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Chapter

Polycyclic Aromatic Hydrocarbons (PAHs) and Their Influence to Some Aquatic Species

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Abstract

Polycyclic aromatic hydrocarbons (PAHs) are ubiquitous environmental pollutants generated primarily during the incomplete combustion of organic materials (e.g., coal, oil, petrol, and wood). Many PAHs have toxic, mutagenic, and/or carcinogenic functions. PAHs are highly lipid soluble which lead to a fast absorption by the gastrointestinal tract of marine mammals. They are immediately distributed in a vast variety of tissues with a notable tendency for localization in body fat. Metabolism of PAHs is obtained via the cytochrome P450-mediated mixed function oxidase system with oxidation or hydroxylation as the first step. PAHs are environmental contaminants that pose significant risk to health of fish. The effect of PAHs on fish is a topic of rising attention in a lot of countries. Different studies using the bile metabolites separated by high-performance liquid chromatography with fluorescence detection were presented. The aim is to compare the levels of PAH metabolites in fish from different areas and fish species. The major metabolite present in all fish was 1-hydroxypyrene. The data confirm the importance of 1-hydroxypyrene as the key PAH metabolite in fish bile and suggest that the European eel is an ideal species for monitoring PAHs.

Keywords: PAHs, organic pollutants, metabolism, fish, 1-hydroxypyrene, European eel

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1. Introduction

Aquatic ecosystems are susceptible to receiving and accumulating contaminants [1]. In particular, polycyclic aromatic hydrocarbons (PAHs) have been identified as general causes of the deterioration of aquatic ecosystems in recent decades [2].

Polycyclic aromatic hydrocarbons (PAHs) are ubiquitous and persistent environmental contaminants found in sediments and associated waters of urbanized estuaries and coastal areas [3–5]. They are a class of compounds found in crude oil and are everywhere in the aquatic ecosystem [6–12]. PAHs are the most toxic pollutants of crude oil and are remembered by the United States Environmental Protection Agency (EPA) as priority toxic components because of its persistence in the environment and are toxic to fishes [13, 14]; thus, PAHs are of special interest following oil spills and in environmental control. They come from natural and anthropogenic sources. The latter can be associated to pyrolysis and incomplete combustion of

organic element [15]. Wastewater, atmospheric deposition, and petroleum spillage are some of the most important PAH sources. PAHs and their intermediate degradation products have the potential to generate toxic or mutagenic effects in fish [16–18] and humans [19]. PAH metabolites in the bile fluid are generally accepted as measures for PAH exposure in fish because of the rapid metabolism of PAH in most vertebrates [3]. Therefore, PAH metabolites in fish are recommended as monitoring parameters in European seas [20, 21].

In this chapter, we briefly review the origin, toxicity, and transformation of PAHs in the aquatic environment, highlighting their efficient metabolism in fish. We also review the presence of PAHs on fish bile and the works reported on that.

2. Organic contamination by polycyclic aromatic hydrocarbons (PAH)

2.1 PAH origin

PAHs are mainly formed during the incomplete combustion of organic matter and during the slow maturation of organic matter accumulated in deep sedimentary environments. These two origins present distinct formation mechanisms that are realized with different kinetics and induce variable molecular distributions (related to stability) [22].

2.1.1 Pyrolytic origin

Pyrolytic PAHs are generated by processes of incomplete combustion of organic matter at high temperatures. The mechanisms involved in their formation involve the production of free radicals by pyrolysis at high temperature (≥500°C) of the fossil material (oils, fuel oil, organic matter, etc.) under oxygen-deficient conditions. PAHs of pyrolytic origin come from the combustion of automotive fuel, domestic combustion (coal, wood, etc.), industrial production (steelworks, aluminum smelters, etc.), and energy production (power stations operating on oil or coal) or incinerators [23].

2.1.2 Petrogenic origin

The process of diagenesis can give rise to petroleum and other fossil fuels containing the so-called petrogenic PAHs. These PAHs are formed at low temperatures (150°C) over long periods of time. They result from exposure of organic matter to adequate conditions of temperature and pressure. The proportion of PAHs in oils varies according to their origin and level of refinement. In general, petrogenic PAH mixtures are marked by a predominance of low molecular weight PAHs, three cycles or less, and substituted PAHs [22].

