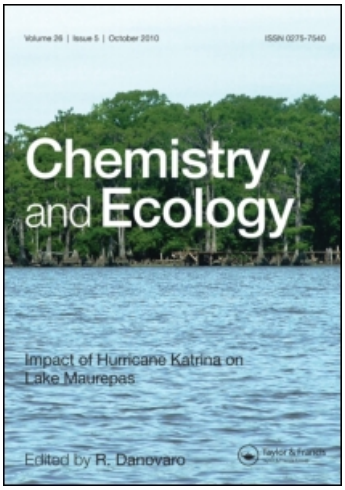

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Assessment of PAHs in water and fish tissues from Great Bitter and El Temsah lakes, Suez Canal, as chemical markers of pollution sources

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Assessment of PAHs in water and fish tissues from Great Bitter and El Temsah lakes, Suez Canal, as chemical markers of pollution sources

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Sea water and fish tissue samples were collected from nine sampling stations from the Great Bitter and El Temsah lakes in the Suez Canal and analysed for polycyclic aromatic hydrocarbon (PAH). The compositions of PAH determined in the dissolved fraction of sea water were measured in order to use them as chemical markers for identifying different sources of PAH pollution in this region. PAHs determined in fish tissues were measured for comparison with human health standards as consumption. The total mean PAHs concentrations in the sea water samples ranged from 0.28 to 39.57 $\mu g\,l^{-1}$ with an overall mean of 10.78 and 12.38 $\mu g\,l^{-1}$ for El Temsah and Bitter Lakes water, respectively. Total PAHs fractions recorded in muscle tissues of all different Osteicthyes fishes collected from Great Bitter lakes ranged from 5.8 to 218.5 $\mu g\,g^{-1}$ with an overall mean of 57.98 $\mu g\,g^{-1}$ during all seasons. However, they ranged from 68 to 623 $\mu g\,g^{-1}$ with an overall mean of 87.69 $\mu g\,g^{-1}$ recorded in El Temsah lake during four seasons (2003–2004). Benzo(a)pyrene was the most dominant PAHs found in the sea water samples from both lakes with an average concentration of 3.8 $\mu g\,l^{-1}$. Dibenzo(a,h)anthracene (DBA) was the most dominant PAHs recorded in fish samples. A maximum of 533 $\mu g\,g^{-1}$ of DBA was recorded in *Dahbana* sp. collected from Bitter lakes during January 2004. However, a maximum of 68.7 $\mu g\,g^{-1}$ was recorded in *Liza carinata* species collected from El Temsah lake during July, 2004. The simultaneous occurrence of isomer ratios PHE/ANT <10 for all stations indicated that the major PAH input to water was from combustion of fossil fuel (pyrolytic source). The average ratios were 1.21 and 12.9 during winter (January 2004) and 4.3 and 8.63 during spring (April 2004) for all water samples of Great Bitter lakes and El Temsah lake, respectively. In addition, the present data demonstrate that PAHs from fossil fuel sources (MW < 178) were the least significant source of PAHs in this region.

Keywords: PAHs; Chemical markers; Suez Canal; Lakes

1. Introduction

The Suez Canal occupies an attractive position worldwide and binds between two different environments: the Mediterranean Sea and the Red Sea. Both of the Mediterranean and Red Sea environments receive oil pollution from anthropogenic sources including chronic discharges

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from oil refineries and loading/unloading operations in addition to accidental sources resulting from oil spills and pipeline leakage. The Mediterranean Sea is more polluted along its coasts than offshore due to the fact that it fringes 18 industrial countries (with higher land-based activities). In contrast, the Red Sea overlooks eight developing countries. Polycyclic aromatic hydrocarbons (PAHs) are a widespread class of environmental chemical pollutants, and some of these are among the most carcinogenic, mutagenic, and toxic contaminants found in aquatic systems [1, 2]. El Nemr *et al.* [3] recorded an average of 0.105 ng g^{-1} (wet weight) of 20 aliphatic hydrocarbons and an average of 5452 ng g^{-1} (wet weight) of 16 PAHs in mussels (*Brachidontes* sp.) collected from 11 sampling stations covering 450 km of the Egyptian Red Sea coasts. El Sikaily *et al.* [4] found that the concentrations of total aliphatic (average 180 ng g^{-1}; wet weight) and PAHs (average 8180 ng g^{-1}; wet weight) were recorded in bivalves (*Modilus auriculatus* and *Donax* sp.) collected from 20 stations along the Mediterranean Sea coast of Egypt (about 500 km).

Thus, the Suez Canal is considered as an exchange water system between these two different environments. The pollution in the Suez Canal province must be studied because we need many

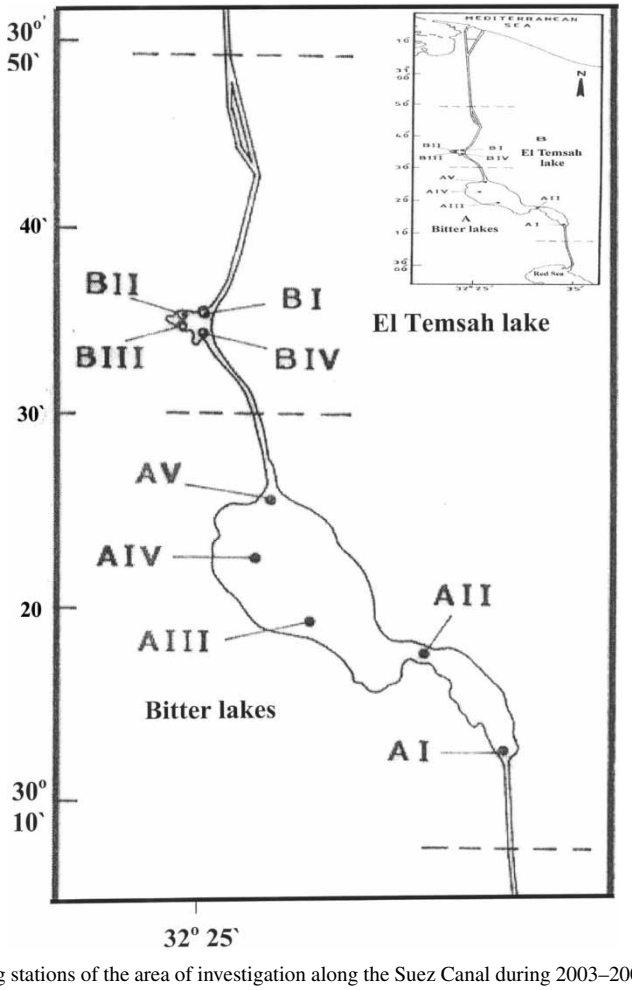

Figure 1. Sampling stations of the area of investigation along the Suez Canal during 2003–2004: A = Great Bitter lakes (AI = Shandoura; AII = Kabrite; AIII = Fanara; AIV = Fayed and AV = Deversoir) and B = El Temsah lake (BI, BII, BIII, and BIV).

interpretations to develop a solid base of information on which to build future monitoring efforts in this area. The total annual oil tanker traffic in the Suez Canal route amounts to 2472 vessels. The quantity of oil is estimated at ~98 million tons during 1996 [5].

