



Polycyclic aromatic hydrocarbon (PAH) profiles of representative aquatic fauna collected from an anthropogenically-disturbed freshwater mangrove swamp in Southern Nigeria

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Abstract: This study evaluated the bio-concentrations of 16 PAH congeners in selected aquatic fauna obtained from the Falcorp freshwater mangrove swamp in the Niger Delta region, Nigeria. Representative samples of mudskipper (*Periophthalmus barbarous*), periwinkle (*Tympanotonus fuscatus*) and crab (*Sesarma alberti*) were collected from 5 sampling points within the study area. The obtained data was analysed using descriptive and inferential statistical tests. The concentrations of PAHs in the samples were as follows: mudskipper (0.0001 to 0.1236mg/kg); crab (0.0019 to 0.0499mg/kg) and periwinkle (0.0009 to 0.0744mg/kg). For the crab specimens, there were no significant variations in PAH concentrations, but with respect to both periwinkles and mudskippers, the observed variations in the PAH values were significant ($p < 0.05$). PCA and correlation analyses revealed significant associations between some of the PAHs in the samples. The detection of varying bio-concentrated PAH levels in the ferally collected freshwater mangrove fauna could be indicative of the widespread ecological distribution of PAH moieties within the study area.

1. Introduction

Polycyclic aromatic hydrocarbons (PAHs) have been described as a family of organic moieties structurally made up of two or more aromatic rings that are fused together (Sahoo *et al.*, 2020; Byiringiro *et al.*, 2024). Their primary formation is known to occur when organic matter, such as wood, fossil fuels, and other carbon-based compounds, burns incompletely. Due to their toxicity, capacity for bioaccumulation and persistence in living things, PAHs are known to pose a serious environmental and public health threat (Meng *et al.*, 2019; Nowakowski *et al.*, 2022; Byiringiro *et al.*, 2025a). Numerous PAHs are known to cause cancer, mutagenesis, and teratogenicity, endangering ecosystems as well as human health. The hydrophobic property of these substances can

cause these moieties to accumulate in biological tissues and sediments, particularly in aquatic environments (Sahoo *et al.*, 2020).

Natural and man-made sources are the two ways that PAHs get into the environment. Natural sources include; forest fires as well as volcanic eruptions whilst the main source of environmental PAHs is anthropogenic activity (Ambade *et al.*, 2022; Byiringiro *et al.*, 2025b). The combustion of household and municipal trash, runoff from urban and agricultural areas, automobile emissions, petroleum exploration and refinement as well as industrial discharges are important anthropogenic sources (Nowakowski *et al.*, 2022). The main sources of PAH introduction into aquatic systems include; leaching from polluted soils, industrial effluents, oil spills as well as atmospheric deposition (Dai *et al.*, 2022).

A major amount of the crude oil production in Nigeria is known to come from the Niger Delta region, which is one of the most important petroleum-producing regions globally (Anyanwu *et al.*, 2020). For many years, this area has been heavily explored and exploited for oil, which has contaminated the environment extensively (Ofori *et al.*, 2021; Byiringiro *et al.*, 2023). Large amounts of PAHs have been introduced into the aquatic and terrestrial ecosystems of the Niger Delta by oil spills, gas flaring, and industrial discharges (Udom *et al.*, 2023). Research has continuously documented high concentrations of PAHs in water, sediment, and biota in this area, which is indicative of the widespread human impacts (Udom *et al.*, 2023; Byiringiro *et al.*, 2025c). The health of the local populations, who mainly depend on the natural resources in the area for their livelihoods, such as agriculture and fishing, is seriously jeopardized by these contaminants (Odigie and Olomukoro, 2020a; Ofori *et al.*, 2021).

Mangrove ecosystems are located in tropical and subtropical areas. Several ecosystem services, including carbon sequestration, water purification, coastal protection, and habitat supply for a variety of terrestrial and aquatic species, are provided by these essential biological systems (Aransiola *et al.*, 2024). By serving as nursery for several fish and shellfish species, mangroves promote local fisheries and biodiversity. Mangroves are also important carbon sinks that help slow down climate change and play a key role in the cycle of nutrients (Nababa *et al.*, 2020). With an estimated total area of over 10,000 square kilometres, the Niger Delta is home to one of the largest mangrove forests in the world (Onyena and Sam, 2020). These mangroves support a rich biodiversity and sustain the livelihoods of local residents, making them essential to the ecological and economic stability of the area. However, pollution, shifting land uses, and climate change are posing a growing threat to the health and functionality of these ecosystems (Onyena and Sam, 2020; Ogbeibu and Oribhabor, 2023).