PAHs represent between 20 and 40% by weight of crude oils which are mainly composed of saturated hydrocarbons. However, they are less than a few percent of the composition of refined gasoline (<0.5% by mass) or kerosene [24].

2.1.3 Biological origin

PAHs can also be formed by microorganisms from biogenic precursors such as diterpenes and triterpenes, steroids, pigments, or quinones in sediments or recent soils [25, 26]; these precursors can come from terrestrial or aquatic biological tissues (plants, animals, bacteria, macro- and microalgae) [27, 28].

2.2 PAH toxicity

The toxicity of several PAHs is a phenomenon that is well-known. Research has been conducted by several environmental groups such as the US Environmental Protection Agency-Toxic Substances Control Act (US EPA-TSCA) and the International Agency for Research on Cancer (IARC). The toxicity of PAHs to aquatic species is affected by metabolism and photooxidation. They are generally harmful in the presence of ultraviolet light. PAHs have moderate to high acute toxicity to aquatic organisms and birds. Mammals can absorb PAHs by various routes, e.g., dermal contact, inhalation, and ingestion [14, 29, 30]. The concentrations of PAHs found in fish are expected to be much higher than in the environment from which they were taken because of their bioaccumulation. Withal, metabolism of PAHs is sufficient to prevent biomagnifications [31, 32].

Teleost fish have an immense capacity to metabolize PAHs because of the enzymes cytochrome P450 in their tissues that oxidatively biotransform PAHs to hydroxylated metabolites [33].

The half-life times of PAHs in various biological tissues (bivalves, crustaceans, and fish) are of the order of a few days to 10 days and are about five times higher for heavy PAHs relative to lower PAHs.

The environmental matrices are moreover complex, containing numerous endogenous or exogenous, mineral or organic molecules between which interactions can take place. Synergistic toxic effects have been observed in particular between metals and PAH quinones [34].

Indeed, the carcinogenic nature of some of these molecules alone or in mixtures is proven. Twelve of these are classified by the International Agency for Research on Cancer (IARC) as probably carcinogenic to humans [35]. After contamination by these substances, they are biotransformed in the liver into different (poly)hydroxy-PAHs.

The risks of PAHs to fish and other aquatic organisms in natural systems are highly uncertain due to the occurrence of complex, incompletely characterized mixtures of these chemicals, large spatial heterogeneity in exposure concentrations, incomplete understanding of the importance of UV-activated PAH toxicity, the biological and physical controls on fish exposure to UV light, and the bioaccumulation of PAHs. These uncertainties are especially great for early-life-stage fish, which might be particularly susceptible to UV-activated because of their small size, lack of protective pigmentation and gill coverings, and ready accumulation of PAHs.

3. Transformations of PAHs in marine ecosystem

3.1 Physical and chemical degradation

Sediments contaminated with PAHs pose a real threat to all living organisms, even those that feed on the benthic prey.

PAHs with a low molecular weight can be found in all environmental matrices, since higher molecular weight compounds are more deeply associated (physically and chemically) with sediments/soils and particles than the other abiotic sample types. PAHs in air can be modified via chemical oxidation and photochemical processes [8], whereas in sediments/soils and the uppermost portion of the water column, degradation of PAHs, particularly lower molecular weight PAHs, occurs via photooxidation [6, 36]. In addition to parent PAHs, oxygenated PAH metabolites formed during these degradation processes can persist associating with sediments up to 6 months after initial addition to the water column and thus can endure in the environment for extended periods of time [37]. In water samples and sediment,

some microorganisms (e.g., fungi, bacteria) have been demonstrated to mineralize PAHs under aerobic conditions, particularly those compounds that contain two- and three-fused rings (e.g., fluorene, naphthalene), to their basic elements or to biodegrade these compounds to more polar degradation products [3, 8]. More information on PAH microbial degradation pathways and identification of degradation can be found in Cerniglia and Heitkamp [38], Juhasz and Naidu [39], and Bamforth and Singleton [40]. Part of research studies have proved that pyrene can be mineralized by certain strains of bacteria (e.g., *Mycobacterium*) under optimum growing conditions in the laboratory, but it is uncertain if this occurs in the natural environment [41, 42]. In contrast, other higher molecular weight PAHs (e.g., five- and six-ring compounds) are not readily degraded by microbes and thus are more likely to accumulate in these environmental media (particularly in fine-grained sediments with high organic carbon content) [3, 39]. Under anoxic conditions, PAHs persist in sediments, particularly in organic sediments [42].

