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# Polycyclic Aromatic Hydrocarbons Levels in Sediment, Benthic, Benthopelagic and Pelagic Fish Species from the Persian Gulf

**Abdolahpur Monikh, F.[1], Hosseini, M.[2], Kazemzadeh Khoei, J.[3] and Ghasemi, A. F.[1]**

[1] Department of Marine Biology, Faculty of Marine Science, Khorramshahr University of Marine Science and Technology, Khorramshahr, Iran

[2] Department of marine biology, Faculty of biological science, Shahid Beheshti University, Tehran, Iran

[3] Academic Center for Education, Culture and Research, Iran

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**ABSTRACT:** In this study, three stations of the north Persian Gulf were analyzed in order to determine the effect of trophic levels on the concentration of harmful PAHs in fish and sediment. In all cases, similar distributions were observed in which benzo(a)pyrene largely predominated and benzo(b)fluoranthene and pyrene were the second major compounds in fish tissues. The predominant components of PAHs in sediment were acenaphthene, pyrene and benzo(ghi)perylene. Based on the molecular weight of PAHs, the concentrations of the compounds vary among species. *Netuma bilineata*, which is carnivorous, classified at a 0.49 to 3.8 trophic level and lives in association with sediment, accumulated the highest concentrations of high molecular weight PAHs, whereas *L. abu*, which is herbivorous and classified at a 0.2 to 2.6 trophic level, tended to accumulate low molecular weight PAHs. Comparison among the stations indicated that the fish and sediment from Tangestan estuary accumulated the highest levels of the compounds.

**Key words:** PAHs, Benthic, Benthplagic, Pelagic, Carcinogens

## INTRODUCTION

Polycyclic aromatic hydrocarbons (PAHs: also called poly nuclear aromatic hydrocarbons), series of organic contaminants, are ubiquitous in the marine environment (Neff, 1985; Aghajanloo *et al.*, 2013; Bhuvaneshwari *et al.*, 2013; Garcia-Flores *et al.*, 2013; ). Uptake of PAHs by aquatic organisms may occur by inhalation, ingestion or skin surfaces (Neff, 1985; Fu and Wu, 2005; Mohebbi Nozar *et al.*, 2013; Mhadhbi and Boumaiza, 2012; Castro-Gutierrez *et al.*, 2012; Zhang *et al.*, 2011; Oluseyi *et al.*, 2011; Owabor v*et al.*, 2010). These contaminants are rapidly transformed into more hydrophilic metabolites that are excreted; therefore, marine organisms exposed to these compounds indicate only trace quantities of PAHs in their tissues (Vuorinen *et al.*, 2006). PAHs are lipophilic substances and their concentrations in organisms are strikingly affected by the content of fat in the organism's tissues (Ciereszko, 2001). In addition, they are strongly affected by behavioral patterns of organisms such as feeding habit, the rate of movement and reproduction status (Vuorinen *et al.*, 2006). Thus, the levels and the compounds of PAHs varied from species to species (Liang *et al.*, 2007; Rose *et al.*, 2012). Concentration of contaminants in fish is of considerable interest because of potential effects on the fish themselves and the top-level organisms that consume these contaminated fish (Ashley et al. 2003; Klumpp *et al.*, 2002). The EPA has concentrated on the sixteen polycyclic aromatic hydrocarbons that are included on their list of 126 priority pollutants. These compounds have been chosen on the basis of frequency of occurrence at hazardous waste sites and toxicity, potential for human exposure. However, eight of these compounds are classified as probable human carcinogens. Combustion of fossil fuel, oil spills and wood are considered as the main sources of PAHs in the environment (Fu and Wu, 2005; Vuorinen *et al.*, 2006). Extraordinarily rapid industrial development,

*Corresponding author E-mail: fazel_abdolahpur2@yahoo.com

particularly in the terms of oil-related activities, and population growth in the coastal areas of the Persian Gulf have resulted in striking increases in the levels of PAHs in the marine environment (Hosseini *et al.,* 2012; Abdolahpur Monikh *et al.,* 2012a). They are mostly discharged into the Persian Gulf from petrochemical and refineries wastewater, domestic sewage and tankers traffic (Abdolahpur Monikh *et al.,* 2012a, b).

