



Universidade Federal do Rio Grande
Instituto de Ciências Biológicas
Pós-graduação em Biologia de
Ambientes Aquáticos Continentais



**Análise cientométrica do uso de organismos
aquáticos para estudo dos efeitos de
hidrocarbonetos policíclicos aromáticos (HPA)**

Fernanda de Lacerda Freire

Orientador: Juliano Zanette
Coorientadora: Fabiana Gonçalves Barbosa

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**ATA DE DEFESA DE DISSERTAÇÃO DE MESTRADO EM BIOLOGIA DE
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RESUMO

A toxicologia aquática busca estudar os efeitos de estressores ambientais que podem afetar organismos aquáticos. Os hidrocarbonetos policíclicos aromáticos (HPAs) estão entre os contaminantes mais relevantes. A cientometria é o estudo quantitativo da ciência, da comunicação na ciência e das políticas científicas, preocupando-se principalmente com a dinâmica científica, analisando a produção, o consumo e a circulação da produção científica. A presente dissertação realizou um estudo cientométrico na área da toxicologia aquática em relação aos HPAs entre os anos de 1945 e 2022. Utilizamos o *software R*, com o auxílio do pacote *bibliometrix* e o *software VOSviewer*, para avaliar a tendência das publicações, colaborações entre países, revistas e criar rede de colaborações, também como investigar os HPAs e organismos presentes em estudos com toxicologia aquática. As análises mostraram um crescimento no número de publicações neste tema ao longo do tempo de forma não linear, na década de 90 observa-se um grande crescimento nos trabalhos, e nos 20 anos seguintes, nas décadas de 2000 e 2010, uma estabilidade na produção científica. Por outro lado, em 2020 é possível observar uma diminuição no número de trabalhos até 2022, o que gera alguns questionamentos, como os PAHs pararam de ser avaliados como contaminantes em toxicologia aquática?. Na maioria dos trabalhos eram testados apenas HPAs, outros contaminantes que foram presentes em combinação com estes, foram os PCBs e metais. O benzo-a-pireno (BaP) foi o HPA mais testado, dos 16 HPAs preferenciais da agencia de proteção ambiental americana (EPA) 15 estão entre os HPAs utilizados, o Benzo[0]oranteno não foi testado em nenhum dos trabalhos com toxicologia aquática. Em mais da metade dos trabalhos, foram utilizados peixes como organismo totalizando 237 espécies, das quais 43% são marinhas, 38% de água doce e apenas 19% eurialinas, sendo a truta arco-íris (*Oncorhynchus mykiss*), o peixe zebra (*Danio rerio*) e o mummicog (*Fundulus heteroclitus*) os mais usados. Os resultados apresentados podem ajudar pesquisadores e agências de fomento no desenvolvimento de novos projetos e políticas ambientais, uma vez que foram identificadas algumas lacunas nas pesquisas com HPAs em toxicologia aquática e na preservação das espécies de peixes, que foi o principal grupo avaliado neste trabalho.

Palavra-chave: toxicologia aquática, *Web of Science*, contaminantes, peixe.

ABSTRACT

Aquatic toxicology is the study of the effects of environmental stressors that can affect aquatic organisms. Polycyclic aromatic hydrocarbons (PAHs) are among the most relevant contaminants. Scientometrics is the quantitative study of science, science communication and science policies, mainly concerned with scientific dynamics, analyzing the production, consumption and circulation of scientific production. This dissertation carried out a scientometric study in the area of aquatic toxicology in relation to PAHs between the years 1945 and 2022. We used the R software, with the aid of the bibliometrix package and the VOSviewer software, to evaluate the trend of publications, collaborations between countries, journals and create a network of collaborations, as well as investigating PAHs and organisms present in aquatic toxicology studies. The analyzes showed a growth in the number of publications on this topic over time in a non-linear way, in the 90s there is a great growth in the works, and in the following 20 years, in the 2000s and 2010s, a stability in the production scientific. On the other hand, in 2020 it is possible to observe a decrease in the number of works until 2022, which raises some questions, how did PAHs stop being evaluated as contaminants in aquatic toxicology?. In most works only PAHs were tested, other contaminants that were present in combination with these were PCBs and metals. Benzo-a-pyrene (BaP) was the most tested PAH, of the 16 preferred HPAs of the American Environmental Protection Agency (EPA) 15 are among the PAHs used, Benzo[0]oranthene was not tested in any of the works with toxicology aquatic. In more than half of the studies, fish were used as organisms, totaling 237 species, of which 43% are marine, 38% freshwater and only 19% euryhaline, including rainbow trout (*Oncorhynchus mykiss*), zebrafish (*Danio rerio*) and the mummichog (*Fundulus heteroclitus*) are the most used. The results presented can help researchers and funding agencies in the development of new projects and environmental policies, since some gaps were identified in research with PAHs in aquatic toxicology and in the preservation of fish species, which was the main group evaluated in this work.

Keywords: aquatic toxicology, *Web of Science*, contaminated, fish.

APRESENTAÇÃO

Essa dissertação está dividida em três segmentos. O primeiro refere-se à introdução geral do tema proposto e as referências utilizadas, seguindo as normas da ABNT. O segundo segmento é representado pelo artigo científico, que trata de um estudo cientométrico acerca do uso de organismos aquáticos para estudo dos efeitos de hidrocarbonetos policíclicos aromáticos, a ser submetido para a revista "*Environmental Science and Pollution Research*". O terceiro segmento contém as considerações finais do trabalho.

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LISTA DE ABREVIACÕES

BaP – Benzo[a]pireno

CYP – citocromo p450

COP – Contaminantes orgânicos persistentes

HPA – Hidrocarboneto policíclico aromático

ISI - *Institute for Scientific Information*

NIOSH - *National Institute of Occupational Safety and Health*

OMS – Organização mundial de saúde

PCB – Bifenilo policorado

US EPA – *United States Environmental Protection Agency*

SCI - *Science Citation Index*

WoS – *Web of Science*

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INTRODUÇÃO GERAL

Toxicologia Aquática

A toxicologia é a ciência que busca estudar os efeitos nocivos decorrentes da interação de estressores ambientais com os organismos, sob condições específicas de exposição. Representa uma ciência utilizada por indústrias e agências reguladoras, e que emergiu em resposta à necessidade de políticas reguladoras em saúde ambiental e humana (Monosson, 2005). O estudo da toxicologia contribui significativamente para o desenvolvimento de outras ciências e atividades humanas diversas. Suas contribuições são cada vez mais decisivas para o desenvolvimento das ciências, nas mais diversas áreas (Ariens et al, 1976; Timbrell, 1999).

A toxicologia subdivide-se em várias áreas, de acordo com a natureza do agente ou maneira como atinge estes sistemas biológicos. A toxicologia ambiental, estuda os efeitos tóxicos causados pela ação de agentes químicos ou resíduos contaminantes no ambiente (água, solo, ar) sobre os organismos, vem se destacando por ter como objetivo direto melhorar a saúde do ambiente e a qualidade de vida, sendo assim uma ciência de inegável importância social no mundo contemporâneo (Zbinden, 1976; Timbrell, 1999).

Dentro da toxicologia ambiental existe a toxicologia aquática, a qual inclui o estudo do transporte, distribuição, transformação e destino final de produtos químicos sobre organismos aquáticos. Na toxicologia aquática também se preocupa com as concentrações ou quantidades de produtos químicos que podem ocorrer no ambiente aquático: na água, sedimentos ou alimentos; de forma a afetar os organismos (Brusick et al, 1980).

Como resultado dessas preocupações, a toxicologia aquática evoluiu como um campo de estudo multidisciplinar, que empresta livremente de várias outras ciências básicas (Ariens et al, 1976; Timbrell, 1999). O conhecimento de ecologia aquática, fisiologia, bioquímica, histologia e comportamento é necessário para entender os efeitos de agentes tóxicos em organismos aquáticos (Leung et al., 2017).

Os efeitos tóxicos podem incluir efeitos letais (mortalidade) e subletais, como alterações no crescimento, desenvolvimento, reprodução, respostas farmacocinéticas, patologia, bioquímica, fisiologia e comportamento. Podem ser expressos, por exemplo, por critérios quantificáveis, como contagem de organismos mortos, porcentagem de eclosão dos ovos, alterações no comprimento e peso, porcentagem de inibição enzimática, número de anormalidades esqueléticas e incidência de tumores (IARC, 1985; Nebert et al, 2004).

Os testes toxicológicos são usados para avaliar as concentrações e a duração da exposição necessária para causar os potenciais efeitos toxicológicos de produtos químicos e resíduos em organismos aquáticos (ASTM, 1980b). Estudar os efeitos de compostos produzidos pelo homem, bem como de outros materiais naturais, com capacidade de alterar a biologia de organismos aquáticos considerando vários níveis de organização, células, organismos individualizados, comunidades e ecossistemas (Landis et al, 2011; Nikinmaa, 2014) se torna cada vez mais importante. Nas últimas décadas o estudo da Toxicologia Aquática tem-se desenvolvido de modo ímpar, devido ao aumento da escassez mundial de água potável e à diminuição dos recursos marinhos, tão importantes para a sustentabilidade da vida no nosso planeta (Hodgson, 2010; Nikinmaa, 2014).

Hydrocarbonetos Policíclicos Aromáticos

O ambiente aquático está contaminado por várias classes de poluentes, dentre os quais os hidrocarbonetos policíclicos aromáticos (HPAs) são considerados uma das categorias mais importantes, devido à sua alta persistência e capacidade de toxicidade em humanos e animais selvagens (IARC, 2018). Os HPAs são substâncias originadas na combustão incompleta da matéria orgânica, durante a queimada de floresta ou a queima de combustíveis fósseis. A sua formação é influenciada por temperatura e pressão (Singh et. al., 2015). De maneira geral, são formados a partir de compostos como hidrocarbonetos/carboidratos, peptídeos e metano. Além destes, compostos insaturados e estruturas cíclicas também podem colaborar para a sua formação (Wey et al., 2006).

A maioria dos HPAs pertence a uma classe de poluentes orgânicos, persistentes, considerados compostos de alta toxicidade, que possuem como características principais a alta hidrofobicidade, baixa reatividade no meio ambiente e grande tendência de se acumular nos tecidos dos organismos vivos (Heath et. al., 1993). Os HPAs fazem parte de um grupo de compostos denominados contaminantes orgânicos persistentes (COPs). Recebem esta denominação por serem compostos tóxicos; persistentes; bioacumuláveis; transportados por longas distâncias através do ar e indutores de efeitos danoso sobre a saúde dos organismos e meio ambiente (Garcia et al., 2014).

São compostos que podem ser encontrados em diferentes compartimentos como ar, solo e água (Neff, 1979). Considerando as propriedades físico-químicas dos HPAs e sua ampla distribuição no ambiente aquático, o risco de contaminação dos organismos por estes compostos é bastante significativo. Devido a sua alta lipossolubilidade, são de rápida absorção nos tecidos de exposição (pulmões, brânquias, intestino e pele) (IARC, 1983; Braun et. Al., 2004; Lachner, Oliveira e Martinez 2015).

Os HPAs de origem terrestre também podem entrar em sistemas aquáticos por meio de injeção de água e deposição atmosférica, causando poluição ao ambiente aquático (Abayi et al., 2021). Derramamentos de óleo são uma importante fonte de HPAs, que tem recebido ampla atenção devido aos efeitos adversos no ecossistema aquático. HPAs de derramamentos de óleo podem ser carregados por correntes para a costa (Tamis et al., 2012). Uma das principais fontes de poluição por HPA, é o vazamento de petróleo, que pode poluir extensivamente os ambientes aquáticos (Hylland, 2006).

O petróleo é uma mistura de HPAs e outras substâncias orgânicas. Em seu estado líquido apresenta-se como uma substância oleosa, inflamável e menos densa que a água (Singh et. al., 2015). Sua presença nos ambientes aquáticos diminui a área de contato entre a superfície e o ar atmosférico, o que impede a trocas gasosas com a atmosfera para o ecossistema aquático (Bielecka et al., 2002). Em ecossistemas de água doce e mixoalinas, o impacto do petróleo e de seus derivados pode ser mais severo do que em águas marinhas, principalmente pela menor movimentação das águas continentais (Woodhead et al., 1999).

A complexidade das misturas formadas depende da fonte emissora, uma vez relacionada com as condições de reação (Samanta, Singh e Jain, 2002). A toxicidade dos compostos também está relacionada às suas propriedades, devido às diferentes estruturas (quantidade de anéis) e arquiteturas (forma como se configuram) de cada composto (Figura 1) (NIOSH, 1983). O Benzo[a]Pireno (BaP), por exemplo, tem efeito mutagênico e teratogênico para uma variedade de organismos (invertebrados, peixes, anfíbios, aves e mamíferos). Os danos causados à saúde destes organismos pelos HPAs ocorrem, geralmente, pela ingestão crônica, que consiste em pequenas quantidades por longos períodos (EPA, 1983).

