ROPME/GC-16/3

ROPME MUSSEL WATCH PROGRAMME 2014

Technical Report: No. 6

INTER-COMPARISON BETWEEN THE CONCENTRATIONS OF CONTAMINANTS IN ROCK AND PEARL OYSTERS

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 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 Mussel Watch survey undertaken in February-July 2014 was to measure inorganic and organic contaminants in sediment and oysters from coastal stations in 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. In principle, Mussel Watch surveys are based on the use of one common bivalve species, which can be found in all sampling stations. However, in the ROPME region it was not possible to find one common bivalve species, which is present in all coastal areas and it was decided to use two different oyster species: Pearl Oyster (Bahrain, Iraq, Saudi Arabia and UAE) and Rock Oyster (I.R. Iran, Oman, UAE).

The two different oyster species live in different environments: Rock Oyster species are attached to the rocks and live in the intertidal zone, while Pearl Oyster species live in the subtidal zone. The different environmental conditions affect the exposure of the two oyster species to contaminants and may influence bioaccumulation. As a consequence, it is risky to directly compare pollution levels between two areas, where different oyster species have been used as sentinel organisms. In addition, physiological differences between the species may also influence their respective bioaccumulation capacity.

In order to investigate differences in the accumulation of contaminants in the two oyster species, an intercomparison experiment was undertaken in Umm Al-Quwain, at the UAE (Stations UAE-7-1 and UAE-7-2), where both oyster species were found.

2. SAMPLING

Surface sediment samples were collected in triplicate from each one of the two UAE stations during the 2014 Mussel Watch campaign on February 2015.

Rock oysters and pearl oysters were collected in different sites from Umm Al-Quwain in UAE (Stations UAE-7-1 and UAE-7-2) in order to investigate the accumulation of contaminants in each species of oysters. The sampling sites and their characteristics are presented in Table 1.

Table 1. Site locations of the inter-comparison between rock and pearl oysters

No. of sampling sites	Country	Date	Site Name			Sampling Location		Sample type		Remarks
			Name	Code	Station	Latitude	Longitude	Bivalve	Sediment	
3	UAE	2/13/2014	Umm Al-Quwain UAE-7	UAE-7-1	1	25°35'N	55°33'E	*Rock oyster*	Sediment	20 individuals /Sta.
				UAE-7-1	2			*Rock oyster*	Sediment	Length range: 4.0-6.5 cm
				UAE-7-1	3			*Rock oyster*	Sediment	T.Mean length: 5.1 cm
				UAE-7-2	1	50 m offshore of R. Oyster stations		*Pearl oyster*	Sediment	20 individuals /Site
				UAE-7-2	2			*Pearl oyster*	Sediment	Length range: 4.2 -8.1 cm
				UAE-7-2	3			*Pearl oyster*	Sediment	T.Mean length: 6.5 cm
		2/18/2014	Dubai (Jebal Ali)	UAE-3	1	25°20'N	55°20'E	*Rock oyster*	Sediment	

Pearl Oyster : ***Pinctada radiata***

Rock oyster : ***Saccostrea cucullata***

Three composite oyster samples were prepared for each one of the two UAE stations. Each composite sample consisted of 20 individuals. In Table 2 are presented the lengths of the individual organisms collected in each sub-station. Overall, the length of the rock oysters ranged from 4 to 6.5 cm with an average of 5.1 cm, whereas pearl oysters ranged from 4.2 to 8.1 cm, with an average of 6.5 cm.

Table 2. Size of individual organisms (Individual length in cm) collected in the stations at Umm Al-Quwain

Ind. No.	Umm Al-Quwain					
	Rock Oyster			Pearl Oyster		
	Stn. 1	Stn. 2	Stn. 3	Stn. 1	Stn. 2	Stn. 3
1	4.6	5.0	6.0	7.5	5.5	5.3
2	4.6	6.2	4.7	7.0	6.5	6.7
3	5.7	5.0	5.2	7.4	7.1	5.6
4	4.0	5.4	6.5	6.7	4.6	5.4
5	4.5	5.2	5.0	6.9	7.5	7.0
6	5.2	4.9	4.7	7.1	6.5	6.4
7	5.1	6.0	6.2	6.8	5.5	5.3
8	4.5	4.5	5.7	7.0	5.6	7.1
9	4.6	5.2	6.0	5.5	5.0	5.8
10	4.3	5.0	5.0	6.7	7.2	5.6
11	4.8	4.5	4.6	8.1	6.8	6.2
12	5.7	5.2	4.9	6.6	4.2	7.6
13	5.0	6.0	5.2	6.6	5.7	7.2
14	4.5	4.5	5.1	7.0	6.2	6.5
15	5.5	4.7	4.4	7.0	5.2	6.8
16	4.7	5.1	5.5	6.5	6.2	7.8
17	4.5	4.5	4.0	6.5	8.1	6.3
18	5.6	5.0	6.0	6.2	5.3	8.1
19	4.5	4.5	5.5	6.7	6.1	6.8
20	5.2	6.0	4.5	7.5	5.7	7.3
L. Range	**4.0 - 5.7**	**4.5 - 6.2**	**4.0 - 6.5**	**5.5 - 8.1**	**4.2 - 8.1**	**5.3 - 8.1**
Mean L	**4.9**	**5.1**	**5.2**	**6.9**	**6.0**	**6.5**

3. ANALYTICAL PROCEDURES

The analytical protocols for measuring petroleum hydrocarbons, chlorinated pesticides and trace elements in sediment and biota (oysters) have been presented in detail in the ROPME Technical Report Nos. 1 & 2 (2016).