In the present study, we examined the accumulation of nine PAHs in the muscle and liver of three fish species from different trophic levels. Besides, we determined the concentration of these compounds in sediment samples. The main aim of this investigation is to assess the effect of feeding habit on PAHs levels in the species.

## MATERIAL & METHODS

Fish and sediment sampling were done at three stations from the Persian Gulf in July 2011. Stations, along the north Persian Gulf, were chosen in relation to contamination gradient (Fig. 1). Station 1 was chosen at Boshehr province, which is a relatively clean area, because it is far from anthropogenic activities and is relatively less affected by contaminated wastewater. Station 2 and 3 were chosen at Tangestan estuary and Hendijan respectively. These stations receive huge amounts of industrial and domestic effluents from Musa estuary and surrounding areas. Fifteen fish of *Netuma bilineata* (benthic fish), *Johnius belangerii* (benthopelagic fish) and *Liza abu* (pelagic fish) were caught from each station. Nine samples of superficial sediments were also obtained from each station using a plastic blade. The samples were placed in plastic boxes, immediately transferred to the laboratory and stored at “20° C until analysis. Before chemical treatment, the samples were allowed to thaw at room temperature for about 6 h. Muscle and liver samples were dissected, freeze-dried for 100 h, and powdered by stainless steel mortar. According to Bordajandi et al. (2003), about 10 gram of the powdered muscles and liver were transferred into a Soxhlet apparatus and extracted by 300 ml of acetone and *n*-hexane (1:1, V/V) in a water bath for 36 h. Extracts were reduced on a rotary evaporator to 1 ml and cleaned by 5 ml of concentrated sulfuric acid, copper powder and a microflorisil column and then passed through a silica gel column to remove lipids and interferences compounds. In order to determine the concentrations of PAHs in the fish samples, an HPLC (model KANUER) equipped with a UV detector system was used. The mobile phase (acetonitrile and water) gradient consists of 40% water and 60% acetonitrile (flow rate 0.7 ml min$^{-1}$) and after 40 min change to 100% acetonitrile. Recovery studies with fortified samples showed that the efficiency exceeded 87% for all compounds determined. The sediment samples were freeze dried and purified by the method described by Schneider et al. (2001). Briefly, about 10 gram of the dried samples was extracted with a Soxhlet apparatus using 300 ml dichloromethane for 10 h. For quality control, 100 µl of deuterated PAH surrogate internal standard mixture (d$^{10}$-2-methylnaphthalene,D$^{10}$-fluorene, d$^{10}$-fluoranthene, d$^{12}$-perylene) was added to the samples. Rotary evaporator was used to reduce the volume of the solvents to approximately 1 ml. In order to eliminate any sulfur in the samples, a few copper chips were added into the samples and left 24 h. The samples were analyzed by GC/MS (Agilent Technologies 5975C). Blanks were run with each batch of the samples to control the procedure. The fish and sediment were analysed for a suite of 9 PAHs; naphthalene (NAP), acenaphthylene (ACY), acenaphthene (ACE), anthracene (ANT), pyrene (PYR), chrysene (CHY), benzo(b)fluoranthene (BbF), benzo(a)pyrene (BaP) and benzo(ghi)perylene (BPY).

Statistical analysis of data was carried out using SPSS statistical package programs. All data were tested for normal distribution with Shapiro-wilk normality test. Significant differences between PAHs concentration in the samples of various stations and species were determined using One-Way analysis of variance (ANOVA) fallowed by Duncan post hoc test. The significance level was set at $\alpha = 0.05$.

## RESULTS & DISCUSSION

Concentrations of total PAH in sediment (Table 1) ranged from 310.76 ng/g dry weight at Boshehr province to 1106 ng/g dry weight at Tangestan estuary. Comparison of PAHs was significantly different between the stations. Generally, there were higher concentrations of total PAH (low molecular weight, medium molecular weight and high molecular weight PAHs) in the sediment of Tangestan estuary compared to the other stations. It is obvious from Table 1, that ACY, PYR and BPY are abundant in Boshehr province and Hendijan sediment. The predominant components of PAHs in the sediment of Tangestan estuary were ACY, PYR, BPY and CHY (Table 1).

