

Occurrence of chemical contaminants in wild-caught fishery products of relevance to Scottish and wider UK Fishing Waters: A Review

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Fera Science Ltd.

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2. Glossary and definitions

AFB1	Aflatoxin B ₁
AMR	Antimicrobial Resistance
ANSES	French Agency for Food, Environmental and Occupational Health & Safety
BaP	Benzo-a-pyrene
BfR	German Federal Institute for Risk Assessment
BFR	Brominated Flame Retardants
BTEX	Benzene, Toluene, Ethylbenzene and Xylenes
CEC	Contaminants of Emerging Concern
CEMP	Co-ordinated Environment Monitoring Programmes
CFIA	Canadian Food Inspection Agency
EE2	17alpha-Ethinylestradiol
EFSA	European Food Safety Authority
EPA	Environmental Protection Agency
EU	European Union
FAO/UN	Food and Agriculture Organization of the United Nations
FBO	Food Business Operator
FSA	Food Standards Agency
FSANZ	Food Standards Australia New Zealand
FSS	Food Standards Scotland
FSIS	(United States) Food Safety and Inspection Service
GC-MS	Gas Chromatography / Mass Spectrometry
GES	Good Environmental Status
GFSI	Global Food Safety Initiative
HBCDD	Hexabromocyclododecane
ICMSF	International Commission on Microbiological Specifications for Foods
IFST	Institute of Food Science and Technology
LBM	Live Bivalve Mollusc
LW	Lipid weight - chemical of interest is measured in the fat portion (after first extracting the fat from the sample). The result is expressed as lipid weight or fat weight.
LOD	Limit of Detection
LOQ	Limit of Quantification
3-MCPD	3-Monochloropropanediol
MC	Microcystin
ML(s)	Maximum Level(s)
MOAH	Mineral Oil Aromatic hydrocarbons (aromatic fraction)
MOE	Margin of Exposure
MOSH	Mineral Oil Saturated Hydrocarbons
MP	Microplastics
MPL	Maximum Permitted Level(s)

MSFD	Marine Strategy Framework Directive
NDNS	National Diet and Nutrition Survey
PAH4	Sum of 4 PAHs benzo(a)pyrene, benz(a)anthracene, benzo(b)fluoranthene and chrysene
PAHs	Polyaromatic Hydrocarbons
PBBs	Polybrominated Biphenyls
PBDEs	Polybrominated Diphenyl Ethers
PCBs	Polychlorinated Biphenyls
PCDD/Fs	Polychlorinated dibenzo-p-dioxins and dibenzofurans
PCNs	Polychlorinated naphthalenes
PFAS	Polyfluoroalkyl Substances
PFCs	Perfluorocompounds
PFHxS	Perfluorohexane sulfonate
PFNA	Perfluorononanoic acid
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctane sulfonic acid
PFUnDA	Perfluoroundecanoic acid
POPs	Persistent organic pollutants
PTEs	Potentially Toxic Elements
PXDD/Fs and PXBs	mixed halogenated dibenzo-p-dioxins, dibenzofurans and biphenyls
SASR	Strategic Assessment of Sampling Resources
SDGs	Scottish Dietary Goals
TBBPA	Tetrabromobisphenol-A
TDS	Total Diet Study
TEF	Toxic Equivalent Factor
TMFs	Trophic magnification factors
UKFSS	United Kingdom Food Surveillance System
USFDA	United States Food and Drug Administration
VMD	Veterinary Medicines Directorate
WHO	World Health Organisation
WHO-TEQ	World Health Organisation Toxic Equivalents
w/w	wet weight. The sample containing the chemical of interest has not been dried to remove water. Also referred to as whole weight or fresh weight.

3. Executive Summary

Understanding the presence and impact of chemical contaminants in fish and seafood is essential for protecting public health, maintaining consumer confidence, and guiding regulatory and monitoring strategies. Seafood is a vital component of the UK diet as well as an important commercial industry, particularly in Scotland where over 60% of UK landings occur. Accordingly, ensuring the safety of these products is a public health priority. This report, commissioned by Food Standards Scotland and conducted by Fera Science Ltd., provides a comprehensive review of the current evidence on chemical contaminants in wild-caught and smoked fish, shellfish, crustaceans, and cephalopods from Scottish and wider UK waters.

The report identified and screened over 3,600 records for inclusion, including peer-reviewed studies, grey literature, regulatory documents, and surveillance data. Ultimately, 125 records were chosen for inclusion to evaluate the occurrence of a wide range of contaminants, both regulated as well as new and emerging, including heavy metals (mercury, cadmium, lead and arsenic), processing contaminants & polycyclic aromatic hydrocarbons (PAHs), dioxins/furans, polychlorinated biphenyls (PCBs), per- and polyfluorinated alkyl substances (PFASs), brominated flame retardants (BFRs), BTEX compounds (benzene, toluene, ethylbenzene, and xylenes), veterinary drug residues, pesticides, naturally occurring or produced compounds (e.g. histamine, microcystins and marine biotoxins), active pharmaceutical ingredients (e.g. painkillers, anti-depressants), personal care products (phenols, phthalates, and parabens) and microplastics. Data on the occurrence and levels reported for the named contaminants are provided and the findings mapped against current UK and EU regulatory frameworks, with particular attention to Maximum Permitted Levels (MPLs) and recent updates in EU legislation.

Contaminants were detected across all species tested, with oily and predatory fish such as mackerel, herring, sea bass, and sprats showing the highest concentrations. While most results were below MPLs, exceedances were observed for cadmium in crab and scallops, lead in mussels, mercury in sea bass, and PAH4 in smoked products such as Arbroath smokies and smoked salmon. PFAS compounds, although not currently regulated in Great Britain, exceeded EU MPLs in several species including cod, crab, and gurnard. The review also highlights the frequent detection of emerging contaminants such as PBDEs, PCNs, and PXDD/Fs, for which no MPLs exist, but which EFSA has identified as potential health concerns.

Microplastics were found in a range of species, with particularly high incidence in langoustine from the Clyde Sea area. Although the toxicological and ecological effect of Microplastics are not yet fully understood, in nephrops such as langoustine, the presence of microplastics is associated with reduced feeding, body mass, and

metabolic rates. In finfish, microplastics were primarily confined to the gills and digestive tracts, with minimal presence in edible muscle tissue. The findings support the inclusion of microplastic monitoring in shellfish safety assessments, particularly given their potential to act as vectors for other chemical contaminants. The report also highlights concerns around emerging and unregulated biotoxins, particularly tetrodotoxins (TTXs) and brevetoxins. TTXs have been detected in two Scottish shellfish samples, while brevetoxins, though not yet found in UK waters, are considered a potential future risk due to favourable environmental conditions. The review notes that these emerging toxins are not currently included in routine monitoring and that validated analytical methods are yet to be developed.

Human medicines were found to be present in some marine environments, particularly in estuarine areas influenced by wastewater discharge. Pharmaceuticals such as paracetamol, ibuprofen, diclofenac, fluoxetine, venlafaxine, and various antibiotics were detected in waterways and their flora, with residues found in fish muscle and liver, especially in species like European flounder from the Clyde estuary. However, detection in edible tissues was limited.

The report also identifies significant data gaps, particularly for fish landed in Scotland. Recent surveillance has focused on samples from England and Wales, leaving limited data on key contaminants such as PFAS, dioxins, PCBs, and inorganic arsenic in Scottish products. Additionally, there is a lack of data on nitrosamines and heterocyclic amines in smoked fish, and minimal information on veterinary drug residues, pesticides, and microcystins in marine species. The presence of pharmaceuticals and personal care products in estuarine environments suggests potential emerging risks that may warrant further investigation.

The review concludes with a set of targeted recommendations for future monitoring and research. These include expanded surveillance of PFAS in high-consumption species, updated testing for inorganic arsenic using improved analytical methods, and focused studies on smoked products and emerging contaminants. Continued monitoring of heavy metals and marine biotoxins is also advised. The findings support FSS's strategic objectives by providing a robust evidence base to inform risk assessment, regulatory policy, and consumer guidance.

4. Introduction

Marine environments are recognised sinks for a range of environmental contaminants, and the bioaccumulation of environmental contaminants and toxins by various marine fish and shellfish species has been widely documented (Bruggeman *et al.* (1984); Magalhaes *et al.* (2003); El-Moselhy *et al.* (2014); Hashizume *et al.* (2014)). Marine shellfish for example, have a recognised potential for bio-accumulating contaminants and some species such as mussels, are commonly used as early indicators of local pollution.

Chemical contaminants end up in the marine environment in different ways. Industrial and urban discharges, agricultural practices, and storm water runoff can all put harmful substances into the rivers and seawater. Rain can also wash chemicals from the land or air into rivers that flow to the sea or to seawater directly. However, not all types of environmental contaminants will accumulate in fish or fishery products.

Bioaccumulation occurs when contaminants increase in concentration in tissues of aquatic organisms from sources such as the surrounding water, food and particles of sediment. Accumulation can occur when chemicals are taken up and stored at a faster rate than they are metabolised or excreted. In general, compounds that accumulate in fish and fishery products do not breakdown easily in the environment. Lipophilic compounds are of particular concern as they dissolve in fats/oils and may stay in the fat tissues of fish and fishery products for long periods of time.

Biomagnification occurs when compounds occur at higher and higher levels as you move up the trophic levels of the food chain. Low concentrations of a compound, in this case chemical contaminants, become a higher concentration in larger predators. An example of this is the biomagnification of mercury in tuna.

It has been reported that fish and fishery products can absorb certain anthropogenic chemical contaminants, including processing contaminants such as PAHs, veterinary drug residues, pesticides, active pharmaceutical ingredients, inorganic substances, microplastics and natural toxins from seawater, sediments, or the food they eat. In contaminated areas, bottom-dwelling fish are especially likely to have high levels of these chemicals because these substances often settle to the bottom where these fish feed. Data from previous studies provided a strong indication that oily fish species such as sardines, sprats, seabass, mackerel and herring, were likely to show the highest levels of lipophilic contaminants (such as POPs), while predatory fish, larger fish and long-lived fish such as shark and marlin would be more prone to

accumulate heavy metals such as mercury and would thus provide a marker for the higher level of the contamination range.

Thus, it has been well established that the consumption of edible species of marine fish and fishery products has the potential to make a significant contribution to the human exposure of a wide range of these contaminants. Eating fish that contain contaminants can cause these contaminants to build up in a person's body. Eating contaminated fish for a long time can increase the risk of illness for adults, but may be especially risky for the developing foetus, babies and children because their bodies are still developing. Depending on the type and level of contaminants, long-term exposure from eating some types of fish can increase the risk of illness, developmental issues, or, in some cases, cancer.

In an effort to reduce or prevent inputs that could cause pollution, affect human health or adversely impact legitimate uses of the marine environment, the Marine Strategy Framework Directive (MSFD) of 2008 encouraged collaboration and coordination between individual EU Member States with the aim of protecting and preserving marine ecosystems (European Union, 2008). In the context of the present study, one of the targets for good environmental status under the EU directive was the limiting of the contamination in fish and other seafood along with compliance with maximum contaminant levels established by European Commission regulation, or other relevant standards. In addressing this aim, the availability of complex and large datasets is limited for the required analyses which should encompass spatial, species and concentration levels over time. This lack of relevant data has presented challenges for regulators and assessors to be able to clearly identify trends or correlations over these time points for surveillance and monitoring purposes.

Data gathering for wild-caught fish and fishery products will address possible concerns of known risks or fill data gaps regarding the levels of chemical contamination from currently regulated and emerging chemical contaminants and toxins.

The Food Standards Agency (FSA) UK and Food Standards Scotland (FSS) have identified that gaps may exist in data regarding the chemical contamination of some wild-caught fish and fishery products species and the aim of this review was to evaluate the occurrence of chemical and toxin contaminants in wild caught fish, and fishery products, of relevance to Scottish and wider UK Fishing Waters. The current investigation, however, is not limited to investigating regulated contaminants but includes other chemicals identified under the Food Standards Agency's emerging risks programmes or that are under review for example by the EFSA CONTAM Panel or are candidate compounds for listing under the Stockholm Convention. Fish species available to consumers in Scotland are sourced from a variety of locations but bearing the context of the current study in mind, the main area targeted for investigation were the North Sea and the Greater North Sea sub-region extending up

to Norway, and the Irish sea. Chemical pollutants are known to adversely affect physiological systems in all animal species studied to date. While many individual chemicals can perturb normal functions, the combined actions of multiple pollutants are of particular concern because they can exert effects even when each individual chemical is present at concentrations too low to be individually effective or below the MLs. The biological effects of pollutants differ greatly between species reflecting differences in the pattern of exposure, routes of uptake, metabolism following uptake, rates of accumulation and sensitivity of the target organs. Thus, understanding of the effects of chemical pollutants in the aquatic environment will require detailed study of many different species, representing the range of taxa present in Scottish (and UK) waters.

There are a wide range of established/regulated, and emerging contaminants that are recognised to be persistent, bio-accumulative and toxic, with the potential to undergo long-range transport. The regulated environmental contaminants are polychlorinated dibenzo-*p*-dioxins and dibenzofurans (PCDD/Fs, dioxins), polychlorinated biphenyls (PCBs), potentially toxic elements (PTEs), polybrominated diphenylethers (PBDEs) and polybrominated biphenyls (PBBs). The emerging contaminants consist of polychlorinated naphthalenes (PCNs), polybrominated dibenzo-*p*-dioxins and dibenzofurans (PBDD/Fs), mixed halogenated dibenzo-*p*-dioxins, dibenzofurans and biphenyls (PXDD/Fs and PXBs), perfluoroalkyl and polyfluoroalkyl substances (PFAS) and pesticides.

The literature review focussed on the various risks posed to the consumer from the chemical contamination of wild-caught and smoked fish, shellfish, crustaceans and cephalopod products. Smoked fish products included both wild-caught and farmed varieties.

The review was to evaluate the literature and data on the occurrence of contamination of fish landed in and exported from Scotland and the rest of the UK for the occurrence of anthropogenic pollutants (e.g. per- and poly-fluoro alky substances (PFAS) dioxins/furans, PCBs, BTEX, BFRs (e.g. PBDEs, PBBs, HBCDDs and TBBPA); processing contaminants (e.g. PAHs, heterocyclic amines and nitrosamines), veterinary drug residues, pesticides, active pharmaceutical ingredients (e.g. diclofenac, 17 β -oestradiol, acetaminophen, metformin); inorganic substances (e.g. toxic metals, mercury, cadmium, lead, arsenic and chromium); microplastics and naturally occurring compounds (e.g. histamine, microcystins and algal toxins).

5. Methodology and scientific approach

This review prioritised chemical and toxic pollutants and where possible, combinations of chemicals which have the greatest potential to arise in wild caught and smoked fish and fishery products in Scotland and wider UK. Acute and chronic contaminant risks which are most likely to be associated with environmental exposure and the smoking/ preserving processes were prioritised. The approach used was risk based, considering both the nature of the chemical hazard (i.e., toxicology), occurrence data and consumption habits of the Scottish/UK consumer.

6. Systematic literature review

A Systematic Review (SR) aims to find all possibly relevant research from multiple sources that fits the pre-specified inclusion criteria to answer the research question or hypothesis. They provide syntheses of the state of knowledge in a field from which future priorities can be identified. This technique was used as a tool to provide the basis for an unbiased and comprehensive evidence base in which future sampling programmes can be designed upon. The SR protocol followed the widely accepted Preferred Reporting Items for Systematic Review and Meta-analysis guidelines (Page *et al.*, 2021).

6.1 Data sources and techniques

6.1.1 *Scientific peer reviewed literature*

Researchers at QUB and Fera Science Ltd. used Web of Science and other databases for searching and obtaining the relevant literature. Numerous commercial databases especially those of the Diaolog/Datastar, Web of Science, Ovid, Scopus and Lens.org) were available.

Using these resources, a literature search for pertinent information on the risks of chemical contamination of wild-caught and smoked fish, shellfish, crustaceans, and cephalopods with relevance to the Scottish wild caught fishing industry and processing practices was performed. An array of the literature search platforms mentioned above in combination with a variety of search strings were applied.

6.1.2 Grey literature

Sources of grey literature (such as that produced by non-profit organisations, special interest groups, professional associations, universities, government, local authorities, international bodies, businesses, market intelligence consultancies, and consumer groups) were included in the review using search engines such as OpenGrey, BASE and Google Scholar.

The database of science and research projects held by Defra (defra.gov.uk) was searched.

Other sources of intelligence and information available to Fera staff were also searched e.g., other organisations websites such as VMD, FSA, trade associations, National Authorities in EU Member States (BfR, Germany), other National Authorities (Food Standards of Australia New Zealand) and other international sources of information such as EFSA, FAO, and TRACES (DGSANTE) who all publish information relevant to food safety.

6.2 Citation-based searching

Along with bibliographic databases, a variety of additional methods were used to minimise procedural bias. Citation chasing exploited connections between research articles to identify relevant records for a review by making use of explicit mentions of one article within another. Citation chasing is a popular supplementary search method because it helps to build on the work of primary research and review authors.

Studies and reviews were used to identify pertinent articles that had not been found initially.

6.4 Definition of the search terms & search-strings

The data sources were interrogated using the agreed list of search terms. The inclusion and exclusion criteria were documented prior to initiating the search. The search was carried out using an iterative approach, with appropriate indexing terms identified from retrieved items being re-inputted to improve retrieval. Identified references and abstracts were placed into a project database (EndNote). The full search terms and plan for the review were agreed with FSS at the start of the project before any searches were undertaken. Key words were agreed, but as an example, terms to be included were the names of all known and regulated contaminants as mentioned above; environmental pollutants; processing contaminants; cold smoking;

hot smoking; surveillance; occurrence; specific fish/fishery products (such as those listed in the tender); intake; toxicity; exposure assessment and risk assessment.

The following search terms were used:

TS=(UK water OR Scotland OR Scottish OR English OR Irish OR 'North Sea' OR Atlantic OR 'Ling Bank' OR 'Forth' OR 'Moray Firth' OR Orkney OR Shetland OR Clyde OR 'North Minch' OR 'Farne Deeps' OR 'Berger Bank' OR Atlantic OR 'Arctic Ocean' OR 'Gulf Finland' OR 'Baltic Sea' OR Finland OR Norway OR Faroe OR Greenland OR Sweden OR Belgi* OR Netherlands OR France) AND (TS=('wild caught fish' OR fish OR 'fishery product*' OR 'Marine fish') AND TS=('emerging contaminant' OR 'environmental contaminant')) AND (TS=(arsenic OR mercury OR 'potentially toxic element*' OR arsenic OR mercury OR cadmium OR lead OR 'inorganic substance*' OR chromium OR 'polychlorinated dibenzo-p-dioxin*' OR dibenzofuran* OR PCDD* OR PCDF* OR PCDD/PCDF* OR dioxin* OR 'polychlorinated biphenyl*' OR PCB OR 'polybrominated diphenylether*' OR PBDE* OR 'polybrominated biphenyl*' OR PBB OR 'polychlorinated naphthalene*' OR PCN* OR 'polybrominated dibenzo-p-dioxin*' OR dibenzofura* OR 'halogenated dibenzo-p-dioxin*' OR dibenzofuran* OR biphenyls OR PXB OR 'brominated flame retardant' OR 'perfluoroalkyl substances' OR PFAS OR pesticide* OR organochlorine OR PAH*))

Smoked search

((((TS=(UK water OR Scotland OR Scottish OR English OR Irish OR 'North Sea' OR Atlantic OR 'Ling Bank' OR 'Forth' OR 'Moray Firth' OR Orkney OR Shetland OR Clyde OR 'North Minch' OR 'Farne Deeps' OR 'Berger Bank' OR Atlantic OR 'Arctic Ocean' OR 'Gulf Finland' OR 'Baltic Sea' OR Finland OR Norway OR Faroe OR Greenland OR Sweden OR Belgi* OR Netherlands OR France)) AND TS=(fish OR 'fishery product' OR salmon OR cod OR haddock OR mackerel OR mussel OR trout OR herring OR scallop OR basa OR kipper)) AND ALL=(smoked)) AND TS=(contaminant OR PAH OR nitrosamine OR chemical OR 'polycyclic aromatic hydrocarbons')

Marine Biotoxins

(((((TS=(UK water OR Scotland OR Scottish OR English OR Irish OR 'North Sea' OR Atlantic OR 'Ling Bank' OR 'Forth' OR 'Moray Firth' OR Orkney OR Shetland OR Clyde OR 'North Minch' OR 'Farne Deeps' OR 'Berger Bank' OR Atlantic OR 'Arctic Ocean' OR 'Gulf Finland' OR 'Baltic Sea' OR Finland OR Norway OR Faroe OR Greenland OR Sweden OR Belgi* OR Netherlands OR France)) AND TS=(fish OR 'fishery product')))) AND ALL=('marine biotoxins' OR azaspiracid OR spirolides OR pinnatoxin OR gymnodimine OR palitoxin OR ciguatera* OR brevetoxins OR tetrodotoxins))

6.5 Article screening to select relevant publications

The output from the literature searches was combined into a single database in EndNote 20. Results were scrutinized to identify the key publications matching the inclusion criteria. After removal of duplicates, publications which did not contain information relevant for the purpose of this study were screened out. A weighted decision matrix was constructed to aid the sifting process.

The following criteria were used:

- Reason 1 = Not relevant. Topic not relevant, e.g. toxicology, wrong species (birds, mammals).
- Reason 2 = Low relevance. Farmed fish, country of no relevance (e.g. tropical waters), fresh water/ rivers.
- Reason 3 = Medium relevance = analytical methods (results for method), topic correct, similar sea temperature but not close geographically (e.g. Canada).
- Reason 4 = High relevance. Correct topic (contaminant / species), comparative region (e.g. Norway, Netherlands).
- Reason 5 = Highest relevance. Relevant results or study (as for 4) for fish from UK or Scottish waters.

A map of sea temperatures was used to assess comparative sea temperatures to consider whether conditions were comparable to UK coastal and near waters. This was used as part of the decision matrix above to determine which regions or locations were comparable and should be included in the literature assessment (Reason 3 or 4) and which should be excluded (Reason 1 or 2). The map is shown in Figure 1 and is a snapshot of surface sea temperatures on a given date.

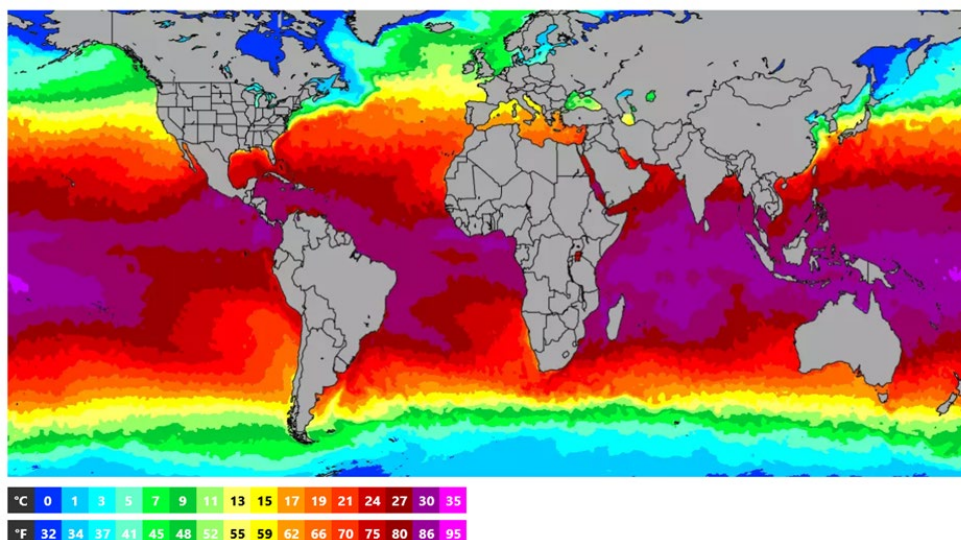


Figure 1. Map of surface sea temperatures, reproduced from <https://www.seatemperature.org/>, downloaded on 4 May 2024.

The number of papers assigned to each reason is shown in the schematic in Figure 2. Publications assigned to Reason 1 and 2 were grouped together ($n = 2627$). Publications with the highest relevance (all assigned to Reason 5 and some Reason 4) were included in the detailed review. Articles which included the target chemicals & species, geographical location, smoking process, quantitative data, analytical methodologies used and describe or refer to the possible adverse food safety impacts from environmental and/or processing contaminants were included. All retained and rejected papers were listed in separate files in a database.

As well as the peer reviewed and grey literature, regulations, some website content and scientific reports (some available from government websites) were included in the review.

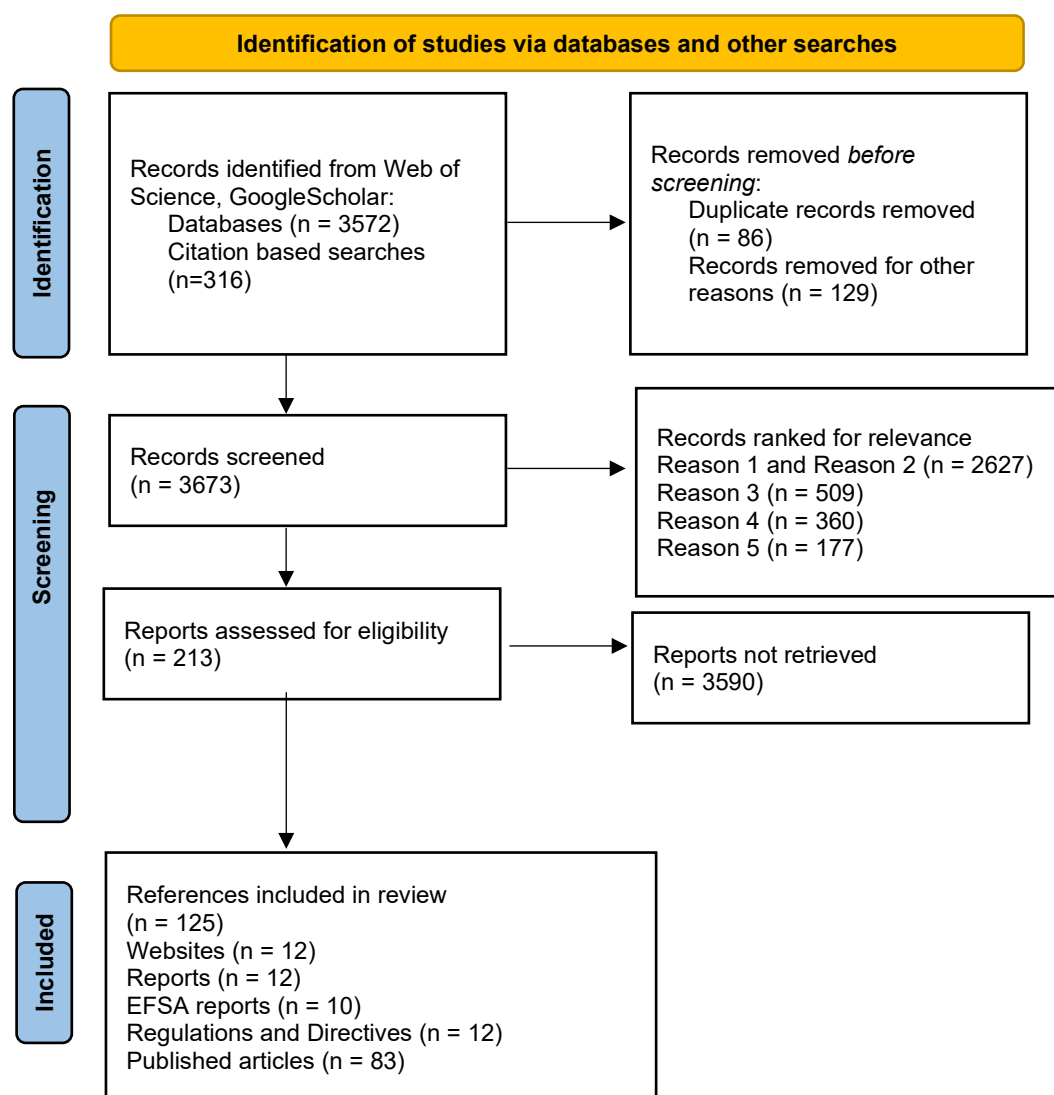


Figure 2. Schematic of the literature search approach

6.5.1 Acquisition of relevant publications

The selected papers were obtained, scrutinised, and grouped into appropriate contaminant areas, such as “those for the detailed review”.

6.5.2 Extract information for analysis

The body of the review and data gap analysis was prepared from the information sourced. The review critically discussed the information in the publications ranked as significant. This data, in combination with information relating to the tonnage of fish by species (or indicator species) landed in Scottish /UK waters (as available), were used to carry out a risk prioritisation and gap analysis exercise.

6.5.3 Review literature identified concerning possible chemical contaminants in wild caught and smoked fish/shellfish/crustaceans and cephalopods

The literature identified above was assigned by topic and reviewed by a team member who was an expert in that contaminant group.

The project team assessed data for both contaminants that are of concern, for example where there are already Maximum Levels in force in the UK or EU, or where emerging issues such as climate change may result in the occurrence of contaminants such as marine biotoxins. These contaminants included anthropogenic pollutants (e.g. per- and poly-fluoro alkyl substances (PFAS), dioxins/furans, PCBs, BTEX, BFRs (e.g. PBDEs, PBBs, HBCDDs and TBBPA); veterinary drug residues, pesticides, active pharmaceutical ingredients (e.g. diclofenac, 17 β -oestradiol, acetaminophen, metformin); inorganic substances (e.g. toxic metals, mercury, cadmium, lead, arsenic and chromium); microplastics and naturally occurring contaminants (e.g. histamine, microcystins and algal toxins).

Where data has been summarised or presented in the main report, where appropriate it is presented in a standardised format using the units for that contaminant that are used for any Maximum Level that is set. For example, results presented in the original source material as ng/g or ng/kg have been converted to μ g/kg. This was to avoid confusion when comparing data sets.

Potential for the formation of hazardous substances during the processing of fish/crustaceans/cephalopods also feature in this review to ensure that known contaminants that may arise during processing were included. Among these various heat-induced compounds, PAHs and heterocyclic amines were mainly associated with the smoking or grilling process. Due to the amino acid composition of fish some toxic compounds like biogenic amines (e.g. histamine) and even nitrosamines may be formed. Particular attention was given to Scottish practises such as traditional methods of production for smoked Scottish salmon and 'Arbroath Smokies'.

This review highlights the current and emerging chemical contaminant risk profile for fish-based food commodities caught and/or processed in Scotland. These were ranked according to the prioritisation scheme described in Section 6.5 (Figure 2), based on chemical hazard and exposure levels. It also highlights evidence gaps that FSS should prioritise through future research and surveillance programmes.

This review supports the FSS and FSA to ensure the chemical contaminants component of its strategy for reducing adverse health effects resulting from consumption of wild caught and smoked fish was based on the most up to date, scientific evidence and enables them to provide advice, guidance and research effectively targeted to the most significant areas of risk within the Scottish and wider UK fishery industry.

7. Current status of the Scottish Sea Fisheries

7.1 Background to Scottish Sea Fisheries

The National Statistics publication, the latest of which at the time the review was conducted was the [Scottish Sea Fisheries Statistics 2022](#), provides annual data on the weight and value of sea fish and shellfish landed by fishing vessels; the structure of the Scottish fishing fleet and employment on Scottish vessels.

The fish species considered as landed in Scotland and exported from Scotland are listed in Table 1, and was based on the most landed and highest value catch species in Scotland from the previous 3 years.

Covid-19 had a detrimental impact on the shellfish and demersal sectors of the Scottish Fishing Industry, due to hospitality closures, whereas the pelagic sector was largely unaffected. However, there are signs that some parts of the fishing industry are recovering from these impacts of Covid-19. The real value of fish landed by Scottish vessels had decreased to a low of £520 million in 2020 due to the impact of Covid-19, the value increased to £617 million in 2022.

The Scottish Fisheries Industry is a key component of the local economy in Scotland. It is important to protect and ensure the safety of fishery produce being landed into Scotland and the rest of the UK by Scottish, other UK and foreign registered vessels.

Table 1. Initial list of wild caught fish and shellfish species for consideration as provided in Annex A of Invitation to Tender. Based on species landed in Scotland and exported from Scotland.

Fish including: Anglerfish Baird's Slickhead Bandfish Bass Bean's Bigscale Blackfish Black Scabbard Fish Blenny Blue Ling Blue Runner Boar Fish Bream Brill Butterfish Catfish Coalfish Cod Comber Common Dragonet Common Fangtooth Dab Dealfish Dogfish Eel Eelpout Flatfish Flounder Garfish Goby Greater Argentine Greater Forkbeard Greater Pipefish Gurnard Haddock Horse Mackerel Hake Halibut Herring Hound John Dory Ling Lizardfish	Lumpsucker Mackerel Megrim Monkfish Mullet Norway Pout Pilchard Plaice Pogge Pollock Pouting Rabbit Fish Rockfish Rockling Round Nose Grenadier Rays Rosefish Rudderfish Saithe Sandeels Sardines Scad Scaldfish Sea Scorpions Shark Skate Smelt Sole Sprats Spurdog Stickleback Sunfish Topknot Torsk/Tusk Trout Tuna Turbot Weever Whiting Witch Wolffish Wrasse Wreckfish	LBMs Scallops Crustaceans including: Common Shore Crab Brown Crab Velvet Crab Spider Crab Common Lobster Squat Lobster Nephrops Norway Lobster Cephalopods including: Squid Octopus Cuttlefish Gastropods including: Periwinkles Whelks
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7.2 Fish categorisation based on feeding patterns

Table 2 lists the fish classified in each category, pelagic, demersal and shellfish / crustaceans, based on landings data provided by FSS. More detailed summaries of landings information are given in Annex A, Tables A.1 - A.5.

Demersal fish are those which live on, or near to the bottom of the sea known as the demersal zone. Demersal fish are also further classified in two groups; benthic that rest on the ocean floor (also known as 'bottom feeders') and benthopelagic, living and feeding near the bottom as well as in midwaters or near the surface.

Pelagic fish get their name from the area that they inhabit called the pelagic zone. Pelagic fish spend most of their life swimming in the water column with little contact with the bottom. The pelagic zone refers to the open, free waters away from the shore, where marine life can swim freely in any direction unhindered by topographical constraints. Different species of pelagic fish are found throughout this zone. Numbers and distributions vary regionally and vertically, depending on availability of light, nutrients, dissolved oxygen, temperature, salinity, and pressure. Pelagic fish are divided, according to length and weight, in large pelagic (like tuna and swordfish) and small pelagic (like anchovy, sardine etc.). Examples of species include forage fish and the predatory fish that feed on them. Coastal pelagic fish inhabit sunlit waters up to about 200m deep, typically above the continental shelf. Oceanic pelagic fish typically inhabit waters below the continental shelf. Examples include larger fish such as mackerel. There is no distinct boundary from coastal to ocean waters so some oceanic fish become partial residents of coastal waters, often during different stages of their lifecycle. However, true oceanic species spend their entire life in the open ocean.

Contamination of pelagic fish will occur from direct uptake from the water and by eating other fish. Biomagnification will occur for substances such as methylmercury and organochlorine compounds for the larger fish that form the top of the food chain.

Similarly for demersal fish sources of contamination will be from water and diet (i.e. other fish they predate) but also contaminated sediment consumed while foraging for food. This is important if chemical contaminants accumulate in sediments on the ocean floor, examples are many environmental pollutants such as PCBs, PBDEs, dioxins etc. which are of concern due to their persistence and long-term stability.

Shellfish are filter feeders, this feeding mechanism means they are susceptible to picking up and accumulating toxins, chemical or bacteriological contaminants from their environment. Species such as mussels and scallops may be used as early indicators of pollution.

Crustaceans are omnivores; some species eat algae, smaller crustaceans such as shrimp are usually scavengers, feeding on very small shellfish and zooplankton, as well as plant debris and dead sea creatures that have fallen to the ocean floor. Larger crustaceans such as lobster and crabs are more likely to be active predators, consuming smaller fish and shellfish, but are also scavengers of other animals and will bioaccumulate contaminants from those sources.

Table 2. Classifications of fish – species included in each group (lists from Scottish Sea Fisheries statistics) for summary tables in Annex A.

Demersal fish	Pelagic fish	Shellfish, crustaceans and cephalopods
Bass Blue ling Brill Cod Haddock Hake Lemon sole Ling Megrim Monkfish Plaice Pollack Saithe Skates and rays Sole Turbot Whiting Wrasses Other demersal* (34% of total catch)	Blue whiting Herring Horse mackerel Mackerel Pilchards Other pelagic* (16% of total catch)	Cockles Cuttlefish Edible crabs Lobsters Nephrops Razor fish Scallops Squid Velvet crabs Whelks Other shellfish* (15% of total catch)

*Details of species included in “other” categories were not provided in the Scottish Sea Fisheries statistics.

7.3 Statistics on Landings – Scottish Vessels and Vessels Landing in Scotland

The data from 2017-21 for landings (tonnage) and value for demersal, pelagic and shellfish are summarised for fish landed by Scottish vessels in Scotland (Annex A, Table A.1), rest of the UK vessels in Scotland (Annex A, Table A.2), foreign vessels into Scotland (Annex A, Table A.3), all vessels into Scotland (Annex A, Table A.4) and Scottish vessels into the rest of the UK (Annex A, Table A.5).

The data from the Scottish Fisheries Statistics (2022) showed a 4 % increase of the real value of landings by Scottish vessels, but there was a 2 % decrease in the amount (tonnage) landed (<https://www.gov.scot/publications/scottish-sea-fisheries-statistics-2022>).

The Scottish commercial fishing industry accounts for a significant proportion of the UK fishing industry. Landings by Scottish vessels in 2022 made up 62 % by value and 67 % of tonnage of all landings by UK vessels, and for the purpose of this report are deemed representative of the UK. The most commonly landed species are shown in Figure 3, and summarised in Table 3.