El Temsah lake is one of the main wetlands in the Suez Canal region and the main source of fish for the area. The lake is the end-point of several wastewater effluents. It lies 76 km from the northern part of the Suez Canal (Port Said). It is impacted by agriculture, domestic wastes, and shipping activities resulting from the governorate of Ismailia (about 3 million persons). On the other hand, Great Bitter lakes are bordered by the cities of Deversoir, located 98 km to the south, and Shandoura, located 135 km to the north. These lakes play a vital role as the major transit area for ships passing through the Suez Canal (figure 1). Tundo *et al.* [6] studied the PAHs in sediments of El Temsah lake using an HP 6890 gas chromatograph coupled to a mass spectrometer. They found that benzo(b + k + j)fluoranthene had the highest concentrations in almost all sampling stations. However, fluorene was the smallest detected concentration in almost all stations. They also indicated that the concentrations of PAH contaminants monitored in El Temsah lake are rather alarming. Mostafa [7] determined the concentrations of PAHs in some sea foods caught from El Temsah lake. The tested samples were tilapia fish (*Oreochromis aureus*), crabs (*Portuns pelagicus*), bivalves (V*enerupis decussata*), clams (*Strombus tricornis*), and gastropopds (*Munes* sp.). The results showed that crabs contained significantly higher concentrations of both total and carcinogenic PAHs ranging from 1318.6 to 3667.4 and 1230.3 to 3442.2 mg kg^{-1}, respectively. Meanwhile, clams contained significantly lower levels with mean values of 28.4 mg kg^{-1} for total PAHs and 24.4 mg kg^{-1} for carcinogenic PAHs. The most frequently detected PAHs in the tested samples were indeno (1,2,3-cd)pyrene, followed by benzo(a)pyrene, dibenzo(a,h)anthracene, and benzo(b)fluoranthene, which are characterized as carcinogenic compounds.

The present investigation aimed to use PAHs recorded in water and fish samples collected from El Temsah and Bitter Lakes as chemical markers for identification of different sources of oil pollution in this area.

2. Materials and methods

2.1 *Sampling actvities*

Surface water samples (1 m) were collected from El Temsah and Great Bitter lakes (figure 1) using a Nisken bottle at each of the nine stations during September 2003 to August 2004). Water samples were extracted in the field, stored at 4 °C, and transported to the laboratory for PAHs analysis using well-established techniques [8]. In addition, fish samples were collected at two sites: Shandoura region (Great Better lakes) and El Temsah lake during September 2003 to July 2004. Gills and muscles of Osteicthyes fishes were collected and stored in pre-cleaned aluminium containers and frozen at −20 °C until analysis. The samples were analysed for PAHs following the same techniques applied for water samples.

2.2 *Extraction*

Sea water samples were extracted three times with 60 ml of dichloromethane in a separating funnel. Sample extracts were combined and concentrated by rotary evaporation to 5 ml. Finally, samples were concentrated under a gentle stream of pure nitrogen to a final volume of 1 ml.

Osteicthyes fish samples were freeze-dried and pooled (10 individuals per station), and then 30 g was Soxhlet-extracted with 250 ml of *n*-hexane for 8 h and then re-extracted for 8 h into

250 ml of dichloromethane [9]. These extracts were combined and concentrated down using a rotary evaporator at 30 °C followed by concentration with a nitrogen gas stream down to a volume of 1 ml.

2.3 *Spectrofluorometric analysis*

Total petroleum hydrocarbons were measured in water and fish samples using the UVF-spectrofluorometer (Sequoia-Turner Model 450) at 360 nm excitation and 415 nm emission according to Parsons *et al.* [10]. The analyses were performed as a chrysene unit. A calibration curve was determined by analysing five separate concentrations (0.5, 1, 2, 4, and 6 mg l^{-1}) of chrysene using *n*-hexane as the solvent. Clean-up and fractionation was performed prior to gas chromatographic/flame ionization detector (GC/FID) analysis by passing the extract through a silica/alumina column.

2.3.1 Adsorption column chromatography. The chromatography column was prepared by slurry packing 20 ml (10 g) of silica, followed by 10 ml (10 g) of alumina and finally 1 g of anhydrous sodium sulphate. Elution was performed using 25 ml of hexane to yield the first fraction (F1, which contains the aliphatic hydrocarbons), then 40 ml of hexane/dichloromethane (90:10) followed by 20 ml of hexane/dichloromethane (50:50) (which combined contain PAHs). The methodology used for the fish samples should be similar to the method in this section.

2.4 *Gas chromatography*

All samples were analysed by a Hewlett Packard 5890 series II GC gas chromatograph equipped with a flame ionization detector (FID). The instrument was operated in splitless mode (3 μl splitless injection) with the injection port maintained at 290 °C and the detector maintained at 300 °C. Samples were analysed on a fused silica capillary column HP-1, with 100% dimethyl polysiloxane (30 m length, 0.32 mm i.d., 0.17 μm film thickness). The oven temperature was programmed from 60 to 290 °C, changing at a rate of 3 °C min^{-1} and maintained at 290 °C for 25 min. The carrier gas was nitrogen flowing at 1.2 ml min^{-1}.

2.5 *Quantification*

A stock solution containing the following PAHs was used for quantification: naphthalene, acenaphthylene, acenaphthene, fluorene, phenathrene, anthracene, fluoranthene, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, pyrene, benzo(a)pyrene, dibenzo(a,h)anthracene, benzo(ghi)perylene, and indeno(1,2,3-cd) pyrene by dilution to create a series of calibration standards of PAHs at 0.1, 0.25, 0.5, 0.75, 1.0, 2.0, 5.0, and 10 μg ml^{-1}. The detection limit was approximately 0.01 μg ml^{-1} for each PAH.

