46	0.14 (0.13–0.16)	0.03	0.23 (0.17–0.33)	0.35	0.01	0.05	0.04 (0.01–0.06)
37	–	–	–	–	nd	–	–	nd	nd	–
44	0.38	0.90 (0.33–3.19)	0.46	0.11 (0.10–0.11)	–	0.15 (0.10–0.26)	0.46 (0.31–0.98)	0.01	–	–
49	0.23 (0.18–0.29)	0.76 (0.46–1.60)	0.26 (0.18–0.36)	0.15 (0.13–0.18)	nd	0.28 (0.22–0.34)	0.53 (0.25–1.50)	nd	nd	–
52	0.52 (0.15–1.44)	2.77 (1.41–7.89)	1.12 (0.19–4.23)	1.33 (1.24–1.51)	0.17	1.21 (1.13–1.33)	1.97 (1.56–3.06)	0.09	–	0.63
60/56	–	0.75	–	–	nd	–	–	nd	nd	–
66/80/95	0.02	–	0.04	–	0.01	–	–	–	0.02 (0.02–0.02)	0.04
70/76	0.13	0.82 (0.25–2.78)	0.13 (0.11–0.16)	0.10	nd	0.19	0.42 (0.20–1.30)	nd	nd	–
74/94	–	0.40 (0.18–0.97)	0.10 (0.07–0.14)	–	nd	0.14	0.17	nd	nd	–

77	–	–	–	–	–	–	–	–	–	–
82	0.12	0.93 (0.22–3.49)	0.27 (0.20–0.37)	0.16 (0.14–0.17)	nd	0.22 (0.1 8–0.28)	0.76 (0.34–2.43)	nd	nd	0.04 (0.04–0.04)
87	0.08 (0.05–0.11)	1.29 (0.21–6.55)	0.19 (0.12–0.31)	0.08 (0.07–0.09)	nd	0.09 (0.04–0.19)	0.54 (0.18–2.98)	nd	nd	–
99/113	0.31 (0.26–0.36)	1.56 (0.52–5.09)	0.55 (0.40–0.74)	0.34 (0.30–0.36)	nd	0.53 (0.41–0.70)	1.07 (0.52–3.05)	nd	nd	0.13 (0.13–0.13)
101/90	0.13 (0.01–0.61)	3.46 (0.84–16.0)	0.25 (0.02–1.15)	0.41 (0.37–0.45)	–	0.59 (0.44–0.84)	1.77 (0.88 5.55)	0.40	–	0.13
105	0.26	0.99 (0.20–4.44)	0.26 (0.14–0.46)	0.08	–	0.23	0.63 (0.31–2.31)	–	–	–
114	–	0.59	–	–	nd	–	–	nd	nd	–
118	0.15 (0.06–0.38)	2.85 (0.52–15.1)	0.87	0.27 (0.22–0.34)	0.01[b]	0.50 (0.34–0.73)	1.61 (0.79–5.55)	–	0.02[b]	0.05 (0.04–0.06)
126	0.24	0.12 (0.11–0.16)	0.08 (0.01–0.43)	0.08	–	0.09	0.22	–	–	–
128	0.21	0.82 (0.17–3.63)	0.44	0.10 (0.09–0.12)	–	0.15 (0.12–0.19)	0.45 (0.26–1.29)	0.06	–	–
138/163/164	0.16 (0.09–0.29)	2.44 (0.42–13.0)	0.24 (0.17–0.40)	0.37 (0.28–0.63)	0.03[c]	0.48 (0.40–0.65)	1.52 (0.70–5.12)	–	0.02[c]	0.07 (0.07–0.08)
153/132	0.40 (0.17–0.68)	3.12 (0.86–12.6)	1.58	0.87 (0.66–1.07)	0.06	1.26 (1.15–1.40)	2.98 (1.47–7.56)	0.01	0.05 (0.04–0.06)	0.22 (0.08–0.38)
156/171	–	0.45 (0.07–1.65)	0.14 (0.10–0.18)	0.06 (0.06–0.06)	nd	0.09 (0.06–0.11)	0.29 (0.13–1.07)	nd	nd	0.02
158	0.57	–	–	–	nd	–	–	nd	nd	–
166	–	–	–	–	nd	–	–	nd	nd	–
169	–	–	0.03 (0.02–0.05)	–	nd	–	–	nd	nd	–
170/190	0.09 (0.03–0.21)	0.65 (0.21–1.82)	0.26 (0.06–0.56)	0.25 (0.23–0.28)	0.02	0.29 (0.29–0.31)	1.11 (0.48–3.07)	–	–	0.05 (0.03–0.08)
179/141	0.14 (0.13–0.14)	1.37 (0.31–4.59)	0.41 (0.33–0.50)	0.25 (0.23–0.27)	nd	0.33 (0.29–0.38)	1.49 (0.56–5.42)	nd	nd	0.06 (0.06–0.06)
180	0.22 (0.12–0.33)	1.05 (0.42–2.56)	0.45 (0.20–0.96)	0.59 (0.54–0.64)	0.04	0.71 (0.69–0.73)	2.48 (1.07–6.90)	0.01	0.03 (0.02–0.04)	0.16 (0.10–0.21)
183	0.15 (0.13–0.17)	0.46 (0.22–0.89)	0.28 (0.22–0.37)	0.23 (0.21–0.25)	nd	0.28 (0.28–0.30)	0.83 (0.39–2.20)	nd	nd	0.06 (0.06–0.07)
187/182/159	0.16 (0.08–0.29)	0.64 (0.29–1.56)	0.28 (0.11–0.63)	0.37 (0.34–0.39)	0.03	0.43 (0.41–0.44)	1.39 (0.65–3.63)	–	0.02 (0.01–0.02)	0.13 (0.07–0.18)
189	–	0.08	0.05	–	nd	0.02	0.04	nd	nd	–
195	0.15	0.10 (0.08–0.12)	0.05 (0.02–0.19)	0.05 (0.04–0.07)	0.02	0.04 (0.04–0.04)	0.26 (0.14–0.72)	–	–	0.01
206	0.05 (0.02–0.16)	0.07 (0.06–0.08)	0.06 (0.02–0.17)	0.07 (0.05–0.09)	0.02	0.06 (0.05–0.07)	0.27 (0.17–0.56)	–	–	0.01
209	0.08 (0.03–0.18)	0.06 (0.03–0.08)	0.08 (0.04–0.20)	0.09 (0.08–0.12)	0.01	0.06 (0.06–0.07)	0.07	–	–	–
∑PCB congeners	3.12 (0.90–8.94)	32.5 (9.90–112)	5.09 (0.87–17.9)	6.81 (5.98–7.32)	0.56	8.84 (7.28–10.9)	24.8 (12.8–66.3)	0.23 (0.19–0.26)	0.50 (0.36–0.70)	1.49 (0.73–1.99)
Aroclor likeness	None	A-1254	None	None	None	None	A-1260	None	None	None

