ROPME/GC-16/3

ROPME MUSSEL WATCH PROGRAMME
2014

Technical Report: No.2

ORGANIC CONTAMINANTS SCREENING

Prepared by:

MESL/IAEA
Monaco, December 2015

For:

REGIONAL ORGANIZATION FOR THE PROTECTION OF THE MARINE ENVIRONMENT

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1. INTRODUCTION

Under the ROPME-IAEA Contaminant Screening Project and the ROPME Mussel Watch Programme, surveys of heavy metal and organic contaminants have taken place in coastal areas of the Inner RSA and the Sea of Oman, collectively known as ROPME Sea Area (RSA). The results of these surveys have been published by ROPME-IAEA (1996, 1998, 1999, 2001, 2005, and 2013). The aim of the survey undertaken in February-March 2014 was to screen for inorganic and organic contaminants in key coastal areas of Bahrain, I.R. Iran, Iraq, Oman, Saudi Arabia and the United Arab Emirates (UAE) and to compare the results with those from earlier surveys from the same areas. This report summarizes the results of organic chemical contaminants in the sediments and biota in the RSA. This report should therefore be considered as a follow up report to the 1996, 1998, 1999, 2001, 2005 and 2013 ROPME-IAEA monitoring reports.

2. SAMPLING METHODOLOGY

From February to July 2014, selected locations along the coast of Bahrain, I.R. Iran, Iraq, Oman, Saudi Arabia and United Arab Emirates (UAE) were sampled for sediment and biota as part of the ROPME Mussel Watch Programme. The sampling stations, locations and the types of samples collected are given in the Table 1 and in Figure 1.

Table 1. Sediment and biota sampling sites in the ROPME Sea Area

Country	Date	Site Name	Code	Station	Latitude	Longitude	Sample type		Remarks
K.Bh	2014-02-18	Askar *	Bah-5	1	26°3' N	50°37' E	Pearl Oyster	Sediment	
	2014-02-17	Marwada	Bah-9	1	26°18' N	51°26' E	Pearl Oyster	Sediment	
I.R.Iran	2014-02-17	Bushehr *	IRAN-2	1	28°49' N	50°52' E	Rock Oyster	Sediment	
	2014-02-19	Dayer	IRAN-2-1	1	27°49' N	51°54' E	Rock Oyster	Sediment	
	2014-02-20	Gavbandi	IRAN-2-2	1	27°7' N	53°1' E	Rock Oyster		
	2014-02-21	Chiru (new site)		1	26°43' N	53°47' E	Rock Oyster		
	2014-02-22	Lengeh *	IRAN-4	1	26°31' N	54°50' E	Rock Oyster		
	2014-02-24	Qeshm Island	IRAN-4-1	1	26°50' N	56°8' E	Rock Oyster		
Iraq	?/07/2014	Shat Al Arab		1			Pearl Oyster		10 Km offshore
OMAN	2014-04-01	Mirbat *	OMAN-8	1	17°0' N	54°40' E	Rock Oyster	Sediment	
	2014-03-14	Masirah	OMAN-8-1	1	20°40' N	58°50' E	Rock Oyster	Sediment	
	2014-02-08	Qalhat	OMAN-8-2	1	22°45' N	59°20' E	Rock Oyster	Sediment	
	2014-02-06	Mina Al Fahal *	OMAN-2	1	23°37' N	58°31' E	Rock Oyster	Sediment	
	2014-02-10	Sohar	OMAN-2-1	1	24°23' N	56°44' E	Rock Oyster	Sediment	
	2014-04-08	Khasab	OMAN-2-2	1	26°11' N	56°14' E	Rock Oyster	Sediment	
KSA	2014-03-06	Ras Tanura *	KSA-3	1	26°33' N	50°12' E	Pearl Oyster	Sediment	
	2014-03-08	Jubail	KSA-2-1	1	27°8' N	49°34' E	Pearl Oyster	Sediment	pleasance harbour (Fanateer)
	2014-03-09	KSA-2	KSA-2-2	2	27°18' N	49°38' E	Pearl Oyster	Sediment	30 km N. Jubail (Ras abu Ali)
	2014-03-09	Al Khafji	KSA-1	1	28°30' N	48°29' E	Pearl Oyster	Sediment	little No. of oysters
UAE	2014-02-13	Umm Al-Quwain *	UAE-7-1	1	25°35' N	55°33' E	Rock Oyster	Sediment	
		UAE-7	UAE-7-1	2			Rock Oyster	Sediment	
			UAE-7-1	3			Rock Oyster	Sediment	
			UAE-7-2	1			Pearl Oyster	Sediment	50 m offshore of R. Oyster stations
			UAE-7-2	2			Pearl Oyster	Sediment	
			UAE-7-2	3			Pearl Oyster	Sediment	
	2014-02-18	Dubai (Jebal Ali)	UAE-3	1	25°20' N	55°20' E	Rock Oyster	Sediment	

*Location sampled during the ROPME Contaminant Screening Programme (1994-2005) and Mussel Watch Programme 2011

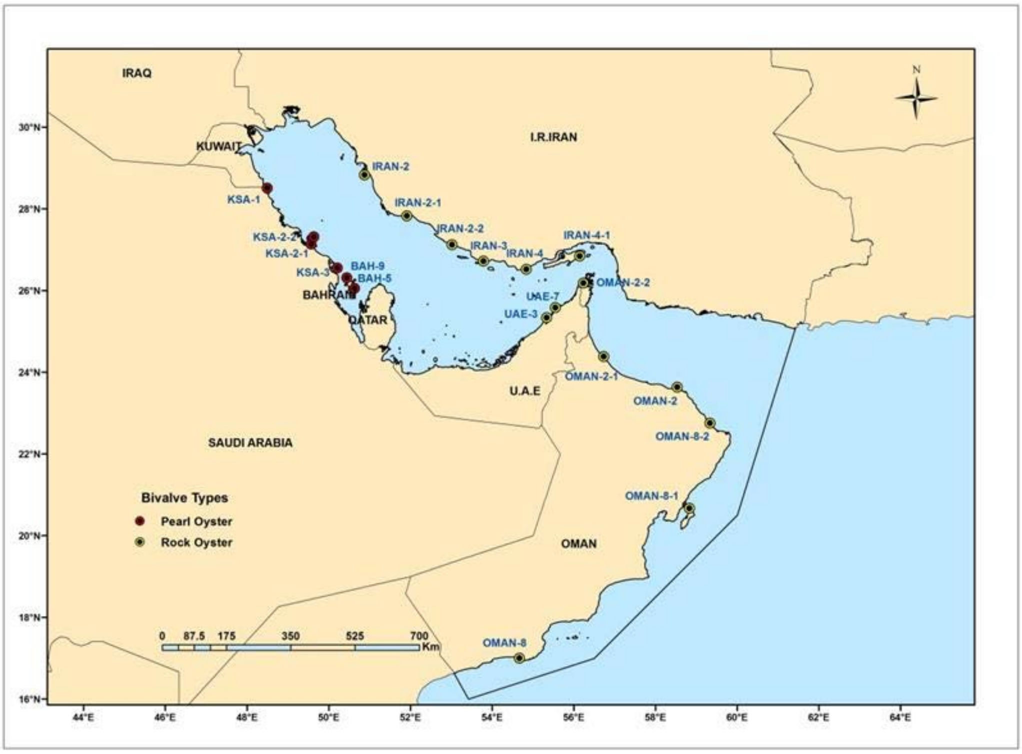

Figure 1. Map of sampling station

3. ANALYTICAL PROCEDURES

The analytical protocols for measuring petroleum hydrocarbons and chlorinated pesticides are detailed in this section.

3.1 SEDIMENT SAMPLES

3.1.1 Hydrocarbons and organochlorine compounds

3.1.1.1 Sample pre-treatment and extraction

Following freeze-drying, the samples were sieved through stainless steel sieves with mesh sizes of 250 µm. Sediments were then homogenized prior to extraction.

The extraction was realized with a microwave oven. Ten to 15 grams of freeze-dried sediment sample were put in the tube of the reactor with 40 ml of a mixture of hexane/dichloromethane (50:50). Internal standards were added, these standards are used for quantifying the overall recovery of the analytical procedures:

- n-C_{24}-d_{50} for the aliphatic hydrocarbon fraction; Friedeline as GC internal standard;
- Hexamethylbenzene for the unresolved compounds from the aromatic hydrocarbon fraction; Friedeline as GC internal standard;

- Naphthalene-d_8, Acenaphtene-d_{10}, Phenanthrene-d^{10}, Chrysene-d_{10} and Perylene-d_{12} (aromatics) for the aromatic hydrocarbon fraction; Fluorene-d_{10} and Benzo(a)pyrene-d_{12} as GC internal standard;
- PCB 29 and PCB 198 for the first fraction, ε-HCH for the second fraction and Endosulfan I-d_4 for the third fraction of organochlorine compounds. TCMX was used as GC internal standard

The operating conditions of the microwave oven were as follows:

Power of the microwave: 1200 Watts;
Temperature increased to 115°C in 10 minutes;
Extraction maintained at 115°C for 30 minutes;
Cooling to ambient temperature within one hour.

After cooling down to room temperature, the solvent mixture was recovered in a 100 ml glass flask. The sediment was then re-extracted with 20 ml of a mixture of hexane/dichloromethane (50:50) using the same microwave conditions. Then, the sediment was rinsed with a few ml of a *n*-hexane:dichloromethane (50:50) solution. A sulphur removal procedure was performed using activated elemental copper in order to avoid sulphur interference when using gas chromatography (GC). Sulphur compounds are especially detectable and can cause interference in the analysis of chlorinated hydrocarbons.

The extracts were then separated into two aliquots: 1/3 for hydrocarbons, and 2/3 for chlorinated hydrocarbons analyses.

3.1.1.2 Clean-up and fractionation

Hydrocarbons

The concentrated extract of about 1 ml was passed through a silica/cyanopropyl SPE glass column of 6 ml. The first fraction containing aliphatic compounds is obtained by eluting with 4 ml of *n*-Hexane. The second fraction containing PAHs is obtained by eluting 5 ml of a *n*- Hexane:Dichloromethane (50:50) solution. Both fractions are concentrated to about 0.5 ml (prior to solvent change from *n*-hexane to isooctane) and analyzed by GC.

Chlorinated compounds

The concentrated extract of about 1 ml was passed through a Na_2SO_4/Florisil SPE column (2g/2g, 6 ml). From this column, three fractions were collected: a first fraction with 10 ml of hexane (containing PCBs, pp' and op DDE and some other pesticides such as HCB, Aldrin, Heptachlor, DDMU); a second fraction with 9 ml of hexane/methylene chloride (90:10) (containing the DDTs, DDDs, and some pesticides such as HCH isomers and chlordane components); and then a third fraction with 7 ml of methylene chloride (containing mainly Dieldrin, Endrin and Endosulfan components).

3.1.2 Total organic carbon and carbonates

The contents of total carbon (TC) and total organic carbon (TOC) were determined by using a CHN analyzer (vario EL cube, Elementar Analysensysteme GmbH, Germany). Approximately 4-18 mg of dry sediment was encapsulated into a tin foil cup and introduced into a combustion furnace. Organic carbon was determined after treating the samples with concentrated H_3PO_4 to remove inorganic carbon. Concentration of total organic carbon is expressed as the percentage of total dry weight. Carbonate content was calculated by subtracting the TOC from the TC content. The quality control was realized by measuring TC and TOC levels in two certified reference material, SMR 1941b from NIST and a synthetic mixture for soil #4 from Eurovector.

	TC Certified value	**TC Measured value**	**TOC Certified value**	**TOC Measured value**
Soil#4	2.417%	2.31%	0.328%	0.38%
SMR 1941b	3.3%	3.11% ± 0.02	2.99 ± 0.24	2.61 ± 0.15 (n=2)

3.2 BIOTA SAMPLES

3.2.1 Hydrocarbons and organochlorine compounds

3.2.1.1 Sample pre-treatment and extraction

✓Petroleum hydrocarbons

Internal standards were added, these standards are used for quantifying the overall recovery of the analytical procedures:

- *n*-C_{24}-d_{50} for the aliphatic hydrocarbon fraction; Friedeline as GC internal standard;
- Hexamethyl benzene for the unresolved compounds from the aromatic hydrocarbon fraction; Friedeline as GC internal standard;
- Naphthalene-d_8, Acenaphtene-d_{10}, Phenanthrene-d_{10}, Chrysene-d_{10} and Perylene-d_{12} (aromatics) for the aromatic hydrocarbon fraction; Fluorene-d_{10} and Benzo(a)pyrene-d_{12} as GC internal standard;

Two to five grams of the samples were extracted with 30 ml of methanol.
The operating conditions of the microwave oven were as follows:
Power of the microwave: 1200 Watts;
Temperature increased to 115°C in 10 minutes;
Extraction maintained at 115°C for 20 minutes;
Cooling to ambient temperature within one hour.

Then, 5 ml KOH (2M) were added to each sample and extracted again with the microwave oven:

Power of the microwave: 1200 Watts;
Temperature increased to 90°C in 5 minutes;
Saponification at 90°C for 10 minutes;
Cooling to ambient temperature within one hour.

After cooling down to room temperature, the solvent was recovered in a 100 ml glass flask. The biota was then poured in a glass funnel containing a plug made of glass wool, and washed with 10–20 ml of methanol.

The resulting mixture was transferred into separatory funnels, with 5 ml of pre-extracted distilled water, and extracted 3 times with hexane (once with 20 ml, twice with 15 ml). The extracts were then combined, filtered through glass wool and dried with anhydrous sodium sulfate. The extracts were concentrated by rotary evaporation down to 15 ml, and then concentrated to about 5 ml under a gentle flow of clean nitrogen.

✓Chlorinated compounds

Internal standards were added to the freeze-dried samples for recovery: PCB 29, PCB 198 for the first fraction, ε-HCH for the second fraction and Endosulfan 1-d_4 for the third fraction. Four to five grams of the samples were extracted with 30 ml of mixture hexane/acetone (90:10) in a microwave oven.
The operating conditions of the microwave oven were as follows:

Power of the microwave: 1200 Watts;
Temperature increased to 115°C in 10 minutes;
Extraction maintained at 115°C for 20 minutes;
Cooling to ambient temperature within one hour.

After cooling down to room temperature, the solvent mixture was recovered in a 100 ml glass flask. The powder of biota was then poured in a glass funnel containing a plug made of glass wool, and then washed with 10–20 ml of hexane.

After extraction, the extracts were concentrated on a rotary evaporator to about 15 ml. The extracts were dried with anhydrous sodium sulfate and concentrated down to 1 ml with nitrogen. The sample extracts were analyzed gravimetrically for hexane extractable organic matter (HEOM).

The extracts were then separated into two aliquots: 3/4 of the aliquot treated with sulphuric acid, followed by Florisil SPE (F1 and F2), and 1/4 of the aliquot for silica and Florisil SPE to obtain fraction 3 (F3).

3.2.1.2 *Clean-up and fractionation*

✓Petroleum hydrocarbons

The extract was passed through a silica/alumina column (silica and alumina were activated first at 200°C for 4 hours and partially deactivated with 5% water). The chromatography column was prepared by packing 5 g of silica with 10 g of alumina and finally 1 g of sodium sulphate was added to the top layer to avoid disturbing them when pouring the solvent. Elution was performed using 20 ml of hexane to yield the first fraction (which contains the aliphatic hydrocarbons), then 30 ml of hexane/methylene chloride (90:10) to recover the second fraction, which contains the aromatic hydrocarbons (PAHs).

✓Chlorinated compounds

The 3/4 of the extract was transferred into Teflon tubes and acidified with sulfuric acid. It was extracted between 4-6 times with the help of a centrifuge. Hexane was combined and concentrated by nitrogen to 1 ml. Then it was passed through a Na_2SO_4/Florisil SPE column (2g/2g, 6 ml). From this column, two fractions were collected: a first fraction with 10 ml of hexane (containing PCBs, pp' and op DDE and some other pesticides such as HCB, Aldrin, Heptachlor, DDMU); and a second fraction with 9 ml of hexane/methylene chloride (90:10) (containing the DDTs, DDDs, and some pesticides such as HCH isomers and chlordane components).

The ¼ of the extract was passed first through a Silica SPE column (1g, 6 ml). From this column, one fraction was collected with 5 ml of hexane:dichlorometane (50:50). This fraction was then passed through a Na_2SO_4/Florisil SPE column (2g/2g, 6 ml). From this column, three fractionation steps were developed: a first fraction with 10 ml of; a second fraction with 9 ml of hexane/methylene chloride (90:10); and then a third fraction with 7 ml of methylene chloride with the compounds of interest (mainly Dieldrin, Endrin and Endosulfan components). Only the third fraction was analysed.

3.2.1.3 *Quantification and quality control*

✓Hydrocarbons

UVF procedure

Emission scans and synchronous excitation/emission scans were recorded to evaluate the relative fluorescence and to characterize the aromatic hydrocarbons in the samples. Standard response curves of fluorescence intensity versus concentration were generated for Kuwaiti crude (ROPME) oil and for the standard aromatic hydrocarbon: Chrysene. Samples were diluted in order to give a reading within the linear calibration range of the fluorometer.

Conditions of the fluorometer were adjusted as follows:

1st procedure

Excitation wavelength fixed: 310 nm

a) Single calibrated measurement: Emission wavelength at 360 nm;

b) Scan: Emission wavelength from 320 nm to 550 nm.

cGC-FID conditions used were as follows:

Aliphatic hydrocarbon fractions were analysed using cGC-FID.

Gas Chromatograph	Agilent 7890
Detector	Flame Ionization Detector (FID)
Injection mode	Splitless
Carrier gas	Helium 1.2 ml min^{-1}
Column	HP-5 (crosslinked 5% Ph Me Silicone) 30 m x 0.25 mm i.d. x 0.25 µm film thickness
Injector temperature	270°C
Detector temperature	300°C
Oven temperature program	60°C initial for 1 min., 60°C to 290°C at 4°C min^{-1}, 290°C for 40 min.

cGC-MS conditions used were as follows:

The aromatic hydrocarbons were analyzed using selective ion monitoring (SIM) to enhance sensitivity.

Gas Chromatograph	Agilent 6890 N
Detector	MSD 5975
Injection mode	Pulsed Splitless
Carrier gas	Helium 1.6 ml min^{-1}
Column	HP-5 (crosslinked 5% Ph Me Silicone) 30 m x 0.25 mm i.d. x 0.25 µm film thickness
Injection specifications	inj. press. 13.99 psi, Constant flow on 13.99 psi at 60°C, Temp. injector 270°C
Transfer line	280°C
Ion source	240°C
Analyser	100°C
Oven temperature program	60°C initial, 60°C to 100°C at 10°C min^{-1}, 100°C to 290°C at 3.5°C min^{-1}, 290°C for 20 min.

- ✓ Chlorinated compounds

Fraction 1 and 2

Conditions used were as follows:

Gas Chromatograph	Hewlett Packard HP6890
Detector	Electron Capture Detector ^{63}Ni (ECD)
Injection mode	Splitless
Carrier gas	Helium 1.2 ml min^{-1}
Column	HP-5 (crosslinked 5% Ph Me Silicone) 30 m x 0.25 mm i.d. x 0.25 µm film thickness
Injection temperature	250°C
Detector temperature	300°C
Oven temperature program	70°C for 2 min., 70°C to 260°C at 3°C min^{-1}, 260°C for 25 min.

Fraction 3

Conditions used were as follows:

Gas Chromatograph	Hewlett Packard HP6890
Detector	Electron Capture Detector ^{63}Ni (ECD)
Injection mode	Splitless
Carrier gas	Helium 0.5 ml min^{-1}
Column	DB-5 (crosslinked 5% Ph Me Silicone) 20 m x 0.10 mm i.d. x 0.40 µm film thickness
Injection temperature	250°C
Detector temperature	310°C
Oven temperature program	100°C for 0.5 min., 100°C to 140°C at 9°C min^{-1}, 140°C for 0.5 min., 140°C to 250°C at 2°C min^{-1}, 250°C for 0.5 min., 250°C to 300°C at 12°C.min^{-1}, 300°C for 20 min.

Appropriate blanks were analyzed with each set of analyses and in addition, the following reference materials were analyzed simultaneously: IAEA-459-ILC (Marine Sediment) and NIST 1941b (Marine Sediment). These reference materials have certified, recommended and information concentrations of petroleum hydrocarbons and chlorinated compounds. Their results are shown in Tables A1, A2, A3 and A4.

Appropriate blanks were analyzed with each set of analyses and in addition, the following certified reference materials were analyzed simultaneously: NIST 2977 (Mussels tissue) and IAEA-432 (IAEA, mussels). These reference materials have certified and reference concentrations of petroleum hydrocarbons and chlorinated compounds. Their results are shown in Tables from B1to B7.

Table A1. Concentrations of aliphatic hydrocarbons (ng g^{-1} dw) in reference sediments with their corresponding information values and uncertainties values (U=2u)

	IAEA-459 -1	IAEA-459 -2	Information	U	NIST 1941b-1	NIST 1941b-2	Cert	U
Ropme Equiv. (μg/g)	559	880	238	40				
Chrysene Equiv. (μg/g)	83	130	39	3.6				
n-C12	175	77			172	127		
n-C13	94	80			124	94		
n-C14	468	360			168	130		
n-C15	143	108			275	230		
n-C16	1278	1075			316	248		
n-C17	162	122	123	17	367	348		
n-C18	1084	924	565	35	142	157		
n-C19	170	148			204	208		
n-C20	1274	1040			139	119		
n-C21	917	678			368	217		
n-C22	1355	1103			160	181		
n-C23	331	254			319	320		
n-C24	1549	1282			153	156		
n-C25	213	364			531	459		
n-C26	1416	1139			250	215		
n-C27	950	711			750	565		
n-C28	1063	811			270	221		
n-C29	524	399			915	775		
n-C30	822	658			333	295		
n-C31	695	525			827	698		
n-C32	398	314			68	105		
n-C33	286	247			81	68		
n-C34	237	222			58	0		
n-C35	316	336			98	111		
n-C36	214	119			0	0		
Pr	119	97	104	17	0	64		
Ph	173	145	136	10	0	106		
Sq	486	373			0	0		
Res Al	39721	31070			11612	99279		
Unres. Al	296455	219906			88684	715518		
Sum n-C14-nC34	15336	12482	8840	960				

Table A2. Concentrations of aromatic hydrocarbons (ng g^{-1} dw) in reference sediments with their corresponding certified (Cert), recommended values (Recom) and uncertainties values (U=2u)

	IAEA-459 -1	**IAEA-459 -2**	**Recom**	**U**	**NIST 1941b-1**	**NIST 1941b-2**	**Cert**	**U**
Naphthalene	57.2	51.8	13.8	2	1403.1	1246.4	848	95
2-Methylnaphthalene	44.3	60.2	10.7*		443.2	410.3	276.0[&]	53
1-Methylnaphthalene	22.9	31.4	7.14*	1.53	201.4	186.6	127.0[&]	14
2,6 -Dimethylnaphthalene	62.1	125.0			202.0	188.5	75.9[&]	4.5
2,3,5-trimethylnaphthalene	152.0	328.2			107.7	85.4	25.5[&]	5.1
C4- Naphthalenes	95.8	323.9			94.5	140.2		
Biphenyl	7.0	6.0			60.4	36.8	74[&]	8
Acenaphthylene	3.8	3.6	4.58*		40.3	84.4	53.3[&]	6.4
Fluorene	38.4	35.7	6.29*	1.16	145.0	79.1	85	15
Acenaphthene	7.0	6.0	3.03*		60.4	36.8	38.4[&]	5.2
C1-Fluorenes	199.8	93.1			224.6	106.9		
C2-Fluorenes	89.1	108.0			253.4	132.4		
C3-Fluorenes	84.1	123.7			148.5	70.4		
Dibenzothiophene	23.8	22.2	6.9*		84.5	75.7		
C1-Dibenzotiophene	36.6	34.9			61.0	56.1		
C2-Dibenzotiophene	110.0	116.6			179.4	188.5		
C3-Dibenzotiophene	109.1	105.0			112.4	144.9		
Phenanthrene	59.3	55.9	27.7	2.1	604.6	546.1	406	44
Anthracene	7.7	8.3	7.71	1.3	68.8	131.8	184	18
1methylphenanthrene	14.5	15.4	7.39	0.85	93.8	89.1	73	5.9
2methylphenanthrene	34.0	34.3	14.6	1.6	135.9	157.0	128.0	14
C2- Phen/Anth	73.0	60.0			285.5	379.4		
C3- Phen/Anth	43.5	54.0			200.7	224.0		
C4- Phen/Anth	25.1	25.1			65.9	198.4		
Fluoranthene	44.0	45.8	34.4	3	242.2	394.7	651	50
Pyrene	43.0	46.4	41.3	3.5	230.2	431.2	581	39
1-MetylPyrene	3.6	4.2	5.6*		18.4	38.6	52.5[&]	2.3
2-MetylPyrene	4.1	4.5			50.1	64.2	78.7[&]	4
4/9-MetylPyrene	6.7	7.8			28.0	56.1	80.1[&]	4.8
C1-Fluor/Pyr	27.0	28.2			149.3	265.1		
Benz(a)anthracene	27.7	32.0	17.2	1	236.8	344.9	335	25
Chrysene+Triphenylene	52.2	45.7	21.7	1.7	562.4	550.5	399	31
C1-Chrysenes	30.4	31.7			326.1	274.8		
C2-Chrysenes	40.7	31.5			164.8	155.1		
C3-Chrysenes	49.7	25.8			60.3	54.2		
Benzo(b+j)fluoranthene	50.4	90.3	37.9	3.3	373.2	509.0	670	21
Benzo(k)fluoranthene	18.8	27.0	18.3	1.5	140.8	153.0	225	25
Benzo(a)fluoranthene	15.2	11.9			116.0	102.5	73[&]	18
Benzo(e)pyrene	25.8	36.9	28.5	3.7	164.4	237.1	325	25
Benzo(a)pyrene	13.3	31.0	22	1.6	160.0	217.8	358	17
Indeno[1,2,3-c,d]pyrene	15.8	24.9	29.2	1.9	76.7	279.4	341	57
Dibenz(a,h)anthracene	8.7	15.4	6.95	0.96	90.3	128.0	53	10
Benzo(g,h,i)perylene	22.5	36.9	34.7	3	124.1	250.2	307	45
Perylene	9.8	16.8	23.6*	8.2	60.5	138.0	397.0	45

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*information values; [&]recommended values

Table A3. Concentrations of polychlorinated biphenyls (PCBs) (ng g^{-1} dw) in reference sediments with their corresponding certified (Cert), recommended values (Recom) and uncertainties values (U=2u)

	IAEA-459 -1	IAEA-459 -2	Recom	U	NIST 1941b-1	NIST 1941b-2	Cert	U
PCB 8	0.92	1.13	0.52*		1.47	1.70	1.65	0.19
PCB 18	0.86	1.16	1.36	0.24	1.20	2.23	2.39	0.29
PCB 28	2.50	2.99	2.58	0.30	2.94	3.68	4.52	0.57
PCB 31	2.26	3.06	2.68	0.63	2.21	2.36	3.18	0.41
PCB 44	1.29	1.61	2.35	0.10	1.94	2.43	3.85	0.20
PCB 49	1.61	2.04	2.47*		2.05	2.52	4.34	0.28
PCB 52	2.39	2.65	2.62	0.24	2.82	3.67	5.24	0.28
PCB 66/95	1.67	1.80	2.33	0.07	5.30	7.08	8.89	1.15
PCB 87	0.85	0.87	1.33*	0.12	0.75	1.10	1.14	0.16
PCB 97	0.76	0.79			0.85	1.21		
PCB 99	1.20	1.24	1.81	0.60	1.84	2.50	2.90	0.36
PCB 101	2.85	2.88	3.61	0.28	2.91	4.05	5.11	0.34
PCB 105	0.85	0.95	1.34	0.21	0.84	1.23	1.43	0.10
PCB 110(77)	2.68	2.83	3.12*		3.43	4.51	4.62	0.36
PCB 118	2.14	2.18	3.02	0.21	2.59	3.21	4.23	0.19
PCB 126	0.52	0.53			0.53	0.90		
PCB 128	0.45	0.45	0.81	0.24	0.44	0.67	0.70	0.04
PCB 138	2.77	2.88	3.62	0.24	2.87	4.23	3.60	0.28
PCB 149	1.78	1.81	3.10	0.74	2.21	3.25	4.35	0.26
PCB 151	0.43	0.47	0.74	0.07	0.61	1.09		
PCB 153	2.63	2.82	3.96	0.27	2.78	4.22	5.47	0.32
PCB 156	0.31	0.31	0.35	0.07	0.45	0.76	0.51	0.09
PCB 169	<0.006	<0.006			<0.006	<0.006		
PCB 170	0.85	0.92	0.91	0.13	1.02	1.60	1.35	0.09
PCB 174	0.71	0.73			0.92	1.47	1.51&	0.39
PCB 177	1.01	1.18	0.51*		0.58	0.92		
PCB 180	1.81	1.92	2.09	0.15	2.10	3.16	3.24	0.51
PCB 183	0.76	0.80	0.71	0.15	0.65	1.04	0.98	0.09
PCB 187	1.16	1.19	1.50	0.26	1.50	2.29	2.17	0.22
PCB 189	0.09	0.09			0.19	0.16		
PCB 194	0.50	0.50	0.60	0.12	0.73	1.03	1.04	0.06
PCB 195	0.16	0.20	0.22	0.03	0.85	1.26	0.65	0.06
PCB 201	0.14	0.15			0.29	0.51	0.78	0.03
PCB 206	0.17	0.18			1.74	2.23	2.42	0.19
PCB 209	0.21	0.20	0.19	0.03	3.77	4.79	4.86	0.45

*information values; &reference values

Table A4. Concentrations of organochlorinated pesticides (ng g^{-1} dw) in reference sediments with their corresponding certified (Cert), recommended values (Recom) and uncertainties values (U=2u)