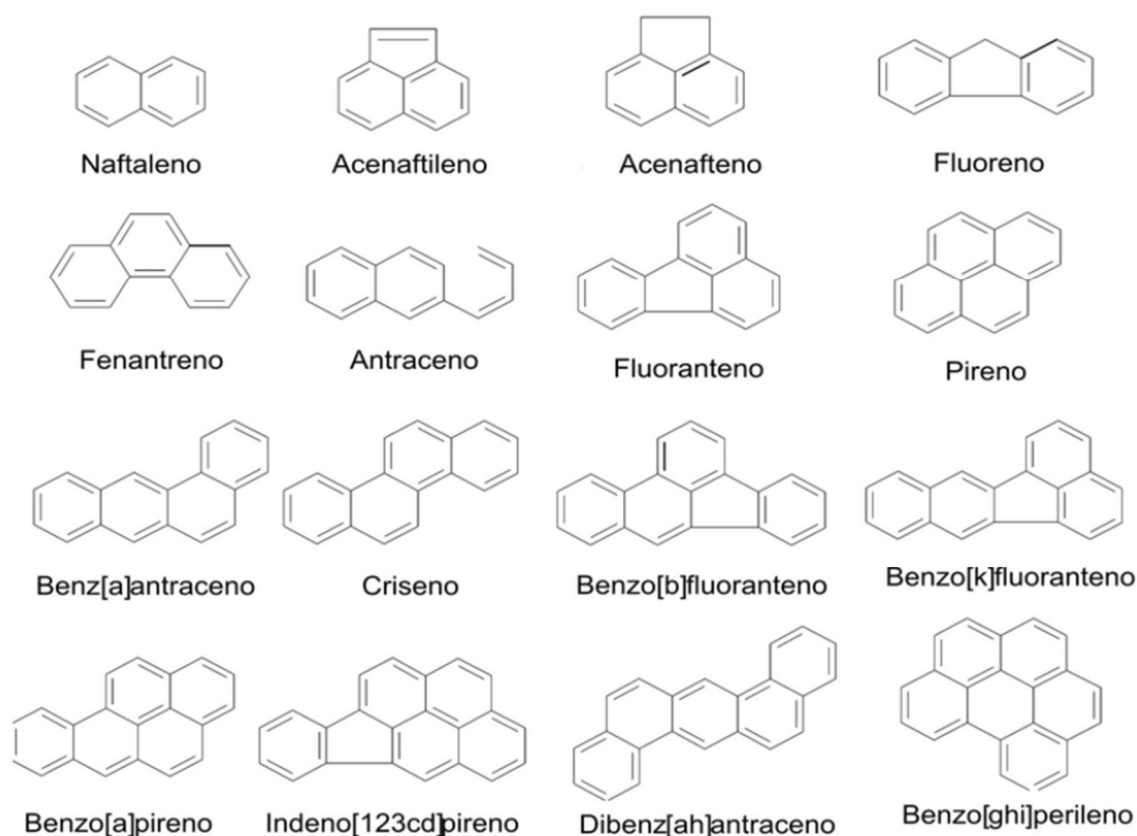


Figura 1. Ilustração das diferentes arquiteturas e estruturas dos 16 HPAs prioritário da EPA. (EPA, 1987; NIOSH, 1983) figura adaptada de Meire et al. 2007.

Com base em suas características tóxicas, a Agência de Proteção Ambiental dos Estados Unidos (US EPA) e a Organização Mundial da Saúde (OMS) identificaram dezesseis HPAs prioritários que devem ser avaliados minuciosamente para determinar a qualidade do ambiente aquático (EPA, 1983). São eles: Acenaftileno, Acenafteno, Antraceno, Benzo[a]antraceno, Benzo[a]pireno, Benzo[b]fluoranteno, Benzo[k]fluoranteno, Benzo[ghi]perileno, Criseno, Dibenz[a,h]antraceno, Fenantreno, Fluoranteno, Fluoreno, Indeno[1,2,3cd]pireno, Naftaleno e Pireno. Estes são considerados os mais tóxicos entre os HPAs conhecidos (Yunker et al, 2002).

A toxicidade dos HPAs tem sido extensivamente estudada. Também foi demonstrado que os HPAs causam múltiplos efeitos nocivos nos peixes (Logan, 2007). De acordo com pesquisas anteriores, o coração do peixe em desenvolvimento é bastante sensível à exposição aos HPAs derivados do petróleo bruto (Incardona et al., 2011). Anormalidades e malformações da função cardíaca e distúrbios circulatórios estão relacionados à exposição aos HPA (Incardona et al., 2014).

Os HPAs estão entre os principais contaminantes orgânicos abordados em estudos ambientais (Netto et al., 2000). Os efeitos tóxicos atribuídos aos HPAs em organismos aquáticos são os mais

variados, de mudanças no comportamento a alterações metabólicas (Gregg et al., 1997; Brown et al. 2017; Jayasundara et al. 2017).

Vários estudos demonstraram que os HPAs são os contaminantes predominantes nos sedimentos marinhos (Medeiros et al., 2005; Chivittz et al., 2016; Volkoff et al., 2019). Em ambientes marinhos, os organismos aquáticos podem ser expostos a HPAs presentes em águas superficiais e sedimentos devido à poluição atmosférica, esgotos industriais e domésticos ou derramamentos de óleo (Bielecka et al., 2002). Devido à persistência dos HPAs, sua toxicidade em organismos aquáticos pode afetar várias gerações (Koyama et al., 2004).

Devido às propriedades genotóxicas, esses contaminantes podem provocar danos na comunidade aquática e na população humana (Netto et. Al., 2000). Os principais efeitos tóxicos dos HPAs levam ao desenvolvimento de mutagênese, teratogênese e carcinogênese. Dentre esses efeitos a carcinogênese é o mais bem explicado. Esses compostos não são diretamente carcinogênicos, necessitam ser ativados metabolicamente por enzimas, incluindo membros da família citocromo P450 (CYP), para então, exercer seus efeitos nocivos sobre o material genético. A ação sobre esse material varia desde mutação com consequências potenciais de formação de tumores (malignos) até desenvolvimento de má formação fetal (Shimada e Fujii-Kuriyama, 2004).

Cientometria e Bibliometria

Diante do desenvolvimento em diferentes campos da ciência, era inevitável surgir a bibliometria ou cientometria, que é definida como o estudo da mensuração do progresso científico e tecnológico e que consiste na avaliação quantitativa e na análise das inter-comparações da atividade, produtividade e progresso científico (Bordóns e Zulueta, 1999). Segundo Spinak (1996, 1998), a bibliometria remonta do final do século XIX e início do século XX, e pode ser definida pela aplicação de análises estatísticas para estudar as características do uso e criação de documentos. Trata-se de um estudo quantitativo da produção de documentos como se reflete nas bibliografias, a partir da aplicação de métodos matemáticos e estatísticos. A bibliometria tem o potencial de introduzir um processo de revisão sistemático, transparente e reproduzível baseado na medição estatística da ciência, dos cientistas ou da atividade científica (Broadus, 1987; Diodato, 1994; Pritchard, 1969).

A Cientometria nasce a partir dos anos 1960, da confluência da documentação científica, da Sociologia da Ciência e da História Social da Ciência, com o objetivo de estudar a atividade científica como fenômeno social e mediante indicadores e modelos matemáticos (Courtial, 1990). Está ligada a dois nomes: Derek de Solla Price e Eugene Garfield. Garfield foi o criador do *Institute for Scientific Information* (ISI), produtor da base de dados *Science Citation Index* (SCI), nos anos 1960, o que permitiu aos trabalhos de Price alçar voo e contribuiu largamente para o crescimento dos

conhecimentos estatísticos dos artigos científicos. A criação do ISI por Garfield permitiu à Cientometria firmar a parte instrumental dos métodos e conceitos anteriormente colocados por Price, a partir de uma nova técnica de avaliação da atividade científica, fundada no estudo de citações (Polanco, 1995).

Em 1978 a criação da revista *Scientometrics*, publicada pela editora Elsevier, foi um elemento importante no cenário de desenvolvimento da cientometria, assinalando o início da acumulação de um *corpus* de conhecimentos e a criação de uma comunidade científica a respeito da medida da ciência. A revista *Scientometrics* veio dar à Cientometria uma visibilidade no meio científico (Rostaing, 1997).

Bordóns e Zulueta (1999) enfatizam que o uso de indicadores bibliométricos para estudar a atividade de pesquisa de um país se baseia na premissa de que as publicações científicas são um produto essencial dessa atividade. Para as autoras, novos conhecimentos adquirem valor quando são divulgados e disseminados no interior da comunidade científica e esse é um mecanismo que contribui para o avanço do conhecimento. Enfatizam ainda que a publicação científica é um resultado importante e tangível da pesquisa e que nesse contexto os indicadores bibliométricos adquirem validade como uma medida indireta da atividade da comunidade científica (Bordóns e Zulueta, 1999).

O número de publicações acadêmicas está aumentando em ritmo acelerado e fica cada vez mais inviável se manter atualizado com tudo o que está sendo publicado. Além disso, a ênfase nas contribuições empíricas resultou em fluxos de pesquisa volumosos e fragmentados (Briner e Denyer, 2012). As revisões de literatura estão cada vez mais assumindo um papel crucial na síntese de resultados de pesquisas anteriores para usar efetivamente a base de conhecimento existente, avançar uma linha de pesquisa e fornecer uma visão baseada em evidências sobre a prática de exercer e sustentar o julgamento e a experiência profissional (Rousseau, 2012). As pesquisas nessa área estão embasadas principalmente no interesse em caracterizar e medir a produção e a produtividade científica e embora os estudos métricos da informação estejam associados ao campo da Ciência da Informação, suas origens podem ser buscadas no campo da Sociologia da Ciência (Hochman, 1994).

A cientometria está relacionada com a demografia da comunidade científica mundial e tem se tornado um tema importante não somente em países mais industrializados, mas também naqueles em desenvolvimento, que pretendem melhor distribuir os seus fundos de suporte à ciência (Courtial, 1990). Utiliza métodos estatísticos para analisar e identificar padrões, irregularidades e tendências que podem existir nas publicações de determinado campo da produção científica (Barbosa *et al.*, 2012).

Existem alguns trabalhos de análise cientométrica que abordam temas de toxicologia, com diferentes contaminantes, em sua maioria herbicidas. Castro et al (2021), por exemplo, realizaram uma análise cientométrica sobre a atrazina. Porém, são muito escassos estudos de análise cientométrica na área de toxicologia aquática. Saiki et al (2021) já abordam o tema da toxicologia aquática, de uma forma mais restrita, em seu trabalho sobre o uso do *Danio rerio* (Peixe zebra) como modelo para teste de contaminação no sedimento. Dessa forma o presente trabalho é o primeiro a avaliar os padrões e tendências da produção científica acerca do uso de organismos aquáticos na avaliação dos efeitos dos HPAs.

Um dos objetivos deste trabalho foi avaliar a utilização de peixes como modelo de estudo nesta área. Analisamos artigos publicados na base de dados Science Citation Index Expanded (SCI-EXPANDED) – Clarivate Analytics Web of Science (WoS) em um intervalo de tempo de 1945a 2022. Buscamos responder às seguintes perguntas: i) Quais países apresentam maior produção científica na área da toxicologia aquática em relação aos HPAs? ii) Houve aumento na produção científica ao longo dos anos na área de toxicologia aquática em relação aos HPAs? iii) Quais os países que mais realizaram colaboração científicas internacionais na área da toxicologia aquática em relação aos HPAs? iv) Quais as palavras-chaves mais utilizadas para pesquisar na área da toxicologia aquática em relação aos HPAs? v) Quais os testes mais utilizados para avaliar a contaminação por HPA em trabalhos na área da toxicologia aquática? vi) Quais os HPAs mais utilizados em trabalhos na área de toxicologia aquática? vii) Quais os organismos modelo mais utilizados na área da toxicologia aquática em relação aos HPAs?. Neste último caso, em relação aos trabalhos com peixes, buscamos responder às seguintes perguntas: i) Houve aumento na produção científica ao longo dos anos na área da toxicologia aquática em relação aos HPAs com peixes? ii) Quais foram as ordens de peixes mais representativas na área da toxicologia aquática em relação aos HPAs?

Referências

- Abayi, J.J.M.; Gore, C.T.; Nagawa, C.; Bandowe, B., Ssebugere, P. 2021. Polycyclic aromatic hydrocarbons in sediments and fish species from the White Nile, East Africa: bioaccumulation potential, source apportionment, ecological and health risk assessment. *Environ. Pollut.*, 278
- Adeniji, O. A., Okoh, O. O., & Okoh, A. I. 2019. Levels of Polycyclic Aromatic Hydrocarbons in the Water and Sediment of Buffalo River Estuary, South Africa and Their Health Risk Assessment. *Arch. Environ. Contam. Toxicol*, 76(4), 657–669
- American Society for Testing and Materials: Standard practice for conducting toxicity tests with larvae of four species of bivalve molluscs. Philadelphia: ASTM, E724-80, 1980b.