For analytical reliability and recovery efficiency of the results, six analyses were conducted on PAH reference materials, HS-5 and 2974 (provided by EIMP-IAEA).The laboratory results showed a recovery efficiency ranging from 92 to 111% with a coefficient of variation (CV) of 8–14% for all studied pollutants (16 PAHs fractions). All solvents were of pesticide grade purchased from Merck, and appropriate blanks (1000-fold concentrates; two for each batch of analysis for both of water and fish samples) were analysed.

3. Results and discussion

Table 1 indicates that the total concentration of dissolved/dispersed petroleum hydrocarbons (DDPH) in water of the investigated area ranged from 14.49 to 23.69 $\mu g\,l^{-1}$, with an average of 18.27 $\mu g\,l^{-1}$. The maximum average of DDPH over the period of monitoring is 21.22 $\mu g\,l^{-1}$ recorded at Kabrite (figure 2). This region is famous for its shipping activities [5]. As shown in table 2, a maximum average concentration of 9.23 $\mu g\,g^{-1}$ of total content of accumulated hydrocarbons was recorded in muscle of *Rhabdosarguss haffara* collected from the Shandoura region (Great Bitter lakes). However, the average distribution of concentrations recorded in fish tissues was higher in El Temsah lake than that recorded in Bitter lakes for all species of fish species using the UVF technique (figure 3).

The residuals of 16 PAH members were identified in water (table 3). Flouranthene was the most dominant PAHs in Bitter lakes, with a maximum of 5.53 $\mu g\,l^{-1}$ recorded for offshore water from the Fayed station. However, benzo(a)pyrene was the most dominant PAHs in El Temsah lake, with a maximum of 3.53 $\mu g\,l^{-1}$ recorded at El Temsah I during April 2004 (spring season). Figure 4 indicates the average distribution of individual PAHs in water collected from both areas during winter and spring 2004. It is obvious that

Table 1. Concentrations ($\mu g\,l^{-1}$) of total dissolved petroleum hydrocarbons determined in water of Bitter and El Temsah lakes during 2003–2004 using the UVF technique.

	2003				2004								
Location	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	July	Aug.	Av.	±S.D.
Shandoura	3	16.1	54.7	13.1	11.8	28.2	21.3	11	22.3	22	23	20.6	13.4
Kabrite	3.47	9.75	55.5	22.1	22.9	48.3	8.58	14.8	14.9	21.8	13.3	21.4	16.3
Fanara	3.88	12.5	65.4	7.5	4.71	55.7	9.08	13.8	11.4	22.3	17.6	20.3	20.7
Fayed	3.35	6.29	74.8	5.93	8.17	23.1	5.08	12	13.8	31.5	12.1	17.8	20.7
Deversoir	2.27	7.58	65.8	6.33	10.8	n.r	10	12.2	10.3	30.2	13.8	16.9	18.7
Temsah I	2.63	15.9	n.r	6.5	6.83	35.3	8.58	13.3	33.9	7.83	14	14.5	11.3
Temsah II	4.25	3.25	55.2	4.25	7.08	41	8.25	14.8	6.08	7.42	8	14.5	17.2
Temsah III	0.85	6.58	46.2	29.3	n.r	45.3	13.3	12.8	27.3	16.4	10.8	20.9	15.6
Temsah IV	1.83	9.83	n.r	34.3	n.r	42.4	14.3	14.3	n.r	15.8	7	17.5	13.8

Note: Av.: average; n.r.: not recorded; S.D.: standard deviation.

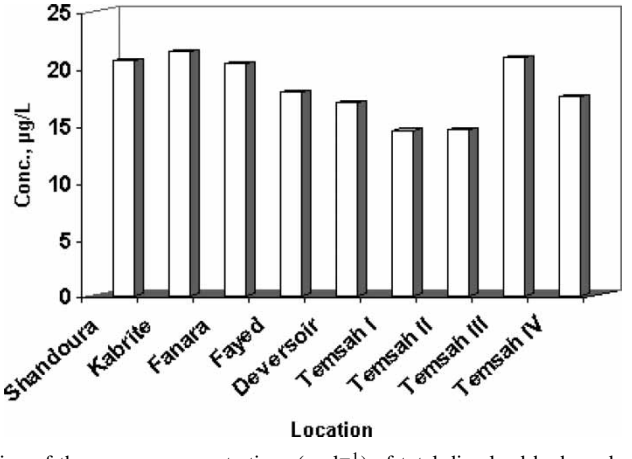

Figure 2. Distribution of the average concentrations ($\mu g\,l^{-1}$) of total dissolved hydrocarbons in water samples collected from the Bitter and El Temsah lakes during 2003–2004 using the UVF technique.

Table 2. Concentration ($\mu g\, g^{-1}$) of total petroleum hydrocarbons recorded in fish species collected from Bitter and El Temsah lakes during September 2003, April 2004, and July 2004 using the UVF technique.

	Bitter lake				El Temsah lake			
Species	Sep.	April	July	Av.	Sep.	April	July	Av.
Helili (G)	n.r.	n.r.	23.21	23.21	1.42	n.r.	6.99	4.206
Helili (M)	n.r.	n.r.	3.61	3.61	2.43	n.r.	6.08	4.255
S. rivulatus (G)	6.10	n.r.	22.09	14.10	18.40	19.46	29.09	22.300
S. rivulatus (M)	2.96	n.r.	3.15	3.06	4.19	3.36	6.17	4.575
S. luridus (G)	1.64	n.r.	n.r.	1.64	n.r.	n.r.	n.r.	n.c.
S. luridus (M)	2.96	n.r.	n.r.	2.96	n.r.	n.r.	n.r.	n.c.
Dahbana (G)	n.r.	n.r.	15.67	15.67	5.30	n.r.	n.r.	5.300
Dahbana (M)	n.r.	n.r.	6.46	6.46	3.91	n.r.	n.r.	3.910
L. carinata (G)	2.14	9.85	11.85	7.95	3.99	16.04	40.51	20.180
L. carinata (M)	0.16	1.98	5.88	2.68	1.05	6.00	2.30	3.117
Lutjauns sp. (G)	2.46	n.r.	21.60	12.03	2.46	n.r.	n.r.	2.460
Lutjauns sp. (M)	n.r.	n.r.	7.43	7.43	n.r.	n.r.	n.r.	n.c.
R. haffara (G)	8.79	22.90	2.40	11.36	n.r.	n.r.	n.r.	n.c.
R. haffara (M)	2.40	2.67	1.45	2.17	n.r.	n.r.	n.r.	n.c.
L. aurata (G)	n.r.	4.10	n.r.	4.10	n.r.	25.28	11.77	18.530
L. aurata (M)	n.r.	2.44	n.r.	2.44	n.r.	9.21	5.24	7.229
Tilapia zilli (G)	n.r.	n.r.	n.r.	n.c.	n.r.	52.54	12.49	32.520
Tilapia zilli (M)	n.r.	n.r.	n.r.	n.c.	n.r.	2.26	4.95	3.606

