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Marine Pollution Bulletin 50 (2005) 835–849
MARINE POLLUTION BULLETIN
www.elsevier.com/locate/marpolbul

Chlorinated hydrocarbons in marine biota and coastal sediments from the Gulf and Gulf of Oman

Stephen de Mora *, Scott W. Fowler, Imma Tolosa, Jean-Pierre Villeneuve, Chantal Cattini

Marine Environment Laboratory, International Atomic Energy Agency, 4 quai Antoine 1er, MC 98000, Monaco

Abstract

The spatial distribution of various organochlorinated compounds was investigated in the Gulf and Gulf of Oman based on marine biota (fish and various bivalves) and coastal sediment collected in Bahrain, Oman, Qatar and the United Arab Emirates (UAE) during 2000–2001. Several potential organic contaminants from agricultural (e.g., DDT and its breakdown products, lindane, endrin, dieldrin, endosulfan) and industrial (PCBs) sources were measured. Sediment burdens for all compounds, even for an apparent hot spot near a refinery in Bahrain, were amongst the lowest reported for surface sediments from other seas. Concentrations of DDTs were low in the muscle and liver of all fish (orange spotted grouper and the spangled emperor) analysed. Similarly, the levels of chlorinated hydrocarbons were low in the various bivalve species, notably rock oysters and pearl oysters. These results contribute to the sparse regional database for organochlorinated compounds in the marine environment. Moreover, they can be used as the most recent end point for elucidating temporal trends. Whereas the levels, albeit relatively low, of $\sum$DDTs in the rock oysters from the Gulf of Oman have remained uniform, there has been an irregular but generally decreasing trend in concentrations of $\sum$PCBs during the last two decades.

Keywords: Biota; Sediments; Pollution; Pesticides; Organochlorinated compounds; DDT; PCBs

1. Introduction

Maintaining good marine environmental quality in the Persian/Arabian Gulf and the Gulf of Oman is crucial for several socio-economic reasons. The region relies heavily upon the sea water itself as a source of fresh water through desalination (Price et al., 1993). The seafood, notably fish and shrimp, is of value for both local consumption and export revenue. However, the relatively fragile ecosystem experiences high temperatures, salinity and UV exposure. As a result, many species function close to their physiological limits (Sheppard, 1993) and the added stress imposed by pollutants is likely to have severe consequences. Such a problem can be exacerbated, given that contaminant inputs undergo more limited dilution and slower dispersion than would occur in open marine systems because the Gulf is a relatively shallow, semi-enclosed sea with poor flushing characteristics and very high evaporation rates (Sheppard, 1993).

The Gulf and Gulf of Oman, collectively known as the ROPME[1] Sea Area (RSA), has undergone several changes in recent years that have contributed to the pollution burdens in the region. Agriculture has been expanding in the region, with the commensurate increase in use and emissions of pesticides and other

* Corresponding author. Tel.: +377 97 97 72 72; fax: +377 97 97 72 76.
E-mail address: s.de_mora@iaea.org (S. de Mora).

[1] ROPME = Regional Organisation for the Protection of the Marine Environment.

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doi:10.1016/j.marpolbul.2005.02.022

agrochemicals (Al-Saleh et al., 1999). Nevertheless, the current database for agrochemical residues in the marine environment of the Gulf remains rather limited, and even more so with respect to the Gulf of Oman (Fowler, 2002a). Ongoing industrial development in the region, even though geographically variable, continues to cause concern. Some key industrial developments, notably in Bahrain, have acted as localised sources of both organic and inorganic contaminants to the marine environment. The waterways are renown for being heavily utilised, especially with respect to oil tanker traffic, with the consequential discharges related to shipping activities. Superimposed on such diverse sources of pollutants, there has been the environmental impact of three wars in the past 25 years. It must be emphasised that the interpretation of successive war-induced effects has relied on good environmental data based on reliable techniques demonstrating good quality control.

The IAEA in partnership with ROPME has conducted surveys of marine contaminants in the Gulf and Gulf of Oman since the early 1980s (Burns et al., 1982; Fowler, 1988; Readman et al., 1996; Villeneuve et al., 1987). This latest survey carried out in 2000–2001 assesses the marine contamination in the same area arising from organochlorinated compounds, comprising both PCBs and several pesticides, based on sediments and local seafood. Sediments were collected from several coastal locations in Bahrain, Oman, Qatar and the UAE. With respect to biota, the focus was on two fish species of commercial importance, namely the orange spotted grouper (*Epinephelus coioides*, known locally as hamoor) and the spangled emperor (*Lethrinus nebulosus*, known locally as sha'ri, shaeri or sheiry), together with various bivalves, particularly oysters. Overall, these new results for sediments and biota contribute to the regional database for the RSA, especially for the Gulf of Oman given the paucity of such information. Concurrent studies of organotin compounds (de Mora et al., 2003) and metals (de Mora et al., 2004a) have been presented elsewhere, and a similar assessment for petroleum hydrocarbons in these samples is under preparation.

2. Methods

2.1. Sample collection

In general, all sampling procedures were carried out according to internationally recognized guidelines (UNEP, 1991). The locations in Bahrain, Oman, Qatar and the United Arab Emirates for the collection of sediments and biota are shown in Fig. 1. The exact coordinates of all sampling sites for sediments and various biota are given in Table 1. Sampling was conducted in March 2000 (Qatar), April 2000 (UAE) November 2000 (Bahrain), and July/August 2001 (Oman).

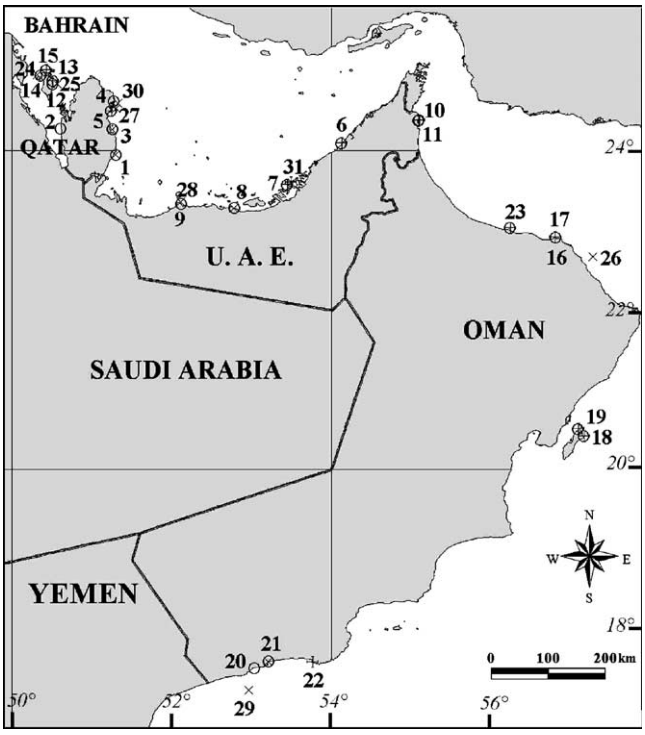

Fig. 1. Location of all sampling sites for sediments (○), fish (×) and bivalves (+) in Bahrain, Qatar, UAE and Oman.

To obtain a suitable amount of material for analysis, the soft parts from 1 to 18 individual bivalves were dissected, drained of excess liquid and then stored in glass bottles before freezing at −18 °C. For fish, 100–300 g of dorsal muscle from a single individual was dissected for the sample. Fish liver tissue was also removed and prepared for analysis in some cases. Analyses of fish reported here, as in the case of two samples from Quriyat, relate to individual fish rather than replicate determinations. All sediment and biota samples were frozen soon after collection/processing and shipped frozen to Monaco for subsequent analyses.

2.2. Analysis

Following freeze drying, sediment samples were sieved through vibrating stacked stainless steel sieves with mesh sizes from 250 to 1000 μm. Sediments were then homogenized prior to extraction. Sub-samples of the biota (fish or shellfish) were transferred to precleaned glass jars and freeze-dried for 4–5 days. The sample was then re-weighed to determine the dry/wet ratio. Following freeze-drying, all biota samples were ground using a porcelain pestle and mortar. Then, a series of internal standards (PCB 29, PCB 198, ε-HCH and Endosulfan I–D_4) was added to the sediment and biota samples for quantifying the overall recovery of the analytical procedures.