4. RESULTS AND DISCUSSION

- *Sediment results*

The grain size analysis of the sediments collected at stations UAE-7-1 and UAE-7-2 are presented in Table 3.

Table 3. Grain size results

Sample name	Clay (%)	Silt (%)	Sand (%)
UAE-7-1-1	0.00	0.00	100.0
UAE-7-1-2	0.00	1.88	98.1
UAE-7-1-3	0.00	0.07	99.9
UAE-7-2-1	0.00	0.00	100.0
UAE-7-2-2	0.00	0.85	99.1
UAE-7-2-3	0.00	0.12	99.9

The concentrations of trace elements, Total Organic Carbon, petroleum hydrocarbons, and diagnostic parameters in sediments from stations at Umm Al-Quwain are presented in Tables 4a, 4b and 5, while detailed concentration of organic contaminants in all stations are presented in Annexes A and B.

Table 4a. Trace elements in sediments from stations at Umm Al-Quwain stations (Ag to Hg)

Sample code	Ag mg kg^{-1}	Al g kg^{-1}	As mg kg^{-1}	Ba mg kg^{-1}	Cd mg kg^{-1}	Co mg kg^{-1}	Cr mg kg^{-1}	Cu mg kg^{-1}	Fe g kg^{-1}	Hg mg kg^{-1}
UAE-7-1-1	0.075	13.6	4.42	176	0.166	4.58	79.7	18.7	9.53	0.0050
UAE-7-1-2	<0.05	21.6	2.82	132	0.108	3.59	31.5	14.7	7.76	0.0010
UAE-7-1-3	0.062	9.26	2.33	65.3	0.096	3.26	78.0	2.98	3.53	0.0017
UAE-7-2-1	0.073	12.7	4.71	147	0.126	4.02	60.6	14.5	8.56	0.0044
UAE-7-2-2	0.061	7.20	2.18	57.4	0.071	2.65	43.1	2.42	2.61	0.0014
UAE-7-2-3	<0.05	23.3	2.67	129	0.115	3.87	60.0	14.9	10.5	0.0013

Table 4b. Trace elements in sediments from stations at Umm Al-Quwain stations (Li to Zn)

Sample name	Li mg kg^{-1}	Mn mg kg^{-1}	Ni mg kg^{-1}	Pb mg kg^{-1}	Se mg kg^{-1}	Sn mg kg^{-1}	Sr mg kg^{-1}	U mg kg^{-1}	V mg kg^{-1}	Zn mg kg^{-1}
UAE-7-1-1	7.11	257	71.2	8.21	<1.25	2.48	1848	1.96	22.4	186
UAE-7-1-2	9.95	229	45.7	33.2	<1.25	1.93	2819	2.43	20.0	44.8
UAE-7-1-3	4.02	164	73.7	2.99	<1.25	<1	4362	2.76	15.5	9.3
UAE-7-2-1	5.62	215	69.7	10.7	<1.25	1.68	2255	1.95	21.5	62.7
UAE-7-2-2	2.92	122	76.3	2.45	<1.25	<1	5102	2.77	12.2	7.2
UAE-7-2-3	9.03	379	47.4	19.2	<1.25	1.93	2346	4.68	25.8	46.9

Table 5. Total organic carbon, hydrocarbons concentrations and diagnostic parameters in sediments at Umm Al-Quwain stations

Sample code	TOC %	TPH equiv. ROPME Oil µg g^{-1} dw	TPH equiv. Chrysene µg g^{-1} dw	TPH equiv. GC-FID µg g^{-1} dw	UCM Aliphatics µg g^{-1} dw	Σ n-C12-C36 µg g^{-1} dw	UCM/n-alk	Σ PAHs ng g^{-1} dw	Parent ΣPAHs ng g^{-1} dw
UAE 7-1-1	0.13	12.0	1.7	26.8	15.8	1.1	14.4	94	9
UAE 7-1-2	0.47	63.0	9.20	142.2	89.7	4.7	19.0	765	93
UAE 7-1-3	0.13	12.0	1.80	25.3	14.9	0.9	17.1	97	10
UAE 7-2-1	0.12	22.0	3.2	49.1	34.8	1.1	32.9	245	21
UAE 7-2-2	0.36	75	11.0	128.1	75.7	4.3	17.5	497	117
UAE 7-2-3	0.29	8	1.2	36.3	18.6	0.4	41.8	236	8

- *Oysters results*

  Oysters are filter feeders organisms exposed to pollutants coming from the water (either dissolved or adsorbed on fine particles) and pollutants re-suspended from the surrounding sediments. Trace elements and persistent organic contaminants, such as PCBs, PAHs, have a high affinity for particulate matter and enter the food web via uptake by the phytoplankton and association with other suspended particles such as detritus and sediments. Therefore, their primary uptake route of contamination is thought to be from ingestion of particulate matter suspended in the overlying waters.