Note: S: Siganus, L: Liza, R: Rhabdosarguss, G: gills, M: muscles; Sep.: September (autumn 2003), April: spring 2004, July: summer 2004; n.r.: not recorded, n.c.; not calculated because no data were available.

the concentrations of total PAHs decreased towards the northern part of the Canal, with a minimum concentration being recorded at Deversoir ($16.92\, \mu g\, l^{-1}$). The trend was different in El Temsah region as a semi-closed region with an average of $16.84\, \mu g\, l^{-1}$ reflecting domestic and/or agricultural activities. It is evident that PAHs concentrations was higher during April (spring season) with the dominance of benzo(a)anthracene as a 4-ring PAH compound.

The concentration of PAH patterns differs according to the emission sources, and several PAH concentration diagnostic ratios have been extensively used in order to identify and

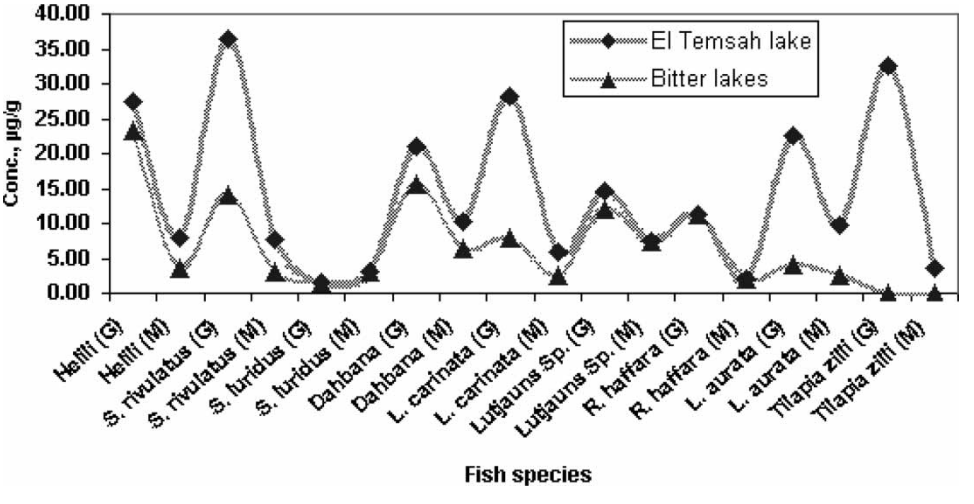

Figure 3. Distribution of the average concentrations recorded in fish tissues collected from Bitter and El Temsah lakes during 2003–2004 using the UVF technique.

Table 3. Concentration ($\mu g\,l^{-1}$) of PAHs fractions recorded in water samples collected from El Temsah and Bitter lakes during January and April 2004.

		Bitter lakes								El Temsah lake			
		Shandoura		Kabrite	Fanara		Fayed		Deversoir	I	II	III	IV
Compound	Date	In	Off	Off	In	Off	In	Off	Off	Off			
Fluorene	Jan.	0.06	0.07	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.04	n.d.	n.d.
	April	n.d.	n.d.	n.d.	0.01	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Phenanthrene	Jan.	0.11	0.12	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.05	0.10
	April	0.12	0.01	0.16	0.16	0.13	0.17	0.23	0.11	0.13	0.12	0.13	0.16
Anthracene	Jan.	0.09	0.10	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.01
	April	0.03	0.04	0.05	0.05	0.02	0.03	0.05	0.02	0.01	0.02	0.02	0.02
Fluoranthene	Jan.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	1.21	2.58
	April	3.14	n.d.	2.07	2.42	2.27	2.43	5.53	2.08	2.49	2.38	2.68	3.08
Pyrene	Jan.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.18	0.63
	April	2.61	n.d.	1.19	0.52	0.98	0.82	3.63	0.99	1.06	0.95	1.58	1.71
Benzo(a)	Jan.	0.79	n.d.	n.d.	0.55	0.29	n.d.	1.78	n.d.	n.d.	n.d.	0.28	0.82
anthracene	April	3.10	n.d.	1.17	18.7	1.90	1.62	6.01	1.50	3.53	2.54	2.45	3.28
Chrysene	Jan.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.11	n.d.	n.d.	n.d.	0.31	0.17
	April	1.61	n.d.	0.84	17.6	0.92	0.90	3.19	0.92	1.96	1.66	1.51	1.92
Benzo(b)	Jan.	0.10	n.d.	n.d.	0.07	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
fluoranthene	April	0.41	0.13	0.31	0.02	0.14	0.11	0.32	0.06	0.49	0.10	0.11	n.d.
Benzo(k)	Jan.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.03
fluoranthene	April	0.03	0.05	0.02	n.d.	n.d.	n.d.	0.09	0.02	0.12	0.02	0.03	0.02
Benzo(a)pyrene	Jan.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.01	n.d.	n.d.	n.d.	n.d.	n.d.
Dibenzo(a,h)	Jan.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.04	n.d.	n.d.	n.d.	n.d.	n.d.
anthracene	April	0.07	0.08	0.08	n.d.	0.08	n.d.	0.16	n.d.	0.07	0.05	0.06	0.06
Benzo(ghi)perylene	Jan.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.02	0.03
	April	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.01	n.d.	n.d.	0.01	n.d.	n.d.
Indeno(1,2,3-cd)	Jan.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.002	n.d.	n.d.	n.d.	n.d.
pyrene	April	n.d.	0.03	n.d.	0.02	n.d.	n.d.	n.d.	0.05	0.04	n.d.	0.02	0.05

Note: In: inshore; Off: offshore; Jan.: January; n.d.: below detection limit.