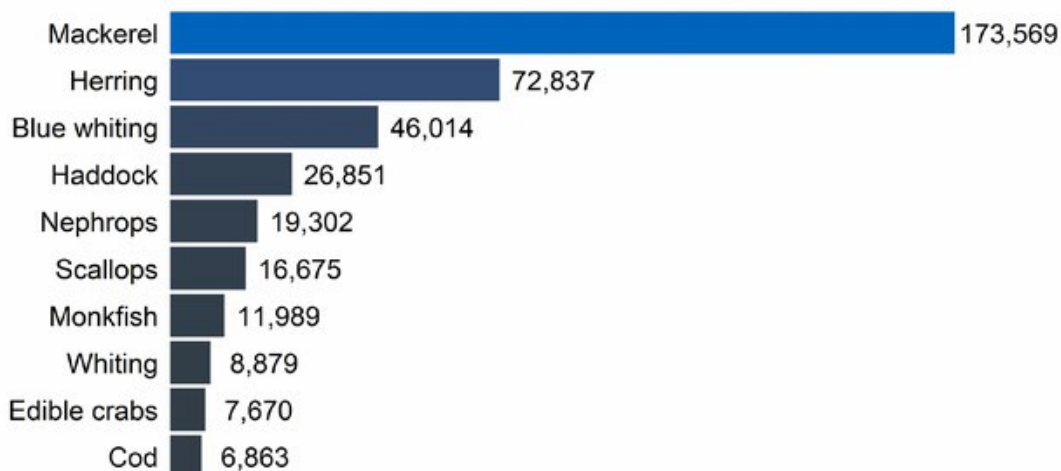


Figure 3. Most commonly landed fish species by Scottish vessels, landed in the UK and abroad (tonnage). Reproduced from <https://www.gov.scot/publications/scottish-sea-fisheries-statistics-2022>.

Table 3. Value and tonnage of most commonly landed fish species in Scotland in 2022 and change from 2021 (data from Scottish Sea Fisheries Statistics 2022).

Classification	Species	Tonnage 2022	Tonnage change from 2021 (%)	Value (thousands of pounds) 2022	Value change from 2021 (%)
Demersal	Haddock	26,851	33	33,998	11
	Monkfish	11,989	-5	35,078	-2
	Cod	6,863	17	25,562	21
	Whiting	8,879	-14	11,832	-20
	Other	28,240	-3	63,657	19
	Total	82,822	6	170,127	9
Pelagic	Mackerel	173,569	-6	213,306	-4
	Herring	72,837	42	49,803	44
	Other	47,005	-29	11,370	-26
	Total	293,411	-3	274,479	1
Shellfish	Nephrops	19,302	-14	82,800	11
	Scallops	16,675	-5	31,742	1
	Edible crabs	7,670	-6	19,119	-1
	Lobsters	1,176	-1	16,255	-14
	Other	8,180	8	22,590	12
	Total	53,003	-7	172,506	5
All fish	Total	429,235	-2	617,112	4

Data available [here](#)

7.4 Classification of fish based on landings and feeding pattern

Mackerel (pelagic fish) remained the most valuable species in 2022. Monkfish was the most valuable demersal species, although the tonnage landed was less than half that of haddock, the most landed demersal species. In addition, in 2022, 19,302 tonnes of nephrops were landed by Scottish vessels with a value of £83 million.

More detailed landings data was available for 2021, and this was used to rank the species that were considered to be most important for this review, in terms of volume of catch and value. Although the tonnage of saithe landed was similar (slightly higher) than cod, in comparison it was low value and it is not generally consumed in the domestic market. Similarly, landings of blue whiting were third largest by tonnage but this fish is generally not consumed directly, but used to make fish meal and oil

that are mainly used in fish feed, animal feed and pet food. Therefore, blue whiting and saithe were not considered as key species for UK consumers.

Four types of shellfish were considered, based on volume of catch and differences in feeding patterns. The only cephalopod caught to any extent was squid and so was used as an example for this group.

For the chemical contamination of fish through the environment it should also be noted that the type of fish demersal or pelagic, oily or non-oily, predatory or non-predatory are important to understand bioaccumulation and biomagnification of chemicals. Information about each of the main key species is listed in Table 4.

Table 4. Key species based on volume and value of catch

Species	Main species from Scottish vessels landed in Scotland					
Dermersal	Feed area	Oily / Non-oily	Fat content ¹	Feeder type	Tonnage 2021	Value 2021 (thousands of pounds)
Cod	Bottom & mid water	Non-oily	0.60%	Predatory	5,696	19,640
Haddock	Bottom	Non-oily	0.60%	Predatory / plankton	20,077	28,812
Monkfish	Bottom	Non-oily	1.50%	Predatory	11,950	32,750
Saithe ²	Bottom	Non-oily	0.50%	Predatory	6,285	6,289
Whiting	Bottom	Non-oily	1.2%	Predatory / scavenge	9,948	13,695
Pelagic						
Blue whiting ²	Middle /opportunistic	Non-oily	3.90%	Predatory	21,349	4,282
Herring	Middle /opportunistic	Oily	9%	Predatory	32,309	19,828
Mackerel	Middle /opportunistic	Oily	Up to 25% ³	Predatory	84,908	96,227
Shellfish						
Edible crabs	Bottom	Non-oily	1.50%	Predatory / scavenge	5,736	13,695
Lobsters	Bottom	Non-oily	1.20%	Predatory / scavenge	1,140	17,311
Nephrops	Bottom	Non-oily	1.40%	Predatory / scavenge	21,815	68,577
Scallops	Bottom	Non-oily	0.80%	Filter	6,715	13,327
Cephalopods						
Squid	Bottom	Oily	7%	Predatory	1,496	5,204

¹Fat content values [here](#) and McCance and Widdowson's Composition of foods integrated dataset (CoFID) but can vary with season, specific habitat, age etc.

²These species included for completeness due to relatively large catch sizes, but not included in contaminants assessment.

³Wallace, P.D., 1991. Seasonal variation in fat content of mackerel (*Scomber scombrus* L.) caught in the western English Channel, Fisheries research Technical Report No. 91.

Table 5. Average and chronic consumption data, (for adults aged 19-64), in g/person/day for key fish species, data from [National Diet and Nutrition Survey Years 1-11](#), 2008-2019.

Species	No. consumers	Chronic consumption (g/person/day)			Acute Consumption (g/person/day)		
		Mean	97.5th Percentile	Max	Mean	97.5th Percentile	Max
Demersal							
Cod (without recipes)	260	33	99	190	120	260	500
Cod (with recipes)	1126	25	69	190	88	230	500
Haddock (without recipes)	111	29	85	98	110	280	390
Haddock (with recipes)	247	24	69	98	87	230	390
Monkfish (without recipes)	9	19	34	38	75	140	150
Whiting (without recipes)	1	17	17	17	69	69	69
Whiting (with recipes)	1	17	17	17	69	69	69
Pelagic							
Herring (without recipes)	10	41	93	99	120	230	240
Herring (with recipes)	25	38	96	99	120	260	290
Mackerel (without recipes)	162	35	78	100	130	300	300
Mackerel (with recipes)	230	31	75	100	100	260	300
Sea bed (pelagic)							
Sole (without recipes)	20	42	66	82	160	200	220
Sole (with recipes)	35	29	77	84	110	200	220
Plaice (without recipes)	11	46	140	150	160	390	410
Plaice (with recipes)	26	34	120	150	130	380	410
Shellfish							
Lobster (without recipes)	16	15	49	53	55	150	160
Lobster (without recipes)	16	15	49	53	55	150	160
Crab (without recipes)	38	17	55	90	68	220	360
Crab (with recipes)	38	17	55	90	68	220	360
Cephalopods							
Squid (without recipes)	35	12	39	40	44	154	160
Squid (with recipes)	53	14	45	53	53	160	210

8. Regulatory Requirements for Chemical Contaminants in Fish and Fisheries Products

8.1 Assimilated EU Legislation

8.1.1 Official Control Requirements for fishery products

Assimilated Regulation (EU) 2019/627 specifies the Official Control requirements in Article 70 and Annex VI, Chapter I. Included in this Official Control requirement is chemical contaminant monitoring to control compliance with Regulation (EC) 1881/2006 and microbiological controls in terms of Regulation (EC) 2073/2005 (both assimilated). Products, which must be compliant, are “fishery products” defined in Assimilated Regulation (EC) 853/2004 as *“all seawater or freshwater animals (except for live bivalve molluscs, live echinoderms, live tunicates and live marine gastropods, and all mammals, reptiles and frogs) whether wild or farmed and including all edible forms, parts and products of such animals.”*

8.1.2 Maximum levels (MLs) permitted for fishery products

Assimilated Regulation (EC) 1881/2006, Annex I, sets out maximum levels permitted for the contaminants lead, cadmium, mercury, dioxins & PCBs and PAHs. A summary of where maximum levels apply for chemical contaminants in fish and fishery products is given in Table 5.

Table 6. Summary of Regulations for Chemical Contaminants in Fishery products

Foodstuff	Environmental Contaminants			Inorganic contaminants				Process Contaminants
	Dioxins	PCBs	PFAS	As	Cd	Hg	Pb	PAHs
Cephalopods								
Crustaceans								
Bivalve molluscs								
Muscle meat fish								
Smoked fish								



Assimilated Regulation (EC) 1881/2006



Commission Regulation EU 2023/915 (not in force in GB)

Assimilated Regulation (EC) 1881/2006, Annex I, Section 3 sets out the maximum levels for lead, cadmium and mercury in foods. The maximum levels that apply to fish and fishery products are presented in Table 7.

Dioxins and PCBs maximum levels are listed in Annex I, Section 5 of the Regulation, these are summarised for fish and fishery products in Table 8.

Maximum permitted levels for polycyclic aromatic hydrocarbons (PAHs) in relation to fishery products are listed in Annex 1, Section 6 and are summarised in Table 8. The regulation includes MLs for both Benzo-a-pyrene (BaP) and the sum of four other PAHs, known as PAH4 as a result of the EFSA opinion that concluded BaP alone is not a suitable indicator for the occurrence of PAHs in food (EFSA, 2008). Fresh, chilled or frozen bivalve molluscs (Annex I, paragraph 6.1.6) fall within the scope of this paper. Checks on these products would fall within the scope of official controls as for other wild caught fish.

Smoked fish, smoked fish products and smoked bivalve molluscs are reviewed under a different category as these types of products are smoked after the point of first sale. These are processed products, any PAHs present occur (or are increased) as a result of the smoking process and it is the responsibility of the FBO to ensure that their product is safe to place on the market. However, these products are within the scope of this review as the purpose is to identify and summarise available data and identify where further testing may be required to provide more information to allow consumer exposure and risk assessment to be carried out.

Maximum permitted levels for dioxins and PCBs are set out in Annex 1, Section 6 of the Regulation and are summarised for fish and fishery products in Table 10.

Assimilated Regulation (EC) 2073/2005, Annex I, Chapter 1 details the microbiological limits relevant to this paper, namely, at paragraph 1.26, histamine in relation to fish products from fish species associated with a high amount of histidine. These are summarised in Table 11. The regulation sets maximum levels for histamine in fisheries products associated with a high level of histidine (particularly fish species of the families: *Scombridae*, *Clupeidae*, *Engraulidae*, *Coryfenidae*, *Pomatomidae*, and *Scombrosidae*) and in fishery products which have undergone enzyme maturation treatment in brine, manufactured from fish species associated with a high amount of histidine.

Live bivalve molluscs (LBMs) are not considered to fall within the definition of 'fishery product' however they are subject to their own official control requirements met by the FSS monitoring programme. Scallops are not subject to monitoring under that programme and as such fall within the scope of this paper in relation to lead, cadmium and PAHs. Gastropods are considered bivalve molluscs for the purposes of interpretation and application of Assimilated Regulation (EC) 1881/2006 as a result of the definition contained in Assimilated Regulation (EU) 1379/2013, Annex I, categories (c) and (i). As such, they fall within the scope of this paper in relation to lead, cadmium and PAHs.

8.1.3 Maximum permitted levels for fishery products introduced in the EU since EU Exit

Since EU Exit the European Commission has published new Regulations amending Regulation (EC) No 1881/2006 reducing the maximum level of mercury in some fish species (Commission Regulation (EU) 2022/617) and introducing maximum levels for PFAS (Regulation (EU) 2022/2388). These amendments, and therefore the maximum levels they stipulate, do not apply in GB, but are summarised in Table 6 (mercury) and Table 10 (PFAS).

Furthermore Regulation (EC) 1881/2006 was replaced in the EU by Regulation (EU) 2023/915. Assimilated European Regulation (EC) 1881/2006 remains in force in Great Britain.

Table 7. Maximum levels for metals in fish and fishery products

Chemical Contaminant	Regulation	Maximum Levels (mg/kg wet weight, unless otherwise stated)	
Cadmium (Cd)	Assimilated Regulation (EC) No. 1881/2006	Muscle meat of fish, excluding species listed in points 3.2.13, 3.2.14 and 3.2.15:	0.05
		3.2.13 Muscle meat of the following fish: mackerel (<i>Scomber</i> species), tuna (<i>Thunnus</i> species, <i>Katsuwonus pelamis</i> , <i>Euthynnus</i> species), bichique (<i>Sicyopterus lagocephalus</i>)	0.1
		3.2.14 Muscle meat of the following fish: bullet tuna (<i>Auxis</i> species):	0.15
		3.2.15 Muscle meat of the following fish: anchovy (<i>Engraulis</i> species), swordfish (<i>Xiphias gladius</i>) sardine (<i>Sardina pilchardus</i>)	0.25
		3.2.16 Crustaceans: muscle meat from appendages and abdomen. In case of crabs and crab-like crustaceans (<i>Brachyura</i> and <i>Anomura</i>) muscle meat from appendages	0.5
		3.2.17 Bivalve molluscs	1
		3.2.18 Cephalopods (without viscera)	1
Lead (Pb)	Assimilated Regulation (EC) No. 1881/2006	3.1.8 Muscle meat of fish	0.3
		3.1.9 Cephalopods	0.3
		3.1.10 Crustaceans	0.5
		3.1.11 Bivalve molluscs	1.5

Chemical Contaminant	Regulation	Maximum Levels (mg/kg wet weight, unless otherwise stated)	
Mercury (Hg) (NB – regulation does not specify between elemental and methyl (organic) mercury due to analytical limitations)	Assimilated Regulation (EC) No. 1881/2006	3.3.1 Fishery products and muscle meat of fish, excluding species listed in 3.3.2. The maximum level for crustaceans applies to muscle meat from appendages and abdomen. In case of crabs and crab-like crustaceans (<i>Brachyura</i> and <i>Anomura</i>) it applies to muscle meat from appendages	0.5
		3.3.2 Muscle meat of the following fish: anglerfish (<i>Lophius</i> species), Atlantic catfish (<i>Anarhichas lupus</i>), bonito (<i>Sarda sarda</i>), eel (<i>Anguilla</i> species), emperor, orange roughy, rosy soldierfish (<i>Hoplostethus</i> species), grenadier (<i>Coryphaenoides rupestris</i>), halibut (<i>Hippoglossus hippoglossus</i>), kingklip (<i>Genypterus capensis</i>), marlin (<i>Makaira</i> species), megrim (<i>Lepidorhombus</i> species), mullet (<i>Mullus</i> species), pink cusk eel (<i>Genypterus blacodes</i>), pike (<i>Esox lucius</i>), plain bonito (<i>Orcynopsis unicolor</i>), poor cod (<i>Tricopterus minutes</i>), Portuguese dogfish (<i>Centroscymnus coelolepis</i>), rays (<i>Raja</i> species), redfish (<i>Sebastes marinus</i> , <i>S. mentella</i> , <i>S. viviparus</i>), sail fish (<i>Istiophorus platypterus</i>), scabbard fish (<i>Lepidopus caudatus</i> , <i>Aphanopus carbo</i>), seabream, pandora (<i>Pagellus</i> species), shark (all species), snake mackerel or butterfish (<i>Lepidocybium flavobrunneum</i> , <i>Ruvettus pretiosus</i> , <i>Gempylus serpens</i>), sturgeon (<i>Acipenser</i> species), swordfish (<i>Xiphias gladius</i>), tuna (<i>Thunnus</i> species, <i>Euthynnus</i> species, <i>Katsuwonus pelamis</i>)	1

	Commission Regulation (EU) 2023/915 (does not apply in GB)	Cephalopods Marine gastropods Anchovy (<i>Engraulis species</i>) Alaska pollock (<i>Theragra chalcogrammus</i>) Atlantic cod (<i>Gadus morhua</i>) Atlantic herring (<i>Clupea harengus</i>) Basa (<i>Pangasius bocourti</i>) Carp (species belonging to the Cyprinidae family) Common dab (<i>Limanda limanda</i>) Mackerel (Scomber species) European flounder (<i>Platichthys flesus</i>) European plaice (<i>Pleuronectes platessa</i>) European sprat (<i>Sprattus sprattus</i>) Mekong giant catfish (<i>Pangasianodon gigas</i>) Pollock (<i>Pollachius pollachius</i>) Saithe (<i>Pollachius virens</i>) Salmon & Trout (<i>Salmo</i> species and <i>Oncorhynchus</i> species, except <i>Salmo trutta</i>) Sardine or Pilchard (<i>Dussumieria</i> species, <i>Sardina</i> species, <i>Sardinella</i> species and <i>Sardinops</i> species) Sole (<i>Solea solea</i>) Striped catfish (<i>Pangasianodon hypophthalmus</i>) Whiting (<i>Merlangius merlangus</i>)	0.3
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Table 8. Maximum levels for PAHs in fish and fishery products

PAHs	Maximum levels (µg/kg)		
	Matrix	Benzo(a)pyrene	Sum of benzo(a)pyrene, benzo(a)anthracene, benzo(b)fluoranthene and chrysene
Assimilated Regulation (EC) No. 1881/2006	6.1.5 Muscle meat of smoked fish and smoked fishery products, excluding fishery products listed in points 6.1.6 and 6.1.7. The maximum level for smoked crustaceans applies to muscle meat from appendages and abdomen. In case of smoked crabs and crab-like crustaceans (<i>Brachyura</i> and <i>Anomura</i>) it applies to muscle meat from appendages.	2	12
	6.16. Smoked sprats and canned smoked sprats (<i>Sprattus sprattus</i>); Smoked Baltic herring ≤14 cm length and canned smoked Baltic herring ≤14 cm length (<i>Clupea harengus membras</i>); Katsuobushi (dried bonito, <i>Katsuwonus pelamis</i>); bivalve molluscs (fresh, chilled or frozen); heat treated meat and heat treated meat products sold to the final consumer	5	30
	6.1.7 Bivalve molluscs (smoked)	6	35

Table 9. Maximum levels for dioxins and PCBs in fish and fishery products

Dioxins & PCBs		Maximum levels		
Regulation	Matrix	Sum of dioxins (WHO-PCDD/F-TEQ)	Sum of dioxins and dioxin-like PCBs (WHO-PCDD/F-PCB- TEQ)	Sum of PCB28, PCB52, PCB101, PCB138, PCB153 and PCB180 (ICES – 6)
Assimilated Regulation (EC) No. 1881/2006	5.3 Muscle meat of fish and fishery products and products thereof, with the exemption of: -wild caught eel - wild caught spiny dogfish (<i>Squalus acanthias</i>) - wild caught fresh water fish, with the exception of diadromous fish species caught in fresh water - fish liver and derived products - marine oils The maximum level for crustaceans applies to muscle meat from appendages and abdomen. In case of crabs and crab-like crustaceans (<i>Brachyura</i> and <i>Anomura</i>) it applies to muscle meat from appendages	3.5 pg/g wet weight	6.5 pg/g wet weight	75 ng/g wet weight

	5.4 Muscle meat of wild caught fresh water fish, with the exception of diadromous fish species caught in fresh water, and products thereof	3.5 pg/g wet weight	6.5 pg/g wet weight	125 ng/g wet weight
	5.4a Muscle meat of wild caught spiny dogfish and products thereof	3.5 pg/g wet weight	6.5 pg/g wet weight	200 ng/g wet weight
	5.5 Muscle meat of wild caught eel (<i>Anguilla anguilla</i>) and products thereof	3.5 pg/g wet weight	10 pg/g wet weight	300 ng/g wet weight
	5.6 Fish liver and derived products thereof with the exception of marine oils referred to in point	-	20.0 pg/g wet weight	200 ng/g wet weight
	5.7 Marine oils (fish body oil, fish liver oil and oils of other marine organisms intended for human consumption)	1.75 pg/g fat	6.0 pg/g fat	200 ng/g fat

Table 10. Maximum levels for histamine in fish and fishery products

	Histamine, Maximum Level
Assimilated Regulation (EC) No. 2073/2005	For fishery products, n = 9, c = 2, m = 100mg/kg, M = 200mg/kg
	For fishery products that have undergone enzyme maturation in brine, n = 9, c = 2, m = 200mg/kg, M = 400mg/kg

Table 11. EU Maximum Levels for Perfluoroalkyl substances in fish and fishery products

European Regulation (EU) 2023/915 (does not apply in GB).						
4.2 Perfluoroalkyl substances	Maximum level (µg/kg)					Notes
Matrix	PFOS	PFOA	PFNA	PFHxS	Sum of PFOS, PFOA, PFNA and PFHxS	1
4.2.2.1.1 Muscle meat of fish, except products listed in 4.2.2.1.2 and 4.2.2.1.3 Muscle meat of fish listed in 4.2.2.1.2 and 4.2.2.1.3, in case it is intended for the production of food for infants and young children	2	0.2	0.5	0.2	2	

4.2.2.1.2 Muscle meat of the following fish, in case it is not intended for the production of food for infants and young children: Baltic herring (<i>Clupea harengus membras</i>); Bonito (<i>Sarda</i> and <i>Orcynopsis</i> species); Burbot (<i>Lota lota</i>); European sprat (<i>Sprattus sprattus</i>); Flounder (<i>Platichthys flesus</i> and <i>Glyptocephalus cynoglossus</i>); Grey mullet (<i>Mugil cephalus</i>); Horse mackerel (<i>Trachurus trachurus</i>); Pike (<i>Esox</i> species); Plaice (<i>Pleuronectes</i> and <i>Lepidopsetta</i> species); Sardine and pilchard (<i>Sardina</i> species); Seabass (<i>Dicentrarchus</i> species); Sea catfish (<i>Silurus</i> and <i>Pangasius</i> species); Sea lamprey (<i>Petromyzon marinus</i>); Tench (<i>Tinca tinca</i>); Vendace (<i>Coregonus albula</i> and <i>Coregonus vandesius</i>); Silverly lightfish (<i>Phosichthys argenteus</i>); Wild salmon and wild trout (wild <i>Salmo</i> and <i>Oncorhynchus</i> species); Wolf fish (<i>Anarhichas</i> species)	7	1	2.5	0.2	8	
4.2.2.1.3 Muscle meat of the following fish, in case it is not intended for the production of food for infants and young children: Anchovy (<i>Engraulis</i> species); Babel (<i>Barbus barbus</i>); Bream (<i>Abramis</i> species); Char (<i>Salvelinus</i> species); Eel (<i>Anguilla</i> species); Pike-perch (<i>Sander</i> species); Perch (<i>Perca fluviatilis</i>); Roach (<i>Rutilus rutilus</i>); Smelt (<i>Osmerus</i> species); Whitefish (<i>Coregonus</i> species other than those listed in 4.2.2.1.2)	35	8	8	1.5	45	
4.2.2.1.4 Crustaceans and bivalve molluscs	3	0.7	1	1.5	5	2

Notes:

1. The maximum level applies to the wet weight.

PFOS: perfluorooctane sulfonic acid

PFOA: perfluorooctanoic acid

PFNA: perfluorononanoic acid

PFHxS: perfluorohexane sulfonic acid

For PFOS, PFOA, PFNA, PFHxS and their sum, the maximum level refers to the sum of linear and branched stereoisomers, whether they are chromatographically separated or not.

For the sum of PFOS, PFOA, PFNA and PFHxS, maximum levels refer to lower bound concentrations, which are calculated on the assumption that all the values below the limit of quantification are zero.

2. For crustaceans, the maximum level applies to muscle meat from appendages and abdomen, that means, that the cephalothorax of crustaceans is excluded. In case of crabs and crab-like crustaceans (Brachyura and Anomura), the maximum level applies to the muscle meat from appendages.

In case of *Pecten maximus*, the maximum level applies to the adductor muscle and gonad only. For canned crustaceans, the maximum level applies to the whole content of the can. As regards the maximum level for the whole composite product, Article 3(1), point (c) and Article 3(2) apply.

9. Contaminants of concern in fish and fishery products

The main measures to protect consumers from exposure to harmful levels of contaminants in fish and seafood are set out in the UK Marine Strategy Part Three (HM Government, 2015) and include Assimilated Regulation (EC) 1881/2006 as amended, which sets out maximum levels for chemical contaminants in food. Under Assimilated Regulation (EC) 178/2002, establishing the general principles of food law, action to protect public health can also be taken for unregulated contaminants on the basis of a risk assessment. Consumer protection is enhanced through precautionary advice to restrict the consumption of certain species at higher risk of contamination, such as oily fish (dioxins, polychlorinated biphenyls) and large predators (mercury).

There are also studies undertaken for the purpose of monitoring the marine environment. The most recent review was published in 2021. It stated there is a considerable amount of data available for the legacy OSPAR Coordinated Environment Monitoring Programmes (CEMP) chemicals (polycyclic aromatic hydrocarbons (PAHs), polybrominated diphenyl ethers (PBDEs), polychlorinated biphenyls (PCBs) and the trace metals cadmium, mercury and lead) which are monitored annually in biota and sediment around Scotland. The review highlighted Contaminants of Emerging Concern (CEC) which should be considered for inclusion in future monitoring, these were: dechloranes, alternative brominated flame retardants, phosphorous flame retardants, antifoulants, per- and polyfluorinated substances (PFAS), benzotriazoles, siloxanes, anticorrosion agents and pharmaceuticals. The pharmaceuticals reported most widely in the environment and that should be considered for inclusion were caffeine and paracetamol (Webster and Lacaze, 2021).

Food Standards Scotland Risk Assessment Team carried out a review in 2021 to collate available data from contaminant surveys of marine species undertaken in Scotland and the UK. The results of the assessment are presented with other data in Table 16 to Table 21. Many of the studies contained results for several classes of contaminants.

9.1 Chemical Contaminant Analysis of Shellfish from Classified Harvesting Areas

The FSS summary included the results of the chemical monitoring of shellfish from classified harvesting areas. Assimilated Commission Implementing Regulation (EU) 2019/627 lays down the official control of Live Bivalve Molluscs (LBMs), such as oysters, mussels and clams. These controls include the classification and monitoring of shellfish production and relaying areas. Shellfish production areas are assessed and classified based on a sanitary survey. The chemical monitoring surveys monitor polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs, dioxins), polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), and heavy metals/trace elements (chromium, manganese, cobalt, nickel, copper, zinc, arsenic (total), selenium, silver, cadmium, mercury (total), and lead). The results of these surveys from 2015-2022 are

summarised below in Table 12. The individual reports and collated data of all individual results from these studies are available as supplementary information.

The results show widespread incidence of all classes of chemical contaminants tested, however very few exceedances of MLs. In fact, only 2 samples in 2015 exceeded MLs, 1 mussel sample exceeded MLs for both Benzo-a-pyrene (BaP) (7.59 µg/kg) and Sum PAH4 (47.08 µg/kg) and 1 scallop sample exceeded PAH MLs (6.06 µg/kg BaP only). These exceedances were from inshore sites of known historical sources of contamination at Loch Leven and Loch Fyne in Scotland respectively and so are not of direct relevance or concern for this review.

Table 12. Summarised results of Chemical Contaminant Analysis of Shellfish from Scottish Classified Harvesting Areas (2015-2022) (Food Standards Scotland, 2021).

Year		No samples	Products tested	Analytes	Results	Comments
2015 ⁽¹⁾		17	Common mussels, Pacific oysters, common cockles, razor clams	Dioxins (PCDDs and PCDFs) Dioxin-like PCBs Non-Dioxin -like PCBs	PCDD/Fs and PCBs in all samples, all within regulatory limits.	
		40	Common mussels, Pacific oysters, common cockles, razor clams, native oysters, queen scallops, surf clams and king scallops	Heavy Metals - Chromium (Cr), Manganese (Mn), Cobalt (Co), Nickel (Ni), Copper (Cu), Zinc (Zn), Arsenic (As), Selenium (Se), Silver (Ag), Cadmium (Cd), Mercury (Hg), Lead (Pb) ⁽²⁾	All regulated metals below MLs.	Metals detected in all samples.
		43	Common mussels, Pacific oysters, common cockles, razor clams, native oysters, queen scallops, surf clams and king scallops	PAHs – 28 compounds including BaP and PAH4.	PAHs detected in all samples. A mussel exceeded BaP and PAH4 ML and a scallop exceeded BaP ML.	Both samples >ML were from sites with historical contamination
2016		28	Common mussels, Pacific oysters, common cockles, carpet clams and razor clams	Dioxins (PCDDs and PCDFs) Dioxin-like PCBs Non-Dioxin -like PCBs	PCDD/Fs and PCBs in all samples, all within regulatory limits.	
		28	Common mussels, Pacific oysters, common cockles, carpet clams and razor clams	Heavy Metals - Chromium (Cr), Manganese (Mn), Cobalt (Co), Nickel (Ni), Copper (Cu), Zinc (Zn), Arsenic (As), Selenium (Se), Silver (Ag), Cadmium (Cd), Mercury (Hg), Lead (Pb)	All regulated metals below ML.	Metals detected in all samples.
		30	Common mussels, Pacific oysters, common cockles, carpet clams and razor clams	PAHs - – 28 compounds including BaP and PAH4.	All samples below ML for BaP and PAH4.	PAHs detected in all samples.

2017	18	Common mussels, Pacific oysters, Common cockles, Surf clams, carpet clams and Razor	Dioxins (PCDDs and PCDFs) Dioxin-like PCBs Non-Dioxin -like PCBs	PCDD/Fs and PCBs in all samples, all within regulatory limits.	
	18	Common mussels, Pacific oysters, common cockles, Surf clams, carpet clams and Razor	Heavy Metals - Chromium (Cr), Manganese (Mn), Cobalt (Co), Nickel (Ni), Copper (Cu), Zinc (Zn), Arsenic (As), Selenium (Se), Silver (Ag), Cadmium (Cd), Mercury (Hg), Lead (Pb)	All regulated metals below ML.	Metals detected in all samples.
	22	Common mussels, Pacific oysters, common cockles, Surf clams, Carpet clams and razor clams	PAHs - 28 compounds including BaP and PAH4.	All samples below ML for BaP and PAH4.	PAHs detected in all samples.
2018	13	Common mussels, Pacific oysters, common cockles, and razor clams	Dioxins (PCDDs and PCDFs) Dioxin-like PCBs Non-Dioxin -like PCBs	PCDD/Fs and PCBs in all samples, all within regulatory limits.	
	20	Common mussels, Pacific oysters, common cockles, razor clams surf clams and native oysters	Heavy metals - Chromium (Cr), Manganese (Mn), Cobalt (Co), Nickel (Ni), Copper (Cu), Zinc (Zn), Arsenic (As), Selenium (Se), Silver (Ag), Cadmium (Cd), Mercury (Hg), Lead (Pb)	All regulated metals below ML.	Metals detected in all samples.
	28	Common mussels, Pacific oysters, common cockles, and Razor clams	PAHs - 28 compounds including BaP and PAH4.	PAHs all below ML for BaP and PAH4	PAHs detected in all samples.
2019	28	Common mussels, Pacific oysters, Common cockles, and razor clams	PAHs – as above	PAHs all below ML for BaP and PAH4.	PAHs detected in all samples.

	28	Common mussels, Pacific oysters, common cockles, and razor clams	Heavy Metals – as above.	All regulated metals below ML.	Metals detected in all samples.
	1	Mussels	Dioxins (PCDDs and PCDFs) Dioxin-like PCBs Non-Dioxin -like PCBs	Below ML	PCDDs, PCDFs and PCBs detected.
2020	5	Common mussels, Pacific oysters, common cockles, surf clams and razor clams	Dioxins (PCDDs and PCDFs) Dioxin-like PCBs Non-Dioxin -like PCBs	PCDD/Fs and PCBs in all samples, all within regulatory limits.	
	18	Common mussels, Pacific oysters, common cockles, surf clams and razor clams	PAHs – as above	PAHs all below ML for BaP and PAH4.	PAHs detected in all samples.
	16	Common mussels, Pacific oysters, common cockles, surf clams and razor clams	Heavy Metals	All regulated metals below ML.	Metals detected in all samples.
2021	13	Common mussels, Pacific oysters, native oysters, common cockles, pullet carpet shells, surf clams and razor clams	Dioxins (PCDDs and PCDFs) Dioxin-like PCBs Non-Dioxin -like PCBs	PCDD/Fs and PCBs in all samples, all within regulatory limits.	
	20	Common mussels, Pacific oysters, native oysters, common cockles, pullet carpet shells, surf clams and razor clams	PAHs- as above	PAHs all below ML for BaP and PAH4.	PAHs detected in all samples.
	26	Common mussels, Pacific oysters, native oysters, common cockles, pullet carpet shells, surf clams and razor clams	Heavy Metals – as above	All regulated metals below ML.	Metals detected in all samples.
2022	20	Common mussels, Pacific oysters, common cockles and razor clams	Dioxins (PCDDs and PCDFs) Dioxin-like PCBs Non-Dioxin -like PCBs	PCDD/Fs and PCBs in all samples, all within regulatory limits.	

	26	Common mussels, Pacific oysters, common cockles and razor clams	PAHs – as above.	PAHs all below ML for BaP and PAH4.	PAHs detected in all samples.
	25	Common mussels, Pacific oysters, common cockles and razor clams	Heavy Metals – as above.	All regulated metals below ML.	Metals detected in all samples.

(1) All data available [here](#)

(2) Regulated metals – lead, mercury and cadmium

Chemical monitoring for shellfish in England, Wales and Northern Ireland is carried out by Food Standards Agency. The results of monitoring for samples collected in England and Wales is available as a data set on the [FSA website](#). Seventy-nine samples are included, all were tested for heavy metals and PAHs. All metal results were below MLs. One sample in 2014 from Merseyside exceeded the ML for PAHs, both BaP and PAH 4. Twenty-three samples were analysed for dioxins and dioxin like-PCBs, all samples were below the MLs. No information about sample type is given. Three additional samples (2 mussels and 1 Pacific oyster) were analysed for PAHs in 2016, all samples were below MLs.

Five samples of mussels and two samples of oysters from Northern Ireland were analysed for PAHs and heavy metals in 2023. In 2022 results of PAHs and heavy metals analysis of seven samples (3 mussels and 4 oysters) were reported. All samples were below MLs (Food Standards Agency, 2023b).

In summary, samples of shellfish have been collected regularly from UK waters from Classified Harvesting Areas and analysed for Dioxins and PCBs, heavy metals and PAHs. In total 225 samples have been analysed from Scottish Classified Harvesting Areas. Only two samples exceeded MLs, both samples were analysed in 2015. These were a mussel that contained 7.59 µg/kg BaP, and 47.08 µg/kg PAH 4 sum and a scallop that contained 6.06 µg/kg BaP. The MLs are 5 µg/kg and 30 µg/kg for PAH 4.

No samples have exceeded MLs for any regulated contaminants since 2016, most recent data is from 2023.

For England and Wales 82 samples have been analysed since 2014. One sample in 2014 from Merseyside exceeded the ML for PAHs, containing 10.59 µg/kg BaP and 52.67 µg/kg PAH 4.

9.2 Anthropogenic pollutants

9.2.1 Polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs) and Polychlorinated biphenyls (PCBs)

The most comprehensive study of fish from Scottish and UK waters is a holistic study of anthropogenic chemical contaminants published in 2018 (Fernandes *et al.*, 2018). The publication reports a Food Standards Agency funded study from 2015 (Fernandes *et al.*, (2015)). It describes the occurrence and spatial distribution of chemical contaminants in

sixteen edible fish species collected from UK and proximate marine waters. Results from the study are summarised in Table 16. PCDD/Fs and PCBs results are also shared in the Contaminants in fish and seafood Marine online assessment tool (Mortimer, 2018). Contaminant occurrence varied with species and location, but all measured contaminants were detected, with sprats, sea bass, sardines, mackerel, and herring showing the highest tissue concentrations. The concentrations of the different contaminants in the various samples were mapped utilising the GPS coordinate data of the capture locations to visualise spatial distribution levels. In terms of catch location, fish sampled from the coasts of southern Britain, north-western France and the Irish Sea appeared to contain proportionately higher levels of some contaminants - e.g. higher levels of PCBs were observed in some fish sampled off the coasts of northern France. In terms of occurrence trends, PCDD/F and PCB concentrations show a modest decline over the last decade but where limited background data is available for emerging contaminants, there is no evidence of downward trends.

In this study 182 samples of edible marine fish were sampled mainly from UK marine regions but extending northerly to the coast of Norway and south to the Algarve. These species (sprats, mackerel, turbot, halibut, herring, grey mullet, sea bass, grey mullet, sardines, etc.) are among those considered to be at the highest risk of contamination with regulated contaminants such as polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs, dioxins), and polychlorinated biphenyls (PCBs).

PCDD/Fs and PCBs were detected in all fish samples at varying concentrations, ranging from 0.03 to 12.5 ng sum WHO-TEQ/kg whole weight, with an average value of 1.4 ng WHO-TEQ/kg whole weight. The sum of ICES-6 PCBs ranged from 0.1 to 145 µg/kg whole weight. However, some species (sea bass, sprats, sardines) showed a greater tendency to bio-accumulate these contaminants with average sum WHO-TEQ values of 2.5, 2.0 and 2.0 ng/kg respectively. These concentrations are lower than those reported (Fernandes *et al.*, 2009b) for fish sampled in the UK 10 years previous with sum WHO-TEQ values of 3.7 and 4.3 ng/kg for seabass and sprat respectively. However, it should be noted that the historical data would have been calculated using WHO-TEF1998 factors which tend to yield higher WHO-TEQ values than when using 2005 WHO-TEFs or the more recent 2022 WHO-TEFs.

A survey of wild caught fish reported in 2025 analysed 51 samples for dioxins and PCBs caught in 2022-23 (FSA Research and Evidence, 2025). The samples analysed were cod (n=5), crab (n=9), cuttlefish (n=3), dog fish (n=1), gurnard (n=1), hake (n=2), herring (n=1), mackerel (n=5), monkfish & anglers (n=3), plaice (n=1), sardines (n=11), sea bass (n=4), skates & rays (n=2), sole (n=2) and squid (n=1) (FSA, 2025). All samples were below the MLs in force (Assimilated Regulation (EC) No 1881/2006).