  The concentrations of trace elements in oysters from the stations at Umm Al-Quwain are presented in Tables 6 and 7.

Table 6. Trace elements (Ag to Li) in oyster samples at Umm Al-Quwain stations

	Ag mg kg^{-1}	Al mg kg^{-1}	As mg kg^{-1}	Ba mg kg^{-1}	Cd mg kg^{-1}	Co mg kg^{-1}	Cr mg kg^{-1}	Cu mg kg^{-1}	Fe mg kg^{-1}	Hg mg kg^{-1}	Li mg kg^{-1}
UAE-7-1 St.1 Rock oyster	5.87	36.9	34.7	0.682	2.85	0.243	0.877	289	125	0.071	<0.4
UAE-7-1 St.2 Rock oyster	8.34	38.8	28.7	1.57	3.15	0.259	1.33	304	186	0.079	<0.4
UAE-7-1 St.3 Rock oyster	4.58	31.4	31.3	0.422	2.59	0.195	0.55	225	120	0.069	<0.4
UAE-7-2 St. 1 Pearl Oyster	0.095	83.4	27.7	1.36	7.62	0.284	1.1	12.1	372	0.03	<0.4
UAE-7-2 St.2 Pearl Oyster	0.093	75.9	33.1	1.58	5.67	0.553	1.02	9.14	304	0.027	<0.4
UAE-7-2 St.3 Pearl Oyster	0.068	71.5	26.8	2.73	4.61	0.735	1.08	7.86	305	0.03	<0.4

Table 7. Trace elements (MeHg to Zn) in oyster samples at Umm Al-Quwain stations

	MeHg mg kg^{-1}	Mn mg kg^{-1}	Ni mg kg^{-1}	Pb mg kg^{-1}	Se mg kg^{-1}	Sn mg kg^{-1}	Sr mg kg^{-1}	U mg kg^{-1}	V mg kg^{-1}	Zn mg kg^{-1}
UAE-7-1 St.1 Rock oyster	0.012	4.36	4.27	0.18	3.43	<0.1	30.8	0.196	1.09	3411
UAE-7-1 St.2 Rock oyster	0.01	4.93	1.05	0.321	3.67	<0.1	59.4	0.238	1.24	4239
UAE-7-1 St.3 Rock oyster	0.013	3.83	0.484	0.132	3.11	<0.1	35.3	0.149	1.08	3384
UAE-7-2 St. 1 Pearl Oyster	0.01	35.2	2.59	0.506	4.28	<0.1	65.3	0.212	2.06	1736
UAE-7-2 St.2 Pearl Oyster	0.01	49.5	4.43	0.649	4.31	<0.1	57.6	0.184	1.8	1254
UAE-7-2 St.3 Pearl Oyster	0.011	13.4	5.5	0.862	4.29	<0.1	56.7	0.269	1.75	873

Silver (Ag) and Cu presented substantially higher concentrations in Rock Oysters in the samples collected at Umm Al-Quwain stations UAE 7-1 (Figures 1 and 2), as it was the case for most of the surveyed stations in the Mussel Watch 2014 campaign (ROPME 2016, Report on ROPME Mussel Watch Programme 2014: Trace Metal Screening"). Similar, relatively higher concentrations of these elements in Rock Oysters were also reported in previous studies in the region (ROPME, 2013; IAEA, 2006; de Mora *et al*., 2004) and could be attributed to differences in the accumulation patterns of these elements in the two oyster species. Zinc concentrations in Rock Oysters form station UAE 7-1were relatively increased, but no similar enhancement was found in Oyster species collected from other RSA coastal areas, neither reported in the scientific literature. On the other hand, Cd concentrations in Pearl Oysters from stations UAE 7-2 were relatively higher but these differences cannot be explained, given the variability of the data. No differences were found between the other trace elements concentrations measured in the two Oyster species from the Umm Al-Quwain stations (Figure 1).

Obtained results reinforced the evidence of a difference in the accumulation pattern of Ag and Cu in the two Oyster species in the ROPME Sea Area, but are not supporting the existence of specifically different patterns in the accumulation of other trace elements in the two oyster species.