Table 1
Locations for the collection of sediments, fish and bivalves

Country and location	Site no.	Location	Sample
Bahrain			
Askar	12	26°03.102′N, 50°37.959′E	Sediments
BAPCO Refinery	13	26°06.138′N, 50°37.773′E	Sediments, pearl oysters
Jasra	14	26°11.098′N, 50°26.523′E	Sediments
North of Meridien Hotel	15	26°16.056′N, 50°31.423′E	Sediments, pearl oysters
Badaiya	24	26°12′N, 50°24′E	Orange-spotted grouper
Fasht Al Adham	25	26°03′N, 50°43′E	Orange-spotted grouper
Oman			
Mina Al Fahal	16	23°37.978′N, 58°30.693′E	Sediments
Ras Al Hamra	17	23°38.363′N, 58°29.495′E	Rock oysters
Ras Al Yei	18	20°31.348′N, 58°57.074′E	Sediments, rock oysters
Hilf	19	20°38.103′N, 58°51.813′E	Sediments, rock oysters
Mughsayl (beach)	20	16°52.956′N, 53°47.605′E	Sediments
Raysut Port Area	21	16°59.0′N, 54°01.0′E	Sediments, spangled emperor
Mirbat	22	16°58.50′N, 54°41.50′E	Sediments, rock oysters
Al Sawadi	23	23°47.260′N, 57°47.633′E	Rock oysters
Quriyat	26	23°20′N, 59°06′E	Orange-spotted grouper
Sagar	29	16°32′N, 53°43′E	Spangled emperor
Qatar			
Umm Said	1	24°56.398′N, 51°37.709′E	Sediments, orange-spotted grouper
Dukhan	2	25°21.069′N, 50°45.718′E	Sediments
Doha	3	25°20.257′N, 51°34.456′E	Sediments, orange-spotted grouper
Ras Laffan	4	25°47.000′N, 51°35.775′E	Sediments
Ras Al Nouf	5	25°37.427′N, 51°32.889′E	Sediments, venus clams
Al Khawr	27	25°40′N, 51°38′E	Orange-spotted grouper
Al Dakhira	30	25°45′N, 51°40′E	Spangled emperor
UAE			
Jebel Ali	6	25°06.991′N, 55°09.115′E	Sediments, pearl oysters, pen shells
Abu Dhabi	7	24°27.957′N, 54°18.294′E	Sediments, pearl oysters
Al Marfa	8	24°06.200′N, 53°29.207′E	Sediments
Al Marfa	8	24°06.200′N, 53°29.207′E	Orange-spotted grouper, Spangled emperor
Al Ruweis	9	24°09.842′N, 52°38.887′E	Sediments
Akkah Head	10	25°28.977′N, 56°21.940′E	Sediments, pearl oysters
Akkah Beach	11	25°28.721′N, 56°21.770′E	Sediments, rock oysters
Dhannah	28	24°12′N, 52°39′E	Orange-spotted grouper, spangled emperor
Abu Dhabi	31	24°29.917′N, 54°21.668′E	Rock scallops

Sediment samples were Soxhlet extracted for 8 h into 250 ml of hexane:methylene chloride (1:1, v/v). Sulfur was removed using activated elemental copper in order to avoid sulfur interferences during gas chromatography, and extracts were concentrated with a rotary evaporator. The Extractable Organic Matter (EOM) was determined by evaporating a measured small volume of this extract on the pan of an electrobalance. The final extracts were separated into two aliquots: 1/3 for determinations of hydrocarbons and sterols, and 2/3 for chlorinated hydrocarbon analyses.

Biota samples were Soxhlet extracted for 8 h with 250 ml of hexane. Extracts were concentrated with a rotary evaporator to approximately 15 ml, and then concentrated to about 5 ml under a gentle flow of clean nitrogen. The Extractable Organic Matter (EOM) was determined by evaporating a measured small volume of this extract on the pan of an electrobalance. For extracts with a lipid content exceeding 100–150 mg, a preliminary step for the removal of the lipids was necessary before further sample purification. Lipid removal was carried out by using concentrated sulfuric acid.

The extracts were passed through a Florisil column (18.5 g), which had been activated for 12 h at 130 °C and partially deactivated with water (0.5% by weight). From this column, three fractions were collected: the first fraction extracted with hexane (65 ml) contained PCBs, *p*,*p*′- and *o*,*p*′-DDE and some other pesticides, such as HCB, aldrin, heptachlor, DDMU; the second fraction eluted with 50 ml of hexane/methylene chloride (70:30) contained the DDTs, DDDs, most of the toxaphene and some pesticides, such as HCH isomers and chlordane components; and the third fraction eluted with methylene chloride (55 ml) contained mainly dieldrin, endrin and the endosulfan components.

The organochlorinated compounds in the extracts were measured using a Hewlett Packard HP6890 gas

chromatograph with an electron capture detector (GC-ECD) and a splitless injector. The injector and detector temperatures were 250 and 300 °C, respectively. For fractions 1 and 3, the column used was an HP-5 (cross-linked 5% Ph Me Silicone; 30 m × 0.25 mm i.d. × 0.25 μm film thickness) with He carrier gas flow rate at 1.0 ml min^{-1} and temperature programme: 70 °C for 2 min, 70–260 °C at 3 °C min^{-1}, 260 °C for 20 min. For fraction 2 and 3, the column used was an HP-5 (cross-linked 5% Ph Me Silicone; 20 m × 0.10 mm i.d. × 0.40 μm film thickness) with He carrier gas flow rate at 0.4 ml min^{-1}. The temperature programme was 100 °C for 0.5 min, 100–140 °C at 9 °C min^{-1}, 140 °C for 0.5 min, 140–250 °C at 2 °C min^{-1}, 250 °C for 0.5 min, 250–300 °C at 12 °C min^{-1}, and finally 300 °C for 15 min.

Appropriate blanks were analysed with each set of samples. Similarly, reference materials (IAEA-383 for sediments from Qatar and UAE; IAEA-408 for sediments from Bahrain and Oman; and IAEA-142 mussel homogenate) were analysed simultaneously for quality assurance purposes.

3. Results and discussion

3.1. Sediments

The content of a variety of organochlorinated compounds in coastal sediments from the RSA are given in Table 2. ∑DDTs represents the summed concentrations of individual compounds comprising DDT and its breakdown products DDD, DDE and DDMU. Similarly, ∑PCBs denotes the total amount of all congeners measured (PCB 44, 49, 52, 87, 101, 105, 118, 128, 138, 149, 153, 170, 180, 187, and 201). Environmental levels were generally low for all compounds by global standards (Fowler, 1990), including the relatively higher values for chlorinated hydrocarbons found offshore from the Bahrain Petrol Company (BAPCO) refinery complex in Bahrain (Site 13).

Considering firstly the agrochemicals, the residues of ∑DDTs (the sum of DDT and the breakdown products DDD, DDE and DDMU) in sediments from the RSA were quite low, being ⩽1.5 pg g^{-1} at 6 of 21 sites examined. The maximum level was 430 pg g^{-1} off the BAPCO refinery in Bahrain. Moreover, all sites in Bahrain had concentrations of ∑DDTs in excess of those found throughout Qatar, UAE and Oman. Excluding Bahrain, the highest levels of ∑DDTs were in Oman, with 85 and 54 pg g^{-1} at Hilf and Al Sawadi, respectively. Whereas the maximum in Hilf cannot be readily explained, the value for Al Sawadi is understandable; it is situated in the Batinah region, which supports the highest population density and the largest agricultural sector in Oman. The maximum value in the UAE was also observed in the Gulf of Oman, namely 52 pg g^{-1} at Akkah Beach. Much lower concentrations, from 0.6 to 37 pg g^{-1}, were seen in Qatar. Also of note are the very low levels (<1 pg g^{-1}) of residues of ∑DDTs measured at Raysut Port and Mughsayl in southern Oman.

Overall, the data for ∑DDTs presented here agree with the few regional data available for comparison that have recently been compiled on a country basis (Fowler, 2002a). Levels in Oman had been found to be typically low; they varied between 28 and 142 pg g^{-1} in wet samples (Burns et al., 1982) and up to 542 pg g^{-1} dry weight (Fowler, 1988). In this later study, ∑DDTs were undetected at some sites, notably Raysut. Previously reported concentrations varied in the range 10–223 and undetected to 189 pg g^{-1} in sediments from Bahrain and the UAE, respectively (Fowler, 1988). Furthermore, the most contaminated site in Bahrain was found to be Askar, the closest location sampled in the vicinity of the BAPCO refinery complex, and no DDT-related compounds were detected at Jebel Ali in the UAE. The present study found a similar lack of DDT-related compounds at Jebel Ali. Table 3 shows data for ∑DDTs from various locations globally for comparison. Overall, the concentrations of ∑DDTs in the RSA are quite low by global standards (de Mora et al., 2004b; Fowler, 1990), and even the maximum value falls well below the sediment quality guideline value of 1600 pg g^{-1} (Long et al., 1995).

DDT degrades relatively slowly in the environment (Woodwell et al., 1971). Recently deposited DDT was evident for the locations noted above for Bahrain, Oman and the UAE. In contrast, *p,p′*-DDT was undetected at some sites in Qatar (Ras Laffan, Ras Al Nouf), Oman (Mina Al Fahal, Ras Al Yei) and most locations in the UAE. Thus, the DDT at these locations was not only very low, but also well aged.

