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ORIGINAL RESEARCH

A scientometric analysis of global trends in polycyclic aromatic hydrocarbon (PAH) research and their ecotoxicological impact on aquatic organisms

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Abstract Polycyclic aromatic hydrocarbons (PAHs) are persistent pollutants that pose serious risks to aquatic ecosystems and remain a challenge for environmental monitoring. To map scientific advances in this field, we conducted a scientometric analysis of 1,336 articles published between 1945 and 2022 in the Web of Science database that investigated the impacts of PAHs on aquatic environments through organismal responses. The analysis revealed a marked increase in publications since the 1990s, with the United States, Canada, and China leading research output. Fish were the predominant model organisms—particularly *Oncorhynchus mykiss, Danio rerio*, and *Fundulus heteroclitus*—and biomarkers and bioassays represented the most frequently used methodological approaches. Despite significant progress, gaps remain regarding adaptive responses and the taxonomic breadth of studied species. By outlining trends, collaborations, and underexplored areas, this review provides a comprehensive overview to guide future research and inform environmental policies aimed at mitigating the impacts of PAHs on aquatic ecosystems.

Keywords Ecotoxicology . PAHs . Scientometric analysis . Aquatic organisms . Biomarkers . Environmental monitoring

Introduction

Aquatic toxicology aims to study the concentrations of stressors that may occur in aquatic environments and the ways in which they interact with and affect aquatic organisms (Rand et al. 1995). Several classes of pollutants contaminate aquatic systems, including polycyclic aromatic hydrocarbons (PAHs), which are formed as by-products of the incomplete combustion of organic matter. PAHs are a common class of organic pollutants that accumulate in natural environments due to inefficient fuel extraction, processing, and use technologies, as well as wildfires (Tsibart and Gennadiev 2013). They are considered key pollutants because of their persistence, environmental stability, and their capacity for bioaccumulation, toxicity, and genotoxicity in both humans and wildlife (Hylland 2006).

Based on their toxic characteristics, the United States Environmental Protection Agency (USEPA) and the World Health Organization (WHO) have identified 16 priority PAHs that are subject to control and regu-

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lation (EPA 1983). They attach to particles in the environment and are found in surface water and suspended particulates (Di Giulio and Clark 2015). Furthermore, the xenobiotic biotransformation process is also one of the main determinants of PAH toxicity, distribution, and excretion (Busby et al. 1999).

A scientometric approach can assess the current status of a scientific topic by demonstrating collaborations among researchers and countries, as well as by highlighting key research subjects over time (Castro et al. 2021). This type of review helps identify research trends, address specific issues, and uncover gaps in the field (Castro et al. 2021). The Web of Science, a highly reliable database, provides access to multidisciplinary information from more than 18,000 high-impact journals, making it an essential tool for high-quality scientific research (Liu 2020).

Our objective was to analyze the trends in scientific production on the impacts of PAHs in aquatic environments. In addition, we sought to determine the extent to which these studies have employed fish as the main model organisms in this field of research. To achieve this objective, we formulated the following research questions:

(i) Which countries have the greatest scientific output in the field of PAH-related aquatic toxicology?

(ii) Has there been an increase in scientific production over the years in the field of PAH-related aquatic toxicology?

(iii) Which countries have engaged in the most international scientific collaborations in the field of PAH-related aquatic toxicology? What are the most frequently used keywords in research on PAH-related aquatic toxicology?

(iv) What are the most commonly used tests to assess contamination by PAHs in the field of aquatic toxicology?

(v) Which PAHs are most frequently studied in the field of aquatic toxicology?

(vi) Which model organisms are most commonly used in studies on PAHs in aquatic toxicology?

(vii) Has there been an increase in scientific production over the years in the field of PAH-related aquatic toxicology using fish?

(viii) Which fish orders are the most commonly used in PAH-related aquatic toxicology?

Materials and methods

We searched the Web of Science – Science Citation Index Expanded in January 2023 using advanced search criteria. The following terms were used: “PAH,” “PAHs,” or “polycyclic aromatic hydrocarbon,” with the following filters applied: (i) only articles in English and (ii) articles published from 1945 to 2022. This time interval was chosen because the first articles indexed in the Web of Science – Science Citation Index Expanded date back to 1945 (Figure 1).