The last Total Diet Study (TDS) that investigated PCDD/Fs and PCBs was reported in 2012 (Fernandes *et al.* (2012)). Samples for the study were collected in 14 locations (retail) across the UK, and prepared (cooked where required) as normal for consumption. They were composited into the food groups that make up the TDS. The fish group

contained the highest contaminant levels among the food groups. It also showed that the decline in contaminant concentrations relative to earlier TDS data, continued, albeit at a slower rate (4.6 ng/kg WHO-TEQ to 3.5 ng/kg WHO-TEQ). It was reported that the rate may be slower than the figures indicate, since the TEQ calculated in 2012 used WHO-TEF2005 (Van den Berg *et al.* (2006)) which tend to yield lower TEQ values than the data computed in earlier TDS.

Madgett *et al.* (2022) studied the variability (inter- and intra-species variation) of the concentrations and distributions of thirty-two polychlorinated biphenyl (Σ PCB32) congeners and nine polybrominated diphenyl ether (PBDE) congeners in twenty-six species covering four trophic levels from different geographic locations around Scotland. The study looked at the food web, results are presented as pooled samples of demersal and pelagic fish from Scottish waters for PCBs and PBDEs. Species included in the samples were haddock, whiting, plaice, herring, sprat, crab, lobster and squid. Other species were also collected such as starfish, whelks and nephrops. Trophic magnification factors (TMFs) were calculated using a traditional method and a balanced method for both the ICES-7 PCBs and BDE47. There were clear differences in congener percentage distribution between sample categories and species, with differences influenced by physiological processes and eco-biological parameters.

A sampling programme targeting appropriate fish species was conducted in 2013 and 2014 to monitor compliance with Good Environmental Status (GES) for Marine Strategy Framework Directive Descriptor 9. The design was based around existing fish stock assessment research vessel surveys, with fish sampled from each trawling location with a probability proportional to the landings by the Scottish fishing fleet. Haddock, monk and herring were selected based on their importance to the human diet (based on fish landings) and to represent different groups of fish (e.g. high trophic level, high fat content). The muscle tissue was analysed for polychlorinated biphenyls (PCBs) and trace metals. PCBs were mainly below detection limits in monkfish and haddock, but above detection limits in herring where concentrations for the ICES6 CBs ranged from < LoD (in one sample only) to 17.5 µg/kg wet weight. Maximum limits were not exceeded in any individual sample for trace metals or PCBs. It was recommended that it would be sufficient for samples to be taken every 6 years to confirm concentrations are below regulatory maximum levels although this seems to be the latest report available (Scottish Marine and Freshwater Science, 2015).

PXDD/F and PXBs are mixed bromo/chloro analogues of PCDD/F and PCBs and share the same sources and toxicological properties as the other analogues, except that PXBs were never intentionally produced (Falandysz *et al.*, 2012). There have been only a few studies carried out to date on the occurrence of these contaminants in foods including fish (Ohta *et al.*, 2008; Fernandes *et al.*, 2011; (2014), Zacs *et al.*, 2015). The 2015 FSA funded study (Fernandes *et al.*, 2015; 2018) reported PXBs were detected at greater frequency than PXDD/Fs, and PXDFs were detected more frequently than PXDDs. Apart from two sea bass samples, at least one PXDD/F congener was detected in all of the 59

analysed samples. Sum parameters are not reported, values found for individual compounds are indicated below.

Data is available for different fish species for a range of contaminants. Results are also presented in Table 16.

Samples from one study were solely from Scottish waters. Results were compliant where MLs exist.

Results from the Fernandes *et al.* (2015 and 2018) were as follows on a whole weight basis. Samples were collected directly from UK and Northern European waters.

Concentration ranges measured for the Sum WHO-TEQ and Sum ICES-6 PCB were:

- Sardines (n=16) WHO-TEQ 0.63 – 4.37 ng/kg and Sum ICES-6 PCB 5.41 – 54.89 µg/kg
- Mackerel (n=41) WHO-TEQ 0.10 – 7.51 ng/kg and Sum ICES-6 PCB 0.86 – 63.64 µg/kg
- Herring (n=19) WHO-TEQ 0.64 – 2.78 ng/kg and Sum ICES-6 PCB 3.76 – 17.84 µg/kg
- Grey mullet (n=26) WHO-TEQ 0.11 – 2.36 ng/kg and Sum ICES-6 PCB 0.89 – 43.76 µg/kg
- Sprat (n=25) WHO-TEQ 0.23 – 4.35 ng/kg and Sum ICES-6 PCB 1.35 – 28.32 µg/kg
- Sea Bass (n=25) WHO-TEQ 0.35 – 12.49 ng/kg and Sum ICES-6 PCB 2.76 – 144.92 µg/kg
- Turbot (n=16) WHO-TEQ 0.07 – 1.91 ng/kg and Sum ICES-6 PCB 0.52 – 17.20 µg/kg

A survey of wild caught fish reported in 2023 analysed 51 samples for dioxins and PCBs. Samples were taken at wholesale fish markets in England and Wales. The samples analysed were cod (n=5), crab (n=9), cuttlefish (n=3), dog fish (n=1), gurnard (n=1), hake (n=2), herring (n=1), mackerel (n=5), monkfish & anglers (n=3), plaice (n=1), sardines (n=11), sea bass (n=4), skates & rays (n=2), sole (n=2) and squid (n=1) (FSA, 2025). Residues detected in all samples. The highest levels found were: PCDD/F WHO-TEQ upper, 0.57 ng/kg whole (ML is 3.5 ng/kg), PCDD/F + PCB WHO-TEQ upper, 1.79 ng/kg whole (ML is 6.5 ng/kg whole) and SUM of ICES 6 upper, 12.01 µg/kg whole (ML is 75 µg/kg). All samples were below the MLs.

For PXDD/Fs

- Sardines (n=7) min - max for individual congeners <0.005 – 0.175 ng/kg fat weight
- Mackerel (n=13) min - max for individual congeners <0.005 – 0.508 ng/kg fat weight
- Sprat (n=13) min - max for individual congeners <0.005 – 1.627 ng/kg fat weight
- Sea Bass (n=15) min - max for individual congeners <0.005 – 1.267 ng/kg fat weight
- Turbot (n=4) min - max for individual congeners <0.005 – 0.3 ng/kg fat weight

For PXBs

- Sardines (n=7) min - max for individual congeners <0.005 – 9.428 ng/kg fat weight
- Mackerel (n=13) min - max for individual congeners <0.005 – 14.582 ng/kg fat weight
- Sprat (n=13) min - max for individual congeners <0.005 – 17.673 ng/kg fat weight
- Sea Bass (n=15) min - max for individual congeners <0.005 – 42.032 ng/kg fat weight
- Turbot (n=4) min - max for individual congeners <0.007 – 7.606 ng/kg fat weight

- The TDS samples (fish group) contained PCDD/F 0.12 ng/kg WHO TEQ (Whole) upper bound
- Non-ortho substituted PCB concentrations – 0.19 ng/kg WHO TEQ (Whole) upper bound
- Ortho substituted PCB concentrations – 0.015 ng/kg WHO TEQ (Whole) upper bound
- PCDD/Fs and PCBs: WHO-TEQ and ICES-6, upper bound summary

Madgett *et al.*, 2022 reported results for Σ PCB32 for pooled samples taken directly from Scottish waters, results expressed as $\mu\text{g/kg}$ lipid weight:

- Pelagic Roundish muscle 198.8–373.9 $\mu\text{g/kg}$
- Pelagic Roundfish Liver 668.6–1202 $\mu\text{g/kg}$
- Demersal Roundfish Muscle <0.02–1858 $\mu\text{g/kg}$
- Demersal Roundfish Liver 57.91–3065 $\mu\text{g/kg}$
- Flatfish Muscle <0.02–40.91 $\mu\text{g/kg}$
- Flatfish Liver <0.05–899.2 $\mu\text{g/kg}$

9.2.2 Brominated flame retardants (BFRs)

9.2.2.1 Polybrominated diphenylethers (PBDEs)

PBDEs are mass produced brominated flame retardants (BFRs) that were incorporated into a number of commonly used commercial materials such as plastics, rubbers, textiles and electronic components. Their occurrence in food has been investigated in studies that also target PBDD/Fs and PBBs (Food Standards Agency, 2006; Fernandes *et al.*, 2009a; Fernandes *et al.*, 2009b; Fernandes *et al.*, 2015; Fernandes *et al.*, 2018) but unlike these contaminants, they show more frequent and abundant occurrence. Fish, particularly oily fish species, generally tend to show higher levels of contamination than other food types. In a 2009 study PBDEs were detected in all samples of fish, fresh water, marine and shellfish (Fernandes *et al.*, 2009b).

An FSA study to investigate the occurrence of existing and emerging (and novel) brominated flame retardant (BFR) chemicals in foods was carried out in 2015 (Fernandes,

et al., 2015a). More than 400 samples, including fish and shellfish, were analysed for total bromine content. A subset were identified as the most likely to contain PBDE and HBCD, these were mainly fish and shellfish, but also included some meat and offal samples. PBDEs occurred in practically all of the measured food and feed samples, in the range of 0.02 µg/kg to 8.91 µg/kg (0.11 µg/kg to 9.63 µg/kg for animal feeds) for the sum of the 17 measured congeners, with highest concentration ranges, and mean values being observed in fish, processed foods and fish feeds.

In the FSA funded study of 2015 (Fernandes *et al.*, 2015; 2018) PBDEs were observed in all samples with all measured congeners being detected apart from BDE-126. For the sum of all measured PBDEs, concentrations ranged from 0.04 µg/kg to 8.87 µg/kg w/w (corresponding to 0.04 µg/kg to 8.63 µg/kg for EU10 list of PBDEs commonly tested for). The highest average values were observed for herring, sea bass, mackerel and sprat (2.08, 2.0, 1.45 and 1.27 µg/kg respectively). The average concentration across all samples was 1.2 µg/kg (or approximately 35 µg/kg on a fat weight basis). (Fernandes *et al.*, 2015; 2018). These results are summarised in Table 16.

Webster *et al.*, (2008) reported data on PBDEs in samples of sediment and biota (fish liver, fish muscle and mussels) from a number of locations around Scotland. PBDEs were measured in rope grown mussels and wild mussels collected from 5 sites around Scotland in 2006. Total PBDE concentrations (sum of tri- to hepta-BDEs) ranged from <LOD to 2.36 µg/kg wet weight, with the highest concentrations found in mussels close to Aberdeen harbour. Most PBDE congeners were below LOD but where residues were detected, BDE47 and BDE99 were the main congeners. PBDEs were detected at low concentrations in flatfish muscle from 11 sites around Scotland, with total PBDE concentrations ranging from <LOD to 1.67 µg/kg wet weight, with BDE47 being the dominant congener. PBDEs were also measured in fish liver collected from Garroch Head in the Clyde, a former sewage sludge dump site, with total PBDE concentrations ranging from 4.1–536.1 µg/kg wet weight.

Webster *et al.*, (2009) tested PBDEs in three species of deep-water fish collected from the Rockall Trough to the west of Scotland, in 2006. PBDEs were detected in both the liver and muscle of the deep-water fish.

Madgett *et al.*, 2022, analysed a range of fish from Scottish waters for PBDEs, results were presented as ΣPBDE9 for pooled data (demersal shark and roundfish, pelagic roundfish and flatfish with categories for liver, muscle and whole for each). Pelagic roundfish liver pools had a significantly higher ΣPBDE9 (8.759–106.7 LW) than the other shark and fish categories, although the highest concentration was measured in one of the pools of flatfish liver (131.8 µg/kg LW). There was also a regional difference observed for the fish species and catshark liver categories. The sample pools collected from the Irish Sea (Clyde and Solway) (particularly the Clyde) had a significantly higher mean concentration of ΣPBDE9 than those from the Northern North Sea and Scottish Continental Shelf. The authors noted this agrees with other previous findings of Webster *et al.* (2008) and Scotland's Marine Assessment 2020 (Marine Scotland, 2020b). In both

cases, the conclusion was that the highest concentrations of PBDEs around Scotland occurred in the Irish Sea (Clyde and Solway) from the Firth of Clyde, an industrial area. EFSA recently published a Scientific Opinion on the Update of the risk assessment of Polybrominated diphenyl ethers (PBDEs) in Food (EFSA, 2024). This stated the main sources in the diet are meat and fish and seafood. The experts concluded that PBDEs may have an adverse effect on the reproductive and nervous systems and that it is likely that current dietary exposure to PBDEs in the European population raises a health concern. The draft opinion recommended continued monitoring of the presence of PBDEs in food.

In summary, PBDEs have been detected in fish from UK waters, some Scottish samples were included, although there were limited sample numbers. Samples were last taken in 2015. Results are presented in Table 16.

Concentration ranges measured for the EU10 were:

- Sardines (n=16) 0.13 – 2.12 µg/kg
- Mackerel (n=41) 0.14 – 3.65 µg/kg
- Herring (n=19) 0.58 – 8.63 µg/kg
- Grey mullet (n=26) 0.08 – 5.36 µg/kg
- Sprat (n=25) 0.31 – 4.56 µg/kg
- Sea Bass (n=25) 0.27 – 5.64 µg/kg
- Turbot (n=16) 0.06 – 0.79 µg/kg
- Various shark species (n=14) 0.04 – 1.91 µg/kg

The most recent EFSA risk assessment concluded that it is likely that current dietary exposure to PBDEs raises a health concern in the European population although there is uncertainty about the relative toxicity of some of the congeners due to gaps in the toxicity data for them.

9.2.2.2 Polybrominated dioxins and biphenyls (PBDD/Fs and PBBs) and other BFRs

Polybrominated dioxins and biphenyls - PBDD/Fs and PBBs occurrence in food in the UK have been confirmed in earlier studies funded by the FSA, including an investigation on TDS samples carried out in 2005 (Food Standards Agency, 2006). The study showed a greater frequency of occurrence of PBDFs, whilst PBBs generally showed very low occurrence.

A later study on individual foods including fish and shellfish (Fernandes *et al.*, 2009a) confirmed these findings.

Concentrations of non-ortho substituted PBBs ranged from <0.001 to 0.002 TEQ ng/kg whole weight PBB, the majority were less than LOQ.

PBDD/Fs ranged from 0.005 (torsk and monkfish) to 0.041 (spurdog) TEQ ng/kg whole weight PBDD/Fs. The next two highest levels (0.036 and 0.029 TEQ ng/kg whole weight PBDD/Fs) were found in a mackerel and herring, two key species for this study.

A further study funded by the FSA found similar results (Fernandes *et al.*, 2015; 2018). This also reported comparable results with the fish group from the TDS study of 2012 (Fernandes *et al.*, 2012). In the same TDS study the fish group sample was also analysed for Hexabromocyclododecane (HBCD) and Tetrabromobisphenol A (TBBPA) Hexabromobenzene (HBB), bis 2,4,6-tribromophenoxy ethane (BTBPE) and decabromodiphenyl ethane (DBDPE). Residues of Alpha-HBCD (0.08 µg/kg whole weight), DBDPE (0.23 µg/kg whole weight and BDE209 (0.17 µg/kg whole weight) were measured. All other analytes were <LOQ.

In the FSA study of BFRs in 2015 (Fernandes, *et al.*, 2015a) α-HBCD remained the most frequently detected HBCD diastereomer, as in previous studies. HBCD occurrence for food and animal feed ranged from <0.01 µg/kg to 10.1 µg/kg (α-HBCD in fish) and 0.66 µg/kg (α-HBCD in fish feed).

Falandysz *et al.*, (2020) investigated the occurrence of polybrominated biphenyls (PBBs), a legacy flame retardant, in fishery products such as medicinal grade cod liver oils and canned liver products, sourced from the North Atlantic during 1972–2017. It also assessed the dietary and supplementary (the oils were commonly administered as dietary supplements to children and youth) intake of PBBs from these products. Summed *ortho*-PBB concentrations ranged from 770 to 1400 pg/g fat in the oils and from 99 to 240 pg/g whole weight in canned livers, with PBB-49, 52, 101 and 153 accounting for most of these levels. Among the more toxic non-*ortho*-PBBs, PBB-126 and PBB-169 were not detected, but PBB-77 concentrations ranged from 0.6 to 5.78 pg/g fat in the oils and 0.06 to 0.126 pg/g whole weight in canned livers.

Webster *et al.*, (2009) tested halogenated persistent organic pollutants (chlorobiphenyls (CBs), polybrominated diphenyl ethers (PBDEs), hexabromocyclododecane (HBCD) and tetrabromobisphenol-A (TBBP-A)) and total lipid content in the liver and muscle of three species of deep-water fish (black scabbard, roundnose grenadier and black dogfish) collected from the Rockall Trough to the west of Scotland, in 2006. HBCD and TBBP-A were not detected in any of the deep-water fish.

The long-term exposure to BFRs via fish consumption was calculated for the Dutch population using data from a survey of 44 samples of fish (freshwater, marine and shellfish) conducted by RIVO-Netherlands Institute for Fisheries Research (van Leeuwen *et al.*, 2006). Samples were analysed for polybrominated diphenyl ethers (PBDE), tetrabromobisphenol-A (TBBP-A) its methylated derivative (me-TBBP-A), and hexabromocyclododecane (HBCD), including its alpha-, beta- and gamma-diastereomers (van Leeuwen *et al.*, 2008).

Non-oily fish from the North Sea / Atlantic contained lower concentrations of BDEs than oily fish (herring) from the same area. The highest median and maximum levels of HBCD were found in freshwater eels. TBBP-A was below the LOD in most samples, Me-TBBP-A was detected in some fish samples but at concentrations close to the LOD.

The data was used to calculate long term exposure to BFRs for the Dutch population. The median intake of the sum of the BDE congeners was 0.18 ng/kg bw/day (using LOD values assumed to be 0.5 x LOD). On this basis, 2.5% of the Dutch population had a total BFR intake above 3.96 ng/kg bw/day via fish consumption only, although calculations were based on total population including both consumers and non-consumers of fish. Herring was the main contributor of all fish and shellfish species studied to the BFR intake. EFSA is working on updates of the EFSA scientific opinions on brominated flame retardants, taking into account new occurrence data and any newly available scientific information.

In March 2021 EFSA published a scientific opinion on hexabromocyclododecanes (HBCDs) in food, (EFSA, 2021). This included data for a range of foods from seven countries, including the UK, from between 2000 and 2010. Experts concluded that current dietary exposure to HBCDs across European countries does not raise a health concern. (EFSA, 2021).

In summary, PBDFs were detected more frequently than PBDDs and PBBs in reported studies. Limited sample numbers from Scottish waters. Most higher levels of PBBs were detected in waters off the south coast of England or northern France. HBCD and TBBP-A were not detected in samples from Scottish waters in samples from 2006.

Concentration ranges measured for the PBDD/F – whole weight basis, upper bound were reported by Fernandes *et al.*, (2015 and 2018):

- Sardines (n=7) 0.012 – 2.12 ng/kg
- Mackerel (n=17) 0.01 – 0.031 ng/kg
- Herring (n=7) 0.014 – 0.034 ng/kg
- Grey mullet (n=8) 0.008 – 0.021 ng/kg
- Sprat (n=11) 0.007 – 0.026 ng/kg
- Sea Bass (n=15) 0.010 – 0.022 ng/kg
- Turbot (n=6) 0.001 – 0.013 ng/kg
- From the 2012 TDS study results for the fish group were:
- Non-ortho-substituted PBB concentrations <0.001 TEQ (ng/kg Whole) upper
- PBDD/F concentrations – 0.016 TEQ (ng/kg Whole) upper

There is very little UK data for other brominated flames retardants, there are some studies for Hexabromocyclododecane (HBCDD), but fewer for Tetrabromobisphenol A (TBBPA), Hexabromobenzene (HBB), bis 2,4,6-tribromophenoxy ethane (BTBPE) and decabromodiphenyl ethane (DBDPE). The recent EFSA opinion indicated current dietary exposure to HBCDs across European countries does not raise a health concern.

9.2.3 BTEX compounds

BTEX is not one chemical, but a group of chemical compounds: Benzene, Toluene, Ethylbenzene and Xylenes. BTEX are made up of naturally occurring chemicals that are found mainly in petroleum products, oil spills are a source of these and volatile organic compounds, e.g. hexane, heptane etc. No relevant publications for Scottish waters were found. A paper by Meniconi *et al.*, (2002) described how total petroleum hydrocarbons (TPH), n -alkanes, isoprenoids, unresolved complex mixtures (UCM), volatile monoaromatic compounds — benzene, toluene, ethylbenzene and xylenes (BTEX), parent and alkylated homologues polycyclic aromatic hydrocarbons (PAH), and terpanes and steranes were characterised for determining correlation to the spilled oil and other known oil sources and environmental assessment in Brazilian coastal waters. Similar reports were found for Nigeria where BTEX compounds were found in fish and shrimp that was attributed to petroleum explorations (Asejeje *et al.*, 2021). Although not relevant geographically these studies indicate the potential for contamination as a result of oil or petroleum spills.

Marine Scotland publishes data about oil and chemical discharges. The most recent report states chemical incidents increased from 2002-2016. They noted published data are only available up to, and including, 2016. The majority of incidents in 2016 were from offshore oil and gas installations, with 274 releases of mineral oils and 200 chemical releases with a smaller number (16 mineral oil releases) from vessels. Mineral oils were the most common of the five pollution categories, there is a lack of assessment criteria for mineral oils. It was noted the majority of spills and discharges were small, and only a low number (<4%) were of unknown volume. As the published data is only available up to and including 2016, this limits the potential to carry out an assessment of the current situation. Marine Scotland stated more recent data (if available) would allow a more up to date assessment to be made (Marine Scotland, 2020).

In summary, no data for Scotland or wider UK for BTEX compounds. Occurrence of these compounds is linked to oil and petroleum spills, the risk from these compounds should be low in the absence of spill incidents.

However, there is a lack of recent data on chemical incidents and spills to allow up to date assessment.

9.2.4 Per- and polyfluoroalkyl substances (PFAS)

Regulatory actions have curbed production of legacy compounds such as perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA) but impacts of regulations on PFAS releases to the marine environment are poorly understood. EFSA set a tolerable weekly intake (TWI) for the main per- and polyfluoroalkyl substances (PFOA, PFOS, PFNA, and

PFHxS) of 4.4 ng/kg body weight per week (EFSA, 2020). PFAS were investigated in a 2004 TDS in the UK which allowed an initial exposure assessment (Food Standards Agency, 2006b) and later in 2012 (Fernandes *et al.*, 2012). Of the food groups tested in the 2012 TDS, the fish group was found to contain the highest total PFAS concentration. Individual foods have also been investigated (Clarke *et al.*, 2010), and all studies report positive identification of PFAS compounds in fish. In the 2015 Fera FSA study PFAS were detected in all of the 50 samples measured (Fernandes *et al.*, 2015; 2018). In general, higher concentrations were observed in sardines, sprats and sea bass, with PFOS, PFOA and PFNA often showing the highest concentration levels. This study provided a baseline for the occurrence of these contaminants in fish.

The most recent data from 2022-23, published in 2025 (FSA Research and Evidence, 2025) is from a survey commissioned by the FSA for wild caught fish. Samples were collected from wholesale fish markets in England and Wales only. Several samples exceeded the EU MLs for some of the PFAS compounds (FSA Research and Evidence, 2025). A broad range of species including fin fish (pelagic and demersal), shellfish and cephalopods were analysed for 13 PFAS compounds. Of the regulated PFAS analytes (linear and branched PFOS, PFOA, PFNA and linear and branched PFHxS) the following were detected above the EU MLs (EU, 2023)

- Three cod samples (1.0, 1.5 and 1.0 µg/kg) exceeded the EU limit (0.5 µg/kg) for PFNA
- Two cod samples (0.52 and 0.47 µg/kg) exceeded the EU limit (0.2 µg/kg) for PFHxS
- Two crab samples (1.8 and 1.1 µg/kg) exceeded the EU limit (0.7 µg/kg) for PFOA
- One of the cod samples (2.6 µg/kg) exceeded the restriction for the sum of PFOS, PFOA, PFNA and PFHxS when the measurement uncertainty was taken into account (2.0 µg/kg for fish). Note there are currently no restrictions for these substances in fish in UK legislation.

Several publications reporting analysis of fish for PFAS from locations in the UK and Northern Europe were found during the literature search. These are collated and summarised in Table 19.

A range of per- and polyfluoroalkyl substances (PFASs) were analysed in marine fish, farmed fish, crustaceans, bivalves and European eel caught in (mostly) Dutch waters, or purchased at Dutch markets (approximately 250 samples, collected between 2012 and 2018) (Zafeiraki *et al.*, 2019). ΣPFAS levels were highest in eels collected from rivers and lakes (average 43.6 ng/g and max 172 ng/g, as reported – equivalent to µg/kg), followed by shrimps collected near the Dutch coast (average 6.7 and max. 33 ng/g ww), and seabass (average 4.5 and max. 9.4 ng/g ww). Most of the farmed fish (e.g. trout, catfish, turbot, salmon, tilapia, pangasius) contained the lowest concentrations in this study (averages ranged from 0.06 to 1.5 ng/g ww). Geographically, levels in marine fish from the northern North Sea (e.g. haddock, whiting, herring) were lower than in the central and southern North Sea (e.g. cod and flatfish).

In summary, between 2006 and 2023 five studies funded by FSA and FSS have been reported that have analysed foods for PFAS compounds. Results of these and studies found in the literature are presented in Table 19.

The TDS study reported in 2006 did not detect any PFAS in fish samples, but samples were pooled which would have diluted any residues making detection of residues less likely.

A second TDS reported in 2012 used a method with significantly improved sensitivity, this resulted in near universal detection of all targeted PFAS. The fish group samples were made up of 140 sub-samples. The highest level found in the fish group was 18.4 µg/kg total PFAS, this was the highest level of all groups in the study.

A food survey for PFAS was reported in 2010. Samples were collected from retail point of sale within the UK. A broad range of fish species were analysed, 72 samples in total, however the sample numbers per species were low (1-8 samples). Samples included freshwater and marine fish. PFOS was most commonly detected and at the highest levels, then PFOSA and to a much lesser extent PFOA, PFNA. Highest levels of PFOS were measured in smoked eel (mean 20 µg/kg, range <1 to 59 µg/kg) and whitebait (Mean 15 µg/kg, range <1 to 40 µg/kg). For crab the mean value found was 6.3 µg/kg and range 2-13 µg/kg.

PFAS were defined as the sum of the 11 individual fluorinated compounds (Σ PFCs) analysed (not the same definition as Regulation 2023/915). The maximum levels found were 63 µg/kg in smoked eels, and 62 µg/kg in whitebait. Mean levels were 21 and 28 µg/kg respectively (lower bound). There were six fish and crustaceans samples with Σ PFCs >15 µg/kg (fish and crustaceans). The Σ PFCs ranges for other key species were: crab 11 to 20 µg/kg, sardines 1 to 7 µg/kg, cod <1 to 4 µg/kg, mackerel and haddock <1 to 3 µg/kg, and herring <1 to 2 µg/kg. No residues were detected in salmon. All results wet weight.

Samples collected in 2015 were reported in 2018, samples of Sardines (8), Mackerel (12), Herring (9), Mullet (7), Sprat (9), and Sea Bass (5) from waters around the UK and the European coastal North Atlantic were analysed for 9 compounds. Residues were detected in all samples. PFOS was detected at the highest concentrations, ranging from 0.16 to 1.84 µg/kg for mackerel to 0.37 to 12.83 µg/kg for mullet, mean values ranged from 0.59 µg/kg for herring to 3.94 µg/kg for sprat. The range for the sum Σ PFCs for all samples in this study was 0.64 to 15.3 µg/kg. The maximum levels for mullet, seabass and sprat all exceeded MLs in Regulation EU 2023/915.

Most recent data from 2022-23 was for samples landed in England and Wales only, some exceedances of EU MLs were found. A broad range of species including fin fish (pelagic and demersal), shellfish and cephalopods were analysed for 13 PFAS compounds. Of the regulated PFAS analytes (linear and branched PFOS, PFOA, PFNA and linear and

branched PFHxS) the following were detected above the EU MLs ((EU, 2022) note there are currently no restrictions for these substances in fish in UK legislation):

- Three cod samples (1.0, 1.5 and 1.0 µg/kg) exceeded the EU ML (0.5 µg/kg) for PFNA
- Two cod samples (0.52 and 0.47 µg/kg) exceeded the EU ML (0.2 µg/kg) for PFHxS
- Two crab samples (1.8 and 1.1 µg/kg) exceeded the EU ML (0.7 µg/kg) for PFOA
- One gurnard sample (0.57 µg/kg) exceeded the EU ML (0.5 µg/kg) for PFNA.
- One of the cod samples (2.6 µg/kg) exceeded the EU ML for the sum of PFOS, PFOA, PFNA and PFHxS when the measurement uncertainty was taken into account (2.0 µg/kg for fish and 5.0 µg/kg for crustaceans). A further two samples (gurnard and sea bass) were at the EU ML.

In addition to the studies reported above, fourteen publications were found that reported PFAS occurrence in fish. One study analysed 140 sea bass samples, from a variety of sites, including wild caught, semi-intensively and intensively reared fish for PFOS and PFOA only. On average, wild caught sea basses (PFOS: 0.112 to 12.405 µg/kg, median 1.345 µg/kg; PFOA: 0.009 to 0.487 µg/kg, median 0.028 µg/kg) showed higher levels than intensively farmed sea basses (PFOS: 0.011 to 0.105 µg/kg, median 0.032 µg/kg; PFOA: 0.009 to 0.051 µg/kg, median 0.021 µg/kg)

Another study reported on the analysis of flounder from the Baltic Sea for 30 PFAS compounds. Seven out of 30 analysed PFAS compounds were detected in the samples, dominated by PFNA which was present in all samples. PFOS and perfluoroundecanoic acid (PFUnDA) were detected in 19 and 17 of the samples, respectively. Concentrations varied with an order of magnitude, with the highest levels detected for PFOS in muscle tissue at 0.36 µg/kg ww.

A review of PFAS levels and human exposure assessment has collated data from many studies for a wide range of foodstuffs (Torres and De-la Torre, 2023). The UK study of Fernandes *et al.*, (2018) on fish reported above was included. It stated that for fish and seafood the priority compounds were PFOA and PFOS, with PFOS being more predominant. They also highlighted higher concentrations were observed in liver than muscle and therefore attention should be paid to these products during risk assessment.

In summary, the most recent study found residues above the EU ML for cod muscle, one of the species with highest landing & consumption in the UK. Three out of 13 samples exceeded the EU ML for PFNA and 2 exceeded the ML for PFHxS. The number of samples analysed was small and only muscle was analysed. Bearing in mind other studies have also reported higher concentrations in liver samples it may be prudent to obtain more data for a larger number of samples for both muscle and liver products (e.g. cod liver oil) for this species.

9.2.5 Polychlorinated naphthalenes (PCNs)

Polychlorinated naphthalenes (PCNs) also show properties of stability, high bio-accumulative potential and persistence, coupled with a similarity in structural configuration to planar PCDD/Fs. Some congeners can contribute to dioxin-like toxicity and have shown a combination of toxic responses such as mortality, embryotoxicity, hepatotoxicity, immunotoxicity, dermal lesions, teratogenicity and carcinogenicity (Behnisch *et al.*, 2003, Blankenship *et al.*, 2000). There have been a few studies confirming occurrence in food and human exposure, COT reported on studies from Spain, China and the UK (COT, 2009). Oily fish tends to show higher levels of contamination than other foods (Fernandes *et al.*, 2010; Fernandes, 2013). EFSA published a scientific opinion on the risks for animal and human health related to the presence of PCNs in feed and food in 2024 (EFSA, 2024a). Due to limited data on other PCN congeners the assessment focussed on hexaCNs. The highest exposure ranged from 0.91 to 29.8 pg/kg bw per day in the general population and from 220 to 559 pg/kg bw per day for breast-fed infants with the highest consumption of breast milk. A margin of exposure (MOE) approach was applied, the estimated MOEs were far above the minimum MOE of 2000 and therefore did not raise a health concern.

A study in 2009 reported results for PCNs in Scottish freshwater and marine fish and shellfish. PCNs measured were PCN-52/60, 53, 66/67, 68, 69, 71/72, 73, 74, & 75. Levels in freshwater fish were more abundant and higher than shellfish and marine fish. Thirty-two samples of marine fish including haddock, cod, hake, herring, mackerel and skate as well as 5 samples of mussels were analysed. For the marine fish the highest levels were measured in 3 samples of spurdog (Fernandes, *et al.*, 2009b).

In the Fera FSA 2015 study PCNs were measured in 76 samples covering 7 species: sardines, mackerel, herring, grey mullet, sprat, seabass and turbot (Fernandes *et al.*, 2015; 2018). The sum of the 12 reported PCNs ranged from 0.7 ng/kg whole weight (ww) for a sample of turbot to 265 ng/kg ww for a sample of sprats. Mackerel and sprats showed the highest concentrations with average values of 68 ng/kg ww and 67 ng/kg ww respectively. An earlier study on individual UK foods (Fernandes *et al.*, 2010) showed an average of 20 ng/kg ww for individual fish samples (salmon, herring, sprats, eels, trout, etc.), and the concentration in the fish group in the last TDS (Fernandes *et al.*, 2012) was 6.6 ng/kg ww. The TDS fish group included both oily and white fish as well as shellfish.

Summary of results

Limited data is available although there were two studies. One study of fish from Scottish waters from 2009 analysed 32 samples of fish and five samples of shellfish. Levels for upper bound sum for PCN (sum PCN-52/60, 53, 66/67, 68, 69, 71/72, 73, 74, & 75) in shellfish (all mussels) ranged from 0.84 to 6.45 ng/kg on whole weight basis, and in fish ranged from 0.3 ng/kg (in a forkbeard) to 62.91 ng/kg in a sample of spurdog. Concentrations found in key species were 0.49 ng/kg in a haddock sample and 26.81 ng/kg in a herring sample.

The 2015 study included 76 samples of mackerel, herring, sprats, sardines, grey mullet, sea bass and turbot from Scottish and UK waters. Concentrations of sum PCNs (sum PCN-52/60, 53, 66/67, 68, 69, 71/72, 73, 74, & 75), lower bound were:

- Sardines (n=12) 5.1 – 63.1 ng/kg
- Mackerel (n=14) 10 – 243 ng/kg
- Herring (n=6) 18.3 – 89.5 ng/kg
- Grey mullet (n=9) 4.2 – 33.5 ng/kg
- Sprat (n=15) 29.4 – 264.5 ng/kg
- Sea Bass (n=13) 13.7 – 48.5 ng/kg
- Turbot (n=6) 0.7 – 15.5 ng/kg

For emerging contaminants e.g. polychlorinated naphthalenes (PCNs), there are no other data to monitor trends. Latest samples were collected in 2015.

9.3 Inorganic Substances - Heavy metals (Potentially Toxic Elements -PTEs)

Metals and other elements may enter marine and aquatic environments and bio-accumulate in species at any point during growth and harvesting.

Metals have been included in the shellfish monitoring programme summarised in Section 9.1 above.

Many studies have been conducted, and these are summarised in Table 17.

In the study by Food Standards Agency Scotland (now FSS) metal elements were measured in fish muscle samples as well a range of other contaminants (see section 9.2, Food Standards Agency Scotland, 2009, Fernandes *et al.*, 2009b). Marine fish (32 samples), freshwater fish (16 samples) and 5 marine shellfish were analysed. Some metals such as manganese, zinc, copper, arsenic, selenium and mercury were detected in all or most of the samples, irrespective of species. In general, silver, nickel, chromium and lead showed the lowest frequency of detection. Mercury occurred most frequently as methyl mercury, the toxic form. Mercury is regulated by the assimilated Regulation (EC) 1881/2006 with a general limit of 0.5 mg/kg for fish.

Mercury – all marine fish were positive for total Hg, range 0.035 to 0.746 mg/kg. All freshwater fish were positive (range 0.029 to 0.454 mg/kg) and all shellfish (0.025 to 0.047 mg/kg). Three samples exceeded the ML for Hg, a ling, a blue ling and a torsk. A subset of samples were analysed for methyl mercury, the levels ranged from 0.14 mg/kg for trout to 0.77 mg/kg for the ling sample that contained the highest total Hg level. The blue ling sample contained 0.66 mg/kg methyl mercury. The methyl mercury analysis was carried out at a different laboratory.

Cadmium – 17 samples of marine fish were positive (0.004 to 0.059 mg/kg), 7 freshwater fish contained residues (0.004 to 0.039 mg/kg).

Lead – seven marine samples were positive for lead (0.005 to 0.009 mg/kg), 10 freshwater samples were positive for lead (0.006 to 0.084 mg/kg) and all five shellfish contained residues (0.242 to 1.551 mg/kg)

Cd and Pb were detected most frequently in shellfish, there were no ML exceedances, however only 5 shellfish (mussels) samples were analysed.

In the UK, the Food Standards Agency conducted a study of metals and other elements as part of a TDS (Food Standards Agency, 2015, Baxter and Brereton, 2015). The study collected samples from 24 Local Authority areas across the UK. Twenty-eight food groups were included, fish was one food group. The elements Al, Mn, Ni, Cu, Zn, As, Se, Sr, Mo, **Cd**, Sb, I, Ba, **Hg** and **Pb** were detected in the fish group sample, elements in bold have maximum permitted levels.

The fish group TDS sample contained lead, cadmium and mercury (total) concentrations below MLs.

- **Mercury** – the concentration measured was 0.0497 mg/kg (similar to the level of 0.056 mg/kg detected in the previous TDS (FSA, 2006)).
- **Cadmium** – the concentration was 0.014 mg/kg.
- **Lead** – the level was just above the LOQ (0.004 mg/kg).

The fish group sample contained the highest Iodine level at 0.811 mg/kg, it also contained the second highest level of selenium (0.29 mg/kg), this is less than the level found in the 2006 TDS of 0.42 mg/kg. The results of the study indicated that current population dietary exposures to most of the metals and elements investigated did not raise specific concern for the health of consumers.

In the study funded by the FSA and reported by Fernandes *et al.* (2015 and 2018) PTEs were measured in all fish muscle samples, concentrations were reported in mg/kg of whole weight (wet weight) tissue. Some metals such as manganese, zinc, copper, arsenic, selenium and mercury were detected in all or most of the samples, irrespective of species. Mercury was reported as total mercury. In general, silver, nickel, chromium and lead showed the lowest frequency of detection. The metals results from this study were shared on-line as part of a marine online assessment tool as an indicator to assess progress against the target set out in the Marine Strategy Part One (HM Government, 2012). Table 13 summarises the regulated metals results, they are reported on the website as given in milligram of metal per kilogram of seawater, however review of the original data set shows results are mg/kg fish tissue (whole weight). Results were from samples collected from 2013-2015.

