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Abiotic pollutant concentrations in fish: A comparative review of wild-caught and aquaculture sources

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ABSTRACT

Background: The levels of contaminants and nutrients in fish from aquaculture and wild-caught sources are a timely and relevant issue for food safety. Contaminants such as heavy metals and metaloids, PCBs, DDT, and PAHs pose toxic risks due to bioaccumulation, while nutrient levels like Se, Zn, and Fe vary depending on diet and habitat.

Objective: This review synthesizes studies evaluating the levels of abiotic contaminants and nutrients in aquaculture and wild-caught fish, in order to compare them.

Scope and approach: In this scoping review, all the published literature on the comparison of heavy metals and metaloids, other contaminants and nutrients in aquaculture fish and wild fish was analysed. The search was conducted in different databases, and 31 studies were selected that met the eligibility criteria.

Key findings and conclusions: The review provides an overview of the comparison between aquaculture and wild fish in terms of heavy metals and metaloids, other contaminants, and nutrients, due to the difference in their environmental conditions, feed and origin. Higher concentrations of some heavy metals and metaloids were observed in wild fish than in aquaculture as well as in other contaminants. The mean Hg and As concentration in wild fish was 0.06 and 3.26 μg/g, respectively; while in aquaculture fish was 0.038 and 1.23 μg/g. The DDT mean concentration in wild fish of 196.48 ng/g, while in aquaculture fish was 44.64 ng/g. The difference in these concentrations does not only depend on the production system, other factors such as age, physiological state or the degree of environmental pollution can have a considerable effect.

1. Introduction

Currently, there is a growing demand for food, including fish, due to the constant increase in population, and among other effects it has led to the overexploitation of all fish stocks in the world (Naylor et al., 2000; Subasinghe et al., 2009). Global demand for aquaculture products is predicted to increase and may even equal or exceed demand for other types of animal protein (Belton et al., 2020; Costello et al., 2020). Since 1990, the consumption rate of fish increased by about 3.1 % annually until 2018, which was higher than that of other protein foods in the same time interval (FAO, 2021). Aquaculture, according to the FAO (Food and Agriculture Organization of the United Nations), is the cultivation under controlled conditions of species that develop in the aquatic environment (fish, mollusks, crustaceans and plants) and are useful to humans (FAO, 2024). In this way, the quality of the environment and the lowest content of pollutants are controlled. Therefore, in this scenario, aquaculture is an alternative to meet these needs, but there is still work to be done to optimize production (Garibaldi et al., 2015; Moffitt & Cajas-Cano, 2014; Naylor et al., 2009). Global aquaculture production in 2022 reached an all-time high of 130.9 million tons, 8.1 million tons more than in 2020 (122.8 million tons). It comprised 94.4 million tons of aquatic animals, such as carps, barbels and other

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cyprinids, and 36.5 million tons of algae. In Europe, in 2022, some 232,100 tons were produced in marine aquaculture (FAO, 2024).

Aquaculture is not only necessary to secure the global food supply, but also it is aligned with some of the Sustainable Development Goals (SDGs). In any case, it is necessary to ensure the integration of sustainability in aquaculture (Macleod et al., 2020; Meng & Feagin, 2019; Troell et al., 2014). Derived from this arises the concept of 'blue revolution' which is promoted by organizations such as the FAO (FAO, 2024). It refers to the transformation towards the sustainable use and management of aquatic resources to improve food production, food security, and economic development, with a focus on aquaculture, fisheries, and conservation of marine and freshwater ecosystems (Subasinghe, 2009). 'Blue revolution' gives special attention to sustainable aquaculture production, addressing environmental concerns, such as habitat destruction, water pollution, eutrophication, biotic depletion, ecological impacts (Ahmed & Thompson, 2019). Another factor to consider is the presence of environmental contaminants that can accumulate in fish, which can pose health risks. In the European Union, the European Commission Regulation 2023/915 and its successive modifications, establishes the maximum limits for different contaminants in food products including fish (R (UE) 2023/915).

Among the most important abiotic pollutants, due to their presence in fish are heavy metals and metaloids, persistent organic compounds (POPs) such as PCBs, dichlorodiphenyltrichloroethane (DDT) and polycyclic aromatic hydrocarbons (PAHs) (FAO/WHO, 2023). These are the pollutants that are the subject of this review, among others.

In this regard, heavy metals and metaloids are among the abiotic pollutants that deserve special attention due to their persistence and bioaccumulation through the food chain, as well as toxic potential (Botwe, 2021). Although heavy metals and metaloids are naturally present in the environment, their overuse and release by various industries have significantly impacted the ecosystem (Ray & Vashishth, 2024a). When heavy metals and metaloids enter aquatic systems, they are solubilized in the water, facilitating their bioavailability to aquatic organisms. These metals are bioaccumulated in the tissues and organs of various species through direct absorption processes from the environment or through the trophic chain. Finally, when consumed by humans, these contaminants are transferred to the organism, which acts as the final receptor in the biomagnification of heavy metals and metaloids (Ray & Vashishth, 2024b). One of the main mechanisms of toxicity is the absorption and accumulation of heavy metals. Once absorbed, heavy metals and metaloids can accumulate in various organs and tissues, causing a few adverse health effects (Jaishankar et al., 2014). Major health problems associated with heavy metal toxicity include neurological damage, cardiovascular disease, renal dysfunction, hepatotoxicity, respiratory problems, and reproductive disorders (Boskabady et al., 2018; Järup, 2003; Witkowska et al., 2021). Especially, the most analysed heavy metal was Hg because this metal is found in the muscle of most fish species and much of it is in the form of methylmercury (MeHg) (70–100%) (Azad et al., 2019; Llull et al., 2017), which accumulates in fish (Hajeb et al., 2010; Kumar Reddy et al., 2023). Another important heavy metal is Cd. It is one of the most toxic heavy metals and poses a significant risk to human health (Järup et al., 1998). Grup 1, IARC (2016) classified Cd as carcinogenic to humans (Group 1).

Other contaminants to consider are PAHs, which are widespread environmental pollutants in the aquatic environment (Amaeze et al., 2015). Contamination of food by PAHs has attracted considerable attention worldwide due to their detrimental impact on human health and well-being due to its bioaccumulation in the aquatic trophic chain (García-Sánchez et al., 2018). Various international organizations classify these compounds as highly hazardous due to their mutagenic, carcinogenic, genotoxic, immunotoxic, teratogenic and endocrine-disrupting potential (Lee et al., 2016).

PCBs, in turn, represent different types of unavoidable harmful by-products from industrial and thermal treatment processes that are commonly found in water and soil (Hu et al., 2014). Classified as the first group of POPs, due to their lipophilicity, they tend to enrich animal epidermal tissue, eventually entering the human body through the food chain (Fechner et al., 2023). Moreover, DDT is a pesticide that was widely used in the past to control insects and prevent both crop pests and the spread of human diseases such as malaria and typhoid fever (Van Den Berg et al., 2017) It is of particular importance because in contact with various media such as oxygen, ultraviolet light and organisms they undergo small transformations that give rise to new substances, which can be even more harmful. These substances are considered to have a relatively acute toxicity and accumulate in adipose tissue with long-term adverse effects on living beings, including humans (Adrián et al., 2016). This contaminant and her metabolites are linked to various health and environmental problems due to their accumulation in the environment and their biomagnification properties in living organisms (Mansouri et al., 2017).

Given the above, the main objective was to compile, compare, and evaluate the information available in scientific literature through a review of the concentration of the abiotic pollutants such as heavy metals and metaloids, other contaminants (PAHs, PCBs, and DDT), as they are the main contaminants present in fish (Ortiz et al., 2008). At the same time, nutrients will also be observed in fish caught in the natural environment and those produced in aquaculture due to their origin and environmental conditions. It is important to note that although a comparison is made, the intent of this review is not to pit production systems against each other; both are necessary for the production of the fish.

2. Methods

2.1. Study design

The review in this study is a scoping review, conducted following the PRISMA extension for scoping reviews (PRISMA-ScR) (Tricco et al., 2018). The PRISMA method is a reporting guideline designed to address poor reporting of systematic reviews, PRISMA 2020 is intended for use in systematic reviews that include synthesis (such as pairwise meta-analysis or other statistical synthesis methods) or do not include synthesis (for example, because only one eligible study is identified) (PRISMA, 2023). This review approach is ideal for addressing broad research questions, such as those posed in this study. The guidelines of the PRISMA 2020 statement were complied with, ensuring transparency in methodology, completeness of the content of the Scoping review, and scientific rigor. In turn, the PRISMA checklist for this type of review was followed (Page et al., 2021).

After compiling the information from the different articles, it was observed that in each article the results were presented in different units. To be able to work on this, we switched to the same units, heavy metals and metaloids (μg/g), other contaminants (ng/g) and nutrients (μg/g). At the same time, the way of expression was maintained, wet weight (ww), dry weight (dw) or lipid weight (lw), because the articles did not explain the percentage of water loss and therefore, it was not possible to express all the results in wet weight. To carry out the graphical representation in box-plots, only the results expressed in wet weight were used.

2.2. Search strategy

A comprehensive literature search (Scopus and ScienceDirect) was conducted in April 2024, using as keywords several concepts (aquaculture, wild, fish, contaminant) within the title, abstract and keywords. The search strategy was the same for two databases consulted, with the exact search terms aquaculture AND wild AND fish AND contaminant. Scopus and Science direct are two multidisciplinary databases. ScienceDirect was used first as it is a solid option due to its coverage and quality. However, to ensure completeness, the search was combined with Scopus as it is a relevant database for the specific topic of the review.