Sediment samples collected from Tangestan estuary generally had significantly higher concentrations of low molecular weight, medium molecular weight and high molecular weight PAHs than the stations that were at Boshehr province and Hendijan. Variation in the concentrations of PAHs among the stations suggests differences in the sources of PAHs. In the Persian Gulf, Musa estuary has one of the largest harbor and industrialized port (Abdolahpur Monikh *et al.,* 2012b). This estuary originates from the


**Fig. 1. A map showing of the Persian Gulf and the stations**

**Table 1. The concentrations (mean and standard deviation) of PAH compounds in sediment samples from the north Persian Gulf (ng/g d. w) and sediments quality guideline**

| PAH | Boshehr province | Hendijan | Tangestan estuary | ERL | ERM | TEL | PEL |
|---|---|---|---|---|---|---|---|
| ACY | 549 ± 76.5[a] | 2163 ± 732.6[b] | 3451 ± 761.44[c] | 44 | 640 | 10 | 130 |
| ACE | 2.9 ± 0.4[a] | 11.7 ± 3.24[b] | 18.64 ± 7.4[c] | 16 | 500 | 10 | 90 |
| ANT | 26.87 ± 8.43[a] | 38.21 ± 14[b] | 57.19 ± 21.8[c] | 853 | 1100 | 50 | 240 |
| BaP | 73.53 ± 21.08[a] | 148 ± 41.88[b] | 283 ± 51.22[c] | 430 | 1600 | 90 | 760 |
| BbF | 41.13 ± 12.4[a] | 77.96 ± 24.82[b] | 135.7 ± 32.09[c] | NA | NA | 70 | 710 |
| CHY | 143.88 ± 48.9[a] | 294.61 ± 72.33[b] | 427.31 ± 73.6[c] | 384 | 2800 | 110 | 850 |
| PYR | 364.6 ± 83.52[a] | 612.94 ± 112[b] | 1063.12 ± 362.12[c] | 665 | 2600 | 150 | 1400 |
| BPY | 522.83 ± 91.06[a] | 914.2 ± 137.5[b] | 1638.5 ± 442.5[c] | NA | NA | NA | NA |
| NAP | 37.12 ± 11.71[a] | 41.05 ± 7.83[a] | 114.7 ± 62[c] | 160 | 2100 | 30 | 390 |
| Total PAHs | 310.76[a] | 703.4[b] | 1106.57[c] | | | | |

ERL, Effect Range Low. ERM, Effect Range Median. TEL, Threshold Effect Level. PEL, Probable Effect Level. Different letters show significant differences of PAHs concentrations between stations

Persian Gulf and is stretched along PETZONE (Petrochemical Special Economic Zone) up to Mahshahr and Sarbandar cities in Iran. It is used as municipal wastes receptors and receives copious amounts of petrochemical wastewaters from PETZONE along its courses (Safahieh *et al.*, 2011). Musa estuary and Tangestan estuary are very near together. Therefore, Tangestan estuary receives different types of contaminants from Musa estuary. These can be explained by the tidal disturbances and redistribution in sediment and water column along the shore. It has been suggested that suspended sediments and other organic particulates might play an important role in the transfer of contaminants to other areas (Safahieh *et al.*, 2011).

