Transfer and Translocation of Polycyclic Aromatic Hydrocarbons within Some Aquaculture Bio-systems in Romania

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This study presents the distribution of polycyclic aromatic hydrocarbons (PAHs) among aquatic compartments of three fish production farms located in Eastern part of Romania. A number of four fish culture species generically named as cyprinid species have been monitored for their PAH content: Cyprinus Carpio – common carp, Hypophthalmichthys molitrix – silver carp, Aristichthus nobillis – bighead carp, Ctenopharyngodon idella – grass carp. Chemical analysis was carried out on samples of scales, gills, liver and muscles. The contamination level with PAHs was quantified by GC – MS measurements. The transfer and translocation of these hydrocarbons along aquatic trophic chain have been analyzed based on partition model between octanol/water. A semi-quantitative correlation has been established for bioaccumulation of PAHs in sediments and their bioconcentration in fish. A rapid method is suggested to assess potential risk of PAH contaminated fish foodstuff on consumer health.

Keywords: aquaculture bio-system, carp species, polycyclic aromatic hydrocarbons (PAHs), bioaccumulation, bioconcentration

Fish represents one of the important dietary items that provide essential nutrients; however, it is evident that in fish body various chemicals may be accumulated in reaction with other environmental factors, such as pesticides or other organic contaminants, most of them being toxic as a result of bioconcentration. The concentration levels of such toxicants are accumulated in fish depending on age, size, fat composition and complexity of food chain [1, 2]. In the last years, the fish production from aquaculture is increasing around the world. In this context, in order to protect the public health by assuring a safe food, the determination of the toxic organic contaminants, generically termed as persistent organic pollutants (POPs), from feed, aquaculture water and fish meat, represents both a target and a pressing necessity [3].

The major sources of surface water pollution are represented by industrial and domestic wastewater and agriculture fertilizers [4] which increase the water pollution content by raising the levels of chemical nutrients, pesticides, heavy metals, petroleum compounds and other substances that modify the natural water composition [5].

The PAH presence in water can be also attributed to both natural hazards (e.g. forest fire, volcano eruptions) and anthropogenic activities. Polycyclic aromatic hydrocarbons constitute a large class of organic compounds containing two or more condensed aromatic rings. Hundreds of individual PAHs may be formed during incomplete combustion or pyrolysis of organic matter, industrial processes, as well as cooking and food processing [6]. A preponderance of PAHs results at high temperature combustion of fossil fuels and from the direct release of oil and by-products [7]. PAHs are potentially hazardous due to their highly mutagenic and carcinogenic effects of the four to seven ring compounds or to highly toxic effects of the two and three ring compounds [8]. Due to their low water-solubility and high lipophilicity, PAHs are persistent in the environment and tend to be readily adsorbed onto organic matter, particularly sediments [9].

Thus, in aquatic systems, the organic contaminants tend to interact with suspended particulate matter, bed sediments and biota through ingestion and surface body interaction.

Benzo[a]pyrene (B[a]P) is a congener of PAHs that should be considered as having the most significant toxicological effect because of its carcinogenicity [10]. A toxicological coefficient - Toxic Equivalent Factor (TEF) is used to assess the toxicity. In this study, the TEF values are used to determine the Totality of Equivalent toxic Quantity (TEQ) in B[a]P. In order to assess PAHs total risk of a sample, TEF and TEQ are defined according to Yu [10].

As in case of other POPs, the PAHs traverse various ecosystems and may be widely dispersed within different environmental components far from the initial sources. Therefore, the transfer and translocation of PAHs towards the trophic chain compartments accompany the bioaccumulation and bioconcentration of these highly toxic pollutants with hazardous health effects on the final contaminated organisms.

This paper is focused on transfer and translocation of the polycyclic aromatic hydrocarbons (PAHs) within three fish production farms located in Eastern part of Romania, with the aim to identify the pollution sources and to assess the potential risk on human health.