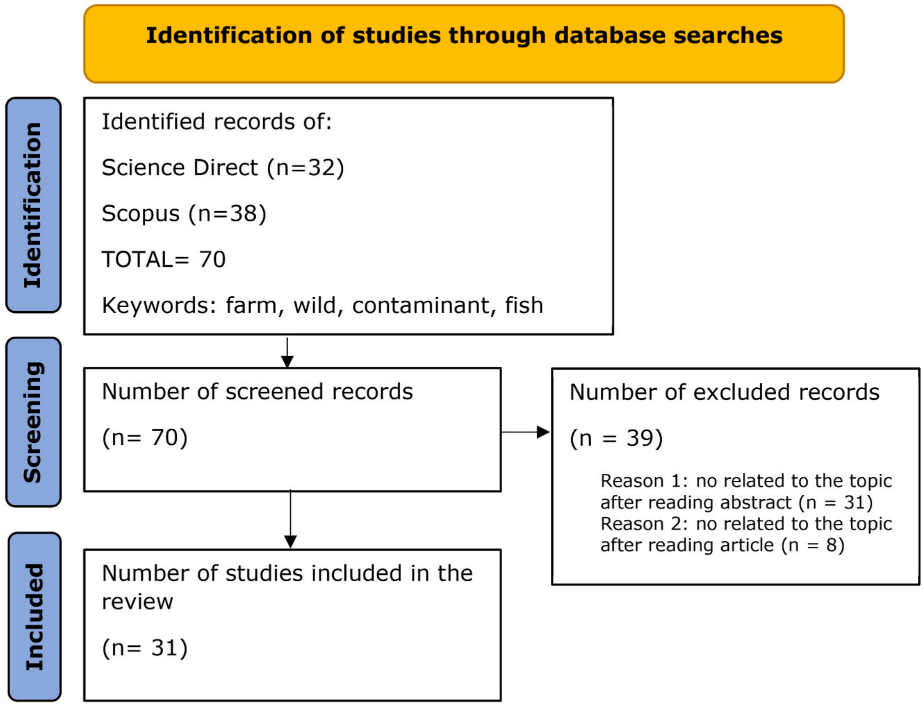

Fig. 1. PRISMA process of selecting eligible studies.

2.3. *Inclusion and exclusion criteria*

Articles had to meet the following inclusion criteria.

- **Publication language**: English
- **Study design**: experimental and/or observational
- **Study exposure variable**: comparison of different abiotic contaminants in both wild and aquaculture fish were selected.
- **Study outcome variable**: analysis of abiotic contaminants (heavy metals, DDT, PCBs, PAHs, Endosulphane, Chlordane and POPs and nutrients) in both wild fish and aquaculture fish.
- **Studies with full text available**: no articles were excluded because they were not available in full text.

2.4. *PRISMA flow diagram*

The title and abstracts of the documents found were analysed and classified depending on their significant interest using Microsoft Excel for the data curation. After eliminating papers not focused on the field of study were excluded in three stages. First, a screening by title was carried out, followed by a screening by abstract, at which point 31 articles were excluded. Finally, a full-text screening was performed, where 8 more articles were excluded. The followed PRISMA flow diagram, and the obtained results of the systematic review are shown in Fig. 1.

3. Results

3.1. *Overview*

Considering the keywords and the inclusion and exclusion criteria, a bibliographic search was carried out in two databases: Scopus and Science Direct and 70 results were obtained. These studies span publication years from 2002 to 2024. Among them, those analysing heavy metals legislated at the European level, DDT, PCBs, PAHs, Endosulphane, Chlordane and POPs were selected. Of the 70 article results, 39 were excluded as they were not related to the topic of this work (such as the study of biotic contaminants or the study of heavy metals in other foods). Finally, a total of 31 articles analysing the abiotic contaminants mentioned above in both wild fish and aquaculture fish were selected. The 31 selected articles were grouped into 6 groups according to the compounds analysed in the different fish: heavy metals in aquaculture (n = 14), heavy metals in wild fish (n = 11), other contaminants in aquaculture fish (n = 11), other contaminants in wild fish (n = 13), nutrients in aquaculture fish (n = 11), nutrients in wild fish (n = 9).

3.2. *Heavy metals and metaloids in aquaculture fish*

The analysis of heavy metals and metaloids in aquaculture fish covers oily fish species such as *Thunnus thynnus* or *Salmon Salar,* and white fish such as *Sparus aurata*, from different regions of the world, with particular interest in the concentration of mercury (Hg), cadmium (Cd), lead (Pb) and arsenic (As). These elements, due to their toxic potential, are of utmost importance in the study of food safety in aquaculture. Of the articles reviewed, 45% focus on heavy metals in aquaculture fish. Among these, 64% analysed Hg, while 71% examined Cd, Pb and As. All selected studies were expressed in μg/g wet weight (μg/g ww), while only two were expressed in μg/g dry weight (μg/g dw) (El Bahgy et al., 2021; Ferreira et al., 2010). Most of the studied species were white-fleshed fish, such as *Cyprinus carpio*, *Oreochromis niloticus*, and *Dicentrarchus labrax*, though some blue-fleshed species like *Salmo salar* were also included. The 29% of the selected studies analyze fish from the Atlantic Ocean, while the remaining fish come from various regions, such as Poland, Norway, China, Vietnam, China and Vietnam (Table 1).

The maximum value of Hg concentration was found in rainbow trout (*Oncorhynchus mykiss*) from Poland, with 0.0548 μg/g ww (Szlinder-Richert et al., 2011), while the minimum value was found in salmon (*Salmo salar*) in Canary Islands, with 0.003 μg/g ww (Rodríguez-Hernández et al., 2017). The average Hg concentration of the selected articles in which the results were presented in wet weight was 0.038 μg/g. Cd was found at its highest concentration in sea bream (*Sparus aurata*) caught in Egypt in July, with a value of 0.475 μg/g dw (El Bahgy et al., 2021), while in species such as pangasius in Cambodia, Cd levels were undetectable (Thanh et al., 2024). The average Cd

Table 1
Heavy metals and metaloids concentration (μg/g) *in different aquaculture fish species.

L	S (TF)	Hg	Cd	Pb	As	S/A	R
Poland	*Cyprinus carpio (Wh)*	0.0373 ± 0.096	0.002 ± 0.002	0.011 ± 0.001	0.008 ± 0.012	NA	Szlinder-Richert et al. (2011)
	Oncorhynchus mykiss (Bl)	0.0548 ± 0.318	0.003 ± 0.005	0.014 ± 0.005	0.005 ± 0.003		
Vietnam China	*Pangasius hypophthalmus (Wh)*	0.0054 ± 0.012	0.003 ± 0.002	0.024 ± 0.012	0.000 ± 0.000		
	Oreochromis niloticus (Wh)	0.0049 ± 0.011	0.003 ± 0.002	0.024 ± 0.012	0.000 ± 0.000		
Canary Islands	*Sparus aurata (Wh)* *Solea vulgaris (Wh)* *Tiburón iridiscente (Wh)* *Pandasius hypophthalmus (Wh)* *Dicentrarchus labrax (Wh)*	0.040±NA	0.010±NA	0.030±NA	0.580±NA	NA	Rodríguez-Hernández et al. (2017)
	Salmo salar (Bl) *Salmo trutta (Bl)*	0.003±NA	0.010±NA	0.020±NA	0.120±NA		
	Penaeus spp *(Se)* *Mytilus galloprovincialis (Se)*	0.020±NA	0.060±NA	0.090±NA	0.720±NA		
Atlantic Ocean (Norway)	*Salmo salar (Bl)*	0.015 ± 0.005	0.002 ± 0.001	0.010 ± 0.001	0.600 ± 0.200	NA	Lundebye et al. (2017)
Atlantic Ocean (Norway)	*Salmo salar (Bl)*	0.0349 ± 3.100	0.010 ± 0.000	0.010 ± 0.000	1.680 ± 0.190	4.3 kg/NA	Jensen et al. (2020)
Pacific ocean (EE. UU and Canada)	*Salmo salar* Chinook *(Bl)*	0.029±NA	NM	NM	NM	NA	Easton et al., 2002
	Salmo salar Salmón rojo *(Bl)*	0.050±NA	NM	NM	NM		
South Australia	*Thunnus maccoyii (Bl)*	0.310±NA	<0.010±NA	<0.010±NA	0.710±NA	102 cm/ NA	Padula et al. (2008)
Atlantic ocean	Thunnus thynnus Macho (Bl)	NM	0.028 ± 0.025	0.030 ± 0.020	NM	130 cm/ Ad	Girolametti et al. (2021)
	Thunnus thynnus Hembra (Bl)	NM	0.014 ± 0.006	0.020 ± 0.020	NM	131 cm/ Ad	
Atlantic ocean	*Salmo salar (Bl)* Alternative Food	0.066 ± 1.000	NM	NM	1.800 ± 1.000	300 g-4 kg/Fr	Berntssen et al. (2010)
	Salmo salar (Bl) Traditional food	0.029 ± 18.000	NM	NM	0.950 ± 13.00	300 g-4 kg/Fr	
Egypt	*Sparus aurata (Wh)* Abril	NM	0.400 ± 0.000	0.400 ± 0.000	NM	NA	El Bahgy et al. (2021)
	Sparus aurata (Wh) Julio	NM	0.475 ± 0.137	1.070 ± 0.121	NM		
China	*Hypophthalmichthys nobilis (Bl)*	NM	NM	0.023 ± 0.002	0.034 ± 0.004	NA	Jiang et al. (2014)
	Oreochromis niloticu (Wh)	NM	0.004 ± 0.000	0.0021 ± 0.006	0.287 ± 0.037		
Brasil	*Oreochromis niloticu (Wh)* Semi intensive 1	0.017 ± 0.000	NM	NM	NM	NA/Ad	Botaro et al., 2012
	Oreochromis niloticu (Wh) Semi intensive 1	0.014 ± 0.000	NM	NM	NM	NA/Yo	
	Oreochromis niloticu (Wh) Semi intensive 2	0.024 ± 0.000	NM	NM	NM	NA/Ad	
	Oreochromis niloticu (Wh) Semi intensive 2	0.015 ± 0.000	NM	NM	NM	NA/Yo	
	Oreochromis niloticu (Wh) Intensive 1	0.024 ± 0.000	NM	NM	NM	NA/Ad	
	Oreochromis niloticu (Wh) Intensive 1	0.014 ± 0.000	NM	NM	NM	NA/Yo	
	Oreochromis niloticu (Wh) Intensive 2	0.031 ± 0.000	NM	NM	NM	NA/Ad	
	Oreochromis niloticu (Wh) Intensive 2	0.025 ± 0.000	NM	NM	NM	NA/Yo	
Mediterranean sea	*Sparus aurata (Wh)*	NM	NM	NM	0.69 ± 0.1	NA	Korkmaz et al. (2022)
	Dicentrarchus labrax (Wh)	NM	NM	NM	0.52 ± 0.37		
Formosa River	*Dicentrarchus labrax (Wh) 1*	NM	0.0088 ± 3.6	0.0517 ± 38	6.527 ± 0.44	14 cm/NA	Ferreira et al. (2010)
	Dicentrarchus labrax (Wh) 2	NM	0.0011 ± 0.200	0.0077 ± 6	5.377 ± 0.07	22.4 cm/ NA	
	Dicentrarchus labrax (Wh) 3	NM	0.0037 ± 0.200	0.0697 ± 8	4.157 ± 0.11	27.3 cm/ NA	
	Dicentrarchus labrax (Wh) 4	NM	0.0024 ± 1.000	0.0407 ± 5	1.027 ± 0.06	35.4 cm/ NA	
Camboya	*Pangasianodon hipoftalmo (Wh)*	0.011 ± 0.005	0.000 ± 0.000	0.006 ± 0.002	0.012 ± 0.007	43,3 cm/ NA	Thanh et al. (2024)

Values are presented as mean ± SE. L. Location; S: Specie; (TF): Type of fish; P: Production; C: Contaminant; W: Wild; A: Aquaculture; Bl: Blue; Wh: White; Se: Seafood A: Age; S: Size; R: Reference; Ad: Adult; Fr.Fry; Yo: Youth NA: No available; NM: No measure. * All results were expressed in μg/g wet weight (μg/g ww), except for studies (El Bahgy et al., 2021) and (Ferreira et al., 2010) which were expressed in μg/g dry weight (μg/g dw).