Overall, the results of 192 samples analysed for lead, cadmium and mercury were included in the summary.

Mercury - Eight samples of sea bass and one of dogfish contained total mercury concentrations above the ML of 0.5 mg/kg.

Cadmium - One sample of dogfish was above the general regulated limit for cadmium (0.05 mg/kg) and a sample of Cornish mackerel was above the higher cadmium limit set for this species (0.1 mg/kg – Assimilated Regulation EC 1881/2006 as amended by 488/2014). Most of these samples were from Southern UK/ Northern France waters and the Irish Sea.

Lead – lead was measured in all species. Sardines range was 0.005 to 0.007 mg/kg, mackerel <0.002 to 0.018 mg/kg, herring <0.002 to 0.064 mg/kg, grey mullet <0.002 to 0.901 mg/kg, sprat 0.005 to 0.226 mg/kg, sea bass <0.002 to 0.157 mg/kg, turbot <0.002 to 0.028 mg/kg and various shark species <0.002 to 0.009 mg/kg. Two mullet samples that were above the ML for lead (0.3 mg/kg), originated from the Pembrokeshire coast (Wales).

Table 13. Summary of results (n=192 samples) from the surveys (years) of regulated metal contaminants in fish sampled at known locations in UK waters.

Contaminant	Mean	95 th Percentile	Maximum	Limit	Species
	mg/kg whole weight				
Lead	0.02	0.07	0.90	0.30mg/kg	All*
Cadmium	0.01	0.02	0.06	0.05mg/kg	All excluding:
	0.03	0.10	0.16	0.10mg/kg	mackerel
	0.03	0.06**	0.06	0.25mg/kg	sardines
Mercury	0.07	0.19	0.43	0.50mg/kg	All excluding:
	0.18	0.82	1.0	1.00mg/kg	halibut, mullet, dogfish

*Species tested: sardines, mackerel, herring, grey mullet sprats, sea bass, turbot, shark (various spp) and other spp - halibut, haddock, plaice, lemon sole, witch, megrim, monkfish.

** indicates use of 90th percentile value.

Table partly reproduced from [Mortimer, 2018](#).

The most recent FSA study of wild caught fish from 2022-23 analysed 152 samples for cadmium, mercury and lead (FSA Research and Evidence, 2025). The results are summarised below and in more detail in Table 14.

Lead – not found above the ML in any sample. It was not detected in any dogfish, gurnard, haddock, hake, and sole samples.

Cadmium - was detected at a concentration of 0.16 mg/kg (0.13 mg/kg minus measurement uncertainty) in one of the mackerel samples. The maximum level for cadmium in mackerel is 0.1 mg/kg. Cadmium was not detected in cod, dog fish, haddock, hake, plaice, sea bass, skates & rays, or sole.

Mercury - reported as total mercury was detected in all samples. It was measured above the maximum level of 0.5 mg/kg in three of the sea bass samples at concentrations of:

- 0.74 mg/kg (0.60 mg/kg minus the measurement uncertainty of 19%)
- 0.69 mg/kg (0.56 mg/kg minus the measurement uncertainty of 19%)
- 0.87 mg/kg (0.70 mg/kg minus the measurement uncertainty of 19%)

Table 14. Summarised metals results for FSA Wild Caught Fish survey (FSA Research and Evidence, 2025).

	No. samples above LOQ	No. samples	Fish species	Conc. Range (mg/kg)
Lead	1	13	cod	0.010
	26	27	crab	<0.005 – 0.05
	10	11	cuttlefish	<0.005 – 0.013
	0	2	dogfish	<0.005
	0	2	gurnard	<0.005
	0	2	haddock	<0.005
	0	5	hake	<0.005
	3	7	herring	<0.005 – 0.008
	3	4	lobster	<0.005 – 0.041
	1	16	mackerel	<0.005 – 0.006
	1	7	monkfish & anglers	<0.005 – 0.010
	2	3	plaice	<0.005 – 0.017
	32	32	sardines	0.007 – 0.034
	2	9	sea bass	<0.005 – 0.013
	3	4	skates & rays	<0.005 – 0.006
	0	6	sole	<0.005
	1	2	squid	<0.005 – 0.009
Cadmium	0	13	cod	<0.005
	15	27	crab	<0.005 – 0.157

	8	11	cuttlefish	<0.005 – 0.022
	0	2	dogfish	<0.005
	2	2	gurnard	0.006 and 0.011
	0	2	haddock	<0.005
	0	5	hake	<0.005
	7	7	herring	0.011 – 0.027
	4	4	lobster	0.016 – 0.047
	15	16	mackerel	<0.005 – 0.075
	1	7	monkfish & anglers	<0.005 – 0.009
	0	3	plaice	<0.005
	32	32	sardines	0.005 – 0.021
	0	9	sea bass	<0.005
	0	4	skates & rays	<0.005
	0	6	sole	<0.005
	2	2	squid	0.007 – 0.010
Mercury	13	13	cod	0.08 – 0.12
	27	27	crab	0.05 – 0.30
	11	11	cuttlefish	0.04 – 0.08
	2	2	dogfish	0.52 and 0.55
	2	2	gurnard	0.61 and 0.14
	2	2	haddock	0.03 and 0.11
	5	5	hake	0.04 – 0.42
	7	7	herring	0.011 – 0.027
	4	4	lobster	0.12 – 0.40
	16	16	mackerel	0.03 – 0.08
	7	7	monkfish & anglers	0.10 – 0.20
	3	3	plaice	0.07 – 0.16
	32	32	sardines	0.02 – 0.05
	9	9	sea bass	0.20 – 0.87
	4	4	skates & rays	0.07 – 0.32
	6	6	sole	0.03 – 0.06
	2	2	squid	both 0.01

A survey of brown crab meat was reported in 2013, 399 samples of brown crabmeat and its products were analysed for cadmium (Bolam and Bersuder, 2013a.) While cadmium was the main element of interest samples were also analysed for a range of other trace elements and heavy metals including arsenic, lead and mercury. For all products, Cd concentrations ranged from 0.01 to 26 mg/kg wet weight (ww). The mean and median Cd concentrations were 3.4 and 2.8 mg/kg ww, respectively.

There is no specific limit for Cd in brown crabmeat, these average concentrations were observed to be higher than the permitted maximum level of 0.50 mg/kg that applies to the muscle from appendages. This study was followed up by a study on cadmium in crab hepatopancreas and other edible tissues from the crab's cephalothorax as this was required following the previous study (Bolam and Bersuder, 2013b). A total of fifty-six live

brown crab (*Cancer pagurus*), representing four geographical locations (Fraserburgh, Aberdeen, Dorset, Newlyn) were obtained. The crabs were killed humanely and immediately dissected, all hepatopancreases was homogenised and bulked into one sample, the remaining edible tissues from the cephalothorax made up a second bulked sample. Replicates (n=6) of both samples were analysed for Cd and a suite of other trace metals. For the hepatopancreas sample, the mean Cd concentration [$\pm$ standard deviation] was 4.0 [$\pm$ 0.18] mg/kg wet weight (ww), while the mean Cd concentration in other edible tissues from the cephalothorax was 0.27 [$\pm$ 0.02] mg/kg ww

A sampling programme targeting appropriate fish species was conducted in 2013 and 2014 to monitor compliance with Good Environmental Status (GES) for Marine Strategy Framework Directive Descriptor 9.

For metals, Cd and Pb were mainly below detection limits, whereas Hg (total) was detected in all samples. Concentrations of Hg were higher in monkfish than in haddock and herring (Scottish Marine and Freshwater Science, 2015).

Madgett *et al.*, (2021) carried out a study to examine the variability of concentrations (inter- and intra- species variation) of three priority heavy metals (Hg, Cd and Pb) and six additional trace metals and metalloids (As, Ni, Se, Zn, Cu and Cr) in twenty-three species across four trophic levels from different locations around Scotland. Samples were analysed by ICP-MS as pooled samples. Results were reported as ranges for sixteen categories, not by species, so it is difficult to compare results to MLs. It was noted flatfish muscle had higher Hg concentrations than other fish muscle, and that flatfish from the Irish Sea had higher concentration of Hg than the other Scottish regions. Trophic magnification factors (TMFs) were calculated using two methods for those metals/metalloids with a significant trophic relationship (Hg, Cd, Cu, Ni and Zn) to refine and improve the application of TMFs used to assess and predict biomagnification risk of metals/metalloids to biota in the environment.

Heavy metal concentrations in commercial deep-sea fish from Rockall Trough were reported by Mormede and Davies (2001). Muscle, liver, gill and gonad tissue were analysed for arsenic, cadmium, copper, lead, and zinc by atomic absorption.

Cadmium - concentrations in muscle tissue ranged from 0.007 to 0.034 mg/kg ww, the maximum level in muscle was 1.178 mg/kg in blue whiting, this would exceed the current ML, although this was not in force at the time of the study.

Lead – median concentrations in muscle ranged from 0.0016 to 0.0094 mg/kg wet weight. The maximum lead concentration in muscle for all 5 categories was below the current ML of 0.3 mg/kg.

Contaminants monitoring of biota (fish and shellfish) and sediment is undertaken in Scottish coastal and offshore areas as part of the UK Clean Seas Environment Monitoring Programme (CSEMP). Marine Scotland (2020) published results of recent monitoring for Hg (total), Pb and Cd. Biota samples were taken between 1999 and 2018. Shellfish (blue mussel) were collected in coastal and estuarine areas only, whilst sediment and fish were

collected from coastal and offshore areas. Metal concentrations in shellfish and fish were compared to the Maximum Levels in Assimilated Regulation (EC) 1881/2006, these apply to muscle. For Hg the MLs are directly comparable as for this study Hg was measured in muscle. However, for Cd and Pb liver samples were analysed which can contain higher concentrations of these contaminants, therefore levels for bivalve mollusc were used as indicator. For biota (fish and mussels) concentrations in all three regions were similar, with mean regional concentrations for all three metals being above the OSPAR Background Assessment Concentration (BAC) but below the maximum permitted levels (detailed results not given) (Marine Scotland, 2020a).

Results are also summarised in Table 17.

In summary, **Mercury** – Unless specifically stated all reported Hg results are for total Hg. Across a range of studies mercury was consistently detected in all species, in the 2009 FSS study all marine fish were positive for Hg, range 0.035 to 0.746 mg/kg and all shellfish contained mercury (0.025 to 0.47 mg/kg). Three samples exceeded the ML for Hg, a ling, a blue ling and a torsk. This study reported levels of methyl mercury for a subset of samples. The levels ranged from 0.14 mg/kg for trout to 0.77 mg/kg (ling), a blue ling sample contained 0.66 mg/kg methyl mercury. The methyl mercury concentrations were similar to the total mercury levels measured in these samples.

In the FSA study of 2015 eight samples of sea bass and one of dogfish contained mercury concentrations above the ML.

In the most recent study of wild caught fish from 2023 Hg was detected in all 152 samples and was detected above the maximum level of 0.5 mg/kg in three of the sea bass samples at concentrations of:

- 0.74 mg/kg (0.60 mg/kg minus the measurement uncertainty of 19%)
- 0.69 mg/kg (0.56 mg/kg minus the measurement uncertainty of 19%)
- 0.87 mg/kg (0.70 mg/kg minus the measurement uncertainty of 19%).

Cadmium – In the 2009 FSS study 17 samples of marine fish contained cadmium (0.004 to 0.059 mg/kg).

In the FSA study from 2015 one sample of dogfish was above the general regulated limit for cadmium (0.05 mg/kg) and a sample of Cornish mackerel was above the higher cadmium limit set for this species (0.1 mg/kg). Most of these samples were from Southern UK/ Northern France waters and the Irish Sea.

In the wild caught fish study published in 2025 cadmium was detected at a concentration of 0.16 mg/kg (0.13 mg/kg minus measurement uncertainty) in one of the mackerel samples (an ML exceedance).

Cadmium was detected in:

- Crab, 15/27 samples - range <0.005 – 0.157 mg/kg
- Cuttlefish, 8/11 samples, <0.005 – 0.022 mg/kg
- Gurnard, 2/2 samples, 0.006 and 0.011 mg/kg
- Herring 7/7 samples, 0.011 – 0.027 mg/kg
- Lobster, 4/4 samples, 0.016 – 0.047 mg/kg

- Mackerel, 15/16 samples, <0.005 – 0.075 mg/kg
- Monkfish & anglers, 1/7 samples, <0.005 – 0.009 mg/kg
- All sardines, n=32, 0.005 – 0.021 mg/kg
- Squid, 2/2 samples, 0.007 – 0.010 mg/kg.
- It was not detected in cod, dog fish, haddock, hake, plaice, sea bass, skates & rays, or sole.

Separate studies for cadmium in crab found cadmium concentrations ranged from 0.01 to 26 mg/kg wet weight (ww). The mean and median Cd concentrations were 3.4 and 2.8 mg/kg ww, respectively. There is no specific limit for Cd in brown crabmeat, these average concentrations were observed to be higher than the permitted maximum level of 0.50 mg/kg that applies to the muscle from appendages.

Lead – in the FSS 2009 study, seven of thirty-two marine samples were positive for lead (0.005 to 0.009 mg/kg), 10 freshwater samples contained 0.006 to 0.084 mg/kg and all five shellfish contained residues (0.242 to 1.551 mg/kg).

FSA 2015 study - lead was measured in all species at the following ranges:

- Sardines 0.005 – 0.007 mg/kg
- Mackerel <0.002 – 0.018 mg/kg
- Herring <0.002 – 0.064 mg/kg
- Grey mullet <0.002 – 0.901 mg/kg
- Sprat 0.005 – 0.226 mg/kg
- Sea bass <0.002 – 0.157 mg/kg
- Turbot <0.002 – 0.028 mg/kg and
- Various shark species <0.002 – 0.009 mg/kg.

Two mullet samples that were above the ML for lead (0.3 mg/kg), were from the Pembrokeshire coast (Wales).

In the 2023 wild caught fish study reported in 2025 lead was not found above the ML in any sample. It was not detected in dogfish, gurnard, haddock, hake, or sole.

It was detected in:

- Cod, one sample, 0.010 mg/kg
- Crab, 26/27 samples, <0.005 – 0.05 mg/kg
- Cuttlefish 10/11 samples, <0.005 – 0.013 mg/kg
- Herring, 3/7 samples, <0.005 – 0.008 mg/kg
- Lobster, 3/4 samples, <0.005 – 0.041 mg/kg
- Mackerel, 1/16 samples, <0.005 – 0.006 mg/kg
- Monkfish & anglers, 1/7 samples, <0.005 – 0.010 mg/kg
- Plaice, 2/3 samples, <0.005 – 0.017 mg/kg
- All sardines, n=32, 0.007 – 0.034 mg/kg
- Seabass, 2/9 samples, <0.005 – 0.013 mg/kg
- Skate & rays, 3/4 samples, <0.005 – 0.006 mg/kg

- Squid, 1/2 samples, <0.005 – 0.009 mg/kg.

The main data from Scotland is from a study from 2009, and a limited number of samples from Scotland for the 2015 study. The most recent study reported in 2025 only included samples landed in England and Wales in 2022-23. Mercury is routinely measured in all samples, most commonly reported as total mercury. Exceedances were found for mercury in three studies. Two samples exceeded the ML for lead (samples from Wales) in the 2015 study.

Given a high proportion of UK fish is landed in Scotland it may be prudent to obtain more up to date data for Scottish landed fish to supplement the results from the 2022-23 study (FSA Research and Evidence, 2025).

9.3.1 Arsenic (Inorganic and total)

There are multiple forms of organic and inorganic arsenic and the most common, arsenobetaine, is non-toxic to humans. Most occurrence data collected during food controls has been reported as total arsenic (EFSA, 2009). Improvements in analytical capability are now allowing determination of the different arsenic species so it is possible to determine between occurrence of the different forms. EFSA published an updated risk assessment of inorganic arsenic in 2024 (EFSA, 2024b), noting that epidemiological studies have indicated chronic intake of inorganic arsenic is associated with increased risk of some cancers including skin, bladder and lung cancer due to the ability of inorganic arsenic to damage DNA. EFSA CONTAM Panel noted inorganic arsenic is a genotoxic carcinogen and applied the margin of exposure (MOE) approach for risk assessment, concluding the MOEs were low and therefore raise a health concern (EFSA, 2024b).

Arsenic was determined in Scottish marine and freshwater fin fish and shellfish (Fernandes *et al.*, 2009b, FSS, 2009). Thirty-two samples of marine fish, 16 fresh water and 5 marine shellfish were analysed for total arsenic and a subset for inorganic arsenic. Total arsenic concentrations were:

- Marine fish = 4.8 mg/kg (John Dory) to 79.18 mg/kg (Cuckoo Ray).
- Freshwater fish = <0.04 mg/kg (trout) to 1.25 mg/kg (trout)
- Shellfish = 1.08-3.53 mg/kg (mussels)

For inorganic arsenic (subset 27 marine fish and 1 shellfish), the concentration range found was <0.005 mg/kg (ling) to 0.149 mg/kg (Spurdog).

A recent study completed by Fera reported results for Inorganic and total arsenic in wild caught fish, all fish were landed in Wales and England (FSA Research and Evidence, 2015). All samples (152) were analysed for total arsenic and a subset (76/152) were analysed for inorganic arsenic. When using the current established method levels of inorganic arsenic were found that would potentially exceed the maximum levels that have been discussed in the EU. However, when a more selective method (HPLC-ICP-MS) that allowed speciation was used, none of the samples would exceed the maximum levels. In fact, the majority of samples (70 out of 76) were below the LOQ of 0.007 mg/kg. The highest level found using the HPLC-ICP-MS method was 0.011 mg/kg in a sample of lobster.

This study and others for arsenic are summarised (Table 18). Two of the studies (Falconer *et al.*, 1983 and Larsen *et al.*, 2003) reported on total arsenic only. The Falconer study reported surveys from 1975 and 1976, samples were from Scottish waters. The concentration of arsenic in the edible tissue of fish was in the range 0.2 to 89.9 mg/kg wet weight (ww). In general, flatfish contained more arsenic than roundfish. All results were for total arsenic, so all forms (inorganic and organic) are included in the total.

The fish group TDS sample had the highest level of arsenic (2 mg/kg), mostly as the organic form, the level of inorganic arsenic was <0.012 mg/kg (Food Standards Agency, 2015, Baxter and Brereton, 2015).

De Gieter *et al.*, (2002) measured total arsenic and inorganic arsenic in fish from the waters around the south coast, French coast, and North Sea. They defined the arsenic as the 'nontoxic fraction' consisting mainly of arsenobetaine, arsenocholine and tetramethylarsonium and the 'toxic species' i.e. inorganic arsenic — arsenite (As(III)) and arsenate (As(V)). The highest total As concentrations were found in lemon sole, dogfish, ray and witch, maximum levels of total arsenic up to 20 mg/kg ww were found. The authors calculated the inorganic 'toxic arsenic' as a ratio of the total arsenic. They reported that the highest levels of inorganic arsenic were found in the species with high total As, concentrations were greater than 0.1 mg/kg (ww). Ratios of (AsTox/AsT%) over 2% were found in seabass, ling, john dory, pouting, dab and brill. The authors noted that species like the flat fish that feed on benthic organisms and smaller fish tended to contain higher concentrations of arsenic.

Larsen *et al.*, (2003) reported similar findings for fish caught in the Baltic and North Sea areas. The highest levels reported were up to 10.9 mg/kg total arsenic. They noted a relationship of increased total arsenic concentration with increased salinity. Similar observations were reported in the review by Zhang *et al.*, (2022).

Heavy metal concentrations in commercial deep-sea fish from Rockall Trough were reported by Mormede and Davies (2001). Median concentrations of total arsenic in the muscle tissue ranged from 1.25 to 8.63 mg/kg ww with the highest levels in monkfish and blue ling.

More recent studies that have measured inorganic arsenic directly (Julshamn *et al.*, 2012 (some Scottish catches), and Polak-Juszczak and Richert, 2021 (Baltic Sea)) have reported results similar to the recent Fera study (FSA Research and Evidence, 2025). Levels of total arsenic were up to 110 mg/kg, whereas inorganic arsenic levels ranged from <0.003 to 0.015 mg/kg depending on the fish species, with inorganic arsenic constituting 3.45 to 5.75% of the total arsenic.

Arsenic results are summarised in Table 18.

In summary, in the survey of wild caught fish and shellfish landed in England and Wales (FSA Research and Evidence, 2025), levels of total arsenic ranged from 0.5 to 38.2 mg/kg. Inorganic arsenic in a subset of these samples ranged from <0.007 to 0.011 mg/kg. Species containing inorganic arsenic were crab, lobster and sardines.

In the study of Julshamn *et al.*, from 2012, fish were caught in Barents Sea, mackerel were caught on the West coast of Scotland:

- Cod total arsenic range was 0.38 to 110 mg/kg, Inorganic As <0.002 to 0.006 mg/kg
- Norwegian spring spawning (NSS) herring total As 1.8 to 34 mg/kg, InAs <0.004 mg/kg
- Mackerel total As n.d to 4.3 mg/kg, InAs <0.003 - 0.006 mg/kg

- Greenland halibut 2.7 to 48 mg/kg, InAs <0.003 - 0.004 mg/kg
- Tusk total As 0.26 to 89 mg/kg, InAs <0.003 - 0.006 mg/kg
- Saithe total As 0.01 to 6.5 mg/kg, InAs <0.003 - 0.015 mg/kg
- Halibut total As 2.4 to 15 mg/kg, InAs <0.004 mg/kg

A 2009 study of Scottish fish found total arsenic in Marine fish ranged from 4.8 mg/kg (John Dory) to 79.18 mg/kg (Cuckoo Ray); Freshwater fish ranged from <0.04 mg/kg (trout) to 1.25 mg/kg (trout) and Shellfish from 1.08 to 3.53 mg/kg (mussels).

Inorganic arsenic was measured in a subset of 27 marine fish and 1 shellfish, concentrations were <0.005 mg/kg (ling) to 0.149 mg/kg (Spurdog), representing 0.05 to 2.53% of total As (Fernandes, *et al.*, 2009b).

Recent data shows that while levels of over 100 mg/kg total arsenic have been measured in fish from UK waters, inorganic arsenic levels are very low, typically <3% of total arsenic and therefore the risk is low. However, there is little recent data specifically for fish landed in Scotland. Even when inorganic arsenic has been reported there is a risk that results are overestimated. Improvements in analytical methodology for inorganic arsenic using HPLC-ICP-MS mean it is possible to obtain more accurate quantification of the levels of inorganic arsenic in foods. So far, a relatively small number of samples have been analysed using this method, however it would be prudent to analyse a broader range of species to gain a more accurate understanding of the occurrence of inorganic arsenic and therefore the overall risk to consumers.

9.4 Polycyclic Aromatic Hydrocarbons (PAHs)

PAHs are monitored as part of the shellfish monitoring programme and these results are summarised in Section 9.1 above.

Other surveys have been carried out that have included PAHs. A study in 2009 on environmental contaminants in Scottish Marine and freshwater fish and shellfish reported results of PAH analysis in five mussels samples (Fernandes *et al.*, 2009b). The concentration range of BaP was 0.13 to 1.69 µg/kg, and for sum PAH4 was 0.85 to 8.94 µg/kg.

The TDS study of 2012 included a fish group sample that was analysed for PAHs. The fish group sample contained 0.12 µg/kg BaP and 0.85 µg/kg sum PAH4 (Fernandes, *et al.*, 2012).

PAHs are used as indicators of environmental pollution. In March 2023 FSA was alerted to a spill of “reservoir fluid” at Poole Harbour. The reservoir fluid was known to contain 15% oil and approximately 4700 L had been discharged accidentally. There are shellfish beds in this area, therefore, to determine any possible adverse impact samples were collected from shellfish beds at key points in the area. In total 21 samples were tested, 3 blue mussels, 3 Pacific oysters, 7 Manila Clams and 8 Common cockles. Levels of BaP

measured ranged from 0.26 to 1.53 µg/kg, and from 1.79 to 8.07 µg/kg for sum PAH4, none of the samples exceeded MLs.

In summary, the 2009 study reported results of PAH analysis in five mussels samples. The concentration range of BaP was 0.13 to 1.69 µg/kg, and for sum PAH4 was 0.85 to 8.94 µg/kg.

The 2012 TDS reported the fish group sample contained 0.12 µg/kg BaP and 0.85 µg/kg sum PAH4.

The samples from the 2023 Poole Harbour incident were all below ML, samples tested were 3 blue mussels, 3 Pacific oysters, 7 Manila Clams and 8 Common cockles collected from harvest beds in the Poole Harbour area. Levels of BaP measured ranged from 0.26 to 1.53 µg/kg, and from 1.79 to 8.07 µg/kg for sum PAH4, none of the samples exceeded MLs.

9.5 Smoked fish products

Scottish practices such as traditional methods of production for smoked Scottish salmon and 'Arbroath Smokies' were considered in relation to the occurrence of contaminants. Arbroath Smokies are salted to reduce moisture, then hot smoked over a fire using oak or beech as fuel. The heat from the embers causes the fish to release moisture increasing humidity. This heat and humidity cook and colour the fish in a time of approximately 1 hour. Smoked salmon is cold smoked (although some hot smoked products are also produced). The salmon is dry cured with salt, rinsed and dried. It is smoked, at a temperature less than 30°C, for up to 48 hours. The exact process will vary at different premises.

Very little information on the occurrence of PAHs in traditional Scottish products was found. A survey of UK sea smoking businesses and products was commissioned by Seafish in 2004, before the introduction of EU maximum levels, to assess the potential impact of the legislation. Analysis of 33 products for PAHs found that all products would have complied with the maximum levels for BaP and PAH4 had they been in force at that time (Watson *et al.*, 2004).

Storelli *et al.*, (2003) analysed samples of smoked seafood for PAHs, as well as PCBs and other organochlorine compounds. The PAHs phenanthrene, fluoranthene, pyrene, benzo(a)anthracene, and benzo(a)pyrene were detected in Scottish salmon. Although a sum of 96.2 µg/kg was detected the sample would comply with the current ML as the compounds measured are not included in sum PAH4.

Another survey carried out in 2010 (Fernandes *et al.*, 2011a) found that of 62 smoked fish products analysed 4 samples were above the maximum level for BaP. Levels of PAH4

ranged from 0.11 to 54 µg/kg in smoked fish. Products tested included smoked salmon, haddock, smokies, kippers, trout and mussels.

A recent review that included 92 papers did not report any findings from Scotland or the rest of the UK (Iko Afe *et al.*, 2021). The paper included results from a Finnish study from 2007, 107 samples of smoked fish were analysed and only 3 were found to contain BaP above 5 µg/kg (Reinik, 2007). This review supported the low number of results found during the current study and highlights the lack of available data for these products. The data found are summarised in Table 20.

As well as PAHs, other compounds of concern could be heterocyclic amines and nitrosamines (N-NAs). EFSA concluded in 2023 that 10 carcinogenic N-NAs occurring in food (TCNAs) could raise a health concern as calculated MOEs were less than 10,000 (EFSA, 2023).

One study of heterocyclic amines (HA) formation in fish reported the occurrence of HAs and PAHs in different cooked muscle foods (beef, salmon, and sardines) after different cooking procedures (barbecuing, grilling and pan-frying) but these were not smoked products (Viegas, 2012). They reported PAH profiles were higher in salmon than chicken and beef. The fat content of the salmon was 20% versus 5% for the beef, the authors suggested the increased PAH8 content may be a function of the higher fat content. It was also noted that HA levels were increased if fish was cooked close to wood charcoal. Increased distance or using an electric grill reduced HA formation.

Iko Afe *et al.* (2021) also reported on other heat-induced compounds such as heterocyclic amines, and nitrosamines in smoked fish and meat. The use of wood charcoal was reported to have induced high production of heterocyclic amines although there was no specific data for fish reported. Nitrosamines were reported in one study of smoked fish (non-UK).

No data specific to Scottish or UK smoked fish was found for nitrosamines or HAs.

Summaries of the studies are given in Table 20.

In summary, the Seafish report, 2004, analysed hot smoked and cold smoked products. For hot smoked products BaP levels ranged from <0.06 to 0.43 µg/kg for mackerel and 0.56 to 1.34 µg/kg for Arbroath smokies.

For cold smoked products, levels ranged from <0.06 to 0.14 µg/kg for kippers, all other species (haddock, cod, whiting, coley and salmon) were below LOQ in the range <0.06 to <0.18 µg/kg.

Low levels of the other PAH4 compounds were found, the highest concentrations were 1.32 and 2.72 µg/kg of chrysene in two Arbroath smokies. None of the 33 samples in the study would have exceeded the ML for PAH4.

Fernandes *et al.*, (2011) reported PAH results in a range of smoked foods, including 62 samples of smoked salmon, haddock, smokies, kippers, trout and mussels. No geographical information was given about the samples, but they were all purchased from UK retail outlets according to a structured sampling plan. Four samples exceeded the ML for BaP, these were three hot smoked salmon samples at 6.31, 7.54 and 10.13 µg/kg and a smokie sample at 9.01 µg/kg. The range for BaP in all samples was 0.03 to 10.1 µg/kg, and for sum PAH4 was 0.11 to 54 µg/kg.

Storelli *et al.*, (2003) reported BaP was absent in all samples analysed except the Scottish salmon (0.7 µg/kg), Danish herring (0.5 µg/kg), and eel (0.3 µg/kg) samples. Benzo(a)anthracene was found in all samples and was present at particularly high levels in Scottish salmon (23.2 µg/kg). The study did not include chrysene and benzo(b)fluoranthene, the other compounds included in the sum PAH4 ML.

Most recent Scottish data is >10 years old (reported 2010), and there are limited sample numbers. A small number of ML exceedances were found. A recent worldwide review did not include any UK data.

It seems there is a data gap for the occurrence of nitrosamines and HA in Scottish or UK smoked fish products as these compounds have not been included in any UK surveys and no evidence of data was found in the published literature.

9.6 Pesticides

Residues of pesticides can occur in fish as a consequence of environmental exposure from water (European Commission, 2021). Some organochlorine (OC) pesticides are included in the 'Stockholm 12' list of persistent organic pollutants (POPs). Some pesticides such as the chlordane, DDT, dieldrin, lindane, toxaphene, hexachlorobenzene, mirex, and bromocyclen have occasionally been found in fish. Other pesticides have also been found in fish such as chlorpyrifos, pendimethalin, trifluralin or the feed additive ethoxyquin. As well as environmental exposure from water, a second and increasingly important pathway of exposure is the ingestion of feed containing a pesticide residue. The Commission developed a working document to evaluate and determine the nature and residues of pesticides in fish. No data on residues are included in this document, it describes how to carry out studies to determine the nature and distribution of pesticide residues in fish originating in exposure from feed. The document SANTE/10252/2021 – Magnitude of pesticide residues in fish, the purpose of which is to support establishing MRLs for pesticide in aquaculture, specially states that residues from environmental contamination of waters or from spray/run-off/drainage might require separate consideration (European Commission, 2021a). Wild fish are known to scavenge excess feed at fish farm sites and therefore this could be a source of pesticides for wild fish (see also section 9.7 Veterinary medicines).

Default maximum residue levels for pesticides set under assimilated Regulation (EC) 396/2005 do not currently apply to fish.

Very few studies of pesticides in wild caught fish were found in literature for the UK. There were many studies reporting pesticides in fish from all over the world, but mainly in relation to practices in aquaculture. A small number of UK studies were found.

The organochlorine pesticides are highly lipophilic and can quickly accumulate in oily fish. In a study funded by FSA and reported by Fernandes *et al.*, (2015 and 2018) a set of 50 fish samples comprising of sardines, herring, mackerel, mullet, sea bass and sprats were analysed for a range of 60 pesticides compounds. Only 5 compounds – p,p'-DDD, p,p'-DDT, p,p'-DDE dieldrin and hexachlorobenzene (HCB) were present above the limits of detection, ranging from 0.2 µg/kg for pp-DDD and HCB to 12 µg/kg for pp-DDE. These pesticides tended to occur at relatively higher levels in mullet, sea bass and herring which originated from Southern UK/ Northern France waters and the Irish Sea.

Macgregor *et al.*, (2010) analysed eels from Scottish waters for a range of persistent organic pollutants (PCB, DDT, HCH, HCB & BDE). They used eels as 'biomonitors' because of their high fat content, longevity and lifestyle behaviour. They spend up to 20 years in freshwater before migrating to the sea to spawn, they consume fish and benthic organisms. Their high proportion of fat means lipophilic contaminants accumulate in their bodies. Samples were collected from 30 sites in Scotland. DDT and its derivatives were detected in almost all samples. α-HCH, β-HCH and HCB concentrations were very low (generally <3 µg/kg or below detection). When compared with 1986 and 1995 data, the results revealed considerable decreases in p,p'-DDE concentrations.

Mormede and Davies (2001a) reported pesticide residues in 38 monkfish and 54 black scabbard from the Rockall Trough. A suite of 19 compounds was measured in different tissues from fish collected in 1998. Σchlordane was calculated as the sum of α-chlordene, γ-chlordene, heptachlor-epoxide, α -chlordane, γ-chlordane, oxychlordane, transnonachlor and heptachlor. ΣDDT was calculated as the sum of o,p'-DDD, p,p'-DDD, o,p'-DDT, p,p'-DDT, o,p'-DDE and p,p'-DDE. Median concentrations of ΣCB (24 congeners), HCB, Σchlordane, ΣDDT and dieldrin ranged from: 40 to 970 µg/kg; 6 to 28 µg/kg; 5 to 130 µg/kg; 10 to 550 µg/kg and 5 to 36 µg/kg lipid weight, respectively, in the organs studied. The data from this study are from samples collected more than 25 years ago, it is not possible to determine if this represents the current situation.

A more recent study reported feed used in salmon aquaculture may contain trace levels of agricultural pesticides and that wild fish continuously feeding on leftover pellets near fish farms over time may be vulnerable to organophosphorus pesticides (Olsvik *et al.*, 2019). The authors carried out tests with chlorpyrifos-methyl (CPM) for 30 days on juvenile Atlantic cod. The exposure led to changes, and a gradual hypoxia challenge test showed that all groups of exposed fish were less tolerant to low oxygen saturation than the controls. The study did not report residues in fish, however highlights the possible unintended consequence of wild fish being exposed to pesticides (and other chemicals) indirectly from aquaculture.

A recent literature review highlighted substances of emerging concern in Baltic Sea surface water (Kanwischer *et al.*, 2022). Data on the occurrence of polar pesticides such as triazine (e.g. atrazine), and urea herbicides (e.g. diuron and chlorotoluron) were reported. Data from four studies of German Baltic Sea coastline waters were summarised in the review, the maximum atrazine level reported was 7.6 ng/L and concentrations of up to 131 ng/L and 136 ng/L were recorded for diuron and chlorotoluron. The authors stated the concentrations were low, but more work was needed on effect-based methods to assess the impact of these and other chemicals analysed (including mixtures of co-occurring compounds) on marine organisms.

In summary, there were few results for Scottish waters or fish caught there, most recent data were from 2015 when 5 pesticide compounds – p,p'-DDD, p,p'-DDT, p,p'-DDE, dieldrin and hexachlorobenzene (HCB) were present above the limits of detection, ranging from 0.2 µg/kg for p,p'-DDD and HCB to 12 µg/kg for p,p'-DDE. Summarised results are presented in Table 16.

Relatively higher levels occurred in mullet, sea bass and herring, and in particular in those which originated from Southern UK/ Northern France waters and the Irish Sea.

An older study reported pesticide residues in monkfish and black scabbard from the Rockall Trough collected in 1998. A suite of 19 compounds was measured in different tissues. Median concentrations of Σ CB (24 congeners), HCB, Σ chlordane, Σ DDT and dieldrin ranged from: 40–970 µg/kg; 6–28 µg/kg; 5–130 µg/kg; 10–550 µg/kg and 5–36 µg/kg lipid weight, respectively, in the organs studied.

9.7 Veterinary drug residues

Veterinary drugs residues are historically associated with aquaculture products (GESAMP, 1997), as its worldwide growth has been accompanied by an increase in their use, mainly for the treatment or prevention of parasitic and microbial diseases (Uchida *et al.*, 2016).

The Veterinary Medicines Directorate (VMD) carry out data collection on veterinary antibiotic resistance and sales each year. Data on antibiotic usage is recorded for food producing animal species, including salmon and trout aquaculture. The latest report noted there has been little change in UK wide total sales since the previous year, and sales were maintained at the level of a 59% reduction since 2014 (VMD, 2023). It was noted that this masks fluctuations in some sectors, for example there was an increase in antibiotic use in salmon farming but a reduction in trout farming. Usage for trout farming had been higher in 2022 as it was used to treat an outbreak of *Aeromonas salmonicida* on a small number of production sites. For both salmon and trout farming, antibiotics are used only to treat specific infections, here is no prophylactic use of antibiotics (VMD, 2023).

However, veterinary drugs residues have been found in wild fish, caught close to aquaculture facilities in Chile (Guardone, 2022) and Carrizo *et al.*, (2021) reported the presence of antibiotics in wild and farmed Chilean salmonids.

There were no literature reports of veterinary drug residues in wild caught fish from Scottish or UK waters. There were several publications in scientific and grey literature about the use of chemicals for fresh and saltwater aquaculture. It must be highlighted that some compounds classed as veterinary medicines here may also be classed as pesticides.

To ensure cost-effective treatment, aquaculture facilities endeavour to ensure that most of an administered medicine is taken up by the target stock. For the potential of contamination of seafish and shellfish it is important to understand the half-life and persistence of chemicals used in aquaculture in water but also in sediments. Chemicals with a long half-life will persist in the environment longer and be available for ingestion by wild fish.

Treatments used in aquaculture typically have a high potential to reach the aquatic environment, primarily because they are added directly to the environment. The medicines and products used on fish farms in the UK are approved and regulated through chemicals legislation (e.g. Biocidal Products Regulations) or veterinary medicines regulations by the Health and Safety Executive (HSE) and VMD respectively.

A review of HorizonScan data for the period 1st January 2020 to 25th November 2024 found 200 RASFF alerts or notifications for veterinary drug residues in fish. Most of the notifications related to products of aquaculture imported to EU Member States, Australia and the USA, the most commonly reported countries of origin were Vietnam, China (and Hong Kong), Thailand, and Indonesia. The most frequently reported veterinary drugs were enrofloxacin and ciprofloxacin, leucomalachite green, and chloramphenicol across various species including tilapia, pangasius, and shrimp and prawns.