To make an assessment of marine sediment with a ranking of low to high impact values, the threshold effect level (TEL), the probable effect level (PEL), the effects range low (ERL) and the effects rang median (ERM) values were applied (Long *et al.,* 1995; Burton, 2002). ERL and ERM values are useful to assess the potential biological and toxicological effects of sediment containing organic contaminants on aquatic, particularly benthic, organisms (Mirza *et al.,* 2012). The obtained concentrations of PAH components in the sediment were compared with the TEL, PEL, ERL and ERM levels. The comparisons indicated that the concentration of all individual PAH in sediment of Boshehr province, Hendijan and Tangestan estuary are higher than TEL, except for few cases. The concentration of ACY in the three stations was higher than TEL, PEL, ERL and ERM, except for Boshehr province that was within ERM level. In general, the levels of PAH components in the north Persian Gulf may be brought about by oil pollution in the region. This gulf has about 800 offshore oil and gas platforms and about 25 oil terminals along its coasts. It is bordered by eight oil-producing states that collectively supply some 60 percent of the oil needed by other countries. The high concentrations of PAHs found in the sediments of the Iranian coasts are an indication of the high magnitude of oil pollution in the Persian Gulf. In this study, we found that the concentrations of medium molecular weight and high molecular weight PAHs in sediment are higher than low molecular weight PAHs. According to earlier reported observations, higher molecular weight PAHs are primarily removed by sedimentation while lower ones through dilution and dissolution, and also tend to be more soluble in water (Wakeham, 1980). Water solubility of PAHs with two to six rings decreases over five orders of magnitude with increasing molecular weight. Thus, PAHs with two and three rings are more likely to be found in aquatic phase in the dissolved form than higher molecular weight PAHs, which tend to be associated with dissolved organic matter (DOM) and sediments (Wakeham, 1980). Brown, (2002) concluded that high molecular PAH was associated with sediment, averaging from 79 to 93%, whereas PAH with low molecular weight tends to be in dissolved phase. This has also been somewhat observed in the current study. Low molecular weight PAHs tend to be volatile and subjected to rapid microbial degradation, thus they have short residence time. Whereas, high molecular weight PAHs have a high particle affinity and low microbial degradation rate and thus accumulate in bottom sediments (Mrozik *et al.,* 2003).

The concentrations of PAHs determined in the liver and muscle tissues of the fish from the Persian Gulf are presented in Table 2 and 3 respectively. In the muscle of *N. bilineata*, the most abundant PAHs are BaP, BbF, PYR and BPY. In the muscle of *J. belangerii*, the most abundant PAHs are ACY, BaP, BbF, PYR and BPY. In the muscle of *L. abu,* NAP, BaP and BbF appear to be the most abundant PAHs. In the liver of *N. bilineata,* NAP, ANT, BaP, BbF, PYR and BPY are the most abundant PAHs. Bap, PYR and BPY are also abundant in the liver of *J. belangerii*. In the liver of *L. abu,* NAP, ACY, BaP and BPY are the most abundant components of the PAHs. High amount of benzo[a]pyrene, the most carcinogenic polycyclic aromatic hydrocarbon, was found in the muscle and liver of the three fish. Previous studies have also shown that benzo[a]pyrene, naphthalene and pyrene are the dominant compounds of PAHs in fish tissues (Krahn *et al.,* 1984; Rainio *et al.,* 1986; Maccubbin *et al.,* 1988. Johnston and Baumann, 1989; Al-Saleh and Al-Doush, 2002; Vives *et al.,* 2004).

The results showed that low molecular weight PAHs were accumulated much less in the fish tissues than high molecular weight PAHs. The concentrations of PAH compounds vary widely with molecular weight (Sverdrup *et al.,* 2002). Varanasi et al. (1992) studied the rate of uptake of PAHs by clam from sediment of the Duwamish Waterway, a contaminated estuary in Puget Sound. They found that high molecular weight PAHs were clearly accumulated by clams and amphipods, but accumulation of low molecular weight PAHs was not as great.

ANOVA was carried out to test whether there is a significant variation in the concentrations of individual PAH among the different species within each sampling site (Table 2 and 3). Significant variations in the levels of the studied low molecular weight, medium molecular weight and high molecular weight PAHs were noted. The total PAH concentrations in the three fish species were in the following order: *L. abu* < *J. belangerii* < *N. bilineata.* The comparison among species indicated that *L. abu,* which is of low level of aquatic food chain (herbivorous), accumulated low molecular mass PAHs (acenaphthylene and naphthalene). Whereas the *N. bilineata*, which is of high level of aquatic food chain (carnivorous), has accumulated greater concentrations of high molecular mass PAHs (anthracene, benzo(a)pyrene, benzo(b)fluoranthene, chrysene, pyrene and benzo(g,h,i)perylene). Fish can effectively biotransform low molecular weight PAHs, preventing biomagnification up the food chain (Yu, 2002). *N. bilineata* feed on sea urchins, crustaceans, fish and prawn sand, and classified at a 0.49 to 3.8 trophic level. *J. belangerii* feed mainly upon crustaceans, mollusca and shrimp (Abdolahpur Monikh *et al.,* 2012a) and classified at a 0.32 to 3.3 trophic level. *L. abu* feed on