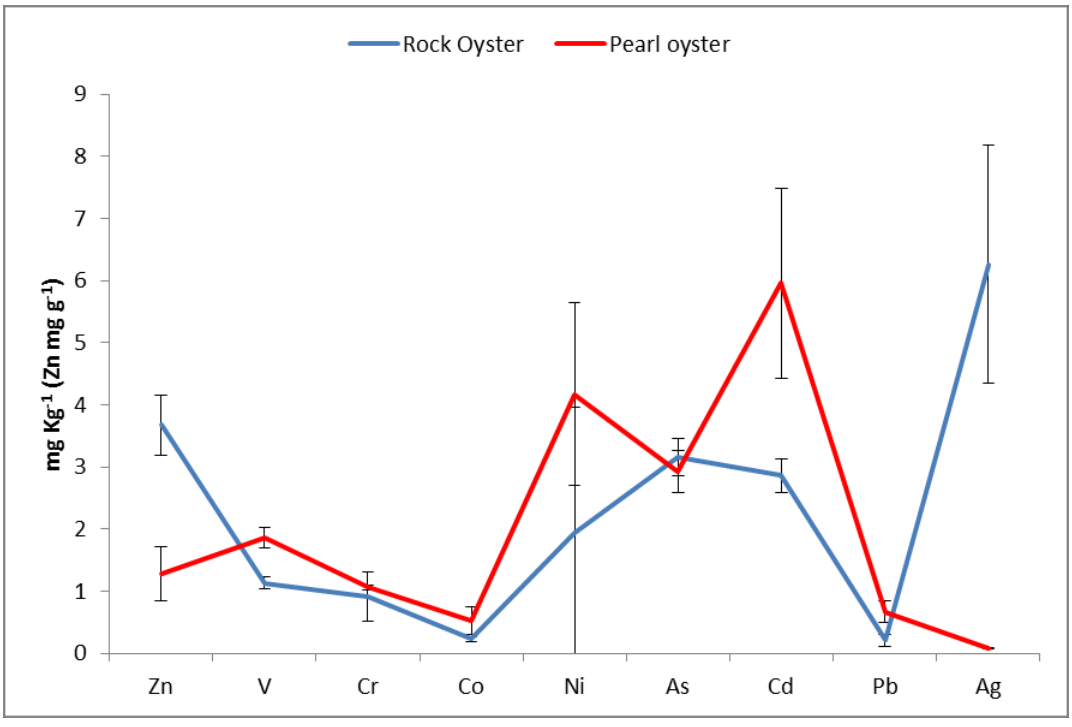

Figure 1. Comparison of trace elements concentrations in Rock and Pearl Oysters from Umm Al-Quwain, UAE stations

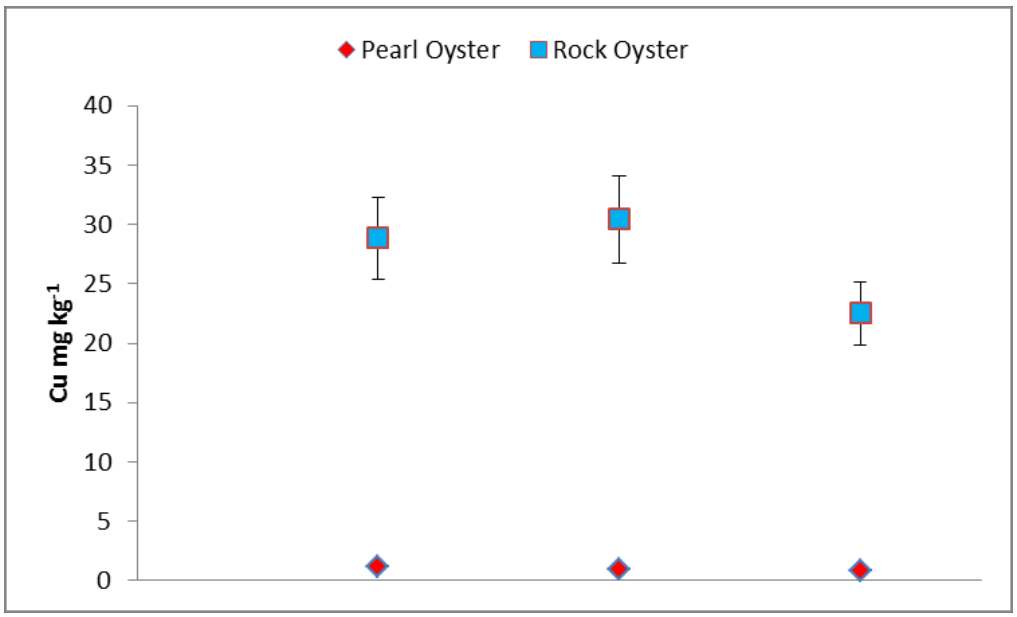

Figure 2. Comparison of Cu concentrations in Rock and Pearl Oysters from Umm Al-Quwain, UAE stations

The concentrations of chlorinated hydrocarbons and petroleum hydrocarbons in the two oyster species from Umm Al-Quwain, UAE stations, are presented in Tables 8 and 9, while detailed concentration of organic contaminants in all stations are presented in Annexes C, D and E.