From the 5,257 records retrieved in the Web of Science, we applied a set of a priori inclusion and

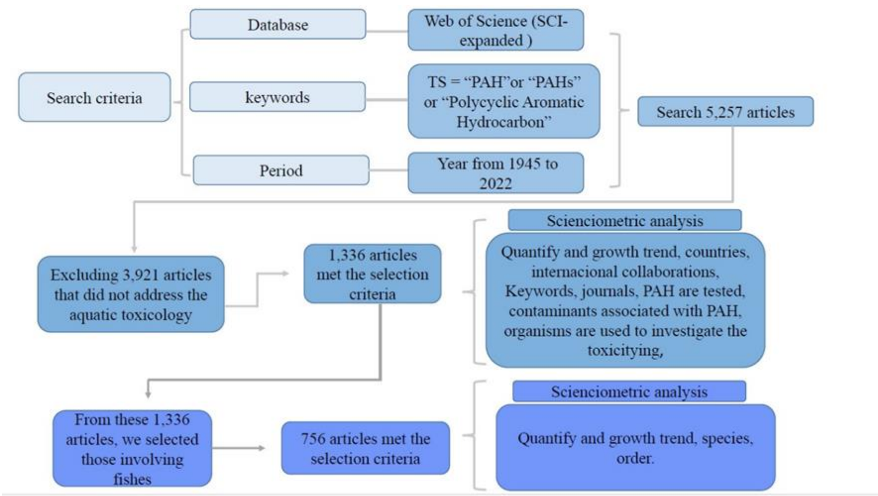

Fig. 1 Flowchart of the Research Methodological Stages

exclusion criteria focused on studies reporting biological (organismal) effects of PAH exposure. We retained only those addressing aquatic or closely associated semi-aquatic organisms—such as water birds, reptiles, amphibians, aquatic plants, and aquatic mammals—because these groups share key PAH exposure pathways with fully aquatic species, including dietary intake of aquatic prey and direct contact with contaminated water and sediments. A single author performed the screening of titles, abstracts, and full texts following these predefined criteria, which were objective and unambiguous, and all screening decisions were carefully documented. We excluded articles that, although still present after applying Web of Science (WOS) filters, focused on: (i) chemical analyses of sediments, water, or fishery products (e.g., fish fillets) without assessing biological effects, or (ii) terrestrial organisms (e.g., rodents, humans, hares). After these exclusions, 1,336 articles remained for our scientometric analysis. All of these articles investigated PAHs; among them, 687 assessed only PAHs, while 649 assessed PAHs together with at least one additional contaminant (e.g., PCBs, metals, herbicides). These mixed-exposure studies were retained because PAHs remained a central analyte, and the biological endpoints specifically addressed PAH effects, allowing their results to contribute validly to the scientometric assessment of PAH-related aquatic toxicology even when other contaminants were examined in parallel.

For the scientometric analysis, we downloaded the articles in BibTeX format and analyzed them in R with the support of the bibliometrix package and VOSviewer software 1.6.18. We employed the bibliometrix R package to clean the dataset and compute key scientometric indicators, including the annual growth rate of publications, country productivity, keyword co-occurrence, and citation network metrics. International collaboration networks and keyword co-occurrence maps were generated and visualized with VOSviewer, applying its standard clustering algorithm and layout settings. To assess temporal trends, we performed simple linear regressions of yearly publication counts, calculating the coefficient of determination (R^2) for each decade and for the entire period to capture the global trend. Before interpreting these models, we verified the assumptions of residual normality and homoscedasticity. For each slope coefficient, 95% confidence intervals were estimated, and statistical significance was defined as $p < 0.05$. Country-level collaboration was determined from the affiliations of first authors and their coauthors. For the analysis of experimental approaches, each study was classified into four, partly overlapping, categories: biomarker tests, bioassays, bioaccumulation studies, and studies that combined biomarkers and bioassays. Because a single study could apply more than one type of test, these categories are not mutually exclusive, and their counts do not add up to the total of 1,336 articles. This methodological framework follows the approach detailed by Castro et al. (2021).

Results and discussion

We identified 1,336 articles on PAH-related aquatic toxicology published between 1945 and 2022. The earliest study retrieved was from 1980, an acute exposure bioassay using the toadfish *Sanopus reticulatus* to evaluate cytochrome P4501A induction by benzo[a]pyrene and beta-naphthoflavone (James and Bend 1980). After this pioneering effort, there was a 10-year gap until 1990, when three articles were published. To better understand publication dynamics, we divided scientific production into four periods. The first period, the 1980s, included only the 1980 study. In the second period, the 1990s, scientific output resumed and expanded globally (Figure 2a). Production in this decade showed linear growth ($R^2 = 0.88$), and PAH-related aquatic toxicology specifically also increased substantially ($R^2 = 0.91$, $p < 1.168e-05$). This expansion reflects the growing global concern over pollution, reinforced by stricter environmental laws implemented at the end of the 1980s (e.g., the Vienna Convention and the Montreal Protocol in 1987). It was also favored by the methodological shift from mammals to alternative models, such as invertebrates and fish, in contaminant testing (Smith et al. 1999).