	21	22	23	24	25	26	27	28	29	30
8/5	0.23 (0.13–0.30)	0.22	0.07 (0.06–0.08)	0.10	0.17	–	–	0.20 (0.17–0.27)	0.07 (0.05–0.11)	–
18/15	0.26	0.16	0.15	–	–	–	–	0.08	0.06	0.50
28/31	0.10 (0.04–0.24)	0.12 (0.07–0.22)	0.01	0.23	0.12	–	–	0.12	–	–
37	–	–	nd	–	–	–	–	–	nd	–
44	2.38	0.19	0.01	0.12	–	–	–	–	–	–
49	0.94 (0.29–3.02)	2.22	nd	0.23	0.31	4.48	1.14	–	nd	–
52	6.19	0.43 (0.31–0.70)	–	0.59 (0.53–0.71)	1.39 (0.73–2.00)	2.93 (2.12–3.86)	2.46 (1.87–3.64)	0.61	0.09 (0.05–0.14)	0.48
60/56	–	–	nd	–	–	–	0.94	–	nd	–
66/80/95	0.02	–	0.01 (0.01–0.02)	–	–	–	–	0.01	0.01 (0.01–0.01)	0.20
70/76	0.94 (0.18–4.84)	0.11	nd	0.10	–	–	–	–	nd	–
74/94	0.44 (0.12–1.61)	–	nd	0.05	–	–	–	–	nd	–
77	–	0.17	–	–	–	–	–	–	–	–
82	1.01 (0.19–5.47)	0.17	nd	0.15	0.72	4.50 (3.41–6.02)	1.55 (1.35–2.01)	–	nd	–
87	1.55 (0.25–9.44)	0.18	nd	0.06	0.08	–	–	–	nd	–
99/113	2.62 (0.70–9.79)	0.24 (0.18–0.32)	nd	0.19 (0.14–0.31)	1.17 (0.62–1.64)	5.73 (5.44–6.14)	2.39 (2.28–2.46)	–	nd	–
101/90	18.2	0.37 (0.32–0.46)	–	0.25 (0.16–0.46)	0.91 (0.46–1.45)	3.72 (265–4.51)	1.92 (1.64–2.11)	–	–	0.12
105	1.50 (0.30–7.45)	0.19 (0.16–0.22)	–	0.05	0.35	–	–	–	–	–
114	1.35	–	nd	–	–	–	–	–	nd	–
118	1.20 (0.08–25.1)	0.37 (0.33–0.45)	–	0.11 (0.07–0.20)	0.77 (0.41–1.19)	1.54 (1.15–1.95)	0.81 (0.60–0.99)	0.04	–	–
126	–	0.23	–	0.07	–	1.35 (0.89–2.34)	0.89	0.01	–	0.02
128	5.84	0.19 (0.16–0.23)	–	0.05	0.39	0.95 (0.66–1.50)	0.49 (0.36–0.78)	–	–	–
138/163/164	1.14 (0.12–21.1)	0.57 (0.46–0.76)	–	0.31 (0.25–0.39)	1.74	7.89 (5.63–13.1)	3.29 (2.55–5.07)	0.08	0.1[c]	0.15 (0.14–0.16)
153/132	1.50 (0.21–19.8)	1.02 (0.89–1.22)	0.03 (0.02–0.03)	0.73 (0.61–0.82)	3.76 (2.60–4.68)	22.8 (17.4–34.2)	8.54 (6.74–11.7)	0.43	–	0.31 (0.24–0.38)
156/171	0.95 (0.15–5.86)	0.09 (0.07–0.15)	nd	0.03	0.20 (0.09–0.39)	1.40 (0.64–2.40)	0.39 (0.23–0.77)	–	nd	–
158	–	–	nd	–	–	38.8 (23.1–53.7)	13.5 (10.5–20.8)	–	nd	–
166	–	–	nd	–	–	–	–	–	nd	–
169	–	–	nd	–	–	–	–	–	nd	–