Table 8. Chlorinated hydrocarbon concentrations (ng g^{-1} dw) in oysters from Umm Al-Quwain, UAE stations

Compounds	**UAE 7-1-1**	**UAE 7-1-2**	**UAE 7-1-3**	**UAE 7-2-1**	**UAE 7-2-2**	**UAE 7-2-3**
	Rock Oyster	**Rock Oyster**	**Rock Oyster**	**Pearl Oyster**	**Pearl Oyster**	**Pearl Oyster**
EOM mg/g	107	110	95	56	47	72
HCB	0.059	0.075	0.056	0.031	0.038	<0.014
α HCH	0.054	0.021	0.038	<0.005	<0.014	0.272
β HCH	<0.033	<0.033	<0.086	0.125	<0.086	0.184
γ HCH-Lindane	0.018	<0.012	<0.012	0.016	0.022	0.126
δ HCH	<0.009	<0.009	0.106	<0.009	<0.022	<0.009
Σ HCHs	0.07	0.02	0.14	0.14	0.02	0.58

Table 8. Chlorinated hydrocarbon concentrations (ng g^{-1} dw) in oysters from Umm Al-Quwain, UAE stations (Contd...)

pp'DDE	0.826	1.498	0.831	1.841	1.188	<0.005
pp'DDD	0.090	0.058	0.066	0.061	<0.037	0.164
pp'DDT	0.053	0.066	0.044	0.101	0.034	<0.001
DDMU	0.015	0.031	0.020	<0.009	<0.009	<0.009
op DDE	0.075	0.099	0.068	0.066	0.068	<0.006
op DDD	0.287	0.178	0.262	0.205	0.022	0.078
op DDT	0.138	0.328	0.096	0.527	0.391	<0.001
Σ DDTs	1	2.3	1.4	2.8	1.7	0.2
Heptachlor	0.048	0.051	0.048	0.053	0.015	<0.006
Aldrin	<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
Endrin	0.206	0.386	0.242	0.385	0.203	0.175
Cis Chlordane	<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
Cis Nonachlor	0.006	0.034	0.006	0.065	0.044	<0.002

Table 8. Chlorinated hydrocarbon concentrations (ng g^{-1} dw) in oysters from Umm Al-Quwain, UAE stations (Contd...)

Trans Nonachlor	<0.075	0.116	0.079	0.218	0.145	<0.028
Heptachlor epox-B (cis)	0.059	0.034	0.047	0.040	<0.014	0.065
Heptachlor epox.A (trans)	0.201	<0.044	<0.117	0.176	<0.117	<0.117
Methoxychlor	<0.129	<0.129	<0.129	<0.129	<0.129	<0.129
a Endosulfan	<0.076	<0.076	<0.028	<0.028	<0.076	<0.076
b Endosulfan	<0.003	<0.003	<0.002	<0.002	<0.003	<0.003
Endosulfan sulfate	<0.084	<0.084	<0.084	<0.084	<0.084	<0.084
Σ 37 PCBs	2	6	2.8	4.7	3.0	0.5

Table 9. Total lipid content and hydrocarbon concentrations in oysters from Umm Al-Quwain, UAE stations

Sample Code	Bivalve type	Lipids mg g^{-1}dw	TPH Equiv. ROPME Oil µg g^{-1} dw	TPH Equiv. Chrysene µg g^{-1} dw	TPH Equiv. GC-FID µg g^{-1} dw	UCM aliphatics µg g^{-1} dw	Σ *n*-C_{12} C_{36} µg g^{-1} dw	ΣPAHs ng g^{-1} dw	parent ΣPAHs ng g^{-1} dw
UAE-7-1-1	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-7-2-1	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

In total, the average lipid content of the Rock Oysters of stations 7-1 was significantly higher than those measured in the Pearl Oysters of stations 7-2 (104 ±8 vs. 58±13 mg g-1 d.w; $p<0.05$) (Table 9). In reference to hydrocarbons, and as it is shown in Figure 3, not significant concentration differences (in mass dry weight) between the two oysters were evidenced for the total petroleum hydrocarbons, UCM, n-alkanes, total PAHs and parent PAHs. Nevertheless, a high variability (high relative standard deviation, RSD) among the 3 sub-sample sites for each oyster species was noticed. Similar to hydrocarbons, organochlorinated compounds, such as, PCBs, DDTs and HCHs (Figure 3), did not exhibit significant concentration differences (in mass dry weight) between the average concentrations of both type of oysters and a high variability was also observed among the three averaged sites.

Table 10. Average concentration results in mass dry weight and relative standard deviation (rsd) for the three samples measured in each sampling station for the two oyster species

Sample code		**AVERAGE n=3**	**RSD %**	**AVERAGE n=3**	**RSD %**
Bivalve type		**Rock Oyster**	**Rock Oyster**	**Pearl Oyster**	**Pearl Oyster**
Lipids	mg g^{-1} dry wt	104	8	58	22
TPH Equiv. ROPME	µg g^{-1} dry wt	28	38	20	29
TPH Equiv. GC	µg g^{-1} dry wt	284	79	281	39
UCM	µg g^{-1} dry wt	200	80	217	44
Σ n-C12-C36	µg g^{-1} dry wt	20	86	10	34
Σ PAHs	ng g^{-1} dry wt	802	29	1238	31
parent Σ PAHs	ng g^{-1} dry wt	111	20	75	33
Σ HCHs	ng g^{-1} dry wt	0.08	79	0.25	119
Σ DDTs	ng g^{-1} dry wt	1.71	28	1.58	81
Σ 37 PCBs	ng g^{-1} dry wt	3.94	50	2.70	78

The average concentrations (n=3) of lipid content and persistent organic contaminants with their standard deviations for the two different oyster species are presented in Figure 3.