The third period, from 2000 to 2019, was characterized by relative stability. The number of articles oscillated around an annual average of 49 publications ($R^2 = 0.70$, $p < 0.14$). Fluctuations were partly linked to major ecological accidents, such as catastrophic oil spills, which triggered environmental impact assessments. Long-term events, such as the Deepwater Horizon spill, sustained interest in monitoring affected ecosystems.

The fourth period (2020–2022) showed an R^2 of 0.73 ($p < 0.24$). In 2022, there was a sharp 74% drop in PAH-related aquatic toxicology publications compared with the previous year, whereas global PAH production decreased by only 14%. This decline cannot be attributed to a single cause. Evidence from a large-scale analysis of life-science research shows that, during the COVID-19 pandemic, many projects not related to COVID-19 slowed down because funding and attention were temporarily redirected to pandemic topics (Riccaboni and Verginer 2022). This broad shift in priorities, together with an increasing scientific focus on emerging contaminants of comparable environmental significance (Li et al. 2024; Harish et al. 2025), provides a plausible explanation for the 2022 decline in publications, independent of changes in global PAH production.

Publication patterns for studies using fish models (Figure 2c) mirrored the overall trend: strong growth in the 1990s, followed by two decades of relative stability, and a pronounced 85% decrease in 2022. This convergence highlights the central role of fish in the historical development of the field, while also reflecting the broader reorientation of aquatic toxicology toward other contaminants.

We identified 48 countries that produced studies on PAH-related aquatic toxicology between 1980 and 2022. The USA accounted for 30% of the articles, followed by Canada (8%) and China (7%) (Supplementary Table S1). Research productivity has been consistently higher in these three countries (Castro et al. 2021). In the United States, the USEPA enforces strict regulations on PAH use, such as the Marine Protection, Research, and Sanctuaries Act, addressing PAHs and their derivatives in aquatic ecosystems (US EPA 2020). In Canada, the Canadian Environmental Protection Act (Bill S-5) established the Priority Substances List (PSL) in 1999 to strengthen environmental protection (CEPA 2021). These legislative frameworks help explain the continuous production of PAH-related research in both countries, reinforced by the need for frequent updates to environmental policies.

China, as a highly industrialized nation, faces severe pollution problems in air, water, and soil. Efforts to mitigate pollution through containment and regulatory plans were often bypassed by industries, leading to the establishment of the "ecological civilization" framework in 2012. This national master plan, implemented until 2020, emphasized the holistic management and valuation of natural resources. By strategically promoting environmental science, toxicology, and pollution research, this policy directly stimulated the country's scientific output in PAH-related fields.

Together, the USA, Canada, and China demonstrate how policy frameworks and national priorities shape research agendas. These countries continuously invest in research, monitoring, and environmental inspection, which helps explain their leadership in global scientific production. Nevertheless, our analysis shows that 78% of articles in the field were published within a single country, while only 22% involved international collaboration (Supplementary Data). Moreover, only 32 countries contributed to collaborative

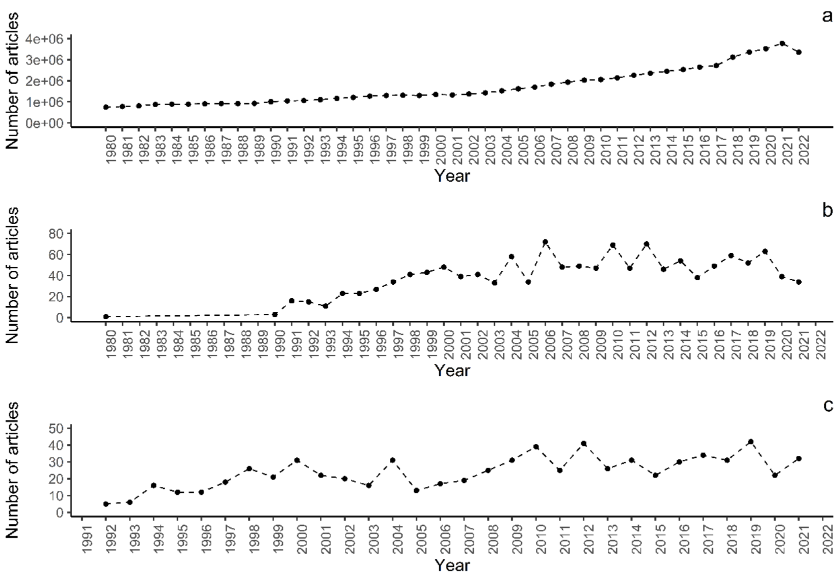

Fig. 2 Articles indexed in the Clarivate Analytics Web of Science – Science Citation Index Expanded: (a) the total number of articles published in the database; (b) the number of articles published on the use of aquatic organisms to assess the effects of polycyclic aromatic hydrocarbons (PAHs) from 1980 to 2022; and (c) the number of articles published using fish to assess the effects of PAHs.

publications (Figure 3). Considering that contaminant dispersion in aquatic systems transcends national boundaries, this limited degree of collaboration remains a major gap. Expanding international networks is crucial for building more comprehensive datasets and improving the global monitoring of PAH pollution.