**Table 2. PAHs concentrations (mean and standard deviation) based on ng/g d. w in the liver of fish from the north Persian Gulf**

| PAHs | Species | Boshehr province | Hendijan | Tangestan estuary |
|---|---|---|---|---|
| NAP | Netuma bilineata | 913.07 ± 131.56 $^{c}$ | 1273.24 ± 141.39$^{b}$ | 1620.58 ± 137.24$^{b}$ |
| | Johnius belangerii | 89.33 ± 21.87$^{a}$ | 192.13 ± 43.25$^{a}$ | 268.4 ± 62.09$^{a}$ |
| | Liza abu | 114.9 ± 42.12$^{b}$ | 198.76 ± 52.75$^{a}$ | 251.33 ± 59.14$^{a}$ |
| ACY | Netuma bilineata | 68.22 ± 23.15$^{a}$ | 136.81 ± 39$^{a}$ | 177.04 ± 60.22$^{a}$ |
| | Johnius belangerii | 89.56 ± 27.08$^{b}$ | 155.24 ± 69.46$^{b}$ | 203.31± 71.31$^{b}$ |
| | Liza abu | 82.62 ± 30.17$^{b}$ | 179.41 ± 52.66$^{c}$ | 211.4 ± 82.33$^{c}$ |
| ACE | Netuma bilineata | 17.44 ± 4.12$^{a}$ | 23.06 ±11.42$^{a}$ | 31.77 ± 12.6$^{a}$ |
| | Johnius belangerii | 30.22 ± 12.71$^{b}$ | 38.9 ± 10.56$^{b}$ | 87 ± 35.17$^{b}$ |
| | Liza abu | 44.58 ± 17.43$^{c}$ | 69.73 ± 28$^{c}$ | 91.17 ± 38.2$^{b}$ |
| ANT | Netuma bilineata | 70.3 ± 24.2$^{c}$ | 152.28 ± 39.21$^{c}$ | 1204.03 ± 292.15$^{c}$ |
| | Johnius belangerii | 57.72 ± 28.91$^{b}$ | 92.19 ± 15.68$^{b}$ | 101.06± 44.19$^{b}$ |
| | Liza abu | 25.62 ± 9.22$^{a}$ | 61.28 ± 30.74$^{a}$ | 54.81 ± 06 $^{a}$ |
| BaP | Netuma bilineata | 1807.15 ± 621.28$^{c}$ | 2937.71 ± 702.18 $^{c}$ | 3426.9 ± 1067.3$^{c}$ |
| | Johnius belangerii | 1033.24 ± 417.66$^{b}$ | 1702 ± 552.81$^{b}$ | 2117.42 ± 810.13$^{b}$ |
| | Liza abu | 662.29 ± 177.09 $^{a}$ | 821.33 ± 204$^{a}$ | 903.18 ± 271.48$^{a}$ |
| BbF | Netuma bilineata | 1621.32 ± 583.09$^{c}$ | 2218.19 ± 720.51 $^{c}$ | 2764.71 ± 833.42$^{c}$ |
| | Johnius belangerii | 92.77 ± 13.54$^{b}$ | 127.2 ± 41.82$^{b}$ | 149.2 ± 31.6$^{b}$ |
| | Liza abu | 40.17 ± 18.55$^{a}$ | 54.1 ± 14.9$^{a}$ | 83.42 ± 27.7$^{a}$ |
| CHY | Netuma bilineata | 103.55 ± 30.8$^{c}$ | 198.42 ± 48.92$^{c}$ | 281.07 ±88.39$^{c}$ |
| | Johnius belangerii | 81.77 ± 28.06$^{b}$ | 112.45 ± 40.5$^{b}$ | 161.27 ± 68.41$^{b}$ |
| | Liza abu | 20.16 ± 8.41$^{a}$ | 45.19 ± 12.87$^{a}$ | 37.91 ± 15 $^{a}$ |
| PYR | Netuma bilineata | 1155.31 ± 438.07$^{c}$ | 2551.63 ± 953.88 $^{c}$ | 3164.15 ± 1032.27$^{c}$ |
| | Johnius belangerii | 402.11 ± 112.74$^{b}$ | 1294.74 ±418.61$^{b}$ | 1635 ± 339.16$^{b}$ |
| | Liza abu | 24.98 ± 7.26$^{a}$ | 44.75 ± 18.34$^{a}$ | 51.28 ± 19.42$^{a}$ |
| BPY | Netuma bilineata | 874.19 ± 201.64 $^{c}$ | 1885.23 ± 357.81 $^{c}$ | 2413.17 ± 891.26$^{c}$ |
| | Johnius belangerii | 317.8 ± 97.33$^{b}$ | 712.18 ± 264.38$^{b}$ | 1103 ± 547.71$^{b}$ |
| | Liza abu | 133.46 ± 54.07$^{a}$ | 163.55 ± 58.31$^{a}$ | 223.64 ± 92.73$^{a}$ |
| Total PAHs | Netuma bilineata | 736.72$^{c}$ | 1264.06$^{c}$ | 1675.92$^{c}$ |
| Total PAHs | Johnius belangerii | 243.83$^{b}$ | 491.89$^{b}$ | 647.29$^{b}$ |
| Total PAHs | Liza abu | 127.64$^{a}$ | 182.03$^{a}$ | 212.01$^{a}$ |