Several other organochlorinated pesticides were measured, but sediment contents were very low and of little environmental concern. The concentrations of HCB and all HCHs, including the maximum lindane signal (100 pg g^{-1}) at Ras Al Nouf in Qatar never exceed the threshold effect level of 320 pg g^{-1} for lindane (ISQG, 1995). They were also very low by global standards as exemplified by data from various locations in Table 3. Lindane concentrations reported here in Bahrain and Oman were low in comparison with previous regional studies that had found up to 160 and 180 pg g^{-1}, respectively, in these two countries (Fowler, 1990). An earlier study in Oman reported lindane in the range 31–214 pg g^{-1} for wet sediments (Burns et al., 1982). Some other interesting observations were the clear indication of prior use of endosulfan near Askar in Bahrain, Akkah Head (“Three Rocks”) in UAE and Ras Al Nouf in Qatar, and the presence of fresh endosulfan in sediments from the BAPCO site, Jasra and north of the Meridien Hotel in Bahrain, from Jebel Ali in the

Table 2
Chlorinated hydrocarbon concentrations (pg g^{-1} dry weight) in sediments from Qatar and UAE (Panel A); Bahrain and Oman (Panel B)

Compounds	Qatar					UAE					
	Umm Said	Dukhan	Doha	Ras Laffan	Ras Al Nouf	Jebel Ali	Abu Dhabi	Al Marfa	Al Ruweis	Akkah Head	Akkah Beach
Panel A											
HCB	3.1	3.2	3.0	1.0	5.4	1.3	0.91	5.8	1.4	7.3	4.2
α-HCH	1.8	0.77	1.6	<0.52	2.0	<0.52	<0.52	<0.52	0.59	1.9	<0.52
β-HCH	<1.2	3.2	2.7	<1.2	4.0	<1.2	<1.2	<1.2	<1.2	<1.2	<1.2
Lindane	3.3	1.5	5.9	21	100	1.2	0.60	<0.53	<0.53	2.6	<0.53
∑HCHs	5.1	5.47	10.2	21	106	1.2	0.6	n.d.	0.59	4.5	n.d.
p,p′-DDT	19	5.6	11	<1.8	<1.8	<1.8	<1.8	5.1	<1.8	<1.8	25
∑DDTs	36.7	23.3	36.2	0.63	17.6	n.d.	1.5	8.96	n.d.	15.4	51.9
cis-Chlordane	<0.68	1.7	<0.68	<0.68	n.a.	3.0	<0.68	3.4	<0.68	<0.68	2.5
trans-Chlordane	<0.66	2.5	<0.66	<0.66	2.1	<0.66	<0.66	<0.66	<0.66	<0.66	<0.66
trans-Nonachlor	<0.43	12	<0.43	0.79	44	<0.43	3.3	0.44	1.4	<0.43	<0.43
Heptachlor	<0.49	<0.49	<0.49	<0.49	<0.49	<0.49	<0.49	<0.49	<0.49	<0.49	<0.49
Aldrin	3.0	1.3	2.1	<0.44	4.4	3.0	0.55	0.67	1.0	17	1.4
Dieldrin	17	6	4.6	<0.92	5.5	3.7	<0.92	<0.92	<0.92	10	<0.92
Endrin	77	27	22	<2.9	14	<2.9	<2.9	<2.9	<2.9	46	<2.9
α-Endosulfan	<0.75	<0.75	<0.75	<0.75	<0.75	<0.75	<0.75	<0.75	<0.75	<0.75	<0.75
β-Endosulfan	28	2.3	1.8	<0.95	<0.95	29	<0.96	<0.96	<0.96	3.4	<0.96
Endosulfan sulfate	<1.3	<1.3	<1.3	<1.3	4.4	<1.3	<1.3	<1.3	2.4	9.7	<1.3
Aroclor 1254	280	160	290	20	230	25	46	13	28	130	22
Aroclor 1260	350	108	500	<10	18	<10	11	<10	14	41	14
∑PCBs	292	81.1	442	5.15	85.1	16.2	32.5	10.1	21.4	58.1	13.3

	Bahrain				Oman					
	Askar	BAPCO	Jasra	North of Meridien Hotel	Al Sawadi	Mina Al Fahal	Ras Al Yei	Hilf	Raysut Port Area	Mughsayl
Panel B										
HCB	6	27	5	6	4.8	10	2.3	2.4	0.94	0.56
α-HCH	<0.45	<0.45	1	1	<0.44	<0.44	<0.44	<0.44	<0.44	<0.44
β-HCH	2	7	3	4	<1.5	<1.5	<1.5	<1.5	<1.5	<1.5
Lindane	2	6	3	6	3.6	1.1	0.75	2.7	1.2	0.74
∑HCHs	4	13	7	11	3.6	1.1	0.75	2.7	1.2	0.74
p,p′-DDT	22	78	97	19	15	<3	<3	30	<3	<3
∑DDTs	88	430	146	90	53.8	22.5	12.7	85.2	0.92	0.7
cis-Chlordane	4	29	17	6	7.1	<0.93	<0.93	<0.93	<0.93	<0.93
trans-Chlordane	2	4	<1	<1	<0.84	<0.84	<0.84	<0.84	<0.84	<0.84
trans-Nonachlor	13	<0.25	5	7	3.5	2.0	<0.25	<0.25	0.63	<0.25
Heptachlor	2	32	<0.25	2	0.55	2.1	<0.22	<0.22	<0.22	<0.22
Aldrin	<0.25	3	<0.25	19	4.2	2.1	0.91	2.9	1.1	0.47
Dieldrin	22	150	15	7	10	1.4	2.2	5.4	0.70	<0.35
Endrin	15	70	37	26	20	18	<2.4	<2.4	<2.4	<2.4
α-Endosulfan	<0.2	16	10	8	1.7	<0.26	<0.26	2.9	<3.5	<3.5
β-Endosulfan	3	13	5	13	7.3	1.1	2.7	3.0	<1.4	<1.4
Endosulfan sulfate	11	8	6	3	5.5	2.0	<0.37	<0.37	<1.4	<1.4
Aroclor 1254	650	5000	220	550	190	510	12	185	<59	<59
Aroclor 1260	390	7200	81	100	66	3600	13	850	22	<6
∑PCBs	628	7411	175	313	130	1900	14.4	334	17.7	n.d.

n.a. = Not analysed; n.d. = not detected.

UAE, Umm Said in Qatar, and Al Sawadi in Oman. Dieldrin was quantifiable in most of the sediments, but was comparatively high (150 pg g^{-1} dry) only near the BAPCO complex (Table 2). In contrast, the maximum endrin concentration (77 pg g^{-1}) occurred in Umm Said, Qatar. Although such concentrations were well within the range previously reported for these pesticides in the RSA (Fowler, 2002a), they were considerably below levels noted for the Shatt al-Arab River in Iraq (Douabul et al., 1987b).

With respect to chlorinated hydrocarbons derived from industrial sources, relatively high levels of all PCBs were observed only near the BAPCO refinery in Bahrain (Table 2), as best exemplified by the concentrations of Aroclor 1254 (5 ng g^{-1}) and Aroclor 1260 (7.2 ng g^{-1}). As shown in Fig. 2, the sediment profiles of the relative

Table 3
World-wide concentrations of ∑DDTs, ∑HCHs and HCB in sediments (ng g^{-1} dry weight)

Area	Survey year	∑DDTs (ng g^{-1})	∑HCHs (ng g^{-1})	HCB (ng g^{-1})	References
Baltic Sea, Northern part	1991–1992	1.9–5.4	5.0–7.0	0.8–0.9	Stranberg et al. (1998)
Baltic Sea, South Western Coast	1993	<0.04–109	<0.04–5.0	0.1–1.3	Dannenberger and Lerz (1996)
Black Sea, Turkey	1995	0.2–7.2	0.08–1.1	0.02–0.3	Fillmann et al. (2002)
Black Sea, Odessa, Ukraine	1995	35–65	1.3–2.3	0.7–1.3	Fillmann et al. (2002)
Black Sea, Romania	1995	0.6–72	0.2–40	5.3–23	Fillmann et al. (2002)
Black Sea, Russian Federation	1995	3.3–12	0.3–0.8	0.02–0.3	Fillmann et al. (2002)
Caspian Sea, Azerbaijan	2000	0.56–13.4	0.20–3.5	0.04–0.6	de Mora et al. (2004b)
Caspian Sea, Iran	2001	0.06–3.9	0.03–0.6	0.01–0.2	de Mora et al. (2004b)
Caspian Sea, Kazakhstan	1996	0.01–0.43 (wet)	0.01–0.25 (wet)		Moore et al. (2003)
Caspian Sea, Kazakhstan	2001	0.01–1.9	0.01–0.3	0.01–0.07	de Mora et al. (2004b)
Caspian Sea, Russia	2000	0.01–1.9	0.01–0.8	0.01–0.04	de Mora et al. (2004b)
China, Hong Kong, Victoria Harbour	1992	1.4–97	<0.1–9.4		Hong et al. (1995)
China, Xiamen Harbour	1993	4.5–311	0.1–1.1		Hong et al. (1995)
Gulf of Alaska, Bering Sea, Chukchi Sea	1990	0.01–0.2	0.04–0.3	0.03–0.08	Iwata et al. (1994a)
India, cities	1989	8–450	0.6–38		Iwata et al. (1994b)
Japan, cities	1990	2.5–12	4.5–6.2		Iwata et al. (1994b)
Kara Sea	1993	n.d.[a]–1.2	n.d.–0.6		Sericano et al. (2001)
Masan Bay, Korea	1997	0.3–89	n.d.–1.3	0.04–0.6	Hong et al. (2003)
Mediterranean Sea, deep basin in NW	1990	1.4–5.5		0.05–0.5	Tolosa et al. (1995)
Mediterranean Sea, offshore Barcelona	1990	5–76		0.4–2.9	Tolosa et al. (1995)
Mediterranean Sea, Rhone prodelta	1987–1988	62–675		11–39	Tolosa et al. (1995)
Off Savannah, Georgia, USA	1997	<0.2–4.3	<0.2–0.9	<0.2–4.7	Loganathan et al. (2001)
United States coastline	1986	0.01–454	0.01–0.77[b]		Wade et al. (1988)
Vietnam, cities	1990	0.4–790	0.4–12		Iwata et al. (1994b)
Vietnam, North coast	1997	6.2–10.4	1.2–33.7	0.1–6.5	Nhan et al. (2001)
Bahrain	2000	0.088–0.430	0.004–0.013	0.005–0.027	This study
Oman	2001	0.0007–0.0852	0.00074–0.0036	0.0006–0.010	This study
Qatar	2000	0.00063–0.0367	0.0051–0.106	0.0010–0.0054	This study
UAE	2000	n.d.–0.0519	n.d.–0.0045	0.0009–0.0073	This study