In summary, no reports or data for veterinary drugs in Scottish fish were found. The risk associated from most veterinary medicines for fish in the literature was not relevant to this study as these applied to fish from aquaculture, and mostly from tropical waters (imported products).

Environmental persistence of veterinary medicines in the seabed could lead to them being ingested by bottom feeding marine animals such as crabs, shrimp and lobsters. No data was found to assess if these compounds occur in wild caught fish and crustaceans. This could be a data gap.

9.8 Pharmaceuticals and personal care products

Nearly 1.2 billion pharmaceutical drugs are prescribed annually in the UK alone, in Scotland this amounted to over 110 million prescription items in 2022-23, an increase of 3.5% from 2021/22 (Public Health Scotland, 2023). Due to significant drug usage by

humans and animals, there are increasing amounts of pharmaceuticals in the environment.

Human excretion is generally considered to be the primary source of pharmaceuticals in the environment. Pharmaceuticals and their metabolites enter wastewater treatment plants as wastewater from this source and also from the disposal of unused or expired drugs in toilets. The physicochemical properties of these compounds such as their stability, high solubility in water and their resistance to biodegradation mean they are difficult to eliminate during water treatment. Pharmaceuticals can also reach the water in other ways, including through emissions from manufacturing (Bobrowska-Korczak *et al.*, 2021).

9.8.1 Human medicines – marine water studies

Bobrowska-Korczak (*et al.*, 2021) analysed muscle tissue of fish caught in the Baltic Sea for 98 multi-class pharmaceuticals including cardiovascular drugs, antidepressants, hypnotics, antibiotics, and sulphonamides. They also tested for heavy metals. Residues of 11 pharmaceuticals were found in fish muscle. The highest concentration was observed for ofloxacin, a fluoroquinolone antibiotic (up to 3.43 µg/kg in cod). Other antibiotics found were metronidazole (max 1.92 µg/kg, turbot), clarithromycin (max 0.44 µg/kg, flounder), sulfadimethoxine (max 0.37 µg/kg flounder) and erythromycin (max 0.17 µg/kg, cod). Other classes of drug included anti-infective/anthelmintic (thiabendazole, up to 2.09 µg/kg in turbot), antipsychotic (promazine, max 1.56 µg/kg, cod), anticonvulsant (carbamazepine max 1.18 µg/kg, cod), antidepressants (fluoxetine max 0.57 µg/kg, perch and tianeptine max 0.53 µg/kg, perch), and the betablocker, bisoprolol (max 0.23 µg/kg, plaice). None of the tested drugs were found in the fish muscle of species such as bream or crucian carp. The levels of pharmaceuticals in fish muscle varied depending on the species. The authors noted that fish can be exposed to drugs by direct exposure in water and from dietary exposure from food webs, as some compounds could bioaccumulate in lower levels of food chains.

McKenzie *et al.*, (2020) analysed a range of drugs including amphetamines, beta-agonists, anti-depressants and antihistamines in sea water. Samples were collected from the Clyde and Forth estuaries and analysed, chiral drugs were found at concentrations in the range 4 to 159 ng/L, with several demonstrating enantiomer enrichment. Paracetamol and caffeine were detected at the highest concentrations, the highest paracetamol concentration was 1056 ng/L in the Forth estuary. Other drugs detected included propranolol, atenolol, bisoprolol, citalopram, venlafaxine and desmethylvenlafaxine. Amphetamine was detected exclusively in the Clyde estuary. It was noted that highest concentrations of compounds were found upriver, closest to highest population areas and samples collected closest to the sea contained negligible levels or levels below the limit of quantification.

Petrie and Moffat (2022) analysed water and fish from the Clyde estuary. The fish species European flounder (*Platichthys flesus*) and common dab (*Limanda limanda*), muscle and liver were analysed. Paracetamol was frequently detected in water (97% of samples). Other drugs frequently detected were anti-convulsants, stimulants (caffeine was found in

100% of samples), antihistamines, beta-blockers, beta-agonists and anti-depressants. Venlafaxine (an anti-depressant) was found in 100% of samples.

None of the drugs were detected in dab muscle or liver. On the other hand, enantiomers of propranolol, fluoxetine, citalopram, and venlafaxine were detected in liver of flounder from the inner estuary. Enantiomer concentrations ranged from 0.11 ± 0.01 µg/kg ww for S(+)-citalopram in muscle to 2.71 ± 0.25 µg/kg wet weight for S(+)-fluoxetine in liver. The authors concluded there was widespread occurrence of drugs in the Clyde Estuary. Many drugs are chiral and this influences their fate and impact on the environment. The enantiomeric composition of some drugs measured in the study differed from their manufactured forms. This difference is important as toxicity studies do not normally account for this and may lead to underestimation or overestimation of environmental risk. Enantioselectivity of fluoxetine, venlafaxine and citalopram was observed in fish (European flounder) from the inner estuary.

The Marine Scotland Review of Hazardous Substances in the Scottish Marine Environment (Webster and Lacaze, 2021) was undertaken to review what data on hazardous substances is available for the Scottish marine environment. The results from Phase 1 of the CONnect study - Contaminants of Emerging Concern and Threat in the Marine Environment project were included in this report. Thirty-two samples (mainly mussels, but also some fish) were screened for several thousand organic pollutants. Substances screened for included industrial chemicals, pharmaceuticals, antipsychotic and antidepressant drugs, Personal Care Products (PCPs), and others. UK mussel sites sampled in 2020 included two from Scotland and two from England. In the two Scottish mussel samples, all pharmaceuticals were below the LOD, though some pharmaceuticals (Mexiletine, Phenazone, Reproterol, Sotalol) were detected in the English samples (Webster and Lacaze, 2021).

The review reported that ICES Working Group on Marine Sediment (WGMS) and the Marine Chemistry Working Group (MCWG) included pharmaceuticals among nine contaminants/contaminant groups that should be given consideration for addition to the OSPAR List of Contaminants of Concern/ Priority Action (Webster and Lacaze, 2021).

Pharmaceuticals have also been found in marine species living in coastal areas. Alvarez-Munoz *et al.*, 2015 reported the occurrence of pharmaceutically active compounds and endocrine disruptors in macroalgae, bivalves and fish from 5 coastal regions in Europe. Four pharmaceutical compounds were found in macroalgae samples, 16 in bivalves and 10 in fish. The highest levels of pharmaceutically active compounds found were the psychiatric drug venlafaxine (up to 36.1 µg/kg dry weight (dw)) and the antibiotic azithromycin (up to 13.3 µg/kg dw) in bivalves from the Po delta (Italy). The authors also reported the detection of dimetridazole, hydrochlorothiazide and tamsulosin in biota samples for the first time.

Moreno-González *et al.*, (2016) analysed 20 pharmaceuticals in fish and molluscs. More pharmaceuticals were detected in fish (particularly golden grey mullet) than in wild and

caged molluscs (17 compared to 10). Psychiatric drugs preferentially bioaccumulated in fish muscle while citalopram bioaccumulated in molluscs. The authors noted the high detection frequency and concentrations of pharmaceuticals found in golden grey mullet showed that this species could be considered as a potential indicator of pharmaceuticals in the coastal environment.

Lolić *et al.*, 2015 reported the presence of non-steroidal anti-inflammatory drugs (NSAIDs) and analgesic pharmaceuticals and metabolites in Portuguese seawaters at concentrations up to 1227 ng/L. For most of the pharmaceuticals the highest concentrations found in seawaters were reported in the Porto coastal area, a densely populated area.

Almeida *et al.*, (2020) conducted a literature review of concentration levels and effects of 17alpha-Ethinylestradiol (EE2 - an oral contraceptive) in freshwater and marine waters and bivalves. They cited more than 25 publications that reported EE2 concentrations in water and bivalves from marine environments. Most reported testing water only, but 7 reported testing bivalves, of these, 5 measured residues up to 310 µg/kg (d.w.). The results available showed that EE2 induced changes on reproductive systems of several species of mussels and oysters using acute and chronic tests, performed with concentrations of environmental relevance or higher.

9.8.2 Personal Care Products

The CONnect (CONTaminants of Emerging Concern and Threat in the marine environment) study for the OSPAR Convention reported the detection of methyl paraben (personal care product) and alkylamines and quaternary alkylammonium surfactants, (surfactants used in a range of consumer products such as hair care products, fabric softeners, and for industrial uses such as hydraulic fracturing fluids) in Scottish mussels (Webster and Lacaze, 2021 and McHugh, 2022). Two Scottish samples and two from England had been analysed in the study. Methyl paraben was quantified in 3 out of 4 samples at levels from 15.1 to 29.1 µg/kg ww, it was also detected in the fourth sample but was below the LOQ. These contaminants were included in the testing programme of the CONnect study to help identify emerging substances of concern. Parabens may act as weak endocrine disrupting chemicals. Methylparaben, used as an anti-fungal agent in a variety of cosmetics and personal care products, was the most frequently detected compound (occurring in 46 out of 48 samples tested) (McHugh, 2022). The risk assessment of the results from the CONnect study stated methyl paraben and alkyl amines and quaternary alkylammonium surfactants to be of most concern in Scottish mussel samples, although this was based on only a very small number of samples (Webster and Lacaze, 2021).

Fussell *et al.*, (2014) analysed a range of foods on sale in the UK for the presence of a range of chemicals including human and veterinary medicines and personal care products. Concern has been raised about the use of nitro-musks (musk-xylene, and musk-ketone) due to their toxicity. They have been replaced in many products by synthetic musks (polycyclic musks such as galaxolide and tonalide). As part of this study 6 musks and 8

parabens were analysed in a range of food products. Of relevance to this review were UK trout, imported fish and imported shrimp. UK trout samples were found to contain residues of parabens and musk chemicals. The authors concluded the combination of the fact that parabens are approved as food preservatives and were found at low concentrations they were not likely to give cause for concern. Residues of musks occurred at higher frequency and higher concentrations in UK trout compared to imported fish. The nitro-musks (such as musk-xylene and musk-ketone) that are no longer used were not detected or were found less frequently than the polycyclic musks. The highest concentrations of galaxolide and tonalide occurred in fish collected from fish farms that were downstream from sewage farms. The study only tested one species of freshwater fish, there is no data on the occurrence of these chemicals in other types of fish or shellfish.

In summary, there was evidence of the occurrence of human pharmaceuticals and personal care products in estuarine and marine environments. Medicines found include paracetamol, ibuprofen, and diclofenac (pain relief/anti-inflammatories); clarithromycin and trimethoprim (antibiotics); carbamazepine and fluoxetine and EE2, also anti-convulsants, stimulants (caffeine), antihistamines, beta-blockers, beta-agonists and anti-depressants, most commonly Venlafaxine.

There were fewer reports of residues in fish. All pharmaceuticals were below the LOD in two Scottish mussel samples sampled in 2020, though some pharmaceuticals (Mexiletine, Phenazone, Reproterol, Sotalol) were detected in the two English mussel samples. Fish from the Clyde estuary, European flounder (*Platichthys flesus*) and common dab (*Limanda limanda*), muscle and liver were analysed for a range of medicines. None of the drugs were detected in dab muscle or liver. Propranolol, fluoxetine, citalopram, and venlafaxine were detected in liver of flounder from the inner estuary.

The 2021 review of hazardous substances in the Scottish Marine environment suggested additional monitoring of pharmaceuticals in biota (i.e. fish and shellfish and sediment) may be required.

For personal care products, the compounds classed as chemicals of emerging concern by the CONnECT study, for which monitoring was suggested were methylparaben, (whose presence and risk evaluation categorised it as potentially of high environmental concern) and alkyl amines and quaternary alkylammonium surfactants.

There is very little data of the occurrence of human medicines or personal care products in UK fish or fishery products.

9.9 Microplastics

Microplastics (MP) are categorised as particles <5 mm (Lau, *et al.*, (2020) and GESAMP, (2016)). They are further classified as primary microplastics that include pellets, powders and plastic microbeads, made for use in products such as cosmetic formulations, cleaning products and for industrial abrasives and secondary microplastics that are formed when larger plastic objects such as shopping bags and food containers break down (GESAMP,

(2016)). They have been observed in the environment and detected in aquatic organisms for more than 50 years (Gouin, (2020)). Multiple studies that have sought to quantify plastic waste predict that the amount of plastic pollution in the ocean will continue to increase over the next several decades (Borelle *et al.*, 2020 and (Lau, *et al.*, (2020))).

The Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) report of 2016 reviewed plastic ingestion by marine fish (GESAMP, (2016)). They noted 89 species of fish had been reported to ingest MP, of which 49 species are commercially important. The report also highlighted that at the level of knowledge at that time it was not possible to interpret the effects of MP on commercial fish species. While it was noted fish ingest MP, the main area of concern was the potential for contaminants or chemicals associated with the plastic being absorbed by the fish as the plastic passed through the fish digestive system. The report recommended research on the retention times of MP in commercial fish species to evaluate exposure time and bioaccumulation of associated contaminants (e.g. PCBs, PBDEs) in the tissues; and to be able to relate the observed effects to MP concentrations (GESAMP, (2016)).

Savoca, *et al.* (2021) carried out a review of literature of plastic ingestion by fish covering four decades of research. They noted since an international assessment conducted for the United Nations in 2016, (GESAMP, 2016) the number of marine fish species found with plastic had quadrupled. This was attributed to an increase in interactions between fish and plastic, rapid expansion of research on this topic and improvements in analytical methodology. Plastic ingestion by marine fish was widespread, the review found reports of 386 species, although most contained fewer than 2 pieces of plastic. Deep sea fish were the least studied, but there was evidence of vertical transport of plastic from the surface to the deep ocean by lanternfish (*Myctophidae*), (Savoca *et al.*, (2021)). While there is much evidence fish species of commercial interest ingest plastic, the risk to humans is still largely unknown. The risk of human consumption of plastic is probably low as most is retained in the fish intestines and stomach and these are typically discarded. However, there is some concern plastic-associated contaminants including phthalates, heavy metals, and POPs may transfer to fish tissues resulting in them occurring in the human food chain (Savoca *et al.*, (2021)).

Murphy *et al.* (2017) reported a study of uptake of MP by fish in Scottish waters, with four demersal and one pelagic species found to have ingested plastic of some size. Samples were collected at different locations in Scottish waters and results showed a range of fish species ingested macroplastic and MP. The size of pieces of plastic found ranged from 0.1 mm to 15 mm, the larger pieces referred to as macroplastic in this paper were fibres from larger items. Fish from coastal regions had ingested more plastic (45.2% to 51.1% contained plastic) compared to offshore fish (0 to 10%). Fibres were the most common type of plastic found (82.1%). The average number of plastic pieces found in fish that ingested plastic was 1.8 ± 1.7 . Of the 84 pelagic and demersal offshore fish, only 2 (2.4%), one sample of megrim and one of greater Argentine, had ingested plastic. This was identified as a clear polystyrene fibre and a black polyamide fibre.

A study of pelagic and demersal fish from the English Channel found a higher incidence of fish containing plastic, all five pelagic and five demersal species had ingested plastic. Of 504 fish samples, 36.5% had ingested plastic (Lusher, *et al.*, (2013)). The size range of plastic ingested was 0.13 to 14.3 mm. The average number of pieces ingested ($n = 1.90 \pm 0.10$) was similar in both publications. In another study (Lusher *et al.* (2016)), it was reported 11% of 761 fish sampled contained MP. In total 2315 particles were found, 89% were less than 5 mm and so classified as microplastics.

A study was carried out to investigate the levels of ingested MP in populations of *Nephrops norvegicus* from the Clyde Sea Area, North Minch and North Sea. The location, size, sex and moult stage appeared to influence the plastic uptake, nearshore had higher levels and the Clyde Sea animals contained more (84% incidence) than those from the North Sea (28.7%) and North Minch (43%) (Welden and Cowie, (2016a)). Microplastics were found in shed stomach linings and it was found males, larger animals and those that had moulted recently contained less plastic. The large proportion of contaminated individuals and size of the microplastic aggregations observed suggested that *Nephrops* are at high risk of microplastic ingestion (Welden and Cowie, (2016a)). A study carried out to feed *N. norvegicus* polypropylene fibres found the plastic-fed langoustine contained MP aggregations similar to the small animals from the Clyde Sea Area. When fed, unfed and plastic-fed individuals were compared, a reduction in feeding rate, body mass, and metabolic rate was observed in the plastic contaminated animals. The authors concluded that high levels of environmental microplastic pollution may cause reduced nutrient availability in the *Nephrops*. They suggested this could result in reduced population stability and affect the viability of local fisheries (Welden and Cowie, (2016b)). No assessment or comment was made about consumption of langoustines or consumer safety.

Scottish haddock (*Melanogrammus aeglefinus*), Greek seabass (*Dicentrarchus labrax*), Icelandic plaice (***Pleuronectes platessa***), Atlantic mackerel (*Scromber scombrus*), Patagonian scallop (*Zygochlamys patagonica*) and Scottish scallop (*Pecten maximus*) ($n = 10$ individuals for each species with the exception of $n = 12$ for haddock), from commercial suppliers were examined to determine the levels and types of micro- and mesoplastics (MPs) (Akoueson *et al.*, 2020). In this publication the authors categorised plastic in the 1-5000 μm range as micro and mesoplastic although mesoplastic has also been categorised as particles of plastic found in the marine environment typically ranging in size from 5 mm to 2.5 cm in other reports. The levels of MP in edible and non-edible tissues in seafood samples intended for human consumption were assessed. Samples taken from typically non-edible (gills, digestive system) and edible (muscle) flesh were analysed separately. Scallops, where all tissues are edible, were analysed whole. Significant differences were observed in the number of particles isolated from the fin fish gills and digestive tissues relative to the control samples, but not in the edible flesh. For scallops, the abundance of particles in the Scottish samples did not vary significantly from the control, although it was higher. However, the scallops from Patagonia showed significantly higher numbers of particles relative to both the blank and the Scottish scallops ($p = 0.000$ for both), they contained 2.03 ± 0.67 particles / g flesh tissue compared to 0.28 ± 0.15 particles / g flesh

tissue in the Scottish scallops. Fourier transform infrared spectroscopy (FTIR) microscopy found that 16 to 60% (depending on species) of particles were polyethylene terephthalate (PET) and polyethylene (PE) in origin. The authors stated the results of the study validate MPs as an emerging risk in the food chain and establish seafood as a vector for the intake of MPs through human ingestion of seafood. They suggested that MP quantification should be included as a food safety measure for shellfish, however as the levels in fin fish were very low this may not be required for fin fish at the moment.

Two reviews, (Gouin, 2020 and Miller *et al.*, 2020) studied bioaccumulation of MP. Gouin (2020), concluded that although MP is consumed by fish they do not bioaccumulate and do not appear to biomagnify as a result of trophic transfer through food webs as more than 99% of results from field studies reported the plastics were found in the gastrointestinal tract. Miller *et al.*, (2020) found their meta-analysis corroborated previous studies that microplastic bioaccumulation occurs within each trophic level but appeared to be more strongly linked to feeding strategies rather than the trophic levels of the fish species. Bioaccumulation of associated chemical additives was more ambiguous and was more strongly linked to exposure of the chemicals themselves. In contrast, they found biomagnification of microplastics across a general marine food web was not supported by current field observations.

In summary, in a study of fish from Scottish waters, fish from coastal regions had ingested more plastic (45.2% to 51.1% contained plastic) compared to offshore fish (0 to 10%). The size of pieces of plastic found ranged from 0.1 mm to 15 mm, the larger pieces referred to as macroplastic were fibres. Of the 84 pelagic and demersal offshore fish, only 2 (2.4%), one sample of megrim and one of greater argentine, had ingested plastic. The average number of pieces ingested was 1.80 ± 1.70 .

A study of pelagic and demersal fish from the English Channel found all five pelagic and five demersal species had ingested plastic. Of 504 fish samples, 36.5% had ingested plastic. The size range of plastic ingested was 0.13 to 14.3 mm. The average number of pieces ingested ($n = 1.90 \pm 0.10$) was similar to the Scottish study.

Nephrops norvegicus populations from the Clyde Sea Area, North Minch and North Sea were investigated for the levels of ingested MP. The location, size, sex and moult stage appeared to influence the plastic uptake, nearshore animals had higher levels and the Clyde Sea animals contained more (84% incidence) than those from the North Sea (28.7%) and North Minch (43%). Microplastics were found in shed stomach linings and it was found males, larger animals and those that had moulted recently contained less plastic. The large proportion of contaminated individuals and size of the microplastic aggregations observed suggested that *Nephrops* are at high risk of microplastic ingestion which may adversely impact the population as animals that consumed plastic had a reduction in feeding rate, body mass, and metabolic rate which could affect population stability.

Evidence of microplastics have been found in fish from waters around the UK. Higher levels have been reported in shellfish tissue than fin fish flesh, for which plastic was confined to the gill and gut tissue. One study reported plastic particles in Scottish scallops, but at a significantly lower level than scallops from Chile (Patagonian scallops) (Akoueson, *et al.*, 2020). Bivalves could contribute to human ingestion of microplastics. It may be prudent to consider adding monitoring to safety assessments for shellfish. There was some concern that chemical contaminants may accumulate in fish following exposure to MP, but any occurrence would be detected via monitoring for those chemicals.

9.10 Naturally Occurring Contaminants – Histamine

Histamine is a biogenic amine which is a naturally occurring substance in the human body. Histamine or “Scombroid fish” poisoning is a foodborne illness most commonly caused by consuming certain species of marine fish (e.g. tuna, herring, mackerel) that have naturally high levels of histamine and possibly other biogenic amines in their tissues. Histamine is produced when bacteria that naturally occur in the skin, gills and guts of fish break down histidine, an amino acid found in the muscles of certain fish species that contain naturally high levels of this amino acid (e.g. mackerel/herring/sardines/tuna). The production of histamine is directly related to the mishandling of food as a result of storage at incorrect temperatures allowing bacteria to grow. Histidine decarboxylase, the enzyme responsible for breaking down histidine into histamine, can remain active even after the bacteria responsible for producing it have been inactivated or killed. Harmful levels of histamine can build up in fish before any signs of spoilage develop, such as a bad smell or taste. For these reasons, control strategies focus on prevention through the use of strict temperature control throughout the food chain.

Levels of above 200 mg/kg have been associated with human illness. However, most cases of illness caused by histamine in fish have been above 200 mg/kg, and often above 500 mg/kg (FSS, 2014). Assimilated Commission Regulation (EC) No 2073/2005 on microbiological criteria for foodstuffs (as amended) lays down standards for fishery products which are associated with high levels of histamine, ($n = 9$, $c = 2$, $m = 100$ mg/kg, $M = 200$ mg/kg) and for fishery products that have undergone enzyme maturation in brine, ($n = 9$, $c = 2$, $m = 200$ mg/kg, $M = 400$ mg/kg).

The Food Standards Agency in Scotland (now FSS) commissioned a project to provide a comprehensive review of current risk management practices for controlling histamine in at-risk fish species throughout the Scottish fish processing chain. Temperature is the key to control histamine formation. The most important control to prevent histamine formation and accumulation is rapid chilling of harvested fish and maintenance of low temperatures ($<2^{\circ}\text{C}$) until the fish is eaten.

The conclusion from this project was that there are potential inherent risks of histamine fish poisoning from eating fish species, such as mackerel and herring. However, by applying appropriate food safety risk management systems, as required by the relevant

hygiene regulations, including maintenance of the cold chain and basic good hygiene practices, food businesses can adequately control these risks (FSS, 2014).

In summary, measures are in place to control histamine formation, these include good hygiene practices and controlled temperature handling of fish to prevent histamine accumulation. Rapid chilling to low temperatures and maintenance of low temperatures until fish is eaten will minimise risk.

9.11 Marine Biotoxins

Marine biotoxins are toxic substances that can accumulate in live bivalve molluscs. There are three groups of regulated marine biotoxins for shellfish:

- amnesic shellfish poisoning toxins (ASP),
- lipophilic toxins (including diarrhetic shellfish poisoning toxins (DSP), azaspiracids (AZAs) and yessotoxins (YTXs)
- paralytic shellfish poisoning toxins (PSP).

Both the FSA and FSS publish advice or guidance to harvesters and processors on their websites. As part of the controls to protect public health, Assimilated Regulation (EC) 854/2004 requires the Competent Authority (CA) to carry out Official Control (OC) monitoring of classified shellfish relaying and production areas to check for the possible presence of toxin producing phytoplankton in the water and biotoxins in the shellfish flesh. FSA and FSS undertake OC monitoring of bivalve flesh and phytoplankton. The monitoring and management system has been in place for many years. A Toxin Risk Management Traffic Light Tool Kit is used as a decision tool, which using the results of the OC monitoring and analysis undertaken by harvesters and food businesses can be used to support food businesses make decisions about harvesting action, including the need for increased testing, positive release or suspension of activities (FSS, 2022).

A comprehensive literature review was carried out in 2014 to support the development of a Monitoring Programme for new or emerging Marine Biotoxins in shellfish in UK waters (Higman *et al.*, 2014). It reviewed available risk assessments, established a list of potential harmful algae threat for UK waters, assessed methods and collated information on sampling. Current, new and emerging toxin risks were ranked using a scoring matrix based on likelihood and severity. This was used to help design the monitoring programme in the UK.

A review to assess the Scottish inshore monitoring programme for biotoxins in shellfish from classified inshore production areas in Scotland was reported in 2020 (FSS, 2020). In this study, the biotoxin patterns observed in shellfish across Scotland throughout the year were established using data collected over a twenty-year period from April 2001 to March 2021. This data was used to assess the current FSS monitoring programme to evaluate

the risk of a toxic event at a particular location going undetected. Based on this, modified schemes were suggested (FSS, 2020).

Therefore, there is comprehensive monitoring in place. Results are reported annually and via websites including [CEFAS](#).

9.11.1 Emerging Marine Biotoxins

In terms of emerging risk, Higman *et al.*, (2014) developed a risk matrix for emerging toxins, assigning a risk level score of 0 to 25, based on a combination of likelihood and severity scores. The most highly ranked with a score of 25 were the PSP toxins from *Alexandrium* species and ASP toxins, followed by OA-group toxins and AZA1-3 which both had a risk level score of 20. All of these toxins are already included in monitoring. Other AZAs (shellfish metabolites) were given a risk level of 16, at the time of the report they were not included in UK monitoring. It was stated that while LC-MS/MS methods would be suitable for their analysis the accuracy of quantitation is potentially compromised without certified standards for instrument calibration. The most recent report for the Biotoxin and Phytoplankton official control monitoring programmes for England and Wales states Azaspiracid group toxins (AZAs), were not detected in samples received in 2022, but it does not mention AZA analogues (CEFAS, 2023).

Brevetoxins and Tetrodotoxins were both ranked next highest risk with a score of 15. A ranking scheme was used for the Toxins. “New” AZAs, PSP toxins and other PSPs analogues were ranked 1, 2 and 3. Brevetoxins were ranked 4 with several other classes of toxins including cyclic imines, palytoxins, tetrodotoxins and cyanobacteria toxins (e.g. microcystins). It was proposed that establishing methods of analysis for brevetoxins and tetrodotoxins would allow screening and confirmation of high-risk samples to reduce risk for consumers.

Brevetoxins are neurotoxins, they have been reported to occur in finfish. There had been no detection of brevetoxins in the UK reported at the time of the Higman report, although these toxins were not included in monitoring. However, it was stated that potentially favourable conditions for the causative organisms (*Karenia brevis*) exist in the UK and blooms of the algae (red tides) that produce these toxins have been reported in New Zealand where sea temperatures are similar to the UK. Turner *et al.*, (2015a) reviewed the potential threat posed by brevetoxins. They concluded the likelihood of brevetoxin occurrence was low in the UK, however introducing monitoring using LC-MS/MS alongside routine monitoring of other lipophilic marine toxins could be used as a precautionary measure. Samples of crustaceans linked to a mortality event in the North East of England were analysed for a range of marine biotoxins. A validated method was not available for emerging lipophilic toxins (brevetoxins and associated metabolites, cyclic imines), however a screening test found no evidence of pinnatoxins, brevetoxins, brevetoxin metabolites or other associated toxin analogues (CEFAS, 2022).

Tetrodotoxin (TTX) is an extremely potent neurotoxin, produced by TTX-producing bacteria found in marine organisms including *Shewanella alga*, species of *Vibrio*, *Pseudomonas*, *Bacillus*, *Alteromonas*, *Aeromonas*, *Pseudoalteromonas*, *Serratia marcescens* and *Shewanella putrefaciens*. This is the toxin found in the Puffer fish and is the most commonly occurring lethal marine poisoning. Turner *et al.*, (2015b) reviewed the potential threat posed by tetrodotoxins. The review highlighted the UK was not prepared at that time for responding to any urgent need to carry out routine monitoring as the analytical methods had not been formally validated by collaborative study. This group also reported the occurrence of TTX in two bivalve shellfish samples (mussels and Pacific oyster) from the English Channel, the first report of the toxin in the UK (Turner, *et al.*, 2015c). TTX has also been found in Europe in Atlantic waters on the Portuguese coast. A larger study on the occurrence of TTX in shellfish from the UK coast was reported in 2017 (Turner, *et al.*, 2017). Samples were collected from 2014-2016 around the coast of the UK and analysed by an LC-MS/MS method. Of 477 samples collected in England, 55 samples contained TTXs above the reporting limit. Fourteen samples were above the Dutch limit of 20 µg/kg, and the highest level was 253 µg/kg in a Pacific oyster sample. Of 670 samples tested from Scotland only 2 were above the reporting limit of 2 µg/kg. There were also 28 samples from Wales and 57 from N. Ireland but none were above the reporting limit (Turner, *et al.*, 2017).

One barrier to obtaining information about these emerging toxins has been a lack of available methods of analysis, a significant factor in this has been the lack of suitable analytical standards and reference materials. The EURL has included the implementation of methods for TTXs in its work programme for 2023-24.

9.11.2 Cyanobacteria Toxins - Microcystins

Microcystins (MCs) are toxins produced by certain species of freshwater cyanobacteria known as blue-green algae. Microcystin is a known hepatotoxin and exposure to this toxin has impacted different marine trophic levels, including small planktonic invertebrates, fish, and large vertebrates. Malbrouck and Kestemont, (2006) reviewed the effects of MCs on fish and discussed the potential effects on food webs, this review was mainly based on freshwater studies.

Microcystins are generally believed to be a concern of freshwater species and some studies have been published on their uptake by fish in freshwater lakes. Rodrigues *et al.*, (2022) reported changes in freshwater fish following exposure to sub-lethal level of microcystins.

However, they are also a marine concern because microcystin-contaminated freshwater is known to be entering marine ecosystems (Miller, *et al.*, 2010). The presence of MC in the black band disease of coral in nine reefs in the wider Caribbean area, including Florida Keys and the Bahamas was reported by Richardson *et al.*, (2007). Miller *et al.*, (2010) reported the deaths of 21 sea otters around the Monterey Bay National Marine Sanctuary in California, USA linked to microcystin intoxication. Carcasses of the dead otters clustered

in areas such as harbours and river mouths which are preferred as foraging sites. Chemical analysis of sea otter tissues in conjunction with the necropsy and histopathology of the tissues confirmed the deaths from MC intoxication. The authors claimed this is the first report of deaths of marine mammals due to cyanotoxins. They also reported significant bioaccumulation and slow depuration of freshwater microcystins by marine oysters, clams, snails and mussels under laboratory conditions that mimic natural exposure. The authors concluded that because sea otters and humans consume many of the same marine foods, their research findings may have exposed a previously unknown health risks for humans when consuming invertebrates harvested at the land-sea interface (Miller *et al.*, 2010).

A review by Preece *et al.*, (2017) reported the occurrence of microcystin producing algal blooms in European coastal waters from the Baltic Sea and the Netherlands to Portugal and Spain, and microcystins have been detected in open water sampling sites in the Gulf of Finland. In the review examples of microcystins being detected in marine mussels and crabs and in the flesh of Tilapia (finfish) were cited. The authors suggested recent findings of toxins in coastal environments may be due to increased nutrient loads that drive harmful cyanobacteria blooms, coupled with environmental conditions related to climate changes. In addition, new toxin-forming strains may have been introduced into coastal waters. Monitoring and research to understand the impact of cyanobacteria and microcystins in coastal areas were recommended.

Microcystins were reported in farmed Mediterranean mussels in Greece. Although both the sea conditions (higher temperature) and the production method are somewhat outside the scope of this review it confirms the occurrence of these toxins in a marine environment (Kalaitzidou, *et al.*, 2021)

Dahlgren *et al.* (2022) analysed the muscle of 20 European flounder caught in south-western areas of the Baltic Sea for microcystins and nodularin (cyanobacterial toxins). Microcystins were not detected in any of the samples. Nodularin was detected in half of the fish samples tested, the mean level was 8.30 ± 12.0 ng/g dry matter (dm), two individual fish had levels of nodularin ≥ 35 ng/g dm, and none had levels over 50 ng/g dm.

In summary, monitoring for regulated marine biotoxins is comprehensive and systems are in place to manage any potential outbreaks to reduce risks to consumers.

Brevetoxins and tetrodotoxins were highlighted as two particular groups of emerging marine biotoxins that are a risk to both shellfish and finfish. There is very little or no information about their occurrence in the UK, although tetrodotoxin has been detected in bivalves from the English Channel, and in 2 out of 670 samples from Scotland.

Microcystins are a growing issue in freshwater areas but there is also some evidence of their impact on marine environments. Some residues of microcystins have been detected in marine shellfish and fish, not from UK coastal waters but from similar regions e.g. Baltic Sea and The Netherlands. Species of interest (indicator species for this study) that have been reported to contain microcystins were marine mussels and crabs.

There are data gaps for these emerging toxins in marine fish and shellfish.

9.12 Co-occurrence and relation to key species

The data from the UK studies on chemical contaminants were used to construct a series of diagrams for all species where there were positive results. Sankey diagrams have been plotted for each group of fish (Figures 4 to Figure 11). These show, where data are available, the co-occurrence of the main chemical contaminants in the individual species. They do not show where the testing produced a negative result (no residue detected or <LOQ). Representations of all results including not-detected results are given in the dashboard diagrams in Figure 12 and Figure 13.

The width of the bands for the species, contaminant and the linking ribbon are indicative of the total number of samples and frequency of detection of a residue above the LOQ. The number of samples and results for each analyte measured are indicated on the diagrams.

Occurrence data for all species included in the initial list supplied by FSS were also used to produce a series of waffle plots. These diagrams represent all analyses carried out and show where residues were less than the LOQ, above the LOQ (i.e. a residue was quantified) and any ML exceedances. These plots also serve to highlight where there were no data for some species. These plots are given in Annex. B, Figure 14 to Figure 17.

Further analysis to consider the co-occurrence of different contaminants in the key species highlighted in Table 4 and consumption data from Table 5 are given below.

9.12.1 Demersal species

The data for key demersal species (identified in Table 4 based on landings volume and consumption data, Table 5), from the UK studies are represented in a Sankey diagram below (Figure 4). This shows different mixtures of contaminants occur in different species. Mercury, lead, cadmium and dioxins and PCBs all occurred in whiting, but there are no results for PFAS as no tests for PFAS were carried out on whiting in the recent wild caught fish survey (FSA Research and Evidence, 2025). Low concentrations of PFAS were reported in whiting from the North Sea by Zafeiraki, *et al.*, (2019) (Table 19). Haddock and cod contained mercury, lead, PFAS and dioxins and PCBs, but no cadmium. Monkfish contained only mercury and PFAS.

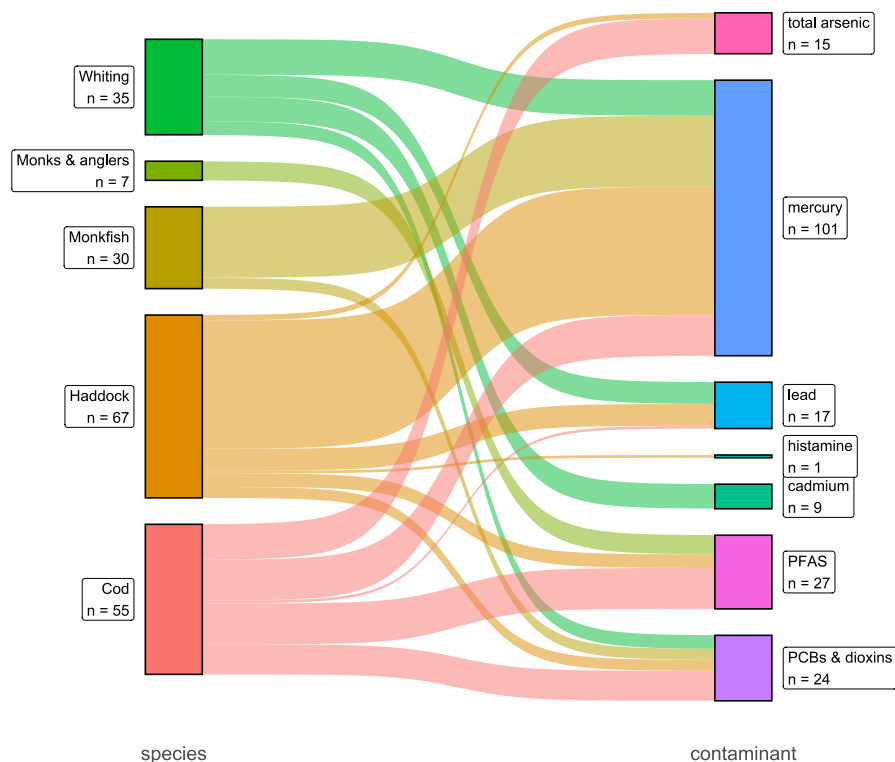


Figure 4. Sankey diagram of chemical contaminants detected in key demersal fish species.