Cooperation in science and technology has long played a central role in the United States–China relationship (Wagner et al. 2015). Alongside Canada, these nations form a strong collaborative cluster that is also reflected in PAH toxicology research. Within Europe, countries such as Norway, the United Kingdom, the Netherlands, Sweden, Finland, Germany, and Denmark exhibit high proportions of co-authored papers—a trend explained not only by geographical proximity but also by regional policies that encourage multinational research initiatives, such as those fostered by the European Union (Glänzel 1999). In Brazil, stronger collaborations are established with France, Portugal, and Italy, likely influenced by historical, cultural, and linguistic ties.

Two main structural factors help explain the uneven distribution of international collaborations: research funding and the size of national scientific communities. Consistent with previous analyses, our results show that large scientific systems—such as the United States, India, China, and Brazil—have lower proportions of internationally co-authored papers (Castro et al. 2021). By contrast, smaller countries such as Finland, Denmark, Iceland, and Sweden often rely more heavily on international partnerships to compensate for limited domestic capacity. This pattern is well documented: smaller or medium-sized nations with robust funding mechanisms frequently act as hubs, attracting researchers from less-resourced countries (Glänzel et al. 1999; Wagner 2009). This tendency also aligns with the preferential attachment dynamics in global research networks, where well-established hubs accumulate collaborations over time (Wagner and Leydesdorff 2005; Wagner et al. 2016).

Finally, public policies play a decisive role in shaping national scientific output. International evidence shows that governments can strongly influence research priorities and collaboration patterns through targeted funding programs and mission-oriented innovation strategies, such as the European Union's Horizon Europe framework and the national research councils of high-income countries. These initiatives create long-term funding streams and stable infrastructures that foster international cooperation and help smaller or emerging research communities gain critical mass (Mazzucato 2018; OECD 2019). The interplay of these policy-driven incentives with structural factors—research funding and the size of national scientific communities—helps explain the asymmetries observed in PAH-related aquatic toxicology research worldwide.

Articles on PAH-related aquatic toxicology have been published in 61 Web of Science journals. The top 20 journals in the ranking account for 94% of these publications (Table 1). *Aquatic Toxicology* has published the most articles (n = 281), followed by *Environmental Toxicology and Chemistry* (n = 221) and *Marine Environmental Research* (n = 203). The current impact factor is widely used as an indicator of journal visibility and scientific standing. Based on the 2024 Journal Citation Reports, the top 20 journals

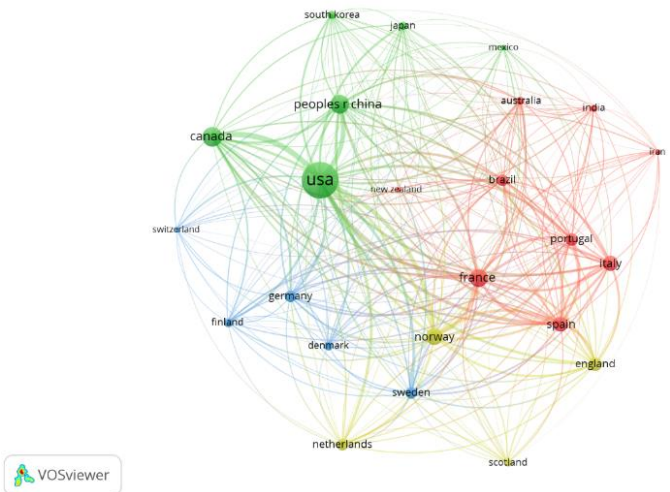

Fig. 3 Collaboration network between countries for articles on polycyclic aromatic hydrocarbons (PAHs) using aquatic organisms. On the map, the circles and their respective sizes indicate the countries and their production; the lines and their thickness indicate the collaboration rate between the countries; and the colors represent the groups that maintain the most partnerships.

publishing research on PAHs and aquatic organisms have an above-average current impact factor (mean = 3.74), highlighting the present-day relevance and visibility of this research area.

Keywords are a very important component of an article: they play a critical role in revealing the core of the research. By analyzing keywords, we have the opportunity to discover the main field or topic of a research (Darko et al. 2019). Keywords provide a good view of the domain of knowledge and how these topics are connected and associated with each other, producing new insights and perspectives on the subject (Darko et al. 2019). The main keyword in the articles was “biomarkers,” followed by “fish” (Figure 4). There were five groups of well-defined words. These groups did not have clear boundaries, and some

Table 1 Ranking of the 20 journals that published the most articles on the use of aquatic organisms to study the effects of polycyclic aromatic hydrocarbons (PAHs) from 1945 to 2022 in the Clarivate Analytics Web of Science – Science Citation Index Expanded.