[a] n.d. = Not detected.
[b] Lindane.

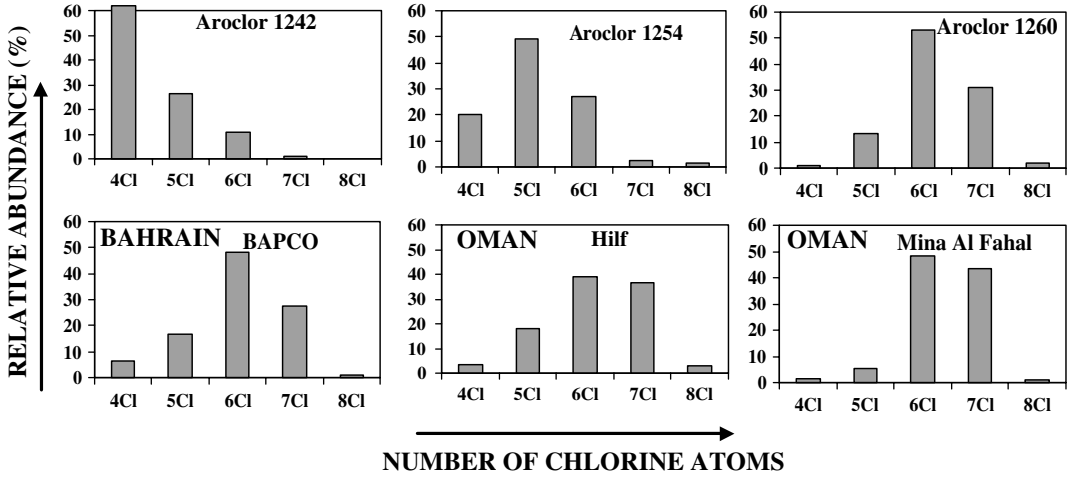

Fig. 2. Relative distribution of PCB congeners according to chlorine substitution (4Cl, tetrachlorobiphenyls 44, 49, 52; 5Cl, pentachlorobiphenyls, 87, 101, 105, 118; 6Cl, hexachlorobiphenyls 128, 138, 149, 153; 7Cl, heptachlorobiphenyls 170, 180, 187; 8Cl, octachlorobiphenyl 201) in sediments from Bahrain and Oman. Aroclor 1242, 1254 and 1260 commercial mixtures (Schulz et al., 1989) are also shown.

distribution of PCB congeners according to chlorine substitution is largely dominated by hexa-chloro, hepta-chloro and penta-chloro congeners indicating the contribution of a highly chlorinated commercial formulation, such as Aroclor 1260 (Schulz et al., 1989). The amounts of PCBs in the sediments from all other locations were not exceptional, and were comparable to levels that have been previously reported for these or nearby sites (Fowler, 2002a). The maximum Aroclor 1254 concentrations in the other three countries were

130 pg g^{-1} at Akkah Head ("Three Rocks") in UAE, 290 pg g^{-1} at Doha in Qatar, and 510 pg g^{-1} at PDO beach at Mina Al Fahal in Oman. At the latter site in Oman, the very high PCB concentration, 3.6 ng g^{-1} quantified as Aroclor 1260, and the significant increase in the relative distribution of hepta-chloro congeners (Fig. 2) is noteworthy and may be specific to land-based inputs from the PDO refinery wastewaters. In summary, the PCB content was fairly low by global standards for nearshore sediments (Fowler, 1990) and never exceeded the sediment quality guideline value of 23 ng g^{-1} dry weight (Long et al., 1995).

3.2. Fish

Reliable data for organochlorinated compounds in edible fish from the RSA are still sparse (Fowler, 2002b; Sadiq et al., 2002). The concentrations of a variety of such compounds in fish are given in Table 4. Levels of ∑DDTs were low in the muscle of all fish analysed. Here, the maximum value of 8.6 ng g^{-1} dry weight was measured in the orange-spotted grouper from Oman. The amounts of these residues in fish from Bahrain were consistently in the narrow range of 0.7–1.1 ng g^{-1} dry weight. In the other countries, fish contained levels of ∑DDTs <0.9 ng g^{-1} in muscle and <13 ng g^{-1} dry weight in liver. These values never exceeded the maximum acceptable concentrations in aquatic species used as food of 14.0 ng g^{-1} (wet weight), i.e., about 70 ng g^{-1} (dry weight) for ∑DDTs. For comparison, earlier studies had found somewhat higher amounts of ∑DDTs in fish muscle. Based on 113 samples of commercially important fish from the northwestern Gulf, ∑DDTs in muscle varied from 2 to 11 ng g^{-1} on a wet weight basis (Douabul et al., 1987a). Concentrations in several species from the coastal waters of Kuwait varied in the range 1.5–32.7 ng g^{-1} (Villeneuve et al., 1987) and 117–292 ng g^{-1} on a wet weight basis in fish from Oman (Burns et al., 1982). This same study noted much higher amounts in fish liver, being 1180–4220 ng g^{-1} on a wet weight basis.

Other chlorinated pesticides, such as lindane, dieldrin, endrin and HCB, were all present in very low concentrations in both muscle and liver samples from fish. Similarly, the levels of endosulfan sulfate were also very low, with a maximum of 2.1 ng g^{-1} in the liver of a spangled emperor from Dhannah near Al Ruweis, UAE. The presence of the endosulfan sulfate residue in liver and not in the muscle of the carnivorous spangled emperor from Dhannah (Table 4) suggests that it may have recently been passed along the food chain to this top predator. There are very few regional data to compare with the results given here. Traces of dieldrin and endrin had been reported for several species of fish from the northwest RSA (Douabul et al., 1987a). Lindane concentrations in fish sampled 20 years earlier in the Gulf of Oman were found to be 24–64 and 3–1550 pg g^{-1} wet weight in the muscle and liver, respectively (Burns et al., 1982). In the same study, the HCB content in muscle and liver was 3–19 and 27–320 pg g^{-1}, respectively.

Concentrations of PCBs as Aroclor 1254 varied in the range 0.12–2.1 ng g^{-1} in fish muscle, and 0.052–29 ng g^{-1} in fish liver. For Aroclor 1260, the levels varied between 0.14–3.8 and 0.35–42 ng g^{-1}, respectively, in muscle and liver. In all cases, the minimum concentration was found in a spangled emperor from Al Marfa, UAE. A comparison can be made with a recent compilation of Aroclor 1254 data from the region, which noted that concentrations in various fish species varied in the range 0.77–58 ng g^{-1} dry weight (Fowler, 2002b). The organochlorine contents reported in this study fell in the lower range of those reported as global comparators (Table 5) and probably reflect the chronic contamination of the area rather than the influence of coastal discharges.

Although, there was no correlation between concentrations of Aroclors in the muscle and liver of individual fish, PCB congener patterns were similar between liver and muscle (Fig. 3). Other studies have also demonstrated that unlike congener profiles, total PCB content does differ dramatically amongst tissues and that PCB differences among tissues can vary with site (Monosson et al., 2003). A clear trend of the greater metabolic activity for the lower chlorinated congeners (Garcia et al., 2000; Sole et al., 2001) was difficult to recognize in these fish samples because of the low concentrations of PCBs, in particular the lower chlorinated congeners.