Experimental part
Sampling sites
Fish, water and sediments sampling has been performed on the inferior hydrographical basin of three rivers: Siret (L1), Prut (L2) and Danube (L3) (fig. 1) by INCDDD Tulcea Group based on the methodology previously reported in [11]. The first location (L1) reflects the pollution sources generated by anthropic activities inside Romania. The local industries potentially responsible for PAH environmental pollution are represented by ferrous and nonferrous mining, metallurgy, machinery, metal goods, transportation equipment, chemicals, petroleum products, refinery, building materials, timber processing, pulp and paper, food processing, textiles, clothing and leather goods production.
The second site (L2) would provide the influence of the trans-boundary pollution between Romania and its neighbour countries outside European Community, Moldova Republic and Ukraine, where dominant activities are based on agriculture production. The last site (L3), being located on the final course of the most important European river, Danube, which traverses eight European countries, will provide a global image on the pollution impact in this highly industrialized region of the world, as a result of application of the common European strategy on Environment and Health.

Materials and methods
The PAH concentrations were determined in water, sediments and fish sampled during spring time (April and May 2008). The water and sediment samples were obtained from both the receiving and discharge ponds. The fish samples were taken from scales, muscles, gills and liver of four fish culture species, generically named as cyprinidae species: Cyprinus Carpio - common carp, Hypophthalmichthys molitrix - silver carp, Aristichthus nobilis - bighead carp, Ctenopharyngodon idella - grass carp. The characteristic features (weight, length and sex) of selected fish species are previously reported in [11]. The solid samples for analysis were prepared by taking two pieces of 1 g each from the fish parts, that were then grinded, mixed and homogenized by using a GRINDOMIX Mill at 10 000 rpm. The extraction and analysis were carried out using the method described below.

The PAHs analyzed were: naphthalene - Naph, acenaphthylene - Aceny, acenaphthene - Ace, anthracene - Ant, fluorene - Flu, phenanthrene - Phen, fluoranthene - Fluor and pyrene - Pyr.

PAHs extraction and analyses
Water, sediment and fish samples were extracted, processed and analyzed following a laboratory validated procedure whose analytical performance are within the limits of extended relative measurement uncertainty $U_{rel}$ = 18% ($k_{rel} = 2$). The reported uncertainty is an expanded relative uncertainty calculated using a coverage factor of $k = 2$, which gives a level of confidence of approximately 95%, according to the EURACHEM/CITAC Guide, Quantifying Uncertainty in Analytical Measurement [12].

Water duplicate samples (500 mL) were extracted by solid-phase extraction procedure. The extraction cartridge (C18) was washed with 2x5 mL Ethyl Acetate, and then conditioned with 2x5 mL methanol followed by 2x5 mL of Millipore water. The water samples were then passed through the cartridge under vacuum. The PAHs were then eluted by passing 5 mL of ethyl acetate.

The duplicate solid samples (2 g of sediments or fish parts) were extracted in ultrasonic bath, into 25 mL dichloromethane for 30 min. The extracted samples were then centrifugated and the supernatant passed through a Whatman PS1 Water-Repellent Phase Separating Paper containing anhydrous Na$_2$SO$_4$. The resultant solution was then concentrated to dryness before adding 1 mL of ethyl acetate.

A Trace Gas Chromatograph (GC) coupled with a Polaris Q Mass Spectrometry (MS) Detection, Thermo Finigan, 2006, in Selected Ion Monitoring (SIM) operation mode, was used. The PAHs were separated on a DB-5MS (5% phenyl methyl polysiloxane) column with 30 m (L) x 0.25 mm (id), 0.25 μm film thickness. The extracts were automatically injected at constant volume (1.0 μL) by using a TriPlus Autosampler. The GC is equipped with a PTV injector and operated at constant temperature (250°C) splitless mode, the helium (99.9999%) carrier gas flow is by electronic pressure control. The oven temperature program for PAHs separation was: 100°C (hold for 1 min), increase by 5°C/min to 145°C (hold for 5 min), increase by 5°C/min to 165°C (hold for 5 min), increase by 20°C/min to 205°C (hold for 5 min) and increase by 20°C/min to 265°C (hold for 12 min). The ion source temperature was set at 300°C, and the MS transfer line at 250°C.