	Sources	Articles	IF*
1	Aquatic Toxicology	281	4.1
2	Environmental Toxicology and Chemistry	221	3.6
3	Marine Environmental research	203	3.0
4	Ecotoxicology and Environmental Safety	150	6.2
5	Archives of Environmental Contamination and Toxicology	79	3.7
6	Ecotoxicology	59	2.4
7	Comparative Biochemistry and Physiology C – Toxicology // & Pharmacology	58	3.9
8	Bulletin of Environmental Contamination and Toxicology	33	2.7
9	Environmental Toxicology	23	4.4
10	Biomarkers	21	2.85
11	Environmental Toxicology and Pharmacology	20	4.2
12	Journal of Toxicology and Environmental Health - Part A- Current Issues	20	2.3
13	Environmental Health Perspectives	18	10.1
14	Toxicological Sciences	15	3.4
15	Toxicology and Applied Pharmacology	11	3.3
16	Comparative Biochemistry and Physiology C - Pharmacology Toxicology // & Endocrinology	9	3.9
17	Toxicology In Vitro	9	2.6
18	Environmental and Molecular Mutagenesis	8	2.3
19	Toxicology	8	4.8
20	Mutation Research - Fundamental and Molecular Mechanisms or Mutagenesis	7	1.8

IF = Impact Factor (Journal Citations Report – 2024)

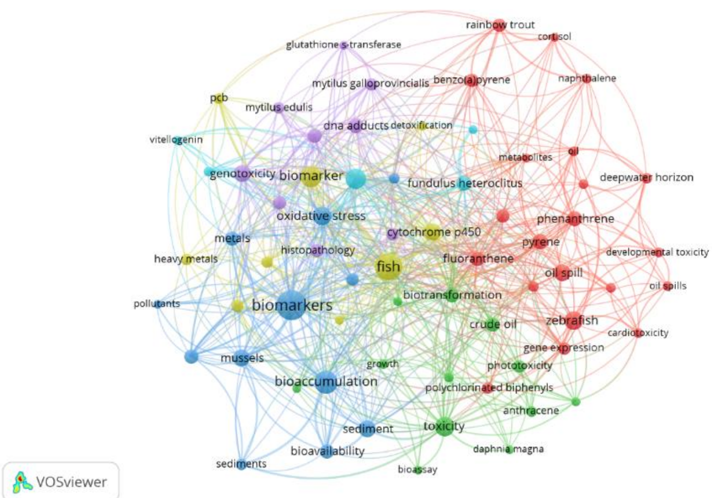

Fig. 4 Co-occurrence network of the authors’ keywords for articles on polycyclic aromatic hydrocarbons (PAHs) using aquatic organisms.

words were found in several groups, showing that there is a strong interaction between them. "Fish" and "cytochrome P450" were the central words that established the most links. The keyword "biomarkers" was also present as the most used test in the papers, which justifies its use as a keyword. Conversely, "fish" was the most used organism: it was included in more than half of the study articles.

Of the 1,336 papers, 687 tested only some types of PAHs. Most PAHs are persistent organic pollutants and highly toxic (Figure 5a). One of the main sources of PAH pollution is petroleum leakage, which can extensively pollute aquatic environments (Hylland 2006). The activities responsible for the increase in PAH levels in environments include petrochemical refining and production of different petroleum fractions, in addition to spillage accidents, urban and industrial sewage, and electricity production (Yunker et al. 2002). Petroleum and its derivatives are the most common sources found in aquatic environments, essentially due to high global demand and growing production (Figure 5b) (Santos et al. 2011).

However, polychlorinated biphenyls (PCBs) and metals were present in the studies, as well as other compounds (organochlorine pesticides – OCPs, dichlorodiphenyltrichloroethane – DDT, 2,3,7,8-tetrachlorodibenzo-p-dioxin – TCDD, and herbicides) (Figure 5a). This is because many papers evaluated environmental health, and most of these compounds pose a health risk and are on the control list (EPA 1994). Many of these contaminants are used by companies that produce pesticides, drugs, and chemicals (such as those used in everyday life). In general, these compounds have been introduced from industrial or urban effluents, oils, fuels, and even from the production and extraction of petroleum or from accumulation in sediments. Indeed, many researchers have demonstrated that PAHs are the predominant contaminants in marine sediments (Figure 5b). The toxicity of the compounds is also related to their properties due to the different architectures of each compound. For example, benzo[a]pyrene, the most mentioned PAH in the articles (n = 272), exerts mutagenic and teratogenic effects in a variety of organisms (EPA 1983). Of the 16 priority PAHs established by the EPA, phenanthrene, pyrene, fluoranthene, naphthalene, and anthracene were mentioned most frequently in the articles (Figure 5c). Of note, of the 16 priority PAHs, only 14 were individually tested in the evaluated articles; benzo[g,h,i]perylene and dibenzo[a,h]anthracene were not considered. Many papers that evaluated the effects of phenanthrene linked its toxicity to its potential to accumulate in sediments and the sensitivity of organisms (n = 716) (Figure 5c). We identified 34 papers in which the 16 priority PAHs were tested. Due to their toxic characteristics, their levels were used to determine the quality of the aquatic environment (Frapiccini et al. 2021).