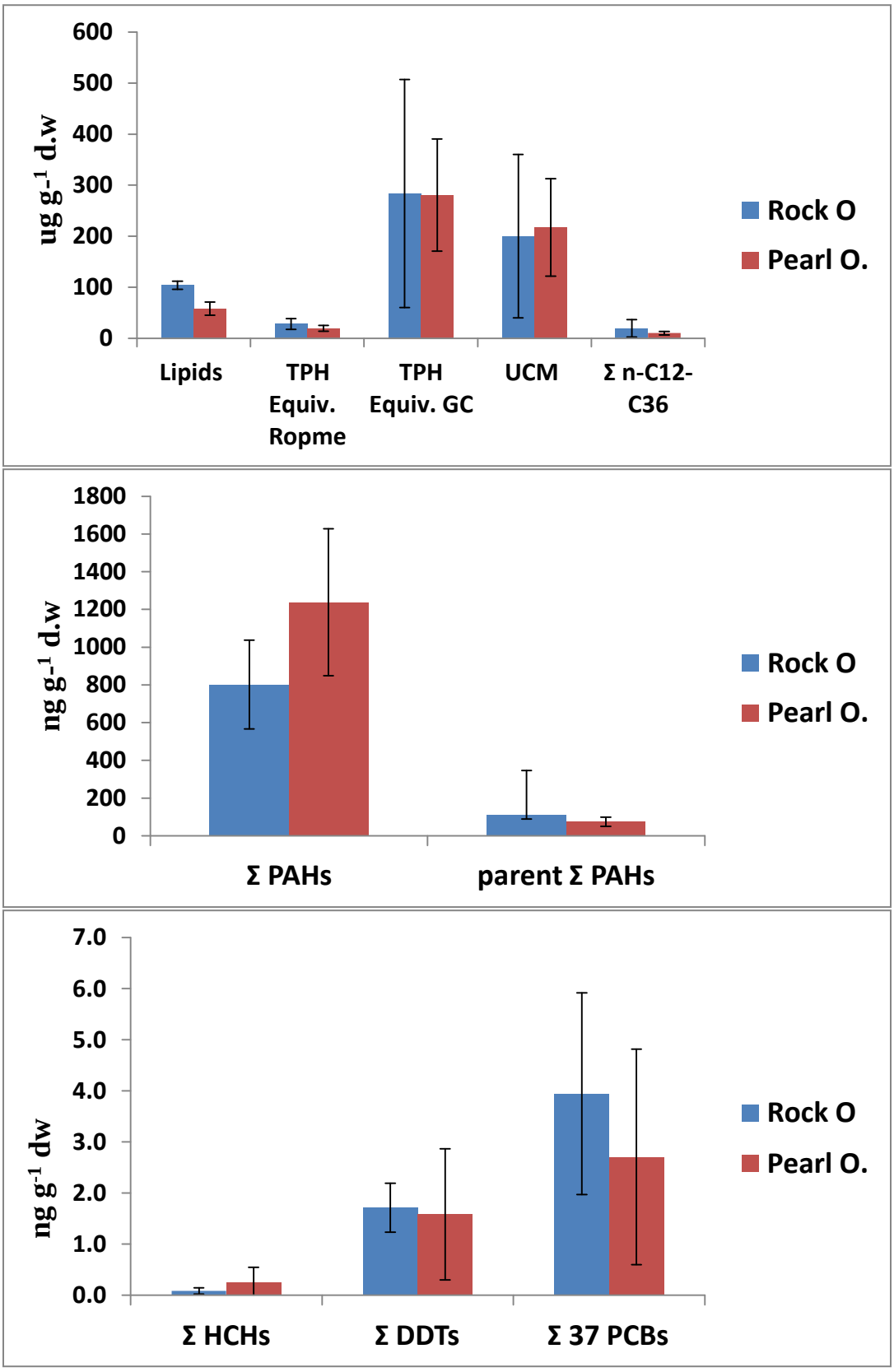

Figure 3. Average concentrations levels (n=3) of lipid content and persistent organic contaminants with their standard deviations for the two different oyster species

It is well-known that tissues rich in lipids, e.g. gonads, accumulate preferentially hydrophobic contaminants, such as POPs because of the highly hydrophobic nature of these contaminants. As the lipid content was significantly different between Rock Oysters and Pearl Oysters, the contaminants concentrations were normalized to the lipid content of each oyster sample, in order to better evaluate existing differences (Table 11).

Table 11. Average normalized-lipid concentration results and relative standard deviation (RSD) for the 3 sample sites of each oyster species

Sample code		**AVERAGE (n=3)**	**RSD %**	**AVERAGE (n=3)**	**RSD %**
Bivalve type		**Rock Oyster**	**Rock Oyster**	**Pearl Oyster**	**Pearl Oyster**
TPH Equiv. ROPME	µg mg^{-1} lipid	0.28	46	0.35	35
TPH Equiv. GC	µg mg^{-1} lipid	2.67	73	5.12	48
UCM	µg mg^{-1} lipid	1.89	74	3.99	52
Σ n-C12-C36	µg mg^{-1} lipid	0.18	81	0.18	45
Σ PAHs	ng mg^{-1} lipid	7.7	30	21.9	37
parent Σ PAHs	ng mg^{-1} lipid	1.08	24	1.30	35
Σ HCHs	ng mg^{-1} lipid	0.001	85	0.004	107
Σ DDTs	ng mg^{-1} lipid	0.016	22	0.030	80
Σ 37 PCBs	ng mg^{-1} lipid	0.037	44	0.050	78