Analytical quality control
The performances of the analytical methods, detection limit, precision, accuracy and uncertainty were assessed by using a SRM – 1647d (NIST) as Certified Reference Material (CRM) [13], according to ISO standards [14, 15] that present measurement procedures of PAHs from different matrices, as water, soil and tissues and their performance criteria. In order to assure the Quality Control (QC) of the results, the calibration and matrix effect was monitored and quantified by standard addition method using the SRM – 1647d (NIST) as CRM. For calibration QC assurance, certified organic solution of PAHs (SRM – 1647d) was used and the accuracy of GC/MS measurement was monitored. The working calibration curve was verified on...
each working day by the measurement of one or more calibration standard solutions. Losses during preparation and matrix interferences were detected and compensated by samples fortifying with measurable concentrations of PAHs SRM - 1647d solution.

Results and discussion

One found out that PAH concentrations in the aquatic environment (table 2) were below the maximum admitted concentration level for surface waters (0.2 mg/L) [16]. Moreover, the limit of total PAHs in water is below 0.1 µg/L [16], while the TEQ values of PAHs in water are below 0.01 B[a]P µg/L, the limit according to EC regulations [17]. However, different concentrations are registered for various contaminants from the three aquaculture farms, which allow assessing the pollution source for each site. In the case of low molecular mass PAHs including naphthalene, acenaphtene and acenaphthylene, the concentration levels were quite small, near detection limit. For three-four aromatic rings components, there were similar levels in the three sites (L1, L2, and L3): around 480·10⁻³ µg/L for anthracene, 100·10⁻³ µg/L for phenanthrene, 57·10⁻³ µg/L for fluoranthene, and 65·10⁻³ µg/L for pyrene (see the data in table 1).

The sequence of decreasing concentrations in PAHs dissolved in water in the investigated farms was as follows: Ant > Phen > Pyr > Fluor > Naph. The highest PAHs concentrations associated with the bioaccumulation through chemical and biochemical stabilization found in the large size fraction (> 250 µm fraction) of sediments represent the sedimentary organic carbon from humus compounds and other organic components [21, 22].

The sequence of decreasing values for PAH components in sediments is quite similar for the three locations with those sequences found in water samples, with minor differences occurring in case of naphthalene and fluoranthene:

L1: Ant > Phen > Pyr > Naph > Fluor
L2: Ant > Phen > Pyr > Fluor > Naph
L3: Ant > Phen > Fluor > Pyr > Naph

In a theoretical approach, the most widespread model for evaluation of distribution of POPs during their transfer and translocation is based on the partition coefficient n-octanol/water (K_{ow}) as well as on the bioaccumulation factor (BAF) defined as the ratio between the concentration of pollutants in the sediment and in water, respectively. In order to obtain dimensionless values for BAF, it should be multiplied by soil density (2.5).

The main advantage of this model is given by the possibility to perform rapid semi-quantitative evaluations of the transfer, persistence and impact on other ecosystem compartments by using real (correct) measurements. For instance, values of concentration in water can be correlated with the existent data on water solubility and octanol – water partition coefficient. The octanol has been selected since it has a carbon/oxygen (C/O) elemental ratio similar to lipids. Lipids solubility in water is rather low (0.58 g/L), while water is quite miscible with octanol (41 g/L). Therefore, K_{ow} is a measure of hydrophobicity, meaning the tendency of an organic compound to be separated from water. Since K_{ow} has a large ranging domain in the case of PAHs, from 0.1 to 10⁷, it is often used in interpretation as log K_{ow} [23].

As it is already accepted, organic chemicals are usually adsorbed especially on organic carbonic materials present in soil or sediments, denoted as Total Organic Carbon (TOC). A linear dependence of K_{ow} with octanol/water partition coefficient has been established [24].