3.2 Biotransformation in the aquatic food web

Pyrolytic PAHs are the most common in aquatic environments. After the emission of pyrolytic PAHs into the atmosphere, the molecules fall back and settle on the surface of the water or soil [23]. Under the action of soil leaching, PAHs are transported to water bodies. These hydrophobic molecules then associate with other particles of the column of water and accumulate in the sediment [23].

In aquatic organisms, exposure to PAHs can occur through dermal exposure, respiration, or consumption of contaminated prey (e.g., annelids, crustaceans) or sediment [43]. Biotransformation of PAHs in aquatic organisms occurs to varying degrees depending on a number of factors, including the rate of uptake, metabolic capability, physical condition, feeding strategy, and age [43, 44]. Invertebrates are capable of PAH uptake from their environment and have been shown to have varying levels of PAH-metabolizing capability [44]. Mollusks generally have lower PAH-metabolizing capability than certain species of polychaetes, crustaceans, and fish [3].

PAH metabolism in fish is mainly conducted by inducible enzymes of the cytochrome P450 family, in particular CYP1A. These enzymes are localized in the membranes of the smooth endoplasmic reticulum, located mainly in the liver, but are also present in other organs. They are expressed and functional from the earliest stages of fish development. These enzymes catalyze the addition of an oxygen atom to the PAH molecule through an NADPH-dependent reaction. CYP1A protein is induced during exposure of the body to PAHs. CYP1A induction is rapid, and activity levels are often increased by a factor of 100 a few hours after exposure. These highly polar conjugated metabolites are then excreted into urine or the bile for rapid rejection over the gastrointestinal tract [14, 43, 45, 46]. Concerning the result of this rapid metabolism in fish, concentrations of parent PAHs are insignificant in muscle and other tissues. Thus, to determinate a recent exposure to PAHs in teleost fish, bile and urine are used, with the preference of bile because of its easy sampling. Otherwise, differences in the metabolism of benzo[a]pyrene (BaP), including differences in the types and proportions of metabolites formed, have been shown between two fish of freshwater [47, 48]. These differences could contribute to variations in susceptibility to these carcinogenic compounds among fish species. Differences in glutathione-S-transferases may also help explain differential susceptibility to chemically induced carcinogenesis among fish species [46]. A number of analytical methods have been developed to measure PAH metabolites in fish bile and are reviewed in [14]. Oil spills, including the Deepwater Horizon (DWH) spill in the Gulf of Mexico in 2010, show the necessity of the need for additional

methods to determine PAH exposure in seafood or protected species (e.g., marine mammals) where species cannot be lethally collected. For example, a rapid, sensitive HPLC-fluorescence method was developed by the US Food and Drug Administration [49] during the DWH spill and was used by federal and Gulf state analytical laboratories as part of the seafood safety response [50]. The development of new analytical methods like those can provide important information on PAH exposure in aquatic organisms.

4. Effects of PAHs on aquatic species

PAHs are an important factor of contamination in the environment but also a risk to human health. In fact, the dangers related to PAHs vary according to their toxicity on the one hand and the many sources of exposure on the other. It has also been proven that carcinogenic and mutagenic effects related to a single compound of PAHs were found. A large number of effects have been identified [51]. In fact, genotoxicity and tumorigenesis observed in fish are linked to the presence of metabolites. Beyond genotoxicity, there are many other effects observed, for example, in behavior, reproduction, and growth.

Benzo[a]pyrene, for example, which is highly studied, leads to a decrease in weight [52] and growth [53], an increase in the gonado-somatic index (GSI) in Japanese medaka (*Oryzias latipes*) [52], DNA breaks in oysters (*Crassostrea gigas*) [54], and DNA adducts in zebrafish and on human liver cells (HepG2) [55]. Teratogenic effects in particular on the heart of sardine (*Clupea pallasii*) [56] and zebrafish [57, 58] have been observed as well as anemia in scorpion fish (*Sebastes schlegelii*) [59]. Benzo[a]pyrene affects the reproduction of isopods (*Oniscus asellus* and *Asellus porcellio scaber*) [53] and accumulates in oocytes in catfish (*Ictalurus punctatus*) [60]; it disrupts the expression of the aromatase (enzyme necessary for the conversion of androgen such as estrogen isosterone) in female mummichog (*Fundulus heteroclitus*) [61] and inhibits the synthesis of testosterone and estradiol in flounder (*Platichthys flesus* L.) [62].