Table 2
Heavy metals and metaloids concentration (μg/g) [a] in different wild fish species.

L	S (TF)	Hg	Cd	Pb	As	S/A	R
Baltic Sea	*Gadus morhua callarias (Wh)*	0.047 ± 0.018	0.001 ± 0.000	0.010 ± 0.000	0.000 ± 0.000	NA	Szlinder-Richert et al. (2011)
	Clupea harengus membras (Bl)	0.066 ± 0.269	0.0021 ± 0.007	0.020 ± 0.026	0.017 ± 0.006		
	Salmo salar (Bl)	0.529 ± 0.134	0.002 ± 0.000	0.016 ± 0.005	0.051 ± 0.021		
China	*Theragra chalcogramma (Bl)*	0.0096 ± 0.069	0.008 ± 0.007	0.011 ± 0.001	0.000 ± 0.000		
	Limanda aspera (Wh)	0.0479 ± 0.144	0.004 ± 0.002	0.016 ± 0.008	0.000 ± 0.000		
Canary Islands	*Polyprion americanus (Wh)*	0.040±NA	0.050±NA	0.030±NA	0.150±NA	NA	Rodríguez-Hernández et al. (2017)
	Stephanoiepis hispidus (Wh)						
	Solea vulgaris (Wh)						
	Dicentrarchus labrax (Wh)						
	Merluccius merluccius (Wh)						
	Dentex dentex (Wh)						
	Sparisoma cretense (Wh)						
	Thunnus thynnus (Bl)	0.040±NA	0.010±NA	0.030±NA	0.190±NA		
	Sardina pilchardus (Bl)						
	Salmo salar (Bl)						
	Parapenaeus spp *(Se)*	0.040±NA	0.020±NA	0.040±NA	0.320±NA		
	Penaeus spp *(Se)*						
	Mytilus galloprovincialis (Se)						
Atlantic Ocean (Norway)	*Salmo salar (Bl)*	0.037 ± 0.015	0.002 ± 0.002	0.010 ± 0.014	2.000 ± 1.100	NA	Lundebye et al. (2017)
Atlantic Ocean (Norway)	*Salmo salar (Bl)*	0.056 ± 12.900	0.010 ± 0.000	0.010 ± 0.000	0.002 ± 0.870	4,3 kg/NA	Jensen et al. (2020)
Pacific ocean (EE. UU and Canada	*Salmo salar* Chinook *(Bl)*	0.029±NA	NM	NM	NM	NA	Easton et al., 2002
	Salmo salar Salmón rojo *(Bl)*	0.050±NA	NM	NM	NM		
South Australia	*Thunnus maccoyii (Bl)*	0.340±NA	<0.010±NA	<0.010±NA	0.570±NA	105 cm/NA	Padula et al. (2008)
Atlantic Ocean	*Thunnus thynnus* Macho *(Bl)*	NM	0.016 ± 0.007	0.130 ± 0.090	NM	130 cm/Ad	Girolametti et al. (2021)
	Thunnus thynnus Hembra *(Bl)*	NM	0.014 ± 0.008	0.090 ± 0.060	NM	131 cm/Ad	
Canada	*Saxidomus giganteus (Bl)*	0.012 ± 0.012	0.087 ± 0.032	NM	4.500 ± 0.480	NA	Laird and Chan (2013)
	Oncorhynchus tshawytscha (Bl)	0.088 ± 0.077	0.007 ± 0.006	NM	0.850 ± 0.190		
	Oncorhynchus nerka (Bl)	0.077 ± 0.028	0.011 ± 0.006	NM	0.640 ± 0.230		
Mediterranean Sea	*Sarda sarda (Bl)*	NM	NM	NM	1.62 ± 0.26	NA	Korkmaz et al. (2022)
	Mullus surmuletus (Bl)	NM	NM	NM	11.21 ± 4.15		
	Sardina pilchardus (Bl)	NM	NM	NM	4.56 ± 1.58		
	Boops boops(Bl)	NM	NM	NM	5.06 ± 0.77		
	Scomber japonicus (Bl)	NM	NM	NM	3.08 ± 1.94		
	Saurida lessepsianus(Bl)	NM	NM	NM	4.73 ± 2.67		
	Trachurus trachurus (Bl)	NM	NM	NM	3.22 ± 0.41		
	Pagrus pagrus (Wh)	NM	NM	NM	25.9 ± 11.1		
	Mullus barbatus (Bl)	NM	NM	NM	NM		
	Sphyraena sphyraena (Bl)	NM	NM	NM	19.4 ± 5		
	Scomber japonicus (Bl)	NM	NM	NM	1.58 ± 0.7		
	Saurida undosquamis (Wh)	NM	NM	NM	NM		
	Mugil cephalus (Wh)	NM	NM	NM	1.26 ± 0.33		
	Solea solea (Wh)	NM	NM	NM	1.48 ± 0.07		
	Nemipterus randalli (Wh)	NM	NM	NM			
	Lithognathus mormyrus (Bl)	NM	NM	NM	8.76 ± 4.41		
Formosa River	*Dicentrarchus labrax (Wh)*	NM	0.0045 ± 1.300	0.0347 ± 12	0.00517 ± 0.63	42,2 cm/NA	Ferreira et al. (2010)
Camboya	*Channa micropeltes (Wh)*	0.039 ± 0.016	0.000 ± 0.001	0.015 ± 0.014	0.012 ± 0.005	39 cm/NA	Thanh et al. (2024)
	Channa micropeltes (Wh)	0.042 ± 0.007	0.000 ± 0.000	0.017 ± 0.006	0.010 ± 0.002	42,4 cm/NA	
	Pangasianodon hipoftalmo (Wh)	0.021 ± 0.008	0.005 ± 0.010	0.008 ± 0.005	0.016 ± 0.003	27,3 cm/NA	

Values are presented as mean ± SE. L. Location; S: Specie; (TF): Type of fish; P: Production; C: Contaminant; W: Wild; A: Aquaculture; Bl: Blue; Wh: White; Se: Seafood A: Age; S: Size; R: Reference; Ad: Adult; Fr.Fry; Yo: Youth NA: No available; NM: No measure.

[a] All results were expressed in μg/g wet weight (μg/g ww), except for the study (Ferreira et al., 2010) which were expressed in μg/g dry weight (μg/g dw).

Table 3
Concentration of other contaminants (ng/g) [a] in different aquaculture fish species.

L	S (TF)	C (ng/g)					S/A	R
		PCBs	PAHs	DDT	Endosulphane	Chlordane		
Poland	*Cyprinus carpio(Wh)*	1.39 ± 1.27	NM	7.97 ± 11.5	NM	NM	NA	Szlinder-Richert et al. (2011)
	Oncorhynchus mykiss (Bl)	5.31 ± 4.71	NM	4.60 ± 3.04	NM	NM		
Vietnam China	*Pangasius hypophthalmus (Wh)*	0.03 ± 0.02	NM	0.29 ± 0.12	NM	NM		
	Oreochromis niloticus (Wh)	0.04 ± 0.70	NM	0.49 ± 0.16	NM	NM		
Canary Islands	*Sparus aurata (Wh)* *Solea vulgaris (Wh)* *Tiburón iridiscente (Wh)* *Pandasius hypophthalmus (Wh)* *Dicentrarchus labrax (Wh)*	1.640±NA	1.180 ±NA	NM	NM	NM	NA	Rodríguez-Hernández et al. (2017)
	Salmo salar (Bl) Salmo trutta (Bl)	2.590±NA	4.110 ±NA	NM	NM	NM		
	Penaeus spp (Se) Mytilus galloprovincialis (Se)	0.150±NA	1.090 ±NA	NM	NM	NM		
Atlantic Ocean (Norway)	*Salmo salar (Bl)*	NM	NM	5.000 ± 1.000	0.600 ± 0.800	0.700 ± 0.300	NA	Lundebye et al. (2017)
Pacific ocean (EE. UU and Canada)	*Salmo salar Chinook (Bl)*	0.051±NA	8.300 ±NA	0.030±NA	NM	NM	NA	Easton et al., 2002
	Salmo salar Salmón rojo (Bl)	5.302±NA	13.000 ±NA	5.641±NA	NM	NM	NA	
South Australia	*Thunnus maccoyii (Bl)*	6.6±NA	NM	NM	NM	NM	102 cm/ NA	Padula et al. (2008)
Tanzania	*Chanos chanos (Bl) Jozani*	0.160±NA	NM	4.13±NA	NM	NM	44 cm/NA	Mwakalapa et al. (2018)
	Chanos chanos (Bl) Shakani	0.490±NA	NM	2.07±NA	NM	NM	43,5 cm/ NA	
	Chanos chanos (Bl) Pemba	0.003±NA	NM	0.18±NA	NM	NM	29,4 cm/ NA	
	Chanos chanos (Bl) Mtwara	0.020±NA	NM	0.08±NA	NM	NM	22 cm/NA	
Maine, Canada, Alaska, Norway	*Salmo salar Maine (Bl)*	12.200±NA	NM	30.000 ±NA	NM	NM	NA	Shaw et al., 2006
	Salmo salar Canada (Bl)	7.200±NA	NM	28.000 ±NA	NM	NM	NA	
	Salmo salar Norway (Bl)	29.500±NA	NM	45.000 ±NA	NM	NM	75–80 cm/3 ye	
Atlantic Ocean	*Salmo salar (Bl) Alternative Food*	NM	NM	21.000 ± 3.000	NM	9.500 ± 5.000	300 g-4 kg/Fr	Berntssen et al. (2010)
	Salmo salar (Bl) Traditional food	NM	NM	4.900 ± 5.000	NM	4.600 ± 1.000	300 g-4 kg/Fr	
China (Pearl River Delta)	*Oreochromis niloticus (Wh)*	NM	33.47 ±NA	10.44±NA	NM	NM	NA/Fr	Kong et al. (2005)
	Aristichthys nobilis	NM	52.38 ±NA	7.93±NA	NM	NM	50 cm/NA	
	Ctenopharyngodon idellus	NM	59.49 ±NA	11.59±NA	NM	NM	52 cm/NA	
	Carassius auratus	NM	25.84 ±NA	13.03±NA	NM	NM	27 cm/NA	
	Siniperca chuatsi	NM	77.12 ±NA	32.44±NA	NM	NM	NA	
China (Hong Kong)	*Aristichthys nobilis*	NM	2.84 ±NA	26.3±NA	NM	NM	NA	Cheung et al., 2007
	Clarias fuscus	NM	24.8 ±NA	40.7±NA	NM	NM	NA	
	Ctenopharyngodon idellus	NM	3.96 ±NA	9.86±NA	NM	NM	NA	
	Mulgil cephalus	NM	12.3 ±NA	27.1±NA	NM	NM	NA	
	Siniperca kneri	NM	12.8 ±NA	82.2±NA	NM	NM	NA	
	Cirrhina molitorella	NM	8.18 ±NA	13.1±NA	NM	NM	NA	
	Monopterus albus	NM	11.3 ±NA	125±NA	NM	NM	NA	
	Channa asiatiea	NM	14.6 ±NA	13.9±NA	NM	NM	NA	
	Channa maculate	NM	13±NA	28.4±NA	NM	NM	NA	
	Oreochromis mossambicus	NM	5.28 ±NA	8.9±NA	NM	NM	NA	
Formosa River	*Dicentrarchus labrax (Wh) 1*	156.1 ± 14.200	NM	75.4 ± 5.300	NM	NM	14 cm/NA	Ferreira et al. (2010)