We observed the following distribution of the types of tests used in the articles: 316 tests assessed the

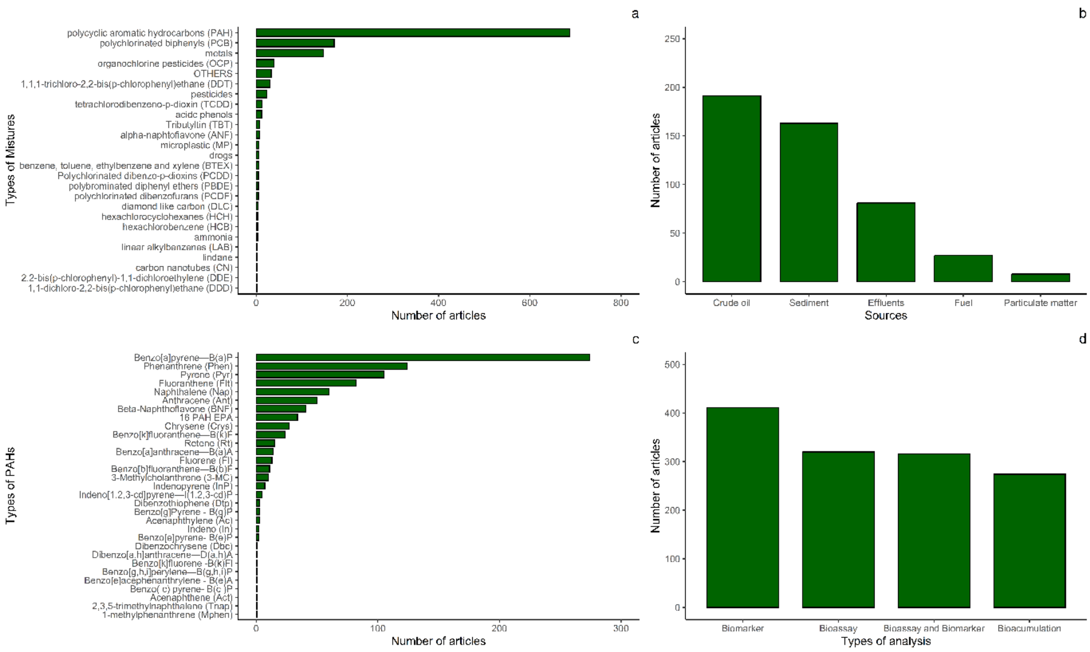

Fig. 5 (a) The number of articles evaluating the effects of polycyclic aromatic hydrocarbons (PAHs) alone or in combination with other contaminants. (b) The number of articles that provide sources of contamination by PAHs. (c) The types of PAHs evaluated in articles using aquatic organisms. (d) The responses (endpoints) evaluated in the articles.

effect of a contaminant or mixtures on target organisms; 409 were biomarker tests, used to asses the expression of biomarkers or to test the specificity of a marker with a contaminant; and 269 evaluated bioaccumulation (Figure 5d). Among all the articles, only 26 evaluated the adaptation of organisms to contaminants at the hereditary level. Moreover, there were 364 biomonitoring studies.

Fish are the most frequently used organisms to evaluate PAH-related aquatic toxicology (n = 756), followed by mollusks (n = 285) and crustaceans (n = 149) (Figure 6a). Fish are considered a standard model for toxicity tests with water, effluents, and sediments (Babić et al. 2017). These species are favored due to their small size, ease of maintenance and reproduction under laboratory conditions, low maintenance cost, external embryonic development, high fertility, embryo transparency, and the availability of transgenic models(Muth-Köhne et al. 2012). In many of the papers, the authors used fish to assess which organisms would be more sensitive to a certain contaminant. Many of these organisms respond to the selective pressures of different habitats by developing a range of life cycle strategies to ensure the maintenance of viable populations and the success of future generations. Many researchers have evaluated the sensitivity of these organisms to contaminants, but few have analyzed the heritability of survival strategies (Dellali et al. 2021).