- American Society for Testing and Materials: Proposed standard practice for conducting bioconcentration tests with fishes and saltwater bi- valve molluscs. In subcommittee ASMT E47.01, 1980d.
- Ariens, E.J., Simonis, A.M., Offermeier, J. 1976. Introductions to general toxicology. New York: academic press. P 13-19
- Barbosa, F. G., Schneck, F., Melo, A. S. 2012. Use of Ecological Niche Models to Predict the Distribution of Invasive Species: A Scientometric Analysis. *Braz. J. Biol.* , 72(4), 821 – 829.
- Bielecka, K., Kaczorek, E., Olszanowski, A., Voelkel, A., 2002. Examination of biodegradation of hydrocarbons in emulsified systems. *J Environ Stud Sci* , 11, 11-16.
- Bordóns, M., zulueta, M. A. 1999. Evaluación de la actividad científica através de indicadores bibliométricos. *Rev Esp Cardiol*, v.52, n. 10, p. 790-800.
- Braun, S, Appel, LG, Schmal, M. 2004. The pollution generated by internal combustion engines powered by diesel – the issue of particulates. Current strategies for reducing and controlling emissions and future trends . *Quím Nova*, v. 27, p. 472-482.
- Briner, R.B., Denyer, D. 2014. Systematic review and evidence synthesis as a practical and academic tool Evidence-Based Management Handbook: Business, Classrooms, and Research , *Acad Manag Learn Educ*, v 13, 3, 415–432
- Broadus, R.N. 1987. Toward a definition of bibliometrics . *Scientometrics*, v. 12 , n . 5 - 6 , p.373-379.
- Brusick DJ, Young RR, Hutchinson C, Vilkas AG, Gezo TA. 1980. Ecological assays. In: *IERL-RTP Procedures Manual: Level 1 Environmental Assessment Biological Tests*, pp. 69-112. EPA 68-02-2681. Washington, D.C.: U.S. EPA, Office of Research and Development.
- Buikema AL, Jr, Niederlehner BR, Cairns J, Jr. 1982. Biological monitoring. IV. Toxicity testing. *Water Res* 16:239-262.
- Callon, M., Coutrial, J-P., Penan, H. 1993. In: *LA SCIENTOMETRIE*. Paris: Presses Universitaires de France, 126p. (Collection Que sais-je?, v. 2727).
- Castro, M.S., Barbosa, F.G., Guimarães, P.S., C.D.M.G. Martins, C.D.M.G., Zanette, J. 2021. A scientometric analysis of ecotoxicological studies with the herbicide atrazine and microalgae and cyanobacteria as test organisms. *Environ. Sci. Pollut. Res.*, 28, pp. 25196-25206, 10.1007/s11356-020-12213-w
- Chivittz, C. C., Pinto, D. P. , Ferreira, R. S. Sopezki, M. S., Fillmann, G. and Zanette, J. 2016.

“Responses of the CYP1A Biomarker in *Jenynsia Multidentata* and *Phalloceros Caudimaculatus* and Evaluation of a CYP1A Refractory Phenotype.” *Chemosphere* 144: 925–31.

Courtial, J. P. 1990. Introduction to scientometrics: from bibliometrics to technology watch. Paris: Anthropos-Economica.

Diodato, V. 1994 . Dicionário de bibliometria Haworth Press , Binghamton, NY

EPA. TCS Management Group, Inc. (1983) Pollution Control Expenditure Estimates

EPA. TCS Management Group, Inc. (1987) Pollution Control Expenditure Estimates

Heath, J. S., Koblis, K., Sager, S., Day, C. , 1993. Risk assessment for total petroleum hydrocarbons. In: Calabrese, e. J. & Kostecki, P. T. ed. Hydrocarbon Contaminated Soils, v. 3, Lewis Publishers, CRC Press. P. 267-302.

Hylland, K. 2006. Polycyclic aromatic hydrocarbon (PAH) ecotoxicology in marine ecosystems. *J. Toxicol. Environ. Health A*, 69, pp. 109-123

Hochman, G. 1994. Science between the community and the market: readings of Kuhn, Bourdieu, Latour and Knorr-Cetina. In: portocarrero, V. (Org.). Philosophy, history and sociology of science: contemporary approaches. Rio de Janeiro: Fiocruz

Hodgson, E. 2010. A Textbook of Modern Toxicology, Wiley-Blackwell, Fouth Edition, ISBN: ISBN-13: 978-0470462065

Hylland, K. 2006. Polycyclic aromatic hydrocarbon (PAH) ecotoxicology in marine ecosystems. *J. Toxicol. Environ. Health A*, 69, pp. 109-123

IARC - international agency for research on cancer 1983. Monographs on the Evaluation of the Carcinogenic Risk of Chemical to Humans, v.31. Lyon, France.

IARC - international agency for research on cancer 2018. Monographs on the Evaluation of the Carcinogenic Risk of Chemical to Humans, v.115. Lyon, France.

Ikenaka, Y., Sakamoto, M., Nagata, T., & Takahashi, H. (2013). Effects of polycyclic aromatic hydrocarbons (PAHs) on an aquatic ecosystem : Acute toxicity and community-level toxic impact tests of benzo [a] pyrene using lake zooplankton community. *J Toxicol Sci.*, 38(1), 131–136.

Incardona, J.P.; Collier, T.K.; Scholz, N.L. 2011. Oil spills and fish health: exposing the heart of the matter. *J Expo Sci Environ Epidemiol .*, 21, pp. 3-4

Incardona, J.P.; Gardner, L.D.; Linbo, T.L.; Brown, T.L.; Esbaugh, A.J.; Mager, E.M.; Stieglitz, J.D.; French, B.L.; Labenia, J.S.; Laetz, C.A.; Tagal, M.; Sloan, C.A.; Elizur, A.; Benetti, D.D.; Grosell, M.; Block, B.A.; Scholz, N.L. 2014. Deepwater Horizon

- crude oil impacts the developing hearts of large predatory pelagic fish. *Pro Natl Acad Sci U. S. A.*, 111, pp. E1510-1518
- Kieth, L.H.; Telliard ES&T, W.A. 1979. special report: priority pollutants: I-a perspective view *Environ Sci Technol*, 13, pp. 416-423
- Koyama, J.; Uno, S. ; Kohno, K. 2004. Polycyclic aromatic hydrocarbon contamination and recovery characteristics in some organisms after the Nakhodka oil spill. *Mar Pollut Bull*, 49, pp. 1054-1061
- Lachner, D., Oliveira, L.F., Martinez, C.B.R. 2015. “Effects of the Water Soluble Fraction of Gasoline on ZFL Cell Line: Cytotoxicity, Genotoxicity and Oxidative Stress.” *Toxicol. In Vitro* 30 (1): 225–30.
- Leung, M. C. K., Procter, A. C., Goldstone, J. V., Foox, J., DeSalle, R., Mattingly, C. J., ... Timme-Laragy, A. R. 2017. Applying evolutionary genetics to developmental toxicology and risk assessment. *Reprod. Toxicol* , 69, 174–186.
- Logan, D.T. 2007. Perspective on ecotoxicology of PAHs to fish *Hum. Ecol. Risk Assess.*, 13, pp. 302-316
- Medeiros, P.M., Bícago, M.C., Castelão, R.M., Rosso, C.D., Fillmann, G., Zamboni, A.J., 2005. Natural and anthropogenic hydrocarbon inputs to sediments of Patos Lagoon Estuary, Brazil. *Environ Int* . 31, 77-87.
- Meire, R; Azeredo, A; Machado J.P.T. 2007. Aspectos ecotoxicológicos de hidrocarbonetos policíclicos aromáticos. *Oecologia Brasiliensis*, ISSN 1981-9366, Vol. 11, Nº. 2, 2007, pags. 188-201. 11. 10.4257/oeco.2007.1102.03.
- Nebert, D.W., Dalton, T.P., Okey ,A.B., Gonzalez, F.J. 2004. Role of aromatic hydrocarbon receptor-mediated induction of CYP1 enzymes in environmental toxicity and cancer. *J. Biol. Chem.* , 279 (2004) , pp . 23847 – 23850 , 10.1074/jbc.R400004200
- Neff, J.M., 1979. HPAs in the Aquatic Environment Sources, fate, and biological effects. London: Appl. Sci.
- Netto, A.D.P., Moreira, J.C., Dias, A.E.X.O., Arbilla, G., Ferreira, L.F.V., Oliveira, A.S., Barek, J., 2000. Assessment of human contamination by polycyclic aromatic hydrocarbons (PAHs) and their nitrated derivatives (NHPAs): a methodological review . *Quím Nova* 23, 765-773.
- Nikinmaa, M.2014. *An Introduction to Aquatic Toxicology*, Academic Press, ISBN: ISBN-10: 0124115748

- NIOSH – National Institute for Occupational Safety and Health . 1983. Petroleum Refinery Workers Exposure to tóxicos Fluid Catalytic Cracker, Coker, and Asphalt Processing Units. DHH, 83-111
- Nwaichi, E. O., & Ntorgbo, S. A. 2016. Assessment of PAHs levels in some fish and seafood from different coastal waters in the Niger Delta. Toxicol. Rep, 3, 167 – 172.
- Pritchard, A. 1969. Statistical bibliography or bibliometrics. J. Doc, 25, p. 348
- Polanco, X. 1995. Aux sources de la scientométrie. Solaris, n.2,.
- Rostaing, H. 1997. La bibliométrie et ses techniques. Toulouse: Sciences de la Société, Marseille: Centre de Recherche Rétrospective de Marseille.
- Rousseau, D.M., 2012 (Ed.) The Oxford Handbook of Evidence-Based Management, Oxford University Press
- Tamis, J.E.; Jongbloed, R.H.; Karman, C.C.; Koops, W.; Murk, A.J. 2012. Rational application of chemicals in response to oil spills can reduce environmental damage . integr. Ambiente. Avaliar. Gerenciar , 8, pp. 231 - 241
- Timbrell,J, 1999. Introduction to toxicology 2ed Philadelphia: Taylor e francis p 1-5
- Saiki, P., Mello-Andrade, F., Gomes, T., Lopes Rocha, T. 2021. Sediment toxicity assessment using zebrafish (*Danio rerio*) as a model system: historical review, research gaps and trends. Sci. Total Environ., 793, p. 148633
- Samanta, S.K., Om V.S., Rakesh K.J. 2002. “Polycyclic Aromatic Hydrocarbons: Environmental Pollution and Bioremediation.” Trends Biotechnol. 20 (6): 243–48.
- Shimada T, Fujii-Kuriyama Y. 2004. Metabolic activation of polycyclic aromatic Hydrocarbons to carcinogens by cytochromes P450 1A1 and 1B1. Cancer Sci 95(1):1–6
- Singh; Ajay; Jonathan D Van Hamme; Ajay Singh; Owen P Ward. 2015. “Recent Advances in Petroleum Microbiology Recent Advances in Petroleum Microbiology.” Microbiol. Mol. Biol. R. 67.503–49.
- Spinak, E. Diccionario enciclopédico de bibliometría, cienciometría e informetría. Caracas: UNESCO – CII/II, 1996.
- Spinak, E. 1998. Scientometric indicators. Cienc. Inf, Brasília, v.27, n.2, p.141-148, maio/ago.
- Volkoff, Savannah J., Joshua S. Osterberg, Nishad Jayasundara, Ellen Cooper, Heileen Hsu-Kim, Laura Rogers, Gretchen E. Gehrke, Saro Jayaraman, and Richard T. Di Giulio. 2019. “Embryonic *Fundulus Heteroclitus* Responses to Sediment Extracts from Differentially Contaminated Sites in the Elizabeth River, VA.” Ecotoxicology 28 (9): 1126–35.

- Wang, H.H.; Huang, W. ; Gong, Y.; Chen, C.M.; Zhang, T.Y.; Diao, X.P. 2020. Occurrence and potential health risks assessment of polycyclic aromatic hydrocarbons (PAHs) in different tissues of bivalves from Hainan Island, China Food Chem. Toxicol., 136, Article 111108
- Wayne G. Landis, W.G. Sofield, R.M. Yu, M. 2011. Introduction to Environmental Toxicology: Molecular Substructures to Ecological Landscapes, Cambridge University Press, Fourth Edition, ISBN: ISBN-13: 978-1439804100
- Wey, M. Y., Chen, J. C., Wu, H. Y., Yu, W. J., Tsai, T. H., 2006. Formations and controls of HCl and HPAs by different additives during waste incineration. Fuel 85, p. 755-763.
- Woodhead, R.J., Law, R.J., Matthiessen, P., 1999. Polycyclic aromatic hydrocarbons insurface sediments around England and Wales, and their possible biological significance. Mar. Pollut. Bull . 38, 773-790.
- Yunker, M.B., Macdonald, R.W., Vingarzan, R., Mitchell, H., Goyette, D., Sylvestre, S., 2002. HPAs in the Fraser river basin: a critical appraisal of HPA rations as indicators of HPA source and composition. Org. Geochem. 33, 489-515.
- Zagatto, P.A.; Bertoletti, E. 2008. Ecotoxicologia Aquática: Princípios e aplicações, 2ª. RiMa, São Carlos
- Zbinden, G. 1976. Progress in toxicology v2 new yorker Springer verlag 117p

ARTIGO CIENTÍFICO

A scientometric analysis of toxicology studies with polycyclic aromatic hydrocarbon using aquatic organisms.

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A scientometric analysis of toxicology studies with polycyclic aromatic hydrocarbon using aquatic organisms.

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ABSTRACT

Polycyclic aromatic hydrocarbons (PAHs) make up a class of organic pollutants widely distributed in aquatic environment. Scientometrics is a study that measures and quantifies scientific progress on a topic, identifying gaps and observing trends. A scientometric analysis was carried out to evaluate the use of aquatic organisms regarding the study of the effect of PAHs and, also the use of fish as biological models in aquatic toxicology, from 1945 to 2022. The search for the articles was carried out on the Web of Science research platform, SCI -expanded. Of the articles with PAH, 1336 were used for scientometric analysis, as they carried out tests on aquatic organisms. The results showed an increase in the number of publications, mainly due to contributions from the USA, Canada, and China. Most of the articles were published in journals with above-average impact in the health area, and the average impact of the journals that published in the area was 3.74, demonstrating the relevance of such studies. About 54% of the studies aimed to evaluate the effect of PAH in aquatic organisms, using biomarkers and 48% using bioassays. Of these, 54% used fish for testing, 20% used mollusc, 11% used crustacean and 15% used another group of aquatic organism. Three species of fish were the main ones used as a model: *Oncorhynchus mykiss* (12%), *Danio rerio* (10%) and *Fundulus heteroclitus* (8%). These findings can point out to researchers and funding agencies the gaps in knowledge about the harmful effects of PAHs and guide the development of new research projects as well as environmental policies.