(continued on next page)

Table 3 (*continued*)

L	S (TF)	C (ng/g)					S/A	R
		PCBs	PAHs	DDT	Endosulphane	Chlordane		
	Dicentrarchus labrax (Wh) 2	260.2 ± 12.900	NM	88.4 ± 10.800	NM	NM	22.4 cm/ NA	
	Dicentrarchus labrax (Wh) 3	237.7 ± 8.300	NM	102.9 ± 5.600	NM	NM	27.3 cm/ NA	
	Dicentrarchus labrax (Wh) 4	2221.1 ± 300.800	NM	658.5 ± 85.600	NM	NM	35.4 cm/ NA	

Values are presented as mean ± SE. L. Location; S: Specie; (TF): Type of fish; P: Production; C: Contaminant; W: Wild; A: Aquaculture; Bl: Blue; Wh: White; Se: Seafood A: Age; S: Size; R: Reference; Ad: Adult; Fr.Fry; Yo: Youth NA: No available; NM: No measure.

[a] All results were expressed in ng/g wet weight (ng/g ww), except for the study (Ferreira et al., 2010) which were expressed in ng/g lipid weight (ng/g lw).

concentration of the selected articles in which the results were presented in wet weight was 0.011 μg/g. Pb levels show considerable variability. The highest concentration found among aquaculture fish was 1.070 μg/g dw in sea bream in Egypt (July) (El Bahgy et al., 2021), while the lowest value recorded corresponds to nile tilapia (*Oreochromis niloticu (Wh))* in China, with 0.0021 μg/g ww (Jiang et al., 2014). The average Pb concentration of the selected articles in which the results were presented in wet weight was 0.02 μg/g. The maximum As concentration was detected in Formosa River in sea bass (*Dicentrarchus labrax)*, with a level of 6.527 μg/g dw (Ferreira et al., 2010), while no As was detected in *Pangasius hypophthalmus (Wh)* and other species (Szlinder-Richert et al., 2011). The average As concentration of the selected articles in which the results were presented in wet weight was 0.56 μg/g.

3.3. Heavy metals and metaloids in wild fish

Fish caught in natural environments reflect a different contamination profile than aquaculture fish, with heavy metal levels depending largely on the type of species, food chain and geographical location. Of the articles reviewed, 35% focus on heavy metals in wild fish. Of the articles included here, 73% analysed Hg and Pb, while 82% of the articles analysed Cd and As. All the studies were expressed in μg/g ww, while only one was expressed in μg/g dw (Ferreira et al., 2010). A mixture of equal proportions of blue-fleshed (*Thunnus thynnus, Sardina pilchardus*) and white-fleshed (*Gadus morhua, Dicentrarchus labrax*) fish was included. The species were mostly caught in the Atlantic Ocean, although catches were also made in the Baltic Sea, the Pacific Ocean, and the Mediterranean Sea (Table 2). In South Australia, Thuna (*Thunnus maccoyii (Bl)*) showed the highest Hg concentration among wild species, with a value of 0.34 μg/g ww (Padula et al., 2008), compared to chinook salmon from the Pacific Ocean, whose Hg level was significantly lower, reaching 0.029 μg/g ww (Easton et al., 2001). The average Hg concentration of the selected articles in which the results were presented in wet weight was 0.06 μg/g. Cd levels were highest in *Saxidomus giganteus* caught in Canada, with a concentration of 0.087 μg/g ww (Laird & Chan, 2013), while in Baltic Sea species such as cod, Cd levels were 0.001 μg/g ww, the lowest value recorded (Szlinder-Richert et al., 2011). The average Cd concentration of the selected articles in which the results were presented in wet weight was 0.014 μg/g. In Atlantic tuna the highest level of Pb was observed with 0.130 μg/g ww (Girolametti et al., 2021), while in salmon in Norway the levels were lower, with 0.010 μg/g ww (Lundebye et al., 2017). The average Pb concentration of the selected articles in which the results were presented in wet weight was 0.03 μg/g Common snapper (*Pagrus pagrus (Wh)*) in mediterranean sea showed the highest As value with 25.9 μg/g dw (Ferreira et al., 2010), while cod in the Baltic Sea shows no detectable As levels (Szlinder-Richert et al., 2011). The average As concentration of the selected articles was in which the results were presented in wet weight 3.37 μg/g.

3.4. Other contaminants in aquaculture

In addition to heavy metals, other contaminants such as PCBs, DDT, PAHs, Endosulphane and Chlordane have been detected in some aquaculture species. Of the articles selected in this review, 35% address other contaminants in aquaculture fish. Of the articles included here, 82% analysed DDT, 64% PCBs, 36% PAHs, 18% Chlordane while only 9% of the articles analysed Endosulphane. All results of the studies were expressed in ng/g ww, while only one was expressed in ng/g lipid weight (μg/g lw) (Ferreira et al., 2010). They include mainly white-fleshed species (*Oreochromis niloticus, Cyprinus carpio*), along with some blue-fleshed species (*Salmo salar*). Aquaculture species come especially from places such as China, although they also come to a lesser extent from places as diverse as Poland, the Canary Islands and the Atlantic Ocean (Norway) (Table 3). In Formosa River, Sea bass (*Dicentrarchus labrax)* trout showed PCB concentrations of 2221.1 ng/g lw (Ferreira et al., 2010), while in the Canary Islands, levels in *Chanos chanos (Bl) Pemba* were 0.003 ng/g ww, indicating lower levels of exposure to industrial pollutants in the latter (Mwakalapa et al., 2018). The average PCBs concentration of the selected articles was in which the results were presented in wet weight 4.28 ng/g. Sea bass (*Dicentrarchus labrax (Wh)) of Formosa River* recorded a high DDT value of 685.5 ng/g lw (Ferreira et al., 2010), compared to pangasius (*Pangasius hypophthalmus)* in Vietnam, which had only 0.001 ng/g ww DDT (Szlinder-Richert et al., 2011). The average DDT concentration of the selected articles in which the results were presented in wet weight was 19.69 ng/g. The highest concentration of PAHs was found in the species *Siniperca chuatsi* obtained from China (77.12 ng/g ww) (Kong et al., 2005) and the lowest concentration was found in the Canary Islands in different species such as *Sparus aurata (Wh)* (1.18 ng/g ww) (Rodríguez-Hernández et al., 2017). The average PAHs concentration of the selected articles in which the results were presented in wet weight was 19.25 ng/g. The concentration of chlordane varied from 9.5 ng/g ww in Atlantic *salmon salar* (Berntssen et al., 2010) to 0.7 ng/g ww in the same species in Norway (Lundebye et al., 2017). Endosulphane was only observed in *Salmo salar* from the Norwegian Atlantic Ocean (Lundebye et al., 2017) with a concentration of 0.6 ng/g ww.

3.5. Other contaminants in wild fish

In wild species, other contaminants also show remarkable variations, especially in the Baltic Sea and the Pacific. Of the articles selected in this review, 42% deal with other contaminants in wild fish. Of the articles included here, 92% analysed DDT, 69% PCBs, 23% PAHs, 31% Endosulphane while only 15% of the articles analysed Chlordane. The 77% of the studies were expressed in ng/g ww, while 23% were expressed in ng/g lw (Ferreira et al., 2010; Manirakiza et al., 2002). These studies include more blue flesh species (*Thunnus thynnus, Sardina pilchardus*) than white flesh species. Wild species come mainly from the EE. UU., but to a lesser extent also from places as diverse as the Baltic Sea, the Atlantic Ocean, the Pacific Ocean and the Mediterranean Sea (Table 4). In Formosa River, a maximum PCBs concentration of 1058.4 ng/g lw

Table 4
Concentration of other contaminants (ng/g) [a] in different wild fish species.