The bioavailability of nutrients and other vital components can be impacted by the potential of these hydrocarbons to change the physicochemical characteristics of sediments (Ambade *et al.*, 2022). Many elements of mangrove ecosystems, such as aquatic fauna, microorganisms as well as flora are negatively affected by PAHs. Exposure to PAHs can harm mangrove plants by reducing growth rates, causing leaf chlorosis, and impairing root function, all of which can lower ecosystem production (Ukhurebor *et al.*, 2021). Particularly susceptible to PAH pollution are the aquatic fauna found in mangrove habitats. These substances have the ability to bioaccumulate in the tissues of aquatic animals that are essential to the food chain, such as fish, crabs, and molluscs (Dai *et al.*, 2022). Both the organisms themselves and higher trophic levels, such as humans, who consume these polluted species, are at risk from PAH bioaccumulation (Iwegbue *et al.*, 2021). Long-term exposure to PAHs in aquatic creatures has been associated with immunosuppression, reproductive failure, and higher mortality rates (Udom *et al.*, 2021). The microbial populations in mangrove sediments, which

are essential to the cycling of nutrients and the breakdown of organic matter, can also be disturbed by PAHs. These disturbances can cause long-term ecological imbalances, which would lower the resilience and recovery capacities of these ecosystems (Eldos *et al.*, 2022).

This study was aimed at ascertaining the tissue concentrations of PAHs in three collected aquatic animals from a freshwater mangrove swamp in Delta State, Nigeria, that is been subjected to varying levels of anthropogenic disturbance. Also, seasonal variations in the biota related PAH levels as well as the bioaccumulation factor (BAF) index values of the aquatic biota derived PAHs were also determined.

2. Methodology

2.1 Study Area and collection of Aquatic Fauna

Falcorp Mangrove Swamp is situated in the Warri South Local Government Area, Delta State, Southern Nigeria. Several locational attributes of the swamp had been previously described by Odigie and Olomukoro (2020a) and as well as Odigie and Olomukoro (2020b).

For this study, five stations previously detailed by Odigie and Olomukoro (2020a) and Odigie and Olomukoro (2020b) were re-visited between February 2022 to July 2023. As earlier described by Odigie and Olomukoro (2020a) and Odigie and Olomukoro (2020b), the distance between each of these stations was about 600 m. The geo referenced coordinates of the respective sampling locations were; Stations 1 (Latitude 05°18.506' N and Longitude 005°42.213'E), 2 (Latitude 05°18.61' N and Longitude 005°41.4'E), and 3 (Latitude 05°33.50° N and Longitude 005°42.65° E). Meanwhile, Stations 4 (Latitude 05°66.202'N and Longitude 005°55.27'E) and 5 (Latitude 05°69.715' N and Longitude 005°48.94'E). At each station, two samples each of mudskipper (*Periophthalmus barbarus*), periwinkle (*Tympanotonus fuscatus*) and crab (*Sesarma alberti*) were ferally collected with the aid of skilled indigent fishermen residing around the study area as earlier reported by Odigie and Olomukoro (2021). The collected faunal specimens were humanely handled and transported to laboratory for PAH analysis.

2.2 PAH Determination

The procedure previously described by Perugini *et al.* (2007) was utilized in performing PAH extraction as well as purification from the collected organisms. This assessment was conducted using composite pools of tissues extracted from crabs, periwinkle soft tissues, and mudskipper tissues, respectively. A 100 mL round-bottomed flask containing 10 mL of 1 M KOH in an ethanolic solution was filled with the assay sample (2 g dw). For three hours, the mixture was kept at 80°C in a re-flex system. Ten millilitres of cyclohexane were used to extract the liquid phases after they had been moved to a separating funnel. After that, they were vigorously shaken for half an hour. After draining, the cyclohexane KOH phase was disposed of.

Ten millilitres of cyclohexane were then used to rinse the liquid phases once more. The anhydrous sodium sulphate column was opened for the samples to pass through. The organic phase was then decreased in pressure and condensed to a volume of 5 mL in a rotary evaporator (Model Buchi B-490). The samples were concentrated in a rotary evaporator (30°C, 19–21 kPa) to a volume of 1 mL after passing through a column loaded with florisil. The extracts were then reconstituted in 1 millilitre of acetonitrile after being gently streamed with nitrogen at room temperature. Gas chromatography-mass spectrometry was used to determine the concentrations of 16 PAHs (Naphthalene, Acenaphthalene I, Acenaphthene II, Florene, Phenanthrene, Anthracene, Fluoranthene, Pyrene, Benzo(a)anthracene, Chrysene, Benzo(b)fluoranthrene, Benzo(k)fluoranthrene, Benzo(k)

pyrene, Indeno(1,2,3-cd) perylene, Dibenzo(a,h)anthracene and Benzo(g,h,i) perylene) on a Agilent 6890 Gas Chromatography-Mass Spectrometry apparatus which had an ion trap. A factor of 4 HP-5MS capillary column (length 30 m, internal diameter 0.25 mm, film thickness 0.25 μ m) was utilized to attain the resolution of PAHs. The injector and transfer line temperatures were 325°C, and the carrier gas was helium, flowing at a rate of 1 millilitre per minute. The GC oven was programmed to operate at 40°C for two minutes, then ramp up to 250°C by 30°C per minute, then ramp up to 320°C by 10°C per minute, and finally hold for an additional two minutes. The mass spectrometer's ion source had an electron energy of 70 eV and a temperature of 150°C. The detector's scanning range was 70–300 m/z while it was in SCAN mode. By matching the mass spectra of each PAH and its retention period with the standard, the PAHs in the sample were identified and expressed in milligrammes per kilogramme.