quantify the contribution of each source of contamination to the specific compartments [11]. They stated that the general distribution of the PAHs in all water samples reflects the high contribution of pyrolytic sources because of the predominance of parent PAHs over their alkylated derivatives. In general, the most important input of PAHs in the investigated area is from atmospheric fallout of oil refinery products via pyrolytic combustion, shipment activities, loading/unloading operations of oil, and natural seeps. Ratio values such as phenanthrene/anthracene (PHE/ANT) and fluoranthene/pyrene (FLU/PYR) had been used by different workers to identify the origin of hydrocarbons [12–14]. Petroleum often contains more phenanthrene relative to anthracene where phenanthrene is a more thermodynamically stable tricyclic aromatic isomer than anthracene. The low PHE/ANT ratio (<10) indicated that the major PAH input was from combustion of fossil fuel, while the high PHE/ANT ratio (>10) suggested that the major PAH was from petrogenic inputs. In addition, a FLU/PYR ratio of less than 1 suggested that the origin of PAH was attributed to petrogenic inputs, and values greater than 1 were related to a pyrolytic origin [15]. As shown in table 4 and figure 5, most of the evidence supports that at a majority of sites sampled during this study in spring (April 2004) and winter (January 2004), the major source of PAHs measured in the water column is from pyrogenic. The occurrence of isomer ratios PHE/ANT <10 for all stations indicated that the major PAH input was from combustion of fossil fuel (pyrolytic source) with an average ratio of 0.3 and 3.23 for Bitter and El Temsah lakes, respectively, during January 2004. However, this ratio amounted to 8.86 and 8.63 for Bitter and El Temsah lakes, respectively, during April 2004. This conclusion is further supported because the FLU/PYR ratio

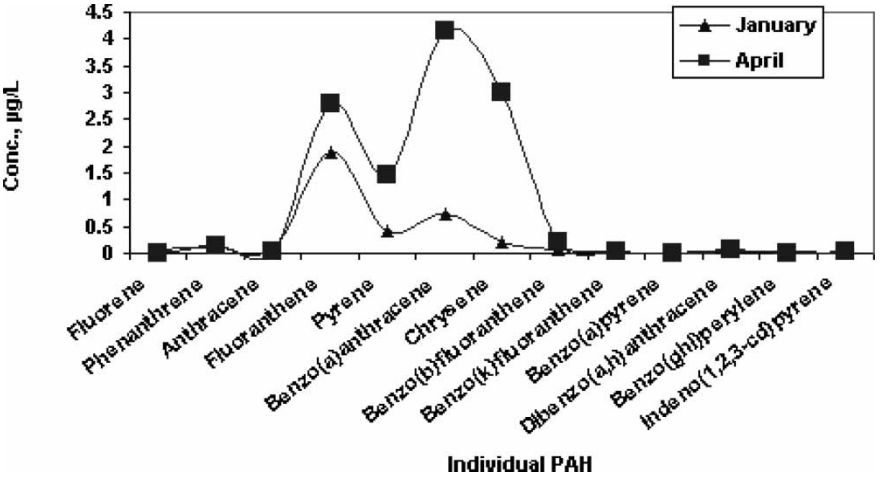

Figure 4. Distribution of the average concentrations of individual PAHs measured in water samples of Bitter and El Temsah lakes during January and April 2004.

was >1 for most sites, with an average value of 2.05 for El Temsah lake during January 2004 and an average ratio of 2.06 and 2.09 for bitter and El Temsah lakes, respectively, during April 2004. However, there were two sites in which the PHE/ANT ratio was >10: Temsah I (April 2004) and IV (January 2004). These data indicated that the major source of PAHs was oil spills.

The TCOMB (sum of PAHs with a molecular weight >178 includes phenanthrene, anthracene, fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, benzo(ghi)perylene, dibenzo(a,h)anthracene, and

Table 4. Percentage concentrations of different PAHs fractions recorded in water samples collected from El Temsah and Bitter lakes during January and April 2004.

		Bitter lakes								El Temsah lake			
		Shandoura		Kabrite	Fanara		Fayed		Deversoir				
Factor	Date	(In)	(Off)	Off	(In)	(Off)	(In)	(Off)	(Off)	I	II	III	IV
T PAHs	Jan.	1.14	0.28	n.c.	0.61	0.29	n.c.	1.9	0.002	n.c.	n.c.	0.3	0.82
	April	11.1	0.35	5.89	39.6	6.45	6.09	19.2	5.76	9.92	7.85	8.58	10.3
T Carc PAHs	Jan.	0.88	n.c.	n.c.	0.61	0.29	n.c.	1.82	0.002	n.c.	n.c.	0.3	0.8
	April	3.59	0.24	1.56	18.8	2.13	1.73	6.51	1.62	4.14	2.69	2.64	3.39
% T Carc	Jan.	77.3	n.c.	n.c.	100	100	n.c.	94	100	n.c.	n.c.	14	19
PAH/T PAHs	April	32.2	69.8	26.4	47.5	33.0	28.5	33.8	28.1	41.7	34.3	30.8	32.9
PHE/ANT	Jan.	1.21	1.21	n.c.	n.c.	n.c.	n.c.	n.c.	n.c.	n.c.	n.c.	n.c.	13
	April	3.69	0.32	2.90	3.34	7.60	5.29	5.03	7.25	11.2	7.82	7.23	8.26
FLU/PYR	April	1.20	n.c.	1.74	4.65	2.31	2.97	1.53	2.09	2.35	2.51	1.70	1.80
BaA/CHR	Jan.	n.c.	n.c.	n.c.	n.c.	n.c.	n.c.	15.7	n.c.	n.c.	n.c.	0.89	12.9
	April	1.92	n.c.	1.39	1.06	2.07	1.80	1.89	1.63	1.80	1.53	1.62	1.71
TCOM	Jan.	1.08	0.21	n.c.	0.61	0.29	n.c.	1.94	n.c.	n.c.	n.c.	2.1	4.4
TFPAH	Jan.	0.06	0.07	n.c.	n.c.	n.c.	n.c.	n.c.	n.c.	n.c.	0.04	n.c.	0.01
	April	22.3	0.69	11.8	79.1	12.9	12.2	38.5	11.5	19.8	15.7	17.2	20.6

Note: In: inshore; Off: offshore; Tcarc: (benzo(a)anthracene + benzo(b)fluoranthene + benzo(a)pyrene + dibenzo(a,h)anthracene + Indeno (1,2,3-cd)pyrene); PHE = phenanthrene; ANT = anthracene; TCOM = sum of PAHs come from pyrolysis processes (MW > 178); TFPAH = sum of PAHs come from fossil (MW < 178); n.c. = not calculated due to one or both concentrations being below the detection limit.