L	S (TF)	C (ng/g)					S/A	R
		PCBs	PAHs	DDT	Endosulphane	Chlordane		
Baltic Sea	*Gadus morhua callarias (Wh)*	0.40 ± 0.39	NA	0.33 ± 0.28	NM	NM	NA	Szlinder-Richert et al. (2011)
	Clupea harengus membras (Bl)	11.76 ± 3.64	NA	16.80 ± 6.01	NM	NM		
	Salmo salar (Bl)	44.68 ± 15.36	NA	50.62 ± 21.0	NM	NM		
China	*Theragra chalcogramma (Bl)*	0.023 ± 0.019	NA	0.034 ± 0.026	NM	NM		
	Limanda aspera (Wh)	0.15 ± 0.09	NA	0.17 ± 0.11	NM	NM		
Canary Islands	*Polyprion americanus (Wh)* *Stephanoiepis hispidus (Wh)* *Solea vulgaris (Wh)* *Dicentrarchus labrax (Wh)* *Merluccius merluccius (Wh)* *Dentex dentex (Wh)* *Sparisoma cretense (Wh)*	0.190±NA	0.490±NA	NM	NM	NM	NA	Rodríguez-Hernández et al. (2017)
	Thunnus thynnus (Bl) *Sardina pilchardus (Bl)* *Salmo salar (Bl)*	2.710±NA	4.320±NA	NM	NM	NM		
	Parapenaeus spp (Se) *Penaeus spp (Se) Mytilus galloprovincialis (Se)*	0.120±NA	0.720±NA	NM	NM	NM		
Atlantic Ocean (Norway)	*Salmo salar (Bl)*	NM	NM	8.000 ± 2.000	0.400 ± 0.300	2.800 ± 1.600	NA	Lundebye et al. (2017)
Pacific ocean (EE. UU and Canada)	*Salmo salar Chinook (Bl)*	0.051±NA	8.300±NA	0.030±NA	NM	NM	NA	Easton et al., 2002
	Salmo salar Salmón rojo (Bl)	5.302±NA	13.000 ±NA	5.641±NA	NM	NM	NA	
South Australia	*Thunnus maccoyii (Bl)*	0.47±NA	NM	NM	NM	NM	105 cm/ NA	Padula et al. (2008)
Tanzania	*Chanos chanos (Bl) Mtwara*	0.004±NA	NM	9.22±NA	NM	NM	22 cm/ NA	Mwakalapa et al. (2018)
	Mugil cephalus (Bl) Pemba	0.030±NA	NM	3.72±NA	NM	NM	25,8 cm/ NA	
Maine, Canada, Alaska, Norway	*Oncorhynchus tshawytscha Alaska (Bl)*	3.900±NA	NM	22.000±NA	NM	NM	NA	Shaw et al., 2006
EE. UU	*Tilapia mossambique (Wh)*	NM	NM	15±NA	NM	NM	NA	Sapozhnikava et al., 2004
Ghana	*Tilapia zili (Wh)*	NM	NM	3.645 ± 1.81	0.713 ± 0.940	NM	NA	Darko et al., 2008
Africa	*Boulengerochromis microlepis (Wh)*	102.700 ± 28.700	NM	909.100 ± 42.500	2.860 ± 2.100	NM	NA	Manirakiza et al. (2002)
	Chrysichthys sianenna (Wh)	35.700 ± 18.100	NM	349.600 ± 19.100	36.100 ± 11.500	NM		
	Oreochromis niloticu (Wh)	166.700 ± 37.400	NM	524.700 ± 34.100	0.500 ± 1.500	NM		
	Lates stappersii (Wh)	126.700 ± 30.000	NM	182.500 ± 27.500	NA ± NA	NM		
	Limnothrissa miodon (Wh)	48.200 ± 14.200	NM	68.300 ± 11.100	NA ± NA	NM		
	Stolothrissa tanganyikae (Bl)	63.500 ± 14.800	NM	124.000 ± 18.800	NA ± NA	NM		
	Lates angustifrons (Bl)	44.900 ± 12.000	NM	95.400 ± 16.500	NA ± NA	NM		
Tanzania	*Oreochromis niloticus (Wh)*	NM	NM	30	200	NM	20–36 cm/NA	Henry & Kishimba, 2006
EE. UU (San Francisco)	*Cymatogaster aggregata RED (Wh)*	445.200 ± 79.500	242.4 ± 64.700	67.700 ± 18.1	NM	30.6 ± 9.900	NA	Brar et al. (2010)
	Cymatogaster aggregata SLB (Wh)	840.000 ± 56.500	246.4 ± 19.100	119.600 ± 10.5	NM	79.9 ± 5.400		
	Cymatogaster aggregata RLC (Wh)	381.100 ± 43.000	392.6 ± 11.100	813.100 ± 192.6	NM	23.6 ± 6.300		
	Cymatogaster aggregata OAK (Wh)	906.100 ± 175.100	191.6 ± 33.700	110.400 ± 23.9	NM	41.8 ± 5.600		
	Cymatogaster aggregata CAT (Wh)	19.500 ± 9.100	28.6 ± 16.700	16.400 ± 5.2	NM	SM ± NA		
	Leptocottus armatus RED (Wh)	752.300 ± 94.900	1009.1 ± 172.100	42.900 ± 42.900	NM	54.9 ± 23.500		
	Leptocottus armatus SLB (Wh)	839.000 ± 144.400	366.3 ± 48.300	139.000 ± 34.300	NM	99.2 ± 26.900		
	Leptocottus armatus RLC (Wh)	1872.900 ± 614.700	902.6 ± 141.000	1945.400 ± 471.800	NM	87.7 ± 15.700		
	Leptocottus armatus OAK (Wh)	1040.300 ± 159.200	698.9 ± 279.700	217.100 ± 101.800	NM	85.2 ± 38.00		
Formosa River	*Dicentrarchus labrax (Wh)*	1058.4 ± 93.700	NM	200.4 ± 33.200	NM	NM	42.2 cm/ NA	Ferreira et al. (2010)

Values are presented as mean ± SE. L. Location; S: Specie; (TF): Type of fish; P: Production; C: Contaminant; W: Wild; A: Aquaculture; Bl: Blue; Wh: White; Se: Seafood A: Age; S: Size; R: Reference; Ad: Adult; Fr.Fry; Yo: Youth NA: No available; NM: No measurel

[a] All results were expressed in ng/g wet weight (ng/g ww), except for studies (Ferreira et al., 2010; Manirakiza et al., 2002) which were expressed in ng/g lipid weight (ng/g lw).

was reported (Ferreira et al., 2010), while in Tanzania showed low levels (0,004 ng/g ww) (Mwakalapa et al., 2018). The average PCBs concentration of the selected articles in which the results were presented in wet weight was 311.57 ng/g. A high concentration of DDT (1009.1 ng/g ww) was reported in *Leptocottus armatus RED (Wh)* from EE. UU (San Francisco) (Brar et al., 2010), while cod from Tanzania showed a minimum value of 0.004 ng/g ww (Mwakalapa et al., 2018). The average DDT concentration of the selected articles was in which the results were presented in wet weight 158.12 ng/g. The highest concentration of PAHs was found in the species *Leptocottus armatus RLC (Wh)* obtained from San Francisco (902.6 ng/g ww) (Brar et al., 2010) and the lowest concentration was found in the Canary Islands in different species such as *Dicentrarchus labrax (Wh)* (0.490 ng/g ww) (Rodríguez-Hernández et al., 2017). The average PAHs concentration of the selected articles was in which the results were presented in wet weight 293.24 ng/g. The concentration of chlordane varied from 99.2 ng/g ww in *Leptocottus armatus SLB (Wh)* from San Francisco (Brar et al., 2010) to 2.8 in *Salmon Salar* in Norway (Lundebye et al., 2017). While Endosulphane obtained the highest concentration in *Chrysichthys sianenna (Wh)* from Africa (Manirakiza et al., 2002) with a concentration of 36.1 ng/g ww.

3.6. Nutrients in aquaculture fish

The analysis of nutrients such as selenium (Se), zinc (Zn), copper (Cu) and iron (Fe) in aquaculture fish shows variability related to the type of production and feeding of each species. Of the articles selected in this review, 35% deal with nutrients in aquaculture fish. Of the articles included here, 82% analyze Cu, 64% Zn while only 27% of the articles analysed Se. The 82% of the studies were expressed in μg/g ww, while 18% were expressed in μg/g dw (El Bahgy et al., 2021; Ferreira et al., 2010). Both white-fleshed (*Cyprinus carpio, Oreochromis niloticus*) and blue-fleshed (*Salmo salar*) species were analysed in the same proportion. Aquaculture species come from locations such as Poland, Norway, and the Atlantic Ocean (Table 5). Bluefin tuna in Australia showed the maximum Se concentration of 0.930 μg/g ww (Padula et al., 2008), while tilapia in Vietnam shows a minimum value of 0.001 μg/g ww (Szlinder-Richert et al., 2011). In farmed Thunnus (*Thunnus maccoyii)* in South Australia, Zn reaches a maximum level of 5.000 μg/g ww (Padula et al., 2008), while in carp and rainbow trout in Poland, the values were undetectable (Szlinder-Richert et al., 2011).

3.7. Nutrients in wild fish

Finally, wild fish show variable levels of essential nutrients, indicating a significant influence from the natural environment. Of the articles selected in this review, 29% deal with nutrients in aquaculture fish. Of the articles included here, 78% analyze Cu, 56% Zn while 44% of the articles analyze Se. All the studies were expressed in μg/g ww, while only one was expressed in μg/g dw (Ferreira et al., 2010). Mainly blue flesh species were studied such as *Thunnus thynnus* and *Sardina pilchardus*, although some white flesh species such as *Gadus morhua* were also included. Catch areas include the Baltic Sea, the Atlantic Ocean, Australia, the Pacific, and the Mediterranean (Table 6). Bluefin tuna in Australia also recorded a high Se value of 1.300 μg/g ww (Padula et al., 2008), while cod in the Baltic Sea show the lowest level of 0.001 μg/g ww (Szlinder-Richert et al., 2011). In starling (*Scomber japonicus)* in Mediterranean Sea, Zn was as high as 8.85 μg/g ww (Korkmaz et al., 2022), while in certain species in the Baltic Sea, Zn levels were as low as 0.001 μg/g ww (Szlinder-Richert et al., 2011).

4. Discussion

In this review, we have compared and evaluated the information available in scientific literature on the concentration of heavy metals and metaloids (Hg, Cd, Pb and As), other contaminants (PCBs, PAHs, DDT, Endosulphane and Chlordane) and nutrients (Se, Cu, Fe, Mn, Zn, Al, Ni and Cr) present in wild-caught fish and fish produced in aquaculture. Only the results of heavy metals and metaloids expressed in μg/g ww were grouped. (Fig. 2). In the same way, only the results of other contaminants expressed in ng/g ww were grouped. (Fig. 3). The number of scientific investigations published over time has been increasing in the last 20 years. This indicates that this is a topic of study that is gaining importance mainly due to the increased interest in health in recent years.