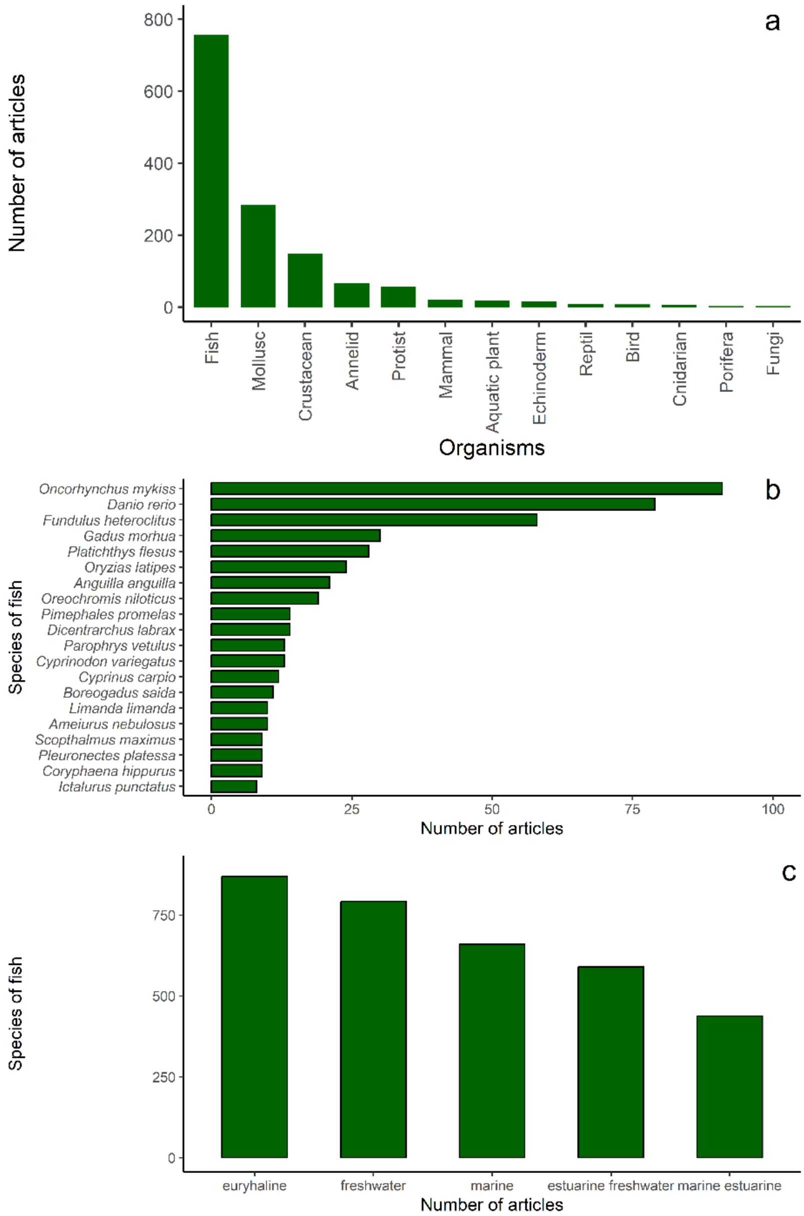

Fig. 6 (a) The species used most frequently in the articles. (b) The fish species evaluated in the articles. (c) The number of fish species in each preferred environment.

Among the 756 articles analyzed, the researchers tested 237 fish species (Supplementary Table S2). The most frequently used fish in the evaluated papers was the rainbow trout, which is considered an ideal model for toxicity tests in the early stages of life. About 12% of all studies with fish used rainbow trout. Its prevalence may be explained by several properties: it is commercially available year-round in Europe and North America at all life stages, easy to maintain in laboratories, has well-understood development, and its early life stages are highly sensitive to pollutants such as PAHs (Poisson et al. 2017).

We determined the preferred environments of each species and the number of articles that considered each habitat: marine (n = 660), freshwater (n = 792), marine and estuarine (n = 438), estuarine and freshwater (n = 590), and marine, estuarine, and freshwater, also known as euryhaline (n = 870) (Figure 6c). These results reveal a marked predominance of studies with euryhaline organisms, which may be related to their remarkable ability to resist and adapt to different environmental conditions. This trend suggests that researchers prioritize organisms capable of surviving in ecological transition zones—such as estuaries, coastal areas, and environments subject to diffuse pollution—which are considered critical for understanding the impacts of polycyclic aromatic hydrocarbons (PAHs) in aquatic ecosystems.