The toxicity of a compound can be enhanced or reduced by endogenous and exogenous factors. For example, in fish, hypoxia [63], geographical origin and fish life history [64], and/or the various PAH compounds [65] can cause variations. The penetration time in the fish embryo and the depuration time can vary considerably. In addition, the effects produced by these molecules, tested individually, do not necessarily follow a dose-effect relationship [52].

4.1 Effects of PAHs on the survival

Survival is a commonly used variable. This variable has made it possible to develop standardized tests in toxicology such as LD50 (lethal dose) or LC50 (lethal concentration) calculations. Although protected in their chorions, fish eggs and then larvae are particularly exposed because, in most cases, they are unable to flee contaminated areas during their early-life stages [66]. It is during development, during the establishment of all organs and systems, that contaminants can pass this barrier. They can affect the development and have long-term consequences. Exposure to PAHs can lead to decreased survival in aquatic organisms during acute exposures. For example, there has been a decrease in survival after early exposure of salmon (*Oncorhynchus gorbuscha*) to dissolve PAHs [67].

In the case of chronic exposure in the early stages, similar effects can be observed. Impairment in survival has been observed in salmon (*Oncorhynchus gorbuscha*) exposed to crude oil [68], in minnow (*Pimephales promelas*) exposed

to contaminated sediment [69], in *Chanos chanos* and capelin (*Mallotus villosus*) exposed to dissolved PAHs (anthracene, B[a]P, pyrene and heavy fuel oil) [66, 70], and in shrimp (*Palaemonetes pugio*) exposed to the pyrene feed which also shows reduced survival [71]. In other studies, survival is not affected by PAHs. This is the case, for example, in terrestrial isopods, where oral administration does not have significant effects on survival [53]. It is also not affected after exposure to BaP in mummichog (*Fundulus heteroclitus*) [72]. PAHs can affect survival in some cases and not in others. This extreme variable may not be the most sensitive for all species or all types of exposure.

4.2 Malformations and growth

PAHs induce malformations during development. They lead to a decrease in skeletal mineralization in bass (*Dicentrarchus labrax*) [73] and craniofacial deformities in scorpion fish (*Sebastiscus marmoratus*) [74]. Jaw malformations [75] in this same fish as well as in zebrafish [58] were also observed. The number of edemas is also increased in scorpion fish (*Sebastes schlegelii*), salmon (*Oncorhynchus gorbuscha*) [67, 76], and medaka (*Oryzias latipes*) [77], as well as the occurrence of hemorrhages in trout (*Oncorhynchus mykiss*) [78]. The impact of PAHs on growth is frequently reflected in a reduction in size and/or weight [67, 79, 80]. This reduction in growth is observed regardless of the mode of administration of PAHs, the concentrations used, and the duration of exposure [59, 70, 81]. Weight reduction is often proportional to contamination [81]. Unfortunately, these are not the only visible damage. A decrease in lipid reserves may be observed and result in a decrease in energy reserves [10, 79].

4.3 Metabolism and osmoregulation

In a PAH study, fish were exposed to the soluble fraction of a crude oil mixture. Structural lesions and morphological differences are noted on the gill [82]. These differences would be related to a metabolism aimed at reducing contact with the pollutant, which would reduce the gill surface and oxygen supply. A reduction in oxygen uptake could compromise the fish metabolism [82].

Osmoregulation problems following exposure of *Sebastiscus marmoratus* to dissolve PAHs have been observed [75]. PAHs would inhibit Na^+/K^+ activity in a dose-dependent manner and play a role in osmoregulation.

4.4 Effect on behavior

The behavioral response of an animal following exposure to stress and/or contaminant (s) is increasingly studied [83–87].

The behavior makes it possible to discriminate a large number of integrating variables from the changes induced by PAHs. Swimming activity can be assessed as well as other aspects such as lethargy, anxiety, social communication, eating behavior, flight response, learning, or reproductive behavior.