Bioaccumulation of PAHs within water/sediment partition

In the table 1 the PAHs levels in the sediments sampled from the three farms are also indicated. It is noticeable that these values are by three magnitude order higher than the corresponding PAH values in water. This is the normal effect of transfer and absorption phenomena of persistent organic pollutants between the main components of aquatic ecosystems.

The values obtained for PAH concentrations in the sediment samples are below admitted limits: (20 mg/kg) for naphthalene and fluoranthene, (50 mg/kg) for anthracene and phenanthrene, and (500 mg/kg) for pyrene [20]. One also found out that the total concentration of PAHs in sediment for all farms is below the allowed limit of 0.5 mg/kg [20]. Moreover, the TEQ values of PAHs in sediments are below 1 mg/kg B[a]P set by the EC regulations [17].

Table 1

<table>
<thead>
<tr>
<th>PAH</th>
<th>W-10³ µg/L</th>
<th>S µg/kg</th>
<th>L1</th>
<th>W-10³ µg/L</th>
<th>S µg/kg</th>
<th>L2</th>
<th>W-10³ µg/L</th>
<th>S µg/kg</th>
<th>L3</th>
<th>W-10³ µg/L</th>
<th>S µg/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Naph</td>
<td>± 7.9</td>
<td>77.3</td>
<td>39.4</td>
<td>± 7.4</td>
<td>49.3</td>
<td>31.6</td>
<td>± 6.1</td>
<td>37.8</td>
<td>± 7.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acc</td>
<td>± 5.5</td>
<td>57.2</td>
<td>25.4</td>
<td>± 4.9</td>
<td>40.5</td>
<td>25.4</td>
<td>± 5.0</td>
<td>17.8</td>
<td>± 3.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aceny</td>
<td>± 3.2</td>
<td>29.7</td>
<td>16.8</td>
<td>± 3.2</td>
<td>23.8</td>
<td>16.8</td>
<td>± 3.2</td>
<td>24.3</td>
<td>± 4.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ant</td>
<td>± 9.2</td>
<td>608.1</td>
<td>604.6</td>
<td>± 9.3</td>
<td>604.6</td>
<td>604.0</td>
<td>± 9.4</td>
<td>164.9</td>
<td>± 32.2</td>
<td></td>
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<tr>
<td>Phen</td>
<td>± 11.1</td>
<td>100.4</td>
<td>101</td>
<td>± 20.1</td>
<td>101</td>
<td>101</td>
<td>± 19.6</td>
<td>164.9</td>
<td>± 32.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fluor</td>
<td>± 11.1</td>
<td>57.2</td>
<td>72.3</td>
<td>± 10.8</td>
<td>72.3</td>
<td>75.6</td>
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<td>153.6</td>
<td>± 29.2</td>
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<tr>
<td>Pyr</td>
<td>± 12.6</td>
<td>159.4</td>
<td>65.2</td>
<td>± 12.7</td>
<td>91.1</td>
<td>65.4</td>
<td>± 16.8</td>
<td>123.3</td>
<td>± 11.3</td>
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<tr>
<td>TEQ</td>
<td>± 1.0</td>
<td>6.7</td>
<td>6.5</td>
<td>± 1.0</td>
<td>6.5</td>
<td>6.5</td>
<td>± 1.0</td>
<td>6.4</td>
<td>± 1.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

If the total concentration of PAHs in water samples of the three sites is expressed in TEQ values, the contamination level is slightly higher at L1 as compared to the farms L2 and L3, this tendency being amplified and much more evident after bioaccumulation of PAHs in sediments and their bioconcentration in fish.

The sequence of decreasing concentrations in PAHs dissolved in water in the investigated farms was as follows: Ant > Phen > Pyr > Fluor > Naph. The highest PAHs concentrations associated with the bioaccumulation through chemical and biochemical stabilization found in the large size fraction (> 250 µm fraction) of sediments represent the sedimentary organic carbon from humus compounds and other organic components [21, 22].
Moreover, for soils or sediments with $TOC > 0.01$, a linear dependence with the bioaccumulation factor is also expected, therefore:

$$BAF = y \cdot K_{TOC} = z \cdot K_{ow}$$

where $y$ and $z$ are correlation coefficients, with $z = 0.41 \cdot y$. Therefore, in logarithmic form, the following dependence should be checked:

$$\log BAF = \log z + \log K_{ow}$$

Such a dependence is represented in figure 2 for the PAHs distribution between water and sediments on the three sites investigated in this work.