The highest concentration of Hg in the selected studies was found in wild fish (0.34 μg/g ww) (Padula et al., 2008). Other authors analysed different species from both wild and aquaculture whitefish, bluefish and shellfish from the Canary Islands area and concluded that, as a general trend, wild fish samples showed the highest concentrations (Rodríguez-Hernández et al., 2017). Another study conducted in salmon (*Salmo salar*) from the Atlantic Ocean reported that total Hg levels in aquaculture salmon were significantly lower than in wild salmon (Lundebye et al., 2017). Catch area and species do not affect as they are the same for aquaculture and wild fish, therefore the variation in concentration may be due to the difference in size, there is a problem due to the fact that vulnerable populations such as pregnant women consume a large amount of oily fish because of its high content of polyunsaturated fatty acids (PUFA), omega-3, especially DHA and EPA. The consumption of oily fish in pregnant women is adequate in quantity but not of the right type, they should consume small oily fish species rich in PUFA and low in Hg, such as sardines or mackerel (Conde Puertas et al., 2015). Also the concentration of abiotic contaminants in aquatic and wild fish may vary by the age of the fish, as Hg concentrations in fish of a given species tend to increase with age, as a consequence of the slow elimination of MeHg and higher intakes due to changes in trophic levels as fish age (they eat more and more fish and prey are larger) (Margarita & Benavente, 2017). In the EU, (R (UE) 2023/915, 2023) the maximum allowable level of Hg in fish flesh is 0.5 μg/g ww, except for species such as tuna, whose maximum allowable level is 1 μg/g ww. These levels coincide with the limits established in the general codex standard for contaminants and toxins in food and feed (CXS 193, 1995). Therefore, taking into account these reference values, no Hg content reported in the literature studied in wild and aquaculture fish exceeds the limits established by the EU. Even being below the established limits, vulnerable populations such as pregnant women and children, exposure to heavy metals and especially to MeHg can cause adverse effects on neurodevelopment (Grandjean & Landrigan, 2006). Regulation of contaminants content in fishery products is not a sufficient measure to prevent exposure of vulnerable groups in the short term since, for example, once-weekly consumption of a predator such as swordfish would be sufficient to exceed Food and Drug Administration (FDA) and the Joint FAO/WHO Expert Committee on Food Additives (JECFA) limits (Domingo et al., 2007). Taking into account vulnerable people, it is necessary that these limits be reduced.

Regarding wild fish, in the Canary Islands area, it was observed that in white fish Cd levels were much higher than in blue fish (Rodríguez-Hernández et al., 2017). In contrast, in aquaculture fish, blue fish such as salmon (*Salmo salar*) from the Atlantic Ocean (Jensen et al., 2020) had higher Cd values than those obtained in white fish such as *Dicentrarchus labrax (Wh)* in the Formosa River (Ferreira et al., 2010). In the EU, Commission Regulation (EC) No. 915/2023 set the maximum

Table 5
Nutrient concentration (μg/g) [a] in different aquaculture fish species.

L	S (TF)	Se	Cu	Fe	Mn	Zn	Al	Ni	Cr	S/A	R
Poland	*Cyprinus carpio(Wh)*	0.009 ± 0.012	0.000 ± 0.000	0.00 ± 0.000	0.000 ±NA	0.000±NA	NM	NM	NM	NA	Szlinder-Richert et al. (2011)
	Oncorhynchus mykiss (Bl)	0.005 ± 0.003	0.000 ± 0.000	0.00 ± 0.000	0.000 ±NA	0.000±NA	NM	NM	NM		
Vietnam China	*Pangasius hypophthalmus (Wh)*	0.000 ± 0.000	0.000 ± 0.000	0.00 ± 0.000	0.000 ±NA	0.000±NA	NM	NM	NM		
	Oreochromis niloticus (Wh)	0.001 ± 0.001	0.000 ± 0.001	0.00 ± 0.000	0.000 ±NA	0.000±NA	NM	NM	NM		
Canary Islands	*Sparus aurata (Wh)* *Solea vulgaris (Wh)* *Tiburón iridiscente (Wh)* *Pandasius hypophthalmus (Wh)* *Dicentrarchus labrax (Wh)*	NM	NM	NM	NM	NM	1.150 ±NA	0.080±NA	NM	NA	Rodríguez-Hernández et al. (2017)
	Salmo salar (Bl) *Salmo trutta (Bl)*	NM	NM	NM	NM	NM	0.460 ±NA	0.210±NA	NM		
	Penaeus spp (Se) *Mytilus galloprovincialis (Se)*	NM	NM	NM	NM	NM	7.830 ±NA	0.310±NA	NM		
Atlantic Ocean (Norway)	*Salmo salar (Bl)*	0.140 ± 0.004	0.380 ± 0.090	2.300 ± 0.900	0.090 ± 0.170	3.400 ± 1.100	NM	NM	NM	NA	Lundebye et al. (2017)
South Australia	*Thunnus maccoyii (Bl)*	0.930 ±NA	0.300 ±NA	NM	NM	5.0000 ±NA	NM	NM	NM	102 cm/NA	Padula et al. (2008)
Atlantic Ocean	*Thunnus thynnus* Macho *(Bl)*	NM	NM	10.000 ± 4.000	NM	NM	NM	NM	NM	130 cm/Ad	Girolametti et al. (2021)
	Thunnus thynnus Hembra *(Bl)*	NM	NM	7.000 ± 2.000	NM	NM	NM	NM	NM	131 cm/Ad	
Atlantic Ocean	*Salmo salar (Bl)* Alternative Food	NM	0.170 ± 3.000	NM	NM	1.100 ± 5.000	NM	NM	NM	300 g-4kg/Fr	Berntssen et al. (2010)
	Salmo salar (Bl) Traditional Food	NM	0.091 ± 90.000	NM	NM	0.550 ± 92.000	NM	NM	NM	300 g-4kg/Fr	
Egypt	*Sparus aurata (Wh)* Abril	NM	0.0182 ± 0.00391	0.064 ± 0.017890	0.0071 ± 0.002	0.017.060 ± 0.005	NM	0.0014 ± 0.162	0.597 ± 0.250	NA	El Bahgy et al. (2021)
	Sparus aurata (Wh) Julio	NM	0.0258 ± 0.002351	0.094 ± 0.005	0.00.9 ± 0.0014	0.0217 ± 0.0018	NM	0.001650 ± 0.299	0.990 ± 0.115		
China	*Hypophthalmichthys nobilis (Bl)*	NM	0.258 ± 0.079	NM	0.779 ± 0.108	NM	NM	NM	0.018 ± 0.006	NA	Jiang et al. (2014)
	Oreochromis niloticu (Wh)	NM	0.148 ± 0.012	NM	0.128 ± 0.018	NM	NM	NM	0.002 ± 0.001		
Mediterranean Sea	*Dicentrarchus labrax (Wh)*	NM	0.1 ± 0.23	0.01 ± 0.01	0.24 ± 0.35	4.26 ± 1.88	0.09 ± 0.15	NM	NM	NA	Korkmaz et al. (2022)
Formosa River	*Dicentrarchus labrax (Wh) 1*	NM	2.457 ± 0.12	NM	NM	NM	NM	NM	NM	14 cm/NA	Ferreira et al. (2010)
	Dicentrarchus labrax (Wh) 2	NM	2.417 ± 0.17	NM	NM	NM	NM	NM	NM	22,4 cm/NA	
	Dicentrarchus labrax (Wh) 3	NM	2.447 ± 0.2	NM	NM	NM	NM	NM	NM	27,3 cm/NA	
	Dicentrarchus labrax (Wh) 4	NM	1.887 ± 0.06	NM	NM	NM	NM	NM	NM	35,4 cm/NA	
Camboya	*Channa micropeltes (Wh)*	NM	0.103 ± 0.020	5.774 ± 2.537	0.494 ± 0.098	5.167 ± 0.690	0.325 ± 0.333	0.016 ± 0.018	0.332 ± 0.383	42,4 cm/NA	Thanh et al. (2024)

(*continued on next page*)

Table 5 (*continued*)

L	S (TF)	Se	Cu	Fe	Mn	Zn	Al	Ni	Cr	S/A	R
	Pangasianodon hipoftalmo (Wh)	NM	0.198 ± 0.030	4.589 ± 0.726	0.267 ± 0.082	7.089 ± 0.980	0.144 ± 0.131	0.008 ± 0.008	0.084 ± 0.031	43,3 cm/ NA	

Values are presented as mean ± SE. L. Location; S: Specie; (TF): Type of fish; P: Production; C: Contaminant; W: Wild; A: Aquaculture; Bl: Blue; Wh: White; Se: Seafood A: Age; S: Size; R: Reference; Ad: Adult; Fr.Fry; Yo: Youth NA: No available; NM: No measure.

[a] All results were expressed in μg/g wet weight (μg/g ww), except for studies (El Bahgy et al., 2021) and (Ferreira et al., 2010) which were expressed in μg/g dry weight (μg/g dw).

level of Cd allowed in fish species at 0.05 μg/g ww, except for species such as tuna and mackerel, whose maximum allowed level is 0.1 μg/g ww. These levels coincide with the limits established in the general codex standard for contaminants and toxins in food and feed (CXS 193, 1995). Of wild fish, only *Saxidomus giganteus (Bl)* exceeds the established limit (0.087 μg/g ww) (Laird & Chan, 2013) and in aquaculture fish only *Penaeus* spp *and Mytilus galloprovincialis* exceeds the established limit (0.06 μg/g ww) (Rodríguez-Hernández et al., 2017).

The highest Pb values were found in wild fish (Girolametti et al., 2021). In other studies, such as Rodríguez-Hernández et al. (2017) an increase in Pb concentration was observed in wild *Salmo salar (Bl)*, having a concentration in aquaculture salmon of 0.02 μg/g ww and in wild salmon of 0.03 μg/g ww. The EU Commission Regulation (EC) No. 915/2023 set the maximum level of 0.3 μg/g ww of Pb allowed in the flesh of different fish species. These levels coincide with the limits established in the general codex standard for contaminants and toxins in food and feed (CXS 193, 1995). From the selected studies no fish exceeded the established maximum limits. Except in the study by El Bahgy et al. (2021), where the values taken as a reference are exceeded. The concentrations in this study were expressed in μg/g dw, as the EU limit is expressed in μg/g ww, it could be assumed that adding the percentage of water lost would be below the limit.