A reduced swimming activity in seabream (*Sparus aurata*) was observed following a 4 days of exposure to dissolved PAHs [88, 89]: phenanthrene, fluorine, and pyrene [89]. An increase in lethargy and a reduction in the number of surface surges have also been observed following exposure to dissolved PAHs in this species [88, 89].

These variables can also be used to evaluate the neurotoxic effects of a contaminant. The reduction of social interactions following exposure to phenanthrene [89] is proven.

The escape response, in the presence of fluoranthene, has been demonstrated in control fish [90]. The fish are placed in a double flow aquarium. A flow of control

water and a flow of water containing fluoranthene are present. Fish that have never been exposed are fleeing fluoranthene. On the other hand, fish that have been previously exposed to a high dose of fluoranthene no longer leak the molecule [90].

Learning and exploration abilities are diminished after exposure to PAHs. For example, discrimination of a familiar object is altered in mice exposed to BaP. In the same vein, dietary exposure of the mother to a mixture containing the 16 priority PAHs of the USEPA leads to behavioral alteration in the next generation, especially in a new environment. The reproductive behavior can also be disturbed. The ability of a male to find a female can be altered, as is the case in amphipods, for example [91].

4.5 Effect on reproduction

PAHs are lipophilic molecules that are transported and found in the ovaries via vitellogenin and/or lipovitellin [60]. They can also result in inhibition of vitellogenin synthesis, as has already been shown in trout after exposure to β-naphthoflavone [92]. This exposure compromises the maturation of the ovaries and causes an increase in apoptosis in gonadal cells [91]. These pollutants lead, for example, to reproductive inhibition in shrimp exposed to pyrene [71]. A decrease in fecundity, number of breeding cycles, and larval survival is observed in different fish species. In mussels, gametes are deformed and are present in small numbers [91].

Females are not the only ones to be affected. Male sperm quality can also be altered after exposure to benzo[b]fluoranthene, as is the case in mice exposed via breast milk [59]. Sperm quality is reduced, and there is also an increase in testicular apoptosis.

5. PAHs in eels

High-performance liquid chromatography (HPLC) is generally used for the determination of PAH metabolites in considerable fish species [93–98] and has been covered by an intercalibration exercise [22].

Although bile metabolites have been measured in many species of fish [13], those selected for biomonitoring programs tend to be common, long-lived species at the top of the food chain, with relatively sedentary life styles and benthic habits [99]. Consequently, the common eel (*Anguilla anguilla*) has been used in studies of PAH contamination [100, 101]. Pleuronectid flatfish are also well-suited to biomonitoring, and the European flounder (*Pleuronectes flesus*), an abundant flatfish in most European estuaries, has been frequently chosen to assess PAH contamination [102, 103].

The study conducted by Ruddock et al. [104] in the Severn Estuary showed that from the six metabolites of polycyclic aromatic hydrocarbons (PAHs) identified and quantified from the bile of *Anguilla anguilla*, *Pleuronectes flesus*, and *Conger conger* collected during 1997, the main metabolite present in all fish was 1-hydroxypyrene with lower proportions of 1-hydroxychrysene and 1-hydroxyphenanthrene and small concentration of three benzo[a]pyrene derivatives. The results approve the importance of 1-hydroxypyrene as the important PAH metabolite in fish bile and suggest that the *A. anguilla* is an excellent species for monitoring PAHs in estuarine ecosystems. 1-Hydroxypyrene is invariably the major metabolite present in the bile of fish exposed to PAH-contaminated sediments [105], and this was confirmed by the results of this work for fish in the Severn Estuary. Pyrene is produced by many petrogenic and pyrolytic processes [43] and has been detected in significant number in sewage outfalls [106]. It is regarded the best general indicator of PAH exposure in fish [100, 107]. The contribution of 1-OH-Phen to the total metabolites detected ranged from approximately 2% in flounders and conger eels to 8% in common eels.

Phenanthrenes are released to the atmosphere during the combustion of fossil fuels, particularly coal, oil, and its refined products [43]. Like all PAHs with two to four benzene rings, phenanthrenes can remain suspended in airborne particles for long periods [108]. Compared to the other PAHs detected, BaP has a very low solubility in water and low bioavailability, but metabolites of BaP are especially important because of their potent mutagenic and carcinogenic properties [109–111].