Keywords: toxicity, Web of Science, fish, PAH, pollutants.

1.Introduction

Aquatic toxicology seeks to study concentrations or amounts of stressors that may occur in the aquatic environment, whether in water, sediments or food in ways that are interacting and affecting aquatic organisms (Rand et al. 1995; Costa et al, 2008). Therefore, it includes the study of transport, distribution, transformation and final destination of chemical products in the

aquatic environment (Costa et al, 2008). The influence of pollutants on aquatic animals varies according to the amount, concentration, duration of exposure and location (Gin et al., 2001, Ingoles et al., 2006).

Contamination of aquatic environments is caused by several classes of pollutants, including polycyclic aromatic hydrocarbons (PAH), which are formed as a by-product of the incomplete combustion of organic matter (World Health Organization, 2010). PAHs are a widespread class of organic pollutants. Its accumulation in natural landscapes is associated with imperfect technologies for extracting, processing, and operating fuel, as well as with fires (Tsibart and Gennadiev, 2013). It is considered one of the most important categories of pollutants due to their high persistence, stability in landscape components, ability to bioaccumulate, toxicity, and genotoxicity in humans and wild animals (IARC, 2018; Abdel-Shafy and Mansour, 2016; ATSDR, 1995).

Based on their toxic characteristics, the United States Environmental Protection Agency (US EPA) and the World Health Organization (WHO) have identified 16 PAH priority compounds that are subjected to control and regulation ((EPA, 1983; EPA, 2020). The main structural unit of PAHs is the benzene ring. Conventionally, the substances of this class of compounds are subdivided, depending on the number of benzene rings, into low molecular weight PAHs, possessing 2 or 3 rings and high molecular weight PAHs, with 4, 5, or 6 rings. The hydrophobicity, persistence, and toxicity of PAHs increase with the growth in the number of benzene rings in their structure (Abdel-Shafy and Mansour, 2016; ATSDR, 1995; Lawal, 2017).

PAH is a hydrophobic chemical generally known to be genotoxic and carcinogenic with the association of particles in the environment (Guo et al., 2007). PAHs can easily pass through the lipid membrane and have the potential to bioaccumulate in aquatic organisms (Nwaichi & Ntorgbo, 2016). Furthermore, the biotransformation process of xenobiotics is also one of the main determinants of PAH toxicity, distribution, and excretion (Busby et al., 1999; Machala et al., 1997). It does not occur only in sediments but is abundantly found in surface water and suspended particulates in water columns (Ikenaka et al., 2013).

One way of studying the current situation of a specific topic in a field of science is using scientometric approaches (for example, showing how different groups of researchers and countries are collaborating or the main subjects researched in a defined time interval) (Bordons and Zulueta, 1999; Bornmann and Leydesdorff, 2014). A scientometric review may be a useful tool in analyzing research tendencies and addressing specific issues of the topic studied, enhancing applied efforts, and investigating existing gaps on a given topic (Barbosa et al, 2012). The Web of Science (WoS) is one of the most reliable databases used in scientific research to search for publications of high quality, containing multidisciplinary information from more than 18,000 scientific journals with high impact (Liu 2019; Liu 2020).

Our objective was to evaluate the tendency of scientific production within the area of aquatic toxicology in relation to PAHs, we also carried out an analysis of the tendency in works using fish as a model. The following questions were asked: i) Which countries have the greatest scientific production in the field of aquatic toxicology in relation to PAHs? ii) Has there been an increase in scientific production over the years in the field of aquatic toxicology in relation to PAHs? iii) Which countries carried out the most international scientific collaboration in the field of aquatic toxicology in relation to PAHs? iv) What are the most used keywords to research in the field of aquatic toxicology in relation to PAHs? v) What are the most used tests to assess contamination by PAH in works in the field of aquatic toxicology? vi) What are the most

used PAHs in works in the field of aquatic toxicology? vii) What are the most used model organisms in the area of aquatic toxicology in relation to PAHs? Regarding the last question, specifically regarding fish, we asked the following questions: i) Has there been an increase in scientific production over the years in the field of aquatic toxicology in relation to PAHs with fish? ii) What were the most representative fish orders in the field of aquatic toxicology in relation to PAHs?

2. Methodology

2.1. Data collection

We conducted the search for publications on WoS, by advanced search criteria in the Science Citation Index Expanded (SCI-expanded), in January 2023. We used topics, and searched for the following terms: “PAH” or “PAHs” or “polycyclic aromatic hydrocarbon”, using as filters: (i) only articles in the English language and (ii) the years between 1945 to 2022. This time interval was chosen because the first articles published in the SCI-expanded were from 1945 (figure 1). Initially, our search resulted in a total of 5,257 articles. Later, we checked the articles manually, by reading the abstract, objective, and methodology sections, in order to exclude those that were not focused on the effect on aquatic organisms. We excluded studies regarding: i) chemical analysis in sediment, water and fisheries (e.g.: fish fillets) that did not include any evaluation of biological effect, and ii) terrestrial organisms (such as rats, humans and hares). Studies with semi-aquatic organisms that present a direct relationship with water (i.e.: water birds, reptiles, amphibians, aquatic plants and aquatic mammals) were not excluded. The search resulted in 1,336 articles to be used in our scientometric analysis (see a list of all articles used in the present study in the Supporting Information table S1). In each selected article, we extracted the following information: (i) publication year, (ii) scientific journal where the study was published, (iii) author(s) nationality, (iv) number of citations, (v) authors keywords, (vi) contaminant studied, (vii) PAH tested, and (viii) organism tested (figure 1).

A second round of exclusion was performed within the 1336 articles found. The articles were checked through, and only those that work with fish were included in the analysis, totaling 756 articles, for which we extracted the following information: (i) publication year and (ii) species of fish used (figure 1).

2.2. Scientometric analysis methods

For the scientometric analysis we downloaded the articles in BibTex and TXT format, and analyzed them on R software (R foundation 2019) with the support of the bibliometrix package (Aria and Cuccurullo, 2017) and the VOSviewer software 1.6.18 (Van Eck and Waltman, 2010). We used simple linear regression to identify trends in the number of articles per year. The R squared value was calculated for each decade in the overall timeline and the r squared value for all years in the global trend.

We determine the collaboration between the countries through the country of author and country of coauthor, where articles with single country publication (SCP) had authors and coauthors from the same country, and articles with multiple country publication (MCP) had researchers that reside in different countries (Li et al., 2009).

3. Results and Discussion

3.1. Characteristics of publication

A total of 1336 articles on PAH used in aquatic toxicology were published between the years 1945 and 2022. The first entry in our search was in 1980, an acute exposure bioassay using the toadfish (*Sanopus reticulatus*) as a target organism,

to evaluate the induction of cytochrome P4501A by the PAHs benzo[a]pyrene and beta-naphthoflavone (James and Bend, 1980). After this first study, there was a ten-year pause until the next publication on the topic, and three articles were recorded in 1990. After, there was growth for the next ten years (figure 2B).

For a better understanding of the growing trend in the number of articles published in the area of aquatic toxicology with PAH, we divided it into four periods: 1) the 80's, in which in 1980, the first and only article of that period was published, which was followed by a pause in scientific production in the area; 2) the 90s, a period in which scientific production on the subject is resumed and it is possible to observe a similarity with global production (figure 2A). As many articles were being published worldwide, the global production in the 90s was intense, leading to a linear growth during all years represented by a R-squared of 0.88. Likewise, the research in the area of aquatic toxicology with PAH also grew a lot in the decade of 90, presenting a R-squared of 0.91 ($p < 1.168 \times 10^{-5}$). This substantial increase in the 1990s can be explained by the improvement of research on PAHs as a result of greater worldwide concern about pollution, as environmental protection institutions began to have stricter laws regarding the use of PAHs (Vienna Convention, 1987). This increase can also be explained by the movement that studies make to replace mammals with invertebrates or fish to assess the effects of contaminants (Smith et al., 1999); 3) from 2000 to 2019, there were moments in which the publications were more constant, leading to a general stability in the average number of publications per year, with annual oscillation in the number of publication around an average of 49 articles, with R-squared of 0.70 ($p < 0.14$). These oscillations can be partially explained by catastrophic events and oil spills triggering several environmental impacts to be studied and evaluated (Figueroa et al., 2005). As mentioned, events like the Deep Water Horizon (DWH) caused long-term damage, that maintained constant studies in the affected areas; and 4) from 2020 to 2022, the R-squared value was 0.73 ($p < 0.24$). This may be related to the 2020 COVID-19 pandemic, reflecting a drop in the publication of articles in 2022, as a possible consequence of the decrease in face-to-face activities in laboratories and the lockdowns in different parts of the world and at different times. A decrease in the number of jobs in the same period also occurred in global production, but in a much less intense way. In fact, whereas production with HPA dropped 74% in 2022, global production decreased only 14%. A very similar pattern to the production of PAHs in aquatic toxicology was the publication pattern with fish as a study model (figure 2C). Again, the 1990s saw the preeminent growth, followed by two decades of a general stability in publications. Likewise, there was a decrease in 2022, reaching values as big as 85%.

3.2. Characteristics of most engaged countries

Analyzes show that 48 countries published about PAH in the area of aquatic toxicology from 1980 to 2022 on the WoS platform. The USA is responsible for 30% of the articles, followed by Canada (8%) and China (7%) (table 1). It has been a tendency for American, Canadian and Chinese researchers to publish more than researchers from other countries (Vanzetto, 2019; Castro et al, 2021).

The Environmental Protection Agency (EPA) has several laws that govern the use of PAHs in the USA, such as the MPRSA (Ocean Dumping Act), which address PAH and its derivatives (chemicals, sewage, and products derived from petroleum) in natural environments (US EPA, 2020). Canada registered in 1999 the environmental protection law, by the Canadian Environmental Protection Agency (CEPA), the introduction of bill S-5, Strengthening Environmental Protection for a Healthier Canada, has a "Priority Substance List" (PSL) (CEPA, 2021). Laws such as those of the EPA and CEPA help to explain why the study with PAH are constant in the USA and Canada and why legislation is always being updated and adapted to the reality of the aquatic environment.

China, a heavily industrialized country, suffers from severe pollution in many spheres (air, water and soil). Massively attempts to reduce this pollution with containment plans and legislation that are often ignored by industries led to the

creation of an “ecological civilization” in 2012. This was highly discussed, and resulted in a master plan for ecocivilization “*natural resources must be properly valued*” and “*holistically managed*” being implemented up to 2020. This master plan was discussed within several ministries.

These three examples show the concerns of these countries with environmental health. As a result, they are constantly investing in research, inspecting, and monitoring the health of the environment, which explains the greatest number of published papers in the field.

3.3. Cooperation of countries

With the advancement of communication technologies, the world is getting faster when it comes to spreading information, which was essential for international collaborations in science, as it facilitated the paths and contacts between researchers (Abt, 2007; Castro et al, 2021). However, the results show that 78% of the articles published in the field were from a single country (SCP) and only 22% of these articles were from multiple countries (MCP) (table 1). These results show that research on PAHs still needs more collaboration between countries, with only about 32 countries collaborating in publications (figure 3). It is especially important when we consider the dispersion of contaminants in the aquatic environment, and how this affects not only the location where an ecological accident occurs but the entire aquatic environment involved, at various levels. There are still few countries interacting with each other, sharing information, and increasing data on problems, which are effective ways to expand databases and increase the spectrum of information generated in systems at a global level to expand access to information.

Knowledge of science and technology has been the basis of relations between the USA and China (Wagner et al, 2015). In fact, USA, and China together with Canada, form a very strong group collaborating with each other, and retaining most of the publications on the subject. However, figure 3 also show other seven countries that publish the most in collaboration (proportional to what was published) (Norway, United Kingdom, Netherlands, Sweden, Finland, Germany and Denmark), probably due to their geographical proximity (Katz, 1994; Glazel, 1999). Brazil has a close collaborative relationship with France, Portugal and Italy.

In general, two factors help to explain the higher percentage of collaborations in these countries: incentives for research and the size of the scientific community. Similar to previous studies, our results show that the USA, India, China and Brazil (countries with the highest population in the ranking) are among the countries presenting the lower number of articles published in international collaboration (Castro et al., 2021). Interestingly, countries with smaller populations tend to have fewer researchers and thus carry out more international collaborations to expanding their research (Glanzel et al., 1999). This was seen in Finland, Denmark, Iceland, and Sweden (countries with the lowest population in the ranking), which were among those that carried out the most collaborative researches. As these small countries also have more resources, they usually import researchers from countries with fewer resources as a way of investing in research and forming scientists.