	IAEA-459 -1	IAEA-459 -2	Recom	U	NIST 1941b-1	NIST 1941b-2	Cert	U
HCB	0.16	0.20	0.18	0.02	6.16	6.40	5.83	0.38
α HCH	0.17	0.19	0.17^{*}		<0.007	<0.007		
β HCH	0.25	0.24	0.23^{*}		0.04	0.10		
γ HCH-Lindane	0.18	0.25	0.47	0.05	0.03	0.05		
δ HCH	<0.317	<0.317			<0.317	<0.317		
pp'DDE	3.23	3.50	3.03	0.27	2.30	2.78	3.22	0.28
pp'DDD	2.97	2.94	2.40	0.27	2.08	2.94	4.66	0.46
pp'DDT	0.71	0.77	1.66	0.33	0.98	1.60	$1.12^{\&}$	0.42
DDMU	2.75	2.73			2.75	2.73		
op DDE	0.50	0.48	0.59	0.05	0.73	0.96	$0.38^{\&}$	0.12
op DDD	0.71	0.72	0.96	0.11	0.23	0.25		
op DDT	0.10	0.09	0.47^{*}		0.17	<0.012		
Heptachlor	0.15	0.13	1.60	0.26	0.16	0.09		
Aldrin	0.05	0.03	0.41	0.01	0.10	0.09		
Dieldrin	<0.156	<0.156	0.62^{*}		<0.156	1.86		
Endrin	<0.294	<0.294	0.95	0.12	<0.294	<0.294		
Cis Chlordane	0.05	0.05			0.24	0.27	0.85	0.11
Trans Chlordane	0.07	0.07	0.14^{*}		0.36	0.40	0.57	0.09
Cis Nonachlor	<0.007	<0.007			0.18	0.06	0.38	0.05
Trans Nonachlor Heptachlor epoxide-A (trans)	<0.003	<0.003			0.11	0.16	0.44	0.07
	<0.826	<0.826			<0.826	<0.826		
Heptachlor epoxide-B (cis)	0.08	0.11	1.71^{*}		0.03	0.04		
Methoxychlor	<1.24	<1.24			<1.24	<1.24		
α Endosulfan	<0.822	<0.822	1.54^{*}		<0.822	<0.822		
β Endosulfan	<0.136	<0.136	2.11^{*}		<0.136	<0.136		
Endosulfan sulfate	<0.197	<0.197			<0.197	<0.197		

*information values; & reference values

Table B1. Concentrations of aliphatic hydrocarbons (ng g^{-1} dw) in reference bivalve material with their corresponding information values and standard deviation

	IAEA 432-1	**IAEA 432-2**	**IAEA 432-3**	**IAEA 432-3-BIS**	***Information values (±s.d)***	**NIST 2977-1**	**NIST 2977-2**	**NIST 2977-3**
ROPME Equiv. (µg/g)	11.26	6.35	11.42	7.5	11±4.9*	120	131	124
Chrysene Equiv. (µg/g)	1.7	0.95	1.7	1.1		18	20	18
n-C12	121	119	142	180		205	158	306
n-C13	111	119	129	157		1149	1076	1230
n-C14	192	201	177	232		947	877	853
n-C15	603	573	523	665		16633	15749	14767
n-C16	725	687	723	817		2689	2602	2573
n-C17	922	893	990	1050	200 ± 140*	7104	6740	6970
n-C18	65	72	70	88	67 ± 68*	421	409	425
n-C19	40	36	41	50		303	292	299
n-C20	46	49	55	68		107	96	93
n-C21	81	37	81	50		236	222	251
n-C22	70	37	38	41		224	219	178
n-C23	45	56	47	46		289	294	276
n-C24	28	58	36	32		93	110	150
n-C25	154	162	159	152		304	305	271
n-C26	4	62	15	25		198	207	203
n-C27	6	104	64	45		250	269	135
n-C28	42	57	31	25		393	372	253
n-C29	65	93	65	69		402	395	268
n-C30	109	130	64	44		878	831	619
n-C31	107	142	110	92		461	437	280
n-C32	185	249	31	25		608	576	270
n-C33	179	208	96	163		96	127	79
n-C34	218	139	30	49		376	128	74
n-C35	<1.61	<1.61	<1.61	<1.61		378	115	44
n-C36	<1.57	<1.57	<1.57	<1.57		<1.57	<1.57	<1.57
Pr	47	36	53	41	140 ± 130*	1471	1392	1201
Ph	50	41	26	38	41 ± 44*	1082	1024	1055
Sq	72	333	112	143		194	142	279
Res Al	15579	15143	13065	14651	18000± 20000*	169008	159147	72731
Unres. Al	15742	10107	23336	17001	38000 ± 43000*	962445	910627	203233
Sum n-C14-nC34	3886	3906	3177	3828	4500 ± 4800*	33013	31255	29285

Table B2. Concentrations of aromatic hydrocarbons (ng g^{-1} dw) in reference bivalve material IAEA-432 with their corresponding recommended values and standard deviation

	IAEA 432	*IAEA 432-2*	*IAEA 432-3*	*IAEA-432-3-BIS*	*Recommended values±s.d.*
Naphthalene	11.1	16.5	24.9	17.2	15 ± 18*
1-Methylnaphthalene	5.3	9.8	12.9	9.3	8.8 ± 9.5*
2-Methylnaphthalene	7.9	4.6	20.1	14.2	14 ± 13*
2,3,5-trimethylnaphthalene	17	27	29	29	
C4- Naphthalenes	3	8	10	12.7	
Biphenyl	5	5	6	6	
Acenaphthylene	0.5	<0.04	<0.04	0.5	
Fluorene	3.2	2.6	2.9	3.4	4.1 ± 2.2
Acenaphthene	2	2	1	1.0	
C1-Fluorenes	5	5	4	5.4	
C2-Fluorenes	5	4	4	4.9	
C3-Fluorenes	3	4	5	3.4	
Dibenzothiophene	1	2	1	1.0	
C1-Dibenzotiophene	1	2	1	1.5	
C2-Dibenzotiophene	2	8	6	6.4	
C3-Dibenzotiophene	5	6	4	5.4	
Phenanthrene	22	21	22	22.5	27 ± 21
Anthracene	1.6	1.0	1.4	1.5	1.5 ± 1.1
1-Methylphenenathrene	5.3	5.2	5.3	6.4	4.2 ± 2.8
2-Methylphenenathrene	7.4	8.2	7.7	8.8	9.4 ± 4.9
C3- Phen/Anth	10	11	9	10.8	
C4- Phen/Anth	3	8	2	2.5	
Fluoranthene	21.2	18.6	19.1	21.6	12 ± 6.5
Pyrene	18	17	17	19.1	13 ± 6.0
C1-Fluor/Pyr	2	2	1	1.5	
Benz(a)anthracene	4.2	3.6	4.3	5.4	3.8 ± 3.1
Chrysene+Triphenylene	7	7	7	7.4	5.5 ± 3.8
C1-Chrysenes	<0.03	<0.03	<0.03	<0.03	
C2-Chrysenes	<0.04	<0.04	<0.04	<0.04	
C3-Chrysenes	<0.03	<0.03	<0.03	<0.03	
C4-Chrysenes	<0.03	<0.03	<0.03	<0.03	
Benzo(b+j)fluoranthene	7.4	3.6	4.3	6.4	4.8 ± 1.7
Benzo(k)fluoranthene	7.9	4.1	4.8	7.4	1.9 ± 1.1
Benzo(a)fluoranthene	<0.03	<0.03	<0.03	<0.03	
Benzo(e)pyrene	4	7	5	7.8	4.5 ± 1.7
Benzo(a)pyrene	5.3	3.1	3.8	3.4	0.9 ± 0.5
Indeno[1,2,3-c,d]pyrene	3	3	3	2.9	
Dibenz(a,h)anthracene	<0.07	<0.07	<0.07	<0.07	
Benzo(g,h,i)perylene	4	4	3	3.9	
Perylene	0.5	2.6	2.4	2.9	5.0 ± 2.8*
Res Ar	1254	610	882	731.7	1500 ± 1800*
Unres. Ar	5414	5528	6085	4771.9	

*Information values

Table B3. Concentrations of aromatic hydrocarbons (ng g^{-1} dw) in reference bivalve material NIST-2977 with their corresponding certified (Cert) and expanded uncertainties (U=2u)

	NIST 2977	*NIST 2977-2*	*NIST 2977-3*	*Cert values±2u*
Naphthalene	16	NQ	14	21.1 ± 1.4*
1-Methylnaphthalene	10	NQ	14	15.6 ± 1.5*
2-Methylnaphthalene	14	NQ	19	17.3 ± 1.7*
2,3,5-trimethylnaphthalene	642	NQ	761	
C4- Naphthalenes	506	NQ	473	
Biphenyl	4	4	5	6.0 ± 1.3*
Acenaphthylene	2	1	1	
Fluorene	9.2	11.2	9.0	10.3 ± 0.13
Acenaphthene	4	4	2	4.9 ± 1.2*
C1-Fluorenes	58	76	55	
C2-Fluorenes	162	225	160	
C3-Fluorenes	179	307	248	
Dibenzothiophene	12	23	17	
C1-Dibenzotiophene	38	114	66	
C2-Dibenzotiophene	530	803	639	
C3-Dibenzotiophene	615	918	716	
Phenanthrene	37.9	38.3	35.8	36.2 ±2.5
Anthracene	6.7	5.3	5.5	6.2 ±1.4*
1-Methylphenenathrene	66.7	68.0	60.7	39.0 ±1.9
2-Methylphenenathrene	826	808	732	
C3- Phen/Anth	882	897	782	
C4- Phen/Anth	459	385	427	
Fluoranthene	52	51	57	38.9 ± 0.63
Pyrene	88	85	86	77.4 ±2.1
C1-Fluor/Pyr	94	94	93	
Benz(a)anthracene	24	22	23	20.19 ±0.87
Chrysene+Triphenylene	80	71	70	78.3 ±6*
C1-Chrysenes	83	82	78	
C2-Chrysenes	56	63	51	
C3-Chrysenes	28	21	20	
C4-Chrysenes	<0.03	<0.03	<0.03	
Benzo(b+j)fluoranthene	19	15	11	15.58 ± 0.52
Benzo(k)fluoranthene	15	14	11	4.02 ± 0.75*
Benzo(a)fluoranthene	<0.03	<0.03	<0.03	
Benzo(e)pyrene	21	20	18	13.29 ± 0.43
Benzo(a)pyrene	3.6	6.3	10.4	5.3 ± 0.61
Indeno[1,2,3-c,d]pyrene	7	4	5	4.76±0.15
Dibenz(a,h)anthracene	2.6	<0.07	2.5	1.47 ± 0.33*
Benzo(g,h,i)perylene	14	12	8	9.45 ±0.37
Perylene	1.5	2.4	3.0	3.69 ±0.38
Res Ar	26814	25007	26949	
Unres. Ar	119459	112038	114898	

*reference values

Table B4. Concentrations of polychlorinated biphenyls (PCBs) (ng g^{-1} dw) in reference bivalve material IAEA-432 with their corresponding recommended values and standard deviation

	IAEA 432	*IAEA 432-2*	*IAEA 432-3*	*Recommended values*	*s.d.*
PCB 8	0.07	0.06	0.05	0.57*	0.32
PCB 18	0.48	0.25	0.20	1.60*	1.70
PCB 28	0.25	0.19	0.20	0.32*	0.26
PCB 31	0.53	0.51	0.38	1.00*	1.04
PCB 44	0.09	0.23	0.19	0.70*	0.68
PCB 49	0.06	<0.036	<0.036	0.29	0.08
PCB 52	0.63	0.41	0.23	1.20*	1.20
PCB 66/95	0.72	0.82	0.78	1.48*	0.95
PCB 87	0.24	0.31	0.34	0.27*	0.11
PCB 97	0.11	0.20	0.23	0.31*	0.16
PCB 99	0.72	0.69	1.03	2.10*	2.40
PCB 101	0.96	1.07	0.96	1.20	0.49
PCB 105	0.17	0.24	0.24	0.50*	0.39
PCB 110(77)	0.42	0.61	0.74	1.12	0.40
PCB 118	0.75	0.89	0.96	1.09	0.42
PCB 126	<0.003	<0.003	<0.003		
PCB 128	0.24	0.26	0.27	0.25*	0.08
PCB 138	1.85	2.12	2.01	2.20	0.84
PCB 149	1.03	1.13	1.22	1.40	0.41
PCB 151	0.45	0.44	0.51	0.40*	0.04
PCB 153	2.56	2.93	2.84	2.80	0.99
PCB 156	0.11	0.10	0.10	0.35*	0.31
PCB 169	<0.003	<0.003	<0.003		
PCB 170	0.06	0.04	0.03	0.57*	0.51
PCB 174	0.07	0.07	0.07	0.26*	0.27
PCB 177	0.36	0.39	0.39	0.26*	0.14
PCB 180	0.24	0.12	0.15	0.20	0.11
PCB 183	0.35	0.40	0.43	0.24*	0.05
PCB 187	0.85	0.93	1.04	0.87*	0.13
PCB 189	0.02	0.02	0.05	0.12*	0.15
PCB 194	0.03	0.04	0.03	0.27*	0.28
PCB 195	0.01	<0.003	0.01	0.22*	0.18
PCB 201	0.04	0.03	0.03		
PCB 206	<0.002	<0.002	<0.002		
PCB 209	0.09	0.11	0.18		

*Information values

Table B5. Concentrations of polychlorinated biphenyls (ng g^{-1} dw) in reference bivalve material NIST-2977 with their corresponding certified (Cert) and expanded uncertainties (U=2u)

	NIST 2977	*NIST 2977-2*	*NIST 2977-3*	*Cert values*	*U*
PCB 8	0.89	0.75	0.88	1.99	0.14
PCB 18	1.22	1.34	0.88	2.24[8]	0.74
PCB 28	3.63	3.52	3.43	5.17	0.36
PCB 31	2.43	3.22	2.31	3.86	0.29
PCB 44	0.96	1.22	1.11	3.22	0.21
PCB 49	0.78	1.43	1.20	2.44	0.27
PCB 52	4.54	4.70	4.29	8.02	0.56
PCB 66/95	4.82	5.18	5.12	8.72	0.71
PCB 87	1.01	1.15	1.12		
PCB 97	1.85	2.07	2.04		
PCB 99	2.97	3.24	3.45	3.00[8]	1.20
PCB 101	5.26	5.59	5.38	10.60	0.90
PCB 105	2.26	2.27	2.23	2.93[*]	0.46
PCB 110(77)	3.74	4.41	4.22		
PCB 118	8.05	8.64	8.24	10.00	0.41
PCB 126	<0.003	<0.003	<0.003		
PCB 128	1.25	1.35	1.38	2.38	0.28
PCB 138	8.39	8.94	8.67	7.94	0.63
PCB 149	3.62	4.03	3.94	8.95	0.67
PCB 151	1.85	2.05	2.01		
PCB 153	7.47	8.02	7.87	14.10	1.30
PCB 156	1.34	1.45	1.45	0.96	0.04
PCB 169	<0.003	<0.003	<0.003		
PCB 170	2.00	2.14	2.20	2.74	0.25
PCB 174	1.19	1.33	1.24		
PCB 177	1.50	1.58	1.50		
PCB 180	3.88	4.11	3.57	6.32	0.72
PCB 183	0.63	0.86	0.72		
PCB 187	3.21	3.58	3.45	4.47	0.32
PCB 189	<0.001	<0.001	<0.001		
PCB 194	1.50	1.53	1.52	0.88	0.03
PCB 195	<0.003	<0.003	<0.003		
PCB 201	0.18	0.17	0.18		
PCB 206	<0.002	<0.002	<0.002		
PCB 209	<0.003	<0.003	<0.003		

*reference values

Table B6. Concentrations of organochlorinated pesticides (ng g^{-1} dw) in reference bivalve material IAEA-432 with their corresponding recommended values and standard deviation

	IAEA 432	*IAEA 432-2*	*IAEA 432-3*	*Recommended values*	*s.d.*
HCB	0.15	0.27	0.35	0.20	0.10
α HCH	0.04	0.04	0.04	0.23*	0.25
β HCH	0.09	<0.033	<0.033	0.22*	0.11
γ HCH-Lindane	0.09	0.04	0.03	0.58*	0.54
δ HCH	<0.009	<0.009	<0.009		
pp'DDE	2.30	2.34	2.37	2.10	1.00
pp'DDD	0.71	0.81	0.61	0.88	0.49
pp'DDT	0.45	0.68	0.36	0.67*	0.46
DDMU	0.35	0.49	0.37		
op DDE	0.12	0.13	0.16	0.62*	0.64
op DDD	0.31	0.12	0.21	1.80*	2.70
op DDT	0.32	<0.001	<0.001	1.80*	2.00
Heptachlor	0.11	0.13	0.13	1.00*	1.00
Aldrin	<0.035	<0.035	<0.035	1.50*	1.40
Dieldrin	6.07	1.97	3.37	1.30*	0.94
Endrin	11.34	6.17	7.50	5.40*	6.90
Cis Chlordane	0.26	1.02	0.97	0.25*	0.10
Trans Chlordane	0.13	0.80	1.96	0.49*	0.58
Cis Nonachlor	<0.002	<0.002	<0.002	0.20*	0.17
Trans Nonachlor	0.21	0.17	0.16	0.53*	0.29
Heptachlor epoxide-A (trans)	0.80	0.35	0.46	11.00*	18.00
Heptachlor epoxide-B (cis)	<0.005	<0.005	<0.005		
Methoxychlor	<0.052	<0.052	<0.052		
α Endosulfan	3.05	1.10	0.90	4.00*	3.60
β Endosulfan	3.26	1.94	5.79	1.80*	2.00
Endosulfan sulfate	1.84	0.92	0.78	1.80*	1.30

*Information values

Table B7. Concentrations of organochlorinated pesticides (ng g^{-1} dw) in reference bivalve material NIST-2977 with their corresponding certified (Cert) and expanded uncertainties (U=2u)

	NIST 2977	*NIST 2977-2*	*NIST 2977-3*	*Cert values*	*U*
HCB	0.14	0.16	0.15		
α HCH	0.20	0.05	0.06		
β HCH	3.27	6.29	5.05		
γ HCH-Lindane	0.30	0.59	0.85		
δ HCH	<0.009	<0.009	<0.009		
pp'DDE	5.65	5.90	5.74	11.80	1.20
pp'DDD	1.65	2.45	1.88	3.92	0.56
pp'DDT	0.64	0.92	0.53	1.32	0.16
DDMU	2.80	2.88	3.03		
op DDE	0.79	0.81	0.77		
op DDD	1.57	1.68	1.38	3.15	0.25
op DDT	0.36	0.58	0.61		
Heptachlor	0.21	0.32	0.30		
Aldrin	<0.035	0.04	0.04		
Dieldrin	10.67	7.97	7.80	5.55	0.61
Endrin	1.81	1.62	2.06		
Cis Chlordane	0.35	0.84	0.58	1.14*	0.39
Trans Chlordane	0.86	1.17	1.02	2.01*	0.39
Cis Nonachlor	0.36	0.21	0.26		
Trans Nonachlor	0.41	0.38	0.35	1.25	0.17
Heptachlor epoxide-A (trans)	0.46	0.24	0.29		
Heptachlor epoxide-B (cis)	0.28	0.47	0.29		
Methoxychlor	<0.052	<0.052	<0.052		
α Endosulfan	0.71	1.01	1.44		
β Endosulfan	1.84	1.22	2.60		
Endosulfan sulfate	3.33	3.01	1.88		

*reference values

4. RESULTS AND DISCUSSION

4.1. PETROLEUM HYDROCARBONS IN SEDIMENTS

Total organic carbon (TOC), concentration of different classes of hydrocarbons and diagnostic parameters at each sediment-sampling site are summarized in the Table 2. Individual concentrations of aliphatic and aromatic hydrocarbons are shown in Annexes A1 to A4. Surface sediments collected in the RSA were characterized by a low content of TOC (0.06 to 1%) with a high predominance of medium sand. Similarly to previous investigations in the same area (Al-Lihaibi and Al-Omran, 1996; de Mora *et al.*, 2010), there was no correlation between the percentage of fine-grained material and either concentrations of TPHs or TOC. In contrast to this finding, other studies (Massoud *et al.*, 1996; Al-Lihaibi and Ghazi, 1997) found a significant correlation between percent of fine-grained sediment and TPH, but none of them found a positive correlation between TOC and either grain size or TPH content, indicating that TOC cannot be used as an indicator for PH pollution in the RSA.

Trends in both TPHs and UCM have been used to identify “hot spots” in the five countries. As can be seen in the Figure 2 and the Table 2, concentration levels of TPHs as ROPME oil equivalents (ROEq.), the sum of total aliphatic and total aromatic hydrocarbons measured by gas chromatography (TPH-GC) in sediments were generally higher in Bahrain, UAE and Saudi Arabian, than in Oman and I.R. Iran.

Table 2. Total organic carbon, hydrocarbon concentrations and diagnostic parameters in sediments from the ROPME Sea Area

Sample Code	**TOC** %	**< 63 um** vol %	**TPH equiv. ROPME Oil** µg g^{-1} dry wt	**TPH equiv. Chrysene** µg g^{-1} dry wt	**TPH equiv. GC-FID** µg g^{-1} dry wt	**UCM aliphatics** µg g^{-1} dry wt	**Σn-C12-C36** µg g^{-1} dry wt	**UCM/n-alk**	**ΣPAHs** ng g^{-1} dry wt	**Parent ΣPAHs** ng g^{-1} dry wt
BAH-5	0.97	5.8	128	19.0	59.7	31.7	1.0	30.4	1232	653
BAH-9	0.61	0.0	2.3	0.4	24.5	11.6	0.4	25.8	6	3
IRAN 2	0.07	0.4	48.0	7.0	16.1	6.1	1.2	5.3	327	53
IRAN 2-1	0.10	63.0	7	1.0	21.8	5.3	2.8	1.9	261	78
OMAN-2	0.10	0.0	67.0	10.0	9.2	0.1	0.5	0.3	34	6
OMAN-2-1	0.06	0.6	19.0	2.9	12.7	0.5	0.7	0.7	37	3
OMAN-8-1	0.38	1.0	24	3.6	66.3	25.7	1.6	16.3	165	60
KSA-1	0.69	0.0	23	3.5	31.0	17.7	0.6	30.3	317	19
KSA-2-1	0.46	10.1	105	15.0	127.5	68.9	2.9	23.8	891	117
KSA-2-2	0.60	0.0	16.0	2.4	32.2	15.7	0.5	32.6	283	18
KSA-3	0.15	0.0	28.0	4.1	85.1	51.3	0.8	67.0	714	81
UAE 7-1	0.13	0.0	12.0	1.7	26.8	15.8	1.1	14.4	94	9
UAE 7-1-2	0.47	1.9	63.0	9.20	142.2	89.7	4.7	19.0	765	93
UAE 7-1-3	0.13	0.1	12.0	1.80	25.3	14.9	0.9	17.1	97	10
UAE 7-2	0.12	0.0	22.0	3.2	49.1	34.8	1.1	32.9	245	21
UAE 7-2-2	0.36	0.9	75	11.0	128.1	75.7	4.3	17.5	497	117
UAE 7-2-3	0.29	0.1	8	1.2	36.3	18.6	0.4	41.8	236	8
UAE 3	0.23	3.6	22.0	3.3	45.9	23.8	0.8	28.7	291	65

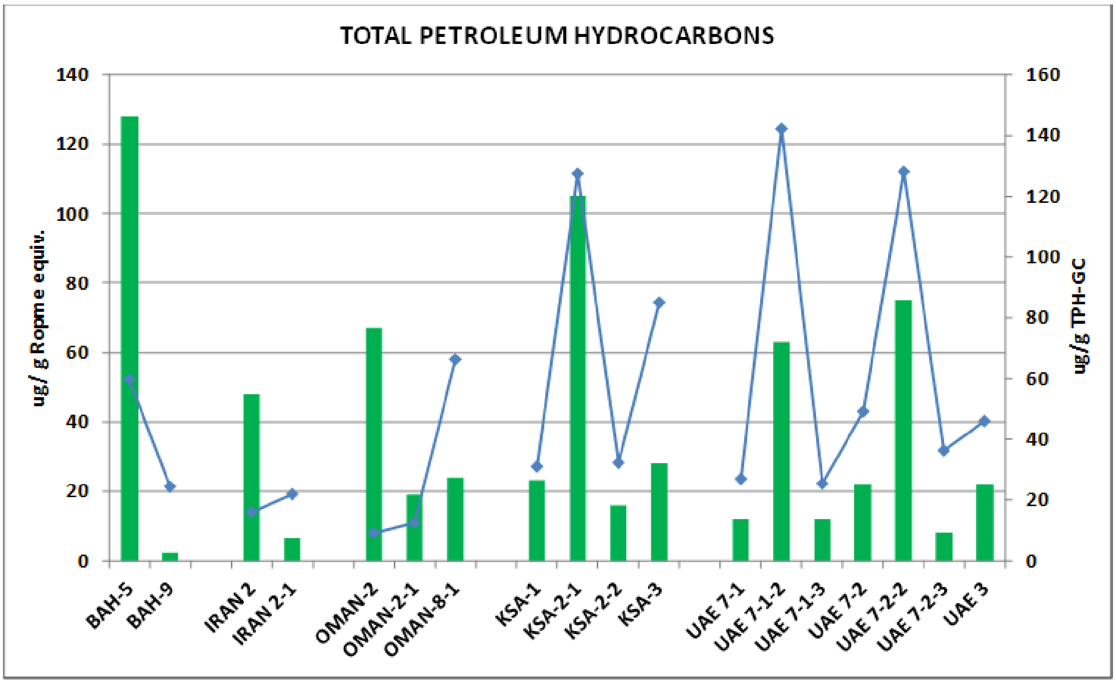

Figure 2. Concentration of hydrocarbons in marine sediments from the RSA as ROPME equivalents (bars) and as the sum of total aliphatic and total aromatic hydrocarbons measured by gas chromatography (in lines)

4.1.1 Bahrain

In Bahrain, the highest concentrations of TPHs were measured in the sediments collected at the Askar site (BAH-5), followed by Marwada (BAH-9). The TPH concentrations in the Askar site contained higher values (128 µg g^{-1} ROEq.) as those measured from 2000 to 2011 (59-20 µg g^{-1}) (ROPME-IAEA, 2013; Tolosa *et al.*, 2005; de Mora *et al.*, 2010). Although Askar was close to the area most heavily impacted by the 1991 oil spill, it appears that it had not impact on the site (Fowler *et al.*, 1993). The hydrocarbon distribution, dominated by a bimodal unresolved complex mixture (UCM) centered at n-C_{22} and n-C_{28} indicated pollution by a mixture of degraded light and heavy petroleum fractions. The triterpane source ratios of the Tm/Ts trisnorhopanes (0.85), evidenced a source of light Arabian crude oil (Tm/Ts=0.88, Sauer *et al.*, 1993). Also the dominance of the n-C_{17} alkane over their homologues n-alkanes indicated an important contribution of biogenic marine algae. The relative high concentration of PAHs (1230 ng g^{-1}) dominated by the higher molecular weight (> 4 aromatic rings) revealed a source of pyrolitic pollution, probably from the increase of motor vehicles in the country. In Marwada (BAH-9), much lower concentrations of TPH (2 µg g^{-1} as ROEq.) were measured and their concentration levels were similar as those measured in 2011(4 µg g^{-1} ROEq). Traces of crude oil hydrocarbons and PAHs from fossil sources were evidenced but no obvious contamination by petroleum hydrocarbons was observed in this site.

4.1.2 I.R. Iran

In I.R. Iran, the highest concentrations of TPHs in sediments were measured in the port of Bushehr (IRAN-2) with values of 48 µg g^{-1} ROEq, similar to those measured in 2011 (65 µg g^{-1}) but much lower than the value measured in 2005 (318 µg g^{-1}; de Mora *et al.*, 2010). In the port of Bushehr, the profile distribution of aliphatic hydrocarbons indicated some remains of a degraded oil product mixed with bacteria-derived hydrocarbons. The sediment from Daier (IRAN-2-1) exhibited lower concentrations of TPHs (6.5 µg g^{-1} ROEq), and its aliphatic profile showed a natural hydrocarbon distribution typical of bacteria, algal and some terrestrial plant waxes.

4.1.3 Oman

The Omani sediment samples exhibited concentrations of TPH from 19 to 67 µg g^{-1} ROEq., with the highest value measured in Mina Al Fahal (OMAN-2). These values are higher than those measured in the 2011, 2005 and 2000 surveys (ROPME-IAEA, 2013, de Mora *et al.*, 2010; Tolosa *et al.*, 2005), but still one order of magnitude lower than those reported in 1990 (Badawy *et al.*, 1993), indicating that the sediments analyzed in the present and previous surveys were not impacted by the oil terminal and refinery plant at this site. The aliphatic profile exhibits traces of fresh diesel oil overlapped with bacterial hydrocarbons. The Tm/Ts trisnorhopanes ratio of 1.7 is close to the diagnostic ratio for the Iranian crude oil (Tm/Ts of 1.5). PAH concentrations are also low (34 ng g^{-1}) in Mina Al Fahal and no pyrolitic input is observed. The TPH concentrations in Masirah site (OMAN-8-1) were also higher that those measured in the previous surveys of 2011, 2005, 2000 reaching concentrations of 24 µg g^{-1} ROEq. The aliphatic distribution in the site of Masirah also show traces of relatively fresh diesel oil overlapped with algal biogenic sources. Here, the Tm/Ts trisnorhopanes ratio of 0.8 is close to the diagnostic ratio for the Light Arabian crude oil (Tm/Ts of 0.88). Finally, the site of Sohar (OMAN-2-1) exhibits the lowest concentrations of TPH (19 µg g^{-1} ROEq.) with an aliphatic profile characterized by fresh diesel oil overlapped with some terrestrial plant waxes.