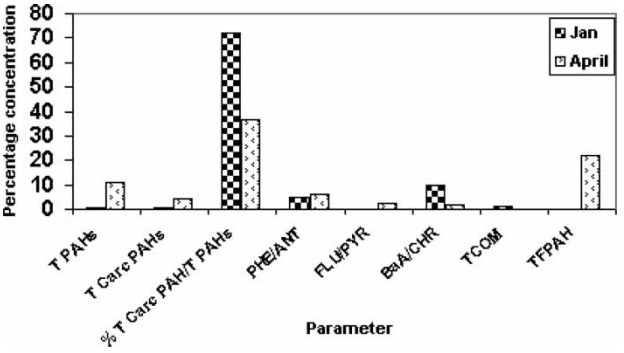

Figure 5. Diagram for percentage concentration of individual PAHs measured in water samples collected from Bitter and El Temsah lakes during January and April 2004.

indeno(1,2,3-cd)pyrene) concentrations ranged from 0.002 to 4.37 $\mu g\,l^{-1}$ representing an average of 98% of total PAHs during winter (January 2004). TF-PAHs (sum of PAHs with molecular weight < 178 includes naphthalene, acenaphthylene, acenaphthene, and fluorene) ranged from 0.01 to 0.07 $\mu g\,l^{-1}$ representing an average of 0.04% of the total anthropogenic PAHs (table 4 and figure 5).

The benzo(a)anthracene/chrysene (BaA/CHR) ratio has also been suggested to identify PAH sources, and this ratio tended to increase as the petrogenic contribution decreased. The ratio values for crude petroleum and fuel oil ranged from 0.24 to 0.4 [16]. The BaA/CHR ratio in this study ranged between 1.06 and 15.74 and between 0.893 and 4.69 for Bitter lake and El Temsah lakes, respectively, during the study period.

The sum of six carcinogenic PAHs (TPAH*CARC*; sum of BaA + BbF + BaP + InP + DBA) recommended by IARC [17] was the highest at Fanara station (inshore water) showing a concentration of 18.75 $\mu g\,l^{-1}$ (table 4). The average percentage of TPAH*CARC* ranged from 36.58 to 71.9% of total PAHs during the period of study.

The average background value for uncooked fish ranges from 0.01 $\mu g\,kg^{-1}$ to 1 $\mu g\,kg^{-1}$ for individual PAHs [18]. Benzo[a]pyrene has been chosen as a general indicator of total PAHs in a given sample. The Joint FAO/WHO Expert Committee on Food Additives has adopted a specification, which requires that the concentration of benzo[a]pyrene should not exceed a limit of 10 $\mu g\,kg^{-1}$. This value is much higher than the average of 0.523, 1.29, 0.872, and 0.508 $\mu g\,g^{-1}$, recorded respectively during September 2003, January 2004, April 2004, and July 2004 in all fish species of the investigated area, indicating a low level of contamination (tables 5 and 6). Figure 6 shows a comparison between TPAHs recorded in the same species of fish tissues collected from both El Temsah and Bitter lakes. It is obvious that contamination by PAHs differs according to kind of fish species, where *Dahbana*, *Helli*, and *L. aurata* species collected from El Temsah region have higher TPAHs than that recorded in Bitter lakes. However, the reverse was found for *R. haffara* and *L. carinata* species. THC includes aliphatic and aromatic components as well plus the unresolved complex mixture (UCM). Concentrations lower than 10 $\mu g/l$ in the water column from industrial effluent have been shown to induce MFO (mixed-function oxidase enzyme) system and may have a chronic exposure issue [19]. This enzyme could clearly affect the levels of hydrocarbon contamination in fish tissues.

The present results showed that the maximum concentrations of 623 and 81.4 $\mu g\,g^{-1}$ for TPAHs and TCARC PAHs recorded respectively in different fish species of the area of our investigation were very much below that given by Mostafa [7] during 2002.

Table 5. Average concentration ($\mu g\, g^{-1}$) of PAHs fractions recorded in fish tissue collected from El Temsah region during September 2003, January 2004, April 2004 and July 2004.

		L. carinata		*R. haffara*	*Dahbana*		*S. luridus*		*T. zilli*		S. rivulatus		*Helli*		L. aurata	
Compound	Date	G	M	M	G	M	G	M	G	M	G	M	G	M	G	M
Naphthalene	Sep.	n.d.	n.d.	n.r.	0.084	n.d.	n.r.	n.r.	n.r.	n.r.	n.d.	n.d.	0.364	n.d.	n.r.	n.r.
	April	n.d.	n.d.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.d.	0.44	n.d.	n.d.	n.r.	n.r.
Acenaphthylene	Sep.	5.060	n.d.	n.r.	n.d.	n.d.	n.r.	n.r.	n.r.	n.r.	n.d.	n.d.	n.d.	n.d.	n.r.	n.r.
	April	n.d.	n.d.	n.r.	n.r.	n.r.	n.r.	n.r.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	4.188
Acenaphthene	Sep.	n.d.	0.03	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.d.	0.434	0.21	n.d.	n.r.	n.r.
	April	n.d.	n.d.	n.r.	n.r.	n.r.	n.r.	n.r.	19.54	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Fluorene	Sep.	6.161	2.34	n.r.	16.87	4.06	n.r.	n.r.	n.r.	n.r.	28.34	6.31	4.0	3.7	n.r.	n.r.
	April	n.d.	n.d.	n.r.	n.r.	n.r.	n.r.	n.r.	n.d.	n.d.	10.28	n.d.	n.d.	n.d.	n.d.	2.28
	July	2.13	n.d.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.d.	0.42	2.43	0.990	n.r.	n.r.
Phenanthrene	Sep.	9.26	4.77	n.r.	20.56	8.27	n.r.	n.r.	n.r.	n.r.	46.05	11.94	7.1	6.3	n.r.	n.r.
	Jan.	3.96	n.d.	n.d.	n.r.	n.r.	n.d.	n.d.	n.d.	n.d.	3.82	n.d.	n.r.	n.r.	n.r.	n.r.
	April	n.d.	n.d.	n.r.	n.r.	n.r.	n.r.	n.r.	3.914	n.d.	n.d.	n.d.	0.12	n.d.	n.d.	4.22
	July	6.29	n.d.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.d.	1.44	1.7	n.d.	n.r.	n.r.
Anthracene	Sep.	8.45	4.92	n.r.	17.91	7.54	n.r.	n.r.	n.r.	n.r.	42.39	10.91	n.r.	n.r.	n.r.	n.r.
	Jan.	4.82	n.d.	n.d.	n.r.	n.r.	n.d.	n.d.	n.d.	n.d.	3.97	n.d.	2.47	0.88	n.r.	n.r.
	April	7.04	2.40	n.r.	n.r.	n.r.	n.r.	n.r.	7.96	n.d.	24.69	1.66	2.40	0.62	4.43	n.d.
	July	1.44	8.63	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	5.46	1.44	2.47	0.88	n.r.	n.r.
Fluoranthene	Sep.	n.d.	n.d.	n.r.	n.d.	n.d.	n.r.	n.r.	n.r.	n.r.	n.d.	n.d.	n.d.	n.d.	n.r.	n.r.
	April	250.6	29.83	n.r.	n.r.	n.r.	n.r.	n.r.	380.1	n.d.	224.5	n.d.	50.7	12.39	204	108
	July	n.d.	17.00	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	6.70	16.50	n.d.	n.d.	n.r.	n.r.
Pyrene	Sep.	n.d.	139.4	n.r.	n.d.	n.d.	n.r.	n.r.	n.r.	n.r.	n.d.	n.d.	n.d.	n.d.	n.r.	n.r.
	April	n.d.	n.d.	n.r.	n.r.	n.r.	n.r.	n.r.	177.2	n.d.	141.5	n.d.	n.d.	n.d.	n.d.	n.d.
	July	n.d.	7.3	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.d.	81.50	n.d.	n.d.	n.r.	n.r.
Benzo(a)anthracene	Sep.	n.d.	217.8	n.r.	122.6	n.d.	n.r.	n.r.	n.r.	n.r.	120.9	n.d.	214	n.d.	n.r.	n.r.
	April	n.d.	n.d.	n.r.	n.r.	n.r.	n.r.	n.r.	68.23	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