3.3. Bivalves

The content of chlorinated hydrocarbons in bivalves from the RSA are presented in Table 6. Previous contaminant screening surveys have underscored the difficulty in making regional comparisons because not all bivalve species that have been used for monitoring purposes are ubiquitous throughout the RSA. As evident in Table 1, a range of biota was investigated. Pearl oysters, *Pinctada radiata*, were collected in Bahrain and the UAE, including Akkah Head in the Gulf of Oman. However, only rock oysters, *Saccostrea cucullata*, could be obtained in Oman. Composite samples were available from only single sites for Venus clams, *Circentia callipyga* (Ras Al Nouf, Qatar); rock scallops, *Spondylus* sp. (Abu Dhabi, UAE); and pen shells, *Pinna muricata* (Jebel Ali, UAE).

Pearl oysters have been used extensively in contaminant screening surveys, and hence, present one of the best possibilities to make sub-regional comparisons of chlorinated hydrocarbon levels. Total PCB concentrations as Aroclor 1254 ranged between 0.1 and 3.7 ng g^{-1} dry in pearl oysters from two of the countries surveyed in 2000 (Table 6). The maximum values were noted in

Table 4
Chlorinated hydrocarbon concentrations (ng g^{-1} dry weight) in fish from Qatar (Panel A), UAE (Panel B), Bahrain (Panel C) and Oman (Panel D)

Compounds	Al Khawr		Umm Said		Doha		Al Dakhira	
	Orange-spotted grouper		Orange-spotted grouper		Orange-spotted grouper		Spangled emperor	
	Muscle	Liver	Muscle	Liver	Muscle	Liver	Muscle	Liver
Panel A: QATAR								
Dry/wet weight ratio	0.21	0.235	0.227	0.407	0.213	0.300	0.226	0.200
HEOM (mg g^{-1})[a]	22	60	8.9	374	17	320	22	179
HCB	0.006	0.050	0.013	0.29	0.012	0.19	0.011	0.046
α-HCH	0.008	0.020	<0.005	0.096	<0.005	0.086	n.a.	0.031
β-HCH	0.066	0.22	0.016	0.54	0.046	0.48	n.a.	0.46
Lindane	<0.006	0.039	<0.006	0.037	<0.006	0.24	n.a.	0.26
∑HCHs	0.074	0.279	0.016	0.673	0.046	0.806	n.a.	0.751
p,p′-DDT	0.015	0.024	0.033	0.73	0.024	0.37	n.a.	0.20
∑DDTs	0.179	0.719	0.208	9.175	0.157	3.717	0.096	1.076
cis-Chlordane	<0.008	0.051	<0.008	0.32	<0.008	0.24	n.a.	0.076
trans-Chlordane	<0.008	<0.012	<0.008	0.077	<0.008	0.050	n.a.	0.049
trans-Nonachlor	0.007	0.063	0.026	0.56	0.013	0.27	<0.004	0.073
Heptachlor	<0.005	<0.010	<0.005	<0.010	<0.005	<0.010	<0.005	<0.010
Aldrin	<0.004	0.041	<0.004	0.29	<0.004	0.74	<0.004	0.35
Dieldrin	0.030	0.24	0.013	0.81	0.017	0.57	0.027	0.42
Endrin	<0.017	0.11	<0.017	<0.043	<0.017	<0.043	<0.017	<0.043
α-Endosulfan	<0.007	<0.015	<0.004	<0.015	<0.004	<0.015	<0.004	<0.015
β-Endosulfan	<0.008	0.057	0.027	1.4	0.026	0.81	<0.005	0.14
Endosulfan sulfate	0.022	0.14	<0.006	0.27	0.008	0.43	<0.006	0.22
Aroclor 1254	0.65	1.6	0.55	24	0.38	29	0.49	3.0
Aroclor 1260	0.84	4.5	1.3	42	1.0	23	0.23	2.3
∑PCBs	1.29	6.04	1.42	49.47	1.24	35.19	0.52	4.44

	Al Marfa				Dhannah			
	Orange-spotted grouper		Spangled emperor		Spangled emperor		Orange-spotted grouper	
Panel B: UAE								
Dry/wet weight ratio	0.211	0.333	0.217	0.245	0.213	0.300	0.225	0.333
HEOM (mg g^{-1})[a]	34	243	34	95	47	175	66	225
HCB	0.029	0.31	0.014	0.066	0.028	0.11	0.062	0.22
α-HCH	<0.005	0.096	0.008	0.019	0.013	0.024	0.016	2.5
β-HCH	0.053	<0.026	0.032	0.083	0.091	0.19	0.091	<0.026
Lindane	<0.004	0.032	<0.004	0.017	0.008	0.010	0.020	<0.009
∑HCHs	0.053	0.128	0.04	0.119	0.112	0.224	0.127	2.5
p,p′-DDT	0.036	0.36	<0.014	0.067	0.069	0.085	0.090	1.1
∑DDTs	0.392	4.267	0.065	0.322	0.45	1.323	0.917	4.996
cis-Chlordane	0.017	0.23	<0.006	0.025	0.034	0.080	0.036	0.18
trans-Chlordane	0.008	0.24	<0.006	<0.012	<0.006	0.010	0.008	0.30
trans-Nonachlor	0.043	0.44	0.005	0.011	0.029	0.065	0.090	0.31
Heptachlor	<0.003	<0.010	<0.003	<0.010	<0.003	<0.010	0.009	<0.010
Aldrin	0.006	0.32	<0.003	0.060	0.007	0.17	0.017	0.39
Dieldrin	0.12	0.44	0.035	0.17	0.14	0.52	0.13	0.48
Endrin	<0.013	0.15	<0.013	0.11	0.067	0.91	<0.013	0.22
α-Endosulfan	<0.004	<0.015	<0.004	<0.015	<0.004	<0.015	<0.004	<0.015
β-Endosulfan	<0.005	0.088	<0.005	0.048	<0.005	0.18	0.033	0.23
Endosulfan sulfate	0.067	0.066	0.061	0.13	<0.006	2.1	0.058	0.66
Aroclor 1254	0.54	5.8	0.12	0.52	1.8	4.0	2.1	5.3
Aroclor 1260	1.1	12	0.14	0.35	2.5	6.1	3.8	8.8
∑PCBs	1.49	16.80	0.24	1.02	3.92	11.47	3.91	12.57

	Badaiya				Fasht Al Adham			
	Orange-spotted grouper (1.6 kg)		Orange-spotted grouper (1.15 kg)		Orange-spotted grouper (1.26 kg)		Orange-spotted grouper (1.03 kg)	
Panel C: Bahrain								
Dry/wet weight ratio	0.22	0.33	0.2	0.29	0.22	0.36	0.24	0.34
HEOM (mg g^{-1})[a]	48	240	29	125	59	280	140	240
HCB	0.082	0.086	0.015	0.061	0.014	0.130	0.025	0.086

Table 4 (*continued*)