Similar trends are observed for most of the contaminants with some slightly higher normalized- lipid concentrations measured in the pearl oysters (Table 11 and Figure 4). However, due to the high variability measured within the 3 sub-stations for each oyster species, no significant concentration difference was observed for all contaminants between the two species, except for the total PAHs, which appears to be relatively enhanced in Pearl Oysters, while concentrations of the pyrolytic-derived PAHs (parent PAHs) are similar in both species. This tendency suggests a higher bioavailability of dissolved oil-derived PAHs to Pearl Oysters, but more data are needed to test this hypothesis.

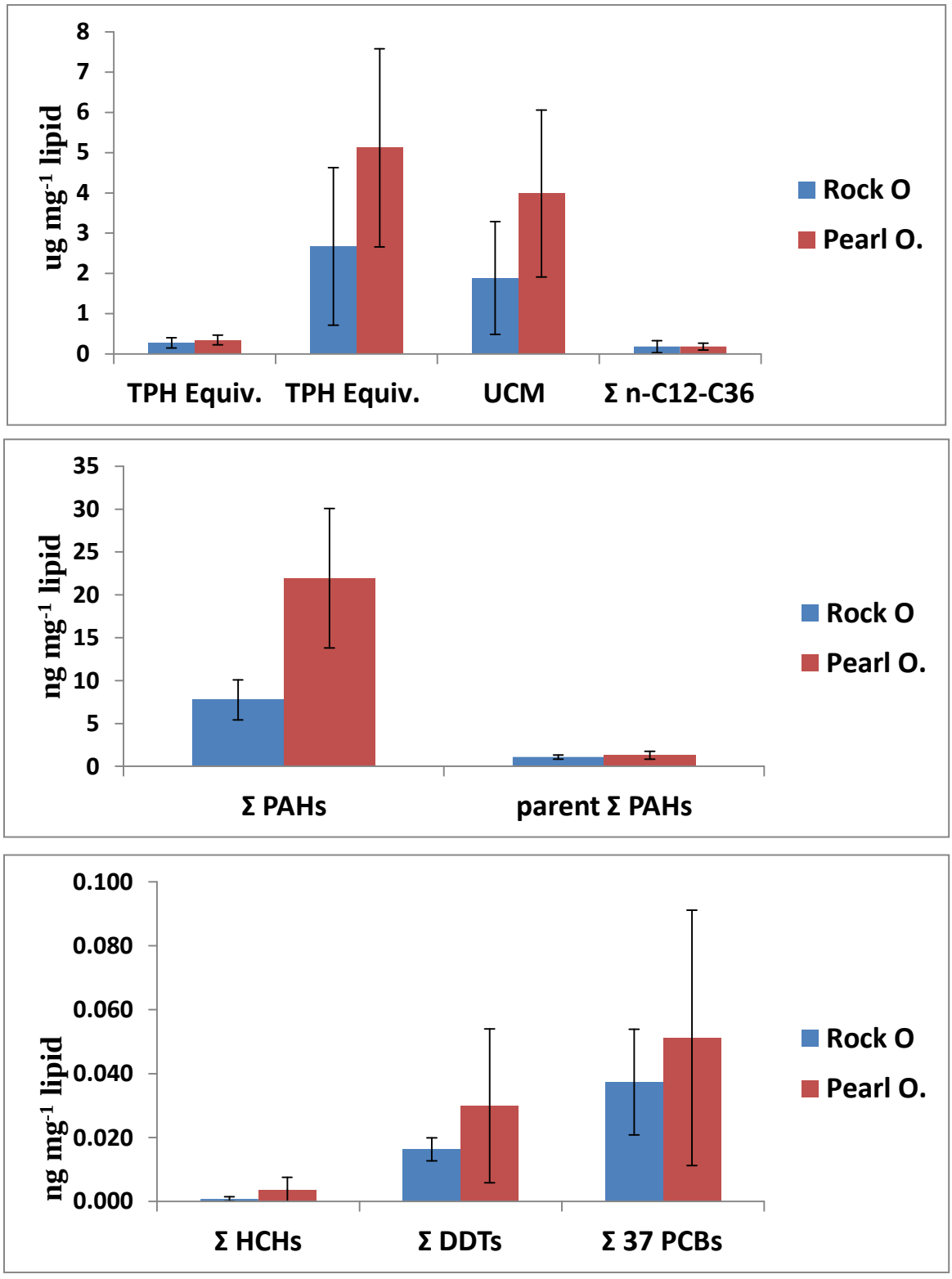

Figure 4. Average normalized-lipid concentration levels (n=3) of persistent organic contaminants with their standard deviations for the two different oyster species

5. CONCLUSION

High variability of trace elements and organic contaminants concentrations was found in the Rock and Pearl Oyster collected from the two sampling sites at Umm Al-Quwain, UAE. Rock Oysters had significantly and consistently higher concentrations of Ag and Cu than Pearl Oysters in the inter-comparison sampling sites. Relatively increased concentrations of these elements in Rock Oysters were also found in all surveyed stations during the present Mussel Watch campaign, as it was reported in previous studies in the ROPME Sea Area.