(*continued on next page*)

Table 1 (*continued*)

Congener IUPAC no.[a]	Site									
	21	22	23	24	25	26	27	28	29	30
170/190	0.28 (0.07–2.81)	0.49 (0.39–0.69)	0.01	0.24 (0.19–0.42)	1.23 (1.13–1.40)	7.80 (5.39–14.3)	2.77 (1.55–5.75)	0.13	–	0.06 (0.04–0.08)
179/141	1.63 (0.25–10.7)	0.46 (0.33–0.73)	nd	0.25 (0.18–0.31)	1.41 (1.38–1.44)	12.2 (7.00–17.1)	3.02 (2.28–4.91)	–	nd	0.07 (0.07–0.07)
180	0.49 (0.16–3.22)	0.91 (0.74–1.27)	0.02	0.65 (0.52–0.89)	3.61 (2.63–5.78)	17.2 (12.4–33.1)	5.77 (3.40–10.7)	0.27	–	0.15 (0.11–0.20)
183	0.29 (0.06–1.41)	0.27 (0.22–0.37)	nd	0.24 (0.21–0.28)	1.25 (1.10–1.51)	6.42 (1.87–14.8)	2.16 (1.52–3.35)	0.09	nd	0.09 (0.09–0.10)
187/182/159	0.25 (0.08–1.65)	0.60 (0.52–0.68)	–	0.40 (0.35–0.47)	2.41 (1.80–3.88)	8.21 (5.37–14.9)	3.03 (2.19–4.96)	0.17	–	0.21 (0.18–0.24)
189	0.19	0.03	nd	–	–	1.58	0.33	–	nd	–
195	0.01	0.15 (0.12–0.20)	–	0.06 (0.03–0.11)	0.88	1.52 (1.02–2.86)	0.45 (0.27–1.00)	0.01	–	0.01
206	–	0.09 (0.04–0.16)	–	0.11 (0.07–0.18)	0.91 (0.27–4.77)	0.80 (0.62–1.33)	0.29 (0.19–0.52)	0.04	–	–
209	–	0.14	–	0.33 (0.26–0.45)	1.33 (0.79–1.87)	–	–	–	–	0.01
∑PCB congeners	10.7 (0.94–1.68)	8.15 (7.47–8.82)	0.20 (0.12–0.32)	5.02 (4.13–6.01)	24.2 (21.5–27.6)	154 (109–226)	54.7 (41.7–83.6)	0.83 (0.48–2.03)	0.22 (0.17–0.28)	1.21 (0.87–1.82)
Aroclor likeness	A-1254	None	None	A-1260	A-1260	A-1260	A-1260	None	None	None

nd = Congener not determined in sediments from sample subsites.