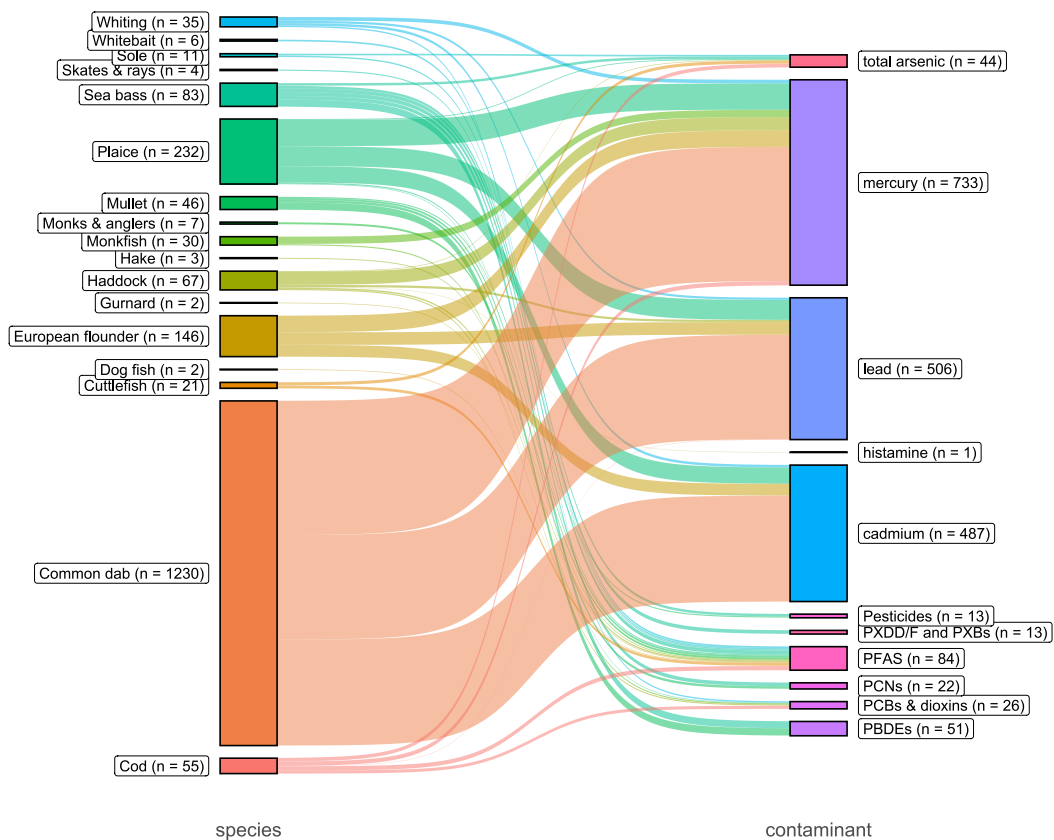


Figure 5. Sankey diagram of chemical contaminants detected in all demersal fish species.

9.12.2 Pelagic species

Figure 6 is a Sankey diagram that shows the reported occurrence of chemical contaminants in key species (identified in Table 4 based on landings volume and the consumption data in Table 5) of pelagic fish where there have been residues of contaminants detected above the LOQ. This diagram does not show where analyses have been carried out but results were below the LOQ, these are shown in the dashboards in Figure 12 and Figure 13. All results, including those below the LOQ, are shown in Figure 14 to Figure 17. Figure 6 highlights where multiple contaminants have been reported in a particular species. Both mackerel and herring have been found to contain all of the main chemical contaminants. The number of herring samples containing residues of PFAS was lower than mackerel, but the overall number of samples tested for these contaminants was much smaller than the other contaminants that have been included in more sampling surveys. The number of residues of mercury and dioxins and PCBs were similar for both fish, but mackerel tended to contain cadmium and lead more frequently. Figure 7 shows the results for the key fish species and also sprats (not classed as a key species in Table 4), the other pelagic species that has been frequently included in surveys.

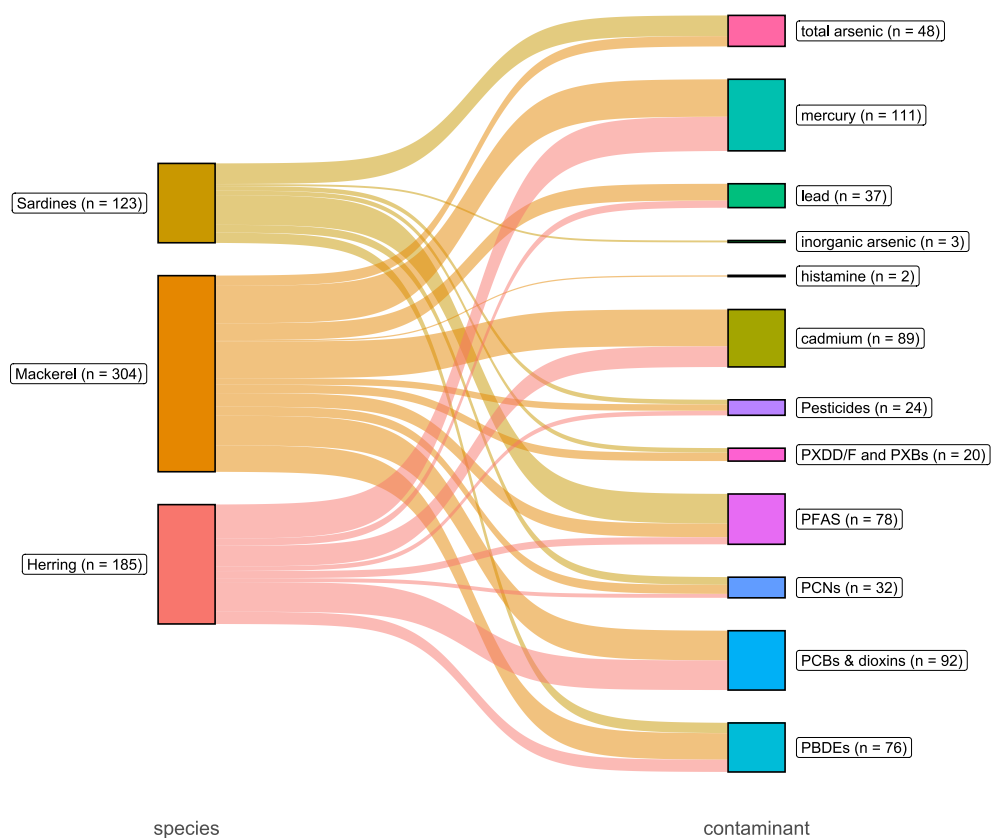


Figure 6. Sankey diagram of chemical contaminants detected in key species of pelagic fish.

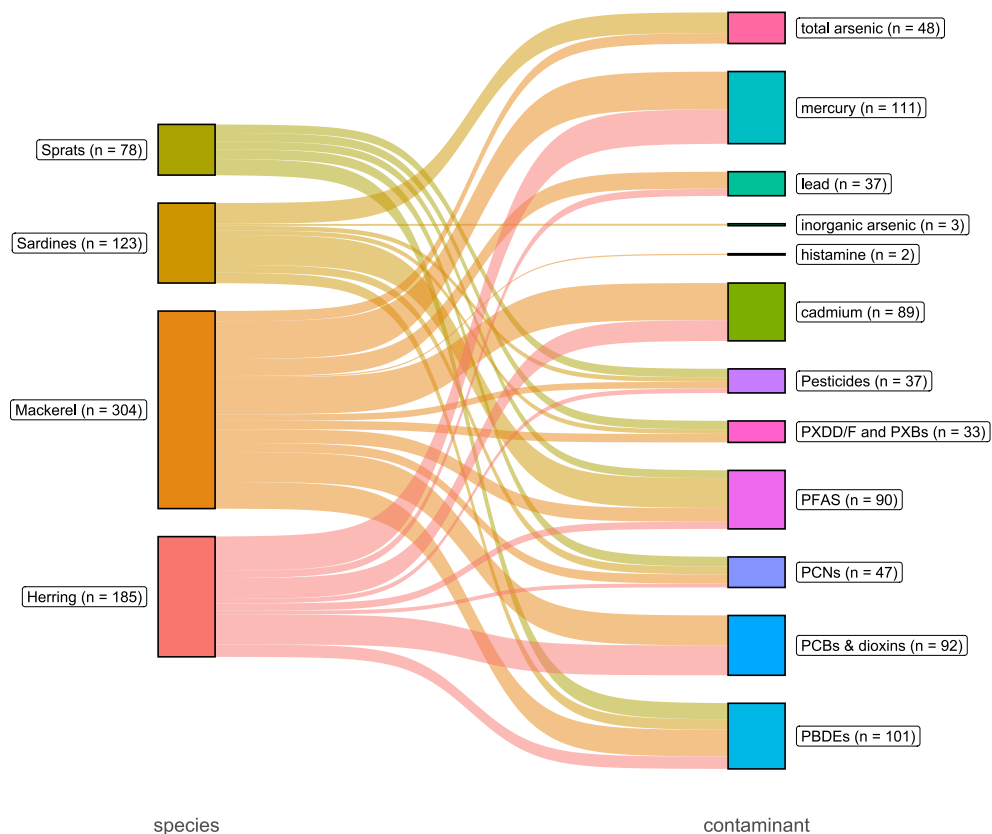


Figure 7. Sankey diagram of chemical contaminants detected in all species of pelagic fish.

9.12.3 Shellfish species

The co-occurrence of the chemical contaminants for the key shellfish species (identified in Table 4 based on landings volume and the consumption data in Table 5) is given in Figure 8. The diagram represents results where a residue was detected above the LOQ. Scallops contained mercury, lead, cadmium and dioxins and PCBs, but no PFAS or inorganic arsenic. Lobsters contained all contaminants. Crab contained cadmium, mercury, total arsenic and inorganic arsenic, PFAS and PCBs and dioxins. Only one sample was reported to contain inorganic arsenic this is quite difficult to see on the diagram as the results are displayed in relative proportion to each other and there were many more reports of residues of the other contaminants. Figure 9 shows all results detected above the LOQ for all species of shellfish analysed in UK surveys. This includes several species that were not ranked as 'key' due to the relatively small catch volumes, or low consumption from the consumption data.

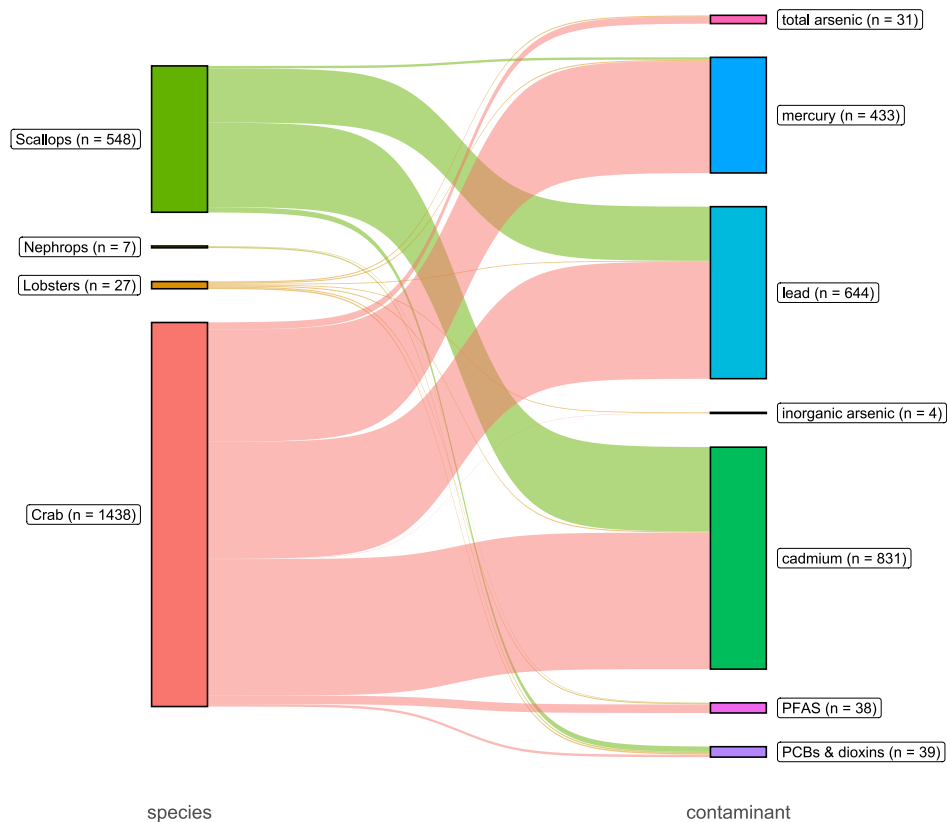


Figure 8. Sankey diagram of chemical contaminants detected in key shellfish species.

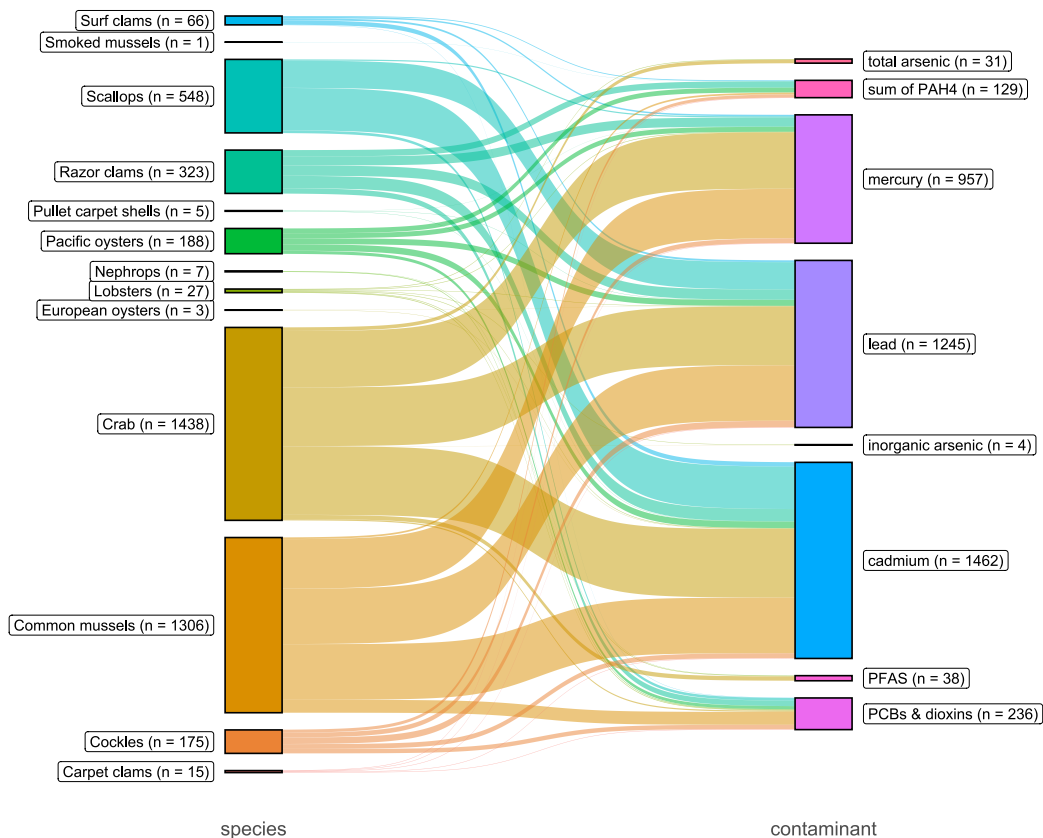


Figure 9. Sankey diagram of chemical contaminants detected in all species of shellfish.

9.12.4 Cephalopods

Figure 10 is a Sankey diagram showing the co-occurrence of all the chemical contaminants in squid, the key indicator species for cephalopods. It should be noted there were very few samples of squid in the studies reported.

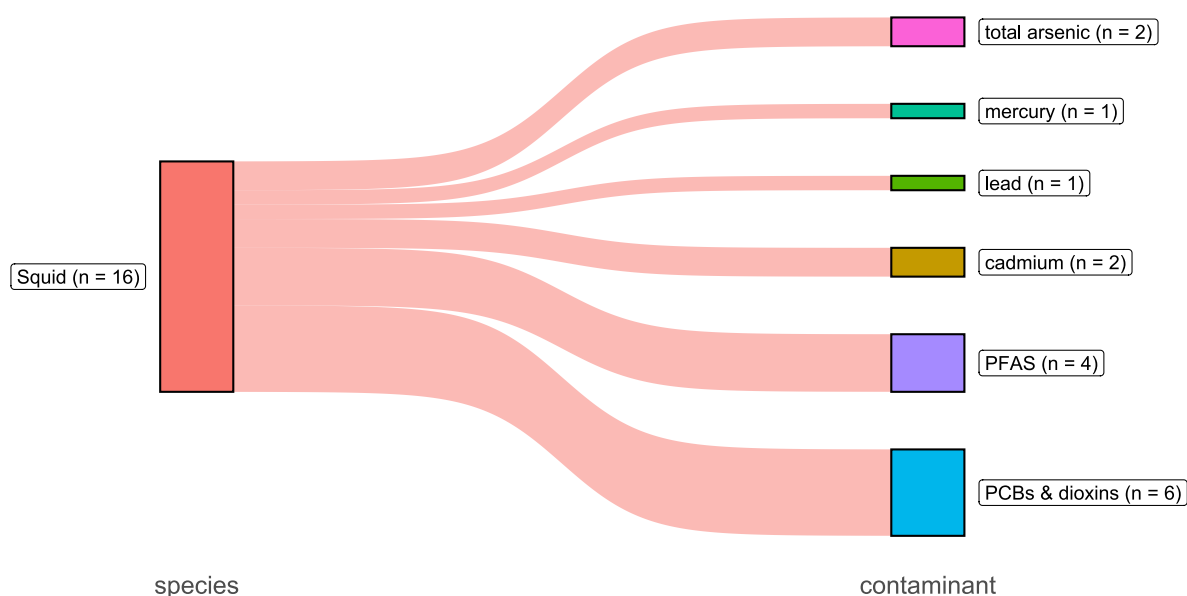


Figure 10. Sankey diagram of chemical contaminants detected in key cephalopod species.

9.12.5 Smoked fishery products

A Sankey diagram of the results for smoked fishery products shows where positive results for PAHs have been reported is given below (Figure 11). The diagram is included for completeness as these samples were only tested for PAHs so there is no information on the occurrence of other chemical contaminants, however it does show visually the different types of products where PAHs have been detected and the relative proportions of different smoked fish products tested.

Two dashboards are presented. The first (Figure 12) is for fish species and the second (Figure 13) for all other species (shellfish). This separation reflects the different biological characteristics, feeding behaviours, and regulatory frameworks that apply to finfish versus shellfish and other marine organisms. Any species/contaminant combination with less than 10 measurements has been excluded for ease of viewing and to avoid over interpretation of the significance of results for small sample sets.

These dashboards also highlight where there are data gaps or species / contaminant combinations with a high level of ML exceedances. They are particularly useful for identifying priority areas for future monitoring and research. For some analytes, e.g. PBDE no ML exist and therefore all residue measurements above LOQ are displayed as orange. In these cases, the orange segment does not imply compliance or safety, but rather the presence of quantifiable residues in the absence of a defined regulatory threshold. This distinction is important for emerging contaminants where risk assessments are still evolving. For PFAS the EU MLs were used to benchmark ML exceedances.

Together, these dashboards provide a simple yet comprehensive overview of the contaminant landscape across UK fish and shellfish species.



Figure 12. Risk dashboard representing results for fish species, data not included where the sample size was $n < 10$.

Footnote 1. PFAS results were compared to EU MLs as there are no MLs in force in GB.

Footnote 2. There are no MLs for some compounds (PBDEs, PCNs, PXDD/F and PXBs, arsenic) therefore no results are flagged as red in the dashboard.

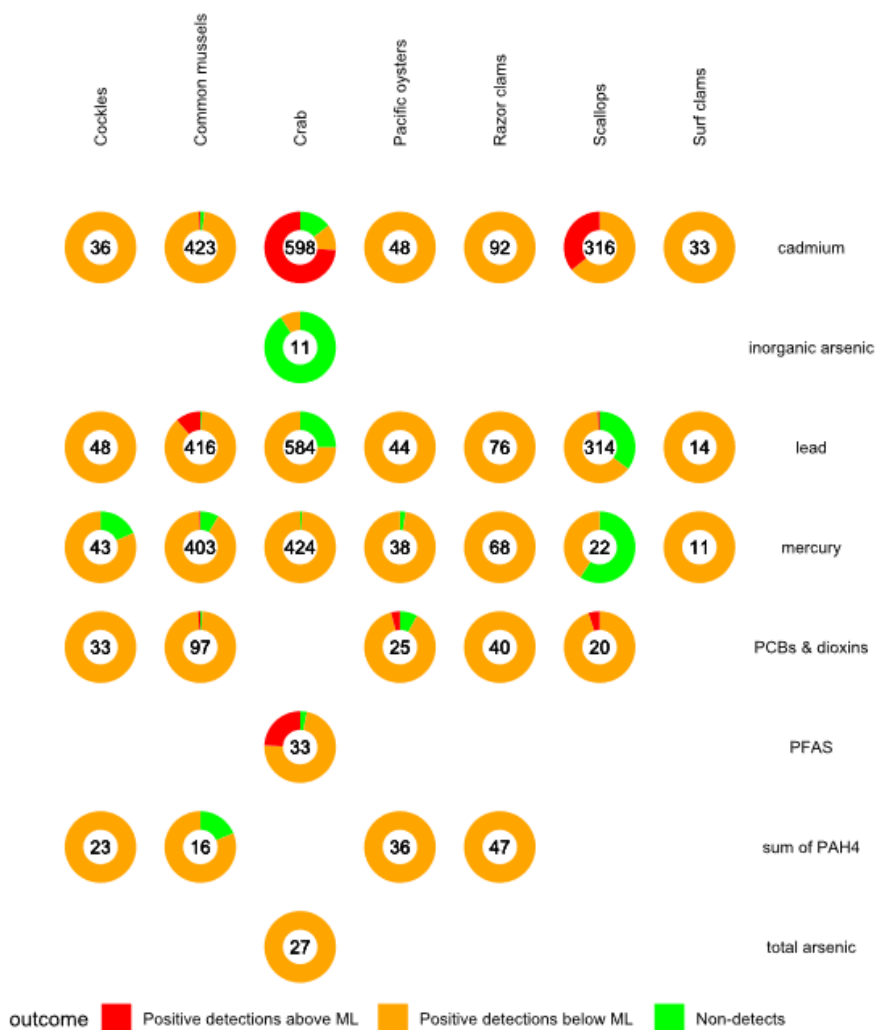


Figure 13. Risk dashboard representing results for shellfish, molluscs and cephalopods species, data not included where the sample size was $n < 10$.

Footnote 1. PFAS results were compared to EU MLs as there are no MLs in force in GB.

Footnote 2. There are no MLs for some compounds (PBDEs, PCNs, PXDD/F and PXBs, arsenic therefore no results are flagged as red in the dashboard).

A table summarising the results presented here (Section 9) for the UK funded studies of contaminants, along with an assessment of where there are data gaps, are given in **Table 15**. This table is the culmination of the report's analytical work, providing a structured overview of the contaminants assessed across species. It integrates data from multiple studies conducted between 2009 and 2025 and uses a traffic light system to visually summarise the strength of the evidence base and the presence of regulatory exceedances or data gaps.

The colours represent the following assessments:

- Red - there is a data gap or ML exceedances have been frequently found.
- Orange – there may not be sufficient data or this is an emerging risk that has not been monitored previously.
- Green – there is a good pool of data and/or regular routine monitoring is already in place.

This colour-coding allows for rapid visual assessment of the robustness of the data for each contaminant/species combination and may support the job of prioritising future monitoring efforts.

More detailed summaries of these studies as well as the key studies found in the literature are summarised in **Table 16** to **Table 21**. These tables present the primary analytical results from the review. They include contaminant concentrations, sample sizes, species tested, sampling locations, and the regulatory context. The tables are arranged by contaminant class and provide a chronological record of data collection, from early studies in 2009 through to the most recent surveys in 2023–2025.

All UK data is also collated in waffle plots in **Figure 14** to **Figure 17**, presented in **Annex B**. They provide a compact, colour-coded summary of analytical results across all species and contaminants. Organised by contaminant class and species group, they allow rapid assessment of the distribution of results across detection thresholds and identify where data are sparse or where regulatory exceedances are more common. This give a visual representation of the number of analyses carried by contaminant and by species as well as showing if results were <LOQ, LOQ – ML or above ML.

These visual and tabular outputs are a key output of the report. They enable both technical and policy audiences to interpret the scope, depth, and limitations of the current evidence base and to identify priorities for future surveillance and risk assessment.

10. Conclusions and Recommendations

The current review provides an extensive assessment of the documented occurrences, regulatory context, and food safety implications of chemical contaminants in wild-caught and smoked fish and fishery products in Scottish and wider UK waters.

While the majority of contaminants were found to be within regulatory limits, exceedances were observed for cadmium in crab and scallops, lead in mussels, mercury in sea bass, and PAH4 in smoked products such as Arbroath smokies and smoked salmon. PFAS compounds, although not currently regulated in Great Britain, exceeded EU maximum permitted levels in several species including cod, crab, and gurnard. Emerging contaminants such as PBDEs, PCNs, and PXDD/Fs were frequently detected, particularly in oily and predatory species, and although no MPLs currently exist for these substances, EFSA has identified several as potential health concerns. Microplastics were found in a range of species, with particularly high incidence in langoustine from the Clyde Sea area.

There is evidence of the presence of microplastics in some species, this may be more of an issue for shellfish rather than finfish. Analysis of chemical contaminants through the usual sampling programmes will address potential concern about contaminant occurrence as a result of the presence of MPs. Other categories where there was little data were pesticides, veterinary medicines, human medicines and personal care products. However, based on the information available these are not deemed to be a priority. Pharmaceuticals and personal care products were detected in estuarine environments and occasionally in fish liver, but not consistently in edible muscle tissue. Monitoring and controls for marine biotoxins are well established, however there may be some data gaps for the emerging toxins brevetoxins and tetrodotoxins. Notably, there are significant data gaps for Scottish-landed fish, particularly for PFAS, dioxins, PCBs, and inorganic arsenic, as well as for smoked products and emerging biotoxins such as tetrodotoxins and brevetoxins.

These findings have implications for food safety and public health, and its results support FSS's strategic objectives by identifying priority areas for surveillance and monitoring, bringing many of the emerging chemical challenges into regulatory focus and suggesting key areas for research investment.

To strengthen the evidence base and address identified gaps in the data, the following is a list of areas where future sampling work could be considered (Based on outputs from Table 15):

- PBDEs in high oil key fish species such as herring and mackerel.
- PBDD/Fs and PBBs and other BFRs (HBCDD, TBBPA, HBB, BTBPE and DBDPE).
- BTEX compounds – these are associated with oil spills so the risk from these will be low in absence of spill incidents.
- PFAS in highly consumed fish such as cod and haddock, as well as less consumed products such as monkfish, scallops and squid. EU ML exceedances were found, a further study to obtain more data is recommended.
- PCNs – most recent data is from 2015, additional more recent data may be required.
- Continued monitoring of metals, there are high incidences of ML exceedances for metals in specific species, e.g. cadmium in crab, and therefore continued surveillance is required.
- Total arsenic and inorganic arsenic, while arsenic is measured frequently recent developments in methodology have shown that concentrations of inorganic arsenic may be lower than previously thought. Additional sampling and analysis using the new methodology would provide accurate data.
- There is little data on PAHs in traditional smoked fish and fishery products and no data available on other potential contaminants such as nitrosamines, heterocyclic amines and other compounds of concern from natural smoking processes so additional studies to provide data on these would be beneficial.

Table 15. Summarised results and data gap analysis of UK funded studies

Report section	Contaminant / category of fish	Species Data Available	Date	Source of samples	Summary and data gap analysis
9.1 and 9.4	Dioxins (PCDDs and PCDFs), Dioxin-like PCBs, Non-Dioxin -like PCBs Heavy Metals	Common mussels, Pacific oysters, common cockles, razor clams, native oysters, queen scallops, surf clams and king scallops	2015 to 2022	Shellfish from Classified Harvesting Areas - Scotland sampled 2015-2022	Approx. 30 samples per year. Small number per species but regular sampling provides reasonable pool of data.
	PAHs				All results below ML 2 samples exceeded BaP and PAH4 in 2015
	PAHs (pollution indicators)	Blue mussels, Pacific oysters, Manila Clams common cockles	2023	Poole Harbour	No samples above ML
9.2.1	PCDD/Fs and PCBs	Fish - Sardines (n=16) Mackerel (n=41) Herring (n=19) Grey mullet (n=26) Sprat (n=25) Sea Bass (n=25) Turbot (n=16)	2015	Caught at sea. Scotland, Irish Sea, S England, N France, Norway, Algarve	Residues detected in all fish species ranging from 0.03 to 12.5 ng sum WHO-TEQ/kg whole weight. Results lower than previous study (10 years before).
		Cod (n=5), crab (n=9), cuttlefish (n=3), dog fish (n=1), gurnard (n=1), hake (n=2), herring (n=1), mackerel (n=5), monkfish & anglers (n=3), plaice (n=1), sardines (n=11), sea bass (n=4), skates & rays (n=2), sole (n=2) and squid (n=1)	2023	Wholesale fish markets England and Wales	Residues detected in all samples, none above ML. The highest levels found were: PCDD/F WHO-TEQ upper, 0.57 ng/kg whole (ML is 3.5 ng/kg) PCDD/F + PCB WHO-TEQ upper, 1.79 ng/kg whole (ML is 6.5 ng/kg whole) SUM of ICES 6 upper, found was 12.01 µg/kg whole (ML is 75 µg/kg)

		Pelagic Roundfish muscle Pelagic Roundfish Liver Demersal Roundfish Muscle Demersal Roundfish Liver Flatfish Muscle Flatfish Liver	2022	Pooled samples directly from Scottish waters	Results reported as for Σ PCB32 for pooled samples, results expressed as $\mu\text{g/kg}$ lipid weight: Pelagic Roundfish muscle 198.8 to 373.9 $\mu\text{g/kg}$ Pelagic Roundfish Liver 668.6 to 1202 $\mu\text{g/kg}$ Demersal Roundfish Muscle <0.02 to 1858 $\mu\text{g/kg}$ Demersal Roundfish Liver 57.91 to 3065 $\mu\text{g/kg}$ Flatfish Muscle <0.02 to 40.91 $\mu\text{g/kg}$ Flatfish Liver <0.05 to 899.2 $\mu\text{g/kg}$
9.2.2.1	PBDEs	Fish - Sardines (n=16) Mackerel (n=41) Herring (n=19) Grey mullet (n=26) Sprat (n=25) Sea Bass (n=25) Turbot (n=16) Various shark species (n=14)	2015	Scotland, Irish Sea, S England, N France, Norway, Algarve	PBDEs were observed in all samples, all measured congeners detected apart from BDE-126. The highest average values were observed for herring, sea bass, mackerel and sprat (2.08, 2.0, 1.45 and 1.27 $\mu\text{g/kg}$ respectively).
		Black scabbard, Roundnose grenadier and Black dogfish	2009	Scottish waters - Rockall Trough	Samples collected in 2006. PBDEs were detected in both the liver and muscle of the deep-water fish.
		Mussels Flatfish (flounder – <i>Platichthys flesus</i> , dab – <i>Limanda limanda</i> and plaice – <i>Pleuronectes platessa</i>)	2008	Scottish waters)	Samples collected 2006. Most mussels below LOD, but BDE47 and BDE99 were main congeners, max level found 2.36 $\mu\text{g/kg}$ ww. Low concentrations (<LOD to 1.67 $\mu\text{g/kg}$ ww) found in flatfish, BDE47 dominant congener.

					Overall assessment - no recent data. Draft EFSA opinion states is likely that PBDEs are a health concern.
9.2.2.2	PBDD/Fs and PBBs	Mussels, starry smooth hound, skate, mackerel, ling, blue ling, cod, spurdog, haddock, horse mackerel, torsk, hake, herring, cuckoo ray, spotted ray, monkfish, John Dory, black scabbard, Greater forkbeard, round nose grenadier, dog fish,	2009	Scottish waters, NE Atlantic and North Sea	PBBs showed low levels of occurrence, most frequently detected congeners were PBB 49 and PBB 52, typically in the range <0.001 – 0.003 µg/kg ww. Higher frequency of brominated furans than brominated dioxins, penta- and hexa-brominated congeners were not detected in any samples. Tri-bromo dioxins (and furans) were detected, particularly in shellfish.
		Fish - Sardines (n=7) Mackerel (n=17) Herring (n=7) Grey mullet (n=8) Sprat (n=11) Sea Bass (n=15) Turbot (n=6)	2015	Scotland, Irish Sea, S England, N France, Norway, Algarve waters	PBDFs detected more frequently than PBDDs and PBBs in reported studies
	Other BFRs (HBCDD, TBBPA, HBB, BTBPE and DBDPE).	Black scabbard, Roundnose grenadier and Black dogfish	2009	Rockall Trough (Scottish waters)	Samples collected 2006. HBCD and TBBP-A were not detected in samples from Scottish waters. No recent data.
9.2.3	BTEX compounds	None	None	None for UK, reports for Nigeria, Brazil	No data. Chemicals linked to oil and petrol spills, risk should be low in absence of spill incidents.

9.2.4	PFAS compounds	Fish, nephrops and cephalopods	2006-2023	Most recent samples from wholesale markets in England and Wales	The most recent study found residues above the EU ML for cod muscle, one of the species with highest landing & consumption in the UK. Three out of 13 samples exceeded the EU ML for PFNA and 2 exceeded the ML for PFHxS. Data gaps exist for liver and samples from Scotland.
9.2.5	PCNs Sum of 12 congeners	Mussels, spurdog, smooth hound, thornback ray, skate, hake, spotted ray, cuckoo ray, dog fish, black scabbard, greater forkbeard, round nose grenadier, ling, blue ling, monk fish, haddock, John Dory, horse mackerel, herring, mackerel, cod, torsk.	2009	Scottish waters	32 fish and 5 shellfish samples across range of species, residues in all samples tested, range 0.3 to 62.91 ng/g whole weight, highest level in spurdog. The most abundant congeners were PCNs 52/60, 53 and the toxicologically significant PCNs 66/67, 68 and 69.
		Sardines (n=12) Mackerel (n=14) Herring (n=6) Grey mullet (n=9) Sprat (n=15) Sea Bass (n=13) Turbot (n=6)	2015	Scotland, Irish Sea, S England, N France, Norway, Algarve waters	76 samples tested. Highest levels reported in mackerel and sprats. Overall assessment - no recent data.
9.3	Heavy metals Mercury	Mussels, Spurdog, Smooth Hound, thornback ray, skate, hake, spotted ray, cuckoo ray, dog fish, black scabbard, greater forkbeard, round nose grenadier, ling, blue ling, monk fish, haddock, John Dory,	2009	Scottish waters	All marine fish were positive for Hg, range 0.035-0.746 mg/kg and all shellfish contained mercury (0.025-0.47 mg/kg). Three samples exceeded the ML for Hg, a ling, a blue ling and a torsk. A subset analysed for methyl mercury levels ranged from 0.14 mg/kg for trout to 0.77 mg/kg

		horse mackerel, herring, mackerel, cod, torsk.			(ling), a blue ling sample contained 0.66 mg/kg, methyl mercury levels were similar to the total mercury concentrations.
		Fish - Sardines (n=16) Mackerel (n=41) Herring (n=19) Grey mullet (n=26) Sprat (n=25) Sea Bass (n=25) Turbot (n=16) Various shark species (n=14)	2015	Scotland, Irish Sea, S England, N France, Norway, Algarve waters	8 seabass and 1 dogfish contained total mercury above ML of 0.5 mg/kg for fish.
		Detected in: Cod (n=13) Crab (n=27) cuttlefish (n=11) dogfish (n=2) gurnard (n=2) haddock (n=2) hake (n=5) herring (n=7) lobster (n=4) mackerel (n=16) monkfish & anglers (n=7) plaice (n=3) sardines (n=32) sea bass (n=9) skates & rays (n=4) sole (n=6) squid (n=2)	2025	Wholesale markets in England and Wales	152 Samples collected in 2022-23. Total mercury was detected in all samples, and above ML in four seabass.
	Heavy metals Cadmium	Mussels, Spurdog, Smooth Hound, thornback ray, skate,	2009	Scottish waters	Seventeen samples contained cadmium

		hake, spotted ray, cuckoo ray, dog fish, black scabbard, greater forkbeard, round nose grenadier, ling, blue ling, monk fish, haddock, John Dory, horse mackerel, herring, mackerel, cod, torsk.			
		Fish - Sardines (n=16) Mackerel (n=41) Herring (n=19) Grey mullet (n=26) Sprat (n=25) Sea Bass (n=25) Turbot (n=16) Various shark species (n=14)	2015	Scotland, Irish Sea, S England, N France, Norway, Algarve waters	One sample of dogfish was above the general regulated limit for cadmium (0.05 mg/kg) and one sample of mackerel were above the higher cadmium ML set for this species (0.1 mg/kg).
		Detected in: Crab, 15/27 samples Cuttlefish, 8/11 samples, Gurnard, 2/2 samples Herring 7/7 samples Lobster, 4/4 samples Mackerel, 15/16 samples Monkfish & anglers, 1/7 samples All sardines, n=32 Squid, 2/2 samples,	2025	Wholesale markets in England and Wales	152 Samples collected in 2022-23. One sample of mackerel was above ML for cadmium. Cadmium was not detected in cod, dog fish, haddock, hake, plaice, sea bass, skates & rays, sole.

	Heavy metals Lead	Mussels, Spurdog, Smooth Hound, thornback ray, skate, hake, spotted ray, cuckoo ray, dog fish, black scabbard, greater forkbeard, round nose grenadier, ling, blue ling, monk fish, haddock, John Dory, horse mackerel, herring, mackerel, cod, torsk.	2009	Scottish waters	In 2009 study 7 of 32 samples were positive for lead. Lead was detected in many species including cod, crab, hake, mackerel, herring, sardines and lobster. No samples above ML.
		Fish - Sardines (n=16) Mackerel (n=41) Herring (n=19) Grey mullet (n=26) Sprat (n=25) Sea Bass (n=25) Turbot (n=16) Various shark species (n=14)	2015	Scotland, Irish Sea, S England, N France, Norway, Algarve waters	Lead was measured in all species in the 2015 study. Two mullet samples above the ML for lead (0.3 mg/kg), were from the Pembrokeshire coast (Wales).
		Detected in: Cod, one sample Crab, 26/27 samples Cuttlefish 10/11 samples Herring, 3/7 samples Lobster, 3/4 samples Mackerel, 1/16 samples Monkfish & anglers, 1/7 samples Plaice, 2/3 samples All sardines, n=32 Seabass, 2/9 samples Skate & rays, 3/4 samples Squid, 1/2 samples	2025	Wholesale markets in England and Wales	152 Samples collected in 2022-23. Lead was not found above the ML in any sample. It was not detected in dogfish, gurnard, haddock, hake, sole.