4.1.4 Saudi Arabia

Much higher range of concentrations, varying from 16 to 105 µg g^{-1} ROEq., was observed in Saudi Arabia samples with the highest value observed in the pleasance harbor of Jubail (KSA-2-1). Here the hydrocarbon distribution shows a mixture of different hydrocarbon sources, including diesel oil severely degraded, heavy crude oil, marine algal and terrestrial plant waxes. The Tm/Ts trisnorhopanes ratio of 0.75 is close to the diagnostic ratio for the Light Arabian crude oil (Tm/Ts of 0.88). On the site of Ras Tanura (KSA-3), the hydrocarbon distribution is typical of severe degraded diesel oil with a Tm/Ts trisnorhopanes ratio of 1. Compared to last survey of 2011, we measured slighter higher concentrations of TPH and higher degradation profiles were observed in the present survey of 2014. Some pyrolitic input of PAHs, likely from the refinery is also evidenced in both sites, Jubail and Ras Tanura. Lowest concentrations of TPH were measured in the other two sites of Saudi Arabia, Al Khafji (KSA-1) and Ras abu Ali (KSA-2-2) with concentrations of 16 to 23 µg g^{-1} ROEq. Both sites exhibits a similar aliphatic distribution characterized by highly degraded diesel fuel oil.

4.1.5 UAE

In the UAE, samples from Umm Al-Quwain (UAE-7-1-2 and UAE-7-2-2) showed the highest contamination with values of 63-75 µg g^{-1} ROEq. These TPH concentrations are in the lower range reported for near-shore marine sediments of the UAE in 1994, namely 0.4-212 µg g^{-1} (Abu-Hilal & Khordagui, 1994), but they are higher than those reported in the previous survey of 2011 (2.3 µg g^{-1} ROEq). Both sites show a hydrocarbon distribution typical of degraded diesel oil with a Tm/Ts trisnorhopanes ratio close to 1 and some pyrolytic input of PAHs. Lower concentration of TPHs was measured in the other sediment sites of Umm Al Quwain (UAE-7-1, UAE-7-1-3, UAE-7-2, UAE-7-2-3: 8-22 µg g^{-1} ROEq.) and Dubai (Jebal Ali, UAE-3: 22 µg g^{-1} ROEq). In these sites, the aliphatic hydrocarbon distribution exhibited a mixture of degraded diesel and crude oil. In the site from Dubai, the concentrations were similar to those measured in 2011 (15 µg g^{-1} ROEq) and pyrolytic sources of PAHs were also evidenced.

According to guidelines for pollution levels in bottom sediments of the RSA (Massoud *et al.*, 1996), concentrations of <15 µg g^{-1} as chrysene equivalents are considered to represent natural background levels for this region. This threshold value was reached in the sediment of Jubail (KSA-2-1) in Saudi Arabia and it was only exceeded in the sediment of Askar in Bahrain (BAH-5). For the rest of the sediments analyzed (Figure 3), and according to these guidelines, the sites analyzed can be categorized as relatively unpolluted areas with values lower than 15 µg g^{-1} as chrysene equivalents.

The TPH concentration, as the sum of total aliphatic and total aromatic hydrocarbons measured by gas chromatography, ranged from 9 to 142 µg g^{-1} (Figure 2). The highest levels were observed in the sediments UAE-7-1-2 and UAE-7-2-2 from Umm Al-Quwain, in UAE, with a distribution typical of a degraded diesel fuel, and in the sediment of KSA-2-1 with a mixed of degraded diesel fuel and heavy crude oil. Whereas total hydrocarbon concentrations >500 µg g^{-1} are generally indicative of significant pollution, values <10 µg g^{-1} are considered to denote unpolluted sediments (Volkman *et al.*, 1992). The TPH levels in sediments reported here are relatively low

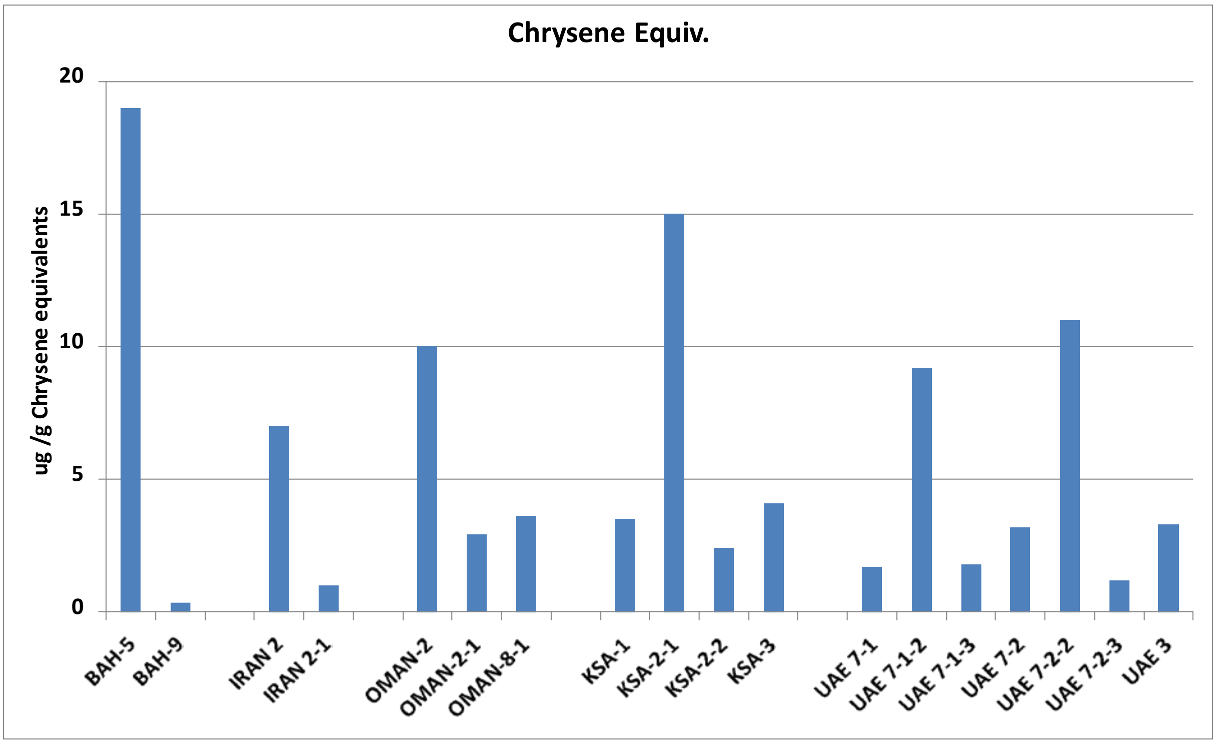

Figure 3. Concentrations of hydrocarbons in marine sediments from the RSA as chrysene equivalents

compared to those in worldwide locations reported as chronically contaminated by oil, such as 60-646 µg g^{-1} in Hong Kong's Victoria Harbour (Hong *et al.*, 1995), 35-2900 µg g^{-1} in the New York Bight (Farrington & Tripp, 1977), and 11-6900 µg g^{-1} along the oil-impacted coastline of Saudi Arabia after the Gulf War (Readman *et al.*, 1996).

Further insights of petrol contamination can be obtained by examining the aliphatic UCM that is often used as a relative measure of chronic, degraded oil contamination. UCM concentrations were typically low (<10 µg g^{-1}) in the North of Oman and I.R. Iran (Figure 4). These low UCM concentrations are comparable to coastal environments distant from hydrocarbon inputs, such as those in the eastern Mediterranean (Gogou *et al.*, 2000), the coastline of Ukraine in the Black Sea (Readman *et al.*, 2002) and in deep-basin sediments from the north-western Mediterranean Sea (Tolosa *et al.*, 1996). The background value of 10 µg g^{-1} was exceeded in all Saudi Arabia, Bahrain and UAE locations. The highest values, up to 90 µg g^{-1}, were measured at UAE (UAE-7-1-2 and UAE-7-2-2) and Saudi Arabia (KSA-2-1 and KSA-3). Considerable biodegradation of petroleum-related inputs at Ras Tanura (KSA-3) site in Saudi Arabia was confirmed by the high ratio of UCM/*n*-alkanes (67) (Figure 4), since values >10 are indicative of chronic/degraded petroleum contamination (Simoneit, 1982). Moderate biodegradation was noticed in the other samples from Saudi Arabia, all samples from UAE, Askar in Bahrain and Masirah in Oman.

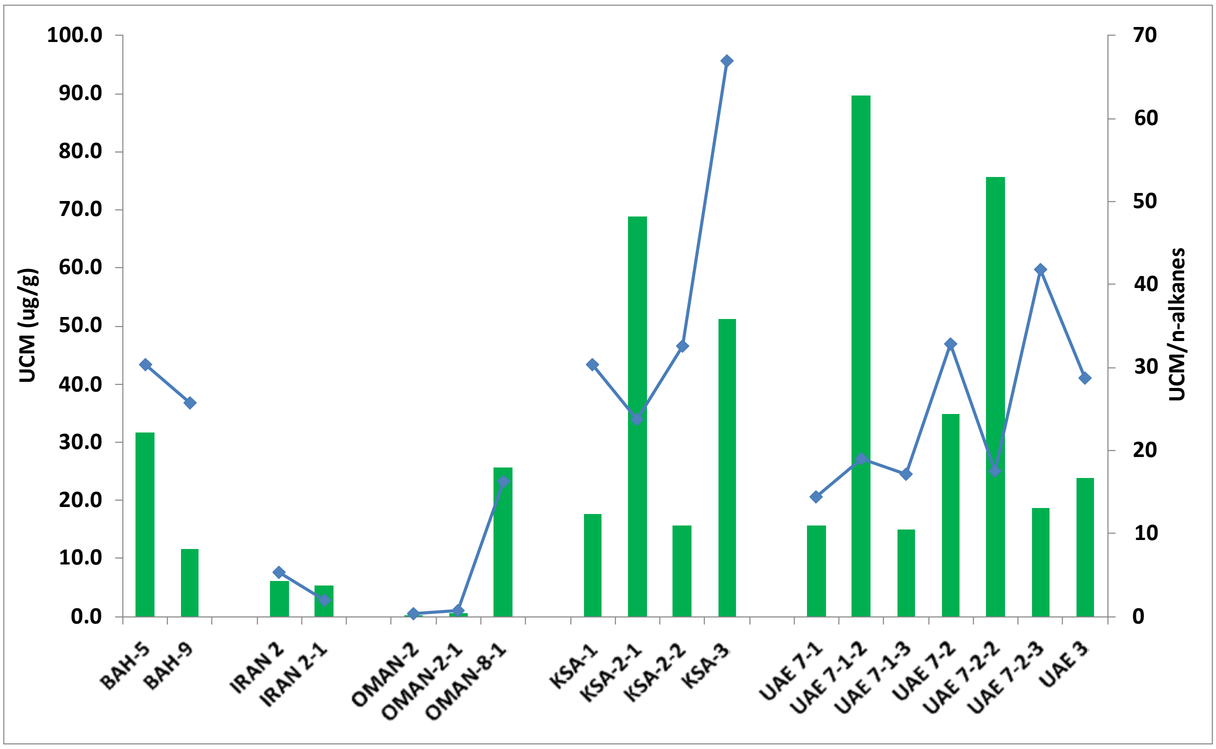

Figure 4. Concentrations of aliphatic unresolved complex mixture (UCM in bars) and UCM/n-alkanes ratio (line) for the sediments from the RSA

The total PAH concentrations in sediments given in the Table 2 and Figure 5 generally mirror those found for the aliphatic UCM concentrations. The total PAH levels were <100 ng g^{-1} in samples from North Oman, and in two samples from UAE (UAE-7-1 and UAE-7-1-3), which are typical of locations distant from contamination sources (Baumard *et al.*, 1998). The moderately contaminated sites, with PAHs values > 100 ng g^{-1} but lower than 500 ng g^{-1}, include the sediments from I.R. Iran (IRAN-2, IRAN-2-1), Masirah (OMAN-8-1) in Oman, Al Khafji (KSA-1) and Ras Abu Ali (KSA-2-2) in Saudi Arabia, and all samples of Umm Al-Quwain excepting the UAE-7-1-2. Exceptionally high concentrations of Σ PAHs were measured in the sediments from Askar (BAH-5): 1200 ng g^{-1} Σ PAHs) in Bahrain, Jubail (KSA-2-1) and Ras Tanura (KSA-3) in Saudi Arabia and Umm Al-Quwain (UAE-7-1-2) in UAE. The high PAH concentration in Askar was 4 times lower than the NOAA sediment quality guideline value for the Effects Range Low (ERL) of 4000 ng g^{-1} dry weight (Long *et al.*, 1995).

The concentrations of parent PAHs, which are usually linked to pyrolitic PAHs, includes *m*/*z*178 (phenanthrene/anthracene), *m*/*z* 202, (pyrene/fluoranthene); *m*/*z* 228 (benzo[*a*]anthracene/chrysene/triphenylene), *m*/*z* 252 (benzofluoranthenes, benzo[*e*]pyrene,benzo[*a*]pyrene, *m*/*z* 276 (indeno[1,2,3-*cd*]pyrene, benzo[*ghi*]perylene), which ranged from 2.5 to 653 ng g^{-1}. Only the site of Askar (BAH-5) approached the value of 0.65 µg g^{-1} but the value is still lower than the concentration of 1 µg g^{-1} assigned to a chronically polluted area where the PAHs are mainly derived from combustion/pyrolysis processes (Baumard *et al.*, 1998).

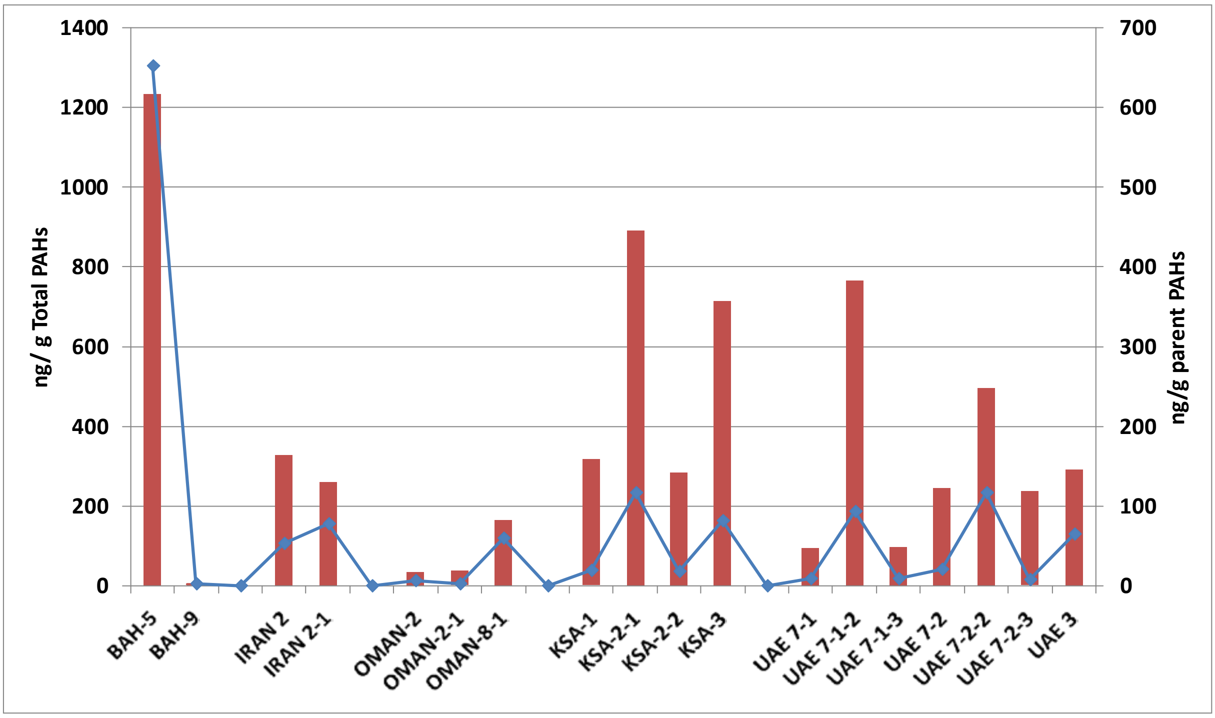

Figure 5. Concentrations of total polycyclic aromatic hydrocarbons (in bars) and total parent PAHs (line) for the sediments from the RSA

The representative PAH sedimentary patterns for the five different countries are shown in Figure 6. A typical profile of petrogenic PAHs, with a predominance of alkyl-substituted dibenzothiophenes and phenanthrenes over their respective parent compounds, was observed at most sites in I.R. Iran, Oman and Saudi Arabia. Pyrolitic sources, evident by the dominance of the unsubstituted PAH over their alkylated homologues and the prevalence of 4-6 rings PAH over the low molecular weight 2-3 rings PAHs, were extremely high at Askar (BAH-5). Other sites, such as Umm Al-Quwain (UAE-7-1-2, UAE-7-2-2) and Dubai (UAE-3) in the UAE and Masirah (OMAN-8-1) in Oman exhibited a slight contribution of combustion-derived PAHs, amongst a higher proportion of petrogenic PAHs.

The high concentrations of pyrolytic PAHs found at Askar (BAH-5) warrant ongoing monitoring at the site. Likewise, a continued watch on the sites of Umm Al-Quwain and Dubai in UAE, I.R. Iran, Oman and Saudi Arabia should be maintained in order to follow any changes in the degree of oil contamination.

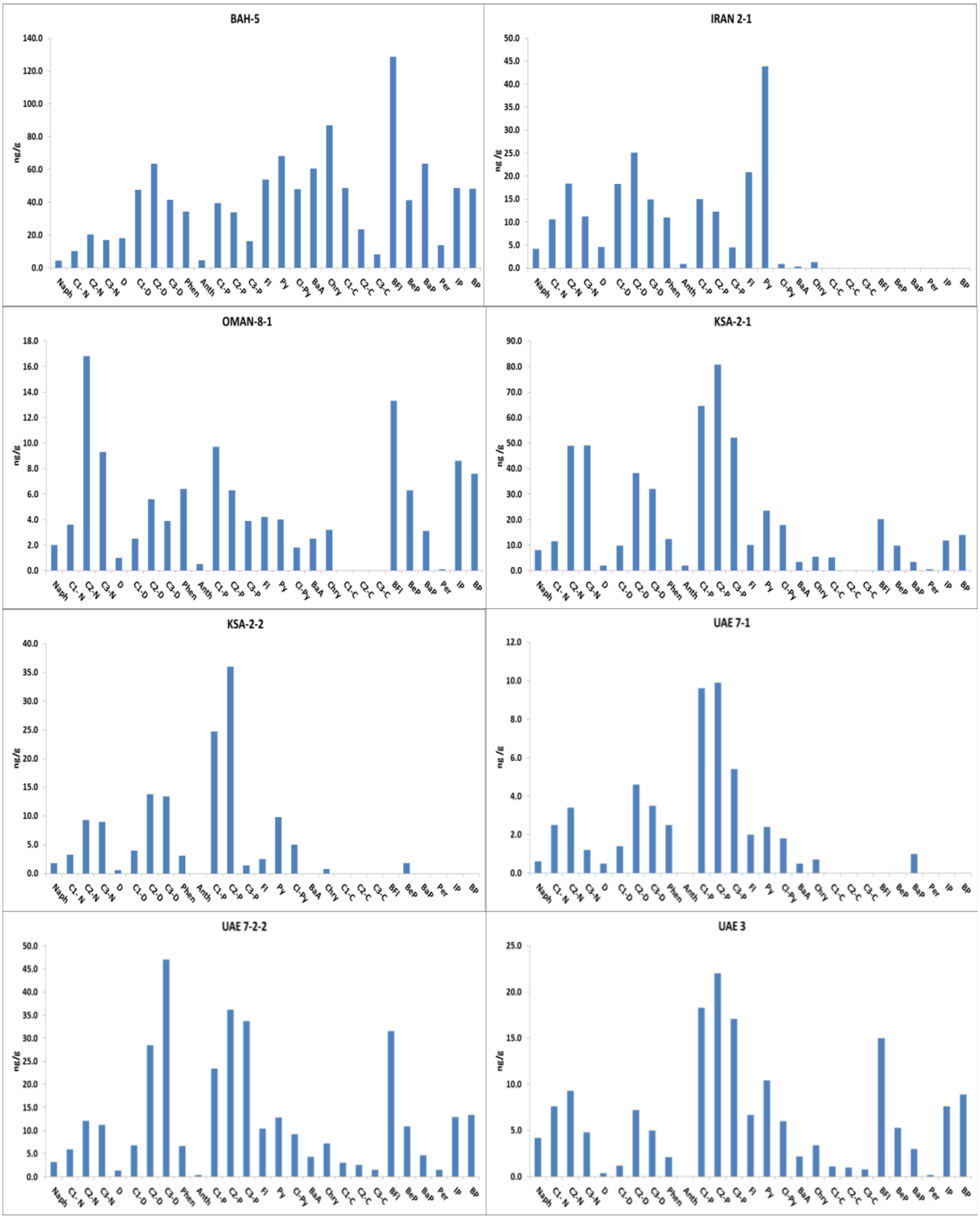

Figure 6. Distribution of selected PAHs in representative sediment samples from the RSA region. Compound codes: Naph: naphthalene; C_1-, C_2-, C_3-N: mono-, di-, and tri-methylnaphthalenes; D: dibenzothiophene; C_1-, C_2-, C_3-D: mono-, di-, and tri-methyldibenzothiophenes; Phen: phenanthrene; Anth: anthracene; C_1-, C_2-, C_3-P: mono-, di-, and tri-methylphenanthrenes; Fl: fluoranthene; Py: pyrene; C_1-Py: mono-methyl pyrenes; BaA: benzo[a]anthracene; Chry: chrysene + triphenylene; C_1-, C_2-C, C_3-C: mono-, di-, and tri-methylchrysenes; BFl: benzo[b]fluoranthene + benzo[j]fluoranthene + benzo[k]fluoranthene + benzo[a]fluoranthene; BeP: benzo[e]pyrene; BaP: benzo[a]pyrene; Per: perylene; IB: indeno[1,2,3-c,d]pyrene; BP: benzo[g,h,i]perylene

4.2 PETROLEUM HYDROCARBONS IN BIVALVES

Sampling locations for the bivalves are listed in Table 1 and the corresponding hydrocarbon concentrations are summarized in the Table 3 and the Figure 7. Individual concentrations of aliphatic and aromatic hydrocarbons are shown in Annexes B1-B6. The concentrations ranged from 0.8 to 174 µg g^{-1} ROEq. dry weight, with the highest concentrations measured in pearl oysters from Jubail in Saudi Arabia (KSA-2-1), and rock oysters from Mina Al-Fahal in Oman (OMAN-2) and Qeshm Island in I.R. Iran (IRAN-4-1). The hot spot values recorded in Jubail and Mina Al-Fahal are in accordance with the highest hydrocarbon concentrations measured in the sediments from these two sites, which presumably reflect chronic contamination by the oil terminal and refinery plant at Mina Al-Fahal and by the pleasance harbor in Jubail. Higher concentrations were reported at the Mina Al Fahal (OMAN-2) site in the previous surveys of 2011 and 2005 (572 µg g^{-1} ROEq. 418 µg g^{-1} of UCM and 13.7 µg g^{-1} PAHs). Similarly, rock oysters from Qeshm Island in I.R. Iran exhibited higher total TPH concentrations in the previous survey of 2011 (917 µg g^{-1} ROEq, 1200 µg g^{-1} TPH-GC).

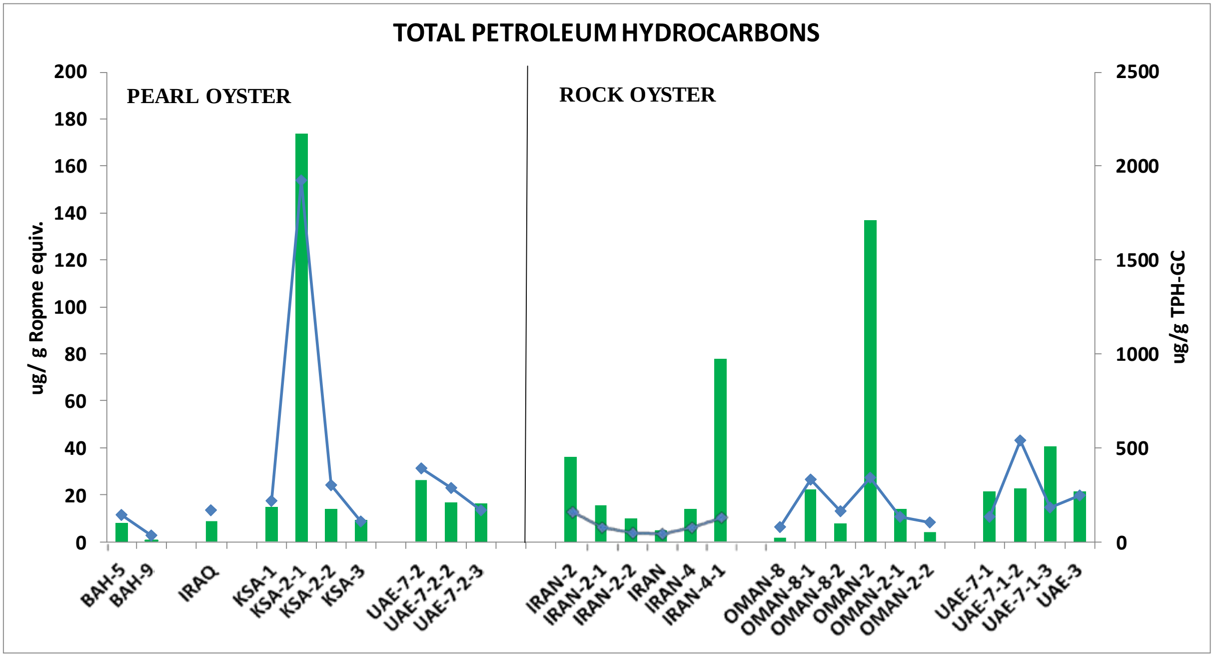

Figure 7. Concentration of hydrocarbons in bivalves from the RSA as ROPME equivalents (bars) and as the sum of total aliphatic and total aromatic hydrocarbons measured by gas chromatography (in lines)

Table 3. Total lipid content and hydrocarbon concentrations in bivalves from the ROPME Sea Area

Sample Code	**Bivalve type**	**Lipids** mg g^{-1} dry wt	**TPH Equiv. ROPME Oil** µg g^{-1} dry wt	**TPH Equiv. Chrysene** µg g^{-1} dry wt	**TPH Equiv. GC-FID** µg g^{-1} dry wt	**UCM aliphatics** µg g^{-1} dry wt	**Σ *n*-C_{12}-C_{36}** µg g^{-1} dry wt	**Σ PAHs** ng g^{-1} dry wt	**Parent Σ PAHs** ng g^{-1} dry wt
BAH-5	Pearl Oyster	28	7.9	1.2	142	112	5.2	780	75
BAH-9	Pearl Oyster	47	0.8	0.1	33	13	4.0	86	9
IRAN-2	Rock Oyster	43	36.1	5.4	171	119	6.6	1038	110
IRAN-2-1	Rock Oyster	84	15.4	2.3	89	53	6.9	1312	95
IRAN-2-2	Rock Oyster	94	9.8	1.5	56	29	7.1	636	76
IRAN	Rock Oyster	115	4.6	0.7	50	18	8.6	362	84
IRAN-4	Rock Oyster	99	13.9	2.1	85	50	7.6	817	85
IRAN-4-1	Rock Oyster	67	77.7	11.6	142	98	6.5	2848	159
IRAQ	Pearl Oyster	86	8.9	1.3	167	117	6.2	481	30
OMAN-8	Rock Oyster	82	1.6	0.2	76	28	8.6	116	12
OMAN-8-1	Rock Oyster	114	22.2	3.3	331	223	15.8	530	64
OMAN-8-2	Rock Oyster	74	7.4	1.1	163	63	20.9	909	103
OMAN-2	Rock Oyster	72	137	20.4	339	196	15.6	3467	135
OMAN-2-1	Rock Oyster	56	13.9	2.1	130	56	17.7	533	49
OMAN-2-2	Rock Oyster	136	4.0	0.6	103	45	10.3	742	39
KSA-1	Pearl Oyster	54	14.5	2.2	216	147	13.2	920	42
KSA-2-1	Pearl Oyster	57	174	25.9	1923	1684	31.8	11997	900
KSA-2-2	Pearl Oyster	41	14.1	2.1	299	234	12.4	763	38
KSA-3	Pearl Oyster	77	9.1	1.4	105	70	8.6	423	23
UAE-7-1	Rock Oyster	107	21.4	3.2	131	89	10.4	541	86
UAE-7-1-2	Rock Oyster	110	22.6	3.4	540	383	39.3	996	123
UAE-7-1-3	Rock Oyster	95	40.4	6.0	180	128	9.5	871	124
UAE-7-2	Pearl Oyster	56	26.2	3.9	388	308	13.2	1688	101
UAE-7-2-2	Pearl Oyster	47	16.5	2.5	285	226	10.8	1016	52
UAE-7-2-3	Pearl Oyster	72	16.3	2.4	168	118	6.4	1010	70
UAE-3	Rock Oyster	103	21.4	3.2	246	175	9.6	1379	86

Other bivalves showing some oil contamination were bivalves from Umm Al-Quwain in UAE (UAE-7-2, UAE-7-1-3), the rock oysters from Bushehr, I.R. Iran (IRAN-2) and Masirah in Oman (OMAN-8-1) (Table 3 and Figure 7). The total PH equivalents and total PAHs were all somewhat elevated in these bivalves indicating some moderate chronic oil contamination, supported by the high UCM concentrations and UCM/n-alkanes ratios derived from degraded crude oil (Figure 8).