Different letters show significant differences of PAHs concentrations between species.

algae and phytoplankton (Abdolahpur Monikh *et al.,* 2012a, Safahieh *et al.,* 2011) and classified at a 0.2 to 2.6 trophic level.

These results confirm that most high molecular weight PAHs in fish increase with increasing trophic levels. Therefore, higher concentration of high molecular weight PAHs in *N. bilineata* could be attributed to its feeding habits (as a carnivorous predator) and its position in aquatic food chains. In addition, this fish is a benthic species and lives in association with sediment, where the concentrations of high molecular weight PAHs are high. Since *L. abu* is a phytoplankton feeder and lives in the upper layer of the water column, where the concentrations of low

**Table 3. PAHs concentrations (mean and standard deviation) based on ng/g d. w in the muscle of fish from the north Persian Gulf**

| PAHs | Species | Boshehr province | Hendijan | Tangestan estuary | Carcinogenicity (ATSDR) |
|---|---|---|---|---|---|
| NAP | Netuma bilineata | 102.42 ±42.03 [a] | 188.13 ± 47.19 | 212.56 ± 56.22 [a] | |
| | Johnius belangerii | 98.25 ± 23 [a] | 197.77 ± 54.67 | 275.15 ± 79 [c] | |
| | Liza abu | 121.3 ± 64.1 [b] | 192.37± 70.23 | 243.03 ± 71.14 [b] | |
| ACY | Netuma bilineata | 38.4 ± 12.7 [a] | 92.3 ± 33.82 [a] | 96 ± 26.27 [a] | |
| | Johnius belangerii | 141.38 ± 40.53 [b] | 226.88 ± 62.91 [c] | 682.07 ± 149.12 [c] | |
| | Liza abu | 43.11 ± 16.81 [a] | 134± 51.09 [b] | 192 ± 53.22 [b] | |
| ACE | Netuma bilineata | 20.54 ± 12.7 [a] | 34.36 ± 10.48 [a] | 36 ± 14.29 [a] | |
| | Johnius belangerii | 34.77 ± 16.23 [b] | 52.88 ± 27.61 [b] | 91.47 ± 38.09 [b] | |
| | Liza abu | 31.56± 11 [b] | 83.75± 33.21 [c] | 116.22 ± 42.36 [c] | |
| ANT | Netuma bilineata | 78.17 ± 38.17 [c] | 165.89 ± 52.06 [c] | 217 ± 105.14 [c] | |
| | Johnius belangerii | 53.18 ± 27.43 [b] | 88.92 ± 36.21 [b] | 109.64 ± 62 [b] | |
| | Liza abu | 32.89 ± 16.11 [a] | 56.17± 21.88 [a] | 61.37 ± 38.03 [a] | |
| BaP | Netuma bilineata | 1612.3 ±322.12 [c] | 2427.1 ± 579.88 [c] | 2980.55 ± 832.15 [c] | * |
| | Johnius belangerii | 1143 ± 337.25 [b] | 1732 ± 461.05 [b] | 2014 ± 734.11 [b] | |
| | Liza abu | 312 ± 97.16 [a] | 618.09 ± 263.14 [a] | 722.69 ± 281.32 [a] | |
| BbF | Netuma bilineata | 1256 ± 489.53 [c] | 1832 ± 559.44 [c] | 2067 ± 716.92 [c] | * |
| | Johnius belangerii | 538.44 ± 237.26 [b] | 1140.33 ± 277.04 [b] | 1663.78 ± 683.28 [b] | |
| | Liza abu | 155.43 ± 63.08 [a] | 383.2 ± 82.22 [a] | 642.1 ± 89.29 [a] | |
| CHY | Netuma bilineata | 118.65 ± 37.15 [c] | 241.5± 31.2 [c] | 293.9 ± 58.18 [c] | * |
| | Johnius belangerii | 76.34 ± 35.22 [b] | 109.22 ± 49.15 [b] | 172.3 ± 42.37 [b] | |