[a] Using nomenclature of Ballschmiter and Zell (1980). Known coeluting congeners listed where appropriate. Single values are maximum concentrations determined when levels were below limits of analytical detection at one or more remaining subsites. Dashes indicate congener concentration were below detection limits in samples from all subsites.

[b] Congeners 118 coelutes with congener 149 on the 30 m column used to screen this sample.

[c] Congener 138 also coelutes with congener 158 on the 30 m column used to screen this sample.

basis: Agana Boat Basin, a small boat harbour in the commercial centre – 5 sites (Fig. 1b); Apra Harbour, a heavily used commercial and military port – 30 sites (Fig. 1c), Agat Marina, a newly constructed small boat harbour in a residential area of limited commercial activity – 6 sites (Fig. 1d), and Merizo Pier, docking site for Cocos Island ferries and small boat harbour in rural residential area well away from industrial activity – 5 sites (Fig. 1e).

Sediments from each harbour were collected and prepared as previously described (Denton et al., 2005). They were analysed in accordance with US EPA SW-846 procedures and protocols (USEPA, 1996) as outlined below. All reagents used were analytical grade and all glassware was detergent-washed, oven baked and solvent rinsed prior to use. Standard stock solutions were purchased from a commercial supplier. All analyses were performed in duplicate and were accompanied by appropriate method blanks and matrix spikes.

Approximately 1 g of air-dried sediment was accurately weighed into a 10 mL Teflon centrifuge tube along with 0.25 g of activated copper to remove elemental sulfur (EPA method 3665A). The samples were extracted with 3 mL of *n*-hexane in a commercial microwave oven (700 W-high energy setting) for sequential periods of 60, 30 and 15 s (see Ganzler et al., 1986). A rotating turntable insured homogeneous distribution of microwave radiation within the unit. Each tube was touched against a vortex mixer for 5 s between heating cycles to ensure the extract was thoroughly mixed. After standing overnight the samples were vortexed one last time before centrifuging at 2500 rpm for 5 min.

The clear extracts were decanted into 3 mL graduated glass centrifuge tubes, placed in a warm water bath (45 °C) and reduced in volume (~0.25 mL) under a gentle stream of nitrogen. Cleanup was accomplished with 60–100 mesh Florisil, activated and stored at 110 °C. The Florisil columns (~0.25 g) were made up in disposable glass Pasteur pipettes and rinsed with 2 × 1 mL volumes of hexane prior to use. Approximately 0.25 mL of hexane was used to complete the transfer process. Each column was then eluted with hexane under gentle pressure. The PCB fraction was recovered in the first 1.5 mL of hexane through the column. The cleaned up extract was reduced in volume to 0.1 mL and transferred to a clean, glass auto-sampler vial fitted with a small-volume (250 μL) insert.

Analysis was carried out using a Varian 3400CX Gas Chromatograph (GC) equipped with an electron capture detector. All samples were initially screened using a 30 m × 0.53 mm i.d. fused silica SPB-5, polymethyl-5% phenyl-siloxane (1.5 μm film thickness) 'megabore' column (Supelco). Gas flows (nitrogen) through the column and detector were 4 mL/min and 26 mL/min, respectively. The column temperature was programmed to hold at 150 °C for the first two min, then increased to 260 °C at a rate of 5 °C/min and held for a further 13 min. Both the

Table 2
PCBs in sediments from all other harbours examined (ng/g dry weight)