The following linear regressions have been obtained for the three farms:

- L1: $\log BAF = 3.50 - 0.058 \log K_{ow}$  \hspace{1cm} (4)
- L2: $\log BAF = 3.19 - 0.013 \log K_{ow}$  \hspace{1cm} (5)
- L3: $\log BAF = 2.49 + 0.142 \log K_{ow}$  \hspace{1cm} (6)

![Fig. 2. Bioaccumulation of PAHs in the sediments of the three farms](Image)

The values of the ordinate intercept provide a measure on the magnitude of PAH transfer between water and sediments, while the slope could be correlated with the hydrophobic character and organic content of sediment components.

A comparison of these three straight lines reveals a similar behavior referring to the bioaccumulation of PAHs in sediments in the two sites, with similar negative slopes, while for the third site the dependence has a positive slope.

The tendencies could be correlated with different adsorbent capacities of these sediments for various compounds with increasing lipophilic character ($K_{ow}$). Indeed, in the first two cases the lines are almost parallel to $\log K_{ow}$ axis, meaning a decreasing capacity for bioaccumulation of high molecular PAHs, which is in agreement with structural composition of the sediments, having sand and clay minerals as dominant components, combined with small fractions of degraded vegetation. The sediments of the site L3 are specific to Danube Delta wet lands, containing highly adsorbent clays combined with vegetable detritic substrate and large pieces of tough reed, these plant parts conferring a higher organic carbon content.

However, as a result of a relatively higher pollutant content in the first two sites, the transfer intensity of PAHs during their bioaccumulation in sediments is decreasing in the sequence: L1 > L2 > L3, thus confirming the highest pollution impact caused by the industrial activity on the site L1, and a relatively low pollution in Danube Delta reservation, which is under special controlled pollution regime.

**Bioconcentration of PAHs in fish**

The presence of PAHs in water and sediments induces the presence of PAHs in fish. Referring to the translocation of PAHs from water to fish, it was suggested the following linear correlation between partition coefficient on bioconcentration fish/water ($BCF$) and $K_{ow}$ [24].

$$BCF = 0.048 \cdot K_{ow}$$

It is supposed that the fat content in fish is approx. 5% lipids, which is considered to be similar to 5% octanol. Such a correlation showed by equation (7) can be used to analyze the translocation of PAHs on trophic chain (phytoplankton and zooplankton, macrophytes, mollusca) and also their bioconcentration in various fish species.

This study is focused on four aquaculture fish species belonging to cyprinid class, all of them being phytophagous. The common carp (Cyprinus carpio) is of indigenous origin, being very widespread in Danube river and its affluents until Danube Delta. Its food consists mainly in: Dreissena molusca, benthonic invertebrates, and aquatic plants and vegetable detritus. The other three cyprinid species: Hypophthalmichthys molitrix - silver carp, Aristichthus nobilis - bighead carp, Ctenopharyngodon idella - grass carp, are originated from China and were introduced and adapted in Europe in 1960 years, with the aim to increase the economic efficiency of natural aquatic basins, being among the most productive species in a less controlled aquaculture regime. On the other hand, they do not need any special food, their nutritional sources being zooplankton, microalgae, vegetal residues, and organic detritus. The second advantage of promoting the new cyprinid species was to minimize the ecological effects, by avoiding eutrophication of natural waters and aquaculture biosystems. As a result, even though they are not predatory fish species, they are intensively involved in the transfer and translocation of persistent organic pollutant, and therefore, a high rate of PAHs bioconcentration in their body is expected and the risk on consumer health should be carefully evaluated.