9.3.1	Heavy metals - total and inorganic arsenic	Mussels, Spurdog, Smooth Hound, thornback ray, skate, hake, spotted ray, cuckoo ray, dog fish, black scabbard, greater forkbeard, round nose grenadier, ling, blue ling, monk fish, haddock, John Dory, horse mackerel, herring, mackerel, cod, torsk.	2009	Scottish waters	Total arsenic ranged from 4.8 (John Dory) to 79.2 mg/kg (Cuckoo Ray). Inorganic arsenic in a subset of samples ranged from <0.005 to 0.149 mg/kg (~2.53% of total).
		Cod, NSS herring, mackerel, Greenland halibut, tusk, saithe and halibut	2021	Barents sea and Scottish waters	Total arsenic found in range of species, range 0.01 to 89 mg/kg. Inorganic was found at <0.002 to 0.015 mg/kg, the highest concentration was in saithe.
		Total Arsenic Detected in: Cod (n=13) Crab (n=27) cuttlefish (n=11) dogfish (n=2) gurnard (n=2) haddock (n=2) hake (n=5) herring (n=7) lobster (n=4) mackerel (n=16) monkfish & anglers (n=7) plaice (n=3) sardines (n=32) sea bass (n=9) skates & rays (n=4) sole (n=6) squid (n=2)	2023	Wholesale markets in England and Wales	152 samples collected in 2022-23. Total arsenic ranged from 0.5 to 38.2 mg/kg. Inorganic arsenic was measured in a subset of these samples (76/152). Levels ranged from <0.007 to 0.011 mg/kg. Species containing inorganic arsenic were crab, lobster and sardines.

9.4	Polycyclic Aromatic Hydrocarbons (PAHs)	Mussels	2009	Scottish waters	5 samples analysed contained concentration range of BaP of 0.13 to 1.69 µg/kg, and for sum PAH4 0.85 to 8.94 µg/kg.
		Blue mussels, Pacific oysters, manila clams and common cockles	2023	Poole Harbour	Levels of BaP measured ranged from 0.26 – 1.53 µg/kg, and from 1.79 – 8.07 µg/kg for sum PAH4, none of the samples exceeded MLs.
9.5	PAHs, heterocyclic amines and nitrosamines.	Smoked fish – cod, haddock, whiting, coley, salmon, mackerel, smokies, kippers	2004	Retail samples	For hot smoked products BaP levels ranged from <0.06 to 0.43 µg/kg for mackerel and 0.56 to 1.34 µg/kg for Arbroath smokies. For cold smoked products, levels ranged from <0.06 to 0.14 µg/kg for kippers, all other species (haddock, cod, whiting, coley and salmon) were below LOQ in the range <0.06 to <0.18 µg/kg.
		Smoked fish and fishery products – smoked salmon, trout, haddock, smokies, kippers, trout and mussels.		Retail samples	62 smoked fish products tested. Four samples were above the proposed (at the time) ML for BaP. Levels of PAH4 ranged from 0.11 to 54 µg/kg in smoked fish. Overall assessment - Most recent data from samples analysed for PAHs in UK is 10 to 20 years old and there are limited sample numbers.

					No UK data in recent literature review. No data for nitrosamines and HA in Scottish or UK smoked fish products
9.6	Pesticides	Fish – 50 samples comprising of sardines, herring, mackerel, mullet, sea bass and sprats.	2015	Scotland, Irish Sea, S England, N France, Norway, Algarve waters	Only DDD-pp, DDE-pp, DDT-pp, dieldrin, HCB found above LOD. Very small number Scottish samples contained residues. DDTs mean 10.7+/- 0.03 ng/g ww for Scottish salmon HCHs mean 1.1 +/- 0.01ng/g HCB 2,2 +/- 0.02ng/g ww (highest HCB levels in the study)
		Fish (including smoked)	2001	Rockall Trough	Samples collected in 1998, residues detected in the organs studied. No recent data.
9.7	Veterinary drugs	None	None	None	No reports of residues in wild caught fish. Reports of emamectin benzoate (EmBz) and teflubenzuron (Tef) in sediment in proximity of marine cage fish farms could be a potential source of exposure for fish.
9.8	Human medicines	Medicines detected in muscle of: Cod, plaice, turbot, flounder, perch, tianeptine. Not detected in muscle of: Bream and crucian carp.	2021	Baltic Sea	Residues of 11 pharmaceuticals were found in fish muscle. Highest concentration was ofloxacin, a fluoroquinolone antibiotic (up to 3.43 µg/kg in cod). Other antibiotics were detected as well as anti-infective/anthelmintic (thiabendazole, up to 2.09 µg/kg in turbot), antipsychotic

					(promazine, max 1.56 µg/kg, cod), anticonvulsant (carbamazepine max 1.18 µg/kg, cod), antidepressants (fluoxetine max 0.57 µg/kg, perch and tianeptine max 0.53 µg/kg, perch), and the betablocker, bisoprolol (max 0.23 µg/kg, plaice). Very little data on human medicines in Scottish caught fish, although some evidence of pharmaceuticals in Scottish estuary water.
	Personal care products - Parabens	4 mussels samples (2 from Scotland, 2 from England)	2022	UK waters	Methyl paraben was quantified in 3 out of 4 samples at levels from 15.1 to 29.1 µg/kg ww, also found in 4 th sample but below LOQ.
9.9	Microplastics	Scottish haddock and scallops.	2020	Scottish waters	Small amount of data available for Scottish fish. Shellfish may be more of an issue than finfish.
		Nephrops	2016	Scottish waters	Animals caught near shore contained higher levels of MPs, and Clyde Sea animals contained more (84% incidence) than those from the North Sea (28.7%) and North Minch (43%). A separate feeding study of MP found reduced feeding rate, body mass, and metabolic rate in the plastic contaminated animals, leading to the conclusion that high levels of environmental microplastic pollution may cause reduced nutrient availability in the

					Nephrops which could result in reduced population stability and affect the viability of local fisheries.
		Five pelagic species - whiting blue whiting, Atlantic horse mackerel, poor cod and John Dory Zeus and five demersal species - red gurnard, Dragonet, redband fish, solenette and thickback sole.	2013	English Channel	All five pelagic and five demersal species from the English Channel had ingested plastic. Of 504 fish samples, 36.5% had ingested plastic. The size range of plastic ingested was 0.13 to 14.3 mm. The average number of pieces ingested ($n=1.90 \pm 0.10$) was similar to the Scottish study.
9.10	Natural toxins - Histamine	Fish	2014	Scotland	Advice in place for controls to minimise risk.
	Microcystins		2018	England	Evidence of microcystins in marine algal blooms in England, but no data in fish. Has been reported in Europe.
9.11	Marine Biotoxins	Shellfish and fish	2022	Scotland	Comprehensive monitoring is in place for established marine biotoxins and recent data is available. There are data gaps for emerging toxins brevetoxins and tetrodotoxins in marine fish and shellfish.

Table 16. Summarised results for studies on environmental contaminants

Study / Reference	Contaminant	Species Data Available	Date	Location Data available	Results, Data gaps or comments
FSA Research and Evidence, 2025. Contaminants monitoring programme for wild caught fish, crustaceans and cephalopods	Dioxins - all 17, 2378-Cl substituted PCDDs and PCDFs. Dioxin-like PCBs - IUPAC numbers 77, 81, 105, 114, 118, 123, 126, 156, 157, 167, 169, and 189. Non Dioxin-like PCBs - IUPAC numbers 28, 52, 101, 138, 153, 180.	SW: Sardines (32) Cuttlefish (11) Monkfish and Anglers (7) Crab (4) Hake (5) Sole (4) Plaice (3) Skates & Ray (2) Gurnard (2) Dogfish (2) Lemon Sole (2) Mackerel (16) Bass (4) SE: Bass (3) NE: Cod (13) Crab (19) Lobster (2) Haddock (2) Squid (2) Wales: Crab (4) Skates & Rays	2023	Fish purchased at wholesale fish markets in South West, South East and North East England and Wales	Dioxin and PCB analysis. Concentrations of dioxins and PCBs were below the UK and EU limits for these compounds. No data for Scottish landed fish

		(2) Lobster (2) Bass (2)			
FSAS, 2009 / Fernandes, <i>et al.</i> , 2009b. Investigation into the Levels of Environmental Contaminants in Scottish Marine and Freshwater Fin Fish and Shellfish	Dioxins and dioxin-like PCBs: PBBs PBDD/Fs PCDD/Fs PCBs PCNs	Fish & shellfish – 32 samples marine fish, 16 fresh water and 5 marine shellfish. Marine fish John Dory (1) Spurdog (3) Smooth Hound (2) Rays (4) Dogfish (2) Skate (2) Hake (3) Greater Forkbeard (1) Grenadier Torsk (2) Black scabbard (1) Monk fish (2) Haddock (1) Mackerel (2) Herring (1) Ling (3) Cod (1) Mussels (5)	2009	Continental shelf edge West of Scotland North Sea	Dioxins and PCBs showed near-universal detection of all analysed dioxins and PCBs, however freshwater species showed higher average concentrations than marine fish or shellfish, with the highest contributions in fin fish from dioxin-like PCBs and in shellfish from dioxins. None of the marine fin fish or shellfish exceeded MLs (4ng/kg WHO-TEQ on a whole weight basis for dioxins and 8 ng/kg WHO-TEQ for combined dioxin and PCB WHO-TEQ, highest detected PCB WHO-TEQ of 3.5ng/kg in a freshwater fish sample). The results of this study confirm the occurrence of a wide range of environmental contaminants in these species and underline the ubiquity and persistence of these compounds. However, for the organic contaminants, no fish or shellfish samples in this study breach the existing regulated levels.

FSA, March 2015 and Fernandes <i>et al</i> 2018. Geographical Investigation for Chemical Contaminants in Fish collected from UK and Proximate Marine Waters Report to the Food Standards Agency	Dioxins Dioxin-like PCBs Non Dioxin-like PCBs PCNs PBDE congeners PBB congeners Brominated dioxins Mixed halogenated dioxins and biphenyls (PXDD/F and PXBs)	Halibut (3) Turbot (16) Sardine (16) Herring (19) Sea bass (25) Sprat (25) Mackerel (41) Grey mullet (26) Megrin (1) Monkfish (1) Haddock (1) Witch (1) Dogfish (8) Lemon sole (1) Spurdog (6) All classes of contaminants were detected. The concentrations of the different contaminants in the various samples were mapped utilising the GPS coordinate data of the capture locations to visualise spatial distribution levels. Concentrations of contaminants appear to vary depending on species and location. It is noted that none of the samples	2015	North Sea and Greater North Sea up to Norway Irish Sea Celtic Sea sub-regions (NW French Coast-European N. Atlantic – Biscay-Algarve	Dioxins, PCBs and PCNs PCDD/Fs, PBDEs and PCBs were detected in all fish samples. Results from this study showed that the most contaminated species for dioxins, PCBs and PCNs included herring, sea bass, mackerel and sprat. Maximum level exceedances: Two exceedances for dioxins were found in one sample each of sea bass and mackerel and one exceedance was found for PCBs for the same sea bass. PBDEs: With the exception of BDE-126, all measured PBDE congeners were detected at various levels. For the sum of all measured PBDEs, concentrations ranged from 0.04 µg/kg to 8.87 µg/kg ww (corresponding to 0.04 µg/kg to 8.63 µg/kg for EU10). The highest average values were observed for herring, sea bass, mackerel and sprat (2.08, 2.0, 1.45 and 1.27 µg/kg respectively). The average concentration across all samples was 1.2 µg/kg (or approximately 35 µg/kg on a fat weight basis).
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		with high levels of contamination were from the North Sea up to Norway. The most contaminated samples were from waters off the Northern coast of France, the South and East coasts of England/UK, Wales, Northern Ireland, the Irish Sea. The highest values were seen in samples received from Northern Ireland.			Pesticides were found in the highest concentrations in mullet, herring and sea bass. Only 5 compounds – pp-DDD, FSA 2015- FS102005 19 of 31 pp-DDT, pp-DDE dieldrin and hexachlorobenzene (HCB) were present above the limits of detection, ranging from 0.2 µg/kg for pp-DDD and HCB to 12 µg/kg for pp-DDE.
Measurement of contaminants in food for Marine Strategy Framework Directive Descriptor 9 (2015)	PCBs Dioxins Dioxin-like PCBs Non dioxin-like PCBs	North Sea Haddock (22) Herring (26) Monkfish (4)	2015	North Sea (OSPAR Region 2 – North and East of Scotland) and West of Scotland (OSPAR region 3)	West Coast of Scotland- 16 monkfish were sampled and analysed (study target = 20), therefore the estimate of the 95th percentile was not as precise as intended. Dioxin TEQs were estimated from PCB levels using established models due to lack of testing capacity. PCBs were found at higher concentrations in herring due to its high lipid content, and were below the LoDs in nearly all haddock and monkfish. Estimated dioxins were all below the EC maximum limit.

Marine Environment Monitoring and Assessment National (MERMAN) Database 2016-2020	Dioxins	Cockles Razor clams Surf clams Mussels Pacific oysters Whiting Dab European plaice European flounder	2016-2020	Inshore, estuarine and coastal locations across Scotland, England, Wales and Northern Ireland including estuaries,	No exceedances for dioxins. All samples contained low levels of dioxins between 0.1-0.3 ng/kg (pg/g). These data are useful background information but are not directly comparable for risk assessing marine species as inshore and coastal areas may have localised historical contamination of sediments due to historical industry and marine vessel activity which can increase contamination in specific areas.
FSS Live Bivalve Mollusc (LBM) Monitoring Data 2015-2021	PCDD/Fs Dioxins & furans, PCBs	Common mussels (43) Pacific oysters (22) Common cockles (25) Surf clams (8) Carpet clams (3) Razor clams (40)	2022	Shellfish from Classified Harvesting Areas - Scotland sampled 2015-2022	During 2016-2021, no samples exceeded MLs for any of the listed contaminants. Approx. 30 samples per year. Small number per species but regular sampling provides reasonable pool of data.
FSAS Survey of Scottish Inshore and Offshore Harvesting Areas for Chemical Contaminants (2006)	Chlorinated Biphenyls (CBs) Pesticides	Mussels (14) Pacific oysters (5) Scallop gonad (10) Scallop muscle (10)	2006	Survey of chemical contaminants in shellfish from 5 coastal and 7 offshore regions around Scotland	All samples of scallop muscle tissue and oysters were within maximum levels for chlorinated biphenyls. Exceedances were found with CBs in mussels (1 sample of 14) and scallop gonads (1 sample of 10).

Flidner <i>et al.</i> , 2020	19 emerging flame retardants and degradation products, 40 per- and polyfluoroalkyl substances (PFAS) and three cyclic volatile methylsiloxanes (cVMS).	Composite samples Eel poult – fillet (3) Eel poult – liver (2) Blue mussel – flesh (3).	2015	NS 1: North Sea— Lower Saxony Wadden Sea; NS 2: North Sea— Schleswig–Holstein Wadden Sea; BS: Baltic Sea— Bodden National Park (Baltic Sea)	Tables of results provided in supplementary information. Only Dec 602 (emerging flame retardant) was detected in all samples of 2015. Dec 604, CI 10-antiDP, 1,5-DPMA, EH-TBB, PBEB, TBP-AE, BATE, BTBPE and HBBz were constantly < limit of quantification (LOQ). Legacy PBDE still dominated in most samples. Concentrations of the cVMS D4, D5 and D6 were below the detection limit at the ESB sampling sites. DP and Dec 603 were observed only in samples from the North Sea. For comparison purposes, the concentrations of the WFD-relevant PBDE congeners BDE-28, -47, -99, -100, -153 and -154 (Σ 6 PBDE) were included in the study. Concentrations of Σ 6 PBDE were mostly higher than those of emerging flame retardants. Concentrations similar to those of Σ 6 PBDE were also observed for TBA in samples from Baltic Sea. Based on the results, authors recommend to consider inclusion of the emerging flame retardants DP
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					and Dec 602 in monitoring in North and Baltic Seas.
Carlsson <i>et al.</i> , 2016	Suite of PFAS, PCBs, PBDEs and OCs	Halibut fillet (6) Unpeeled shrimp (9) Peeled shrimp (5)	2008-2012	Halibut – Tromso Shrimp -Malangen and Kvænangen regions	The overall concentrations of POPs, including the dioxin-like PCBs, as well as PFAS were well below the European guidelines for human consumption, and hence, human dietary exposure through moderate consumption of these organisms falls within TDIs or benchmark doses. $\Sigma 6$PCB in halibut, peeled and unpeeled shrimps was 2.7, 0.1 and 1.3 ng/g ww, respectively. These concentrations are well below the EU guidelines (75 ng/g ww for fish and Crustacean meat) of non-dioxin like PCBs in food. Median Σpolychlorinated biphenyls (PCB) were 4.9 and 2.5 ng/g ww for halibut and unpeeled shrimps, respectively. The halibut fillets were dominated by PCBs, which contributed to 50% of the total POPs load, followed by ΣDDTs; 26% and PFASs (18%), whereas shrimps were dominated by PFASs (74%). ΣPBDEs (polybrominated diphenyl ethers) contributed to 1–4% of the total POP load.

					Significantly higher levels of PBDEs, PCBs, OCs were found in halibut compared to shrimp. This is indicative of the biomagnification of these compounds, due to the longer lifespan and higher trophic level status of halibut compared to shrimp.
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Table 17. Summarised results of studies on heavy metals, lead, cadmium and mercury

Study / Reference	Contaminant	Species Data Available (no. samples)	Results (range, mg/kg)	Date	Location Data available	Results, data gaps or comments
FSA Research and Evidence, 2025.	Lead	cod (13) crab (27) cuttlefish (11) dogfish (2) gurnard (2) haddock (2) hake (5) herring (7) lobster (4) mackerel (16) monkfish & anglers (7) plaice (3) sardines (32) sea bass (9) skates & rays (4) sole (6) squid (2)	0.010 <0.005 – 0.05 <0.005 – 0.013 <0.005 <0.005 <0.005 <0.005 <0.005 – 0.008 <0.005 – 0.041 <0.005 – 0.006 <0.005 – 0.010 <0.005 – 0.017 0.007 – 0.034 <0.005 – 0.013 <0.005 – 0.006 <0.005 <0.005 – 0.009	2023	Fish purchased at wholesale fish markets in South West, South East and North East England and Wales	All results given in Table 14. No data for Scottish landed fish. Lead – not found above the ML in any sample. It was not detected in dogfish, gurnard, haddock, hake, sole. It was detected in one cod sample (0.010 mg/kg), all but one crab samples, 10/11 cuttlefish, 3/7 herring (<0.005 – 0.008 mg/kg), 3/4 lobster <0.005 – 0.041 mg/kg), and all sardines,
	Cadmium	cod (13) crab (27) cuttlefish (11) dogfish (2) gurnard (2) haddock (2) hake (5) herring (7) lobster (4)	<0.005 <0.005 – 0.157 <0.005 – 0.022 <0.005 0.006 and 0.011 <0.005 <0.005 0.011 – 0.027 0.016 – 0.047	2023	Fish purchased at wholesale fish markets in South West, South East and North East England and Wales	No data for Scottish landed fish Cadmium - was detected at a concentration of 0.16 mg/kg (0.13 mg/kg minus measurement uncertainty) in one of the mackerel samples. The maximum level for

			mackerel (16) monkfish & anglers (7) plaice (3) sardines (32) sea bass (9) skates & rays (4) sole (6) squid (2)	<0.005 – 0.075 <0.005 – 0.009 <0.005 0.005 – 0.021 <0.005 <0.005 <0.005 0.007 – 0.010			cadmium in mackerel is 0.1 mg/kg. Cadmium was detected in 15/27 crab samples, 8/11 cuttlefish, 2/2 gurnard, 7/7 herring, 4/4 lobster, 15/16 mackerel and all sardines. It was not detected in cod, dog fish, haddock, hake, plaice, sea bass, skates & rays, sole.
		Mercury	cod (13) crab (27) cuttlefish (11) dogfish (2) gurnard (2) haddock (2) hake (5) herring (7) lobster (4) mackerel (16) monkfish & anglers (7) plaice (3) sardines (32) sea bass (9) skates & rays (4) sole (6) squid (2)	0.08 – 0.12 0.05 – 0.30 0.04 – 0.08 0.52 and 0.55 0.61 and 0.14 0.03 and 0.11 0.04 – 0.42 0.011 – 0.027 0.12 – 0.40 0.03 – 0.08 0.10 – 0.20 0.07 – 0.16 0.02 – 0.05 0.20 – 0.87 0.07 – 0.32 0.03 – 0.06 both 0.01	2023	Fish purchased at wholesale fish markets in South West, South East and North East England and Wales	No data for Scottish landed fish Mercury was detected in all samples.
Investigation into the Levels of Environmental		Mercury	Fish & shellfish – 32 samples marine fish, 16		2009	Continental shelf edge West of Scotland	Other metals tested - chromium, manganese, cobalt, nickel, copper, zinc, arsenic, selenium, silver.

Contaminants in Scottish Marine and Freshwater Fin Fish and Shellfish (FSAS, 2009 / Fernandes, et al., 2009b)			fresh water and 5 marine shellfish. Marine fish John Dory (1) Spurdog (3) Smooth Hound (2) Rays (4) Dogfish (2) Skate (2) Hake (3) Greater Forkbeard (1) Grenadier (1) Torsk (2) Black scabbard (1) Monk fish (2) Haddock (1) Mackerel (2) Herring (1) Ling (3) Cod (1) Mussels (5)	0.035 0.455, 0.442, 0.301 0.453, 0.397 0.126-0.297 0.316, 0.364 0.092, 0.124 0.093, 0.106, 0.271 0.218 0.176 0.539, 0.404 0.267 0.086, 0.213 0.079 0.029, 0.107 0.037 0.113, 0.629, 0.746 0.102 0.025-0.047		North Sea	For the heavy metals, some minor exceedances of the maximum limits for mercury occur in torsk, ling and blue ling. Concentrations were between 0.025 mg/kg to 0.75 mg/kg however most of the mercury was in the more toxic organic form (methylmercury). Three samples of marine fish were above the 0.5 mg/kg regulatory maximum level (ML) (torsk, ling and blue ling, 0.54, 0.746 and 0.629 mg/kg respectively).
		Cadmium	Marine fish John Dory (1) Spurdog (3)	<0.003 0.007, 0.007, 0.021 0.004, 0.012	2009		Cadmium highest levels were found in mussels.

		Smooth Hound (2) Rays (4) Dogfish (2) Skate (2) Hake (3) Greater Forkbeard (1) Grenadier (1) Torsk (2) Black scabbard (1) Monk fish (2) Haddock (1) Mackerel (2) Herring (1) Ling (3) Cod (1) Mussels (5)	<0.003-0.011 0.007, 0.017 <0.003, 0.007 All <0.003 0.004 0.007 Both <0.003 0.059 Both <0.003 <0.003 0.016, 0.037 0.004 All <0.003 <0.003 0.104-0.216			Levels of cadmium were lower than lead (0.10-0.22 mg/kg). Regulatory MLs for cadmium are 1.0 for bivalve molluscs. One black scabbard fish sample exceeded ML for cadmium but was within the bounds of MU.
	Lead	Marine fish John Dory (1) Spurdog (3) Smooth Hound (2) Rays (4) Dogfish (2) Skate (2) Hake (3) Greater Forkbeard (1) Grenadier (1)	<0.005 All <0.005 0.006, 0.007 All <0.005 <0.005, 0.006 Both <0.005 All <0.005 0.009 <0.005 <0.005, 0.009 <0.005	2009		Lead highest levels were found in mussels. Levels of lead were 0.24-1.55 mg/kg. Regulatory MLs for lead are 1.5 mg/kg for bivalve molluscs. One mussel sample exceeded ML for lead but was within the bounds of MU.

			Torsk (2) Black scabbard (1) Monk fish (2) Haddock (1) Mackerel (2) Herring (1) Ling (3) Cod (1) Mussels (5)	Both <0.005 0.007 Both <0.005 <0.005 <0.005, <0.005, 0.005 <0.005 0.242-1.551			
Geographical Investigation for Chemical Contaminants in Fish collected from UK and Proximate Marine Waters Report to the Food Standards Agency (FSA, March 2015, Fernandes et al 2018)		Cadmium	Sardine (16) Mackerel (41) Herring (19) Grey mullet (26) Sprat (25) Sea bass (25) Turbot (16) Shark (14) (various sp.)	0.005 - 0.06 0.003 - 0.162 0.004 - 0.017 <0.002 - 0.005 0.004 - 0.023 <0.002 - 0.007 <0.002 <0.003 - 0.055	2015	North Sea and Greater North Sea up to Norway Irish Sea Celtic Sea sub-regions (NW French Coast- European N. Atlantic – Biscay- Algarve	Heavy Metals Highest accumulation of heavy metals lead, cadmium and mercury were found in sea bass, dogfish, mackerel and mullet. Maximum level exceedance: Cadmium in 1 sample of mackerel
		Lead	Sardine (16) Mackerel (41) Herring (19) Grey mullet (26) Sprat (25) Sea bass (25) Turbot (16) Shark (14)	0.005 - 0.07 <0.002 - 0.018 <0.002 - 0.064 <0.002 - 0.901 0.005 - 0.226 <0.002 - 0.157 <0.002 - 0.028 <0.002 - 0.009	2015		Maximum level exceedances: Lead in 2 samples of mullet

		(various sp.)				
	Mercury,	Sardine (16) Mackerel (41) Herring (19) Grey mullet (26) Sprat (25) Sea bass (25) Turbot (16) Shark (14) (various sp.)	0.034 - 0.073 0.03 - 0.351 0.013 - 0.075 0.01 - 0.117 0.009 - 0.061 0.095 - 0.737 0.018 - 0.263 0.061 - 1.008	2015		Mercury was found above LOD in all samples. Maximum level exceedances: Lead in 2 samples of mullet.
Measurement of contaminants in food for Marine Strategy Framework Directive Descriptor 9 (2015)	Mercury Cadmium, Lead	North Sea Haddock (22) Herring (26) Monkfish (4) North Sea - the 95th percentile of the mercury distribution in monkfish was significantly below the regulatory level, based on only four fish which did not adequately represent the target sampling population.	Mercury exceeded the LoD in all samples. Mercury was higher in monkfish which has a low lipid content but the highest trophic level. Cadmium and lead were mainly below detection limits in all three species whilst The 95th percentiles of the distributions of trace metal concentrations were estimated for each species and area. These were	2015	North Sea (OSPAR Region 2 – North and East of Scotland) and West of Scotland (OSPAR region 3)	Edible muscle tissue of three species (Herring, Haddock and Monkfish) from two locations (North Sea and West Coast of Scotland) were analysed for PCBs and trace metals (cadmium, lead and mercury).

		West Coast of Scotland Haddock (20) Monkfish (16) West Coast of Scotland- 16 monkfish were sampled and analysed (study target = 20), therefore the estimate of the 95th percentile was not as precise as intended.	significantly below the regulatory levels except mercury in monkfish			
Marine Environment Monitoring and Assessment National (MERMAN) Database 2016-2020	Mercury Cadmium	Cockles Razor clams Surf clams Mussels Pacific oysters Whiting Dab European plaice European flounder	Exceedances for mercury include 2 mussel samples from Beaulieu Firth and Leith Docks, Scotland at levels of 0.55 and 0.88 mg/kg. All samples below MLs contained levels of mercury between 0.006 – 0.48 mg/kg	2016-2020	Inshore, estuarine and coastal locations across Scotland, England, Wales and Northern Ireland including estuaries,	These data are useful background information but are not directly comparable for risk assessing marine species as inshore and coastal areas may have localised historical contamination of sediments due to historical industry and marine vessel activity which can increase contamination in specific areas.

	Lead		Exceedances for cadmium include 3 European plaice samples from England, 3 mussel samples from Scottish estuaries between 1.1-1.5 mg/kg. All samples below MLs contained levels of cadmium between 0.002 µg/kg – 0.995 mg/kg. Exceedances for lead include 47 samples of mussels from Scottish estuaries at levels between 1.5-7.2 mg/kg. All samples below MLs contained low levels of lead between 0.0007-1.48 mg/kg			
FSS Live Bivalve Mollusc (LBM) Monitoring Data 2015-2021	Cadmium Mercury Lead	Common mussels (43) Pacific oysters (22)		2022	Shellfish from Classified Harvesting Areas -	Approx. 30 samples per year. Small number per species but regular sampling provides reasonable pool of data.

		Common cockles (25) Surf clams (8) Carpet clams (3) Razor clams (40)			Scotland sampled 2015-2022	
FSAS Survey of Scottish Inshore and Offshore Harvesting Areas for Chemical Contaminants (2006)	Cadmium Mercury Lead	Mussels (14) Pacific oysters (5) Scallop gonad (10) Scallop muscle (10) Most samples were within maximum EC regulatory levels/guideline concentrations. All samples tested for mercury, cadmium and lead fell below the MLs. (Mercury 21 samples <LoD 0.02-0.04 mg/kg, Cadmium 0.08-0.77 mg/kg 1 sample <LoD, Lead 0.1-0.61 14 samples <LoD)		2006	Survey of chemical contaminants in shellfish from 5 coastal and 7 offshore regions around Scotland	

						landings due to the lack of information on origin of crab meat used for production. It should be noted that there is no ML for brown meat therefore the ML for white meat has been used for comparison for the results of brown and mixed brown/white crab meat only.
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Table 18. Summarised result of studies on arsenic (total and inorganic).

Study / Reference	Contaminant	Species (Number of samples, n)	Conc. Range (mg/kg)	Date	Location Data available	Data gaps or comments
FSA, 2025. Contaminants monitoring programme for wild caught fish, crustaceans and cephalopods	Arsenic – total arsenic	Fish – 152 samples Cod (13) Crab (27) Cuttlefish (11) Dogfish (2) Gurnard (2) Haddock (2) Hake (5) Herring (7) Lobster (4) Mackerel (16) Monkfish & Anglers (7) Plaice (3) Sardines (32) Sea Bass (9) mg/kg Skates and Rays (4) Sole (6) Squid (2)	1.2-9.4 8-38.2 8-17.6 15.4, 24.8 2, 3 1.5, 4.4 2.7-5 1.3-1.7 6.9-19.5 1-1.8 7.3-11.9 9.8-10.4 1.9-3.5 0.5-1.7 13-33.2 5.4-28.7 3.3, 3.9	2023	Samples landed in England and Wales. Fish purchased at wholesale fish markets in South West, South East and North East England and Wales	No results from Scotland. Using the current solvent extraction method, 13 samples were found to contain levels of arsenic at concentrations equal to or in excess of the previously suggested EU maximum levels after consideration of measurement uncertainty: • Haddock – 1 sample (0.022 mg/kg minus the MU of 14%) • Herring – 3 samples 0.024 to 0.048 mg/kg (0.021 to 0.041 mg/kg minus the MU of 14%) • Herring – 1 sample 0.020 mg/kg (0.017 mg/kg minus the MU of 14%) • Sardines – 8 samples 0.035 to 0.050 mg/kg minus the MU of 14%) • Sole – 1 sample (0.020 mg/kg minus the MU of 14%).
	Inorganic arsenic	Current method FSG 456 Subset of 76 samples Cod (5) Crab (11) Cuttlefish (8) Dogfish (2)	<0.005-0.017 <0.005-0.028 <0.005-0.014 <0.005, 0.005	2023	Samples landed in England and Wales	The established solvent extraction method consistently

	Inorganic arsenic	Gurnard (2) Haddock (2) Hake (3) Herring (4) Lobster (3) Mackerel (6) Monkfish & anglers (3) Plaice (3) Sardines (8) Sea bass (9) Skates & rays (2) Sole (3) Squid (2) HPLC-ICPMS method 69 samples InAs 7 samples InAs >LOQ Crab (1) Lobster (3) Sardines (3)	<0.005, 0.006 0.006, 0.025 <0.005-0.009 0.020-0.048 0.030-0.047 0.021-0.042 <0.005-0.012 <0.005-0.019 0.041-0.058 <0.005-0.011 <0.005, 0.014 <0.005-0.023 0.008, 0.010 <0.007 >0.007 0.009 0.009-0.011 0.009-0.010			gave higher InAs levels. It has been reported that some other arsenic species are extracted, these were monomethylarsonic acid (MMA) 100%, and trimethylarsine oxide (TMAO) 3 - 10%. It is proposed that the presence of these substances contributes to the higher results for the solvent method. The HPLC-ICPMS method is more selective and allows different species to be reported separately, thus results reported are for InAs only and these were lower than the values found using the established method. InAs concentrations predominantly below LOQ of 0.0007 mg/kg.
Julshamn <i>et al.</i> , 2021	Arsenic and inorganic arsenic	Cod total arsenic Inorganic As NSS herring total As InAs Mackerel total As InAs Halibut tot As InAs	0.38-110 <0.002-0.006 1.8-34 <0.004 n.d – 4.3 <0.003-0.006 2.7-48 <0.003-0.004	2021	NE Atlantic, West Scotland	Mackerel only species caught West Coast of Scotland.

		Tusk total As InAs Saithe total As InAs Halibut total As, InAs	0.26-89 <0.003-0.006 0.01 – 6.5 <0.003-0.015 2.4 -15 <0.004			
FSS Live Bivalve Mollusc (LBM) Monitoring Data	Arsenic (total)	Shellfish Cockles (24) Mussels (58) Oysters (26) Razors (42) Clams (11)	0.67-2.34 0.82-2.163 1.07-2.408 1.43-1.52 1.2-6.36	2015-2022	Shellfish from Classified Harvesting Areas - Scotland sampled 2015-2022	Approx. 30 samples per year. Small number per species but regular sampling provides reasonable pool of data.
Investigation into the Levels of Environmental Contaminants in Scottish Marine and Freshwater Fin Fish and Shellfish (FSAS, 2009) / Fernandes <i>et al.</i> , 2009b	Arsenic (total and inorganic) Total arsenic	Fish & shellfish – 32 samples marine fish, 16 fresh water and 5 marine shellfish. Marine fish John Dory (1) Spurdog (3) Smooth Hound (2) Rays (4) Dogfish (2) Skate (2) Hake (3) Greater Forkbeard (1) Grenadier Torsk (2) Black scabbard (1)	 0.48 8.31-11.5 16.2, 22.4 29.1-79.18 19.7, 21.1 16.9, 25.8 0.85-2.5 8.81 6.56 1.97, 3.19 1.41	2009	Scottish Marine and Freshwater Fin fish and shellfish – fish landed in 2008.	Data >15 years old. Higher levels As in marine fish than freshwater, but mostly as organic As. Highest level 79.18 mg/kg was found in a Cuckoo Ray Freshwater fish = <0.04 mg/kg (trout) to 1.25 mg/kg (trout)

	Inorganic As	Monk fish (2) Haddock (1) Mackerel (2) Herring (1) Ling (3) Cod (1) Mussels (5) Spurdog (3) Smooth Hound (2) Rays (4) Dogfish (2) Skate (2) Hake (1) Greater Forkbeard (1) Grenadier Torsk (2) Monk fish (2) Haddock (1) Mackerel (1) Herring (1) Ling (3) Cod (1) Mussels (1)	9.37, 11.52 3.65 1.82, 2.19 2.18 3.97-24.1 7.43 1.08-3.53 0.059-0.149 <0.009, <0.011 <0.015-0.039 <0.016, 0.018 <0.013, 0.019 <0.006 <0.006 <0.005 <0.005, <0.008 <0.006 <0.009 <0.016 0.042 <0.008-<0.01 <0.008 0.089			Inorganic arsenic (subset 27 marine fish and 1 shellfish) Inorganic As represented 0.05-2.53% of total As.
Fernandes <i>et al.</i> , 2015.	Total arsenic	Halibut (3) Turbot (16) Sardine (16) Herring (19) Sea bass (25)	1.77-4.23 1.34-9.24 0.937-4.70 1.31-3.12 0.82-4.49	2013-2015	UK and proximate marine waters,	Total arsenic measured as part of Potentially Toxic Elements (PTE) screen using ICP-MS. No speciation carried out.

		Sprat (25) Mackerel (41) Grey mullet (26) Megrim (1) Monkfish (1) Haddock (1) Witch (1) Dogfish (8) Lemon sole (1) Spurdog (6)	1.4-4.52 0.49-2.38 0.136-2.11 5.03 6.53 20.4 35.9 10.2-33.8 21.7 4.64-10.19		including the North Sea extending up to Norway, the Irish sea and the Celtic sea to the North-Western coast of France, and the European coastal North Atlantic regions, including Biscay and the Algarve.	
De Gieter <i>et al.</i> , 2002	Total arsenic (AsT) was measured, then further classed as: Non-toxic arsenic fraction - defined as arsenobetaine (AB), arsenocholine (AC) and tetramethylarsonium ion (TeMA) and	Dogfish (20) Ray (20) Conger (1) Cod (5) Pollack (1) Pouting (5) Saithe (5) Whiting (5) Ling (5) Hake (1)		2002	French coast Bristol channel Bay Seine Northern North Sea Southern North Sea	Results presented as diagrams so not easy to summarise as ranges not presented in paper. Highest total As concentrations were found in lemon sole, dogfish, ray, and witch. Average total As concentrations in these fish species were higher than 20 mg/kg WW. The same species

	Toxic arsenic (AsTox) – defined as inorganic arsenic—arsenite (As(III)) and arsenate (As(V))—and organic arsenic compounds—monomethylarsonic acid (MMA) and dimethylarsinic acid (DMA).	Angler (20) Pomfret (2) Seabass (1) Mullet (1) Dab (13) Plaice (17) Lemon sole (20) Common sole (16) Sand sole (9) Brill (5) Megrim (6) Gurnard (1) John dory (1) St. James (27) Whelks (4) Crab (2) Shrimp (1)			Boulogne-Lands End	as well as the other flatfishes contained the highest amounts of toxic As (> 0.1 mg/kg WW). Toxic fractions (AsTox/AsT%) above 2% were found in the following six species: seabass, ling, john dory, pouting, dab, and brill. In a worst-case scenario (when fish has been dried or smoked and the toxic As level is high; for example 0.5 mg/kg WW), the As content of North Sea marine food may reach harmful levels.
Larsen and Francesconi, 2003	Arsenic	Herring, location (n) North Sea (3) Kattegat (34) Belt (12) Baltic (23) Cod North Sea (10) Kattegat (35) Belt (23) Baltic (24) Flounder North Sea (-)	Mean (As) ± SE 2.17 ± 0.23 1.71 ± 0.08 0.77 ± 0.08 0.98 ± 0.14 5.31 ± 0.97 4.77 ± 0.49 1.00 ± 0.24 0.66 ± 0.11 -	2003	Baltic Sea, Belt Sea, Kattegat and North Sea	Individual arsenic concentrations ranged from 0.04 to 10.9 mg/kg wet mass, and there was a positive linear relationship between arsenic concentration and salinity for all three species (r^2 0.44 to 0.72, all $P < 0.001$). The arsenic levels in fish from the North Sea and Kattegat were significantly higher than those from the Belt and Baltic ($P < 0.01$).