No significant differences were found in the accumulation of petroleum hydrocarbons and chlorinated hydrocarbons between the two Oyster species. A slight increase of some more petrogenic PAH compounds was noticed in Pearl oysters (while concentrations of the pyrolytic-derived PAHs (parent PAHs) were similar in both species), but the variability of data is very important and the number of samples very small to allow for conclusions. The normalization of organic contaminants concentrations to the lipid content of the organisms, showed relatively higher normalized concentrations of all groups of organic contaminants in Pearl Oysters, but the very important variability of the results within each Oyster species do not allow for conclusions. Furthermore, this result was mainly caused by differences in the lipid content of the organisms (the Rock Oysters had higher lipid content than the Pearl Oysters), which needs further investigation to exclude a possible artifact due to sampling.

The results of the present study suggest that only Ag and Cu appear to have a different accumulation pattern in the two Oyster species, which could be further investigated. For the remaining trace elements and the organic contaminants, no clear conclusions could be drawn on their relative accumulation in the two Oyster species at Umm Al-Quwain station, because of high variability of data for the same species and location.

In order to further investigate contaminants accumulation mechanisms and biological process, a fit-for-purpose laboratory study is needed, addressing the effects of the metabolism, food availability, physiological condition and reproductive cycle on the accumulation of contaminants in the two oyster species.

6. ACKNOWLEDGEMENTS

This was a collaborative project between the IAEA and ROPME, financially supported by both organizations. The Agency is grateful for the support provided to its Marine Environment Laboratory by the Government of the Principality of Monaco.

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Annex A. Concentrations of aliphatic hydrocarbons (ng g^{-1} dw) in sediments from Umm Al-Quwain station, UAE

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

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

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

Annex C. Concentrations of aliphatic hydrocarbons (ng g^{-1} dw) in bivalves from Umm Al-Quwain station, UAE

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

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

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

Annex E. Concentrations of PCBs (ng g^{-1} dw) in oysters from UAE

ng/g^{-1} dw	UAE 7-1-1	UAE 7-1-2	UAE 7-1-3	UAE 7-2-1	UAE 7-2-2	UAE 7-2-3
	Rock Oyster	Rock Oyster	Rock Oyster	Pearl Oyster	Pearl Oyster	Pearl Oyster
PCB 8	0.089	0.386	0.091	0.130	0.120	<0.004
PCB 18	<0.155	0.436	<0.155	0.428	0.435	<0.155
PCB 28	<0.123	0.177	<0.123	<0.123	<0.123	<0.044
PCB 31	0.146	0.361	0.130	0.252	0.186	<0.033
PCB 44	<0.056	0.126	0.160	<0.056	0.059	<0.025
PCB 49	<0.036	<0.036	<0.036	<0.036	<0.083	<0.036
PCB 52	<0.425	<0.425	<0.425	<0.19	<0.19	<0.19
PCB 66/95	0.034	0.063	0.025	0.025	<0.011	<0.011
PCB 87	<0.048	0.091	<0.024	0.118	0.096	<0.024
PCB 97	<0.016	0.059	<0.016	0.356	0.202	<0.016
PCB 99	0.131	0.297	0.116	0.697	0.391	<0.024
PCB 101	<0.115	0.142	<0.115	<0.055	<0.055	<0.055
PCB 105	0.034	0.069	0.028	0.043	<0.027	<0.013
PCB 110 (77)	<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
PCB 126	0.144	0.305	0.142	0.370	0.252	<0.003
PCB 128	0.021	0.062	0.013	0.119	0.080	<0.003
PCB 138	0.241	0.398	0.249	0.192	0.096	<0.031
PCB 149	<0.155	0.209	<0.155	<0.155	<0.063	<0.063
PCB 151	0.054	0.103	0.036	0.024	0.012	<0.004
PCB 153	0.509	0.749	0.511	0.537	0.152	<0.026
PCB 156	0.064	0.069	0.028	0.034	0.029	<0.002
PCB 169	<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
PCB 174	0.025	0.054	0.024	0.119	0.099	<0.004
PCB 177	0.055	0.099	0.058	0.045	0.037	<0.002
PCB 180	0.086	0.081	0.052	0.128	0.067	<0.003
PCB 183	0.036	0.103	0.024	0.202	0.114	<0.004
PCB 187	0.327	0.611	0.323	0.509	0.329	<0.004
PCB 189	0.020	0.019	0.028	0.016	0.013	<0.001

Annex E. Concentrations of PCBs (ng g^{-1} dw) in oysters from UAE (Contd...)

PCB 194	0.009	0.037	0.018	0.033	0.022	<0.002
PCB 195	0.031	0.017	0.034	0.059	0.096	<0.003
PCB 201	<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
PCB 209	0.640	0.892	0.621	0.189	0.095	<0.003

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