Compounds	Badaiya				Fasht Al Adham			
	Orange-spotted grouper (1.6 kg)		Orange-spotted grouper (1.15 kg)		Orange-spotted grouper (1.26 kg)		Orange-spotted grouper (1.03 kg)	
α-HCH	0.009	0.028	<0.006	<0.014	<0.006	0.048	<0.006	0.029
β-HCH	0.055	0.390	<0.020	0.065	0.041	0.140	<0.020	0.140
Lindane	0.014	0.110	0.016	0.130	0.009	0.050	<0.005	0.028
∑HCHs	0.078	0.528	0.016	0.195	0.05	0.238	n.d.	0.197
p,p′-DDT	0.043	0.290	0.056	0.110	<0.024	0.190	0.070	0.110
∑DDTs	0.699	5.317	1.092	6.429	0.725	2.377	0.741	1.53
cis-Chlordane	0.024	0.120	<0.009	0.140	0.033	0.069	0.030	0.130
trans-Chlordane	<0.009	0.030	<0.009	<0.023	<0.009	<0.023	0.035	0.078
trans-Nonachlor	0.026	0.350	0.016	0.340	0.019	0.200	0.037	0.100
Heptachlor	<0.004	<0.010	<0.004	<0.010	<0.004	<0.010	<0.004	<0.010
Aldrin	<0.003	0.310	<0.003	0.210	<0.003	0.310	<0.003	0.150
Dieldrin	0.092	0.190	0.100	1.100	0.120	0.360	0.210	0.720
Endrin	<0.014	0.460	<0.014	0.380	<0.014	1.100	<0.014	1.400
α-Endosulfan	<0.002	<0.006	<0.002	<0.006	<0.002	<0.006	<0.002	<0.006
β-Endosulfan	0.025	0.030	<0.003	0.081	<0.003	0.170	<0.003	0.064
Endosulfan sulfate	0.032	0.009	0.049	0.100	0.055	0.270	<0.003	0.056
Aroclor 1254	1.000	11.000	0.790	6.000	0.750	4.500	1.400	3.300
Aroclor 1260	2.700	34.000	1.700	14.000	1.500	8.800	1.600	6.300
∑PCBs	4.18	40.1	2.92	23.1	2.39	14.3	3.28	8.19
	Quriyat				Raysut Port Area		Sagar	
	Orange-spotted grouper (1)		Orange-spotted grouper (2)		Spangled emperor		Spangled emperor	
Panel D: Oman								
Dry/wet weight ratio	0.24	0.35	0.22	0.37	0.24	0.39	0.23	0.33
HEOM (mg g^{-1})[a]	140	315	59	295	27	315	29	280
HCB	<0.002	0.10	0.008	0.041	0.007	0.067	0.009	0.072
α-HCH	0.004	0.021	<0.003	<0.011	<0.003	<0.011	0.007	<0.011
β-HCH	0.23	0.86	0.11	0.66	0.040	0.68	0.042	0.58
Lindane	<0.003	0.043	<0.003	0.029	<0.003	0.021	<0.003	0.027
∑HCHs	0.234	0.924	0.11	0.689	0.04	0.701	0.049	0.607
p,p′-DDT	1.10	1.10	0.53	1.50	0.13	1.20	0.12	0.32
∑DDTs	8.58	25.5	4.561	26.04	0.688	10.99	0.6	12.93
cis-Chlordane	0.13	0.27	0.11	0.25	<0.006	0.19	<0.006	0.18
trans-Chlordane	0.026	0.056	0.021	0.049	<0.006	0.035	<0.006	0.010
trans-Nonachlor	0.082	0.26	0.038	0.28	0.007	0.14	0.007	0.16
Heptachlor	<0.003	<0.006	<0.003	<0.006	<0.003	<0.006	<0.003	<0.006
Aldrin	0.032	0.10	0.010	0.095	<0.002	0.17	<0.002	0.18
Dieldrin	0.160	0.36	0.080	0.39	0.024	0.46	0.043	0.40
Endrin	0.078	0.48	0.097	0.61	0.048	0.86	n.a.	0.67
α-Endosulfan	0.058	<0.012	0.023	<0.012	0.007	<0.012	<0.001	0.051
β-Endosulfan	0.071	0.35	0.016	0.18	0.011	0.21	0.069	0.23
Endosulfan sulfate	<0.002	0.10	0.060	0.045	0.014	0.20	0.042	0.14
Aroclor 1254	1.40	6.80	1.40	6.10	0.40	3.60	0.34	3.80
Aroclor 1260	3.60	8.50	1.40	7.00	0.27	2.40	0.27	2.30
∑PCBs	5.16	13.6	2.76	11.1	0.80	5.37	0.45	4.86

n.a. = not analysed; n.d. = not detected.

[a] Hexane extractable organic matter.

oysters from Abu Dhabi and BAPCO. Both samples exhibited a chlorination level plot (Fig. 4) similar to the adjacent sediment and to the highest chlorinated commercial mixtures (Fig. 2). As high levels of other chlorinated compounds were also measured in these individuals, a local source of mixed contaminants near these locations is strongly suggested. Nevertheless, when compared to PCB data from previous surveys in the RSA, the concentration observed at Abu Dhabi was not particularly elevated; for example, PCB concentrations ranging from <1.0 to 71 ng g^{-1} dry have been reported in pearl oysters from the region since the late 1970s (Fowler, 2002b).

The rock oyster is another bivalve species that has been continually used in pollution assessments carried out in UAE, Oman and Iran. The total PCB concentration quantified as Aroclor 1254 (1.1 ng g^{-1}) in rock oysters from Akkah Beach in the Gulf of Oman (Table 6) is low in comparison with most earlier data for these countries (Fowler, 2002a). Likewise, total PCB levels

Table 5
World-wide concentrations of ∑PCBs, ∑DDTs in fish samples (ng/g dry weight; converted using dry/wet weight ratio of 0.23)

Area	Species	Tissue[a]	Survey year	∑PCBs (ng g^{-1})	∑DDTs (ng g^{-1})	References
Ebro Delta, NW Mediterranean Sea	Sea bass	M	1993	19–27	11–17	Pastor et al. (1996)
Ebro Delta, NW Mediterranean Sea	Red mullet	M	1993	38–88	19–73	Pastor et al. (1996)
Hudson river estuary, NY, USA	Mumichogs	L	1994	652–5796		Monosson et al. (2003)
Australia, Sydney harbour	Flat-tail mullet	M	1995	1013–2065	369–382	Roach and Runcie (1998)
Australia, Sydney harbour	Sea mullet	M	1995	4330–16,443	630–5039	Roach and Runcie (1998)
Eastern Aegean Sea, Turkey	*Mullus barbatus*	M	1995	<13	50–91	Kucuksezgin et al. (2001)
NW Mediterranean Sea	*Mora moro*	M	1996	60–104	32–55	Sole et al. (2001)
NW Mediterranean Sea	*Mora moro*	L	1996	3330–23,913	3239–7086	Sole et al. (2001)
Italian Adriatic Sea	Mackerel	M	1997	217–383	84–141	Stefanelli et al. (2004)
Italian Adriatic Sea	Red mullet	M	1997	54–132	14–33	Stefanelli et al. (2004)
Qatar	Orange-spotted grouper	M	2000	0.5–1.3	0.1–0.2	This study
Qatar	Orange-spotted grouper	L	2000	4.4–49	0.7–9.2	This study
UAE	Orange-spotted grouper	M	2000	1.5–3.9	0.4–0.9	This study
UAE	Orange-spotted grouper	L	2000	12.5–16.8	4.3–5.0	This study
UAE	Spangled emperor	M	2000	0.2–3.9	0.1–0.4	This study
UAE	Spangled emperor	L	2000	1.0–11.5	0.3–1.3	This study
Bahrain	Orange-spotted grouper	M	2000	2.4–4.2	0.7–1.1	This study
Bahrain	Orange-spotted grouper	L	2000	8.2–40	1.5–6.4	This study
Oman	Orange-spotted grouper	M	2001	2.7–5.2	4.6–8.6	This study
Oman	Orange-spotted grouper	L	2001	11–14	25–26	This study
Oman	Spangled emperor	M	2001	0.6–0.8	0.6–0.7	This study
Oman	Spangled emperor	L	2001	4.8–5.4	11–13	This study

[a] M = muscle; L = liver.

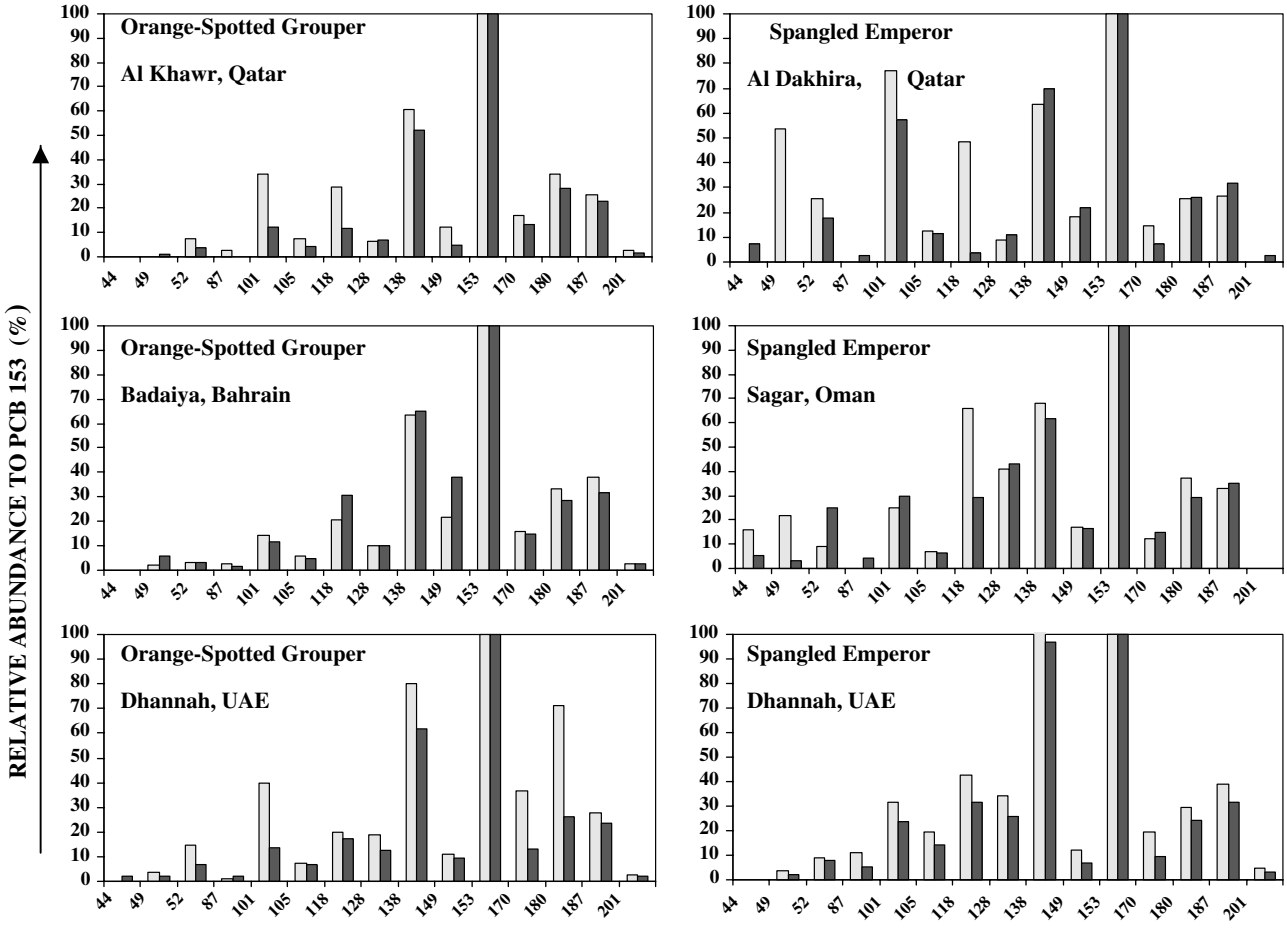

Fig. 3. PCB profiles, related to congener No. 153, in muscle (light bars) and liver (dark bars) of Orange-spotted grouper and Splanged emperor.