3.4. Journal analysis

Articles on PAH were published in 61 WOS journals, all articles in the area of aquatic toxicology. The top 20 journals in the ranking account for 94% of PAH publications (table 2). The journal “Aquatic toxicology” published the most articles (281), followed by “Environmental Toxicology and Chemistry” (221) and “Marine Environmental Research” (203). The impact factor (IF) and the h-index are commonly associated with prestige and used to evaluate scientific journals. The top 20 papers in publications on PAH with aquatic organisms have an above-average IF (4.0), according to the JCR 2021-2022 have an above-average IF (3.74), demonstrating the relevance of research on PAH with aquatic organisms for the

scientific community (Zuanazzi et al, 2020). It is interesting to draw attention to “Environmental Health Perspectives”, which had the highest impact factor among all recovered journals (9.03), followed by “Ecotoxicology and Environmental Safety” (6.29). These are journals with research characteristics focused on environmental health, which have great prestige in the scientific community. They are listed among the top 20 publications on PAH with aquatic organisms, demonstrating the importance of this research.

3.5. Co-occurrence keywords

Keywords are a very important component of an article, since 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; Li et al. 2019). The keyword provides a good image of the domain of knowledge, observe how these topics are connected and associated with each other, providing insights and new perspectives on the subject (Darko et al. 2019). The main keyword found in the recovered articles was “biomarkers”, followed by “fish” (figure 4). As a whole, five groups of well-defined words were formed. These groups did not have clear boundaries and the words were floating among groups, showing that there is a strong interaction between them. “Fish” and “Cytochrome p450” were the central words that established the most links.

“Biomarkers” were also present as the most used tests in the papers, which justifies its use as a keyword. Conversely, “fish” was the most used organism, being employed in more than half of the study articles. Other words that appear on the map are fish species, such as “*Fundulus heteroclitus*”, “*Danio rerio*” and “*Oncorhynchus mykiss*”, corresponding to the three most studied fish species (see below). In addition, other aquatic appear, such as “*Mytilus edulis*” (mollusc) and “*Daphnia magna*” (crustacean) encompass the second and third groups of aquatic organisms, respectively, that are most frequently employed as model organism in the recovered articles (figure 6A).

The only word related to a catastrophic event that appears in the word network is Deep Water Horizon (DWH), an Oil Spill that began on April 20, 2010, in the Gulf of Mexico at ~1500 m depth (Whitehead et al., 2011). Effects of this event on several groups of organisms, such as vertebrates, benthic microbial eukaryotes, and benthic macrofauna and meiofauna, have been reported (Antonio et al., 2011; Whitehead et al., 2011; Montagna et al., 2013; Bik et al., 2012). The early and long-term influences of this unprecedented deep-water ecosystem change are emerging more slowly. Probably the reason for this event being the only word related to environmental catastrophe in the network is that constant biomonitoring works are taking place in the area.

3.6. PAH analysis

Of the 1336 papers, 687 tested only some types of PAH, For example, if the paper was about the consequences of urban sewage discharges, only the PAHs present in that discharge were tested. Most PAHs belong to a class of persistent organic pollutants considered to be highly toxic compounds (figure 5 A) (Heath et al., 1993). The United States Environmental Protection Agency (US EPA) put 16 PAHs on the list of priority pollutants for monitoring in 1979 (Kieth and Telliard, 1979). One of the main sources of PAH pollution is petroleum leakage, which can extensively pollute aquatic environments (Hylland, 2006). Because of the persistence of PAHs, their toxicity in aquatic organisms would last for a long time, even several generations (Koyama et al., 2004). However, PCBs and metals were very present in the studies, as well as other compounds (OCPs, DDT, TCDD and herbicides) (figure 5 A). This is because many papers are being carried out to evaluate 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 were introduced from industrial or urban effluents, oils, fuels and even in the production and extraction of petroleum or from accumulation in the sediment. Several studies have previously demonstrated that PAHs are the predominant contaminants in marine sediments (Combi et al., 2020) (figure 5B).

Those responsible for the increase in levels of PAHs in environments are activities from petrochemical refining industries and production of different petroleum fractions, in addition to spillage accidents, urban and industrial sewage and electricity production (Yunker et al., 2002; Sisino et al., 2003). Petroleum and derivatives are the most common sources found in aquatic environments, essentially due to the high world demand and growing production (figure 5B)(Santos et al., 2011). In marine environments, aquatic organisms can be exposed to PAHs present in surface waters and sediments due to atmospheric pollution, industrial and domestic sewage, or oil spills (Magi et al., 2002). Assessing the environmental impact of oil spills is a major challenge, as the composition of crude oil is highly variable, involving complex mixtures of chemicals with different environmental behaviors and toxicities (figure 5B).

The toxicity of the compounds is also related to the properties due to the different architectures of each compound, Benzo[a]Pyrene (BaP), the most present PAH in the articles (272), for example, has a mutagenic and teratogenic effect for a variety of organisms (invertebrates, fish, amphibians, birds and mammals) (EPA, 1983). Of the 16 priority PAHs for studies established by the EPA, Phenanthrene, Pyrene, Fluoranthene, Naphthalene and Anthracene were the ones that were most present (Fig. 5C). However, of the 16 EPA priorities, only 15 were tested in the evaluated articles, the results show us that Benzo[o]Oranthene (B[o]O) was not used for tests with aquatic toxicology. Many papers evaluating the effects of phenanthrene have been linked to its potential for sediment accumulation and sensitivity of organisms (716) (figure 5C). A total of 34 papers were found in which the set of 16 EPA's priority PAH were tested. Due to their toxic characteristics they were used in detail to determine the quality of the aquatic environment (IARC, 1985 and Frapiccini et al., 2021).

The following distribution was observed between the types of tests used in the articles: 316 were to assess the effect of a contaminant or mixtures on target organisms; 409 were biomarker tests, to assess the expression of a biomarker determinant or to test the specificity of a marker with a contaminant and 269 were bioaccumulation tests (figure 5D). Among all the articles, only 26 evaluated the adaptation of organisms to contaminants, at the hereditary level and 364 were biomonitoring studies. Some of these biomonitoring studies, as Page et al. (2005), followed the consequences of oil spills for years, whereas other papers, as Heintz (2007), simulated contamination-dependent extinction risk.

3.7. Most tested organism

Of all known vertebrate groups, fish are the most diverse and widely distributed (Nelson, Grande, and Wilson, 2016). They were the most used organisms for research with PAH in aquatic toxicology tests (756 articles), followed by mollusks (285 articles) and crustaceans (149 articles) (figure A). Marine mollusks have been identified as economically important species in global aquaculture (Lee et al., 1996). Their global distribution, sedentary lifestyle, and cheaper acquisition costs make them one of the preferred taxa used as bioindicators (Dellali et al., 2001a ; Sellami et al., 2014). Fish is considered a standard model for toxicity tests with water, effluents and sediments (Babić et al., 2017; Ribeiro et al., 2020). This circumstance is related to their small size, easy maintenance and reproduction in laboratory conditions, low maintenance cost, external embryonic development, high fertility, transparency of embryos and transgenic models available (Braunbeck et al., 2005; Muth-Köhne et al., 2012).

In many papers, fish were used in an associated way to assess which 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 papers have evaluated the sensitivity of these organisms to contaminants, but few have had this profile of analyzing the heritability of survival strategies (Dellali et al., 2021).

3.8. Most tested fish

As already mentioned, the first papers with fish date from 1980, being the first record of a toxicity test to evaluate the effects of BaP in the fish *Sanopus reticulatus*, in which the induction of CYP1A was evaluated (figure 1C). Over the years, fish began to be seen as viable alternatives to mammals, for carrying out toxicological tests, presenting very similar responses and a faster reproductive cycle, with more efficient breeding (Smith et al., 1999).

Among the 756 articles analyzed, a total of 237 different species of fish were tested (Table S2). The preferred environments of each species were identified, and the number of articles for each habitat was measured.

only marine (660 papers) and freshwater (792 papers), in which they can be marine and estuarine (438 papers) and estuarine and freshwater (590 papers), and for those who transited in the three environments (marine, estuarine and water sweet) were identified as euryhaline (870 papers) (Figure 6C). These results show us that there is a lot of work with euryline organisms, perhaps due to their resistance and adaptation to different environments, but a curiosity was the little demand for or serine or freshwater or marine organisms were the two groups with fewer publications, which shows this gap in estuaries in the area of aquatic toxicology. Among the evaluated papers evaluated that used fish as target organisms, the orders Salmoniformes (*Oncorhynchus mykiss* - rainbow trout), Cypriniformes (*Danio rerio* - zebrafish), Cyprinodontiformes (*Fundulus heteroclitus* - mummichog) and Perciformes (*Dicentrarchus labrax* – snook) were the most representatives, followed by species with greater representation within each order (fig 6 B) (table 3).

The most used fish in scientific productions was the rainbow trout, which is considered an ideal model for toxicity tests in the early stages of life (ELS). In about 12% (91 of 756) of all studies with fish, the presence of rainbow trout was verified. Among its properties that may explain this prevalence, we may include: it is commercially available at all life stages throughout the year in Europe and North America, it is easy to maintain in the laboratory, its development is well known, and its ELS are sensitive to numerous pollutants, including PAHs (Le Bihanic et al., 2014b; Valotaire and Borel, 2017).

The zebrafish has been widely used for toxicity tests, gaining more and more space in laboratories (Bowley et al., 2021). Due to highly conserved genetic and molecular processes across animals, many metabolic processes, such as cell signaling and structure, anatomy, physiology, immunology, and development can be similar in different vertebrates and even to humans. In this case, it was previously shown that zebrafish genome has approximately 70% similarity with human genome (Hill et al., 2005; Howe et al., 2013). Due to its advantages as a model system, multiple biomarker responses in zebrafish have been used to assess the ecotoxicological impact of traditional and emerging pollutants in the world (Pereira et al., 2019; Trigueiro et al., 2020, Stara et al., 2020, Stara et al., 2021). In 1992 the Organization for Economic Cooperation and Development (OECD) published the test guideline for acute toxicity test of chemicals (OECD n° 203), recommending the use of zebrafish *Danio rerio* in ecotoxicity testing strategies for aquatic environments (OECD, 2019). *Fundulus heteroclitus* ranked third is an estuarine fish that is widely distributed throughout the coast of the eastern United States. A species of killifish commonly known as the mummichog or Atlantic killifish, it occurs along the Atlantic coast of North America (Rutherford, 1996). Because mummichog readily acclimates to sudden and extreme changes in salinity, this organism has been extensively used to study osmoregulation in vertebrates (Wood and Marshall, 1994, Burnett et al., 2007). in fact, mummichog have played an important role in the study of osmoregulation and continues to be an important model in this field, becoming a valuable tool for studying accommodation to both fresh and salt water, yielding critical

contributions to the understanding of teleost osmoregulation (Evans 2008; Evans, Piermarini, and Choe 2005; Burnett et al., 2007). Studies have shown that killifish are highly tolerant to waterborne PAH exposure. Notably, killifish can survive exposure to very high concentrations of PAH (Di Giulio and Clark, 2015). Several studies used differential display or subtractive hybridization to examine gene expression in response to contaminants. Meyer et al. (2005) employed this approach to identify genes differentially expressed in PAH-tolerant and -susceptible populations. Because killifish successfully inhabit and tolerate a wide variety of environmental conditions, they have great potential for the investigation of genome–environment interactions, specially because its genome has now been fully sequenced (Burnett et al., 2007). Among the 20 most used species, three are on the IUCN Red List in risk categories: *Gadus morhua* (Atlantic Cod) is considered vulnerable; *Anguilla anguilla* (European Eel) (last evaluated in 2018) is considered critically endangered; and *Cyprinus carpio* (Eurasian Carp) was evaluated as endangered (table 3). The other fish are considered of little concern. Nevertheless, the most used fish in studies, *Oncorhynchus mykiss*, has insufficient data, showing that much has been studied about its ability to bioaccumulate contaminants and adaptation to them, but little data was obtaining regarding its population situation, which can be worrying since it is a fish of economic interest to the population (IUCN, 2022).

4. Conclusion

The number of publications with PAH using aquatic organisms has continuously increased since 1980, the year of the first publication. In the last 4 decades, the pattern has remained, with variations occurring from one year to the next, but nothing too out of the ordinary or worrying to generate a void. Nevertheless, in the last years, 2020, 2021, and 2022, there has been a notable decrease in the number of papers. The cause of this event could be the COVID-19 pandemic, which made it impossible for the researchers to go to the field and many review works were carried out during this period. Another possibility is that new contaminants have emerged and the PAHs, which have been in evidence for many years, have been left aside, giving place for these new ones to come into evidence. This is something very worrying, as PAHs are still harmful and may be chronically contaminating the aquatic environment since they are increasingly available through oil spills, fuels, and effluents.

The most engaged countries in the PAH theme are those with stricter laws in this regard, such as the US, Canada, and China. This pattern was not seen in Germany, which presents very few publications even presenting very strict laws. Perhaps, this occurred because of its small size. Concerning contaminants, most articles only evaluated PAH in isolation, giving preference to one of the 16 EPA priorities. Mixtures with other contaminants, such as PCBs and metals were observed, but these comprise very few in relation to the total number of studies that were found.

Regarding the organisms used, fish was the most employed, partly because of its great diversity and its great socioeconomic potential. The most used fish was *Oncorhynchus mykiss*, and surprisingly, it is classified by the IUCN as insufficient data, which is a little contradictory, since it was the organism that obtained the highest number of published articles. Meanwhile, *Danio rerio* and *Fundulus heteroclitus* were the other two most published species, which was expected since they are widely used for toxicological tests. Of the fish used in the articles, three were classified as vulnerable by the IUCN, showing the importance of these works to understanding how fish react to these contaminants. Works like this are of great contribution to the scientific community, as they identify gaps in knowledge and make it possible to improve these problems. Based on this paper and these results, we can develop projects trying to address these gaps and do a self-assessment to improve collaborations, invest more in publications and not neglect contaminants that are very harmful to the aquatic environment such as PAHS.