	July	n.d.	10	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.d.	27.80	n.d.	n.d.	n.r.	n.r.
Chrysene	Jan.	n.d.	n.d.	18	n.r.	n.r.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.r.	n.r.	n.r.	n.r.
	July	n.d.	12	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.d.	n.d.	n.d.	n.d.	n.r.	n.r.
Benzo(b)fluoranthene	Sep.	n.d.	241.3	n.r.	19.32	n.d.	n.r.	n.r.	n.r.	n.r.	n.d.	n.d.	n.d.	n.d.	n.r.	n.r.
	Jan.	n.d.	n.d.	6	n.r.	n.r.	n.d.	n.d.	n.d.	n.d.	24.5	n.d.	n.r.	n.r.	n.r.	n.r.
	July	n.d.	16.1	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.d.	1.91	11	n.d.	n.r.	n.r.
Benzo(k)fluoranthene	Jan.	n.d.	n.d.	8.8	n.r.	n.r.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.r.	n.r.	n.r.	n.r.
	July	n.d.	3.36	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.d.	n.r.	n.d.	n.d.	n.r.	n.r.
Benzo(a)pyrene	Sep.	n.d.	0.03	n.r.	n.d.	n.d.	n.r.	n.r.	n.r.	n.r.	1.67	n.d.	n.d.	0.380	n.r.	n.r.
	Jan.	n.d.	n.d.	1.6	n.r.	n.r.	n.d.	n.d.	n.d.	0.29	n.d.	n.d.	n.r.	n.r.	n.r.	n.r.
	April	0.568	n.d.	n.r.	n.r.	n.r.	n.r.	n.r.	1.01	n.d.	0.60	n.d.	n.d.	n.d.	1.30	n.d.
	July	n.d.	0.280	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	0.12	n.d.	n.d.	n.d.	n.r.	n.r.
Dibenzo(a,h)anthracene	Sep.	47.45	12.53	n.r.	52.17	9.61	n.r.	n.r.	n.r.	n.r.	85.76	21.38	54	14	n.r.	n.r.
	Jan.	83	13	20.7	n.r.	n.r.	66	6	84	14.0	68.00	19.00	n.r.	n.r.	n.r.	n.r.
	April	143.1	47.1	n.r.	n.r.	n.r.	n.r.	n.r.	101.2	19.9	176.1	13.2	60.2	6.7	110	28.2
	July	91	68.7	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	0.62	n.d.	91.4	8.3	n.r.	n.r.
Benzo(ghi)perylene	Jan.	n.d.	0.23	10.8	n.r.	n.r.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.r.	n.r.	n.r.	n.r.
Indeno(1,2,3-cd)pyrene	Sep.	n.d.	n.d.	n.r.	n.d.	0.74	n.r.	n.r.	n.r.	n.r.	n.d.	n.d.	n.d.	n.d.	n.r.	n.r.
	Jan.	n.d.	0.23	10.8	n.r.	n.r.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.r.	n.r.	n.r.	n.r.
	April	n.d.	n.d.	n.r.	n.r.	n.r.	n.r.	n.r.	n.d.	n.d.	9.726	n.d.	n.d.	n.d.	n.d.	n.d.

Note: n.d.: below detection limit; n.r.: not recorded.

Table 6. Average concentration ($\mu g\, g^{-1}$) of PAHs fractions recorded in fish tissue collected from Shandoura region (Bitter lakes) during September 2003 and January, April, and July 2004.