Congener IUPAC no.[a]	Agana Boat Basin Sites					Merizo Pier Sites				
	1	2	3	4	5	1	2	3	4	5
8/5	1.04	1.88 (1.57–2.29)	0.18	–	–	0.13	0.23 (0.10–0.40)	0.12	0.28	0.79 (0.49–1.07)
18/15	–	0.55	0.54	0.68	–	0.38	0.5	–	–	0.24 (0.17–0.42)
28/31	0.15	0.67	0.21	0.08	–	–	0.24 (0.11–0.54)	0.06	0.09	0.33 (0.17–0.72)
37	–	–	–	–	–	nd	–	–	–	–
44	–	–	0.04	0.06	0.18	0.12	0.25	–	–	0.60 (0.37–0.83)
49	0.23	1.18 (0.51–2.15)	–	–	–	nd	0.39	–	–	0.57 (0.41–0.79)
52	1.41 (0.60–2.18)	2.41 (1.58–3.61)	0.28 (0.12–0.41)	0.41	0.66	0.09	0.57 (0.48–0.76)	0.49	0.59	1.40 (0.89–1.83)
60/56	–	–	–	–	–	nd	–	–	–	–
66/80/95	–	1.56	0.22	0.07	–	–	0.21	–	–	–
70/76	0.10	–	–	–	0.28	nd	–	–	–	0.59 (0.50–0.72)
74/94	0.11	0.73	–	–	0.11	nd	0.11	–	–	0.32 (0.18–0.46)
77	–	–	–	–	–	–	–	–	–	–
82	0.43 (0.30–0.60)	0.96 (0.54–2.50)	0.11	–	0.32	nd	–	0.06	0.07	0.29 (0.16–0.40)
87	0.61	1.03	0.06	–	0.61	nd	–	0.05	–	0.84
99/113	1.07 (0.70–1.44)	2.43 (1.98–3.28)	0.33	–	0.45	nd	0.09	0.11 (0.09–0.11)	0.12 (0.09–0.15)	0.62 (0.50–0.87)
101/90	1.29 (0.81–1.84)	3.46 (2.31–6.57)	0.40	0.11	0.42 (0.10–0.98)	–	0.18 (0.14–0.27)	0.16 (0.15–0.17)	0.23 (0.13–0.39)	1.15 (0.66–1.75)
105	0.61	0.67 (0.50–0.86)	0.26	–	0.56	–	0.10 (0.07–0.18)	0.07	0.25	0.37 (0.18–0.53)
114	0.69	4.83	–	–	–	nd	–	–	–	–
118	1.20 (0.80–1.87)	2.43 (1.91–3.70)	0.36	0.09	1.2	0.05	0.14 (0.11–0.22)	0.13 (0.10–0.16)	0.21 (0.10–0.51)	0.99 (0.51–1.41)
126	–	0.59	0.26	0.10	–	0.12	0.09 (0.05–0.19)	–	–	–
128	0.35 (0.24–0.59)	0.66 (0.48–1.23)	0.35	0.10	0.36	–	–	0.07	0.05	0.23 (0.11–0.41)
138/163/164	1.71	4.33	0.68	0.13	1.01	–	0.19	–	0.13	0.88
153/132	1.93 (1.34–2.78)	4.47 (2.88–9.64)	0.68	0.14	0.33 (0.09–0.88)	–	0.19 (0.15–0.27)	0.20 (0.18–0.24)	0.22 (0.14–0.31)	0.76 (0.82–1.14)
156/171	0.39	0.51 (0.33–1.11)	0.12 (0.08–0.16)	0.02	0.23	nd	–	0.02	0.02	0.09 (0.04–0.20)
158	7.00	17.3	–	–	5.48	nd	–	–	–	–
166	–	–	–	–	–	nd	–	–	–	–
169	–	–	–	–	–	nd	–	–	–	–
170/190	0.45 (0.33–0.68)	1.10 (0.61–2.47)	0.42	0.13	0.22	–	0.09 (0.07–0.14)	0.06 (0.05–0.07)	0.04 (0.03–0.06)	0.11 (0.08–0.21)
179/141	0.91 (0.67–1.27)	2.25 (1.34–5.83)	0.29 (0.27–0.31)	–	0.57	nd	0.08	0.10 (0.09–0.10)	0.10 (0.06–0.18)	0.36 (0.17–0.72)
180	1.14 (0.83–1.55)	2.35 (1.61–4.70)	0.49	0.15	0.29	–	0.13 (0.11–0.16)	0.15 (0.13–0.16)	0.09 (0.07–0.13)	0.22 (0.16–0.36)
183	0.54 (0.44–0.68)	0.88 (0.52–1.67)	0.16	–	0.07	nd	0.03	0.04 (0.04–0.05)	0.04	0.07 (0.04–0.12)
187/182/159	0.83 (0.57–1.07)	1.60 (1.23–2.66)	0.30	0.11	0.14	–	0.12 (0.09–0.17)	0.12 (0.11–0.13)	0.06 (0.04–0.09)	0.12 (0.09–0.18)
189	–	0.05	–	–	–	nd	–	–	–	–
195	0.06	0.23	0.25	0.10	0.04	–	0.09 (0.06–0.15)	0.05	–	0.02
206	0.19 (0.15–0.24)	0.30	0.27	0.12	0.05	–	0.08 (0.05–0.15)	–	–	–
209	–	–	0.28	0.12	0.05	–	0.10 (0.06–0.18)	–	–	0.05
∑PCB congeners	17.9 (9.23–27.5)	39.9 (23.5–79.1)	2.71 (0.70–6.98)	0.80 (0.34–1.99)	4.07 (1.04–9.17)	0.32 (0.13–0.68)	3.16 (1.88–4.14)	1.57 (1.25–1.88)	1.96 (1.72–2.14)	11.3 (6.57–15.5)
Aroclor likeness	A-1260	A-1254	None	None	None	None	None	None	None	None