5. Declarations

5.1 Ethics approval.

Not applicable in this section.

5.2 Consent to participate

Not applicable in this section.

5.3 Consent for publication.

Not applicable in this section.

5.4 Availability of data and materials

The authors declare that (the/all other) data supporting the findings of this study are available within the article (and its supplementary information files).

5.5 Competing interests.

The authors declare that they have no competing interests

5.6 Funding.

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6. References

- Abdel-Shafy HI, Mansour MS (2016) A review on polycyclic aromatic hydrocarbons: Source, environmental impact, effect on human health and remediation. *Egypt J Pet*. <https://doi.org/10.1016/j.ejpe.2015.03.011>
- Abt AH (2007) The future of single-authored papers. *Scientometrics*. <https://doi.org/10.1007/s11192-007-1822-9>
- Antonio FJ, Mendes RS, Thomaz SM (2011) Identifying and modeling patterns of tetrapod vertebrate mortality rates in the Gulf of Mexico oil spill. *Aquat Toxicol* 105:177-179
- ATSDR. (1995). Toxicological profile for polycyclic aromatic hydrocarbons/Agency for Toxic Substances and Disease Registry (ATSDR). U.S. Department of Health and Human Services. <https://doi.org/10.3109/15569529909037564>
- Barbosa FG, Schneck F, Melo AS (2012) Use of Ecological Niche Models to Predict the Distribution of Invasive Species: A Scientometric Analysis. *Braz. Arch. Biol. Technol*. <https://doi.org/10.1590/S1519-69842012000500007>

Babić S, Barišić J, Višić H, Sauerborn Klobučar R, Topić Popović N, Strunjak-Perović I, Čož-Rakovac R, Klobučar G (2017) Embryotoxic and genotoxic effects of sewage effluents in zebrafish embryo using multiple endpoint testing. *Water Res.* <https://doi.org/10.1016/j.watres.2017.02.049>

Bik HM, Halanych KM, Sharma J, Thomas WK (2012) Dramatic shifts in benthic microbial eukaryote communities following the Deepwater Horizon Oil Spill. *PLoS ONE*, 10.1371/journal.pone.0038550

Bowley G, Kugler E, Wilkinson R, Lawrie A, van Eeden F, Chico TJA, Evans PC, Noël ES, Serbanovic-Canic J (2021) Zebrafish as a tractable model of human cardiovascular disease. *Br. J. Pharmacol.* 10.1111/bph.15473

Braunbeck T, Boettcher M, Hollert H, Kosmehl T, Lammer E, Leist E, Rudolf M, Seitz N (2005) Towards an alternative for the acute fish LC50 test in chemical assessment: the fish embryo toxicity test goes multi-species - an update. *ALTEX* 22:87-102.

Burnett KG, Bain LJ, Baldwin WS, Callard GV, Cohen S, Di Giulio RT et al (2007) *Fundulus* as the premier teleost model in environmental biology: Opportunities for new insights using genomics. *Comp. Biochem. Physiol Part D: Genomics and Proteomics* <https://doi.org/10.1016/j.cbd.2007.09.001>

Busby WF, Ackermann JM, Crespi CL (1999) Effect of methanol, ethanol, dimethyl sulfoxide, and acetonitrile on in vitro activities of cDNA-expressed human cytochromes P-450. *Drug Metab Dispos* 27:246-249.

CEPA (2021) Lei S-5, Canadian Environmental Protection Act 1999 and related bills and documents. <https://www.canada.ca/en/environment-climate-change/services/canadian-environmental-protection-act-registry/related-documents.html> . Access in December 2022

Core Team R (2019) R: a language and environment for statistical computing. R Foundation for Statistical Computing, Viena Recuperado de <https://www.R-project.org/>

Costa, C.R., Olivi, P., Botta, C.M.R., Espindola, E.L.G. (2008) Toxicity in aquatic environments: discussion and evaluation methods. *Review, Química Nova*, Vol. 31, N7, 1820-1830

Darko A, Chan APC, Huo X, Owusu-Manu DG (2019) A scientometric Analysis and Visualization of Global Green Building Research. *Build Environ* <https://doi.org/10.1016/j.buildenv.2018.12.059>

Dellali M, Gnassia M, Barelli M, Roméo P (2001) The use of acetylcholinesterase activity in *Ruditapes decussatus* and *Mytilus galloprovincialis* in the biomonitoring of Bizerta Lagoon. *Comp Biochem Physiol C Toxicol Pharmacol* 10.1016/s1532-0456(01)00245-9

Dellali M, Khallouli A, Falodah AH, Harrath F, Alwasel S, Beyrem H, Gyedu-Ababio T, Rohal-Lupher M, Boufahja F (2021) Effects of metallic Au/TiO₂ nanoparticles on *Unio ravoisieri*: evaluation using biomarkers of oxidative stress and toxicity . *Environ. Sci. Pollut. Res.* 28:18176–18185

EPA. TCS Management Group, Inc. (1983) Pollution Control Expenditure Estimates

EPA. Eco Update. (1994) Using toxicity tests in ecological risk assessment

Evans DH, Piermarini PM, Choe KP (2005) The multifunctional fish gill: Dominant site of gas exchange, osmoregulation, acid-base regulation, and excretion of nitrogenous waste. *Physiol. Rev.* 85:97–177.

Evans DH (2008) Teleost fish osmoregulation: What have we learned since August Krogh, Homer Smith, and Ancel Keys. *Am J Physiol Regul Integr Comp Physiol* 295:704–713.

Figueras A, Lora-Tamayo E, Tintoré J, Pérez F, Albaigés J, Sánchez F, Murado AG, Rodríguez EE, Hernán R (2005) The lessons of the Prestige catastrophe. Superior Council of Scientific Investigations, Madrid

Fiorino E, Sehonova P, Phalova L, Blahova J, Svobodova C, Faggio C (2018) Effects of glyphosate in early life stages: comparison between *Cyprinus carpio* and *Danio rerio* in the Environment. *Environ Sci Pollut Res Int.* 10.1007/s11356-017-1141-5

- Frapiccini E, Cocci P, Annibaldi A, Panfili M, Santojanni A, Grilli F, Marini M, Palermo FA (2021) Assessment of Seasonal Relationship between Polycyclic Aromatic Hydrocarbon Accumulation and Expression Patterns of Oxidative Stress-Related Genes in Muscle Tissues of Red Mullet (*M. barbatus*) from the Northern Adriatic Sea. *Environ. Toxicol. Pharmacol.* 10.1016/j.etap.2021.103752
- Gin KYH, Huda MDK, Lim WK, Tkalic P (2001) An oil spill-food chain interaction model for coastal waters *Mar. Pollut. Bull.* 40:590-597
- Giulio RT Di, Clark BW (2015) The Elizabeth River Story: A Case Study in Evolutionary Toxicology. *J Toxicol Environ Health B Crit Rev* . 10.1080/15320383.2015.1074841
- Glanzel W, Schubert A, Czerwon HJ (1999) A bibliometric analysis of international scientific cooperation of the European Union (1985–1995) *Scientometrics* 45(2):185–202.
- Heintz RA (2007) Chronic exposure to polynuclear aromatic hydrocarbons in natal habitats leads to decreased equilibrium size, growth, and stability of pink salmon populations *Integr. Environ. Assess. Manag.*, 3: 351-363
- Hill AJ, Teraoka H, Heideman W, Peterson RE (2005) Zebrafish as a model vertebrate for investigating chemical toxicity *Toxicol. Sci.* 86:6-19.
- Howe K, Clark MD, Torroja CF, Torrance J, Berthelot C, Muffato M, Collins JE, Humphray S, McLaren K, Matthews L (2013) The zebrafish reference genome sequence and its relationship to the human genome *Nature*, 496:498-503.
- Ingole B, Sivadas S, Goltekar R, Clemente S, Nanajkar M, Sawant R, Silva CD', Sarkar A, Ansari Z (2006) Ecotoxicological effect of grounded MV River Princess on the intertidal benthic organisms off Goa. *Environ. Int.*, 32:284-291
- IUCN (2022). IUCN Red List of Threatened Species. Version 2022-2 . <https://www.iucnredlist.org>. Accessed on December 23, 2022
- James MO, Bend JR, (1980) Induction of polycyclic aromatic hydrocarbons of cytochrome p-450-dependent mixed function oxidases in marine fish. *Toxicol Appl Pharmacol.* [https://doi.org/10.1016/0041-008X\(80\)90012-5](https://doi.org/10.1016/0041-008X(80)90012-5)
- Lawal AT (2017) Polycyclic aromatic hydrocarbons: A review. *Cogent Environ. Sci*, <https://doi.org/10.1080/23311843.2017.1339841>
- Li K, Rollins J, Yan E (2018) Use of Web of Science in published research and review articles from 1997 to 2017: a selective, dynamic, cross-domain, content-based analysis. *Cienciometria* 115:1–20.
- Li C, Ji X, Luo X (2019) Phytoremediation of Heavy Metal Pollution: A Bibliometric and Scientometric Analysis from 1989 to 2018. *Int J Environ Res Public Health.* 10.3390/ijerph16234755
- Lee KM , Kruse H , Wassermann O (1996) Seasonal Fluctuation of Organochlorines in *Mytilus Edulis* L. from the South West Baltic Sea. *Chemosphere.* [https://doi.org/10.1016/0045-6535\(96\)00103-8](https://doi.org/10.1016/0045-6535(96)00103-8)
- Liu W (2019) The Data Source of This Study is Web of Science Core Collection? Not Enough. *Scientometrics.* 121:1815 - 1824.
- Liu W (2020) A Matter of Time: Publication Dates in Web of Science Core Collection. *Scientometrics.* 126:849 - 857.
- Katz JS (1994) Geographical proximity and scientific collaboration. *Scientometrics.* 31:31–43.
- Machala M, Nezveda K, Petrivalský M, Jarosová A, Piačeka V, Svobodová Z (1997) Monooxygenase activities in carp as biochemical markers of pollution by polycyclic and polyhalogenated aromatic hydrocarbons: choice of substrates and effects of temperature, gender and capture stress. *Aquat Toxicol.* 37:113-123
- Meador JP, Stein JE, Reichert WL, Varanasi U (1995) Bioaccumulation of polycyclic aromatic hydrocarbons by marine organisms. *Rev Environ Contam Toxicol*, 143:79-165

Meyer JN, Volz DC, Freedman JH, Di Giulio RT (2005) Differential display of hepatic mRNA from killifish (*Fundulus heteroclitus*) inhabiting a Superfund estuary. *Aquat Toxicol* 73:327–41.

Mohanty R, Das SK, Patri M (2017) Modulation of Benzo[a]Pyrene Induced Anxiolytic-Like Behavior by Retinoic Acid in Zebrafish: Involvement of Oxidative Stress and Antioxidant Defense System *Neurotox. Res.* , 10.1007/s12640-016-9694-5

Montagna PA, Baguley JG, Cooksey C, Hartwell I, Hyde LJ, Hyland JL, Kalke RD, Kracker LM, Reuscher M, Rhodes ACE (2013) Deep-sea benthic footprint of the deepwater horizon blowout *PLoS ONE*, 10.1371/journal.pone.0070540

Muth-Köhne E, Wichmann A, Delov V, Fenske M (2012) The classification of motor neuron defects in the zebrafish embryo toxicity test (ZFET) as an animal alternative approach to assess developmental neurotoxicity. *Neurotoxicol. Teratol.* 10.1016/j.ntt.2012.04.006

Nelson JS, Grande T C, Wilson MV (2016) *Fishes of the World*. 5. ed. John Wiley & Sons, New Jersey

OCDE (2020) Researchers (indicator). <https://doi-org.ez40.periodicos.capes.gov.br/10.1787/20ddfb0f-en> Accessed on December 9, 2022

OECD (2019) Guidelines for the Testing of Chemicals. Section 2: Effects on Biotic Systems Test No. 203: Fish, Acute Toxicity Testing Organization for Economic Cooperation and Development, Paris, France

Page DS, Boehm PD, Brown JS, Neff JM, Burns WA, Bence AE (2005) Mussels document loss of bioavailable polycyclic aromatic hydrocarbons and the return to baseline conditions for oiled shorelines in Prince William Sound, Alaska. *Mar. Environ.* 10.1016/j.marenvres.2005.01.002

Pereira AC, Gomes T, Ferreira Machado MR, Rocha TL (2019) The zebrafish embryotoxicity test (ZET) for nanotoxicity assessment: from morphological to molecular approach *Environ. Pollut.*, 10.1016/j.envpol.2019.06.100

Ribeiro RX, Brito RS, Pereira AC, Monteiro KBS, Gonçalves BB, Rocha TL (2020) Ecotoxicological assessment of effluents from Brazilian wastewater treatment plants using zebrafish embryotoxicity test: a multi-biomarker approach. *Sci. Total Environ.* <https://doi.org/10.1016/j.scitotenv.2020.139036>

Santos, HFD, Cury JC, Carmo FL, Santos AL, Tiedje J, Elsas JDV, Rosado AS, Peixoto RS (2011) Mangrove Bacterial Diversity and the Impact of Oil Contamination Revealed by Pyrosequencing: Bacterial Proxies for Oil Pollution. *PLoS ONE*. <https://doi.org/10.1371/journal.pone.0016943>

Rand, G. M.; Wells, P. G.; McCarty, L. S. *Em Fundamentals of Aquatic Toxicology: Effects, Environmental Fate, and Risk Assessment*; Rand, G. M., ed.; 2nd ed., Taylor & Francis: Washington, 1995, cap. 1.