2.3 Statistical analyses

Descriptive statistics were used to summarize the PAH data derived for the respective sampled stations. Additionally, the mean PAH data sets were subjected to student T test and Kruskal Wallis non-parametric statistical test using SPSS 20.0 software. This was done to determine if the observed differences in the data sets were statistically significant at 95% and 99% probability levels. Multivariate analysis of the data sets encompassing PCA and cluster tests was conducted using PAST 4.03 statistical software.

3. Results and Discussion

3.1 Bio-Concentrations of PAHs

Table 1 showed the concentrations of the various PAHs in the mudskipper, crab and periwinkle specimens. For the mudskipper, the highest mean concentration was recorded for Dibenzo(a,h)anthracene (0.1236mg/kg) while the least concentration was that of Indeno(1,2,3-cd) perylene (0.0001mg/kg). For crab, the least concentration was 0.0019mg/kg (Benzo(g,h,i) perylene) while the highest was 0.0499mg/kg (Dibenzo(a,h) anthracene). The lowest PAH in periwinkle was Benzo(g,h,i) perylene (0.0009mg/kg) and the maximum was Pyrene (0.0744mg/kg).

Table 1. Concentrations of PAHs in the respective aquatic fauna

Parameter Unit - mg/Kg	Mudskipper  $\pm$ S.E	Crab  $\pm$ S.E	Periwinkle  $\pm$ S.E	P- value	Significant- Level
Naphthalene	0.0017 $\pm$ 0.0006	0.0040 $\pm$ 0.0019	0.0025 $\pm$ 0.0007	0.441	P>0.05
Acenaphthalene I	0.0358 $\pm$ 0.0099	0.0184 $\pm$ 0.0014	0.0190 $\pm$ 0.0019	0.080	P>0.05
Acenaphthene II	0.0791 $\pm$ 0.0193	0.0354 $\pm$ 0.0117	0.0407 $\pm$ 0.0140	0.099	P>0.05
Florene	0.0384 $\pm$ 0.0055 ^a	0.0282 $\pm$ 0.0018 ^b	0.0226 $\pm$ 0.0032 ^b	0.018	P<0.05*
Phenanthrene	0.0562 $\pm$ 0.0194	0.0248 $\pm$ 0.0030	0.0227 $\pm$ 0.0023	0.078	P>0.05
Anthracene	0.0217 $\pm$ 0.0047	0.0160 $\pm$ 0.0027	0.0117 $\pm$ 0.0008	0.118	P>0.05
Fluoranthene	0.0346 $\pm$ 0.0038 ^a	0.0280 $\pm$ 0.0017 ^b	0.0218 $\pm$ 0.0031 ^b	0.016	P<0.05*
Pyrene	0.0239 $\pm$ 0.0023 ^b	0.0228 $\pm$ 0.0024 ^b	0.0744 $\pm$ 0.0196 ^a	0.003	P<0.01**
Benzo(a)anthracene	0.0260 $\pm$ 0.0028 ^a	0.0192 $\pm$ 0.0017 ^b	0.0178 $\pm$ 0.0026 ^b	0.044	P<0.05*
Chrysene	0.0271 $\pm$ 0.0016	0.0216 $\pm$ 0.0022	0.0235 $\pm$ 0.0028	0.217	P>0.05
Benzo(b)fluoranthrene	0.0169 $\pm$ 0.0040 ^a	0.0108 $\pm$ 0.0011 ^b	0.0066 $\pm$ 0.0014 ^b	0.039	P<0.05*
Benzo(k)fluoranthrene	0.0125 $\pm$ 0.0031	0.0077 $\pm$ 0.0010	0.0067 $\pm$ 0.0012	0.139	P>0.05
Benzo(k)pyrene	0.0055 $\pm$ 0.0023	0.0025 $\pm$ 0.0009	0.0017 $\pm$ 0.0003	0.276	P>0.05
Indeno(1,2,3-cd) perylene	0.0001 $\pm$ 0.0000	0.0049 $\pm$ 0.0028	0.0000 $\pm$ 0.0000	0.208	P>0.05
Dibenzo(a,h)anthracene	0.1236 $\pm$ 0.0149 ^a	0.0499 $\pm$ 0.0145 ^b	0.0011 $\pm$ 0.0004 ^b	0.000	P<0.001***
Benzo(g,h,i) perylene	0.0009 $\pm$ 0.0002	0.0019 $\pm$ 0.0009	0.0006 $\pm$ 0.0005	0.359	P>0.05

3.2 Seasonal variations in PAH concentrations

Acenaphthalene II was found to have the maximal mean content in the Mudskipper specimens collected in the dry season (0.07 mg/kg) (Table 2). Benzo (k) pyrene, Indeno (1, 2, 3-cd) perylene, and Benzo (g, h, I perylene had the lowest levels of PAHs (0.00 mg/kg). Dibenzo (a, h) anthracene had the greatest PAH levels during the wet season (0.13 mg/kg), whereas Indeno (1, 2, 3-cd) perylene and Benzo (g, h, I perylene had the lowest levels (0.00 mg/kg).