| | Liza abu | 27.93 ± 11.2 [a] | 40.28 ± 16.32 [a] | 45.2 ± 16.84 [a] | |
| PYR | Netuma bilineata | 943.21 ±186.29 [c] | 1733 ± 420.03 [c] | 2128.21 ± 506.82 [c] | |
| | Johnius belangerii | 488.02 ± 144.67 [b] | 1228.08 ± 240.3 [b] | 1751.33 ± 407.19 [b] | |
| | Liza abu | 8.02 ± 2.99 [a] | 9.61 ± 1.13 [a] | 9.9 ± 2.33 [a] | |
| BPY | Netuma bilineata | 902.77 ±127.35 [c] | 1925 ± 507.75 [c] | 2358.86 ± 658.48 [c] | |
| | Johnius belangerii | 522.86 ± 138.24 [b] | 1023 ± 469.35 [b] | 1698.05 ± 645.17 [b] | |
| | Liza abu | 89.67 ± 31.02 [a] | 143.28 ± 56.32 [a] | 157.52 ± 46.04 [a] | |
| Total PAHs | Netuma bilineata | 563.6 [c] | 959.80 [c] | 1154.45 [c] | |
| Total PAHs | Johnius belangerii | 344.02 [b] | 644.34 [b] | 939.75 [b] | |
| Total PAHs | Liza abu | 91.32 [a] | 184.52 [a] | 243.33 [a] | |

ATSDR = Available at http://www.atsdr.cdc.gov/HAC/PHA/popile/pop_p4.html. Different letters show significant differences of PAHs concentrations between species.

molecular weight PAHs are high, thus it is not surprising that the levels of low molecular weight PAHs in this species are higher in comparison to the other species. Physiological factors such as lipid levels, the rates of uptake and elimination, behavior patterns and rates of feeding play important roles in PAHs accumulation in fish (Meador *et al.,* 1995). In studies within Puget Sound and in other areas of United States (Myers *et al.,* 1994: Stehr *et al.,* 2004), strong correlations have been found between concentrations of high molecular weight PAHs in sediment and bottom fish species.

Regional differences in the concentrations of total PAH of fish were examined for each species. The average concentrations of total PAHs were from 91.32 to 1154.45 and 127.64 to 1675.92 ng $g^{-1}$ dry weight in muscle and liver respectively. The highest total PAH concentrations in *N. bilineata*, *J. belangerii* and *L. abu* were found in Tangestan estuary. Generally, a decreasing trend in the total PAH concentration was found moving east along the north shore of the Persian Gulf to Boshehr coasts. The differences in the concentrations of total PAH among the stations might reflect the contamination in the respective areas. The fact that total concentration of some petrochemical-related and oil-related PAHs in the north Persian Gulf decreased with distance from Musa estuary is strong evidence that the PAHs in this estuary were sourced from petrochemical and petroleum activities. Unlike metals and some ionizable organic compounds, the bioavailability of PAHs is affected by only a few environmental variables such as organic carbon and sediment surface area.