A recent study conducted by Baali et al. [2] on bile metabolites of PAHs in 18 European eels (*Anguilla anguilla*), 7 moray (Muraenidae), and 28 conger eels (*Conger conger*) from Moroccan waters (Moulay Bousselham lagoon and Boujdour) shows the presence of two polycyclic aromatic hydrocarbon (PAH) metabolites, 1-hydroxypyrene (1-OH-Pyr) and 1-hydroxyphenanthrene (1-OH-Phen). The high-performance liquid chromatography with fluorescence detection method was used to separate the bile metabolites.

The goals of the present study were to compare the levels of PAH metabolites in eels from the lagoon and sea and also to compare levels of PAH metabolites between the different eels.

In this study the PAH metabolites (1-OH-Pyr and 1-OH-Phen) were detected in all species. The results of this investigation show that the concentration of 1-OH-Pyr was high for *Anguilla anguilla* than the other species (**Figure 1**). The conger eels represent the species with the lower concentration of 1-OH-Pyr. This result reflects the low degree of contamination in Boujdour coast (**Figure 1**). Thus, the presence of high concentration of 1-OH-Pyr and 1-OH-Phen in the bile of the European eels and morays reflects the high degree of contamination in the lagoon which is due to the anthropogenic activity in Moulay Bousselham lagoon. From the comparison between the contamination of the European eels and morays belonging to Moulay Bousselham lagoon, the results show that the first species present a higher concentration of PAH metabolites than the second one (**Figure 1**). This conclusion confirms that the *Anguilla anguilla* is more suitable species for monitoring PAH contamination. The European eels spend most of their life in muddy sediment which usually present a high PAH concentration levels. The pollutants in sediment are easily accumulated [112–114]. Accordingly, it is recognized that sediment contamination has a particular interest with regard to aquatic ecosystem quality. Sediment is an important source of pollutants and the factor with the high impact on the deterioration of the water quality. Although the feeding habit of the European eels may result in higher exposure to PAHs whence the high concentration of 1-OH-Pyr and 1-OH-Phen in the bile of this species [115], the accumulation of PAHs from the surrounding water is considered more efficient than impacted food [116]. The level of PAH metabolites in fish bile varies according to the area. The results show that Boujdour Sea is not a polluted site [117]. Moulay Bousselham lagoon is a semi-closed area; the concentration of pollutants in this site is higher than Boujdour Sea because of its lower water circulation. In the lagoon PAHs are easily accumulated than that in the sea [112]. Our results confirm that 1-OH-Pyr is the major metabolite present in fish bile [104, 105] and the best indicator of PAH exposure in fish [100, 107]. It was found that 1-OH-Pyr is the dominant compound in eel bile [118–120]. The results show that the levels of PAHs in Morocco are lower than those obtained in the other regions. As a conclusion of this study, the possible health risk of PAH contamination in Boujdour coast and Moulay Bousselham lagoon might be low compared to the other European sites.

The concentration of 1-OH-Pyr varies significantly with length ($p < 0.05$) for each species. The results obtained in this study [2] show that the concentration of PAH metabolites does not always increase with the size; there are obviously factors which can affect the exposure of this pollutant such as species differences, age, sex, maturity, and diet.