Table 2. Seasonal variation of PAHs in mudskipper specimens

Parameter	Dry season	Wet season	P-value	Significance Level
Unit – mg/Kg	$\bar{X} \pm S.E$	$\bar{X} \pm S.E$		
Naphthalene	0.005±0.004	0.001±0.0003	0.027	P<0.05*
Acenaphthalene	0.047±0.018	0.029±0.012	0.392	P>0.05
Acenaphthene	0.101±0.041	0.067±0.020	0.427	P>0.05
Florene	0.052±0.010	0.029±0.005	0.040	P<0.05*
Phenanthrene	0.092±0.048	0.033±0.005	0.143	P>0.05
Anthracene	0.029±0.009	0.017±0.004	0.192	P>0.05
Fluoranthene	0.036±0.007	0.034±0.004	0.741	P>0.05
Pyrene	0.027±0.004	0.022±0.003	0.302	P>0.05
Benzo(a)anthracene	0.033±0.004	0.022±0.003	0.046	P<0.05*
Chrysene	0.029±0.003	0.026±0.002	0.378	P>0.05
Benzo(b)fluoranthrene	0.025±0.008	0.014±0.005	0.235	P>0.05
Benzo(k)fluoranthrene	0.020±0.006	0.009±0.003	0.092	P>0.05
Benzo(k)pyrene	0.011±0.005	0.003±0.002	0.103	P>0.05
Indeno(1,2,3-cd) perylene	0.0001±0.000	0.0001±0.000	0	P>0.05
Dibenzo(a,h)anthracene	0.107±0.030	0.134±0.015	0.379	P>0.05
Benzo(g,h,i) perylene	0.0008±0.0002	0.001±0.000	0.667	P>0.05

For the crab specimens, Dibenzo (a, h) anthracene had the maximal mean value in the dry season (0.07 mg/kg) (Table 3). Benzo (g, h, I perylene had the lowest PAH level (0.00 mg/kg). While Benzo (g,h,i) perylene had the lowest wet season values (0.00 mg/kg), Dibenzo (a, h) anthracene had the greatest PAH (0.06 mg/kg) during the wet season. For the examined periwinkle specimens, pyrene had the highest reading during the dry season (0.01 mg/kg) (Table 4). In contrast, benzo (g,h,i) perylene and indeno (1, 2, 3-cd) perylene (0.00 mg/kg) had the lowest PAH levels. Pyrene had the highest PAH levels during the wet season (0.11 mg/kg), while Indeno (1, 2, 3-cd) perylene and Benzo (g,h,i) perylene had the lowest levels (0.00 mg/kg). Every aquatic organism is known to either adapt or modify its metabolic processes in response to contaminants (Di Giulio *et al.*, 2020). Sixteen PAH congeners were found to be present at measurable levels in the mudskippers from the Falcorp mangrove. Amongst the detected PAHs in the respective mudskippers, Acenaphthene had maximal concentration followed by Phenanthrene, Fluorene, Acenaphthylene, and Chrysene. The concentrations of PAHs in the three aquatic faunas were all below those recorded for PAHs in aquatic organisms in previous studies (Zhang *et al.*, 2019; Qin *et al.*, 2020; Lambiasi *et al.*, 2021; Saunders *et al.*, 2022; Shi *et al.*, 2024), however, they were similar to those recorded in Ogbonna and Origbe (2021) which ranged from 0.002 to 0.005mg/kg. Another study reported the detection of PAHs in crabs with concentrations ranging from 0.012 to 0.022mg/kg (Ifemeje and Destiny, 2022).

Table 3. Seasonal variation of PAHs in crab specimens

Parameter	Dry season	Wet season	P-value	Significance Level
Unit – mg/Kg	$\bar{X} \pm S.E$	$\bar{X} \pm S.E$		
Naphthalene	0.005±0.004	0.003±0.002	0.696	P>0.05
Acenaphthalene	0.020±0.003	0.017±0.001	0.250	P>0.05
Acenaphthene	0.038±0.021	0.034±0.015	0.884	P>0.05
Florene	0.029±0.003	0.028±0.002	0.846	P>0.05
Phenanthrene	0.020±0.004	0.028±0.004	0.270	P>0.05
Anthracene	0.018±0.005	0.015±0.003	0.524	P>0.05
Fluoranthene	0.026±0.003	0.009±0.002	0.470	P>0.05
Pyrene	0.027±0.005	0.019±0.002	0.131	P>0.05
Benzo(a)anthracene	0.022±0.003	0.017±0.002	0.163	P>0.05
Chrysene	0.025±0.003	0.019±0.003	0.172	P>0.05
Benzo(b)fluoranthrene	0.012±0.002	0.010±0.001	0.534	P>0.05
Benzo(k)fluoranthrene	0.009±0.002	0.007±0.001	0.312	P>0.05
Benzo(k)pyrene	0.004±0.002	0.002±0.001	0.406	P>0.05
Indeno(1,2,3-cd) perylene	0.011±0.000	0.002±0.003	0.299	P>0.05
Dibenzo(a,h)anthracene	0.077±0.031	0.057±0.021	0.601	P>0.05
Benzo(g,h,i) perylene	0.001±0.000	0.003±0.002	0.401	P>0.05