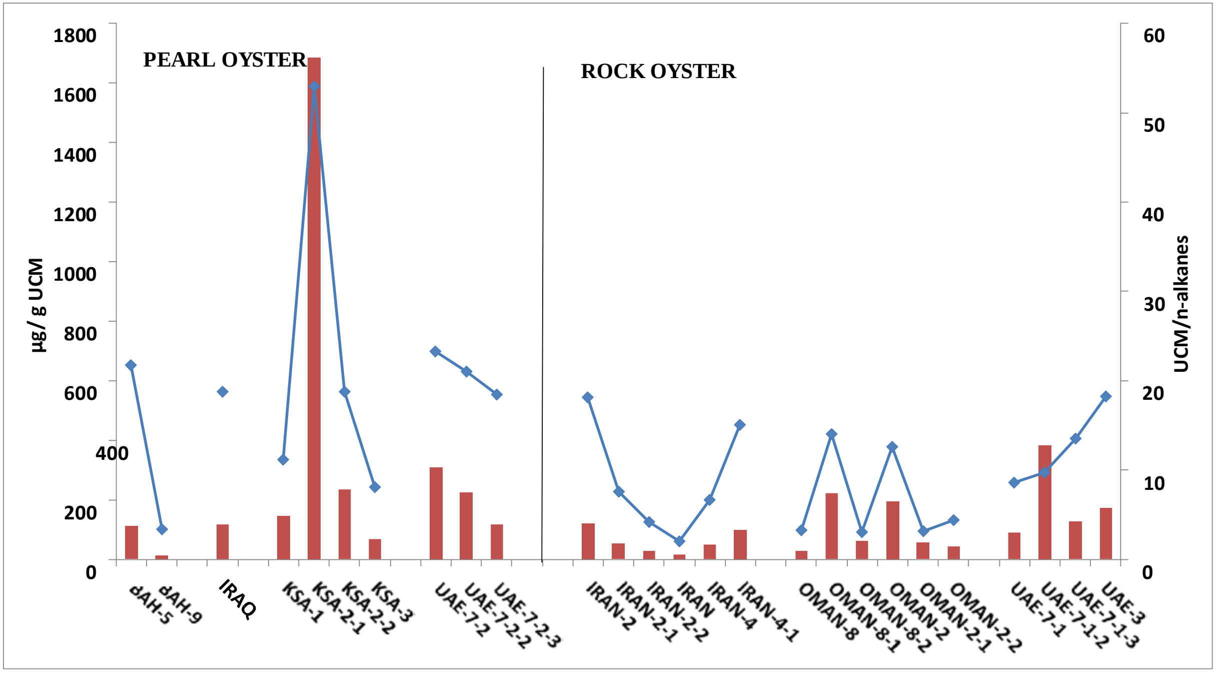

Figure 8. Concentrations of unresolved complex mixture of aliphatics hydrocarbons(UCM) (in bars) and UCM/n- alkanes ratio (line) for the bivalves from the RSA

It is noteworthy that concentrations from Mirbat (OMAN-8) are much lower than those measured in the previous survey of 2011 and similar to those measured in the surveys performed in 2000 and 2005 (Tolosa *et al.*, 2005; de Mora *et al.*, 2010). On the other hand, the pearl oysters from Marwada in Bahrain (BAH-9) exhibited the lowest levels of PHs from the seven countries (1 µg g^{-1} ROEq., 13 µg g^{-1} of UCM and 86 ng g^{-1} of total PAHs) and those of Askar (BAH-5) did not exhibit the highest concentrations recorded in the sediment.

The concentration of total PAHs, which includes the sum of unsubstituted PAHs (parent PAHs) and the sum of alkyl substituted homologues, ranged from 0.09 to 11.9 µg g^{-1} dry weight (Figure 9).

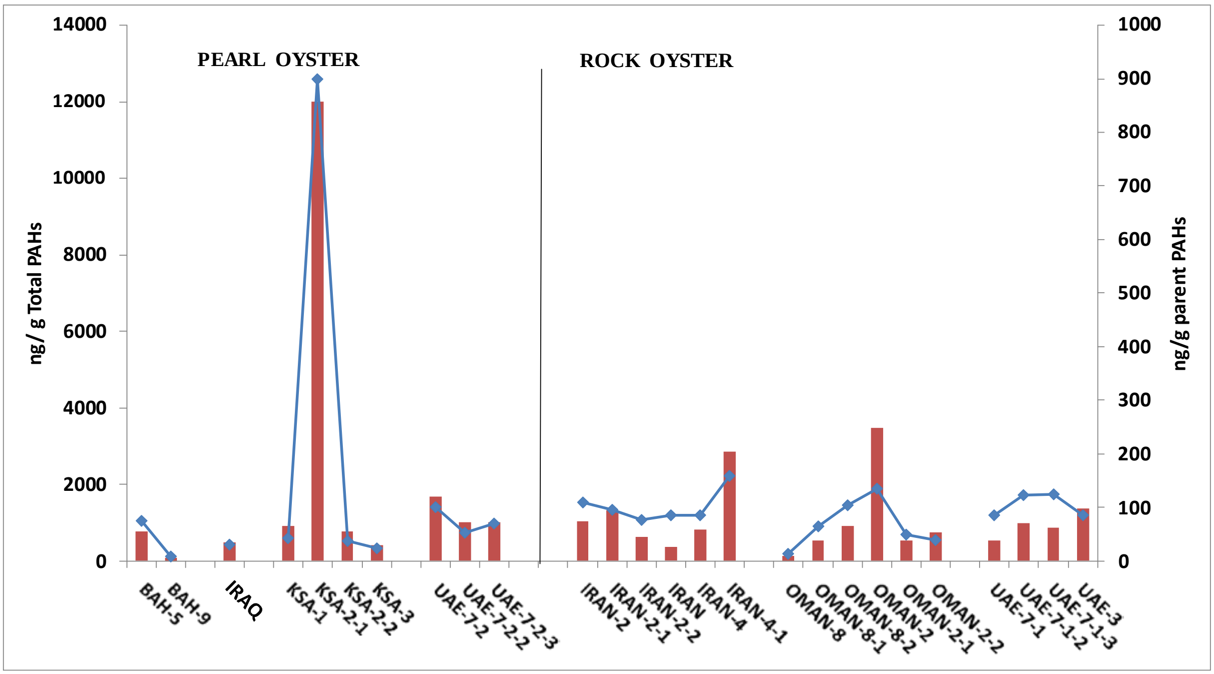

Figure 9. Concentrations of total polycyclic aromatic hydrocarbons (in bars) and total parent PAHs (line) for the bivalves from the RSA

Similarly to the total hydrocarbons (Figure 7), the maximum levels of total PAHs were recorded in the pearl oysters at Jubail Saudi Arabia (KSA-2-1), and rock oysters from Mina Al-Fahal in Oman (OMAN-2) and Qeshm Island in I.R. Iran (IRAN-4-1). The high concentration levels of Jubail in Saudi Arabia are in the range of concentrations reported for the intertidal molluscs contaminated by the Erika oil spill in the Bay of Biscay, France (Tronczynski *et al.*, 2004). The total PAHs concentrations measured in Mina Al-Fahal (OMAN-2) and Qeshm Island (IRAN-4-1) are lower than those measured in 2011 (de Mora *et al.*, 2010). If we exclude these three contaminated sites from the RSA, the levels of total PAHs for the sites left were only slightly higher than those obtained for mussels collected in 2002 from unoiled reference sites in Prince William Sound (Alaska), an area that was heavily oiled by the 1989 *Exxon Valdez* oil spill (3–355 ng g^{-1} dry weight; Page *et al.*, 2005).

The concentrations of total parent PAHs in bivalve tissues ranged from 10 to 900 ng g^{-1} dry weight, with the highest values again measured in pearl oysters from Jubail (KSA-2-1), followed by the rock oysters of Qeshm (IRAN-4-1), Bushehr (IRAN-2), Mina al Fahal (OMAN-2), Qalhat (OMAN-8-2) and Umm Al-Quwain (UAE-7-1-2, UAE-7-1-3). By global standards these levels correspond from low to moderate pollution levels (Baumard *et al.*, 1998). In the rest of bivalves including the pearl oysters of Bahrain and Irak, parent PAH concentration levels were lower than 100 ng g^{-1}, which are typical of locations distant from combustion sources.

The representative PAH patterns (Figure 10) showed a typical profile of petrogenic PAHs, with a predominance of methylated phenanthrenes and dibenzothiophenes over the parent compounds. As is usually the case for oil derived products from the Middle

East, most of the bivalves from Bahrain, I.R. Iran and Iraq, exhibited higher concentrations of alkylated dibenzothiophenes compared to alkylated phenanthrenes. However, the different PAH pattern observed for the bivalves of Oman, Saudi Arabia and UAE, where concentrations of alkylated phenanthrenes were higher than those of alkylated dibenzothiophenes, likely suggest either oil source different from the Middle East or, more likely, a more degraded crude oil.

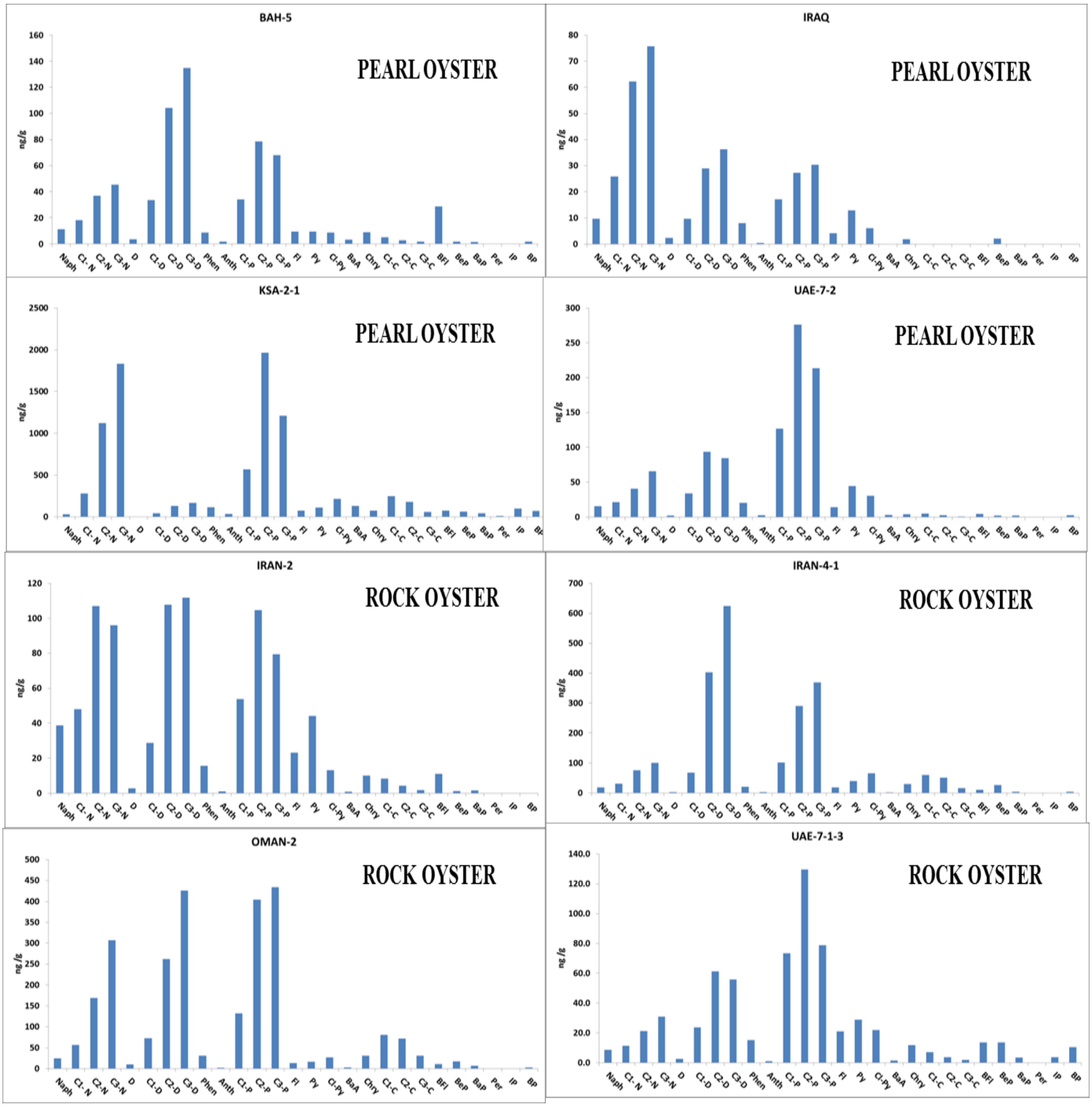

Figure 10. Distribution of selected PAHs in representative bivalve samples from the RSA region. Compound codes are those described in the Figure 6

A minor input of combustion-derived PAHs was suggested by the low concentrations of high molecular weight PAHs, e.g. benzo(a)anthracene, benzofluoranthenes and benzo(a)pyrene, in all bivalves although somewhat higher in the rock oysters from Umm Al-Quwain (UAE-7-1-3) and Bushehr (IRAN-2), and in the pearl oysters from Askar (BAH5).

Interestingly, the PAH sedimentary pattern in Askar (BAH-5) showed a very different profile to that of the bivalves from the same sites (Figures 6 and 10). The pearl oysters from this site were more enriched in low-molecular weight and more water soluble PAHs (petrogenic compounds), whereas the sediment showed a greater contribution of high-molecular weight combustion-generated PAHs. These differences suggest that bivalves were less exposed to the contamination adsorbed onto sediment grains, and they were mainly contaminated by the oil present in the water column. Furthermore, the low bioavailability of pyrolytic PAHs may be linked to their enhanced binding to particulate matter, especially soot particles, thereby making them less readily available for accumulation by organisms (Thompson *et al.*, 2000; Torsen *et al.*, 2004).

4.3 TEMPORAL TRENDS IN PETROLEUM HYDROCARBONS

To follow the temporal trend of the petroleum hydrocarbon pollution levels, a comparison of the recent data with that obtained for the same sediment samples collected during the Contaminant Screening Project in 2000, 2005 and 2011 has been performed as shown in the Figures 11 and 12.

As can be seen in the Figure 11, there has been an irregular but generally increasing trend in total petroleum hydrocarbons from 2000-2005 to 2014 in most of the sediment sites surveyed, excepting the site of the port Bushehr in I.R. Iran (IRAN-2) where total petroleum hydrocarbons are still decreasing slightly from the high concentrations recorded in 2005.

Concerning PAHs (Figure 12), a sharp increase of PAHs concentrations was observed in the recent sediments from Ras Tanura in KSA (KSA-3), Askar in Bahrain (BAH-5), port of Bushehr in I.R. Iran (IRAN-2) and, whereas in Mina Al Fahal (OMAN-2), Masirah (OMAN-8-1) and Umm Al-Quwain in UAE (UAE-7), PAH concentration varied little over the last 5-10 years. It is noteworthy the on-going high concentrations of pyrolitic PAHs measured at Askar (BAH-5) for the last 14 years.

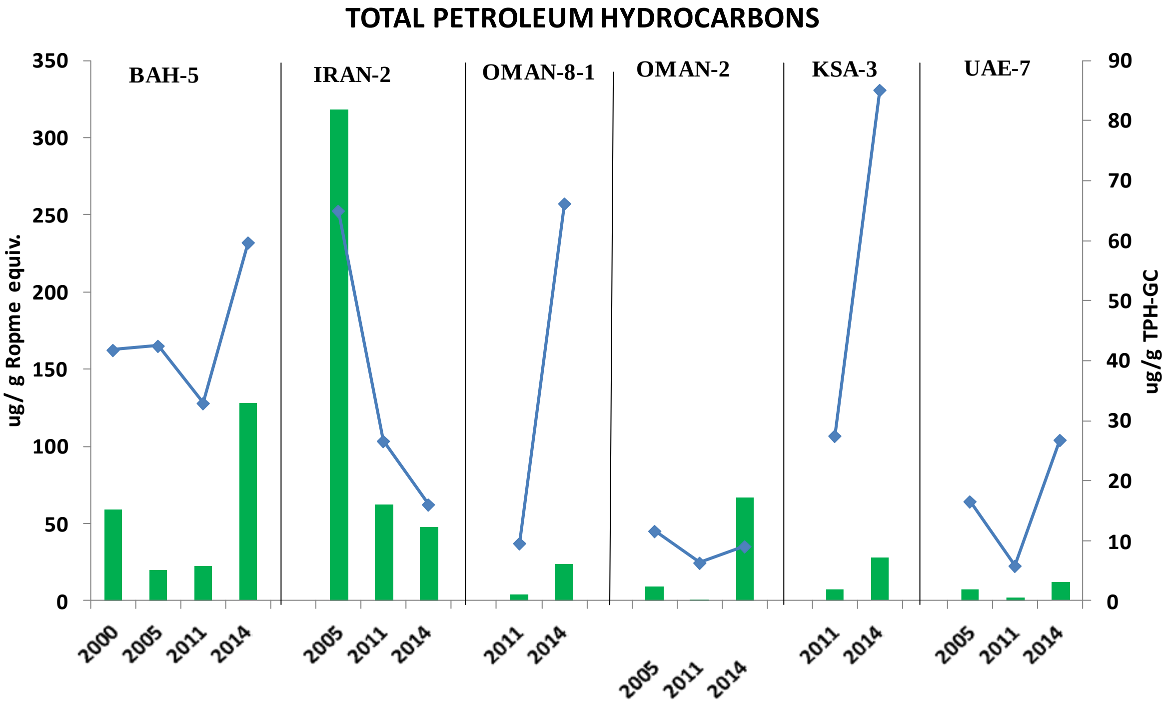

Figure 11. Temporal trend of total petroleum hydrocarbons in sediments from the RSA as ROPME equivalents (bars, left y-axis) and as sum of total aliphatic and total aromatic hydrocarbons measured by gas chromatography (in lines, right-axis)

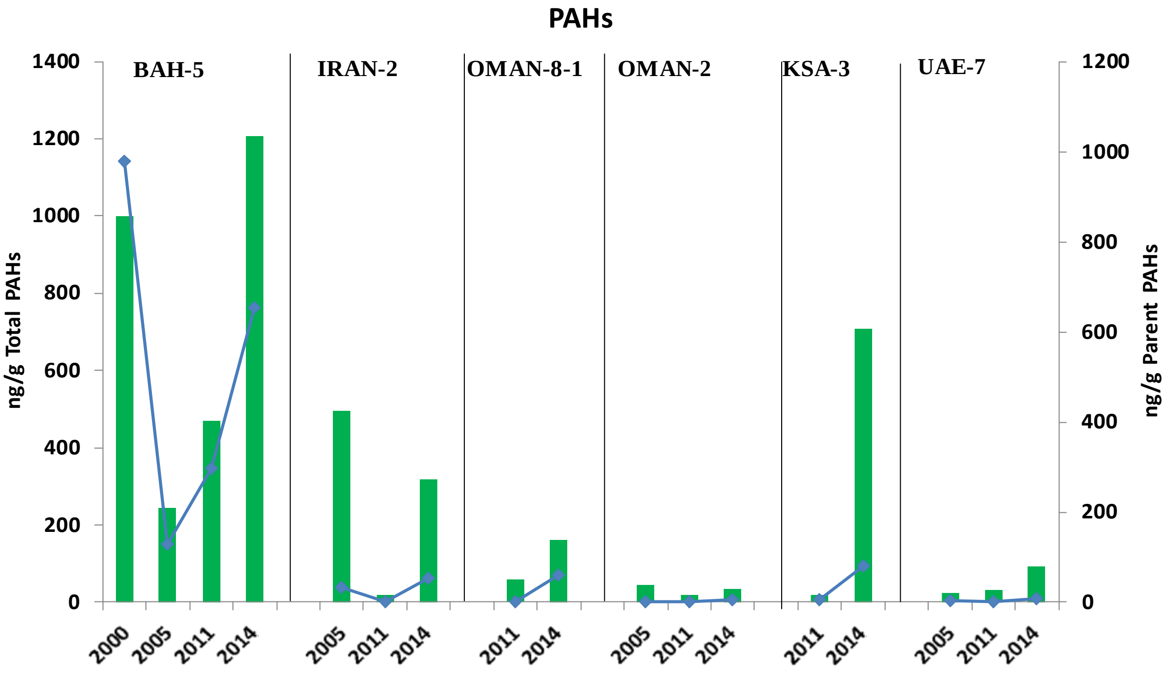

Figure 12. Temporal trend of polycyclic aromatic hydrocarbons in sediments from the RSA as total PAHs (bars, left y-axis) and as sum of parent PAHs (in lines, right-axis)

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Evaluation of the temporal trends of petroleum hydrocarbons by using the bivalve tissue generally provide similar trends as those shown by the sediments (Figures 13 and 14). It is also interesting to note that most of the sites are exhibiting an increase on the combustion derived PAHs, excepting at the more contaminated sites, e.g., Qeshm Island (IRAN-4-1), Mirbat (OMAN-8) and Mina Al-Fahal (OMAN-2). As it was shown in the previous surveys, the coarse sediments from Mina Al-Fahal (OMAN-2), with ~100% sand fraction, did not exhibit important petroleum contamination whereas the bivalve samples exhibited high levels of petroleum hydrocarbon concentrations reflecting certainly the chronic contamination of the Omani waters by the oil terminals and refineries plants. Nevertheless, the PHs concentrations including the parent PAHs are decreasing for the last 9 years.

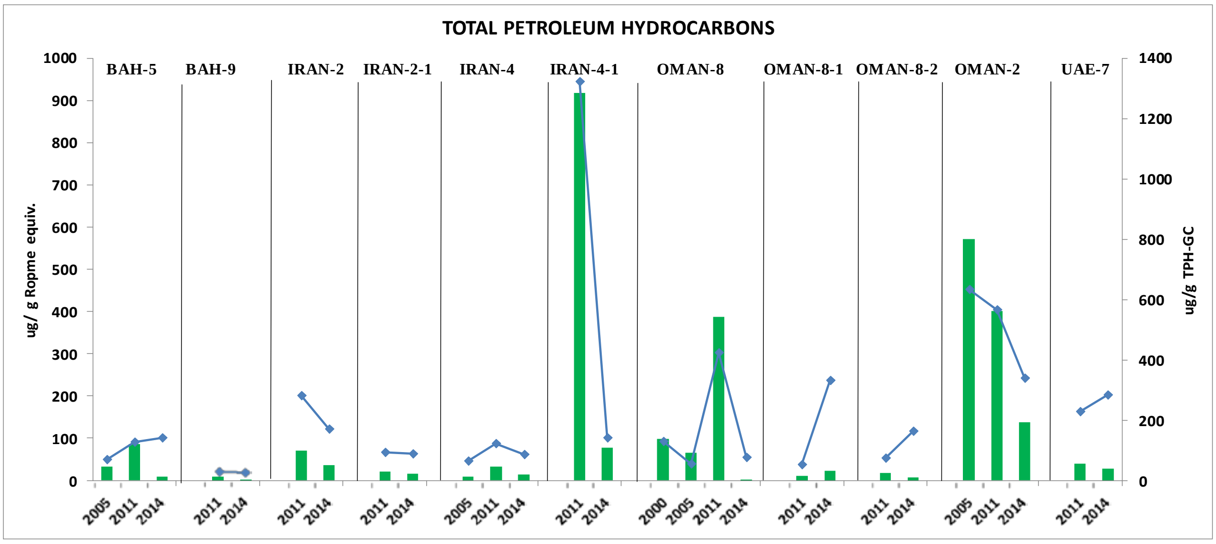

Figure 13. Temporal trend of total petroleum hydrocarbons in bivalves from the RSA as ROPME equivalents (bars, left y-axis) and as sum of total aliphatic and total aromatic hydrocarbons measured by gas chromatography (in lines, right-axis)

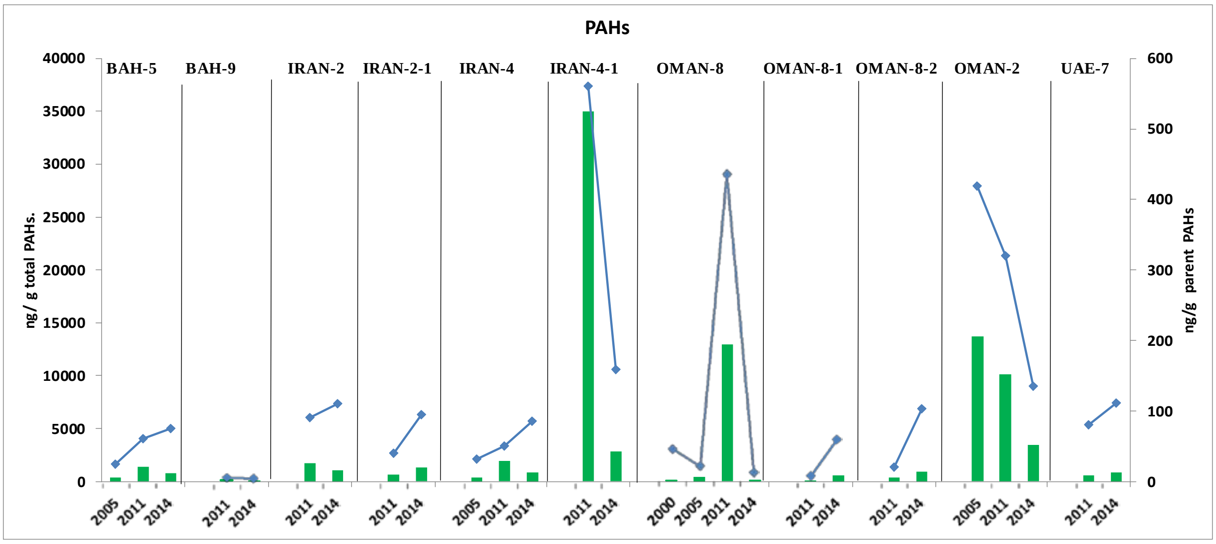

Figure 14. Temporal trend of polycyclic aromatic hydrocarbons in bivalves from the RSA as total PAHs (bars, left y-axis) and as sum of parent PAHs (in lines, right-axis)

4.4 ORGANOCHLORINE COMPOUNDS IN SEDIMENTS

The concentrations of a variety of organochlorinated compounds in coastal sediments from the RSA are presented in the Table 4 and Annexes C.1 and C.2. Environmental levels were very low for all compounds by global standards (Fowler, 1990) (Table 5).

Regarding the agrochemicals, the residues of Σ DDTs (the sum of DDT and the breakdown products DDD, DDE and DDMU) in sediments from the RSA were quite low, in most of the countries with values lower than 500 pg g^{-1}, with the exception of stations in I.R. Iran, where the Σ DDTs levels reached values of 1700 pg g^{-1}. These values of Σ DDTs are much higher than those previously measured in the previous surveys of 2011 and 2005 in Bushehr (IRAN-2), with values of 30 to 236 pg g^{-1} (ROPME-IAEA, 2013; de Mora *et al.*, 2010).

Overall, the data for Σ DDTs presented here agree with the few regional data, compiled on a country basis and available for comparison (ROPME-IAEA, 2013; de Mora *et al.*, 2010; de Mora *et al.*, 2005; Fowler, 2002a). The Table 6 shows data for Σ DDTs from various locations globally for comparison. Overall, the concentrations of Σ DDTs in the RSA are quite low by global standards (de Mora *et al.*, 2004; Fowler, 1990), and, all values, fall well below the sediment quality guideline value of 1,600 pg g^{-1} (Long *et al.*, 1995), excepting the sediment of Daier (IRAN-2-1) with 1700 pg g^{-1}.

Table 4. Chlorinated hydrocarbon concentrations (pg g^{-1} dw) in sediments from RSA

	BAH-5	**BAH-9**	**IRAN 2**	**IRAN 2-1**	**OMAN-2**	**OMAN-2-1**	**OMAN-8-1**	**KSA-1**	**KSA-2-1**	**KSA-2-2**	**KSA-3**
HCB	<18	<18	<38	72	<38	<38	<38	<18	<38	<18	<18
α HCH	<7	16	<7	<7	<13	13	13	<7	<7	<7	<7
β HCH	<11	<6	20	14	57	11	140	<6	<11	<11	<11
ϒ HCH-Lindane	<7	<7	26	50	<16	<16	29	<7	<7	<7	<16
δ HCH	<317	<317	<317	<317	<317	<317	<317	<317	<317	<317	<317
∑ HCHs	**0**	**16**	**46**	**64**	**57**	**25**	**182**	**0**	**0**	**0**	**0**
pp'DDE	29	<8	243	607	<8	54	93	<19	41	<8	26
pp'DDD	15	10	9	101	21	21	76	<3	8	<3	<6
pp'DDT	28	<26	588	542	<11	39	166	123	70	<26	<26
DDMU	<8	<6	66	273	12	<6	57	<6	<6	<6	<6
op DDE	<8	<8	<19	33	<8	<8	50	<8	<8	<8	<8
op DDD	18	<15	<15	26	<15	<8	26	<8	<8	<8	<15
op DDT	<12	<12	113	150	<12	<12	29	<12	<12	<12	<12
∑ DDTs	**90**	**10**	**1019**	**1732**	**33**	**114**	**497**	**123**	**119**	**0**	**26**
Heptachlor	<86	<86	<86	<86	<86	<86	<86	<86	<86	<86	<86
Aldrin	<10	<10	<10	<21	<21	<10	38	<10	<10	<10	<10
Dieldrin	<156	<156	<156	<156	<156	<156	<156	<156	<156	<156	<156
Endrin	<294	<294	<294	<294	<294	<294	<294	<294	<294	<294	<294
Cis Chlordane	12	14	17	28	39	13	38	13	<7	<4	11
Trans Chlordane	<8	<8	<8	<8	<8	<8	<8	<8	<8	<8	<8
Cis Nonachlor	<7	<7	<7	14	<7	<7	<12	<7	<7	<7	<7
Trans Nonachlor	<3	<3	<3	11	16	<7	42	<7	<3	<3	<7
Heptachlor Epox-A (trans)	<826	<826	<826	<826	<826	<826	<826	<826	<826	<826	<826
Heptachlor Epox-B (cis)	<27	<27	<27	<27	<27	<27	<75	<27	<27	<27	<27
Methoxychlor	<1240	<1240	<1240	<1240	<1240	<1240	<1240	<1240	<1240	<1240	<1240
α Endosulfan	<822	<822	<822	<822	<822	<822	<822	<822	<822	<822	<822
β Endosulfan	<136	<136	<136	<136	<136	<136	<136	<136	<136	<136	<136
Endosulfan sulfate	<197	<197	<197	<197	<197	<197	<197	<197	<197	<197	<197
∑37 PCBs	**453**	**119**	**139024**	**456**	**154**	**322**	**1118**	**0**	**160**	**10**	**101**

Table 4. Chlorinated hydrocarbon concentrations (pg g^{-1} dw) in sediments from RSA (Contd...)