Table 6
Chlorinated hydrocarbon concentrations (ng g^{-1} dry weight) in bivalve molluscs

Compound	UAE						Qatar	Bahrain		Oman				
	Jebel Ali		Abu Dhabi		Akkah Head		Ras Al Nouf	BAPCO	Meridien Hotel	Al Sawadi	Ras Al Hamra	Ras Al Yei	Hilf	Mirbat
	Pearl oysters	Pen Shells	Rock scallops	Pearl oysters	Pearl oysters	Rock oysters	Clams	Pearl oysters	Pearl oysters	Rock oysters	Rock oysters	Rock oysters	Rock oysters	Rock oysters
Dry/wet weight ratio	0.162	0.263	0.169	0.155	0.203	0.273	0.129	0.13	0.18	0.23	0.22	0.23	0.24	0.22
HEOM (mg g^{-1})[a]	35	21	39	54	39	97	27	32	37	92	52	87	78	93
HCB	0.025	0.016	0.073	0.29	0.013	0.024	0.057	0.019	0.024	0.028	0.018	0.043	0.017	0.034
α-HCH	0.014	0.027	<0.005	0.083	<0.005	0.028	0.17	0.012	0.010	0.027	0.006	0.004	0.004	0.008
β-HCH	0.050	0.18	0.027	0.085	0.021	0.24	0.23	0.035	0.029	0.11	0.12	0.14	0.038	0.16
Lindane	0.021	0.026	0.006	0.026	<0.004	<0.004	0.15	0.083	0.054	0.013	0.014	0.011	0.023	0.016
∑HCHs	0.085	0.233	0.033	0.194	0.021	0.268	0.55	0.13	0.093	0.15	0.14	0.155	0.065	0.184
p,p′-DDT	0.11	0.026	0.22	0.54	0.028	0.18	0.14	0.350	0.260	2.00	0.25	0.34	1.90	0.69
∑DDTs	0.137	0.106	1.077	5.881	0.133	1.815	0.154	1.495	0.708	3.383	0.897	1.74	4.644	1.566
cis-Chlordane	<0.006	0.27	0.17	0.19	0.025	0.47	n.a.	0.092	0.150	<0.006	0.016	<0.006	<0.006	<0.006
trans-Chlordane	<0.006	0.011	0.011	0.078	0.021	0.059	<0.006	<0.009	0.049	0.095	0.012	0.16	0.076	0.54
trans-Nonachlor	<0.004	<0.004	<0.004	<0.004	<0.004	0.015	<0.004	0.009	0.044	0.020	0.15	0.13	0.010	0.21
Heptachlor	<0.003	<0.003	0.004	0.060	<0.003	<0.003	<0.003	<0.004	<0.004	<0.003	<0.003	<0.003	<0.003	<0.003
Aldrin	<0.003	0.014	0.022	0.11	0.012	0.020	<0.003	<0.003	<0.003	0.031	0.063	0.071	0.12	0.072
Dieldrin	0.016	0.60	0.22	1.2	0.055	0.23	0.006	0.100	0.310	0.53	0.79	0.32	0.15	1.00
Endrin	<0.013	<0.013	0.043	0.080	0.18	0.38	<0.013	<0.014	<0.014	<0.009	0.12	0.30	0.27	0.48
α-Endosulfan	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.002	<0.002	0.075	0.081	<0.001	n.a.	0.076
β-Endosulfan	<0.005	0.039	<0.005	0.094	0.027	<0.005	<0.005	0.025	0.014	0.058	0.040	0.009	0.030	0.040
Endosulfan sulfate	<0.006	0.016	<0.006	<0.006	<0.006	<0.006	<0.006	0.041	0.029	<0.002	0.032	0.034	n.a.	0.012
Aroclor 1254	0.21	0.25	1.2	3.7	<0.078	1.1	1.3	3.000	1.600	1.90	1.60	1.20	2.70	1.30
Aroclor 1260	0.13	<0.062	0.34	3.0	<0.062	0.30	0.11	2.400	0.590	0.77	1.30	0.34	4.40	1.00
∑PCBs	0.203	0.303	1.14	3.59	0.131	0.515	0.245	5.79	2.80	2.36	3.22	1.19	4.77	1.98

n.a. = Not analysed.
[a] Hexane extractable organic matter.

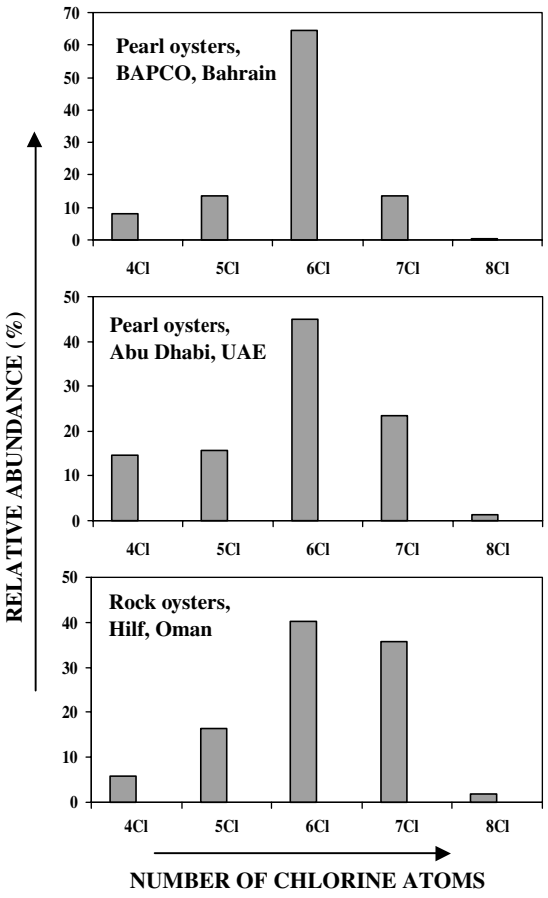

Fig. 4. Relative distribution of PCB congeners according to chlorine substitution (4Cl, tetrachlorobiphenyls 44, 49, 52; 5Cl, pentachlorobiphenyls, 87, 101, 105, 118; 6Cl, hexachlorobiphenyls 128, 138, 149, 153; 7Cl, heptachlorobiphenyls 170, 180, 187; 8Cl, octachlorobiphenyl 201) in bivalve mollusks from Bahrain, UAE and Oman.

(1.2–2.7 ng g^{-1} dry weight as Aroclor 1254) in the rock oysters from Oman (Table 6) were also low relative to concentrations that have been measured in previous studies (Badawy et al., 1988; Burns et al., 1982; Fowler, 1988). The maximum value was measured in rock oysters from Hilf and the chlorination profile (Fig. 4), as evident in sediments from Oman (Fig. 2), showed a significant increase in the relative distribution of heptachloro congeners. It is of interest to examine the recent concentration values in the context of temporal data for this species from Oman stations surveyed since 1980. As can be seen in Table 7, there has been an irregular but generally decreasing trend in PCB concentrations over the last two decades. These compounds are indeed persistent and although three of the most recent data points are defined by only single composite samples, they include some of the lowest PCB concentrations measured to date in rock oysters from the RSA.