It can be observed that the concentration of As was higher in wild fish than in aquaculture fish in studies by authors such as Korkmaz et al. (2022), in which different species from the Mediterranean Sea were studied. In the selected studies total As was analysed but the most toxic is inorganic arsenic (iAs), the predominant As in fish is organic As (oAs) (Pagliai et al., 1998) which belongs to the non-toxic species, that is why the EU legislation (R (EU) 2015/1006) has not yet established a maximum residue level for As in fish. EFSA has published a scientific opinion on the health risks associated with complex organoarsenic species in food, focusing on the most common ones: arsenobetaine, arsenolipids and arsenosugars. The highest levels of complex organoarsenic species were detected in fish, crustaceans, mollusks and seaweeds. The assessment concluded that dietary exposure to arsenobetaine and arsenosugar glycerol is unlikely to pose health concerns. However, due to insufficient data, no conclusions could be drawn for the other types of arsenosugars or for arsenolipids (EFSA, 2024).

This variability in the concentration of heavy metals and metaloids may be due to various factors such as size, age, physiological state, habitat preferences, degree of contamination, feeding behavior, ecological needs, growth rates of aquatic organisms, among others (Urgilez, 2024). It is also worth mentioning the role of aquaculture, since it is the cultivation under controlled conditions of species that develop in the aquatic environment, controlling the diet of fish based on feed and the environment (FAO, 2024). Fish in the wild base their diet on other aquatic species, which generates a greater bioaccumulation of heavy metals and metaloids, since they are substances with a high chemical stability to biodegradation processes, so that living beings are unable to metabolize them, generating pollution by bioaccumulation and a multiplying effect on the concentration of the pollutant in the trophic chain (Mancera-rodríguez & Álvarez-león, 2006).

The R (2015/1006) refers to the maximum limit to the sum of PCBs in blended fat of animal origin with a maximum limit of 40 ng/g lw. It also refers to fishery products with a maximum limit of 75 ng/g ww. Of the articles selected, all were below the established limit except for the wild fish from Africa expressed in ng/g lw (Manirakiza et al., 2002) and from the EE. UU (San Francisco) expressed in ng/g of ww (Brar et al., 2010), the white fish from aquaculture and wild fish from the Formosa River whose values were expressed in ng/g lw and were above the established limit (Ferreira et al., 2010). The U.S. Food and Drug Administration (FDA) has established temporary limits for PCB residues in various foods. For fish and shellfish, the limit is 2000 ng/g ww. Considering this limit, none of the selected articles reach this threshold (FDA, 2000). In the case of DDT, a higher concentration was found in wild fish than in aquaculture. Other authors such as Ferreira et al. (2010) agree with this statement since they found higher DDT concentrations in the same species *(Dicentrarchus labrax (Wh))* in wild fish than in aquaculture fish. The U.S. Food and Drug Administration (FDA) has established temporary limits for DDT residues in various foods. For fish and shellfish, the limit is 5000 ng/g ww. Considering this limit, none of the selected articles reach this threshold (FDA, 2000). For PAHs, there is no maximum limit for fish meat, only reference is made to smoked fish, which is not included in our review since it is not fresh.

The highest concentration of DDT, PCBs and PAHs in wild fish is due, on the one hand, to their enormous ubiquity in the environment and, on the other hand, to their environmental persistence (Hernández-Moreno et al., 1970).

Depending on the concentration, Cu can have an essential nutritional function, or it can be toxic. Considering normal Cu concentration, it is necessary to produce blood cells and the regulation of cellular function in general (Etxebeste, 2023). If toxic it is of concern because it is one of the major contaminants in food from aquatic environments (Jarosz-Krzemińska et al., 2021). Cu can cause metabolic, renal, cardiovascular, hepatic, neurological and respiratory damage. In addition, the presence of this contaminant can be aggravated by other variables such as the processing method used for consumption (Jagdish et al., 2018). Observing the data from the articles collected, a higher concentration of Cu was found in white fish than in oily fish, both aquaculture and wild. As observed in the Formosa River estuary where Cu concentration was higher (Ferreira et al., 2010) than the Cu concentration of the study in the Atlantic Ocean (Berntssen et al., 2010). The EFSA decreed the tolerable upper intake level (UL) where the level for Cu is 5 mg/day (Turck et al., 2023). Therefore, the concentrations found in the studies are positive for the nutrients and no adverse health effects are likely to be observed in most individuals in the general population.

The UL values for Zn established by EFSA for men/women and pregnant women are 25 mg/day (Turck et al., 2023), while the values established by FAO (2006) are 1 mg/kg/day, equivalent to 70 mg/day for 70 kg adults. All Zn values in the samples are below the values established by EFSA and FAO. Therefore, the concentration found should be safe for human consumption with respect to this element and provide beneficial effect. At adequate concentrations Zn has a critical effect on homeostasis, immune function, and oxidative stress (Etxebeste, 2023). However, high doses of this element have toxic effects, so acute zinc poisoning is a rare occurrence (Plum et al., 2010).

It is important to highlight the presence of nutrients such as selenium (Se) that provide beneficial effects on brain development. It is worth mentioning that Se is necessary for humans in small concentrations (Burger et al., 2013) and could be found in fish, where it binds with high

Table 6
Nutrient concentration (μg/g) [a] in different wild fish species.

L	S (TF)	Se	Cu	Fe	Mn	Zn	Al	Ni	Cr	S/A	R
Baltic Sea	*Gadus morhua callarias (Wh)*	0.001 ± 0.001	0.000 ± 0.000	0.00 ± 0.000	0.000 ±NA	0.001 ±NA	NM	NM	NM	NA	Szlinder-Richert et al. (2011)
	Clupea harengus membras (Bl)	0.018 ± 0.006	0.000 ± 0.000	0.01 ± 0.000	0.001 ±NA	0.001 ±NA	NM	NM	NM		
	Salmo salar (Bl)	0.057 ± 0.022	0.002 ± 0.001	0.05 ± 0.020	0.003 ±NA	0.006 ±NA	NM	NM	NM		
China	*Theragra chalcogramma (Bl)*	0.000 ± 0.000	0.000 ± 0.000	0.00 ± 0.000	0.000 ±NA	0.000 ±NA	NM	NM	NM		
	Limanda aspera (Wh)	0.000 ± 0.000	0.000 ± 0.000	0.00 ± 0.000	0.000 ±NA	0.000 ±NA	NM	NM	NM		
Canary Islands	*Polyprion americanus (Wh)* *Stephanoiepis hispidus (Wh)* *Solea vulgaris (Wh)* *Dicentrarchus labrax (Wh)* *Merluccius merluccius (Wh)* *Dentex dentex (Wh)* *Sparisoma cretense (Wh)*	NM	NM	NM	NM	NM	0.280 ±NA	0.040 ±NA	NM	NA	Rodríguez-Hernández et al. (2017)
	Thunnus thynnus (Bl) *Sardina pilchardus (Bl)* *Salmo salar (Bl)*	NM	NM	NM	NM	NM	1.080 ±NA	0.050 ±NA	NM		
	Parapenaeus spp *(Se)* *Penaeus* spp *(Se)* *Mytilus galloprovincialis (Se)*	NM	NM	NM	NM	NM	5.410 ±NA	0.080 ±NA	NM		
Atlantic Ocean (Norway)	*Salmo salar (Bl)*	0.45 ± 0.45	0.57 ± 0.57	3.9 ± 3.9	0.1 ± 0.1	4.2 ± 4.2	NM	NM	NM	NA	Lundevye et al., 2017
South Australia	*Thunnus maccoyii (Bl)*	1.300 ±NA	0.360 ±NA	NM	NM	5.000 ±NA	NM	NM	NM	105 cm/ NA	Padula et al. (2008)
Atlantic Ocean	*Thunnus thynnus* Macho *(Bl)*	NM	NM	8.000 ± 3.000	NM	NM	NM	NM	NM	130 cm/ Ad	Girolametti et al. (2021)
	Thunnus thynnus Hembra *(Bl)*	NM	NM	17.000 ± 8.000	NM	NM	NM	NM	NM	131 cm/ Ad	
Canada	*Saxidomus giganteus (Bl)*	0.430 ± 0.050	1.790 ± 0.570	NM	1.430 ± 0.330	NM	NM	NM	NM	NA	Laird and Chan (2013)
	Oncorhynchus tshawytscha (Bl)	0.480 ± 0.170	0.860 ± 0.240	NM	0.920 ± 0.840	NM	NM	NM	NM		
	Oncorhynchus nerka (Bl)	0.480 ± 0.170	1.360 ± 1.320	NM	0.460 ± 0.480	NM	NM	NM	NM		
Mediterranean Sea	*Sarda sarda (Bl)*	NM	0.63 ± 0.61	0.01 ± 0.01	0.11 ± 0.15	4.38 ± 0.83	NM	NM	NM	NA	Korkmaz et al. (2022)
	Mullus surmuletus (Bl)	NM	0.06 ± 0.14	NM	0.53 ± 0.33	3.97 ± 1.4	0.17 ± 0.28	NM	NM		
	Sardina pilchardus (Bl)	NM	0.23 ± 0.21	0.01 ± 0.01	0.74 ± 0.42	6.69 ± 2.59	NM	NM	NM		
	Boops boops(Bl)	NM	NM	0.01 ± 0.01	0.22 ± 0.31	7.58 ± 3.13	NM	NM	0.08 ± 0.15		
	Scomber japonicus (Bl)	NM	0.54 ± 0.58	0.01 ± 0.01	0.08 ± 0.17	5.23 ± 3.46	NM	NM	0.22 ± 0.49		
	Saurida lessepsianus (Bl)	NM	NM	NM	0.2 ± 0.45	4.5 ± 1.83	NM	NM	NM		
	Trachurus trachurus (Bl)	NM	0.34 ± 0.35	NM	0.25 ± 0.25	4.43 ± 1.09	NM	NM	NM		
	Sparus aurata (Wh)	NM	0.24 ± 0.41	NM	NM	6.2 ± 1.9	NM	NM	NM		
	Pagrus pagrus (Wh)	NM	0.27 ± 0.42	0.01 ± 0.01	0.33 ± 0.57	5.38 ± 0.95	0.48 ± 1.18	NM	NM		
	Mullus barbatus (Bl)	NM	NM	NM	NM	NM	NM	NM	NM		
	Sphyraena sphyraena (Bl)	NM	NM	NM	0.36 ± 0.56	5.26 ± 0.66	0.36 ± 0.56	NM	NM		
	Scomber japonicus (Bl)	NM	0.34 ± 0.54	0.01 ± 0.01	NM	8.85 ± 3.36	0.01 ± 0.03	NM	NM		

(*continued on next page*)

Table 6 (*continued*)