From an ecological perspective, the greater representation of euryhaline species reflects their physiological plasticity in the face of variations in salinity, dissolved oxygen, and contaminants. However, the relatively low number of studies with strictly estuarine species is striking. Estuaries are highly productive ecosystems and serve as nursery grounds for numerous species of ecological and economic importance, yet they remain underexplored in aquatic toxicology research. This gap becomes even more critical when considering that several estuarine and coastal species are listed in threatened categories on the IUCN Red List due to habitat loss, overfishing, and pollution. Among the 20 most commonly used species, three are already at risk: *Gadus morhua* is classified as vulnerable, *Cyprinus carpio* as endangered, and *Anguilla anguilla* as critically endangered (Supplementary Table S3) (IUCN 2022). The absence of targeted research on other threatened taxa, combined with the concentration of efforts on least-concern species, limits the potential to integrate aquatic toxicology into conservation needs.

Among the studies evaluated, the orders Salmoniformes, Cypriniformes, Cyprinodontiformes, and Perciformes were the most represented (Figure 6b, Supplementary Table S2). The focus on these groups can be explained by their economic and scientific relevance: salmonids are classical models in ecotoxicology due to their sensitivity and fishing importance; cyprinids include species of easy handling and wide distribution; cyprinodontids, such as annual killifish and *Fundulus heteroclitus*, are notable for their tolerance to extreme environments; and perciforms encompass an enormous trophic and ecological diversity. Nevertheless, the diversity of aquatic species studied remains restricted when compared with the wide variety of organisms exposed to PAHs in natural environments. This asymmetry becomes even more evident when confronted with IUCN assessments, which list hundreds of fish species as threatened, yet many remain absent from ecotoxicological literature on PAHs.

In this context, the role of model species such as *Danio rerio* and *Oncorhynchus mykiss* deserves attention. Zebrafish is consolidated due to its short life cycle, ease of reproduction in laboratory conditions, and extensive genomic knowledge, while O. mykiss, although the most used species in bioaccumulation and adaptive response studies, presents limited information regarding its own population status, despite its economic interest (IUCN 2022). This paradox—an abundance of toxicological data but a lack of conservation data—reinforces the urgency of an integrated approach. While model species are fundamental for protocol standardization, extrapolating results to wild species, many of them threatened, is neither simple nor straightforward. Expanding the range of organisms employed in toxicological studies, including species of greater relevance to the IUCN, is essential for advancing ecotoxicology that directly informs conservation and provides solid support for environmental management policies.

Conclusion

Our scientometric analysis shows that research on PAH-related aquatic toxicology has expanded markedly since the 1990s, followed by a recent decline that likely reflects a shift of attention toward emerging contaminants. The United States, Canada, and China remain leading contributors, while Europe stands out for stronger international collaborations. Yet, only 32 of the 48 participating countries engage in cross-national studies, underlining the need to broaden cooperative networks. Despite the maturity of the field, important knowledge gaps remain. Research is still heavily centered on fish, with limited investigation of other aquatic organisms such as mollusks, crustaceans, and aquatic plants. Studies examining the combined toxicity of contaminant mixtures are scarce, leaving uncertainties about interactive effects. In addition, research contributions from developing countries are underrepresented, restricting a truly global understanding of PAH impacts.

Addressing our research questions, the analysis of author keywords revealed that “biomarkers” and “fish” were the most frequently used terms, underscoring the dominance of biomarker-based assessments and the central role of fish models. Likewise, among the 16 priority PAHs defined by the U.S. EPA, phenanthrene, pyrene, fluoranthene, naphthalene, and anthracene emerged as the most commonly investigated compounds, reflecting their relevance in environmental risk assessment.

To move the field forward, we recommend: (i) diversifying model organisms to include under-studied taxa and habitats, (ii) expanding assessments of mixture toxicity under realistic environmental scenarios, and (iii) fostering international collaboration—particularly supporting research capacity in developing regions. Policymakers should integrate these priorities into environmental monitoring and regulatory frameworks so that PAH risk management reflects ecological complexity and regional realities. By identifying these gaps and setting clear research and policy directions, this review provides a consolidated yet forward-looking roadmap for mitigating the impacts of PAHs on aquatic ecosystems.

Competing interests The authors declare that they have no competing interests.

Authors’ contributions All authors contributed to the study conception and design. FLF conducted the literature search. FLF, FGB, MSC and JZ were involved in the analysis and interpretation of data. FLF, FGB, MSC and JZ drafted the manuscript. The study was supervised by FGB, MSC and JZ. All authors read and approved the final manuscript.

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List of abbreviations	
PAHs	polycyclic aromatic hydrocarbons
WHO	World Health Organization
USEPA	The United States Environmental Protection Agency
USA	The United States of America
PSL	Priority Substance List
PCBs	Polychlorinated Biphenyls
OCPs	Organochlorine Pesticides
DDT	Dichlorodiphenyltrichloroethane
TCDD	2,3,7,8-Tetrachlorodibenzo-p-dioxin
OECD	Organization for Economic Cooperation and Development
IUCN	International Union for Conservation of Nature

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