nd = Congener not determined in sediments from sample subsites. All PCB congeners were below analytical detection limits in sediments from Agat Marina with the following exceptions (range only): PCB 8: sites 4 and 5 (0.14–0.25 ng/g); PCB 18: sites 1, 2, 4 and 5 (0.12–0.91 ng/g); PCB 44: sites 1, 5 and 6 (0.04–0.18 ng/g); PCB 118: site 5 (0.07 ng/g); PCB 187: site 5 (0.54 ng/g).

[a] Using nomenclature of Ballschmiter and Zell (1980). Known coeluting congeners listed where appropriate. Single values are maximum concentrations determined when levels were below limits of analytical detection at one or more remaining subsites. Dashes indicate congener concentration were below detection limits in samples from all subsites.

injector and detector temperatures were held constant at 280 °C and 325 °C, respectively.

PCB quantification was accomplished using a 20-congener calibration standard representing PCB homologues Cl_2 to Cl_{10} (NOAA, 1993). All calculations were based on peak area comparisons of components sharing identical retention times in both sample and standard. The "total" PCB content of the sample was calculated from the sum of the individual congener data ($\sum_{20}$PCB). Undetectable congeners were set to zero for this process.

Samples yielding $\sum_{20}$PCB concentrations of 1 ng/g or more were reanalysed for the original suit of congeners, plus 16 others commonly used for screening food and human tissues, on a 60 m × 0.25 mm i.d. fused silica MDN-5S, polymethyl-5% phenyl-siloxane (0.25 μm film thickness) capillary column (Supelco), under the chromatographic conditions described earlier (Denton et al., 2006). Complete chromatographic separation of all congeners was achieved on this longer column, although several are known to coelute with other PCB congeners present in commercial PCB mixtures.

The surrogate, PCB 103 (100 pg/μL), and internal standard, pentachloronitrobenzene (250 pg/μL), were, respectively, added to the samples before (50 μL) and after (10 μL) extraction and cleanup to account for variations in method recoveries and automated GC injection efficiencies. Full procedural blanks were periodically carried out in accordance with standard QA/QC protocols. PCB recoveries (as Aroclor 1254) from a soil standard reference material (RTC PCB in Soil [Catalog No CRM911-050; Lot No J911]) ranged from 0.57 to 1.69 ng/g with a mean of 1.3 ng/g and were within acceptable limits of the certified mean (1.34 ng/g; range 0.61–2.07 ng/g). Method detection limits for individual chlorobiphenyls in the standard mix ranged from 0.03 to 0.49 ng/g.

Data from the current study are presented in Tables 1 and 2 for each congener in the standard mix. PCB concentrations in marine and estuarine sediments from various Pacific locations are presented in Table 3 for comparison. Baseline levels for total PCBs in clean coastal sediments are <1 ng/g and are a reflection of PCB background arising from atmospheric transport (Fowler, 1986; Phillips, 1986). In grossly polluted situations receiving inputs from localized point sources, levels as high as 61,000 ng/g have been reported (Nisbet, 1976).