Table 4. Seasonal variation of PAHs in periwinkle specimens

Parameter	Dry season	Wet season	P-value	Significance Level
Unit – mg/Kg	$\bar{X} \pm S.E$	$\bar{X} \pm S.E$		
Naphthalene	0.002±0.0009	0.003±0.0009	0.827	P>0.05
Acenaphthalene	0.003±0.0009	0.019±0.003	0.890	P>0.05
Acenaphthene	0.054±0.029	0.032±0.015	0.453	P>0.05
Florene	0.034±0.003	0.016±0.003	0.003	P<0.01*
Phenanthrene	0.021±0.004	0.024±0.003	0.515	P>0.05
Anthracene	0.013±0.002	0.011±0.0005	0.003	P<0.01*
Fluoranthene	0.033±0.002	0.015±0.003	0.515	P>0.05
Pyrene	0.105±0.035	0.055±0.022	0.305	P>0.05
Benzo(a)anthracene	0.015±0.004	0.019±0.003	0.002	P<0.01*
Chrysene	0.034±0.004	0.018±0.002	0.219	P>0.05
Benzo(b)fluoranthrene	0.008±0.003	0.006±0.001	0.362	P>0.05
Benzo(k)fluoranthrene	0.011±0.002	0.005±0.0008	0.002	P<0.01*
Benzo(k)pyrene	0.002±0.0006	0.001±0.0004	0.469	P>0.05
Indeno(1,2,3-cd) perylene	0.000±0.000	0.000±0.000	0.008	P<0.01*
Dibenzo(a,h)anthracene	0.002±0.001	0.002±0.0005	0.520	P>0.05
Benzo(g,h,i) perylene	0.0006±0.0005	0.00 ±0.00	0.703	P>0.05

Lower molecular weight compounds, known to be more accessible and possibly more hazardous in aquatic species (Meng *et al.*, 2019), were shown to predominate in the PAH profile of mudskippers. Benzo[a]pyrene concentrations in food are limited to 10 µg/kg by a specification set by the Joint FAO/WHO Expert Committee on Food Additives. Although, Benzo[a]pyrene was found in

mudskipper specimens collected from Falcorp mangrove in this investigation, the reported values were well below the recommended limit. It has been documented that aquatic creatures can quickly absorb hydrocarbons, especially PAHs, and that significant concentrations of these compounds can build up in their tissues (Honda and Suzuki, 2020). Remarkably, there were no discernible variations in the overall amounts of PAHs between periwinkles and crabs. The quantities of some of the PAH moieties such as dibenzo(a,h)anthracene, benzo[a]anthracene, pyrene, fluorene, and fluoranthene, were noticeably greater in mudskippers. The order of the total PAH burden was Mudskipper > Crab > Periwinkle.

Crabs and molluscs are vital to maintaining the ecological services and functions of mangrove ecosystems, such as serving as fish stock nursery sites, which are essential to the local economy (Edwin-Wosu and Dirisu, 2022). These organisms play a crucial role in connecting higher trophic levels with primary detritus at the base of the food web. Through their consumption of litter and bioturbation, crabs in particular help recycle nutrients, changing the physicochemical characteristics of the soil and improving the retention of organic carbon below ground (Rodrigues-Filho *et al.*, 2023). The quantity and diversity of species like crabs and molluscs are important markers of the bioavailability of anthropogenic pollutants and their biological implications, as contaminants have a substantial impact on the diversity and functioning of mangrove biota (Rullens *et al.*, 2019).

3.3 PCA for biota associated PAHs

The PCA results based on the PAH congeners' correlation matrix are presented in Table 5. On the data sets comprising 16 components examined in the water samples, the PCA was carried out. With Eigenvalues < 1, the PCA of the data sets produced 23 variables under 16 components (PC1-PC16). Each of these variables accounted for 100.25 percent of the variance in water quality. Components 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, and 16 each contributed the following proportions: 35.72, 29.69, 16.93, 10.14, 4.84, 1.02, 0.55, 0.34, 0.26, 0.18, 0.15, 0.09, 0.04, 0.02, 0.01 and 0.00 percent, respectively (Table 5). Acenphthalene 11 and Dibenzo (a, h) anthracene were the criteria of interest for each component (0.46 and 0.86) 2; Pyrene and Acenphthlene 11 (0.73) (0.57) 3; Pyrene; Phenanthrene (0.73) (0.73) Fluoranthene, Florene (0.39), and Florene (0.63) (0.53) 7; Benzo (a) anthracene (0.71) and Chrysene (0.55) 8 (0.55) 9; anthracene (a) benzo (0.37) 10; anthracene (0.39), 12; benzo (b) fluorenthrene (0.54) 11; naphthalene (0.77) 13; Benzo (a) anthraene and naphthalene (0.33) (0.54) Indeno (1, 2, 3-cd) perylene (0.94), Benzo (k) pyrene (0.95), and 16 Benzo (g, h, I perylene (0.98).

The scatter plot of the PAH congeners in the biota of Falcorp mangrove swamp and their relationships are displayed in Figures 1 and 2. Phenanthrene, Acenphthlene I and II, Dibenzo (a, h) anthracene with Mudskipper, Periwinkle and Benzo (k) fluoranthrene, Benzo (g, h, I perylene, and positive-negative clusters with Crab and Benzo (b) fluoranthrene was present in components 1 and 2. There are positive relationships between Chrysene, Benzo (a) anthracene, Benzo (b) fluoranthrene, Benzo (k) fluoranthrene, Benzo (k) perylene, Benzo (a, h) anthracene, Florene, Phenanthrene, Fluoranthrene, Benzo (g, h, I perylene, and Acenphthalene II. Indeno (1,2,3-cd) perylene, anthracene, and naphthalene have a negative association (Figure 3).