With respect to PCBs in samples other than oysters, the concentrations were quite low in the Venus clam from Qatar. The Aroclor 1254 content was only 0.11 ng g^{-1} dry weight (Table 6), much lower than previous measurements of 0.5–3.8 and 10 ng g^{-1} dry weight for clams from Kuwait (Fowler, 2002b) and elsewhere in the world (Table 8). The rock scallop sample from Abu Dhabi had a very low content of Aroclor 1254, namely 1.2 ng g^{-1} dry weight (Table 6). This level was an order of magnitude lower than that, 11 ng g^{-1} dry, found in a rock scallop sampled further west off Bidya, UAE in 1994 (Fowler, 2002b). The only other data available for Aroclor 1254 in rock scallops from the region came from 1983 to 1984 surveys at Askar, in Bahrain, which reported concentrations of 19.2 and

Table 7
Average concentrations and ranges of PCBs in rock oysters (*Saccostrea cucullata*) from several locations along the coast of Oman and two locations on the east coast of UAE (adapted from Fowler, 2002b)

Country	Collection date	PCBs (ng g^{-1} dry weight)[a]
Oman	September 1980[b]	17.4 (7.8–39.5)
”	January 1983	8.5 (6.0–12.0)
”	October 1983	23.7 (0.3–68.7)
”	January 1984	5.2 (1.9–11.4)
”	March 1984	3.8 (1.4–7.3)
”	April 1984	2.0 (0.1–4.0)
”	May 1984	4.5 (1.2–9.3)
”	July 1984	3.6 (1.5–8.1)
”	September 1985	8.4 (6.4–11.0)
”	April 1986	9.1 (6.4–13.0)
”	September 1986	3.4 (1.0–6.0)
UAE	June 1994[c]	5.6
Oman	August 1997[c]	2.4
UAE	April 2000[c]	1.1
Oman	July 2001	1.7 (1.2–2.7)

[a] PCB concentrations quantified as Aroclor 1254.
[b] Data from Burns et al. (1982) converted using dry/wet weight ratio of 0.23.
[c] Single composite samples from Dhadnah in 1994, Musandam in 1997 and Akkah Beach in 2000.

Table 8
World-wide concentrations of ∑PCBs, ∑DDTs in bivalve samples (ng/g dry weight; converted using dry/wet weight ratio of 0.23)

Area	Species	Survey year	∑PCBs (ng g^{-1})	∑DDTs (ng g^{-1})	References
Tokyo Bay, Japan	*Mytilus galloprovincialis*	1994	32–365	3.5–52	Monirith et al. (2003)
Italian Adriatic Sea	Mussel	1997	12–63	1.8–9.3	Stefanelli et al. (2004)
Mersey estuary, England	*Mytilus edulis*	1998	135–456	19–74	Connor et al. (2001)
Malaysia	*Perna viridis*	1998	0.21–22	0.26–3.5	Monirith et al. (2003)
Indonesia	*Perna viridis*	1998	0.4–12	0.4–13	Monirith et al. (2003)
India	*Perna viridis*	1998	0.9–48	2.6–65	Monirith et al. (2003)
Philippines	*Perna viridis*	1998	1.7–61	0.3–3.5	Monirith et al. (2003)
Hong Kong	*Perna viridis*	1998	1.3–32	33–4348	Monirith et al. (2003)
Russia	*Cremomytilus grayamus*	1999	243–304	2.1–2.6	Monirith et al. (2003)
Izmit Bay, Bay of Marmara Sea	Mussels	1999	20–121		Telli-Karakoc et al. (2002)
China	*Perna viridis*, *Mytilus edulis*	1999–2001	1.3–13	252–2739	Monirith et al. (2003)
Egyptian Red Sea coast	Brachiodontes sp.	2000	29–289	543–3356	Khaled et al. (2004)
UAE	Pearl oysters	2000–2001	0.1–3.6	0.13–5.9	This study
UAE	Rock oysters	2000–2001	0.5	1.8	This study
UAE	Rock scallops	2000–2001	1.1	1.1	This study
UAE	Pen shells	2000–2001	0.3	0.1	This study
Qatar	Clams	2000–2001	0.2	0.2	This study
Bahrain	Pearl oysters	2000–2001	2.8–5.8	0.7–1.5	This study
Oman	Rock oysters	2000–2001	1.2–4.8	0.9–4.6	This study

7.0 ng g^{-1} dry weight, respectively (Fowler, 1988). The concentrations of organochlorinated compounds, including Aroclor 1254 for example, in the pen shell sample were not especially noteworthy (Table 6). This behaviour contrasts sharply with their ability to accumulate high levels of many metals (de Mora et al., 2004a).

The various bivalves have also been used for monitoring several organochlorinated pesticides. The concentrations of all the pesticide residues were generally low in bivalve species analysed (Table 6). With respect to the pearl oysters, only the sample from Abu Dhabi gave any indication of contamination. For example, the highest level of ∑DDTs, 5.9 ng g^{-1} dry, was found in these oysters. However, most of the DDT had degraded to *p*,*p*′-DDE, thereby indicative of an earlier contamination episode. Many of the other pesticides, such as lindane and HCB, were also elevated in the oysters from Abu Dhabi, but the levels were not exceptional when compared with concentrations measured previously in these species from the region (Badawy et al., 1988; Fowler, 2002a).

Rock oysters contained chlorinated pesticide concentrations that were relatively low and quite similar to those measured in pearl oysters and the other bivalve species (Table 6). The residue levels of ∑DDTs ranged from 0.9 to 4.6 ng g^{-1} dry weight, with the highest concentrations of 3.4 and 4.6 ng g^{-1} found in oysters from Al Sawadi and Hilf, Oman. Similar to the sediments, roughly half of the ∑DDTs concentrations in these individuals was present as *p*,*p*′-DDT, suggesting relatively fresh inputs of DDT at those two locations. As

Table 9
Average concentrations and ranges of ∑DDTs in rock oysters (*Saccostrea cucullata)* from several locations along the coast of Oman and two stations on the east coast of UAE (adapted from Fowler (2002a))

Country	Collection date	∑DDTs (ng g^{-1} dry weight)
Oman	September 1980[a]	2.7 (1.03–4.4)
”	October 1983	4.9 (3.0–7.7)
”	January 1984	0.58 (0.16–0.86)
”	March 1984	0.37 (0.10–0.60)
”	April 1984	0.43 (0.14–0.86)
”	May 1984	0.40 (0.32–0.47)
”	July 1984	0.46 (0.15–0.66)
”	September 1985	2.9 (2.2–3.3)
”	April 1986	3.3 (1.1–8.4)
”	September 1986	2.1 (1.3–2.9)
UAE	June 1994[b]	2.5
Oman	August 1997[b]	1.2
UAE	April 2000[b]	1.8
Oman	July 2001	2.4 (0.9–4.6)

[a] Data from Burns et al. (1982) converted using dry/wet weight ratio of 0.23.
[b] Single composite samples from Dhadnah in 1994, Musandam in 1997 and Akkah Beach in 2000.

noted previously for the sediments, Al Sawadi is close to the main agricultural region of Oman. However, the reason for the maximum content in oysters from Hilf is not apparent. As in the case with PCBs, it is instructive to examine the temporal data for ∑DDT residues in rock oysters that have been periodically monitored outside the Strait of Hormuz since 1980 (Table 9). Clear the levels of ∑DDTs in the rock oysters, while relatively low, have varied little over the last two decades. These low, fairly constant concentrations of ∑DDTs present in oysters from urbanized and remote areas attest both to their environmental persistence, and their chronic input to the RSA, most likely via long-range atmospheric transport.

4. Conclusions

Although the sampling coverage in some areas has not been comprehensive, several pertinent findings and general conclusions are highlighted based on the screening results from the four countries surveyed in 2000 and 2001. In particular, the new results on organochlorine compounds have proven useful in expanding the existing time-series data sets for the region. Whereas PCB concentrations in oyster populations have appeared to decrease over the past two decades, concentrations of DDT compounds have varied little during that time. Such data sets are unique and should be extended to sediments in well-defined locations so that the countries can better evaluate temporal changes and recovery potential in areas that have been contaminated, such as Akkah beach in UAE and off the BAPCO refinery in Bahrain.

Aside from the above specific aspects that should be given attention in future monitoring work, there remain gaps in knowledge of the spatial and local distributions of some of these key contaminants in the RSA. Most existing reliable data have been obtained for the northwestern region of the RSA near Kuwait and Saudi Arabia. Areas in Iraq and Iran around the Shatt Al-Arab have been little surveyed, as is the case for many locations along the eastern and southeastern shores of the RSA. Because the Shatt Al-Arab drainage system is the most likely source for the large-scale input of agrochemicals and many other industrial and urban contaminants to the RSA, this is a critical area to screen for organochlorinated compounds, as well as other potential contaminants originating from land-based sources.

Acknowledgments

This was a collaborative project between the IAEA and ROPME, financially supported by both organisations. The IAEA Marine Environment Laboratory operates under agreement between the International Atomic Energy Agency and the Government of the Principality of Monaco. We acknowledge with gratitude the logistic support received in each country: in Bahrain from the Ministry of Housing, Municipalities and Environment; in Oman from the Ministry of Regional Municipalities and Environment; in Qatar from the Ministry of Municipal Affairs and Agriculture; and in the UAE from the Federal Environment Agency. Finally, we thank Dr. Nahida Al-Majed from ROPME for assistance organising the field studies and with sample collection in Bahrain and Oman, and Jean Bartocci for assistance with preparing figures.

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