L	S (TF)	Se	Cu	Fe	Mn	Zn	Al	Ni	Cr	S/A	R
	Saurida undosquamis (Wh)	NM	NM	NM	NM	NM	NM	NM	NM		
	Mugil cephalus (Wh)	NM	0.25 ± 0.42	0.01 ± 0.01		12.4 ± 3.2	NM	NM	0.26 ± 0.27		
	Solea solea (Wh)	NM	NM	NM	0.09 ± 0.21	3.83 ± 1.1	NM	NM	NM		
	Nemipterus randalli (Wh)	NM	NM	NM	NM		NM	NM	NM		
	Lithognathus mormyrus (Bl)	NM	NM	NM	NM	6.01 ± 0.94	NM	NM	NM		
Formosa River	*Dicentrarchus labrax (Wh)*	NM	1.227 ± 0.19	NM	NM	NM	NM	NM	NM	42,2 cm/ NA	Ferreira et al. (2010)
Camboya	*Channa micropeltes (Wh)*	NM	0.106 ± 0.014	3.838 ± 0.609	0.434 ± 0.119	5.248 ± 0.595	0.116 ± 0.207	0.007 ± 0.004	0.134 ± 0.06	39 cm/ NA	Thanh et al. (2024)
	Pangasianodon hipoftalmo (Wh)	NM	0.201 ± 0.078	8.401 ± 5.222	0.345 ± 0.125	7.075 ± 0.587	5.095 ± 6.94	0.020 ± 0.025	0.202 ± 0.172	27,3 cm/ NA	

Values are presented as mean ± SE. L. Location; S: Specie; (TF): Type of fish; P: Production; C: Contaminant; W: Wild; A: Aquaculture; Bl: Blue; Wh: White; Se: Seafood A: Age; S: Size; R: Reference; Ad: Adult; Fr.Fry; Yo: Youth NA: No available; NM: No measure.

[a] All results were expressed in μg/g wet weight (μg/g ww), except for the study (Ferreira et al., 2010) which were expressed in μg/g dry weight (μg/g dw).

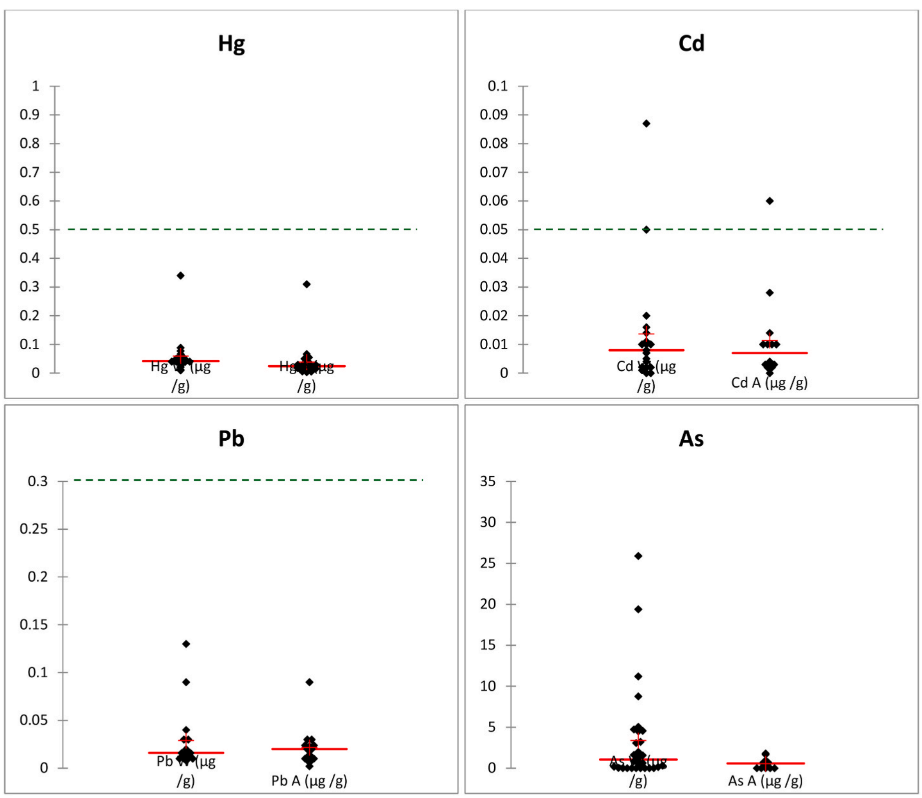

Fig. 2. Concentration of heavy metals expressed μg/g wet weight (μg/g ww) in different species of A (aquaculture) and W (wild fish). - - - - -Maximum limit of contaminant presents in fresh fish established by the European union (R (UE) 2023/915) and Codex Alimentarius (CXS 193–1995).

affinity to Hg reducing its bioavailability and toxicity (Burger et al., 2013). Se detections are below the UL for Se consumption according to FAO (2006) in men/women (0.4 mg/day) and children (0.15 mg/day) and according to EFSA man/woman (0.255 mg/day) (Turck et al., 2023), so no adverse health effects are likely to be observed in most individuals. Dietary toxicity in humans is rare. Excessive Se intake can cause selenosis, dermatitis, alopecia, increased mortality rate, increased risk of prostate cancer and non-melanoma skin cancer (Rayman, 2020).

4.1. *Study limitations and strengths*

There are limitations in this review because some of the selected studies did not provide information on water content, which led to the results being expressed in different concentration units. This lack of uniformity makes direct comparison between data difficult and may also influence the estimation of average values, altering their precision. Therefore, we recommend that, in future studies, data be reported using the same units to ensure better comparability and accuracy in the analyses. Another important limitation of this review is that not all studies

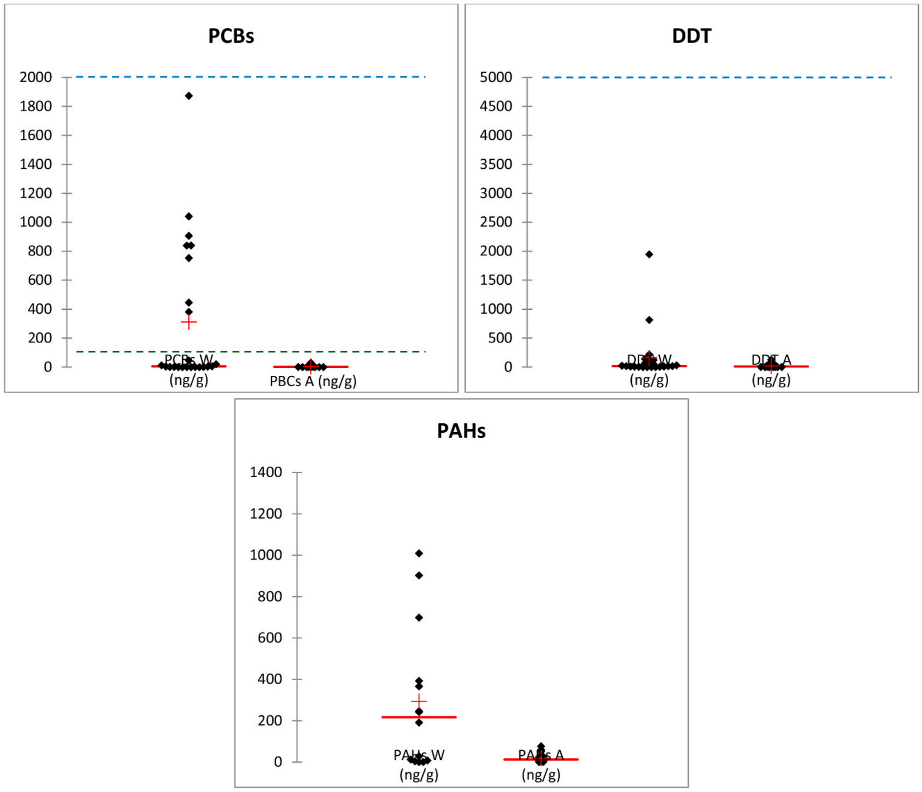

Fig. 3. Concentration of other contaminants expressed ng/g wet weight (ng/g ww) in different species of A (aquaculture) and W (wild fish).
- - - - Maximum limit of contaminant present in fresh fish established by the European union (R (UE) 2015/1006).
- - - - Maximum limit of contaminant present in fresh fish established by the FDA.

specify the concentrations of MeHg and iAs, which are the most toxic forms of Hg and As, respectively. This lack of specificity hinders an accurate assessment of the associated toxicological risk. Therefore, we recommend that future studies include data on these contaminant forms to improve the accuracy and quality of risk assessments.

Although the objective of this study was to compile contaminants present in a natural way and by the industrial activities, it is also worthy to mention that there could be other possible sources of contaminants or compounds potentially toxic to humans and the environment present in fish that are important to mention, such as antibiotics (it is essential to highlight that the number of them allowed in marine aquaculture is much lower than that allowed in livestock farming) and sunscreen products (Grimmelpont et al., 2023; Noorzai et al., 2025). In Europe, the antibiotics that are allowed in marine aquaculture are regulated R (EU) 37/2010.

This review also has strengths. It is a novel review, as no other review article with the same study objective has been published. In addition, many articles on the topic of study have been included, which favours the certainty of the results.

5. Conclusion

Considering the data, a higher concentration of heavy metals and metaloids such as Hg and As, and other contaminants such as DDT or PAHs is found in wild fish than in aquaculture fish, although most of the elements were within the limits established for safe consumption by the general population. Even so, it is necessary to reduce the concentrations of these abiotic contaminants as there are vulnerable populations such as pregnant women and children where there may be serious health effects. Even so, with the data available today in the scientific literature it is difficult to determine the effect of wild fish compared to aquaculture fish in relation to contamination by heavy metals and metaloids, other contaminants, and nutrients since various factors such as species, location and environmental influences interact in a complex way. The differences found in some research papers are probably not solely attributable to the production system (wild vs. aquaculture). Factors such as size, age, physiological state, habitat, degree of environmental pollution, diet, growth rates of aquatic organisms seem to have a greater effect. Further studies are needed to determine the effect of the production system on the presence of these contaminants to develop strategies to reduce their presence in fish and so enhance food safety.

CRediT authorship contribution statement

I. Casanova-Martínez: Writing – review & editing, Writing – original draft, Conceptualization. **E. Hernández-López:** Writing – review & editing, Writing – original draft, Conceptualization. **A.J. Signes-Pastor:** Writing – review & editing, Supervision, Conceptualization. **E. Sendra:** Writing – review & editing, Supervision, Conceptualization. **Á.A. Carbonell-Barrachina:** Writing – review & editing, Supervision, Conceptualization. **M. Cano-Lamadrid:** Writing – review & editing, Supervision, Conceptualization.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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