Table 5. Eigenvectors and eigenvalues for the bio-concentrated PAHs

	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7	PC 8	PC 9	PC 10	PC 11	PC 12	PC 13	PC 14	PC 15	PC 16
Naphthalene	-0.01	0.02	-0.01	-0.02	-0.01	0.02	-0.07	0.08	-0.02	-0.29	-0.34	0.77	0.33	0.09	-0.25	-0.14
Acenaphthalene 1	0.03	0.15	0.27	-0.05	0.64	-0.40	0.14	-0.15	-0.07	-0.51	0.03	-0.07	-0.09	-0.11	0.02	0.01
Acenaphthene II	0.46	0.73	-0.02	-0.46	-0.15	0.05	-0.10	-0.01	0.02	0.01	0.04	-0.02	0.02	-0.01	0.01	0.00
Florene	0.07	0.07	0.10	0.06	0.39	0.63	0.14	0.08	-0.41	0.13	-0.39	-0.20	0.13	-0.04	-0.02	0.01
Phenanthrene	0.06	0.12	0.88	0.31	-0.32	0.04	-0.01	0.02	0.04	0.02	0.01	0.02	0.01	-0.02	0.00	0.00
Anthracene	-0.01	-0.04	0.09	0.01	0.31	0.19	-0.77	0.14	-0.10	0.09	0.39	0.20	-0.15	-0.09	0.00	0.00
Fluoranthene	0.09	0.00	-0.06	0.15	0.10	0.53	0.06	-0.36	0.65	-0.30	0.13	0.02	-0.05	0.05	0.05	-0.02
Pyrene	-0.16	0.57	-0.31	0.73	0.05	-0.11	-0.02	0.07	-0.03	0.05	0.03	0.02	-0.01	0.00	0.00	0.00
Benzo(a)anthracene	0.05	0.00	0.06	-0.04	0.23	-0.11	-0.03	0.71	0.57	0.12	-0.26	-0.15	0.04	0.02	0.01	-0.02
Chrysene	0.07	0.00	0.01	-0.02	0.05	0.19	0.55	0.43	-0.13	-0.04	0.61	0.27	-0.07	0.04	-0.02	-0.02
Benzo(b)fluoranthrene	0.01	0.03	0.10	-0.03	0.31	-0.15	0.14	-0.31	0.20	0.59	0.20	0.14	0.54	-0.13	-0.07	-0.01
Benzo(k)fluoranthrene	0.01	0.05	0.07	-0.04	0.17	-0.05	0.15	-0.17	0.08	0.42	-0.23	0.36	-0.71	0.19	-0.03	-0.01
Benzo(k)pyrene	0.00	0.02	0.07	0.00	0.11	-0.05	-0.08	-0.03	-0.07	0.00	0.10	-0.12	0.18	0.95	0.09	-0.02
Indeno(1,2,3-cd) perylene	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	-0.03	0.00	-0.10	0.26	0.10	-0.07	0.94	0.17
Dibenzo(a,h)anthracene	0.86	-0.31	-0.12	0.35	0.02	-0.16	-0.03	-0.01	-0.08	0.02	-0.03	0.02	0.00	0.00	-0.01	0.00
Benzo(g,h,i) perylene	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.02	0.03	-0.04	-0.01	0.07	0.03	0.05	-0.19	0.98
Eigenvalue	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
% variance	35.72	29.69	16.93	10.14	4.84	1.02	0.55	0.34	0.26	0.18	0.15	0.09	0.04	0.02	0.01	0.00

NB: Bolded values exceeded standards. According to [Grimm and Yarnold \(2000\)](#), loadings > 0.71 are typically regarded as excellent, and loadings < 0.32 very poor. However, [Nair et al. \(2010\)](#) stated that the component with the highest Eigenvalue is taken to be the most significant and should be one or greater for proper considerations during PCA. Factor loadings values of > 0.75, between 0.75–0.5 and 0.5–0.3 are classified as strong, moderate and weak respectively, based on their absolute values.