	UAE 7-1	**UAE 7-1-2**	**UAE 7-1-3**	**UAE 7-2**	**UAE 7-2-2**	**UAE 7-2-3**	**UAE 3**
HCB	45	<38	<18	<18	<38	<18	<18
α HCH	<7	<7	<7	<7	<7	<7	<13
β HCH	18	39	<11	<11	35	<11	47
ϒ HCH-Lindane	<7	<7	<7	<7	<7	<7	39
δ HCH	<317	<317	<317	<317	<317	<317	<764
∑ HCHs	**18**	**39**	**0**	**0**	**35**	**0**	**85**
pp'DDE	<8	30	<19	<19	69	<8	<19
pp'DDD	<3	79	<3	<3	61	<3	<6
pp'DDT	<11	<11	63	92	90	<11	40
DDMU	<6	38	<6	<6	13	<6	<6
op DDE	<8	22	<8	<8	<8	<8	<8
op DDD	<8	150	<8	<8	39	<8	<8
op DDT	<12	<12	<12	<12	<23	<23	<23
∑ DDTs	**0**	**318**	**63**	**92**	**271**	**0**	**40**
Heptachlor	<86	<86	<86	<86	<86	<86	<86
Aldrin	<10	<10	<10	<10	<10	<10	<21
Dieldrin	<156	<156	<156	<156	<156	<156	<156
Endrin	<294	<294	<294	<294	<294	<294	<294
Cis Chlordane	<7	<4	<7	12	11	22	12
Trans Chlordane	<8	<8	<8	<8	<8	<8	<8
Cis Nonachlor	<7	<7	<7	<7	<7	<7	<7
Trans Nonachlor	<3	<3	<3	<3	<3	<3	<3
Heptachlor Epox-A (trans)	<826	<826	<826	<826	<826	<826	<826
Heptachlor Epox-B (cis)	<27	<27	<27	<27	<27	<27	<27
Methoxychlor	<1240	<1240	<1240	<1240	<1240	<1240	<1240
α Endosulfan	<822	<822	<822	<822	<822	<822	<822
β Endosulfan	<136	<136	<136	<136	<136	<136	<136
Endosulfan sulfate	<197	<197	<197	<197	<197	<197	<197
∑37 PCBs	**0**	**598**	**4**	**4**	**2685**	**0**	**32**

Table 5. Worldwide concentrations of Σ DDTS, Σ HCHS and HCB in sediments (ng g^{-1} dry weight)

Area	Survey Year	Σ DDTs	Σ HCHs	HCB	References
Baltic Sea, South Western Coast	1993	< 0.04-109	< 0.04-5.0	0.1-1.3	(Dannenberger & 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.*, 2004)
Caspian Sea, Iran	2001	0.06-3.9	0.03-0.6	0.01-0.2	(de Mora *et al.*, 2004)
Caspian Sea, Kazakhstan	2001	0.01-1.9	0.01-0.3	0.01-0.07	(de Mora *et al.*, 2004)
Caspian Sea, Russia	2000	0.01-1.9	0.01-0.8	0.01-0.04	(de Mora *et al.*, 2004)
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	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	nd-1.2	nd-0.6		(Sericano *et al.*, 2001)
Masan Bay, Korea	1997	0.3-89	nd-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	1987-88	62-675		11-39	(Tolosa *et al.*, 1995)
Savannah, Georgia, USA	1997	<0.2-4.3	<0.2-0.9	<0.2-4.7	(Loganathan *et al.*, 2001)
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)
Svalbard, Northwegian Artic fjord	2009		0.007-0.1		(Ma et al., 2015)
Yangtse river estuary, East China Sea	2008	0.04-4.5	0.1-0.99		(Zhou et al., 2014)

Note: nd= not detected

Table 6. Concentrations of Σ DDTs, Σ HCHs and HCB in sediments from RSA (ng g^{-1} dry weight)

Area	**Survey Year**	**Σ DDTs**	**Σ HCHs**	**HCB**	**References**
Bahrain	2000	0.088-0.430	0.004-0.013		(de Mora *et al.*, 2005)
Oman	2001	0.0007-0.0852	0.00074-0.0036		(de Mora *et al.*, 2005)
Qatar	2000	0.00063-0.0367	0.0051-0.106		(de Mora *et al.*, 2005)
UAE	2000	nd-0.0519	nd-0.0045		(de Mora *et al.*, 2005)
Bahrain	2005	0.003-0.256	0.007-0.022	0.001-0.042	(de Mora *et al.*, 2010)
I.R Iran	2005	0.035-0.312	nd-0.0155	0.003-0.092	(de Mora *et al.*, 2010)
Kuwait	2005	0.014-3.808	0.006-0.032	0.002-0.022	(de Mora *et al.*, 2010)
Oman	2005	0.005-0.079	0.001-0.016	0.003-0.029	(de Mora *et al.*, 2010)
Qatar	2005	0.0025-0.093	nd-0.009	0.003-0.053	(de Mora *et al.*, 2010)
Saudi Arabia	2005	0.004-0.139	0.001-0.037	0.0015-0.014	(de Mora *et al.*, 2010)
UAE	2005	0.0007-0.087	nd-0.012	0.003-0.016	(de Mora *et al.*, 2010)
Bahrain	2011	0.013-0.082	0.002-0.011	0.003-0.012	ROPME -IAEA, 2013
I.R. Iran	2011	0.020-0.131	0.055-0.192	0.007-0.017	ROPME -IAEA, 2013
Kuwait	2011	0.017-0.076	0.002-0.023	0.009-0.013	ROPME -IAEA, 2013
Oman	2011	0.011-0.094	0.015-0.038	0.006-0.016	ROPME -IAEA, 2013
Qatar	2011	0.005-0.028	0.008-0.041	0.016-0.022	ROPME -IAEA, 2013
Saudi Arabia	2011	0.030-0.076	0.003-0.024	0.005-0.018	ROPME -IAEA, 2013
UAE	2011	0.013-0.053	0.005-0.028	0.003-0.042	ROPME -IAEA, 2013

Note: nd= not detected.

The pesticide pp′DDT gradually degrades in the environment into pp′DDE and pp’DDD through biological and photochemical transformations (Woodwell *et al*., 1971; Guenzi and Beard, 1976; Purnomo *et al*., 2008; Thomas *et al*., 2008; Yao *et al*., 2006). The pp′DDT/(pp′DDE + pp′DDD) ratio is usually used to know whether DDT input has occurred recently or not (Jiang *et al*., 2009; Li *et al*., 2006). This ratio was >1 at the port of Bushehr (IRAN-2), Masirah (OMAN-8-1) and the pleasance harbor of Jubail (KSA-2-1) in Saudi Arabia, pointing to a possible fresh input of DDT in these sites, probably linked to public health emergencies or the presence of DDT in some antifouling paints (UNEP, 2007; Van den Berg, 2009). In the rest of the sites, including the site of Daier (IRAN-2-1) in I.R. Iran, the diagnostic ratios indicated an old usage of DDT.

Several other organochlorinated pesticides were measured, but their sediment contents were very low and of little environmental concern. The concentrations of HCB (range: n.d. to 72 pg g^{-1}) and all HCHs (range: from n.d. to 182 pg g^{-1}), including the maximum lindane signals of 50 and 26 pg g^{-1} for Daier site (IRAN-2-1) and Bushehr port (IRAN-2), never exceeded the threshold effect level of 320 pg g^{-1} for lindane (ISQG, 1995). Lindane concentrations reported here for Bushehr (IRAN-2) are similar to those measured in 2011 for the same location (ROPME-IAEA, 2013), but are still very low by global standards as exemplified by comparison with data from various locations (Table 5). Indeed, the higher values of I.R. Iran were in the same range as those reported in previous regional studies that had found up to 306 pg g-1 in Oman (Fowler *et al*., 2002a) and compare with those in surface sediment samples from the Chukchi Sea, Bering Sea, Gulf of Alaska and Norwegian high Arctic from 7 to 210 pg g^{-1} (Iwata *et al*., 1994a; Ma *et al*., 2015). The predominance of β-HCH over all other isomers of HCHs in most of the sites indicates that HCHs in the area are mainly originated from the historical usage of technical HCH, as α-HCH and γ-HCH are the less resistant HCH isomers and can be converted to β -HCH in aged environment samples (Walker *et al*., 1999).

Very low levels of chlordane compounds up to 39 pg g^{-1} were also measured in most of the sediments of Bahrain, I.R. Iran and Oman with a slight predominance of the cis chlordane isomer over the trans chlordane. This distribution may also indicate an aged source because usually trans chlordane is more susceptible to degradation than its isomer cis in the environment (Bidleman *et al*., 2002; Chen *et al*., 2007). Endosulfan compounds, Endrin compounds, and methoxychlor were not at all detected in any of the sediment samples. For all the pesticides investigated in this study, all of the sites showed lower levels than the ISQG values (CCME, 2002).

With respect to chlorinated hydrocarbons derived from industrial sources, relatively low levels of PCBs, as ∑37 PCBs congeners, were observed in Bahrain, Oman, Arabia Saudi and UAE (nd. to 2685 pg g^{-1}). As shown in the Figure 15 and in contrast to these values, the site of Bushehr (IRAN-2) in I.R. Iran exhibited relatively high concentration levels of PCBs reaching the value of 139 ng g^{-1} whereas the site of Daier (IRAN-2-1) in I.R. Iran exhibited very low levels (456 pg g^{-1}). Excepting for the levels of the port of Bushehr, the amounts of PCBs in the rest of the sediments were comparable to levels that have been previously reported for these or nearby sites (de Mora *et al.*, 2010; de Mora *et al.*, 2005; Fowler, 2002a). In summary, the PCB content was fairly low by global standards for near shore sediments (Fowler, 1990) and they fell well below the Canadian sediment quality guideline value of 23 ng g^{-1} dry weight (Long *et al.*, 1995). Concentrations of total PCBs <2 ng g^{-1} are common in marine environments where atmospheric deposition may prevail, such as Gulf of Alaska (Iwata *et al.*, 1994a), Kara Sea (Sericano *et al.*, 2001), the coastline of Ukraine in the Black Sea (Filleman *et al.*, 2002) and in deep-basin sediments from the Northwestern Mediterranean Sea (Tolosa *et al.*, 1995) and Indian Ocean (Cheng *et al.*, 2015).

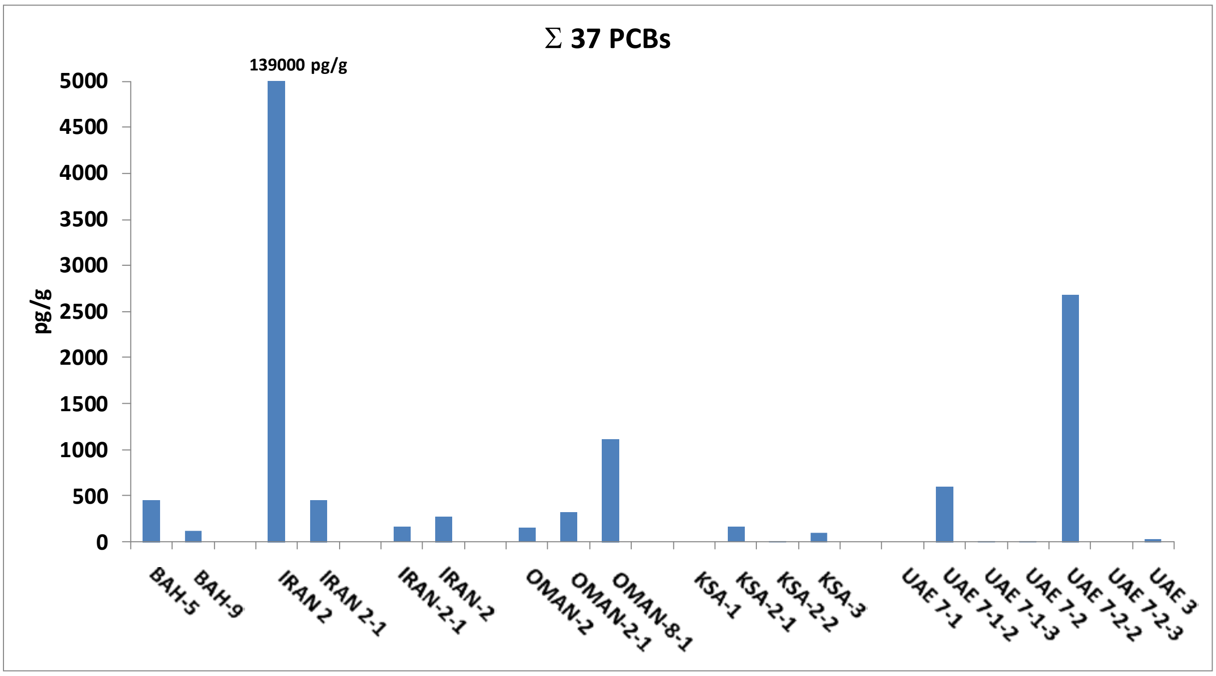

Figure 15. Concentrations of PCBs (as the sum of 37 congeners) in marine sediments from the RSA region

The sediment profiles of the relative distribution of PCB congeners according to chlorine substitution in the sites exhibiting the highest PCB concentration are shown in Figure 16. In the site of Bushehr (IRAN-2), the homolog pattern of PCBs was unique. Decachlorobiphenyl (PCB 209), which is only present in rarer Aroclor technical mixtures, such as, Aroclor 1268, was found at extremely higher concentrations than the other PCBs congeners, and the nonachlorobiphenyl PCB 206 was found at the next highest concentration. This pattern distribution indicates the contribution of a highly chlorinated commercial formulation, which could be related to a locally industrial production of chemicals, such as titanium tetrachloride and pigments (Zhang *et al.*,

2015) or to its generation in thermal refuse treaters (Ishikawa *et al*., 2007). Similar profile distributions have been found in sediments from the Houston Ship Channel in Texas, USA where it was pointed to unusual Aroclor mixtures used in the past or to more recent sources from local industry (Howell *et al*., 2008). In contrast to the profile of Bushehr, the rest of sediments from Bahrain, I.R. Iran, Oman, KSA and UAE exhibited a classical pattern more related to the lower chlorinated commercial mixtures, e.g. Aroclor 1242, Aroclor 1254 and Aroclor 1260. As an example, in Askar (BAH-5) sediment, the pattern profile was largely dominated by the trichloro and hepta-chloro congeners, evidencing the mixture of lower and higher chlorination commercial mixtures (Aroclor-1242 and Aroclor-1260; Schulz *et al.*, 1989). In Oman and UAE, the high contribution of the lower chlorinated PCBs evidenced a locally lower chlorinated commercial mixture, e.g. Aroclor 1242 or a preferencial atmospheric transport of the lower chlorinated congeners. Also in sediments, it has been suggested that the organic matter type and source influence contaminant concentration due to differential sorption affinities (Edgar *et al*., 2003).

The presently low organochlorinated contamination levels recorded in most of the sediments from the RSA correspond to atmospheric inputs, but the recent PCB distribution of the port of Bushehr in I.R. Iran, enriched in relatively heavy congeners, reveals a contamination by local sources.

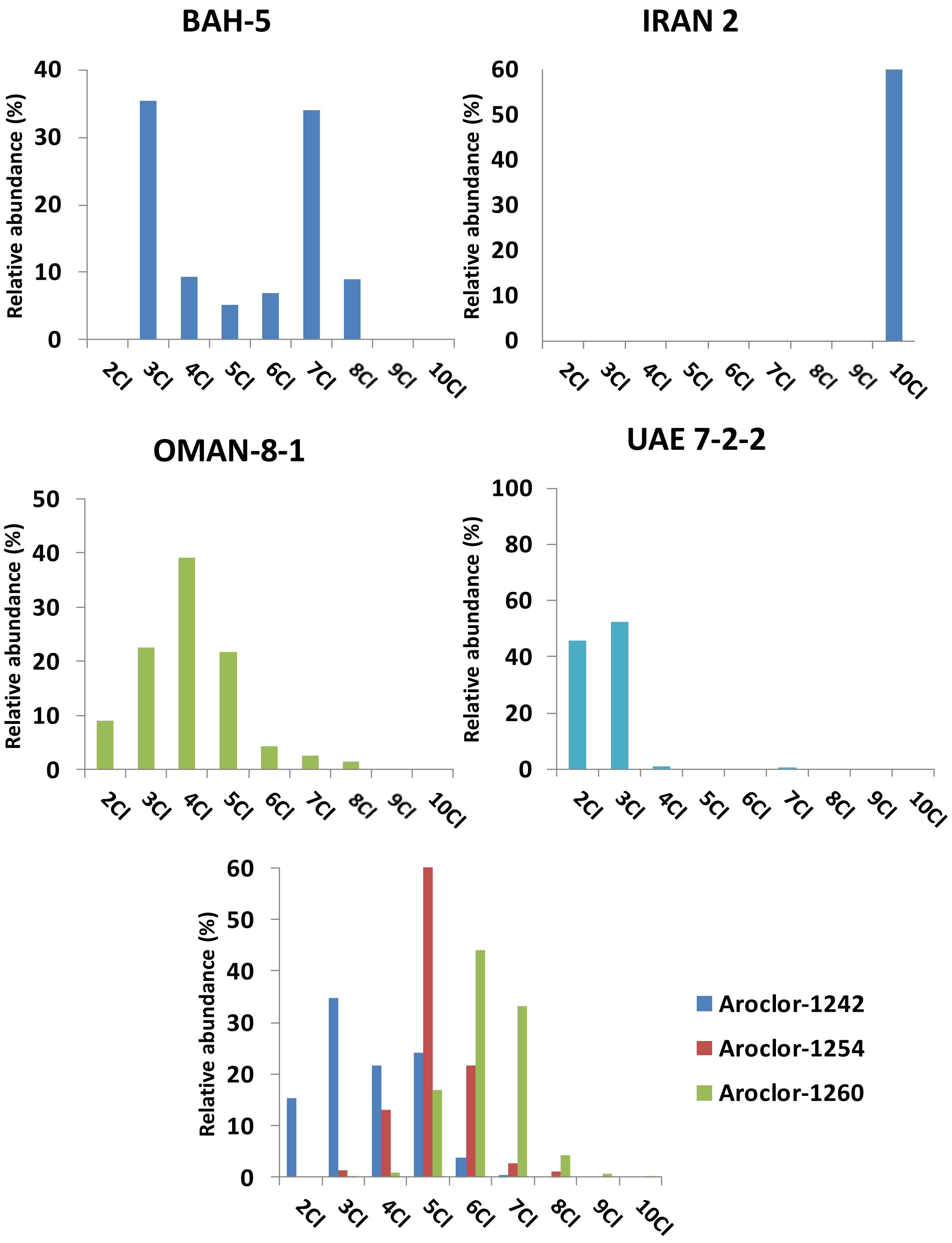

Figure 16. Relative distribution of PCB congeners according to chlorine substitution (2Cl, dichlorophenyls 8; 3Cl, trichlorobiphenyls: 18, 28, 31; 4Cl, tetrachlorobiphenyls 44, 49, 52; 5Cl, pentachlorobiphenyls 95(+66, 4Cl), 87, 97, 99, 101, 105, 110(+77, 4 Cl), 118, 126; 6Cl, hexachlorobiphenyls 128, 138, 149, 151, 153, 156, 169;7Cl, heptachlorobiphenyls 170, 174, 177, 180, 183, 187, 189; 8Cl, octachlorobiphenyl 194, 195, 201; 9Cl, nonachlorobiphenyl 206; 10Cl, decachlorobiphenyl 209) in selected sediments from RSA. Aroclor 1242, 1254, 1260 commercial mixtures (Shulz *et al*., 1989) are also shown

4.5 ORGANOCHLORINE COMPOUNDS IN BIOTA

The levels of chlorinated hydrocarbons in bivalves from the RSA are summarized in the Table 7 and detailed PCB concentrations are shown in Annexes D. As shown in the Table 1, a range of biota was investigated. Pearl oysters (*Pinctada radiata*) were collected in Bahrain, Iraq, Saudi Arabia and the UAE; rock oysters (*Saccostrea cucullata*) in I.R. Iran, Oman and the UAE.

Total PCB concentrations as ∑37 PCBs ranged from < 0.5 ng g^{-1} in the pearl oyster from UAE-7-2-3 to 10.9 ng g^{-1} in rock oysters from Mina Al Fahal (OMAN-2 (Table 7 and Figure 17). When compared to PCB data from previous surveys in the RSA and those worldwide (Table 8), the concentration observed in Bahrain, Iraq, Saudi Arabia, UAE, I.R. Iran and Oman were not particularly elevated; for example, the PCB concentrations ranging from <1.0-71 ng g^{-1} dry have been reported in pearl oysters from the region since the late 1970s (Fowler, 2002b).

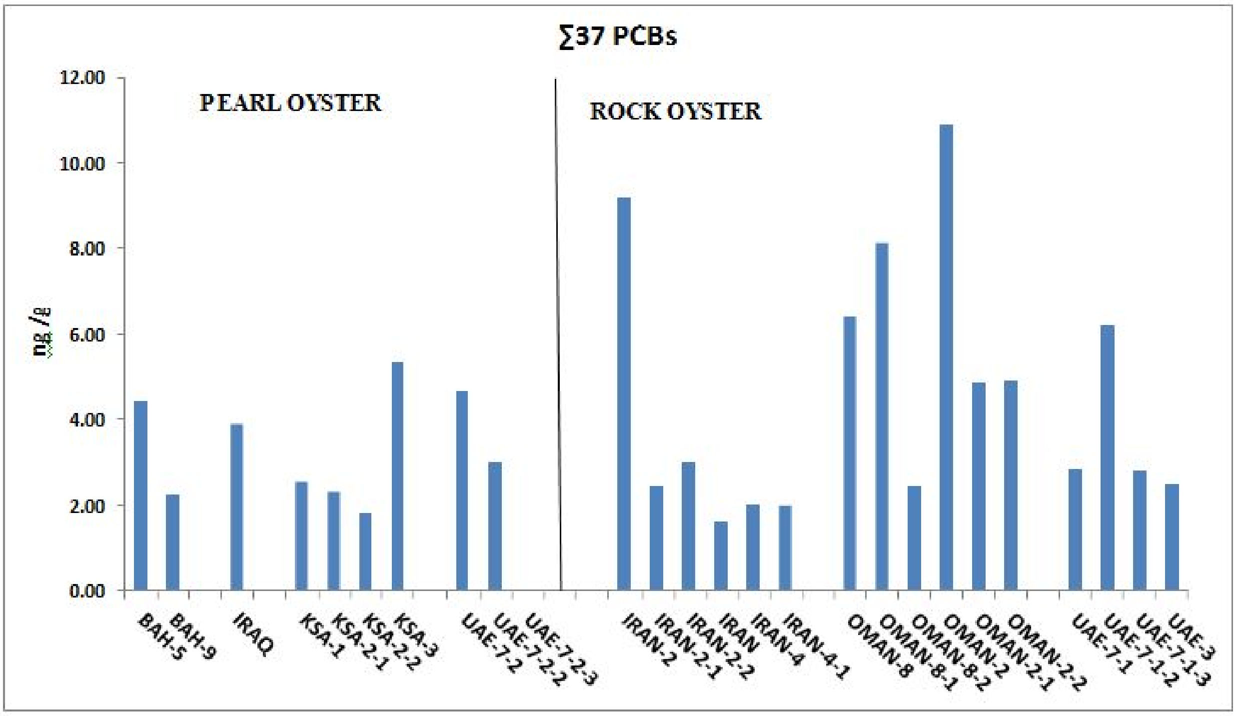

Figure 17. Total PCB concentrations as ∑37 PCBs in bivalves from the RSA

The rock oyster is the bivalve species that has been continually used in pollution assessments carried out in I.R. Iran, Oman and the UAE. Total PCB levels (2.4–10.9 ng g^{-1} dry weight as ∑37 PCBs) in the rock oysters from Oman (Table 7) fell in the same range as those measured in 2011 and 2005 (0.2-15 ng g^{-1} dry weight), ROPME-IAEA, 2013; de Mora *et al.*, 2010) and are low relative to concentrations that have been measured in previous studies (Badawy *et al.*, 1988; Burns *et al.*, 1982; Fowler, 1988). Similarly to 2011 and 2005, the maximum values were measured in rock oysters from Mina Al Fahal (OMAN-2: 10.9

ng g^{-1}) and Mirbat (OMAN-8: 6.4 ng g^{-1}). In I.R. Iran, total PCB levels in rock oysters ranged from 2 to 9.2 ng g^{-1}, with the highest values measured in Bushehr (IRAN-2).

Typical chlorination level plots from the biota samples and PCB commercial mixtures, such as those of Aroclor (Schulz *et al.*, 1989) are illustrated in the Figure 18. As shown in this figure, small differences were observed in the distribution profiles of PCB congeners according to the chlorine substitution. Most of the representative distribution of PCBs in bivalves contained more than one Aroclor mixture. Most of the profiles were largely dominated by hexa-chloro, penta-chloro and hepta-chloro congeners evidencing a contribution of a high chlorinated commercial formulation (e.g. Aroclor 1260) mixed with the lower chlorinated commercial Aroclor 1254. Only the pearl oysters from Umm Al-Quwain (UAE-7-2), exhibited high percentage of lower chlorinated congeners which also evidenced a contribution of the Aroclor 1242 overlapping the other more heavy commercial mixtures. It is also noteworthy, the high contribution of the decachlorobiphenyl 209 in the rock oysters from I.R. Iran and UAE, which could be related to the locally industrial sector or generation in thermal activities.

Interestingly, the PCBs bivalve patterns in the ROPME area contrasted with those observed in the sediments from the same locations where higher percentage of lower chlorinated congeners were measured (Figure 16). These differences suggest a selective bioavailability of higher chlorinated congeners likely preferentially associated to the finest fraction compared to the specific association of low chlorinated congeners with the sand-size fractions (Pierard *et al.*, 1996). Moreover, differential uptake of chlorinated congeners by bivalves has been related with sediment composition (sediment mineralogy) (Edgar *et al.*, 2006).

Table 7. Chlorinated hydrocarbon concentrations (ng g^{-1} dw) in bivalve molluscs from RSA

Compounds	**BAH 5 Pearl Oyster**	**BAH 9 Pearl Oyster**	**IRAN 2 Rock Oyster**	**IRAN 2.1 Rock Oyster**	**IRAN 2.2 Rock Oyster**	**IRAN Rock Oyster**	**IRAN 4 Rock Oyster**	**IRAN 4.1 Rock Oyster**	**IRAQ Pearl Oyster**
EOM mg/g	28	47	43	84	94	115	99	67	86
HCB	0.034	0.041	<0.025	0.029	0.033	<0.014	<0.025	<0.025	0.104
α HCH	<0.014	0.015	<0.014	<0.014	<0.014	<0.005	<0.014	<0.014	<0.005
β HCH	<0.033	<0.086	0.108	0.135	<0.033	<0.086	0.091	<0.086	<0.033
γ HCH-Lindane	0.071	0.034	0.025	0.031	0.016	0.038	0.021	<0.012	0.047
δ HCH	<0.009	<0.009	0.127	0.188	0.199	0.185	0.057	0.064	<0.009
Σ HCHs	0.07	0.05	0.26	0.35	0.21	0.22	0.17	0.06	0.05
pp'DDE	0.609	0.955	21.428	13.273	6.252	0.959	2.628	0.544	0.830
pp'DDD	0.044	0.092	5.199	2.699	0.576	0.097	0.381	0.059	0.232
pp'DDT	0.203	0.269	8.194	3.948	2.729	0.348	0.712	0.070	0.071
DDMU	<0.012	<0.009	1.353	0.452	0.285	0.105	0.222	0.039	0.045
op DDE	0.141	0.239	0.795	0.750	0.285	0.094	0.262	0.081	0.088
op DDD	0.032	0.024	1.017	1.589	0.219	0.238	0.169	0.083	0.050
op DDT	0.455	0.517	2.139	1.465	1.020	0.229	0.436	0.177	0.141
Σ DDTs	1.5	2.1	40.1	24.2	11.4	2.1	4.8	1.1	1.5
Heptachlor	0.114	0.037	0.071	0.056	0.088	0.051	0.029	0.030	0.025
Aldrin	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035
Dieldrin	0.052	<0.009	0.201	0.174	0.333	0.307	0.166	0.324	0.617
Endrin	0.088	0.031	0.046	0.034	0.122	0.181	0.126	<0.002	0.287
Cis Chlordane	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008
Trans Chlordane	<0.014	<0.014	<0.014	<0.014	<0.014	<0.014	<0.014	<0.014	<0.014
Cis Nonachlor	0.032	0.022	<0.002	<0.002	<0.002	<0.002	0.054	0.015	0.010
Trans Nonachlor	<0.075	<0.075	0.407	0.186	0.322	0.209	0.209	<0.028	<0.075
Heptachlor epoxide-B (cis)	0.020	0.015	0.063	0.054	0.023	0.028	0.021	0.017	<0.005
Heptachlor epoxide-A (trans)	0.132	0.118	0.145	<0.117	<0.117	<0.117	<0.117	<0.117	0.160
Methoxychlor	<0.129	<0.129	0.351	0.345	0.212	0.451	0.164	0.363	<0.129
a Endosulfan	<0.076	<0.076	<0.028	<0.076	<0.076	<0.076	<0.076	<0.076	<0.076
b Endosulfan	<0.003	<0.003	<0.002	<0.003	<0.003	<0.003	<0.003	<0.002	<0.003
Endosulfan sulfate	0.344	<0.202	<0.084	<0.084	<0.084	<0.084	<0.084	<0.084	0.317
Σ 37 PCBs	4.4	2.2	9.2	2.4	3.0	1.6	2.0	2.0	3.9

Table 7. Chlorinated hydrocarbon concentrations (ng g^{-1} dw) in bivalve molluscs from RSA (Contd...)