Sellami B, Khazri A, Louati H, Boufahja F, Dellali M, Sheehan D, Aissa, P, Driss MR, Mahmoudi E, Beyrem H (2014) Effects of permethrin on biomarkers in Mediterranean clams (*Ruditapes decussatus*). *Bull Environ Contam Toxicol.* 10.1007/s00128-014-1225-6.

Sisinno CLS, Netto ADP, Rego ECP, Lima GS (2003) Polycyclic aromatic hydrocarbons in industrial solid waste: a preliminary assessment of the potential risk of environmental and human contamination in waste disposal areas. *Public Health Notebook*. 10.1590/s0102-311x2003000200035

Smith DA, Schurig GG, Smith SA, Holladay SD (1999) Tilapia (*Oreochromis niloticus*) and rodents exhibit similar patterns of inhibited antibody production following exposure to immunotoxic chemicals. *Vet Hum Toxicol.* 41(6):368-73

Stara A, Pagano M, Capillo G, Fabrello J, Sandova M, Albano M, Zuskova E, Velisek J, Matozzo V, Faggio C (2020) Acute effects of neonicotinoid insecticides on *Mytilus galloprovincialis*: A case study with the active compound thiacloprid and the commercial formulation calypso 480 SC. *Ecotoxicol Environ Saf.* <https://doi.org/10.1016/j.ecoenv.2020.110980>

Trigueiro NSS, Canedo A, Braga DLDS, Luchiari AC, Rocha TL (2020) Zebrafish as an emerging model system in the Global South: two decades of research in Brazil. *Zebrafish*. 10.1089/zeb.2020.1930

Tsibart A S, Gennadiev A N (2013) Polycyclic aromatic hydrocarbons in soils: Sources, behavior, and indication significance (a review). *Eurasian Soil Sci.* 46(7): 728–741.

US EPA (US Environmental Protection Agency) (2020) Integrated Risk Information System (IRIS). Washington, DC: Office of Research and Development.

US EPA (Environmental Protection Agency) (2006) Approaches for the Application of Physiologically Based Pharmacokinetic (PBPK) Models and supporting Data in Risk Assessment (Final Report) Washington, D.C. EPA/600/R-05/043F

Van Eck NJ, Waltman L (2010) Software research: VOSviewer, a computer program for bibliometric mapping. *scientometrics* 84:523–538.

Vanzetto GV, Thom A (2019) Bibliometric study of nanoscale zero valence iron toxicology used in soil remediation. *Environ Pollut.* 10.1016/j.envpol.2019.05.092

Vienna Convention on the Law of Treaties Montreal. (1987)

Wagner CS, Bornmann L, Leydesdorff L (2015) Recent Developments in China–U.S. Cooperation in Science. *Minerva* 53:199–214.

Whitehead A, Dubansky B, Bodinier C, Garcia TI, Miles S, Pilley C, Raghunathan V, Roach JL, Walker N, Walter RB, Rice CD, Galvez F (2011) Genomic and physiological footprint of the deepwater horizon Oil Spill on resident marsh fishes. *Proc. Natl. Acad. Sci.* <https://doi.org/10.1073/pnas.1109545108>

Witze A (2016) Research gets increasingly international. *Nature*. <https://doi.org/10.1038/nature.2016.19198>

Wood C, Marshall W (1994) Ion balance, acid–base regulation, and chloride cell function in the common killifish, *Fundulus heteroclitus*: a euryhaline estuarine teleost. *Estuaries*. <https://doi.org/10.2307/1352333>

Yunker MB, Macdonald RW, Vingarzan R, Mitchell H, Goyette D, Sylvestre S (2002) PAHs in the Fraser river basin: a critical appraisal of PAH ratios as indicators of PAH source and composition. *Org. Geochem.* 33:489–515.

Yu D, Xu Z, Pedrycz W, Wang W (2017) Information sciences 1968–2016: A retrospective analysis with text mining and bibliometric Inf. Sci. <https://doi.org/10.1016/j.ins.2017.08.031>

Zuanazzi NR, Ghisi NC, Oliveira EC (2020) Analysis of global trends and gaps for studies about 2,4-D herbicide toxicity: A scientometric review. *Chemosphere* .10.1016/j.chemosphere.2019.125016

FIGURE CAPTIONS

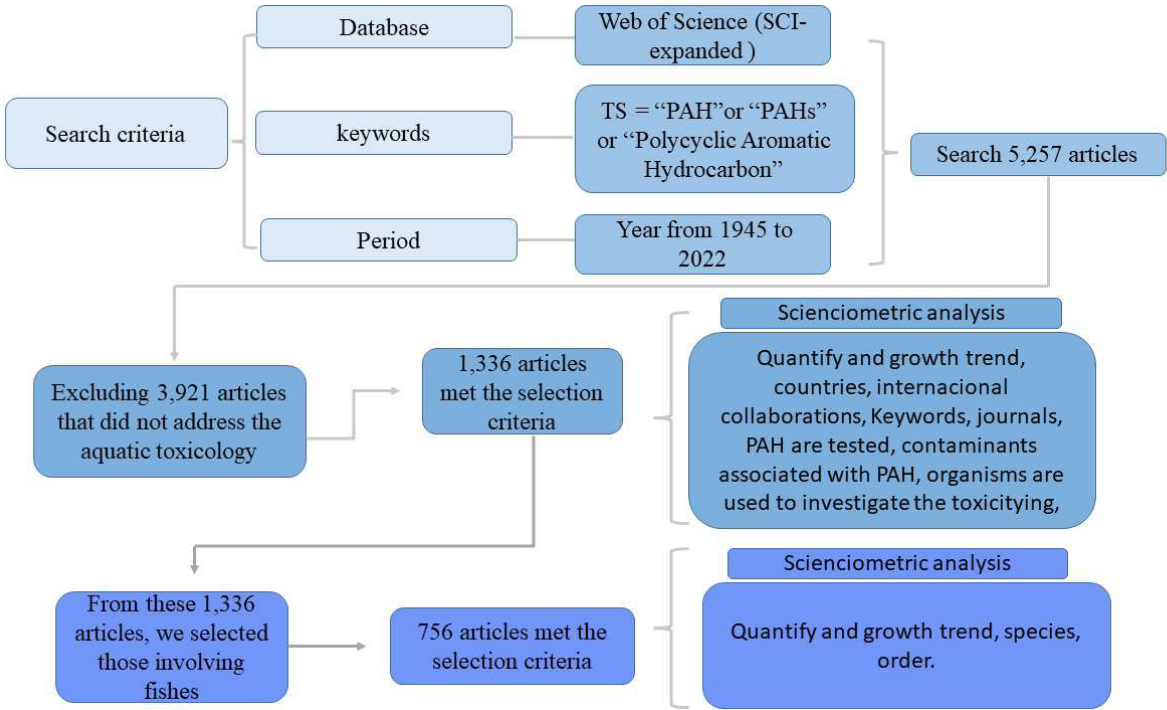


Figure 1: Flowchart of the research methodological stages.

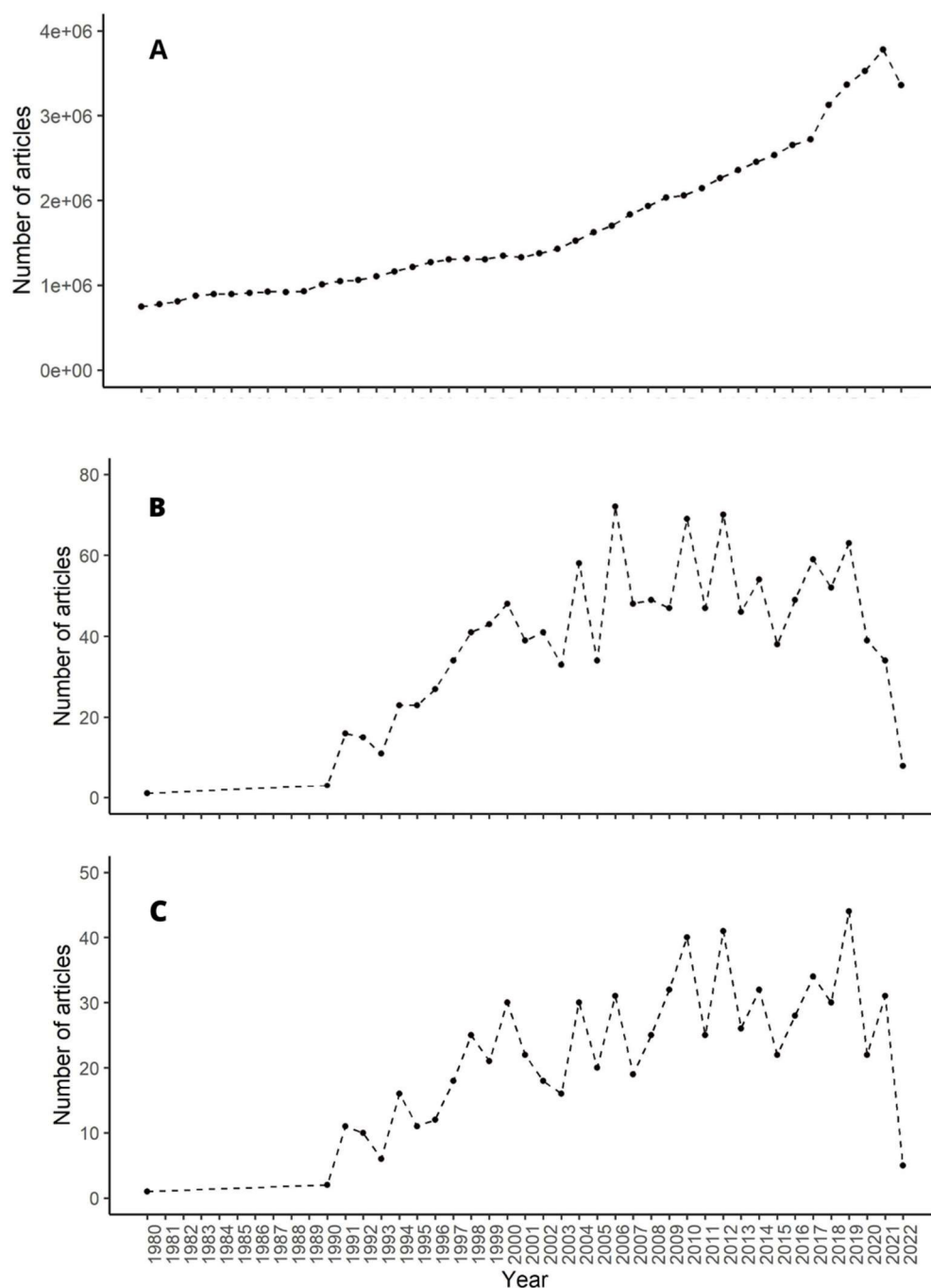


Figure 2: Articles indexed in the Science Citation Index Expanded (SCI-EXPANDED) – Clarivate Analytics Web of Science (WoS). A: Total articles published in the database. B: Number of articles published on the use of aquatic organisms to assess the effects of PAHs in the period 1980 to 2022. C: Number of articles published using fish to assess the effects of PAH.