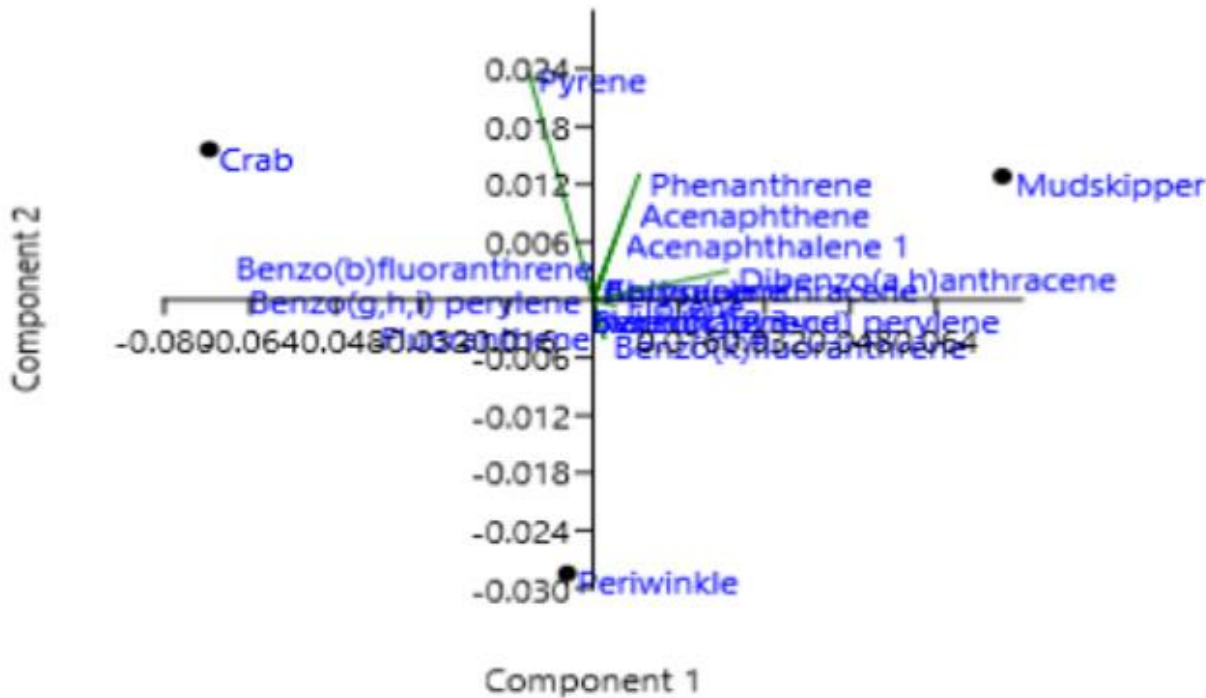


Figure 1. Scatterplot of biota associated PAHs

With percentages of 35.72%, 29.69%, 16.93%, and 10.14%, respectively, principal components PC1, PC2, PC3, and PC4 in this study contributed the most to the overall variance in

PAH concentrations in biota. These factors were significant in explaining the heterogeneity in the distribution of PAHs, as evidenced by loadings higher than 10 percent. The following were the primary parameters for each principal component: With loadings of 0.46 and 0.86, respectively, Acenaphthylene II and Dibenzo(a,h)anthracene dominated PC1, followed by Acenaphthylene II (0.73) and Pyrene (0.57) in PC2, Phenanthrene (0.73) in PC3, and Pyrene in PC4 (0.73). These properties were critical in describing the levels of PAH contamination in the biota samples.

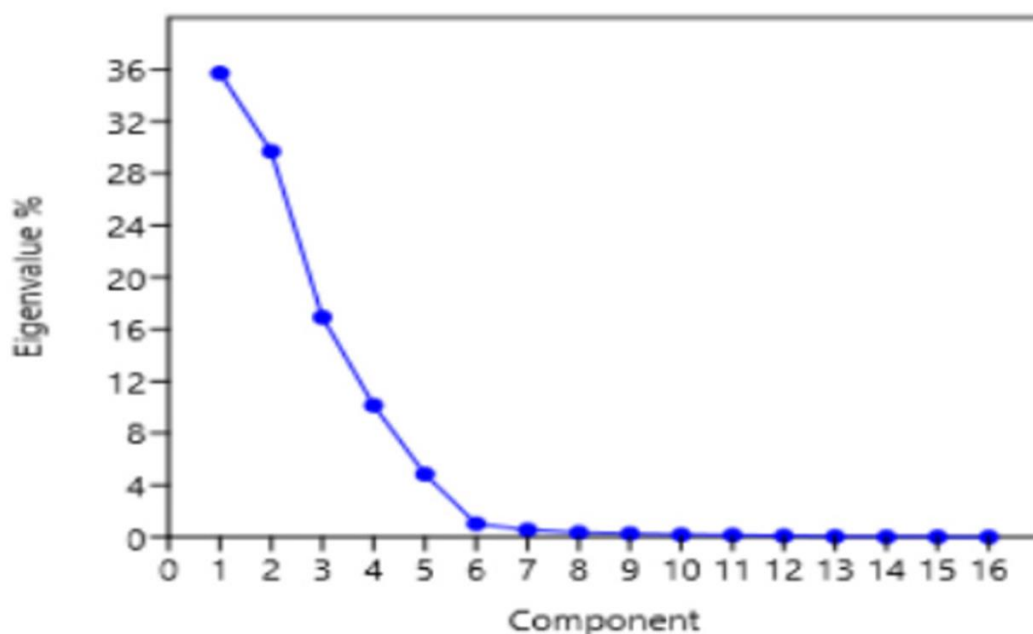


Figure 2. Screenplot of biota associated PAHs

According to the source attribution, a primary cause of the reported PAH levels is hydrocarbon contamination, mostly from anthropogenic activities. Hydrocarbon contamination particularly in areas where crude oil exploration is/has been conducted has been observed for sediments collected from these areas around the world (Odigie and Olomukoro, 2020). The results are consistent with other studies which have documented the widespread effects of hydrocarbon pollution in aquatic habitats (Ukhurebor *et al.*, 2021; Ambade *et al.*, 2022; Dai *et al.*, 2022). Despite the standard PCA criterion of >1 to identify significant components, the eigenvalues for all principal components (PC1–PC16) were less than 1. This trend would imply that the eigenvalues obtained in this study fall short of statistical significance standards, suggesting that the parameters in these components have little effect on the biota.