		L. carinata		*R. haffara*		*Dahbana*		N. japonica		*Helili*		L. aurata		*Lutjanus sp.*		*S. luridus*		S. rivulatus	
Compound	Date	G	M	G	M	G	M	G	M	G	M	G	M	G	M	G	M	G	M
Naphthalene	Sep.	n.d.	n.d.	n.d.	n.d.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.d.	0.001	n.d.	n.d.	n.d.	n.d.
	July	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.r.	n.r.	0.54	n.d.	n.r.	n.r.	n.d.	n.d.	n.r.	n.r.	n.d.	n.d.
Acenaphthylene	Sep.	n.d.	n.d.	n.d.	n.d.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	April	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.d.	13.54	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.
	July	n.d.	n.d.	0.89	n.d.	n.d.	n.d.	n.r.	n.r.	1.00	n.d.	n.r.	n.r.	n.d.	n.d.	n.r.	n.r.	n.d.	n.d.
Acenaphthene	Sep.	n.d.	n.d.	n.d.	n.d.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	1.85	n.d.	n.d.	n.d.	n.d.	n.d.
	April	0.26	n.d.	n.d.	n.d.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.d.	n.d.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.
	July	n.d.	0.30	n.d.	n.d.	n.d.	n.d.	n.r.	n.r.	n.d.	n.d.	n.r.	n.r.	n.d.	0.73	n.r.	n.r.	n.d.	n.d.
Fluorene	Sep.	4.278	5.733	15.36	3.986	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	10.6	5.3	28.2	6.1	10.9	5.5
	Jan.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	3.47	n.d.	n.d.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.
	April	n.d.	n.d.	n.d.	n.d.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.d.	0.22	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.
	July	1.40	n.d.	n.d.	n.d.	n.d.	n.d.	n.r.	n.r.	8.01	n.d.	n.r.	n.r.	1.81	n.d.	n.r.	n.r.	0.74	n.d.
Phenanthrene	Sep.	8.403	11.44	27.05	7.206	n.r.	0.31	n.r.	n.r.	n.r.	1.53	n.r.	n.r.	20.2	10.6	39.7	12.9	21.3	10.8
	April	2.67	1.07	n.d.	n.d.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.d.	5.49	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.
	July	n.d.	2.92	5.47	1.58	n.d.	0.63	n.r.	n.r.	2.71	1.53	n.r.	n.r.	25.1	n.d.	n.r.	n.r.	n.d.	1.78
Anthracene	Sep.	7.816	9.973	24.01	6.464	n.r.	1.88	n.r.	n.r.	n.r.	1.75	n.r.	4.51	18.5	9.3	72.2	14.2	18.6	8.7
	Jan.	n.d.	n.d.	n.d.	n.d.	17	3.8	n.d.	n.d.	7.64	n.d.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.
	April	78.94	2.51	9.14	1.69	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	1.41	4.51	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.
	July	2.52	3.19	10.6	n.d.	n.d.	n.d.	n.r.	n.r.	7.02	1.75	n.r.	n.r.	n.d.	n.d.	n.r.	n.r.	1.20	3.15
Fluoranthene	Sep.	n.d.	n.d.	n.d.	n.d.	n.r.	36.42	n.r.	n.r.	n.r.	n.r.	n.r.	85.92	256	n.d.	202	n.d.	n.d.	n.d.
	Jan.	n.d.	n.d.	n.d.	n.d.	238	73	n.d.	n.d.	220	n.d.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.
	April	46.45	29.64	n.d.	n.d.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	43.53	85.92	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.
	July	6.5	n.d.	n.d.	n.d.	n.d.	n.d.	n.r.	n.r.	43	n.d.	n.r.	n.r.	n.d.	n.d.	n.r.	n.r.	n.d.	n.d.
Benzo(a)anthracene	Sep.	n.d.	n.d.	n.d.	n.d.	n.d.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	17.28	n.d.	n.d.	51.1	n.d.	n.d.	n.d.
	April	n.d.	n.d.	n.d.	n.d.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	5.497	17.28	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.

Chrysene	Sep.	n.d.	n.d.	n.d.	n.d.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	5.10	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	Jan.	n.d.	133	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.
	April	n.d.	n.d.	n.d.	n.d.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.d.	5.10	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.
Benzo(b)fluoranthene	Jan.	n.d.	21.3	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.
Benzo(k)fluoranthene	Sep.	n.d.	n.d.	n.d.	n.d.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Benzo(a)pyrene	Sep.	0.254	n.d.	n.d.	n.d.	n.r.	n.r.	n.r.	n.r.	n.r.	0.76	n.r.	1.53	n.d.	0.286	n.d.	n.d.	n.d.	n.d.
	Jan.	n.d.	2.03	n.d.	n.d.	1.2	n.d.	n.d.	n.d.	n.d.	n.d.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.
	April	n.d.	0.22	n.d.	n.d.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.d.	1.534	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.
	July	0.31	n.d.	0.57	n.d.	n.d.	n.d.	n.r.	n.r.	0.77	0.76	n.r.	n.r.	n.d.	n.d.	n.r.	n.r.	n.d.	0.65
Dibenzo(a,h)anthracene	Sep.	51.45	24.84	149.6	24.34	n.r.	20.56	n.r.	9.95	n.r.	54.29	n.r.	14.13	128	42	186	24	26.5	9.8
	Jan.	137	27	124	n.d.	533	36	8	10	326	17.9	82.70	12.90	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.
	April	82.45	57.64	175.1	29.46	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	73.02	14.13	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.
	July	17	33.2	22	14.3	29.3	5.21	n.r.	n.r.	35	36.3	n.r.	n.r.	61.5	32.5	n.r.	n.r.	11.9	26.4
Benzo(ghi)perylene	Sep.	n.d.	n.d.	n.d.	n.d.	n.r.	n.r.	n.r.	n.r.	n.r.	4.73	n.r.	n.r.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	Jan.	1	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	4.73	0.23	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.
Indeno(1,2,3-cd)pyrene	Sep.	n.d.	n.d.	n.d.	n.d.	n.r.	n.r.	n.r.	6.18	n.r.	n.r.	n.r.	9.46	n.d.	n.d.	n.d.	57.3	n.d.	n.d.
	Jan.	2	n.d.	n.d.	n.d.	18	n.d.	6	6	12.7	n.d.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.
	April	n.d.	n.d.	n.d.	n.d.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	217.5	9.463	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.
	July	4.56	n.d.	n.d.	n.d.	n.d.	n.d.	n.r.	n.r.	3.44	n.d.	n.r.	n.r.	n.d.	n.d.	n.r.	n.r.	n.r.	n.r.

Note: n.d.: below detection limit; n.r.: not recorded.

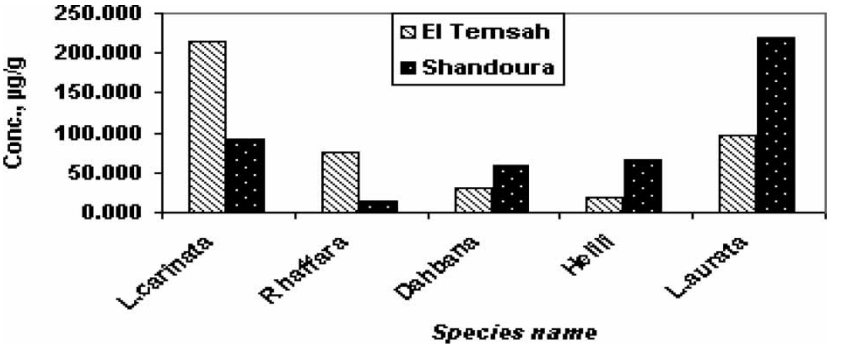

Figure 6. Distribution of total PAHs ($\mu g\, g^{-1}$) in fish samples collected from Bitter and El Temsah lakes during 2003–2004.

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