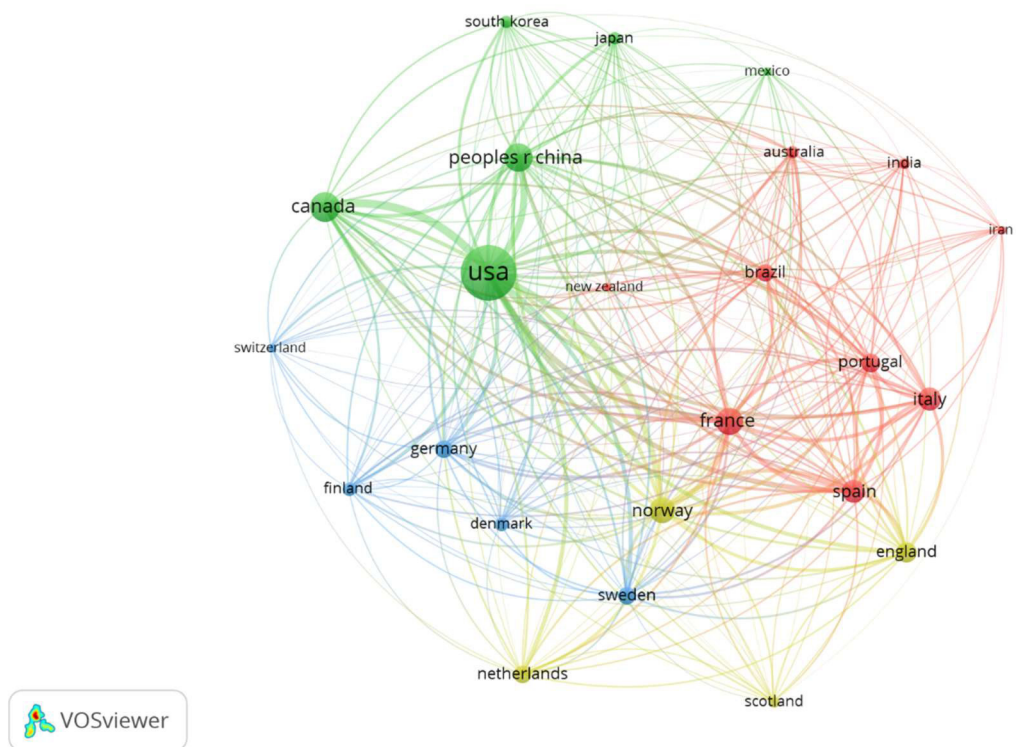


Figure 3: Collaboration network between countries on articles on polycyclic aromatic hydrocarbons (PAHs) using aquatic organisms. On the map, the circles and their respective sizes indicate the countries and their production, while the lines and their thickness indicate the collaboration rate between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

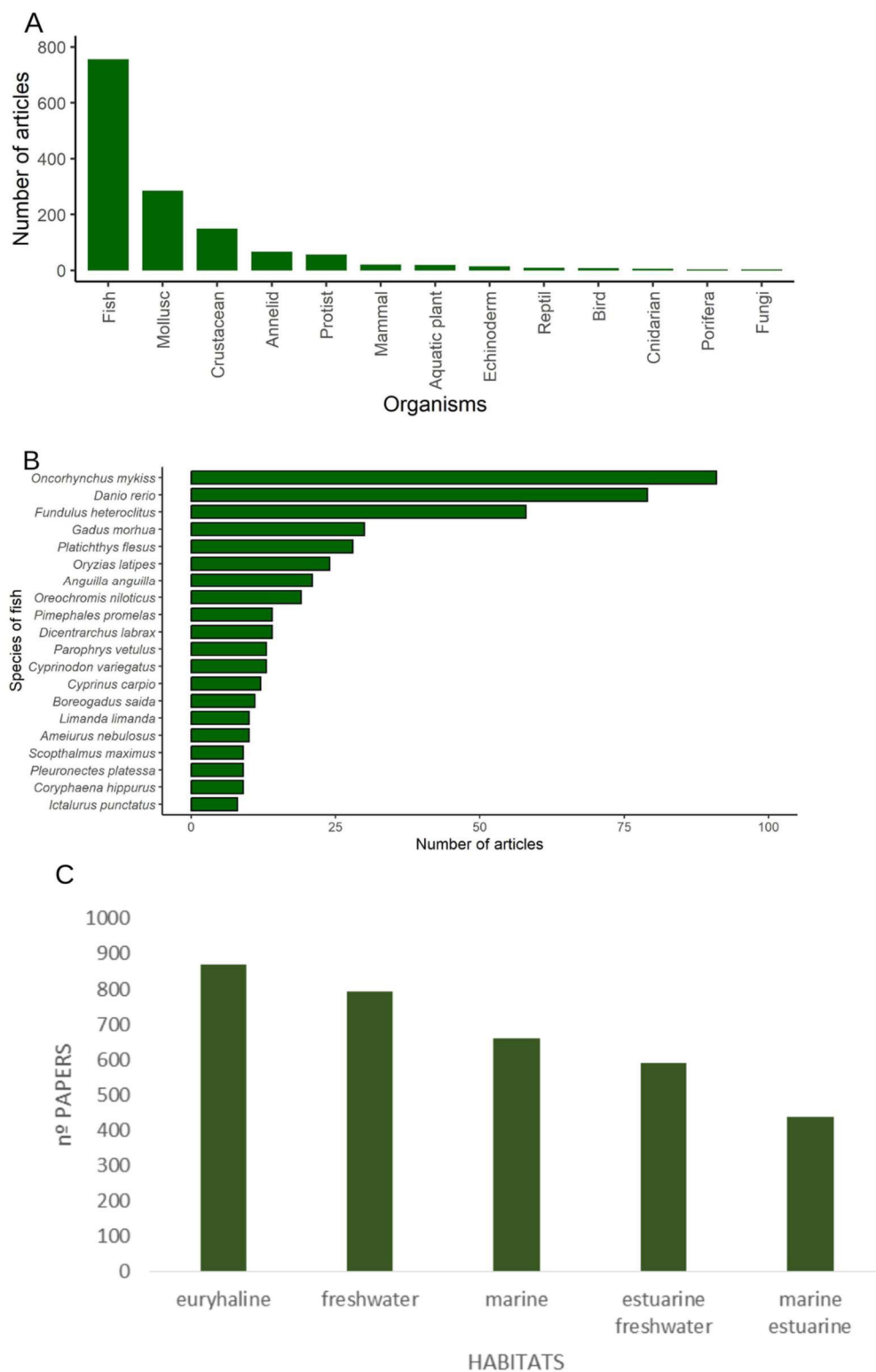


Figure 6: Number of articles published on the use of aquatic organisms to study the effect of polycyclic aromatic hydrocarbon (PAH) indexed in the Science Citation Index Expanded (SCI-EXPANDED) – Clarivate Analytics Web of Science (WoS) : A: Species frequently used in articles. B: Fish species evaluated in the articles analyzed. C: Number of fish species by preferred environments

TABLES

Table 1: Ranking of the twenty most productive countries that published articles on the use of aquatic organisms to study the effects of PAH between the years 1945 to 2022 in the Science Citation Index Expanded (SCI-EXPANDED) - Clarivate Analytics Web of Science (WoS).

	Country	Articles	SCP	% ¹	MCP	% ²
1	USA	404	347	85.89	57	14.10
2	Canada	111	90	81.08	21	18.91
3	China	103	85	82.52	18	17.47
4	France	81	65	80.24	16	19.75
5	Spain	70	54	77.14	16	22.85
6	Norway	68	38	55.88	30	44.11
7	Italy	61	46	75.40	15	24.59
8	United kingdom	54	38	70.37	16	29.62
9	Portugal	45	37	82.22	8	17.77
10	Brazil	35	28	80.00	7	20.00
11	Netherlands	30	20	66.66	10	33.33
12	Sweden	30	20	66.66	10	33.33
13	Korea	22	15	68.18	7	31.81
14	Finland	21	13	61.90	8	38.09
15	Germany	21	13	61.90	8	38.09
16	Denmark	19	12	63.15	7	36.84
17	Australia	18	12	66.66	6	33.33
18	Japan	13	7	53.84	6	46.15
19	India	12	10	83.33	2	16.66
20	Iran	11	9	81.81	2	18.18
	Total ³	1229	959	78.03	270	21.96

USA United States of America. SCP number of single country publications. MCP number of multiple country publications. 1 Percentages of SCP in respect to total publication in the country, 2 percentages of MCP in respect to total publication in the country, 3 total number of published articles.

Table 2: Ranking of the twenty journals that published most articles on the use of aquatic organisms to study the effects of PAH between 1945 and 2022 in the Science Citation Index Expanded (SCI-EXPANDED) - Clarivate Analytics Web of Science (WoS). The number of publications and impact factor (If. JCR) are shown.

	Sources	Articles	IF
1	Aquatic toxicology	281	5.20
2	Enviromental toxicology and chemistry	221	3.74
3	Marine enviromental research	203	3.13
4	Ecotoxicology and enviromental safety	150	6.29
5	Archives of enviromental contamination and toxicology	79	2.80
6	Ecotoxicoly	59	2.82
7	Comparative biochemistry and physiology c-toxicology//& pharmacology	58	3.22
8	Bulletin of enviromental contamination and toxicology	33	2.65
9	Enviromental toxicology	23	4.11
10	Biomarkers	21	2.85
11	Enviromenatl toxicology and pharmacology	20	4.86
12	Journal of toxicology and enviromental health-part a-current issues	20	4.52
13	Enviromental health perspectives	18	9.03
14	Toxicology sciences	15	3.43
15	Toxicology and applied pharmacology	11	4.21
16	Comparative biochemistry and physiology c-pharmacology toxicology // & endocrinology	9	3.22
17	Toxicology in vitro	9	3.5
18	Environmental and molecular mutagenesis	8	3.21
19	Toxicology	8	4.80
20	Mutation research-fundamental and molelucar mechanisms or mutagenesis	7	2.43

Table 3. Ranking of most used fish in articles and their status on the IUCN Red List

	Order	Species of fish	Popular name	Number of article	IUCN
1	Salmoniforme	<i>Oncorhynchus mykiss</i>	Rainbow trout	91	DD
2	Cypriniforme	<i>Danio rerio</i>	Zebra fish	79	LC
3	Cyprinodontiforme	<i>Fundulus heteroclitus</i>	Mummichog	58	LC
4	Gadiforme	<i>Gadus morhua</i>	Atlantic cod	30	VU
5	Pleuronectiforme	<i>Platichthys flesus</i>	European flounder	28	LC
6	Cyprinodontiforme	<i>Oryzias latipes</i>	Medaka	24	LC
7	Anguilliforme	<i>Anguilla anguilla</i>	European eel	21	CR
8	Cichliforme	<i>Oreochromis niloticus</i>	Nile tilapia	19	LC
9	Perciforme	<i>Dicentrarchus labrax</i>	Snook	14	LC
10	Cypriniforme	<i>Pimephales promelas</i>	Fathead minnow	14	LC
11	Cyprinodontiforme	<i>Cyprinodon variegatus</i>	Sheepshead minnow	13	LC
12	Pleuronectiforme	<i>Parophrys vetulus</i>	English sole	13	LC
13	Cypriniforme	<i>Cyprinus carpio</i>	Common carp	12	PT
14	Gadiforme	<i>Boreogadus saida</i>	Arctic cod	11	LC
15	Siluriforme	<i>Ameiurus nebulosus</i>	Brown bullhead	10	LC
16	Siluriforme	<i>Limanda limanda</i>	Common dab	10	LC
17	Perciforme	<i>Coryphaena hippurus</i>	Common dolphinfish	9	LC
18	Pleuronectiforme	<i>Pleuronectes platessa</i>	European plaice	9	LC
19	Pleuronectiforme	<i>Scophthalmus maximus</i>	Turbot	9	LC
20	Siluriforme	<i>Ictalurus punctatus</i>	Channel catfish	8	LC

DD- Data Deficient; VU- Vulnerable; CR-Critically Endangered; PT- Endangered e LC- Least Co

Considerações Finais

Os resultados encontrados em nossa pesquisa responderam às perguntas propostas e também nos permitiram ter um panorama do estado atual da pesquisa com HPAs no uso de organismos aquáticos. O número de publicações acerca deste tema aumentou consideravelmente no decorrer dos anos 90, passando por um período de estabilidade e seguida por uma queda brusca. É de grande preocupação se a queda nas publicações com HPA na área da toxicologia aquática mantiverem o padrão de 2022 e continuarem a diminuir, pois a contaminação continua, os veículos que disponibilizam HPA no meio aquático ainda são uma realidade e petróleo, combustíveis e efluentes (principais vias de contaminação por HPA do meio aquático) ainda estão muito presente no ecossistema aquático.

Os países que mais demonstram engajamento com os HPAs foram EUA, Canadá e China, e estes mantiveram relações de colaborações entre si, possuindo o maior número de colaborações, porém de forma não proporcional ao número de publicações. Os países que mais realizaram publicações colaborativas foram Japão, Noruega, Finlândia e Coreia, que relativo ao número de artigos publicados foram os que mais mantiveram colaborações.

Este é um tema que tem ganhado reconhecimento ao longo dos anos. Isso pode ser visto na qualidade dos jornais que mais publicaram artigos sobre HPAs, a maioria dos jornais possuem fator de impacto acima da média. O *Aquatic Toxicology* foi o jornal que mais publicou sobre HPAs e seu fator de impacto é de 5.20. O *Environmental Health Perspectives* e *Ecotoxicology and Environmental Safety* foram os jornais com maior fator de impacto, 9.03 e 6.29 respectivamente.

Sobre as palavras-chave de autores, encontramos a palavra-chave “biomarkers” com maior centralidade no mapa e com o maior número de ocorrências, demonstrando novamente um predomínio de trabalhos que utilizam biomarcadores em suas análises. Ainda sobre as palavras-chave de autores, encontramos grande destaque para a palavra-chave “fish”, demonstrando que peixes foram os organismos modelos principais e “Cytochrome p450”, que está muito relacionado e esteve presente na maioria dos trabalhos. Tais resultados corroboram com a contagem total de organismos, testes, marcadores e até mesmo as espécies de peixes usadas.

Nossos resultados demonstram um grande predomínio de países como EUA, Canadá e China nas publicações deste tema, porém também destaca a presença do Brasil dentro do top 10 países que mais publicam, demonstrando que este tema tem potencial de seguir se desenvolvendo aqui, uma vez que o Brasil possui a maior rede hidrográfica do mundo e grandes fontes de poluição, como portos muito influentes internacionalmente. Apesar disso, o Brasil apresentou uma baixa colaboração internacional, se comparado com os outros países. O que se nota de diferente é que as políticas

ambientais dos países que mais publicaram são mais rígidas que no Brasil. Portanto, o investimento em trabalhos com produtos tóxicos é uma preocupação na qual muitos países investem muito mais. Sugerimos também a busca por espécies endêmicas do Brasil que sejam pouco estudadas e que possam vir a ter alta capacidade de adaptação e ação como bioindicadores de HPAs.

Tendo conhecimento destas informações, as mesmas podem auxiliar novos pesquisadores a se integrar rapidamente, bem como apontar às agências de financiamento as lacunas presentes neste assunto e suas principais tendências, o que pode vir a orientar o desenvolvimento de novos projetos de pesquisa, bem como melhorar políticas ambientais.