The results of analysis regarding the level of PAHs in the significant anatomic-morphological parts: scales, muscles, gills and liver, for all the four species of fish sampled from the three farms are presented in figures 3 - 6.

The dominant PAHs are presented in the table 2. It can be noted that for most of the samples from the sites L1 and L2 the dominant contaminants are naphthalene, phenanthrene and fluoranthene, while for the site L3 the dominant PAH is anthracene. This is in agreement with intensive industrial activity in the North region of the farm L1, and combustion of fuels and agriculture residues responsible for the main transboundary pollution source at location L2. As referring to the high level of anthracene evidenced in all fish samples from the farm L3, this can be mainly explained by the large commercial traffic on Danube, with potential for introduction of PAH through exhaust combustion of fuel. As regards the overall concentration values for dominant contaminants in various anatomic-morphologic parts, these are higher in scales and gills, due to the permanent and direct contacts with water, phytoplankton, zooplankton and filtered sediments, and still significant even at lower content in liver and muscles as a result of metabolic processes. PAHs are absorbed through the gills, scales and guts, all three being chemical...
Fig. 3. PAH concentrations in fish scales samples of different carp species: A. common; B. grass; C. silver

Fig. 4. PAH concentrations in fish muscle samples of different carp species: A. common; B. grass; C. silver

Fig. 5. PAH concentrations in fish gill samples of different carp species: A. common; B. grass
exchange surfaces - a large surface area separated by membrane that consists in one or a few cell layers. The path of chemicals from surface towards the tissues is the transport through the epithelium into blood, incorporation into blood (binding to plasma proteins), transport via systemic circulation of freely dissolved and plasma-bound chemicals in various tissues and disposal inside tissues. The liver represents the transport pathway for compounds from guts to blood; at this level the most important metabolic processes taking place are biodegradation and binding to various carriers [25].

Fig. 5. PAH concentrations in fish gill samples of different carp species: C. silver; D. bighead

Fig. 6. PAH concentration in fish liver samples of different carp species: A. common; B. grass; C. silver; D. bighead

<table>
<thead>
<tr>
<th>Sample</th>
<th>Location</th>
<th>Common carp</th>
<th>Grass carp</th>
<th>Silver carp</th>
<th>Bighead carp</th>
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<tr>
<td></td>
<td></td>
<td>Na</td>
<td>Phe</td>
<td>Flu</td>
<td>NO sample</td>
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<tr>
<td>Scales</td>
<td>L1</td>
<td>Na</td>
<td>Phe</td>
<td>Flu</td>
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<td>Na</td>
<td>Phe</td>
<td>Flu</td>
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<td></td>
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<td>Ant</td>
<td>Phe</td>
<td>Flu</td>
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<tr>
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<td>Ant</td>
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<td>Phe</td>
<td>Flu</td>
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<td>Ant</td>
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<td>Na</td>
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<td>Flu</td>
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<td>L2</td>
<td>Na</td>
<td>Phe</td>
<td>Flu</td>
<td>NO sample</td>
</tr>
<tr>
<td></td>
<td>L3</td>
<td>Ant</td>
<td>Ant</td>
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<td>Ant</td>
</tr>
<tr>
<td>Liver</td>
<td>L1</td>
<td>NO sample</td>
<td>NO sample</td>
<td>-</td>
<td>Na</td>
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<tr>
<td></td>
<td>L2</td>
<td>Na</td>
<td>Phe</td>
<td>Flu</td>
<td>-</td>
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<tr>
<td></td>
<td>L3</td>
<td>Ant</td>
<td>Ant</td>
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</tbody>
</table>

Table 2
DOMINANT PAHs IN ANATOMO-MORPHOLOGICAL PARTS OF FISH
Evaluation of potential PAHs impact on consumer health

The toxicological potential of low molecular PAHs and the genotoxicity and carcinogenicity of contaminants with many condensed aromatic rings are the topics of intensive studies in order to establish the limits of PAH occurrence in foods, dietary exposure and related health effects [26].