Risk-based concentrations (RBCs) for some compounds of PAH in the muscle tissue of fish consumed by humans are 270, 810, 4055, 405, 43, 0.43 and 0.043 μg $g^{-1}$ d. w for naphthalene, acenaphthene, anthracene, pyrene, chrysene, benzo(b)fluoranthene and benzo(a)pyrene respectively. RBCs are based on consumption of 54g per day of fish by adults and a target cancer risk of $10^{-5}$ (EPA Region III, 2000). The comparison showed that the concentrations of naphthalene in *J. belangerii* and pyrene, chrysene, benzo(b)fluoranthene and benzo(a)pyrene in all the species were higher than RBCs, except for pyrene and chrysene in *L. abu* of Boshehr province.

The north Persian Gulf was comparable to those of other studies carried out in polluted areas (Table 4). On average, total PAH concentrations in fish from the north Persian Gulf were much higher than those in *Mullus barbatus* and *Serranus cabrilla* from Tarragona, Mediterranean (Escartin and Porte, 1999), except for *L. abu* from Boshehr province. The concentrations of total PAH in this study were higher than those reported by Rose et al. (2012) in *Chrysichthys nigrodigitatus* and *Tilapia guineensis* from Lagos Lagoon, Nigeria. Our findings for total PAH in fish were also higher than the results reported by Malik et al. (2008) (after conversion ng/g d. w into ng/g w. w) in *Channa punctatus* from Gomti River, India, except for few cases in *L. abu* of Boshehr. Neff (1997) studied PAHs concentrations in *Lopholatilus chamaeleonticeps* from New York. The concentrations of total PAH in present study were higher than those reported by Neff (1997). Amodio-Cocchieri et al. (1993) studied the PAHs concentrations in different fish species from the Bay of Naples, Italy. The comparison indicated that the concentrations of total PAH in the fish from the Persian Gulf were lower than those in fish from the Bay of Naples. McGill et al. (1987) studied PAHs in *Limanda limanda* from the British North Sea. The comparison showed that the total PAH of our study was much lower than that reported by McGill et al. (1987).

**Table 4. Comparison of total PAH in the muscle of fish collected from the Persian Gulf with species from different parts of the world**

| Location | Species | Σ PAH (ng/g d. w) | References |
|---|---|---|---|
| Tarragona, Mediterranean | Mullus barbatus | 164.9 | Escartin and Porte (1999) |
| Tarragona, Mediterranean | Serranus cabrilla | 62.9 | |
| Lagos Lagoon, Nigeria | Chrysichthys Nigrodigitatus | 153.120 | Rose et al. (2012) |
| Lagos Lagoon, Nigeria | Tilapia guineensis | 62.24 | |
| Gomti River, India | Channa punctatus | 34.89 (ng $g^{-1}$ w. w) | Malik et al . (2008) |
| New York | Lopholatilus chamaeleonticeps | 26 | Neff (1997) |
| The Bay of Naples, Italy | Engralis enchrasicholus | 965 | Amodio-Cocchieri et al., 1993) |
| The British North Sea | Limanda limanda | 2345 | McGill et al., (1987) |

## CONCLUSION

In this study, we have showed that Tangestan estuary has the highest concentration of some persistent and carcinogenic compounds of PAHs in comparison to the other areas. These contaminants are brought to this estuary from Musa estuary via suspended sediments and other organic particulates. The comparison among species indicated that the concentrations of PAH compounds in fish are strongly affected by trophic level and the feeding habits. In addition, the results showed that the benthic fish are exposed to sediment-associated compounds of PAHs, which are the most toxic compounds. Therefore, people how consume ûsh from this area should eat a diversity of ûsh to avoid consuming harmful quantity of PAHs. Our study also showed that the concentrations of most individual PAH in Tangestan estuary were higher than the TEL, PEL, ERL and ERM guidelines, suggesting that PAHs accumulation in sediments of this estuary were likely to cause serious toxicity.

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