Compounds	**OMAN 8 Rock Oyster**	**OMAN 8.1 Rock Oyster**	**OMAN 8.2 Rock Oyster**	**OMAN 2 Rock Oyster**	**OMAN 2.1 Rock Oyster**	**OMAN 2.2 Rock Oyster**	**KSA 1 Pearl Oyster**	**KSA 2.1 Pearl Oyster**	**KSA 2.2 Pearl Oyster**	**KSA 3 Pearl Oyster**
EOM mg/g	82	114	74	72	56	136	54	57	41	77
HCB	0.455	0.047	0.610	0.712	1.343	0.079	0.042	<0.025	<0.025	<0.014
α HCH	0.124	0.044	0.059	0.236	0.298	0.101	<0.014	<0.005	<0.014	<0.005
β HCH	0.237	<0.086	0.114	0.364	0.405	0.228	<0.033	<0.033	<0.033	<0.033
γ HCH-Lindane	0.140	0.036	0.091	0.118	0.125	0.132	<0.012	<0.005	<0.005	<0.012
δ HCH	0.080	0.035	<0.009	<0.009	<0.009	0.079	0.048	0.026	0.033	<0.009
Σ HCHs	0.58	0.12	0.26	0.72	0.83	0.54	0.05	0.03	0.03	0.03
pp'DDE	0.597	5.474	0.492	0.642	0.707	0.761	0.999	0.683	0.688	1.121
pp'DDD	0.480	8.402	0.156	1.645	0.788	0.594	0.096	0.265	<0.037	0.108
pp'DDT	0.180	2.731	0.071	0.319	0.173	0.145	0.145	0.407	0.425	0.179
DDMU	0.064	0.601	0.058	0.161	0.137	0.063	0.030	0.045	0.012	<0.009
op DDE	0.041	0.213	0.070	0.128	0.129	0.184	0.129	0.017	0.105	0.269
op DDD	1.042	0.727	0.694	1.824	0.521	4.019	0.150	0.119	0.065	0.057
op DDT	0.474	0.324	0.073	0.107	0.047	0.218	0.270	0.579	0.368	0.492
Σ DDTs	2.9	18.5	1.6	4.8	2.5	6.0	1.8	2.1	1.7	2.2
Heptachlor	<0.006	0.065	0.264	1.339	0.132	0.316	0.025	0.050	0.035	0.043
Aldrin	<0.093	<0.035	<0.093	<0.035	<0.093	<0.093	<0.035	<0.035	<0.035	<0.035
Dieldrin	0.167	<0.009	0.087	0.229	0.271	0.474	0.033	0.133	0.252	0.127
Endrin	<0.007	0.074	0.324	0.400	0.616	0.238	0.237	0.306	0.349	0.637
Cis Chlordane	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008
Trans Chlordane	<0.014	<0.014	<0.014	<0.014	<0.014	<0.014	<0.014	<0.014	<0.014	<0.014
Cis Nonachlor	0.060	<0.002	0.008	0.040	0.008	0.017	0.032	0.047	0.038	0.047
Trans Nonachlor	<0.028	<0.075	0.081	0.300	<0.075	<0.075	<0.075	<0.028	<0.075	<0.075
Heptachlor epox-B (cis)	<0.014	<0.014	<0.014	<0.014	<0.014	<0.014	0.019	0.128	0.027	0.016
Heptachlor epox.A (trans)	<0.044	<0.044	0.320	0.246	<0.044	<0.044	<0.117	<0.117	<0.044	<0.117
Methoxychlor	<0.129	<0.052	0.506	<0.129	0.295	0.134	<0.129	<0.129	0.148	<0.129
a Endosulfan	<0.076	<0.028	<0.076	<0.076	<0.028	<0.076	<0.076	<0.076	<0.076	<0.076
b Endosulfan	<0.003	<0.002	<0.003	<0.003	<0.003	<0.002	<0.003	<0.003	<0.003	<0.003
Endosulfan sulfate	<0.084	<0.084	<0.084	0.205	<0.202	<0.084	<0.084	<0.084	<0.084	0.251
Σ 37 PCBs	6.4	8.1	2.4	10.9	4.9	4.9	2.5	2.3	1.8	5.4

Table 7. Chlorinated hydrocarbon concentrations (ng g^{-1} dw) in bivalve molluscs from RSA (Contd...)

Compounds	**UAE 7-1 Rock Oyster**	**UAE 7-1-2 Rock Oyster**	**UAE 7-1-3 Rock Oyster**	**UAE 7-2 Pearl Oyster**	**UAE 7-2-2 Pearl Oyster**	**UAE 7-2-3 Pearl Oyster**	**UAE 3 Rock Oyster**
EOM mg/g	107	110	95	56	47	72	103
HCB	0.059	0.075	0.056	0.031	0.038	<0.014	0.028
α HCH	0.054	0.021	0.038	<0.005	<0.014	0.272	0.024
β HCH	<0.033	<0.033	<0.086	0.125	<0.086	0.184	<0.033
γ HCH-Lindane	0.018	<0.012	<0.012	0.016	0.022	0.126	0.021
δ HCH	<0.009	<0.009	0.106	<0.009	<0.022	<0.009	<0.009
Σ HCHs	0.07	0.02	0.14	0.14	0.02	0.58	0.05
pp'DDE	0.826	1.498	0.831	1.841	1.188	<0.005	0.886
pp'DDD	0.090	0.058	0.066	0.061	<0.037	0.164	0.058
pp'DDT	0.053	0.066	0.044	0.101	0.034	<0.001	0.016
DDMU	0.015	0.031	0.020	<0.009	<0.009	<0.009	0.030
op DDE	0.075	0.099	0.068	0.066	0.068	<0.006	0.056
op DDD	0.287	0.178	0.262	0.205	0.022	0.078	0.039
op DDT	0.138	0.328	0.096	0.527	0.391	<0.001	0.382
Σ DDTs	1.5	2.3	1.4	2.8	1.7	0.2	1.5
Heptachlor	0.048	0.051	0.048	0.053	0.015	<0.006	0.021
Aldrin	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035
Dieldrin	0.489	0.619	0.312	0.194	0.064	0.071	0.276
Endrin	0.206	0.386	0.242	0.385	0.203	0.175	0.379
Cis Chlordane	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008
Trans Chlordane	<0.014	<0.014	<0.014	<0.014	<0.014	<0.014	<0.014
Cis Nonachlor	0.006	0.034	0.006	0.065	0.044	<0.002	0.048
Trans Nonachlor	<0.075	0.116	0.079	0.218	0.145	<0.028	<0.075
Heptachlor epox-B (cis)	0.059	0.034	0.047	0.040	<0.014	0.065	0.025
Heptachlor epox.A (trans)	0.201	<0.044	<0.117	0.176	<0.117	<0.117	0.187
Methoxychlor	<0.129	<0.129	<0.129	<0.129	<0.129	<0.129	0.326
a Endosulfan	<0.076	<0.076	<0.028	<0.028	<0.076	<0.076	<0.028
b Endosulfan	<0.003	<0.003	<0.002	<0.002	<0.003	<0.003	<0.003
Endosulfan sulfate	<0.084	<0.084	<0.084	<0.084	<0.084	<0.084	<0.084
Σ 37 PCBs	2.8	6.2	2.8	4.7	3.0	0.5	2.5

Table 8. Worldwide concentrations of ∑PCBs, ∑DDTs in bivalve samples (ng g^{-1} dry weight; converted using dry/wet weight ratio of 0.23)

Area	Species	Survey Year	Σ PCBs	Σ DDTs	References
Kuwait	Bivalves	2009-2012	< 2.5-340[a]	<2.5-190[a]	Ali *et al*, 2015
China	*Mytilus edulis*/*Ostrea edulis*	2005	3.3-25	55-2680	Jin *et al*., 2008
China	Seven species of mollusks	2006-2007	0.34-30	1.8-578	Wang *et al*., 2008
Korea	Bivalves	2007	7.9-8.9 [a]	48-108[a]	Byun *et al*., 2013
Sweden	Bivalves	2001-2002	1.7-4.3	1.4-4.4	Pikkarainen (2007)
UAE/Bahrain	Pearl oysters	2000-2001	0.1-5.8	0.13-5.9	(de Mora *et al*., 2005)
Oman	Rock oysters	2000-2001	1.2-4.8	0.9-4.6	(de Mora *et al*., 2005)
UAE/Bahrain	Pearl oysters	2005	0.16-3.46	0.02-1.33	(de Mora *et al*., 2010)
I.R. Iran/Oman/UAE	Rock oysters	2005	0.81-18.35	0.85-19.1	(de Mora *et al*., 2010)
Bahrain/Qatar/UAE	Pearl oysters	2011	1.4-6.5	0.7-1.5	ROPME -IAEA, 2013
I.R. Iran	Rock oysters	2011	2.7-6.8	3.8-218	ROPME-IAEA, 2013
Oman/UAE	Rock oysters	2011	2.2-27	0.9-4.8	ROPME-IAEA, 2013

[a] ng g^{-1}, lipid weight

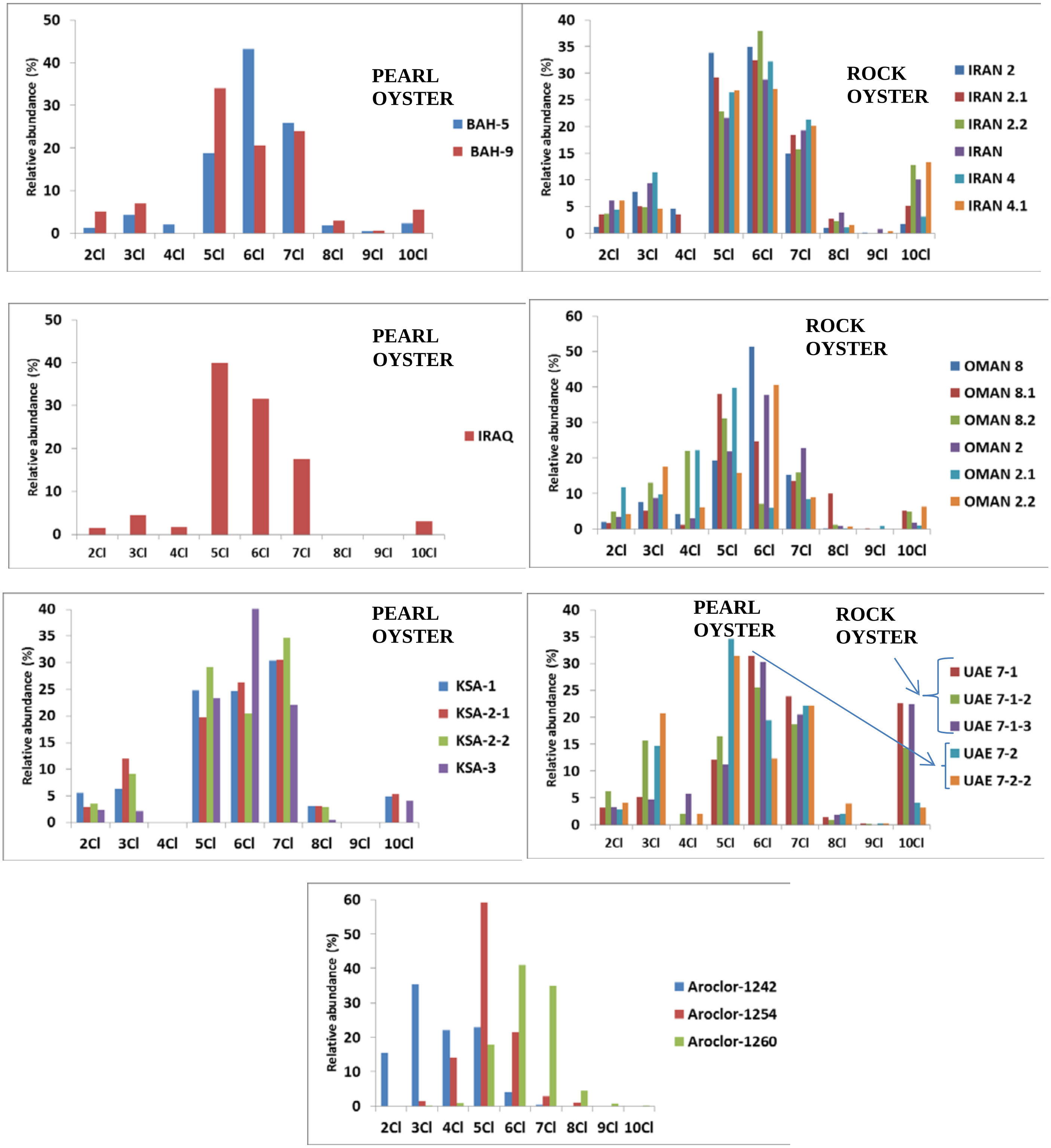

Figure 18. Relative distribution of PCB congeners according to chlorine substitution (2Cl, dichlorophenyls 8; 3Cl, trichlorobiphenyls: 18, 28, 31; 4Cl, tetrachlorobiphenyls 44, 49, 52; 5Cl, pentachlorobiphenyls 95(+66, 4Cl), 87, 97, 101, 105, 110(+77, 4 Cl), 118, 126; 6Cl, hexachlorobiphenyls 128, 138, 149, 153, 156, 169; 7Cl, heptachlorobiphenyls 170, 174, 177, 180, 183, 187, 189; 8Cl, octachlorobiphenyl 194, 195, 201; 9Cl, nonachlorobiphenyl 206; 10Cl, decachlorobiphenyl 209) in bivalve mollusks from RSA. Aroclor 1242, 1254, 1260 commercial mixtures (Shulz *et al*., 1989) are also shown

The various bivalves have also been used for monitoring several organochlorinated pesticides. Excepting the high concentrations of DDTs in the rock oysters from I.R. Iran (Table 7 and Figure 19), the concentrations of the rest of the pesticide residues such as Lindane, Dieldrin, Endrin, HCB, *cis*-chlordane, Dieldrin and Endosulfan sulfate were low in all bivalve species analyzed compared with concentrations measured previously in these species from the region (Badawy *et al.*, 1988; Fowler, 2002a). With respect to the DDTs, most of the sites of I.R. Iran and the site of Masirah (OMAN-8-1) in Oman gave an indication of contamination. In I.R. Iran, the highest level of Σ DDTs, 70 ng g^{-1} dry, was found in the oysters from Bushehr (IRAN-2), followed by those from Dayer (IRAN-2-1: 24 ng g^{-1} dry) and Gavbandi (IRAN-2-2: 11.4 ng g^{-1} dry). Although, these values are much lower than the DDT concentrations measured in rock oyster from Dayer in 2011 (218 ng g^{-1} dry), the recent values from Bushehr are on the borderline of 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 Σ DDTs (Environment Canada, 2001). As DDT in bivalves is mainly metabolized to DDD and not to DDE (Kwong *et al.*, 2009), the ratio of DDE/DDD > 1 in most of the oyster samples, indicates that DDE in the mollusks was mainly derived from the ambient environment or from their diets rather than biotransformation of fresh DDT. Only the oyster samples from Masirah, Mina Al Fahal and Sohar in Oman, exhibited DDE/DDD <1 suggesting some relatively fresh input of DDT which is metabolized to DDD in the oyster.

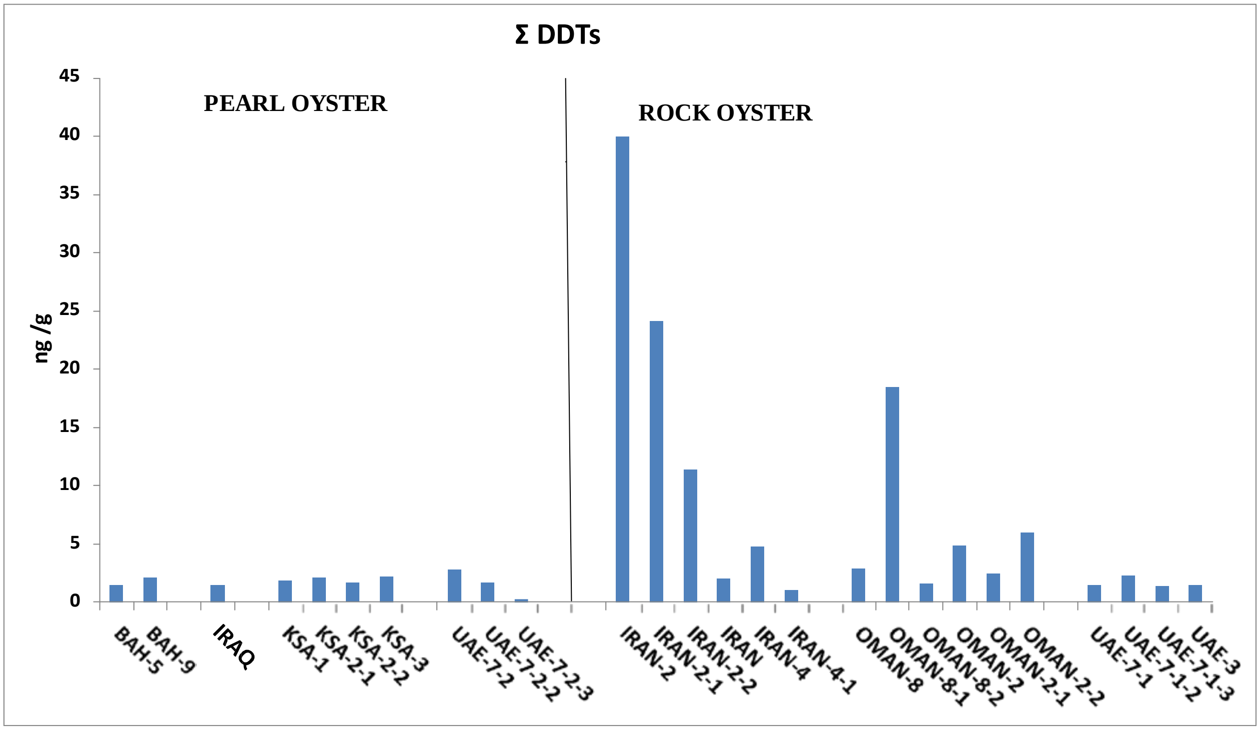

Figure 19. Total DDT concentrations in bivalves from the RSA

Excepting the high concentrations of DDTs in I.R. Iran, the organochlorine contents reported in this present study fell in the lower range of those reported as global comparators (Table 8) and probably reflect the atmospheric contamination of the area rather than the influence of coastal discharges. Additional studies should be carried out to monitor the levels of DDTs in edible biota from the ROPME Area, and in particular from I.R. Iran.

4.6 TEMPORAL TRENDS IN PCB COMPOUNDS

To follow the temporal trend on the PCBs pollution levels, a comparison of the recent data with those obtained for the same sediment samples collected during the contaminant screenings of 2011, 2005 and 2000 has been performed, as shown in the Figure 20.

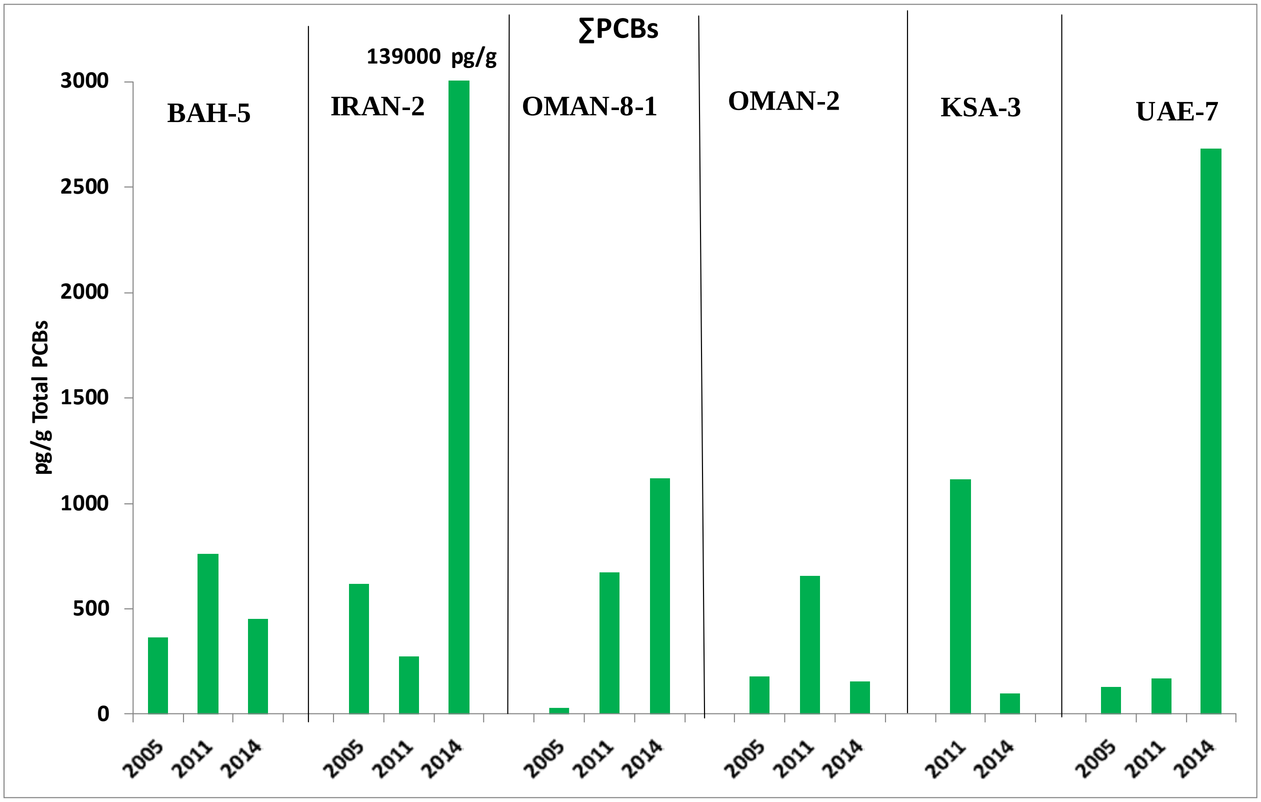

Figure 20. Temporal trend of total PCBs in sediments from the RSA as sum of 37 congeners

As can be seen in the Figure 20, there has been a slight decrease in total PCBs over the last 3 years in the sediment from Bahrain, Minal Al Fahal in Oman and Ras Tanura in Saudi Arabia. In contrast, a significant increase was observed at Bushehr Port in I.R. Iran and Umm Al Quwain in UAE. However, the low level contents of PCBs in all sediment sites surveyed, excepting that from Bushehr Port, reflect the background levels of PCBs in the region, most likely via long-range atmospheric transport. Evaluation of the temporal trends by using bivalves provided a small decreasing trend in PCB concentrations over the last 3 years on most of the sites (Figure 21), excepting the site of Bushehr (IRAN-2) in I.R. Iran. Overall, the relatively low concentrations levels varied little over the last 14 years and might reflect the background levels of PCBs in these sites, which are likely driven by atmospheric transport and not from primary sources.

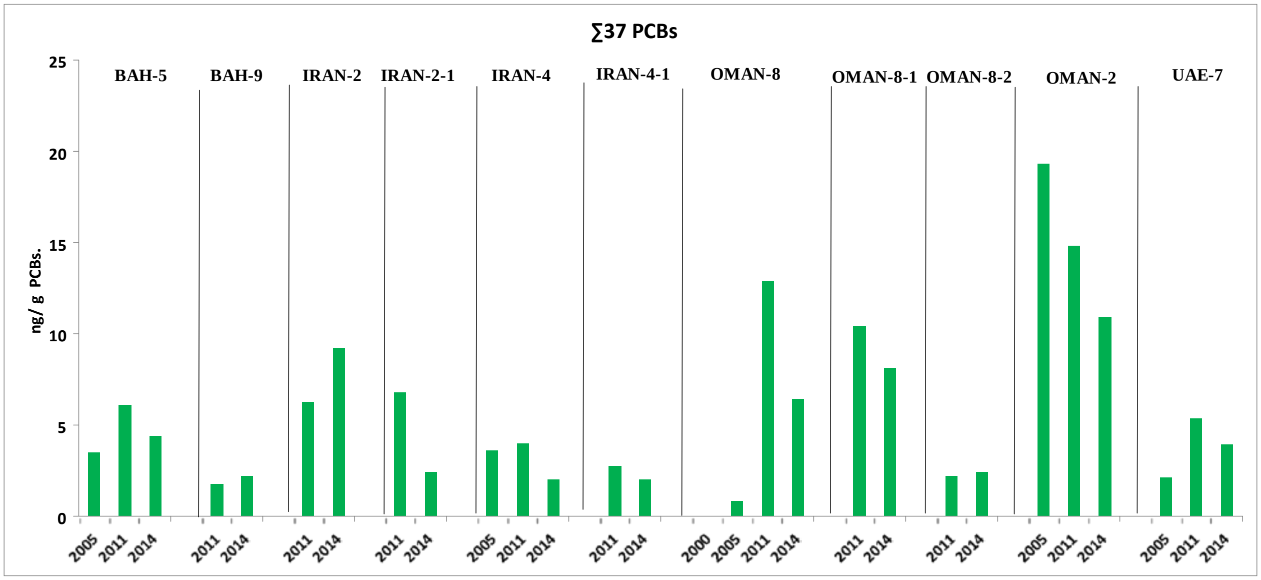

Figure 21. Temporal trend of total PCBs (ng/g dry weight) in bivalves from the RSA as sum of 37 congeners

It is also of interest to examine the recent concentration values in the context of temporal data for the bivalves from Oman stations surveyed since 1980. As can be seen in the Table 9, there has been an irregular but generally decreasing trend in PCB concentrations over the last two decades until 2011, where the concentrations levels exhibited a slight increase that remains at similar levels in 2014. Similar trend was observed in bivalves from I.R. Iran, whereas in UAE a significant decrease was observed in the last 3 years for the rock oysters.

Table 9. Average concentrations and ranges of PCBs in rock oysters (*Saccostrea cucullata)* from several locations along the coasts of Oman, UAE and I.R. Iran (Adapted from Fowler, 2002b)

Country	**Collection date**	**[c]PCBs (ng g^{-1} dry weight)**
Oman	[a]September 1980	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)
	[b]August 1997	2.4
	July 2001	1.7 (1.2-2.7)
	February 2005	1.8 (0.25-6.6)
	February 2011	7.5 (2.9-9.6)
	February 2014	**[d]6.27 (2.4-10.9)**
UAE.	[b]June 1994	5.6
	[b]April 2000	1.1
	February 2005	0.77
	February 2011	12.4 (6.7-18)
	February 2014	**[d]3.6 (2.5-6.2)**
I.R. Iran	February 2005	1.9
	February 2011	5.4 (4.6-5.9)
	February 2014	**[d]3.4(1.6-9.2)**

Note: [a] Data from (Burns *et al.*, 1982) converted using dry/wet weight ratio of 0.23;

[b] Single composite samples from Dhadnah (1994), Musandam (1997) and Akkah Beach (2000);

[c] PCB concentrations quantified as Aroclor 1254. [d] PCB concentrations as sum of 37 congeners.

4.7 TEMPORAL TRENDS IN DDT COMPOUNDS

As with PCBs, it is instructive to examine the temporal data for ΣDDT residues by comparing the recent data with those obtained for the same sediment and biota samples collected during the contaminant screenings of 2011, 2005 and 2000 (Figures 22 and 23).

As can be seen in the Figure 22, a substantial increase trend over the last 3 years was detected for those sediments with the highest concentrations levels, such as, Bushehr (IRAN-2), Masirah (OMAN-8-1) and UAE-7. For the sediments from Bahrain, Saudi Arabia and Mina Al Fahal in Oman, the relatively low concentrations levels varied little over the last 14 years and might reflect the background levels of DDTs in these sites, which are likely driven by atmospheric transport and not from primary sources. The increasing trends observed in the sediments were consistent with the increasing trends observed in the bivalves from Bushehr (IRAN-2) and Masirah (OMAN-8-1) (Figure 23). On the other hand, the DDT levels of the rock oysters from Dayer (IRAN-2-1) exhibited a sharp decrease from 2011 to 2014 and very small variations of ΣDDTs concentrations over the last 5–10 years are observed in the bivalves from Bahrain, UAE and most of the Oman samples, excepting the rock oysters of Masirah.

It is also interesting to examine the recent concentration values in the context of temporal data for the rock oysters that have been periodically monitored outside the Strait of Hormuz since 1980 (Table 10). It is clear that the levels of Σ DDTs in the rock oysters from Oman, have varied little over the last two decades, excepting for the substantial increase observed in the rock oysters of Masirah site in 2014. In UAE, the low, fairly constant concentrations of ΣDDTs present in rock oysters, derives most likely via long-range atmospheric transport. In contrast, although the concentration levels of DDTs have significantly decrease from 2011 to 2014 in I.R. Iran, the prevailing concentrations levels in bivalves attests for the inputs derived from primary sources.