In the current study, total PCB concentrations in sediments from Agat Marina were consistently less than 1 ng/g indicating a relatively clean environment. PCB profiles here were dominated by the more environmentally mobile Cl_2–Cl_3 congeners (Atlas and Giam, 1981; Bright et al., 1995), which suggest that contamination was the result of long distance transport rather than from inputs of a local source. Somewhat higher values were observed at the majority of sites at Merizo Pier, with a maximum mean value of 11.3 ng/g recorded at Site 5 adjacent to the Cocos Island ferry departure point. In the inner harbour area of Agana Boat Basin, still higher values of 17.9 ng/g and 39.3 ng/g were recorded at Sites 1 and 2, respectively.

Sedimentary levels of PCBs were <10 ng/g at over half the sites visited in Apra Harbour implying a relatively clean environment overall. Pockets of heavily contaminated sediment were, however, found at Sites 1 (92.4 ng/g), 7 (298 ng/g) and 26 (154 ng/g) indicating distinct and localized point sources of PCBs in the Hotel Wharf, Commercial Port and Dry Dock Island areas. Interestingly, the PCB profiles from sediments in these areas matched those of the technical PCB mixtures, Aroclor 1254 (Sites 1, 7, 8, 12) and Aroclor 1260 (Sites 6, 17, 25, 26, 27). It is possible that some of the older electrical transformers in the area were primary sources of PCBs in the past. Records indicate that a transformer located at one of the two electrical substations at the southern end of Dry Dock Island was retrofilled in March 1997, following the discovery that it contained 360 mg/kg PCBs (Ogden Environmental and Energy Services Co. Inc., 1997).

Technical PCB mixtures usually contain no more than 15 or so dominant congeners (>2% by weight) with several others present only in trace amounts (De Voogt et al., 1990). As a result of this and the differing rates of microbial

Table 3
PCB concentrations in marine and estuarine sediments from various Pacific locations

Location	Site	Depth (cm)	Fraction	Total PCB (ng/g)	Reference
Japan	Osaka Bay	0–5	Bulk sediment	2.5–240	Tanabe et al. (1991)
Thailand	Chao Phraya Estuary, Bangkok	0–5	Bulk sediment	11	Iwata et al. (1994)
Vietnam	Ho Chi Minh City	0–5	Bulk sediment	2.3–8.9	Iwata et al. (1994)
Papua New Guinea	Port Moresby	0–5	Bulk sediment	3.3–24	Iwata et al. (1994)
Vanuatu	Efate Island	0–5	Bulk sediment	<0.07–0.20	Harrison et al. (1996)
Tonga	Tongatapu Island	0–5	Bulk sediment	0.13–12.1	Harrison et al. (1996)
Fiji	Suva Harbour/Rewa River	0–5	Bulk sediment	<0.17–69	Morrison et al. (1996)
Australia	Brisbane River Estuary	Surface	Bulk sediment	ND–58	Shaw and Connell (1980)
Australia	Parramata Estuary, NSW	0–5	Bulk sediment	160	Iwata et al. (1994)
USA	Elkhorn Slough, CA	5–7.5	Bulk sediment	25–147	Rice et al. (1993)
Mexico	San Quintin Bay	Surface	Bulk sediment	All < 10	Gutierrez Galindo et al. (1996)

breakdown, certain congeners are more commonly found in the environment. Congener prevalence was calculated here as: total number of samples with detectable congener concentrations expressed as a percentage of the total number of samples analysed. Abundance was estimated as: number of times each congener ranked among the top 10 most abundant congeners, expressed as a percentage of the total number of samples analysed. The results of this analysis showed that congeners prevalent in 70% of the samples, or more, generally ranked among the top 10 most abundant PCBs at least 25% of the time (e.g., PCB 52, 101, 113, 118, 153, 170, 179, 180, 183, and 187). The notable exceptions were congeners 82 and 156, which ranked among the top 10 most abundant congeners <10% of the time. All PCBs with a prevalence of less than 20% also had very low abundances (e.g., PCB 37, 60, 77, 114, 166, 169, and 189). In general, the rank order of congener prevalence and abundance was similar to that reported by McFarland and Clarke (1989) for various environmental samples. We therefore conclude that there is nothing distinctly unusual about the PCB profiles in Guam sediments

This preliminary study indicates low-level PCB contamination in Agat Marina, around the Merizo Pier, in the outer Agana Boat Basin, and in some parts of Apra Harbour. The concentrations found at contaminated sites in Agana Boat Basin and Apra Harbour are high enough to require some remediation before any open water disposal following dredging.

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