3.4 Cluster analysis, Euclidean similarity and distance indices

Figure 3 revealed the cluster combination based on the Ward approach, while Table 6 displays the similarity and dissimilarity as determined by Euclidean distance. The PAH properties at each station were entirely different, with values less than 1, based on the cluster combinations. Clustering patterns among PAH characteristics were discovered by the scatter plot relationships. Periwinkle associated PAHs displayed a negative cluster with Benzo(k)fluoranthene and Benzo(g,h,i) perylene, whereas Phenanthrene, Acenaphthylene I and II, and Dibenzo(a,h)anthracene showed positive clusters with mudskipper. Crab and PAH moieties like benzo(b)fluoranthene and benzo(g,h,i) anthracene were found to have mixed positive and negative clusters. A number of PAHs, such as Benzo(a)anthracene, Chrysene, Fluorene, Phenanthrene, Fluoranthene, and Acenaphthylene

II, showed a positive association with one another, but Naphthalene, Anthracene, and Indeno(1,2,3-cd) perylene showed a negative correlation.

Table 6. Euclidean similarity and distance indices

Biota	Mudskipper	Periwinkle	Crab
Mudskipper	0.00		
Periwinkle	0.09	0.00	
Crab	0.15	0.08	0.00

NB: Ward-Euclidean: 0 and < 1; complete dissimilarity, ≥ 1 ; complete similarity, critical level of significance (C) = 0.05. The bolded values indicated similarity

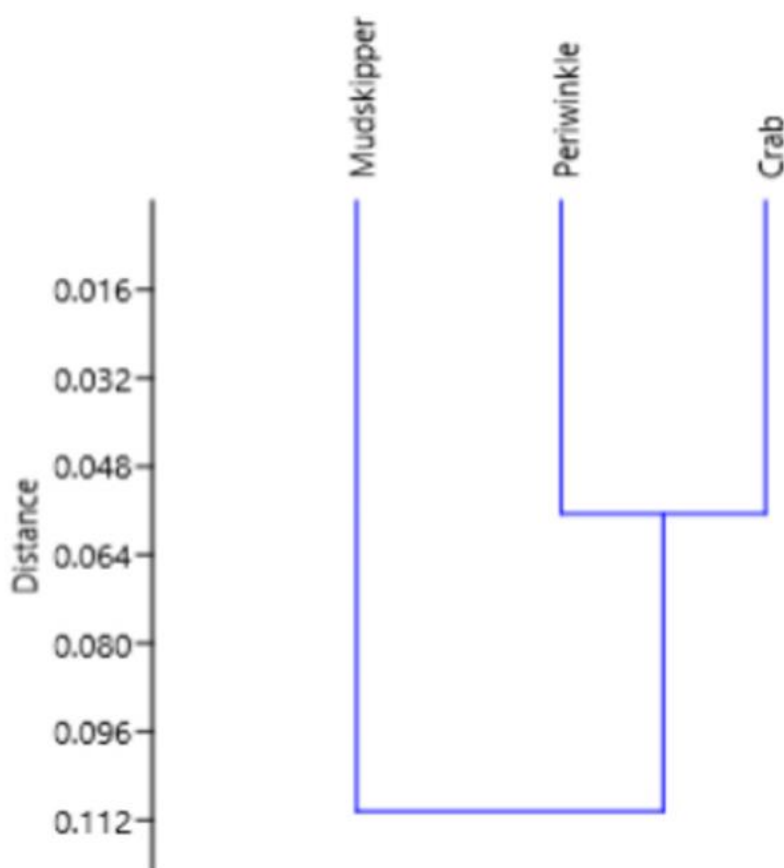


Figure 3. Cluster analysis of the biota associated PAHs

With similarity values below 1, the cluster analysis dendrogram revealed that the dominant physical and chemical circumstances in the faunal specimens were very different. The mudskipper and periwinkle, as well as the crab and periwinkle, did, however, share certain similarities, suggesting possible exposure or bioaccumulation pathway overlaps.

4. Conclusion

Results presented in this study indicated the varying levels of bioaccumulated PAHs in examined fauna ferally collected from a mangrove swamp in Delta State, Nigeria, that has been anthropogenically disturbed. The results show that PAH concentrations vary across biota and are considerable, especially in mudskippers. Hydrocarbon contamination was found to be a significant

contributor by Principal Component and Cluster Analyses, which highlighted its possible effects on aquatic ecosystems and food safety.

The detection of varying bio-concentrated PAH levels in the ferally collected freshwater mangrove fauna could be indicative of the widespread ecological distribution of these hydrocarbon pollutants within the study area. This trend would infer that there is an urgent need for the relevant public environmental monitoring agencies to conduct more follow up hydrocarbon pollutant assessment coupled with environmental monitoring activities across all the anthropogenically altered areas within the Niger Delta region.

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Compliance with Ethical Standards: This article does not contain any studies involving human or animal subjects.

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