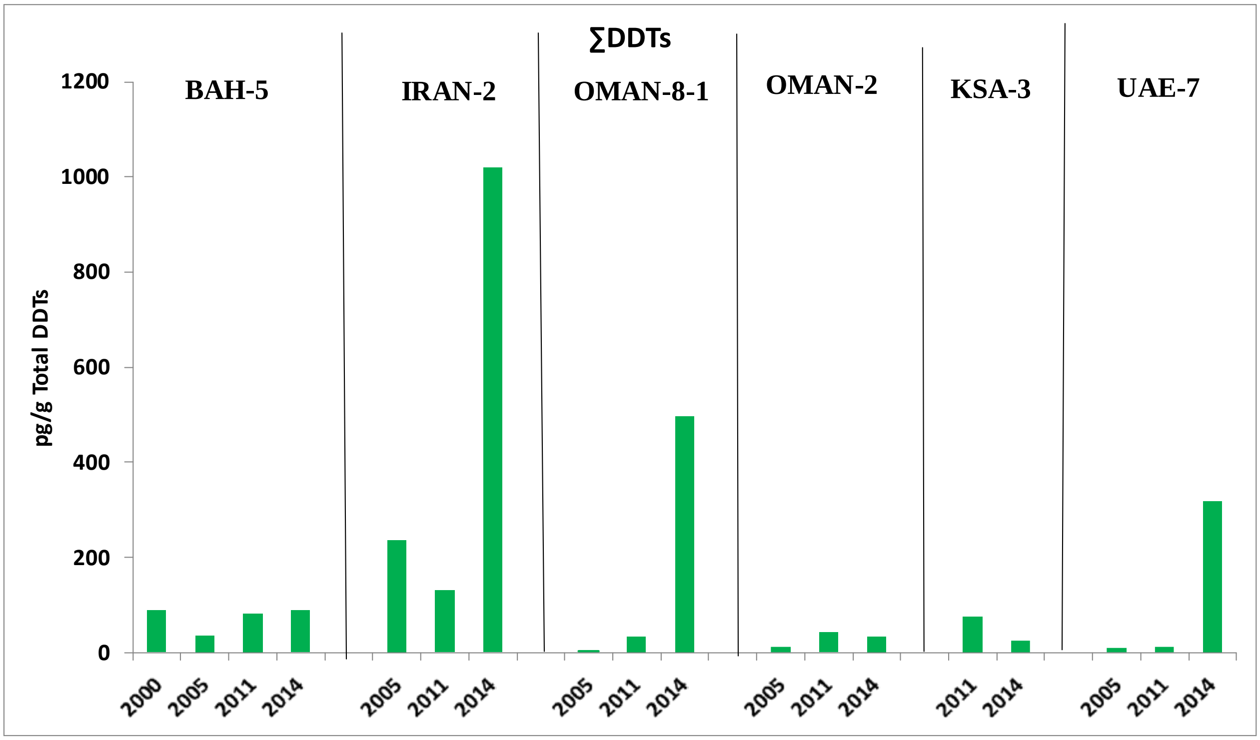

Figure 22. Temporal trend of ∑ DDTs in sediments from the RSA

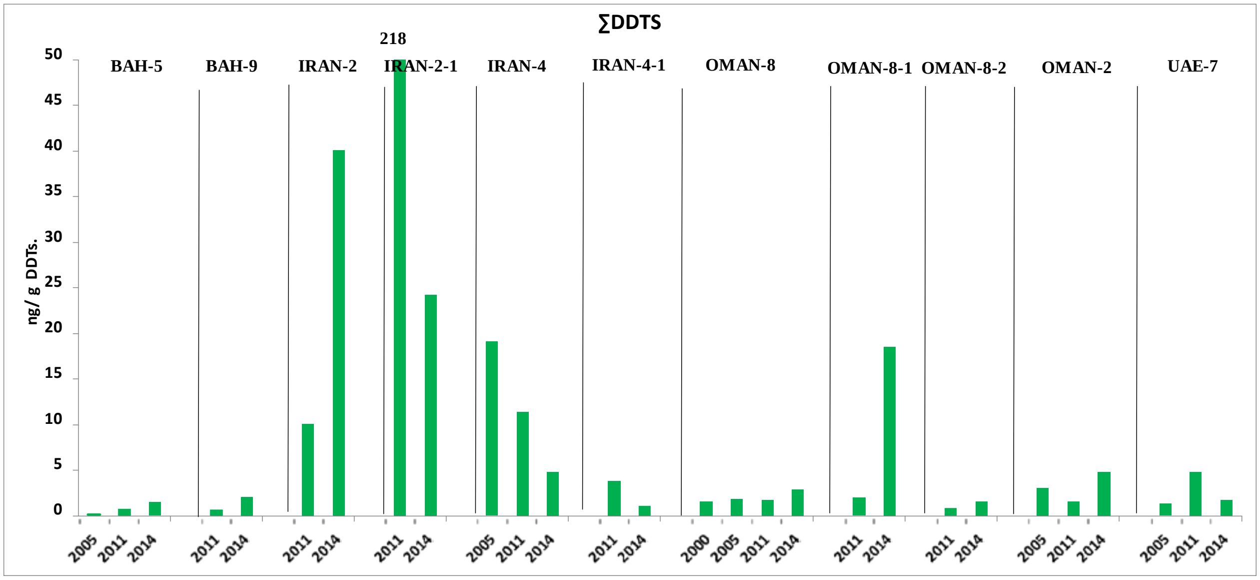

Figure 23. Temporal trend of ∑ DDTs (ng/g dry weight) in bivalves from the RSA

Table 10. Average concentrations and ranges of Σ DDTs in rock oysters (*Saccostrea cucullata)* from several locations along the coasts of Oman, UAE and I.R. Iran (Adapted from Fowler, 2002a)

Country	**Collection Date**	**Σ DDTs** (ng g^{-1} dry weight)
Oman	[a]September 1980	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)
	[b]August 1997	1.2
	July 2001	2.4 (0.9-4.6)
	February 2005	3.53 (0.851-11.45)
	February 2011	1.6 (0.9-2.0)
	February 2014	**6.1(1.6-18.5)**
UAE	[b]June 1994	2.5
	[b]April 2000	1.8
	February 2005	0.901
	February 2011	4.6 (4.3-4.8)
	February 2014	**1.6 (1.4-2.3)**
I.R. Iran	February 2005	19.1
	February 2011	56.4 (3.8-218)
	February 2014	**13.9 (1.1-40.1)**

Note: [a] Data from (Burns *et al.*, 1982) converted using dry/wet weight ratio of 0.23;

[b] Single composite samples from Dhadnah (1994), Musandam (1997) and Akkah Beach (2000).

5. SUMMARY AND CONCLUSIONS

Although the RSA has always been regarded as a heavily polluted water body with respect to oil, the present Mussel Watch results from the six countries surveyed in 2014 indicates that oil pollution is only a problem in some limited areas of the RSA. Extremely high concentrations of combustion-derived PAHs were found in the sediment from Askar, Bahrain (BAH-5) and the pearl oysters from Jubail, Saudi Arabia (KSA-2-1) which warrants the on-going monitoring of these chronically polluted sites. Likewise, a continued watch on certain sites of Oman and I.R. Iran, e.g. Mina Al Fahal and Qeshm Island should be maintained in order to follow any changes in the degree and type of oil contamination. Similar to the sediments, high concentrations of petroleum hydrocarbons were also measured in pearl oysters from Jubail in Saudi Arabia (KSA-2-1), and rock oysters from Mina Al Fahal (OMAN-2) and Qeshm Island in I.R. Iran (IRAN-4-1). These specific sites merit intensive monitoring. Nevertheless, the continued general monitoring of hydrocarbon contamination within the RSA is certainly recommended, owing to the enormous oil production and the large number of oil tankers transiting through the region.

Except for the oysters from Jubail, Saudi Arabia (KSA-2-1), Qeshm Island (IRAN-4-1) and Mina Al Fahal (OMAN-2), the levels of PHs in various bivalve species were comparable to the concentrations observed in relatively unpolluted areas elsewhere in the world. Approximately twenty-three years after the greatest oil spill in the RSA, PH concentrations in biota have decreased to values reported before the 1991 Gulf War.

The spatial distribution of various organochlorinated compounds was investigated in the RSA and the Sea of Oman, based on marine bivalves and coastal sediment collected in Bahrain, I.R. Iran, Iraq, Oman, Saudi Arabia and the United Arab Emirates during 2014. Several organochlorinated 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, were extremely low by global standards, but exhibited some relative increased concentrations compared to the previous surveys in Bushehr, I.R. Iran and Umm Al-Quwain in UAE. Except for the high concentrations of DDTs in rock oysters from I.R. Iran, the organochlorinated compounds contents reported in the present study fell in the lower range of those reported as global comparators and probably reflect atmospheric contamination of the area rather than the influence of coastal discharges. Additional studies should be carried out to monitor the levels of DDTs in more edible biota from the ROPME Sea Area, and in particular from I.R. Iran, where the concentration levels of pp'DDT in bivalves decreased substantially in Dayer (IRAN-2-1) but increased in Bushehr (IRAN-2), which may indicate relatively recent usage inputs of DDT in the region. These results contribute to the sparse regional database for organochlorinated compounds in the marine environment. Moreover, they can be used and integrated in the contaminant's data base for studying temporal trends. Whereas the levels, albeit relatively low, of Σ DDTs in the rock oysters from the Sea of Oman have remained uniform, there has been an irregular but generally decreasing trend in concentrations of Σ PCBs during the last two decades, followed by some relative increase in the 2011 that remained quite uniform in 2014.

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Annex A.1. Concentrations of aliphatic hydrocarbons (ng g^{-1} dw) in sediments from Bahrain, I.R. Iran, Oman and Saudi Arabia

	BAH-5	**BAH-9**	**IRAN 2**	**IRAN 2-1**	**OMAN-2**	**OMAN-2-1**	**OMAN-8-1**	**KSA-1**	**KSA-2-1**	**KSA-2-2**	**KSA-3**
n-C12	12	< 0.6	83	219	1.5	6.3	5.3	4.4	15	1.2	21
n-C13	7.4	1.4	71	235	13	16	19	2.1	10	1.8	7.2
n-C14	25	< 0.6	92	266	28	44	54	7.2	24	5.3	17
n-C15	25	17	93	181	53	50	175	23	56	15	74
n-C16	31	< 1	144	389	43	43	200	18	60	15	56
n-C17	322	146	86	163	64	45	464	94	417	79	108
n-C18	12	4.8	110	218	35	18	105	17	23	15	119
n-C19	20	16	35	69	25	20	90	29	105	24	90
n-C20	14	15	177	310	19	19	80	16	28	15	18
n-C21	71	36	25	53	19	22	82	47	155	38	48
n-C22	34	29	98	148	24	27	59	33	64	18	24
n-C23	52	22	22	36	22	31	60	32	106	24	28
n-C24	26	12	37	47	14	24	35	20	128	0	21
n-C25	47	13	14	44	13	33	32	16	193	14	19
n-C26	33	7.4	11	27	11	30	15	13	222	14	19
n-C27	59	38	6.3	77	16	54	20	74	316	69	21
n-C28	29	16	7.8	30	10	27	14	20	269	15	18
n-C29	57	57	15	149	19	66	12	83	230	85	15
n-C30	25	10	3.6	23	7.1	33	13	10	150	7.7	13
n-C31	55	6.5	20	122	16	96	14	8.1	152	10	15
n-C32	18	3.1	< 1.3	3.8	7.2	17	< 1.3	5.4	88	6.9	10
n-C33	34	< 1.4	5	< 1.4	1.7	< 1.4	14	2.4	34	< 1.4	1.7
n-C34	20	< 1.4	< 1.4	< 1.4	3.7	7.0	< 1.4	4.3	30	2.2	4.2
n-C35	13	< 1.4	< 1.4	< 1.4	8.0	10	15	3.0	20	6.9	< 1.4
n-C36	< 1.4	< 1.4	< 1.4	< 1.4	< 1.4	< 1.4	< 1.4	< 1.4	< 1.4	< 1.4	< 1.4
Pr	< 0.7	< 0.7	132	88	21	< 0.7	97	98	143	83	282
Ph	35	< 0.7	78	74	23	< 0.7	131	56	125	52	150
Sq	< 0.7	< 0.7	< 0.7	< 0.7	< 0.7	< 0.7	< 0.7	< 0.7	< 0.7	< 0.7	< 0.7
Res Al	6050	4602	4146	7316	3633	3454	11101	4119	9805	4074	7689
Unres. Al	31651	11573	6126	5320	133	523	25676	17651	68923	15705	51328

Annex A.2. Concentrations of aliphatic hydrocarbons (ng g^{-1} dw) in sediments from UAE

	UAE 7-1	UAE 7-1-2	UAE 7-1-3	UAE 7-2	UAE 7-2-2	UAE 7-2-3	UAE 3
n-C12	14	40	8.3	11	12	18	18
n-C13	13	36	5.2	6.5	23	7.2	4.5
n-C14	16	68	5.3	9.3	44	5.0	7.2
n-C15	30	194	19	28	113	25	16
n-C16	51	285	34	46	200	12	16
n-C17	92	461	81	115	356	147	70
n-C18	78	444	69	84	423	0.6	16
n-C19	89	505	78	130	456	21	32
n-C20	90	444	75	84	475	5.4	19
n-C21	88	479	71	84	463	32	36
n-C22	70	412	62	68	428	3.9	26
n-C23	58	368	53	64	333	30	39
n-C24	50	263	44	52	262	5.4	41
n-C25	45	198	40	49	187	35	46
n-C26	32	142	26	29	143	8.0	47
n-C27	33	94	23	32	77	27	68
n-C28	35	56	25	28	67	11	68
n-C29	52	64	32	37	53	19	95
n-C30	22	49	27	13	73	3.7	45
n-C31	58	86	32	51	70	29	83
n-C32	13	12	2.7	< 1.3	13	< 1.3	8.7
n-C33	21	21	23	25	29	< 1.4	13
n-C34	13	1.4	7.8	1.8	9.4	< 1.4	7.3
n-C35	16	7.8	26	14	11	< 1.4	7.5
n-C36	13	< 1.4	< 1.4	< 1.4	< 1.4	< 1.4	< 1.4
Pr	35	267	34	87	192	83	41
Ph	54	255	41	88	291	33	30
Sq	< 0.7	< 0.7	< 0.7	< 0.7	< 0.7	< 0.7	< 0.7
Res Al	3425	12521	3112	4016	10633	3462	4986
Unres. Al	15756	89678	14893	34835	75685	18627	23795

Annex A.3. Concentrations of aromatic hydrocarbons (ng g^{-1} dw) in sediments from Bahrain, I.R. Iran, Oman and Saudi Arabia (Contd…)

	BAH-5	**BAH-9**	**IRAN 2**	**IRAN 2-1**	**OMAN-2**	**OMAN-2-1**	**OMAN-8-1**	**KSA-1**	**KSA-2-1**
Naph (N)	4.3	< 0.03	5.6	4.2	1.0	3.0	2.0	1.2	8.1
C1-N	10	< 0.04	14	11	1.8	3.8	3.6	1.5	12
C2-N	20	2.2	35	18	5.0	7.9	17	6.2	49
C3-N	17	< 0.01	84	11	3.7	8.2	9.3	5.2	49
C4-N	5.2	0.6	15.9	5.3	2.2	2.6	5.8	7.5	50
Biphenyl	3.8	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Acenaphthylene	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	1.2
Fluorene	4.5	0.2	2.0	2.3	0.2	0.4	1.0	1.1	4.9
Acenaphthene	3.8	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
C1-Fluorenes	6.3	< 0.03	17	22	2.6	2.6	7.6	15	45
C2-Fluorenes	10	< 0.03	9.5	7.6	2.7	2.6	11	55	134
C3-Fluorenes	8.7	< 0.03	6.9	5.4	< 0.03	1.3	8.7	65	94
Dibenzothiophene	18	< 0.02	5.1	4.6	0.4	0.4	1.0	0.6	2.0
C1-DBT	48	< 0.02	16.0	18.3	0.8	< 0.02	2.5	2.6	9.8
C2-DBT	64	< 0.02	22	25	1.0	0.7	5.6	18	38
C3-DBT	41	< 0.02	9.6	14.9	1.0	1.0	3.9	15	32
Phenanthrene	34	0.3	7.3	11.0	1.9	1.2	6.4	3.8	12
Anthracene	4.6	< 0.02	0.9	0.9	0.3	< 0.02	0.5	0.3	2.0
C1- Phen/Anth	39	< 0.03	15	15	2.7	< 0.03	9.7	28	65
C2- Phen/Anth	34	< 0.03	11	12	1.2	< 0.03	6.3	39	81
C3- Phen/Anth	16	< 0.02	5.2	4.5	0.9	< 0.02	3.9	23	52
C4- Phen/Anth	71	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	9.5	22
Fluoranthene	54	0.3	12	21	1.6	< 0.02	4.2	2.7	10
Pyrene	68	0.8	30	44	1.3	0.6	4.0	9.9	24
C1-Fluor/Pyr	48	< 0.02	1.1	0.9	0.7	< 0.02	1.8	5.5	18
Benz(a)anthracene	61	0.5	< 0.04	0.3	0.4	< 0.04	2.5	0.2	3.4
Chrysene	87	0.6	0.9	1.3	0.7	0.9	3.2	1.1	5.5
C1-Chrysenes	49	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	5.1
C2-Chrysenes	24	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
C3-Chrysenes	8.3	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
C4-Chrysenes	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Benzo(b+k)Fluor	105	< 0.11	< 0.11	< 0.11	< 0.11	< 0.11	12	< 0.11	19
Benzo(a)fluoranthene	24	< 0.11	< 0.11	< 0.11	< 0.11	< 0.11	0.9	< 0.11	1.3
Benzo(e)pyrene	41	< 0.09	0.8	< 0.09	< 0.09	< 0.09	6.3	< 0.09	9.8
Benzo(a)pyrene	64	< 0.04	1.1	< 0.04	< 0.04	< 0.04	3.1	< 0.04	3.4
Indeno[1,2,3-c,d]Py	49	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25	8.6	< 0.25	12
Dibenz(a,h)anth.	25	< 0.24	< 0.24	< 0.24	< 0.24	< 0.24	4.3	< 0.24	4.3
Benzo(g,h,i)perylene	48	< 0.14	< 0.14	< 0.14	< 0.14	< 0.14	7.6	< 0.14	14
Perylene	14	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	0.1	< 0.04	0.5
Res Ar	7132	6919	1642	4689	4236	5647	16174	4689	7191
Unres. Ar	14842	1399	4182	4500	1175	3028	13396	4500	41588

Annex A.4. Concentrations of aromatic hydrocarbons (ng g^{-1} dw) in sediments from Saudi Arabia (Contd…) and UAE

	KSA-2-2	**KSA-3**	**UAE 7-1**	**UAE 7-1-2**	**UAE 7-1-3**	**UAE 7-2**	**UAE 7-2-2**	**UAE 7-2-3**	**UAE 3**
Naph (N)	1.8	1.6	0.6	4.0	1.3	1.7	3.2	2.3	4.2
C1-N	3.3	2.6	2.5	6.7	3.9	4.4	5.9	5.4	7.6
C2-N	9.3	14	3.4	17	5.4	7.2	12	15	9.3
C3-N	9.0	31	1.2	21	1.2	4.1	11	7.1	4.8
C4-N	6.0	40	2.1	27	1.3	5.8	16	4.7	3.0
Biphenyl	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	0.9	< 0.03	< 0.03
Acenaphthylene	< 0.02	< 0.02	< 0.02	0.7	< 0.02	< 0.02	0.7	< 0.02	< 0.02
Fluorene	1.0	4.2	0.8	4.3	0.4	1.2	2.1	2.4	2.6
Acenaphthene	0.2	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	0.9	< 0.03	< 0.03
C1-Fluorenes	14	59	14	55	10	22	26	24	19
C2-Fluorenes	52	153	12	124	13	44	52	60	55
C3-Fluorenes	54	97	9.1	123	9.7	32	33	50	36
Dibenzothiophene	0.6	1.9	0.5	1.4	0.3	0.6	1.3	0.5	0.4
C1-DBT	4.0	11.7	1.4	13.4	1.4	4.7	6.8	2.7	1.2
C2-DBT	14	33	4.6	46	4.7	13	29	7.6	7.2
C3-DBT	13	21	3.5	44	3.9	9.2	47	3.8	5.0
Phenanthrene	3.1	9.6	2.5	9.9	0.7	2.6	6.6	2.0	2.1
Anthracene	< 0.02	< 0.02	< 0.02	0.1	< 0.02	< 0.02	0.4	< 0.02	< 0.02
C1- Phen/Anth	25	43	9.6	58	9.4	23	23	16	18
C2- Phen/Anth	36	59	9.9	66	11	26	36	17	22
C3- Phen/Anth	1.4	39	5.4	52	7.2	18	34	8.5	17
C4- Phen/Anth	16	9.4	2.7	< 0.02	< 0.02	3.8	19	0.6	4.4
Fluoranthene	2.5	11	2.0	8.3	1.8	2.6	10	1.4	6.7
Pyrene	9.8	20	2.4	18	2.7	6.7	13	3.6	10
C1-Fluor/Pyr	5.0	9.7	1.8	11	1.9	3.3	9.2	1.4	6.0
Benz(a)anthracene	< 0.04	5.3	0.5	2.7	0.6	0.6	4.3	0.3	2.2
Chrysene	0.8	4.6	0.7	5.0	1.1	1.2	7.2	0.7	3.4
C1-Chrysenes	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	3.0	< 0.02	1.1
C2-Chrysenes	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	2.5	< 0.02	1.0
C3-Chrysenes	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	1.5	< 0.02	0.8
C4-Chrysenes	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Benzo(b+k)Fluor	< 0.11	10	< 0.11	18	< 0.11	2	25	< 0.11	15
Benzo(a)fluoranthene	< 0.11	1.4	< 0.11	< 0.11	< 0.11	0.3	6.4	< 0.11	0.5
Benzo(e)pyrene	1.8	5.1	< 0.09	8.0	1.5	1.4	11	< 0.09	5.3
Benzo(a)pyrene	< 0.04	2.8	1.0	3.9	1.1	1.2	4.6	< 0.04	3.0
Indeno[1,2,3-c,d]Py	< 0.25	5.5	< 0.25	9.3	< 0.25	< 0.25	13	< 0.25	7.6
Dibenz(a,h)anth.	< 0.24	3.2	< 0.24	< 0.24	< 0.24	< 0.24	4.3	< 0.24	< 0.24
Benzo(g,h,i)perylene	< 0.14	5.3	< 0.14	9.3	< 0.14	1.8	13	< 0.14	8.9
Perylene	< 0.04	0.5	< 0.04	1.2	< 0.04	< 0.04	1.5	< 0.04	0.2
Res Ar	2784	3912	1051	3413	1002	1089	5148	6968	9295
Unres. Ar	9619	22158	6540	36566	6322	9179	36592	7214	7802

Annex B.1. Concentrations of aliphatic hydrocarbons (ng g^{-1} dw) in bivalves from Bahrain, I.R.Iran and Iraq

	BAH-5	BAH-9	IRAN-2	IRAN-2-1	IRAN-2-2	IRAN	IRAN-4	IRAN-4-1	IRAQ
Bivalve type	Pearl Oyster	Pearl Oyster	Rock Oyster	Rock Oyster	Rock Oyster	Rock Oyster	Rock Oyster	Rock Oyster	Pearl Oyster
n-C12	386	399	250	513	745	663	596	210	<0.96
n-C13	291	270	287	180	466	563	600	72	<0.96
n-C14	441	353	395	416	530	675	563	212	31
n-C15	515	826	818	925	988	1259	1233	630	2044
n-C16	1018	695	1151	1073	1099	1649	1188	602	956
n-C17	717	1016	946	1134	897	1204	1022	728	2113
n-C18	308	73	210	227	296	275	193	132	144
n-C19	377	57	198	183	381	387	165	201	161
n-C20	153	46	623	656	468	611	325	374	97
n-C21	210	60	184	141	112	84	132	314	152
n-C22	187	81	340	443	266	404	263	440	67
n-C23	105	36	135	216	144	125	152	472	61
n-C24	129	48	130	281	122	119	204	470	56
n-C25	138	3.7	150	156	85	84	274	400	33
n-C26	76	10	160	121	97	124	178	309	64
n-C27	111	4.6	46	64	60	80	141	204	91
n-C28	<1.2	10	50	47	42	44	78	121	53
n-C29	<1.2	<1.2	60	38	34	54	78	132	61
n-C30	<1.57	<1.2	70	54	87	60	97	130	40
n-C31	<1.39	<1.57	140	45	53	93	71	139	<1.51
n-C32	<1.57	<1.57	136	35	40	90	62	149	<1.51
n-C33	<1.57	<1.57	91	<1.57	<1.57	<1.57	<1.57	<1.57	<1.57
n-C34	<1.64	<1.64	<1.64	<1.64	39	<1.61	<1.64	29	<1.61
n-C35	<1.61	<1.61	<1.57	<1.61	<1.61	<1.61	<1.61	<1.61	<1.61
n-C36	<1.57	<1.57	<1.57	<1.57	<1.57	<1.57	<1.57	<1.57	<1.57
Pr	160	570	215	319	294	261	265	202	634
Ph	422	164	241	460	197	135	225	362	999
Sq	<1.13	<1.13	610	47	49	227	114	114	48
Res Al	19811	17255	31069	21514	19472	27366	23355	24491	30146
Unres. Al	112294	13445	119279	52803	29299	17529	50278	97732	116933

Annex B.2. Concentrations of aliphatic hydrocarbons (ng g^{-1} dw) in bivalves from Oman and Saudi Arabia

ng/g^{-1} dw	OMAN 8 Rock Oyster	OMAN 8.1 Rock Oyster	OMAN 8.2 Rock Oyster	OMAN 2 Rock Oyster	OMAN 2.1 Rock Oyster	OMAN 2.2 Rock Oyster	KSA 1 Pearl Oyster	KSA 2.1 Pearl Oyster	KSA 2.2 Pearl Oyster	KSA 3 Pearl Oyster
n-C12	367	688	568	291	333	280	944	1590	933	710
n-C13	274	494	685	522	442	221	717	1080	606	430
n-C14	702	1123	810	915	1033	697	984	1431	782	499
n-C15	1461	3370	4409	2953	4039	1670	3548	4420	2986	2004
n-C16	1853	3536	4720	3233	4311	2576	1721	2981	1442	960
n-C17	2778	4421	6568	4313	5770	3277	3761	5711	3680	2265
n-C18	163	143	586	240	293	205	268	1959	207	167
n-C19	71	145	1424	369	216	324	296	2548	396	504
n-C20	239	84	317	189	141	364	153	1828	112	106
n-C21	311	147	96	129	42	51	258	2000	319	121
n-C22	139	96	64	174	34	19	74	1645	109	64
n-C23	31	151	86	220	51	151	76	1390	278	56
n-C24	27	175	67	301	55	78	60	1336	134	45
n-C25	78	200	86	403	96	100	87	1176	133	34
n-C26	15	220	67	295	86	71	35	471	99	49
n-C27	27	63	59	157	78	32	42	154	112	83
n-C28	11	91	36	140	80	32	33	80	106	95
n-C29	23	158	61	167	99	33	6.8	<1.2	<1.2	131
n-C30	19	94	74	133	118	65	30	<1.28	<1.39	161
n-C31	19	180	71	181	129	50	46	<1.51	<1.39	123
n-C32	23	105	20	110	107	20	20	<1.51	<1.64	<1.51
n-C33	16	128	<1.57	66	65	12	<1.57	<1.64	<1.64	<1.57
n-C34	<1.64	<1.64	<1.64	136	91	<1.64	<1.61	<1.64	<1.64	<1.64
n-C35	<1.61	<1.61	<1.61	<1.61	<1.61	<1.61	<1.61	<1.61	<1.61	<1.61
n-C36	<1.57	<1.57	<1.57	<1.57	<1.57	<1.57	<1.57	<1.57	<1.57	<1.57
Pr	234	347	628	471	121	223	1047	2371	771	872
Ph	29	610	236	590	55	114	1688	2379	610	294
Sq	714	489	97	248	99	118	54	240	617	628
Res Al	38044	48940	72279	57487	53636	40129	48879	163993	41663	26418
Unres. Al	27994	222655	62679	196102	55618	44788	146848	1683788	233627	69640

Annex B.3. Concentrations of aliphatic hydrocarbons (ng g^{-1} dw) in bivalves from UAE

ng/g^{-1} dw	UAE 7-1 Rock Oyster	UAE 7-1-2 Rock Oyster	UAE 7-1-3 Rock Oyster	UAE 7-2 Pearl Oyster	UAE 7-2-2 Pearl Oyster	UAE 7-2-3 Pearl Oyster	UAE 3 Rock Oyster
n-C12	993	3955	672	768	695	286	380
n-C13	2103	2464	521	504	473	234	303
n-C14	487	3011	533	746	638	395	534
n-C15	1491	7905	1659	2804	2653	1532	1633
n-C16	1436	7878	1894	1798	1502	895	1786
n-C17	1971	9989	2204	3875	3137	1936	2850
n-C18	80	454	113	419	232	112	178
n-C19	104	580	160	617	396	115	254
n-C20	102	363	77	188	98	49	130
n-C21	118	422	134	398	202	102	179
n-C22	98	260	83	184	92	49	91
n-C23	166	342	141	180	99	83	92
n-C24	81	224	91	217	98	93	151
n-C25	138	373	149	201	98	85	157
n-C26	125	258	127	66	36	49	176
n-C27	56	202	106	60	58	51	126
n-C28	76	150	85	28	27	49	86
n-C29	134	129	123	27	25	44	80
n-C30	146	132	167	59	41	62	90
n-C31	193	98	152	20	66	89	96
n-C32	70	100	135	45	54	26	80
n-C33	230	<1.57	101	<1.57	21	28	52
n-C34	<1.64	<1.64	62	40	19	33	50
n-C35	<1.61	<1.61	<1.61	<1.61	<1.61	<1.61	<1.61
n-C36	<1.57	<1.57	<1.57	<1.57	<1.57	<1.57	<1.57
Pr	533	2749	681	2102	1441	747	710
Ph	186	951	263	1365	987	319	499
Sq	136	478	214	<1.13	54	30	332
Res Al	31948	137095	36078	47222	40733	23590	39694
Unres. Al	89007	383215	128244	308233	225930	117835	174501

Annex B.4. Concentrations of aromatic hydrocarbons (ng g^{-1} dw) in bivalves from Bahrain, I.R. Iran and Iraq