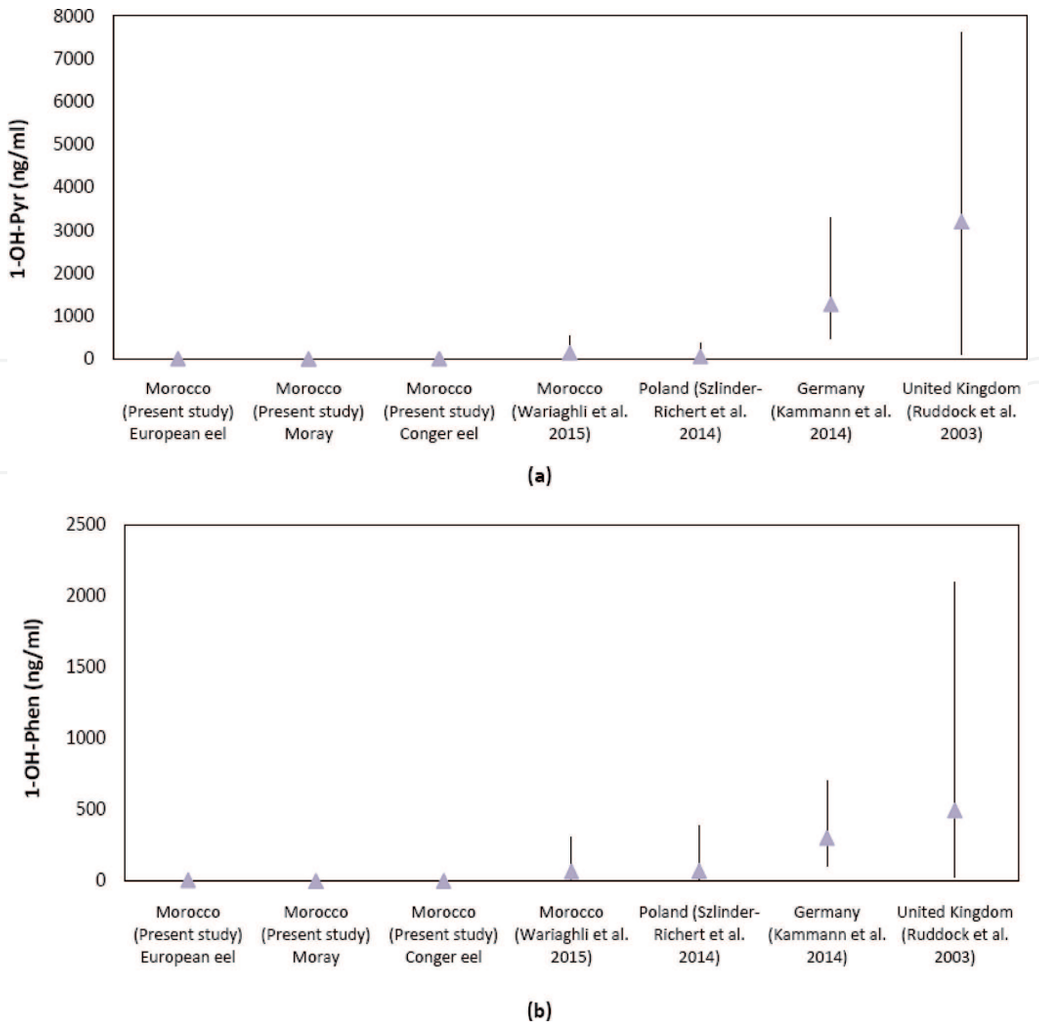


Figure 1.
Bile metabolite 1-hydroxypyrene (a) and 1-hydroxyphenanthrene (b) concentrations detected in European eels (Anguilla anguilla) collected from different areas and eels from Morocco (conger, moray, and European eel) as mean (triangles) and range (panels).

6. Conclusion

PAHs are originally organic compounds that are created from the partial combustion of organic elements or pyrolysis of organic material. These compounds are associated to the treatment of wood, oil, coal, and gas in order to produce the energy.

PAHs are transferred in the air in gas or particle aspect, and they are accumulated by wet and dry deposition. The transported elements play important role in the chemistry of the atmosphere. These particles also have significant impact in human health, because many PAHs are classified as probable human carcinogens.

The other faculty of PAHs is the capacity of degrading microorganism such as bacteria, fungi, and algae. It concerns the failure of organic compounds through biotransformation into less complex metabolites and through mineralization into inorganic minerals.

In this chapter, many effects on the biology of species following exposure to PAHs have been demonstrated. At the end of these organic studies on fish, it has been shown that the PAH biliary metabolites studied have the potential to describe the state of exposure of fish to organic pollutants (PAHs).

The study of a possible contamination of eels from different countries shows that 1-hydroxypyrene (1-OH-Pyr) is the dominant pollutant present in fish bile and is the best general indicator of PAH contamination.

Of the different eels investigated, European eels (*Anguilla anguilla*) contained the highest metabolite concentrations. This species looks like the most suitable for monitoring PAH contamination in the environment.

Using the studies conducted by several authors, we found that the rivers and lagoon contain PAH concentrations much higher than the coastal waters. These results appear normal in view that there is low water exchange in the rivers and lagoon ecosystems.

Finally we conclude that the quantification and identification of the metabolites in fish bile can give a rapid indication on the level of PAH contamination.

Conflict of interest

The authors declare that they have no competing interests.

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