Table 3 presents the calculated TEQ values of PAHs in various fish parts sampled from the three farms; values higher than the admitted limit of 2 μg/kg [17] were found for all the samples. A comparison on the four species of corps reveals the higher TEQ values for common carp and silver carp, with the fat content over 5%/kg. The highest values obtained for indigenous common carp could be explained by his preference for food based on Dreissena molusca, a species with maximum bioconcentration capacity of PAHs among the trophic chain in aquaculture biosystems.

In order to obtain a preliminary image on the potential risk on consumer health, one tried to apply the same model of PAH transfer and translocation based on the partition coefficient n-octanol/water ($K_{ow}$) for bioconcentration factors ($BCF$) between water and fish. Relevant for this analysis are only the edible fish parts, meaning the muscle tissues. The linear dependences obtained are illustrated in figure 7 for common carp and figure 8 for silver carp.

The corresponding equations for regression lines are as follows:

- for common carp:

  L1: $\log BCF = 4.17 - 0.144 \log K_{ow}$
  L2: $\log BCF = 3.62 - 0.104 \log K_{ow}$
  L3: $\log BCF = 3.27 - 0.049 \log K_{ow}$

- for silver carp:

  L1: $\log BCF = 4.17 - 0.189 \log K_{ow}$
  L2: $\log BCF = 4.45 - 0.270 \log K_{ow}$
  L3: $\log BCF = 4.78 - 0.371 \log K_{ow}$

For the lines of the two carp species negative slopes are obtained, confirming the dominant bioconcentration of low molecular PAHs, which are toxic but less carcinogenic. Since the silver carp is less adapted to specific habitat of various aquaculture biosystems, the regression lines (fig. 8) are convergent on the left side of the diagram (the same ordinate intercepts), with small tendency of splitting for high molecular PAHs. On the contrary, for common carp the three lines are almost parallel, and the highest PAH bioconcentration is found for L1 sites, due to the higher population in Dreissena molusca. Once again this is confirmed by the higher pollution impact on this site as a result of the intensive industrial activity. It can be also confirmed that fish contamination with PAHs is a very sensitive marker to assess both total organic pollution and specific contaminants responsible for the dominant toxic effect, as it was the anthracene in case of L3 site.

Based on these semi-quantitative evaluations, some recommendation can be proposed in order to minimize the risk for the consumer health. In case of relatively high polluted site, L1, caution should be taken for population groups sensitive to toxic effects of naphthalene,
phenanthrene and fluoren, particularly on consuming common carp.

Another potential risk should be mentioned on fish products of farm L3 from Danube Delta, where, even though the PAH content is relatively lower than for the other farms, the main food for the inhabitants of this location is almost daily fish food intake. In this context, the rigorous application of EC regulations on pollution control on the Danube river is beneficial for human health, even though persistence of PAH in aquatic compartments of biosystems is still able to cause harmful effects as a result of previous historical pollution.

Conclusions

The analyses of PAHs contents and their transfer and translocation within aquatic compartments of three aquaculture farms located in Eastern part of Romania revealed the following aspects referring to Environment & Health relation.

While the possible sources for anthracene and phenanthrene discharged in Siret hydrographical basin are the industrial wastewaters from electronics and electro-technical industries, oil refinery and petrochemical industry, the main PAH sources from Prut hydrological basin are provided by fuel combustion and agricultural activities. As referring to the high level of anthracene in Danube river, this can be assessed to the large commercial traffic, with potential for introduction of PAH through exhaust combustion of fuel.

The model of PAH transfer and translocation among biosystem compartments has been applied and developed both for bioaccumulation of PAHs in sediments and their bioconcentration in fish body. Firstly, the transfer process + bioaccumulation, can be correlated with the capacity of sediments to accommodate organic pollutants with various molecular weight, thus allowing to assess either their dominant toxic effect (two and three ring PAHs) or carcinogenic effects (four to seven ring PAHs). Secondly, the translocation process + bioconcentration, provides a very sensitive tool in assessing the risk on human health.

This semi-quantitative approach could be used as a rapid method for estimation of potential risk on consumer health.

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