	BAH-5	**BAH-9**	**IRAN-2**	**IRAN-2-1**	**IRAN-2-2**	**IRAN**	**IRAN-4**	**IRAN-4-1**	**IRAQ**
Bivalve type	**Pearl Oyster**	**Pearl Oyster**	**Rock Oyster**	**Rock Oyster**	**Rock Oyster**	**Rock Oyster**	**Rock Oyster**	**Rock Oyster**	**Pearl Oyster**
Naph (N)	11	7.6	39	28	35	29	34	19	10
C1-N	18	12	48	29	39	29	48	31	26
C2-N	37	16	107	47	77	47	83	76	62
C3-N	45	8.2	96	37	80	35	68	101	76
C4-N	34	3.7	41	22	46	8	27	58	30
Biphenyl	<0.05	1.4	4.5	3.7	3.7	3.6	4.8	3.6	2.8
Acenaphthylene	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Fluorene	2.0	0.8	2.0	1.0	1.7	1.1	1.5	2.0	1.9
Acenaphthene	1.4	0.6	0.9	0.6	0.6	0.6	0.8	0.9	0.9
C1-Fluorenes	6.9	2.0	29	13	17	13	18	10	53
C2-Fluorenes	16	2.0	7.5	7.8	11	2.3	10	15	9
C3-Fluorenes	24	1.4	8.6	16	13	2.5	8.6	25	14
Dibenzothiophene	3.4	0.4	2.7	1.4	2.2	1.3	1.5	3.0	2.4
C1-DBT	33.5	1.2	28.9	25.1	19.4	3.2	26.6	68	9.7
C2-DBT	104	2.7	108	150	48	26	81	403	29
C3-DBT	135	2.9	112	366	45	18	75	624	36
Phenanthrene	8.5	2.2	16	11	11	9	15	21	8.0
Anthracene	1.6	0.4	1.1	1.2	1.7	0.8	1.5	3.2	0.5
C1- Phen/Anth	34	4.3	54	44	33	22	50	102	17
C2- Phen/Anth	79	4.3	105	127	40	21	77	291	27
C3- Phen/Anth	68	2.2	80	151	27	9.2	59	369	30
C4- Phen/Anth	34	1.0	28	122	15	<0.03	40	293	8.5
Fluoranthene	10	3.3	23	17	17	19	22	19	4.2
Pyrene	10	1.2	44	40	39	52	37	40	13
C1-Fluor/Pyr	8.5	1.4	13	11	5.2	2.5	11	66	6.1
Benz(a)anthracene	3.2	0.2	0.9	0.6	0.2	<0.03	0.2	1.4	<0.03
Chrysene	8.9	1.4	10	9.5	3.4	2.1	8.4	30	1.9
C1-Chrysenes	5.0	0.6	8.4	9.1	2.2	1.1	5.5	61	<0.03
C2-Chrysenes	2.8	<0.04	4.3	3.7	<0.04	<0.04	1.9	51	<0.04
C3-Chrysenes	1.8	<0.03	1.8	1.0	<0.03	<0.03	<0.03	16	<0.03
C4-Chrysenes	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Benzo(b+k)Fluor	18	<0.03	7	9	<0.03	<0.03	<0.03	10	<0.03
Benzo(a)fluoranthene	11	<0.03	4.3	5.6	<0.03	<0.03	<0.03	0.7	<0.03
Benzo(e)pyrene	1.6	<0.03	1.4	<0.03	<0.03	<0.03	0.2	27	2.1
Benzo(a)pyrene	1.4	<0.07	1.6	1.0	0.9	1.1	1.0	3.6	<0.07
Indeno[1,2,3-c,d]Py	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07
Dibenz(a,h)anth.	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07
Benzo(g,h,i)perylene	1.8	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	3.6	<0.05
Perylene	0.2	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Res Ar	2004.4	1123	4856	5214	3821	1653	2658	3004	11493
Unres. Ar	8376.5	1371	15784	9512	3798	3623	8500	16464	8523

Annex B.5. Concentrations of aromatic hydrocarbons (ng g^{-1} dw) in bivalves from Oman and Saudi Arabia

	OM.-8	**OM-8-1**	**OM-8-2**	**OM-2**	**OM-2-1**	**OM-2-2**	**KSA-1**	**KSA-2-1**	**KSA-2-2**	**KSA-3**
Bivalve type	**Rock Oyster**	**Rock Oyster**	**Rock Oyster**	**Rock Oyster**	**Rock Oyster**	**Rock Oyster**	**Pearl Oyster**	**Pearl Oyster**	**Pearl Oyster**	**Pearl Oyster**
Naph (N)	11	11	36	25	28	9.5	6.7	32	10	13
C1-N	10	11	41	57	48	14	7.2	278	9.1	17
C2-N	17	22	73	169	94	28	21	1123	23	37
C3-N	16	30	64	308	80	33	43	1832	43	48
C4-N	7.0	17	26	175	31	21	31	817	35	29
Biphenyl	2.3	2.8	5.0	8.5	5.5	2.4	<0.05	12	2.5	2.4
Acenaphthylene	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	1.7	<0.5	<0.5
Fluorene	1.6	1.3	2.7	3.2	2.8	1.4	1.7	20	1.4	1.7
Acenaphthene	0.3	0.3	0.7	1.0	1.3	<0.04	0.5	3.2	<0.04	0.2
C1-Fluorenes	5.4	12	10	19	11	6.5	30	357	30	13
C2-Fluorenes	2.3	8.1	21	34	9.1	7.8	103	635	92	32
C3-Fluorenes	<0.04	10	24	30	5.8	15	143	683	103	30
Dibenzothiophene	0.8	0.8	1.7	10	1.8	1.6	1.2	3.5	0.9	0.5
C1-DBT	1.6	6.3	16.0	72	7.6	19.2	19.0	43	13.0	4.3
C2-DBT	1.8	29	68	262	17	96	50	133	39	13
C3-DBT	1.8	70	40	426	21	164	46	165	33	11
Phenanthrene	6.0	11	20	31	18	7.8	8.7	116	9.4	5.2
Anthracene	0.8	1.3	1.7	2.4	1.5	0.8	1.5	33	1.8	1.4
C1- Phen/Anth	7.5	25	100	132	36	36	80	567	66	35
C2- Phen/Anth	6.0	58	174	404	28	75	125	1964	111	54
C3- Phen/Anth	11	62	62	434	16	92	94	1209	66	36
C4- Phen/Anth	<0.03	67	32	552	19	56	62	520	38	16
Fluoranthene	2.1	21	23	14	7.8	6.8	6.7	74	5.5	4.0
Pyrene	1.8	11	51	17	12	4.9	22	109	18	8.7
C1-Fluor/Pyr	0.8	7.6	7.2	27	8	11	13	215	8.9	8.5
Benz(a)anthracene	0.8	1.0	0.7	2.7	0.8	0.8	<0.03	130	0.9	1.7
Chrysene	1.0	8.1	2.5	31	5.3	7.8	0.7	73	1.8	2.1
C1-Chrysenes	<0.03	8.3	1.7	81	7.1	8.4	<0.03	247	<0.03	<0.03
C2-Chrysenes	<0.04	6.6	<0.04	72	4.3	3.8	<0.04	180	<0.04	<0.04
C3-Chrysenes	<0.03	<0.03	<0.03	31	1.8	1.4	<0.03	58	<0.03	<0.03
C4-Chrysenes	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Benzo(b+k)Fluor	<0.03	<0.03	<0.03	11	<0.03	4	<0.03	67	<0.03	<0.03
Benzo(a)fluoranthene	<0.03	2.0	<0.03	<0.03	<0.03	<0.03	<0.03	6.2	<0.03	<0.03
Benzo(e)pyrene	<0.03	4.8	1.7	17	2.3	3.5	2.2	61	<0.03	<0.03
Benzo(a)pyrene	<0.07	2	1.7	6.6	1.5	2.2	<0.07	41	<0.07	<0.07
Indeno[1,2,3-c,d]Py	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	100	<0.07	<0.07
Dibenz(a,h)anth.	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	6.5	<0.07	<0.07
Benzo(g,h,i)perylene	<0.05	<0.05	<0.05	2.7	<0.05	<0.05	<0.05	71	<0.05	<0.05
Perylene	<0.03	<0.03	<0.03	<0.03	<0.03	0.3	<0.03	12	<0.03	<0.03
Res Ar	8068	12206	14821	15994	12447	8501	3328	9967	1814	2155
Unres. Ar	1859	47053	13444	69369	8141	9956	16497	65391	21399	7215

Annex B.6. Concentrations of aromatic hydrocarbons (ng g^{-1} dw) in bivalves from UAE

	UAE-7-1	**UAE-7-1-2**	**UAE-7-1-3**	**UAE-7-2**	**UAE-7-2-2**	**UAE-7-2-3**	**UAE-3**
Bivalve type	**Rock Oyster**	**Rock Oyster**	**Rock Oyster**	**Pearl Oyster**	**Pearl Oyster**	**Pearl Oyster**	**Rock Oyster**
Naph (N)	6.3	17	8.6	16	14	23	18
C1-N	12	16	11	21	15	21	13
C2-N	23	34	21	41	32	50	25
C3-N	26	58	31	66	62	74	32
C4-N	27	42	30	52	49	57	28
Biphenyl	2.4	3.8	2.9	3.8	3.5	4.5	1.0
Acenaphthylene	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Fluorene	1.7	3.1	1.7	2.8	2.6	3.7	2.0
Acenaphthene	0.4	0.7	0.5	0.7	0.5	0.7	0.5
C1-Fluorenes	16	33	22	54	49	47	33
C2-Fluorenes	31	76	57	167	122	136	122
C3-Fluorenes	22	51	35	171	95	99	106
Dibenzothiophene	1.3	3.3	2.6	2.1	2.1	1.2	2.2
C1-DBT	12.1	30	23.8	34	28	17.5	36
C2-DBT	31	67	61	94	61	39	106
C3-DBT	33	53	56	85	41	28	81
Phenanthrene	11	20	15	20	17	23	17
Anthracene	0.9	1.7	1.0	2.6	1.2	1.7	2.2
C1- Phen/Anth	41	90	73	127	92	84	133
C2- Phen/Anth	68	142	130	276	154	127	256
C3- Phen/Anth	44	76	79	213	87	81	185
C4- Phen/Anth	33	48	65	121	41	33	91
Fluoranthene	15	23	21	14	8.0	9.0	15
Pyrene	17	30	29	45	22	20	40
C1-Fluor/Pyr	15	18	22	31	12	14	21
Benz(a)anthracene	1.3	1.2	1.4	3.1	1.4	1.7	0.5
Chrysene	9.1	13	12	4.2	2.4	4.0	3.2
C1-Chrysenes	6.3	7.3	7.1	5.2	<0.03	<0.03	<0.03
C2-Chrysenes	3.2	3.5	3.8	2.6	<0.04	<0.04	<0.04
C3-Chrysenes	0.9	1.4	1.9	0.9	<0.03	<0.03	<0.03
C4-Chrysenes	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Benzo(b+k)Fluor	11	12	14	5	<0.03	4	5
Benzo(a)fluoranthene	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Benzo(e)pyrene	7.8	12	14	2.1	<0.03	2.0	1.7
Benzo(a)pyrene	2.2	1.2	3.6	2.4	<0.07	1.7	1.2
Indeno[1,2,3-c,d]Py	3.2	2.8	3.8	<0.07	<0.07	1.2	<0.07
Dibenz(a,h)anth.	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07
Benzo(g,h,i)perylene	7.6	7.3	10	2.6	<0.05	1.5	<0.05
Perylene	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Res Ar	2678	5011	3217	4086	2198	3934	7925
Unres. Ar	6951	14736	12890	28747	16471	23054	24197

Annex C.1. Concentrations of PCBs (pg g^{-1} dw) in sediments from Bahrain, I.R. Iran, Oman and Saudi Arabia

pg/g^{-1} dw	BAH-5	BAH-9	IRAN 2	IRAN 2-1	OMAN-2	OMAN-2-1	OMAN-8-1	KSA-1	KSA-2-1	KSA-2-2	KSA-3
PCB 8	<91	<91	<91	116	<39	96	99	<39	<91	<39	<91
PCB 18	<40	<17	102	110	<40	41	117	<17	<40	<17	77
PCB 28	33	23	18	38	13	21	39	<10	11	10	12
PCB 31	128	<30	<30	<30	<74	<30	95	<30	<30	<30	<30
PCB 44	<83	<83	<83	<83	<83	<83	<184	<83	<83	<83	<83
PCB 49	<19	<19	<19	<19	<35	<19	70	<19	38	<19	<19
PCB 52	42	58	<29	46	47	<29	367	<12	<29	<12	<29
PCB 66/95	24	<9	<19	29	27	165	<9	<9	<9	<9	<9
PCB 87	<23	<23	<60	<23	<23	<60	68	<23	<23	<23	<23
PCB 97	<17	<17	<17	59	<17	<17	43	<17	<17	<17	<17
PCB 99	<42	<42	<18	<42	58	<18	130	<18	<18	<18	<42
PCB 101	<147	<53	<53	<53	<53	<53	<147	<53	<53	<53	<53
PCB 105	<36	<36	<36	<36	<36	<36	<36	<36	<36	<36	<36
PCB 110(77)	<62	<62	<62	<62	<62	<62	<62	<62	<62	<62	<62
PCB 118	<127	<127	<127	<363	<127	<127	<127	<127	<127	<127	<127
PCB 126	<37	<37	<37	<37	<37	<37	<37	<37	<37	<37	<37
PCB 128	<10	<10	<10	<25	<10	<10	<10	<10	<10	<10	<10
PCB 138	<73	<73	<73	<201	<73	<73	<73	<73	<73	<73	<73
PCB 149	<72	<72	<72	<203	<72	<72	<72	<72	<72	<72	<72
PCB 151	17	14	<12	<5	<12	<12	46	<5	<12	<5	<12
PCB 153	<127	<51	<51	<127	<51	<51	<51	<51	<51	<51	<51
PCB 156	14	<6	17	<13	<6	<6	<6	<6	17	<13	<13
PCB 169	<6	24	<6	<6	<6	<6	<6	<6	<6	<6	<6
PCB 170	24	<2	6	17	9	<2	6	<2	<2	<3	5
PCB 174	14	<4	10	14	<6	<4	8	<4	<4	<4	7
PCB 177	15	<5	<11	<5	<5	<5	13	<11	37	<11	<11
PCB 180	49	<13	<13	27	<13	<13	<13	<13	<24	<13	<24
PCB 183	13	<5	<5	<11	<5	<11	<5	<5	<5	<5	<11
PCB 187	39	<11	<25	<25	<25	<11	<25	<11	<25	<11	<25
PCB 189	<4	<4	16	<4	<4	<4	<4	<9	<4	<9	<4
PCB 194	41	<4	19	<4	<9	<4	<4	<9	<4	<9	<4
PCB 195	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
PCB 201	<5	<12	<12	<5	<5	<5	15	<12	<12	<5	<12
PCB 206	<4	<9	621	<4	<4	<4	<4	<9	<9	<9	<4
PCB 209	<38	<16	138215	<16	<16	<16	<16	<16	57	<16	<16

Annex C.2. Concentrations of PCBs (pg g^{-1} dw) in sediments from UAE

pg/g^{-1} dw	**UAE 7-1**	**UAE 7-1-2**	**UAE 7-1-3**	**UAE 7-2**	**UAE 7-2-2**	**UAE 7-2-3**	**UAE 3**
PCB 8	<39	<39	<39	<39	1232	<39	<39
PCB 18	<17	<17	<17	<17	236	<17	<17
PCB 28	<5	<5	<5	<5	805	<5	16
PCB 31	<30	<30	<30	<30	365	<30	<30
PCB 44	<83	<83	<83	<83	<83	<83	<83
PCB 49	<19	<19	<19	<19	<19	<19	<19
PCB 52	<12	<12	<12	<12	30	<12	<29
PCB 66/95	<9	66	<9	<9	<19	<9	<9
PCB 87	<23	93	<23	<23	<60	<23	<23
PCB 97	<17	<43	<17	<17	<17	<17	<17
PCB 99	<18	<18	<18	<18	<42	<18	<18
PCB 101	<53	207	<53	<53	<147	<53	<53
PCB 105	<36	<36	<36	<36	<36	<36	<36
PCB 110(77)	<62	<62	<62	<62	<62	<62	<62
PCB 118	<127	<127	<127	<127	<127	<127	<127
PCB 126	<37	115	<37	<37	<37	<37	<37
PCB 128	<10	<10	<10	<10	<10	<10	<10
PCB 138	<73	<73	<73	<73	<73	<73	<73
PCB 149	<72	<72	<72	<72	<72	<72	<203
PCB 151	<5	<5	<5	<12	<5	<5	16
PCB 153	<51	<51	<51	<51	<51	<51	<51
PCB 156	<6	<6	<6	<13	<6	<13	<13
PCB 169	<6	<6	<6	<6	<6	<6	<6
PCB 170	<2	<2	4	4	16	<2	<2
PCB 174	<4	26	<4	<4	<4	<4	<6
PCB 177	<5	<5	<5	<11	<5	<5	<11
PCB 180	<24	25	<13	<13	<24	<13	<13
PCB 183	<5	26	<5	<5	<5	<5	<5
PCB 187	<11	<11	<11	<11	<11	<11	<25
PCB 189	<4	<4	<4	<4	<4	<4	<4
PCB 194	<4	<4	<4	<4	<4	<9	<4
PCB 195	<4	<4	<4	<4	<4	<4	<4
PCB 201	<5	39	<5	<5	<5	<5	<5
PCB 206	<4	<4	<4	<4	<4	<4	<4
PCB 209	<16	<16	<16	<16	<16	<16	<16

Annex D.1. Concentrations of PCBs (ng g^{-1} dw) in bivalves from Bahrain, I.R. Iran and Iraq

ng/g^{-1} dw	BAH 5 Pearl Oyster	BAH 9 Pearl Oyster	IRAN 2 Rock Oyster	IRAN 2.1 Rock Oyster	IRAN 2.2 Rock Oyster	IRAN Rock Oyster	IRAN 4 Rock Oyster	IRAN 4.1 Rock Oyster	IRAQ Pearl Oyster
PCB 8	0.055	0.115	0.110	0.085	0.110	0.100	0.089	0.121	0.059
PCB 18	<0.155	<0.155	<0.155	<0.155	<0.155	<0.155	<0.155	<0.155	<0.414
PCB 28	<0.123	<0.123	0.333	<0.123	<0.123	<0.123	<0.123	<0.123	<0.123
PCB 31	0.192	0.157	0.376	0.123	0.147	0.152	0.235	0.092	0.176
PCB 44	0.088	<0.056	0.224	0.085	<0.025	<0.056	<0.025	<0.056	0.069
PCB 49	<0.036	<0.083	0.205	<0.083	<0.036	<0.036	<0.036	<0.036	<0.083
PCB 52	<0.19	<0.19	<0.425	<0.19	<0.19	<0.19	<0.19	<0.19	<0.19
PCB 66/95	0.032	<0.02	0.529	0.069	0.092	0.043	0.066	0.056	0.079
PCB 87	0.138	0.153	0.127	<0.048	0.080	0.055	0.085	0.090	0.050
PCB 97	<0.016	<0.037	0.116	<0.037	<0.037	<0.016	<0.016	<0.016	<0.016
PCB 99	0.274	0.365	0.478	0.180	0.219	0.202	0.116	0.168	0.472
PCB 101	0.116	<0.055	0.611	0.140	0.233	<0.115	0.183	0.151	0.195
PCB 105	0.045	0.045	0.167	<0.027	<0.027	<0.013	<0.027	<0.027	0.081
PCB 110(77)	<0.061	<0.061	0.313	0.236	<0.061	<0.061	<0.061	<0.137	0.155
PCB 118	<0.076	<0.076	0.483	<0.076	<0.194	<0.076	<0.076	<0.076	0.237
PCB 126	0.220	0.201	0.288	0.082	0.064	0.054	0.088	0.067	0.287
PCB 128	0.137	0.106	0.126	0.035	0.051	0.044	0.045	0.041	0.075
PCB 138	0.560	0.138	0.793	0.181	0.257	0.113	0.182	0.150	0.397
PCB 149	0.233	<0.155	0.509	<0.155	0.204	<0.155	<0.155	<0.155	0.158
PCB 151	0.046	0.031	0.218	0.076	0.106	0.075	0.062	0.059	0.083
PCB 153	0.840	0.140	1.487	0.376	0.458	0.197	0.319	0.250	0.488
PCB 156	0.082	0.049	0.080	0.116	0.061	0.041	0.046	0.030	0.031
PCB 169	0.011	<0.006	0.013	<0.006	0.007	<0.006	<0.006	0.007	<0.003
PCB 170	0.154	0.028	0.071	0.016	0.011	0.006	0.022	0.014	0.012
PCB 174	0.091	0.057	0.094	0.044	0.057	0.050	0.053	0.054	0.071
PCB 177	0.090	0.028	0.167	0.055	0.041	0.020	0.042	0.063	0.098
PCB 180	0.071	0.037	0.197	0.058	0.087	0.020	0.046	0.040	0.033
PCB 183	0.218	0.131	0.179	0.053	0.069	0.067	0.070	0.051	0.058
PCB 187	0.496	0.248	0.649	0.213	0.197	0.148	0.197	0.169	0.402
PCB 189	0.021	0.010	0.009	0.007	0.013	0.003	0.003	0.009	0.011
PCB 194	0.012	0.010	0.030	<0.006	0.008	0.019	<0.006	0.010	<0.006
PCB 195	0.049	0.033	0.033	0.042	0.053	0.037	<0.003	<0.003	<0.008
PCB 201	0.017	0.024	0.026	0.023	0.008	0.007	0.022	0.021	<0.003
PCB 206	0.022	0.012	0.005	<0.004	<0.002	0.013	<0.004	0.008	<0.004
PCB 209	0.100	0.125	0.158	0.124	0.386	0.164	0.063	0.264	0.121

Annex D.2. Concentrations of PCBs (ng g^{-1} dw) in bivalves from Oman and Saudi Arabia

ng/g^{-1} dw	OMAN 8	OMAN 8.1	OMAN 8.2	OMAN 2	OMAN 2.1	OMAN 2.2	KSA 1	KSA 2.1	KSA 2.2	KSA 3
	Rock Oyster	Rock Oyster	Rock Oyster	Rock Oyster	Rock Oyster	Rock Oyster	Pearl Oyster	Pearl Oyster	Pearl Oyster	Pearl Oyster
PCB 8	0.131	0.139	0.117	0.372	0.570	0.206	0.141	0.068	0.065	0.130
PCB 18	<0.155	<0.414	<0.155	<0.155	<0.155	0.447	<0.414	<0.414	<0.414	<0.155
PCB 28	<0.123	<0.123	<0.044	0.549	0.203	<0.123	<0.044	<0.123	<0.044	<0.123
PCB 31	0.483	0.426	0.314	0.394	0.269	0.415	0.162	0.277	0.165	0.119
PCB 44	0.106	0.091	0.533	0.323	1.077	0.302	<0.056	<0.025	<0.025	<0.025
PCB 49	0.163	<0.036	<0.083	<0.036	<0.083	<0.083	<0.083	<0.083	<0.083	<0.036
PCB 52	<0.19	<0.19	<0.19	<0.19	<0.19	<0.19	<0.19	<0.19	<0.19	<0.19
PCB 66/95	0.394	0.060	0.299	0.909	0.412	0.332	0.032	0.024	<0.02	0.051
PCB 87	<0.048	0.077	<0.048	<0.024	<0.024	<0.048	0.105	<0.024	0.106	0.165
PCB 97	0.040	0.058	0.037	0.106	0.062	<0.037	<0.037	<0.016	<0.016	<0.037
PCB 99	0.184	0.390	0.261	0.359	0.345	0.336	0.215	0.220	0.202	0.259
PCB 101	<0.055	0.316	<0.055	0.388	1.051	<0.115	<0.115	<0.055	<0.055	0.367
PCB 105	<0.027	0.066	0.030	0.111	<0.027	<0.027	0.064	0.083	0.057	0.096
PCB 110(77)	0.204	0.409	<0.061	<0.061	<0.061	<0.061	<0.061	<0.061	<0.061	<0.061
PCB 118	0.202	0.410	<0.076	0.316	<0.076	<0.076	<0.194	<0.076	<0.076	<0.194
PCB 126	0.213	1.319	0.124	0.199	0.064	0.103	0.218	0.125	0.166	0.312
PCB 128	<0.003	0.093	0.042	0.136	0.027	0.048	0.089	0.111	0.097	0.226
PCB 138	0.355	0.530	<0.067	1.082	0.075	0.131	0.175	0.119	0.081	0.760
PCB 149	<0.155	0.375	<0.155	0.844	<0.063	<0.063	<0.155	<0.063	<0.155	0.289
PCB 151	0.055	0.114	0.023	0.232	0.051	0.024	0.028	0.064	0.019	0.059
PCB 153	2.854	0.781	0.085	1.637	0.115	1.759	0.209	0.107	0.067	0.976
PCB 156	0.037	0.103	0.015	0.177	0.019	0.028	0.128	0.111	0.091	0.112
PCB 169	<0.003	0.022	0.006	<0.003	<0.003	<0.003	<0.003	0.095	0.017	0.011
PCB 170	<0.001	0.076	0.014	0.134	0.022	0.022	0.030	0.010	0.015	0.089
PCB 174	0.064	0.040	0.030	0.106	0.235	0.080	0.100	0.089	0.117	0.084
PCB 177	0.063	0.099	0.018	0.357	0.017	0.038	0.039	0.047	0.022	0.109
PCB 180	0.091	0.208	0.100	0.402	0.042	0.073	0.100	0.044	0.039	0.053
PCB 183	0.201	0.190	0.060	0.282	0.041	0.029	0.170	0.199	0.194	0.206
PCB 187	0.562	0.448	0.159	1.199	0.051	0.196	0.314	0.313	0.224	0.631
PCB 189	<0.001	0.046	0.006	<0.001	<0.001	<0.001	0.021	<0.001	0.019	0.011
PCB 194	<0.002	0.069	<0.002	0.042	<0.002	<0.002	0.019	<0.002	0.024	0.014
PCB 195	<0.003	0.744	<0.003	<0.003	<0.003	<0.003	0.031	0.061	0.021	<0.008
PCB 201	0.013	0.007	0.028	0.051	0.012	0.031	0.030	0.012	0.007	0.008
PCB 206	<0.002	0.016	<0.002	<0.002	0.039	<0.002	<0.002	<0.002	<0.002	<0.002
PCB 209	<0.003	0.421	0.117	0.192	0.053	0.306	0.126	0.124	<0.003	0.220

Annex D.3. Concentrations of PCBs (ng g^{-1} dw) in bivalves from UAE

ng/g^{-1} dw	UAE 7-1	UAE 7-1-2	UAE 7-1-3	UAE 7-2	UAE 7-2-2	UAE 7-2-3	UAE 3
	Rock Oyster	**Rock Oyster**	**Rock Oyster**	**Pearl Oyster**	**Pearl Oyster**	**Pearl Oyster**	**Rock Oyster**
PCB 8	0.089	0.386	0.091	0.130	0.120	<0.004	0.292
PCB 18	<0.155	0.436	<0.155	0.428	0.435	<0.155	<0.414
PCB 28	<0.123	0.177	<0.123	<0.123	<0.123	<0.044	<0.123
PCB 31	0.146	0.361	0.130	0.252	0.186	<0.033	0.273
PCB 44	<0.056	0.126	0.160	<0.056	0.059	<0.025	0.069
PCB 49	<0.036	<0.036	<0.036	<0.036	<0.083	<0.036	0.094
PCB 52	<0.425	<0.425	<0.425	<0.19	<0.19	<0.19	<0.19
PCB 66/95	0.034	0.063	0.025	0.025	<0.011	<0.011	<0.02
PCB 87	<0.048	0.091	<0.024	0.118	0.096	<0.024	0.056
PCB 97	<0.016	0.059	<0.016	0.356	0.202	<0.016	<0.016
PCB 99	0.131	0.297	0.116	0.697	0.391	<0.024	0.118
PCB 101	<0.115	0.142	<0.115	<0.055	<0.055	<0.055	<0.055
PCB 105	0.034	0.069	0.028	0.043	<0.027	<0.013	<0.027
PCB 110(77)	<0.061	<0.061	<0.061	<0.061	<0.061	<0.061	<0.061
PCB 118	<0.076	<0.194	<0.076	<0.076	<0.076	<0.076	<0.076
PCB 126	0.144	0.305	0.142	0.370	0.252	<0.003	0.276
PCB 128	0.021	0.062	0.013	0.119	0.080	<0.003	0.086
PCB 138	0.241	0.398	0.249	0.192	0.096	<0.031	0.098
PCB 149	<0.155	0.209	<0.155	<0.155	<0.063	<0.063	<0.063
PCB 151	0.054	0.103	0.036	0.024	0.012	<0.004	0.019
PCB 153	0.509	0.749	0.511	0.537	0.152	<0.026	0.112
PCB 156	0.064	0.069	0.028	0.034	0.029	<0.002	0.064
PCB 169	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
PCB 170	0.127	0.195	0.060	0.013	0.006	<0.001	0.159
PCB 174	0.025	0.054	0.024	0.119	0.099	<0.004	0.064
PCB 177	0.055	0.099	0.058	0.045	0.037	<0.002	0.042
PCB 180	0.086	0.081	0.052	0.128	0.067	<0.003	0.045
PCB 183	0.036	0.103	0.024	0.202	0.114	<0.004	0.114
PCB 187	0.327	0.611	0.323	0.509	0.329	<0.004	0.289
PCB 189	0.020	0.019	0.028	0.016	0.013	<0.001	0.007
PCB 194	0.009	0.037	0.018	0.033	0.022	<0.002	0.016
PCB 195	0.031	0.017	0.034	0.059	0.096	<0.003	<0.008
PCB 201	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
PCB 206	0.006	0.010	<0.004	0.012	0.006	<0.002	<0.002
PCB 209	0.640	0.892	0.621	0.189	0.095	<0.003	0.207

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