		Kattegat (19) Belt (23) Baltic (24)	2.72 ± 0.16 0.89 ± 0.08 0.89 ± 0.10			North Sea and Kattegat salinity was higher than the Belt and Baltic Seas. Although it is well known that marine fish contain much higher concentrations of arsenic than freshwater fish, the data reported here are the first showing a relationship between the total arsenic concentration in fish and salinity.
Baeyens <i>et al.</i> , 2009	Total and toxic (sum of As(III), As(V), monomethylarsenic (MMA), and dimethylarsenic (DMA)) As	19 different fish and 4 shellfish species. Dogfish (20) Thornback Ray (20) Conger (1) Atlantic Cod (5) Saithe (5) Pouting (5) Whiting (5) Ling (5) Angler (20) European Seabass (1) Dab (13) European Plaice (17) Lemon Sole (20) Common Sole (16) Sand Sole (9) Witch (5) Megrim (6)	Total As %ToxAs 2 1-6 4 0.59 60.2-36 0.84 2.37 1.18 3.1-7 1.33 1.8-5.7 1.33 2.5-5.4 2.20 4.0-6.5 1.37 2.1-8.5 2.00 4.1-13.7 0.93 1.10 4.00 6.5-21 1.86 7.7-26 1.30 14.9-76 0.58 4.1-4 9 1.45 4.1-35 1.53 9.4 -49 0.85 3.8-12.8 1.34	2009	North Sea	Most of the As compounds present in fish and shellfish (mostly arsenobetaine (AB)) are not toxic or have a very low toxicity. The intake of toxic As compounds by the Belgian population were estimated. These were 5.8 pg/day for an average consumer and 9.5 pg/day for a high level consumer. They are much lower than the TDI of 140 pg/day (for a 70 kg person) set by the Joint FAO/WHO Expert Committee in 1989 [39] and are comparable to toxic As intake rates observed in US, Canada and UK.

		Brill (5) Turbot (1)	1.4-2.9 17.90	2.50 0.89			
		Great Scallop (27) Whelks (4) Common Shrimp (1) Edible Crab (2)	0.99-3.61 16.5-66 5.20 37-41	0.75 0.32 3.27 0.75			
Polak-Juszczak and Richert, 2021	Total Arsenic (TAs) Total Arsenic and inorganic arsenic (As(III) and As(V))	Cod (30) Herring (45) Sprat (40) Flounder (40) Cod (15) Sprat (15) Herring (15) Flounder (15)	0.229-0.651 0.232-0.958 0.362-1.234 0.162-1.523 Mean TAs 0.412 0.629 0.476 0.776	 iAs% 4.85 3.18 4.20 2.89	2021	Baltic Sea	Sprat muscle had the highest mean content of total arsenic (0.636 mg/kg), lower mean levels were found in the muscles of herring (0.460 mg/kg) and flounder (0.588 mg/kg), and the least was in cod (0.390 mg/kg). Organic and inorganic forms arsenic were determined in a subset of samples (n=15 for each species). Estimated daily intake values for inorganic arsenic in herring, cod, sprat, and flounder at 0.51×10^{-5} mg/kg b. w. day were below the FAO/WHO reference dose. Current data indicate that inorganic arsenic compounds pose no risk to the health of consumers of fish from Baltic Sea.

Table 19. Summarised results from studies on PFAS

Study / Reference	Contaminant	Species Data Available / Description of study	Results Range µg/kg	Results Mean µg/kg	Date	Location Data available	Data gaps or comments
Clarke <i>et al.</i> , 2010	PFOS PFHxSK PFHxA PFHpA PFOA PFNA PFDeA PFUnA PFDoA PFBSH PFOSA TH-PFOS (tetrahydro-PFOS) ΣPFCs = sum of compounds listed	Whitebait (4), Eel (6), Carp (6) Sprats (3), Sardines (6), Cod (4) Mackerel (4), Haddock (4) Trout (4), Herring (4) Plaice (2), Salmon (8), Sole (2) Oysters (2), Crab (6), Crayfish (1), Prawns (2), Langoustine (1)	8-62 <1-63 <1-8 3-8 1-7 <1-4 <1-3 <1-3 <1-1 <1-2 <1-1 <1 <1 1-1 11-20 2 <1-1 <1 ΣPFCs	28 11 5 5 4 2 2 1 <1 <1 <1 <1 <1 <1 16 2 1 <1 ΣPFCs	2010	Samples were collected at retail in the UK, all 4 countries, 10 regions	All results wet weight. Samples were collected in 2007 and 2008. PFOS most commonly detected and at the highest levels, then PFOSA and to much lesser extent PFOA, PFNA. Highest levels PFOS seen in smoked eel and whitebait. PFAS defined as sum of PFCs measured. Results were used to calculate estimated exposure. The lower bound estimate for PFOS dietary intake in the UK of 1 ng/kg/day was estimated from the results of this study, was calculated as a consumer- rather than population-based estimate, which gave a higher result that was stated to be comparable to estimates from other countries at the time. However EFSA have reduced the TWI since this paper was published.
FSA, 2025. Contaminants	PFNA, linear and branched		Sum EU PFAS		2023	Samples landed in	The following were detected above the EU MLs ((EU, 2022) note there

monitoring programme for wild caught fish, crustaceans and cephalopods	PFHxS, linear and branched PFOS PFDA, linear PFBS PFDoA PFHpA PFHxA PFPeA PFBA PFOA	cod (13) crab (27) cuttlefish (11) dogfish (2) gurnard (2) haddock (2) hake (5) herring (7) lobster (4) mackerel (16) monkfish & anglers (7) plaice (3) sardines (32) sea bass (9) skates & rays (4) sole (6) squid (2)	0.03-2.58 0.28-2.49 0.11-<0.45 0.13, 0.27 0.06, 2.06 0.18, 0.30 0.03-<0.45 0.13-<0.45 0.46-1.26 0.03-0.85 0.20-0.34 0.24-0.77 0.22-2.09 0.12-2.00 0.11-1.49 0.12-<0.45 0.90, 0.10			England and Wales. Fish purchased at wholesale fish markets in South West, South East and North East England and Wales	are currently no restrictions for these substances in fish in UK legislation): • Three cod samples (1.0, 1.5 and 1.0 µg/kg) exceeded the EU ML (0.5 µg/kg) for PFNA • Two cod samples (0.52 and 0.47 µg/kg) exceeded the EU ML (0.2 µg/kg) for PFHxS • Two crab samples (1.8 and 1.1 µg/kg) exceeded the EU ML (0.7 µg/kg) for PFOA • One gurnard sample (0.57 µg/kg) exceeded the EU ML (0.5 µg/kg) for PFNA. • One of the cod samples (2.6 µg/kg) exceeded the EU ML for the sum of PFOS, PFOA, PFNA and PFHxS when the measurement uncertainty was taken into account (2.0 µg/kg for fish and 5.0 µg/kg for crustaceans). A further two samples (gurnard and sea bass) were at the EU ML.
Food Standards Agency 2006a	15 PFAS compounds PFOSA PFBS PFHxS PFOS PFPeA PFHxA	2004 Total Diet samples, covered a range of food groups including 'Fish'	PFOS <5±<1 PFOA <3±<0.6 Sum PFAS <LOQ		2004	Retail UK	Nothing detected above LOQ for any compounds in fish group – samples were pooled which will dilute any residues making detection less likely. PFOS was detected at concentrations above the limit of

	PFHpA PFOA PFNA PFDeA PFUnA PFDoA PFTdA PFHdA PFOdA Sum PFAS = sum of compounds listed						determination in the potatoes, canned vegetables, eggs and sugars & preserves food groups.
Fernandes <i>et al.</i> , 2012	Perfluoroalkyl substances (PFAs) PFOSA PFBSH PFHxS PFOS PFHxA PFHpA PFOA PFNA PFDeA PFUnA PFDoA Sum PFAS = sum of compounds listed	Fish (140 sub samples to make up Fish TDS sample).	Total PFAS 18.4		2012	TDS Study. Retail UK, 986 individual foods composited into 19 food groups.	A range of individual compounds were detected in the fish group, total PFAS was 18.4 µg/kg (the highest of all food groups). A significant improvement in the measurement sensitivity of PFAS since the last TDS study resulted in near universal detection of all targeted analytes in this study. The fish and offal groups show generally higher concentrations of most PFAS relative to the other foods. Comparison with the (only) previous TDS study (Food Standards Agency 2006a) is limited because of the very different reporting levels, which resulted in most analytes

							remaining undetected in the earlier work.
Fernandes <i>et al.</i> , 2018 (& 2015)	PFAS - PFOSA PFBSH PFHxS PFOS PFOA PFNA PFDeA PFUnA PFDoA	Sardines (8) Mackerel (12) Herring (9) Mullet (9) Sprat (9) Sea Bass (5)	0.78-3.59 0.22-4.92 0.16-1.84 0.37-12.83 1.51-9.44 1.28-10.79 Results for PFOS as the most predomina nt compound	2.18 1.12 0.59 2.58 3.94 3.82 Results for PFOS as the most predominant compound		Waters around the UK and the European coastal North Atlantic. Extended north to the coast of Norway and south to the Algarve. Included fishing grounds such as the North Sea and the Greater North Sea sub- region, Biscay, the Algarve and the Irish Sea with Celtic sea sub- regions.	50 fish samples covering 6 species were analysed for PFAS with positive detection in all samples. The higher concentrations were generally seen in sardines, sprats and sea bass, with PFOS, PFOSA and PFOA usually showing the highest values Results are presented for individual PFAS as ranges and mean, with no results for a sum parameter other than a statement e range in this study was 0.64 to 15.3 µg/kg ww. It is difficult to make comparison to earlier studies on fish in the UK because of the very different method sensitivities, which resulted in most analytes remaining undetected in earlier work. All analytes were detected in all species. The spatial distribution of this occurrence showed that fish taken from waters around the Southern UK/Northern French coasts and the Irish Sea tended to show higher levels of most contaminants, but contamination is

							also evident for locations off the east coast of the UK. Mullet, seabass and sprat max levels all exceeded MLs in Reg EU 2022/2388 (MLs were not in force at time of study).
Barbarossa <i>et al</i> , 2016	Perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA)	Sea bass (wild, semi-intensively and intensively reared), 140 in total. Wild caught sea basses Intensively farmed sea basses	PFOS 0.112-12.41 PFOA 0.009-0.487 PFOS 0.011-0.105 PFOA 0.009-0.051	PFOS 1.345 PFOA 0.028 PFOS 0.032 PFOA 0.021 (median values)	2016	14 sites - NE Atlantic France, Italy and Adriatic Sea, Greece	Significant differences among the various rearing systems were also observed, with extensively-farmed subjects presenting relatively higher levels of both compounds compared to intensively farmed. Diet and habitat are likely the main causes of such differences: a higher contamination seems, at least for PFOS, the consequence of biomagnification for predatory habits of this fish, while the feed employed for its farming is apparently a minor source of exposure.
Dahlgren <i>et al.</i> , 2022	PFOA, PFNA, PFOS, PFDA, PFUnDA, PFDoDA (residues found) PFBA, PFPeA, PFBS, PFBS, PFHxA,	Flounder muscle (20) PFOA PFNA PFOS PFDA PFUnDA		0.012 ± 0.013 0.050 ± 0.061 0.116 ± 0.091	2022	Hanöbukten, south-western parts of the Baltic Sea	Concentrations of Σ PFAS in this study at 0.3 ng/g ww in muscle tissue are one order of magnitude lower than previously reported in flounder from the Gulf of Finland (5.3 ng/g, Järv <i>et al.</i> , 2017). The paper reported seven out of 30 analysed PFAS compounds

	PFHpA, PFHpA, PFPeS, PFHxS, PFHpS, PFOA, PFNA, PFOS, PFDA, PFUnDA, PFNS, PFDS, PFDODA, PFTrDA, PFDODS, PFTDA, PFHxDA, PFOcDA, 4:2- FTSA, 6:2- FTSA, 8:2- FTSA, 5:3- FTCA, 6:2- FTUCA, 8:2- FTUCA, 10:2- FTUCA, 11CIPF3OUdS 451, 9CIPF3ONS35 1 (all below LOD)			0.038 ± 0.044 0.041 ± 0.034			were detected in the samples, dominated by perfluorononanoic acid (PFNA) which was present in all samples. Perfluorooctane sulfonate (PFOS) and perfluoroundecanoic acid (PFUnDA) were detected in 19 and 17 of the samples, respectively. Concentrations varied with an order of magnitude, with the highest levels detected for PFOS in muscle tissue at 0.36 ng/g ww. PFDODA was detected in 3 samples, but not analysed further so concentrations were not given. The Σ PFAS values ranged from 0.02 and 0.95 ng/g in muscle tissue.
Androulakakis <i>et al.</i> , 2022	13 PFCAs (C3–C14, C16 and C18) 7 PFASs 3 FASAs	Eelpout muscle (3) Herring muscle (3) Bream muscle (6) Roach muscle (5)	46-66 16-39 100-325 56-100	57 25 190 77	2022	North Sea & Baltic Sea (Herring from Sweden)	Samples collected 61 sites across Europe. Few marine species. In general found freshwater fish had higher residues than coastal/marine fish. All analyzed

	4 PFAPAs 3 PFPI's 5 FTOHs 2 PAPs 2 diPAPs 6 FTAS 3 FTUAs 2 FASEs 3 FTSAAs 2 PFECAs 1 CI-PFESA.	Harbour porpoise liver (5) Otter liver (20) Seal liver (11) Buzzard liver (12)	357-2692 1942- 20236 244-1517 217-1092	1079 6321 803 426		Otter & porpoise Hartlepool, UK)	specimens were primarily contaminated with PFOS, while the three PFPI's included in this study exhibited frequency of appearance (FoA) 100 %. C9 to C13 PFCAAs were found at high concentrations in apex predator livers, while the overall PFAS levels in fish fillets also exceeded ecotoxicological thresholds. Data reported in supp information for marine fish : linear PFOS 1.35 - 62.65ng/g branched PFOS 0.15 - 0.82 ng/g ww. Full results available. The findings of this study show a clear association between the PFAS concentrations in apex predators and the geographical origin of the specimens. Samples collected in urban and agricultural zones were highly contaminated compared to samples from pristine or semi-pristine areas.
Schultes <i>et al.</i> , 2020	28 target PFASs	Cod (10 per year for 16 years, 1981, 1990, 2000-13). Perfluorooctane sulfonate was dominant and occurred in all samples. The pattern of long-chain	Σ PFOS 2.58 - 19.1		1981-2013	Sweden south-east of Gotland in the Baltic Sea (~56° 53'N, 18° 38'E)	Perfluorooctane sulfonate was the dominant compound in all but 2 samples from 1981 (in which FOSA was the dominant PFAS), with geometric mean concentrations ranging from 2.58 to 19.1 ng/g (sum of linear and branched isomers, Σ PFOS),

		PFCAs (C8-C13) was dominated by odd-numbered chain-length compounds (e.g. PFUnDA and PFNA) over their adjacent even-chain homologues. No short-chain PFAAs were detected, presumably due to their low bioaccumulation potential compared to longer-chain-length PFCAs. Time-trend analysis revealed no significant trend for PFOA, which could be attributed to its lower bioaccumulation potential.					accounting for 42 to 80% of $\Sigma 28$PFASs. The highest individual PFOS concentration was found in a sample from 2005 (35.5 ng/g), whereas 2012 showed the highest PFOS geometric mean concentrations (19.1 ng/g). The ratio of branched to linear PFOS isomers averaged 0.09 over all years, with no significant trend over time.
Fliedner <i>et al.</i> , 2020	19 emerging flame retardants and degradation products, 40 per- and polyfluoroalkyl substances (PFAS) and three cyclic volatile	Composite samples of: Eel poult – fillet (3) and liver (2). Samples collected in 2015. PFAS concentrations were usually higher in samples from the	PFOS 0.202, 0.487 and 0.921 3.7 and 9.1		2015	NS 1: North Sea—Lower Saxony Wadden Sea; NS 2: North Sea—Schleswig—Holstein Wadden Sea; BS: Baltic Sea—	Tables of results provided in supplementary information. PFAS with carbon chain lengths < 8 carbon atoms were not detected in any sample. Based on the results, it should be considered to include the emerging flame retardants DP and Dec 602 and the long-chain perfluoroalkyl substances PFNA, PFDA, PFUnDA and PFDoDA in regular monitoring in the North and

	methysiloxanes (cVMS).	North Sea sites compared to samples from the Baltic Sea. PFOS dominated in most samples. PFNA, PFDA, PFUnDA, PFOSA and PFOS residues detected.				Bodden National Park (Baltic Sea)	Baltic Seas. Increasing trends over time were detected for PFNA, PFDA and PFDoDA at the Baltic Sea site and for PFDA at one North Sea site.
Carlsson <i>et al.</i> , 2016	Suite of PFAS, PCBs, PBDEs and OCs	Halibut fillet (9) Unpeeled shrimp (9) Concentrations of perfluorooctane sulfonate (PFOS) – the most abundant PFASs – were 0.9 and 2.7 ng/g ww in halibut and shrimp, respectively.	0.611-6.162 0.5486-11.127	2.189 2.189	2008-2012	Halibut – Tromso Shrimp - Malangen and Kvænangen regions	Based on mean concentrations, linear PFOS dominated (range: 0.2–1.7 ng/g ww), followed by PFTrA (range: 0.1–2.3 ng/g ww) and PFUnA (range: 0.1—1.2 ng/g ww) in the halibut fillets. Levels of PFOS and PFAAs were higher in the shrimps compared to halibut fillets. However, this may reflect the higher protein content in these tissues or a direct uptake of PFAS from the water into the shrimps. This is also a reflection of the different contamination pathways for PFAS compounds compared to older legacy POPs, like PCBs. Authors recommended that the protein content of food items is analysed and included when PFAS concentrations are discussed and/or normalised, in a similar manner as legacy POPs

							are normalised to lipid content or extracted organic matter.
Byns <i>et al.</i> , 2022	15 PFAS compounds. PFBA PFBS PFPeA PFHxA PFHxS PFHpA PFNA PFOA PFOS PFDA PFUnDA PFDS PFDoDA PFTrDA PFTeDA	Med scaldfish (9) Atlantic herring (10) Three bearded rockling (11) Whiting (26) Surmullet (9) European plaice (29) Common sole (23) Flying crab (29) Brown shrimp (20)	8-23 8-94 31-243 14-76 11-41 3-49 2-54 4-63 7-44	15 33 106 43 23 18 26 18 17	2022	10 sites in the Belgian North Sea and the Western Scheldt estuary (mouth of Scheldt to Oostende)	Target analytes PFBA, PFBS, PFPeA, PFHxA, PFHxS, PFHpA, PFDS and PFTeDA were not detected in any matrix. PFOS concentrations in the present study are lower in both fish (<i>P. platessa</i>) and crustaceans (<i>C. crangon</i> and crab sp.) compared to the studies from 2003. Overall, similar contamination profiles were found among fish and invertebrate species. PFOS was predominant in all matrices and species except for <i>C. harengus</i> (herring), where PFOA was predominant in liver tissue. <i>C. harengus</i> is, due to its pelagic feeding behaviour, more likely to experience a greater exposure to PFOA compared to sediment-associated species. Authors stated almost no information is available on the PFAS accumulation in fish and invertebrate species in the North Sea. Using data from this study to calculate human exposure they

							concluded that the monitoring of PFAS in commercially available fish is strongly advised.
Kumar <i>et al.</i> , 2022	13 PFAAs analysed in the study samples are: PFHxA PFHpA PFOA PFNA PFDA PFUnDA PFDoDA PFTrDA PFTeDA PFHxS PFHpS PFOS PFDS	Baltic herring (30) Sprat (6) Salmon (8) Perch (10) Burbot (5) Smelt (2), Bream (9) Lamprey (2) Fresh water fish Vendace (2) Whitefish (10) Pike (5) Pike-perch (4) Roach (5). Pooled samples made up of 3-30 fish each depending on species.	2.28-8.48 0.89-3.00 2.58-5.78 2.62-6.49 0.73-3.08 20.13-45.99 0.77-4.32 10.11 5.29-6.21 0.29-3.60 1.09-2.97 1.33-3.46 0.82-2.89		2022	Baltic Sea and selected freshwater locations in Finland.	PFOS was detected in all Baltic Sea fish samples and in >80% fish samples from freshwaters. PFOS contributed between 46 and 100% to the total PFAA concentration in Baltic Sea fish samples and between 19 and 28% in fish samples from freshwaters. Long-chain PFCAs (PFNA, PFDA, PFUnDA) were also frequently detected in both Baltic and freshwater fish. Moderate consumption of most Baltic fishes (200 g/week) resulted in an exceedance of $\sum$ PFAS-4 TWI (4.4 ng/kg body weight/week) derived by EFSA, which warrants continued monitoring of a range of fish species. The authors stated additional PFAS homologues or at least the $\sum$ PFAS-4 must be monitored in the fishes of the Baltic Sea and inland waters rather than PFOS only, to track the use and occurrence of PFASs that have replaced PFOS and related chemicals and for their temporal assessments.

Jarv, <i>et al.</i> , 2017	13 different PFNA compounds: PFHpA PFOA PFNA PFDA PFUnA PFDaA PFTTrA PFTeA PFHxS PFHpS PFOS PFDS	Herring (12) Baltic herring (East Gulf of Finland) Baltic herring (West Gulf of Finland) Sprat (6) Perch (6) Flounder (6) Salmon (1) River Lamprey (2) – muscle. The concentrations of PFHxA, PFHpA, PFTeA and PFHpS were in all cases below the limit of quantitation.		5.01 ± 0.28 5.33 ± 0.49 8.90 ± 1.04 9.43 ± 2.71 7.69 ± 0.82 5.47 5.85 ± 0.74	2017	Gulf of Finland	Depending on the compounds included in the sum total herring and sprat samples may contain levels above the EU MLs. No information is given on individual PFCs detected. Paper also includes data on PCBs, PBDEs, and organotin compounds.
Kowalczyk <i>et al.</i> , 2020	17 perfluoroalkyl compounds (C6-C15 chain length: PFHxA, PFHpA PFOA PFNA PFDA PFUnA PFDaA PFTTrA PFTeA,	Beaked redfish liver (19) Beaked redfish fillet (19) Cod liver (20) Cod fillet (20) The authors used the Maximum Likelihood	PFOS max MLE 2.194 PFOS max MLE 0.217 PFOS max MLE 0.994 PFOS max MLE 0.091		2020	Arctic Ocean 1. Station 698/9 WH 355: N79°02.206' E008°43.231' ; 2. Station 702 WH 355: N79°43.989' E009°05.767' ; 3. Station 712 WH 355: N80°05.818' E010°52.592'	Out of 17 analysed substances, only six perfluoroalkyl acids (PFAAs) were detected in the fish. The most frequently quantified substances were PFOS and perfluoroundecanoic acid (PFUnA) in liver (100%) and fillet (at least 40% and 70%, respectively) of beaked redfish and cod, and in belly flap of beaked redfish (100%). Beaked redfish liver (2.194 µg/kg ww) contained concentrations twice as high as cod liver

	Perfluoroalkane sulphonic acids PFBS PFHxS PFHpS, PFOS PFDS FOSA N-Et-FOSA N-N-Me-FOSA	Estimation (MLE) to estimate PFAA concentrations.				in the zone of Svalbard	(0.994 µg/kg ww). Similar liver concentrations were detected for the longer-chained PFUnA. Next highest concentrations were PFNAMLE (0.358 µg/kg ww) and PFDAMLE (0.383 µg/kg ww) in beaked redfish liver, and PFNAMLE in liver of cod (0.184 µg/kg ww). Paper does not give results as sum of 4 PFAS, but levels of PFOS in muscle reported are well below ML in Reg EU 2022/2388. It includes table of historical results for PFAAs in cod and Beaked redfish from Arctic, Baltic and North Seas 2004-8.
Pasecnaja <i>et al.</i> , 2022	Collated data for a range of fish species	A comprehensive review summarising data from a number of food groups. PFOS could be considered as the dominant perfluorinated analyte in the most food matrices, because this compound has a relatively high accumulation potential				Results from all over Europe including UK (data from Fernandes <i>et al.</i> , 2018).	Critical evaluation of the performance characteristics of reviewed analytical methodologies revealed that the sensitivity of quantification procedures was largely insufficient for objective risk assessment according to the guidelines proposed by the European Food Safety Authority.

		in food webs. According to the available data, the major contributors to PFASs intake through human diet in the European countries are fish, meat, and eggs. The published data indicate that the current daily intake of PFASs in a number of European countries likely exceed the TDI of 0.63 ng/kg b.w./day established by EFSA in 2020.					
Torres and De-la-Torre, 2023	Review – summarises PFAS data in a range of foodstuffs. Data presented as ΣPFAS, the number of individual compounds included in the sum value is noted.	Review of global data on PFAS occurrence in foods. Data summarised by food category in tables. There is a table for seafood and separate one for freshwater fish. For seafood, data from 21 publications are summarised. Samples from a mix of marine and estuarine areas.				Results from fish from global sources covering a range of locations: USA, Saudia Arabia, Red Sea, China, UK, Norway, Australia, African countries, Central and	Contains summary of studies from around the world of possible interest, several cited above. Range for UK results 2.18-7.73 ng/g, was similar to other studies. Highest range values were 5.58-24.1 ng/g (USA) and prawns (20.1-44.4 ng/g) and fish muscle, including mullet & sea bream, (0.5-138.6 ng/g) from Australia. Estimated dietary intake included for 7 studies, where it had been given in original paper. Highest EDI

		Number of PFAS compounds analysed ranged from 8-23. Data sets had either 0% (2 studies) or 100% detection rate, apart from 1 study (99.2%). The number of samples per study was not given. LOD / LOQ not provided, so difficult to compare results where 0% occurrence cited.				S. America. Results from all over the world, includes data from several other papers cited here, including Fernandes et al, 2018 for UK data.	was 29.53 ng/kg bw/day (calculated for PFOS only as the major component) for South China prawns.
Valdersnes <i>et al.</i> , 2017	16 perfluorinated analytes; PFBS PFHxS PFOS PFDS PFOSA PFBA PFPeA PFHxA PFHpA PFOA PFNA PFDA PFUDA	Cod liver (200) The dominant PFAS was PFOS, which was quantified in 72% of the livers and the highest concentration found was 21.8 µg/kg wet weight. For the other PFAS determined, concentrations above the LOQ of the method were found for the following compounds,		mean±SD 2.3±0.7	2017	Coast of Norway	The levels of PFAS in cod liver along the Norwegian coast were low. Geographical differences in the levels of PFOS were found, with the highest concentration in the East, compared to North and West. It is likely that this difference is due to higher population density in the East area and its closeness to urbanized and industrialized regions in the Baltic and Northern Europe.

	PFDoDA PFTrDA PFTeDA	number of samples in brackets: PFUdA (35) PFTrDA (20) PFDA (11) PFOSA (4) PFDoDA(3) PFOA (2) PFNA (1) PFBS, PFHxS, PFDS, PFBA, PFPeA, PFHxA, PFHpA, PFTeDA were not found in concentrations above the LOQ in any of the samples.		3.8±1.6 1.3±0.8 4.0±2.0 2.9±0.3 2.6±0.4 2.4			LOQs were quite high for some analytes, e.g. >20ug/kg for PFHpA and PFTeDA.
Zafeiraki, <i>et al.</i> , 2019	PFBS PFHxS PFOS PFDS) PFBA PFPA PFHxA PFHpA PFOA PFNA PFDA PFUnDA PFDoDA (PFTrDA	Shellfish Shrimp (13) Mussels (4) North Sea crab (brown meat) (6) North Sea crab (white meat) (7) Marine fish (muscle) Herring (7) Hake (4) Cod (8) Mackerel (3) Common dab (11)	0-32.9 0.5-14.9 1.5-8.2 0-0.78 0-1.10 0-0.4 0-2.3 0-1.17 0-3.0	6.7 5.0 3.4 0.28 0.24 0.20 0.93 0.75 1.10	2012-2018	The Netherlands – mostly Dutch waters or Dutch markets	Supplementary information gives detailed information on where samples were caught, and individual results for all samples. Short chain compounds were generally not detected. PFOS was detected at higher frequency than other PFAAs. ΣPFAS levels were highest in eels collected from rivers and lakes (average 43.6 ng/g and max 172 ng/g), followed by shrimps collected near the Dutch coast

	PFTeDA	Haddock (7)	0-2.0	0.43			(average 6.7 and max. 33 ng/g ww), and seabass (average 4.5 and max. 9.4 ng/g ww). Most of the farmed fish (e.g. trout, catfish, turbot, salmon, tilapia, pangasius) were among the lowest contaminated samples in this study (averages ranged from 0.06 to 1.5 ng/g ww). Geographically, levels in marine fish from the northern North Sea (e.g. haddock, whiting, herring) were lower than in the central and southern North Sea (e.g. cod and flatfish).
		Plaice (15)	0-3.9	1.07			
		Sole (10)	0.5-2.8	1.70			
		Whiting (6)	0-0.40	0.18			
		Sea bass (7)	2.4-9.4	4.50			
		Farmed fish					
		Eel (4)	0.36-2.5	1.5			
		Trout (7)	0-1.30	0.22			
		Catfish (7)	0-0.47	0.10			
		Salmon - Norway (7)	0-0.50	0.11			
		Salmon – Scotland (7)	0-0.10	0.06			
		Pangasius (7)	0-1.10	0.33			
		Turbot (6)	0-0.70	0.12			
		Tilapia (7)	0-0.50	0.11			

Table 20. Summarised results of studies on smoked fish and fishery products

Study / Reference	Contaminant	Species (n=number of samples)	Results	Date	Location Data available	Data gaps or comments
Watson et al., 2004. Seafish Report No. SR557.	22 PAHs including benzo(a)pyrene, benz(a)anthracene, benzo(b)fluoranthene and chrysene	Arbroath smokies (2) Mackerel (7) Haddock (5) Kipper (10) Whiting (3) Cod (3) Halibut (1) Coley (1) Salmon (1)	BaP µg/kg 0.56, 1.34 <0.06-0.43 <0.06-<0.18 <0.06-0.14 (3) <0.18) <0.06-<0.18 <0.06-<0.17 <0.06 <0.06 <0.18	2004	UK smokehouses - including Scottish businesses	The report summarised results from a questionnaire sent to businesses registered on the Seafish suppliers database (in 2004) as smoked product suppliers and to other businesses known to be smokers. Study is now 20 years old. It was commissioned in 2004 to assess the impact of the (at that time) proposed introduction of Max Levels for PAHs. It presents stats on the number and type of businesses, and gives a useful diagram of smoking processes. All the BaP results are well below the 5 µg/kg limit proposed at the time, the highest was 1.34 µg/kg for a hot smoked, traditional kiln, Arbroath smoky. Only 2 of the 33 products analysed exceeded 0.5 µg/kg of BaP. The authors stated full analysis data shows considerable variations in levels between the different

						PAHs and product types and processes. Given the wide range of variables and the relatively small number of samples, it may be difficult to draw further conclusions from the data. The different toxicity of the various PAHs would have to be taken into account.
FERA 2010 – Survey for PAHs in cereals, cereal products, vegetables, vegetable products and traditionally-smoked foods	28 PAHs, including benzo(a)pyrene, benz(a)anthracene benzo(b)fluoranthene and chrysene	Smoked haddock (9) Smoked mackerel (11) Smoked cod loin (1) Smoked kipper fillet (1) Smoked salmon (24) Smoked rainbow trout (15) Arbroath smokies (1) Smoked mussels (1)	BaP, range, µg/kg <0.03-0.1 <0.06-1.04 <0.06 <0.05-0.2 <0.07-10.13 <0.07-2.47 1.46 0.68	2010	Samples purchased at retail throughout the UK, included Scottish products	For smoked fish products the mean BaP level was 0.68 µg/kg (range 0.03-10.1), for the sum of PAH4 mean was 4.02 µg/kg (range 0.11-54 µg/kg). The sum 28 PAH compounds mean was 90 µg/kg (range 3.3-658 µg/kg). 4 samples of smoked fish contained benzo[a]pyrene concentrations above the EU limit of 5 µg/kg.
Storelli <i>et al.</i> , 2003	PAHs PCBs Chlorinated pesticides (DTs: p,p'-DDE, p,p'-DDT, o,p'-DDT, p,p'-DDD, and o,p'-DDD) Hexachlorocyclo-	Sample type (n=10) Salmon Denmark Scotland Norway Swordfish Italy Denmark Herring France Denmark Denmark	BaP, mean ± SD, µg/kg ND 0.7 ± 0.01 ND ND ND ND 0.5 ± 0.01 ND	2003	Included smoked fish from Scotland, Denmark, Italy	Study is now 20 years old. Results reported as ND (not detected but no indication of a LOQ given). Benzo(a)pyrene, was reported as absent in all of the samples except the Scottish salmon (0.7 ng/g), Danish herring (0.5 ng/g), and eel (0.3 ng/g) samples.

	hexane isomers (aHCH 1 bHCH 1 gHCH)	Eel Denmark Bluefin tuna Denmark Salmon Scotland	0.3 ± 0.01 ND PCBs mean 26 ± 0.04 µg/kg Total PCBs (lipid wt) 317.9 µg/kg DDTs mean 10.7 ± 0.03 µg/kg ww HCHs mean 1.1 ± 0.01 µg/kg HCB 2,2 ± 0.02 µg/kg ww (highest HCB levels in the study).			Benzo(a)anthracene was found in all of the samples and was present at particularly high levels in Scottish salmon (23.2 ng/g) PCBs - the highest values were for Danish herring (29 ng/g), eel (30 ng/g), and Scottish and Danish salmon (26 ng/g). Scottish salmon had the highest HCH concentrations (2.2 µg/kg ww).
Visciano <i>et al.</i> , 2006	PAHs	Atlantic salmon (<i>Salmo salar</i>) Raw fillets (24)	BaP mean 3.67 ± 3.99 µg/kg Range <LOD- 9.88 µg/kg Σ PAHs mean 231.77 ± 46.56 µg/kg	2006	Norway and Ireland	Raw fillets of <i>Salmo salar</i> from Norway or the Irish Sea were sampled in a modern smokehouse and examined for PAH content. The same fillets, labelled with an identification number, were sampled immediately after the smoking process and analyzed. No significant difference (P < 0.01) was observed between raw and

		Smoked fillets (n=24)	Σ PAHs range 142.21-303.56 $\mu\text{g/kg}$ BaP mean 3.20 ± 2.05 $\mu\text{g/kg}$ Range 0.74- 7.71 $\mu\text{g/kg}$ Σ PAHs mean 226.27 ± 38.12 $\mu\text{g/kg}$ Σ PAHs range 161.34-286.90 $\mu\text{g/kg}$			smoked samples in the concentrations of six PAHs, but significant differences were found for fluorene, anthracene, fluoranthene, benz[a]anthracene, and benzo[ghi]perylene. Results confirm that PAHs concentrations in smoked fish are the product of both sea pollution and the smoking process. Study is 18 years old.
Afe <i>et al.</i> , 2021	PAHs Nitrosamines Heterocyclic amines Heavy metals Biogenic amines	Review article of occurrence of chemical contaminants in smoked foods, no examples for UK smoked fish for PAHs given despite data from many other countries and 92 papers cited.		2021	Review – global results	No Scottish or UK data reported.

Table 21. Summarised results of study on histamine

Study / Reference	Contaminant	Species Data Available	Date	Location Data available	Data gaps or comments
FSAS study, reviewing of the risk management practices employed throughout the fish processing chain in relation to controlling histamine formation in at-risk fish species (2013)	Histamine	Atlantic herring (<i>Clupea harengus</i>) Atlantic mackerel (<i>Scomber scombrus</i>) Atlantic herring contained histamine varying from 42 mg/kg to 236 mg/kg, whilst stored at temperatures from 2 to 10°C for storage time periods at 2 to 13 days. Atlantic mackerel contained histamine varying from 2 mg/kg to 1090 mg/kg, whilst stored at temperatures from 2 to 22°C for storage time periods at from 1 to 10 days. (Klausen & Lund, 1986, Mackie <i>et al.</i>, 1997, Lokuruka & Regenstein, 2007, Prester <i>et al.</i>, 2009).	1986 - 2013	Laboratory based studies – under conditions of temperature abuse.	Literature review identifying papers, which examined histamine formation in various at-risk fish species stored at different temperatures. The majority of the examined studies were laboratory based and were carried out at extreme temperature abuse conditions.
	Histamine	North Atlantic Salmon (<i>Salmo salar</i>) Coho salmon (<i>Oncorhynchus kisutch</i>) Two separate studies carried out on storing Atlantic salmon (<i>Salmo salar</i>) in different packaging atmospheres at 2°C. Both showed that although histamine formed in the product, the rate of accumulation was slow and only low levels (<20 mg/kg) of histamine had accumulated by the time the product was considered spoiled (de la Hoz <i>et al.</i>, 2000 – examined		Laboratory based studies – under conditions of temperature abuse.	Literature review data on laboratory based studies

		refrigerated salmon stored under CO₂ enriched and air atmospheres; Emborg <i>et al.</i>, 2002 Histamine formation has also been reported to be negligible in Coho salmon (<i>Oncorhynchus kisutch</i>) stored in ice in a chill room at 2°C for 24 days (Aubourg <i>et al.</i>, 2007). A Danish study of biogenic amine formation in cold-smoked salmon (<i>Salmo salar</i>) during chilled storage (5°C) detected histamine above regulatory limits (>200 mg/kg EU limit for Scombridae and Clupeidae fish) at the end of shelf-life (5 to 9 weeks) (Jørgensen <i>et al.</i>, 2000). In a survey of Norwegian smoked or cured salmon and trout products from leading retailers and manufacturers in Norway, 35 samples were tested. 30 had a histamine content below the general level of 100 mg/kg, two samples had concentrations between the general and the maximum EU limit for Scombridae and Clupeidae fish of 200 mg/kg, and three samples had histamine content above the maximum level. The highest concentration found was 370 mg/kg (Julshamn, 2008). In both the Danish and the Norwegian studies no samples reached levels considered to be toxic (<500 mg/kg).			
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Annex A: Tables of Landings of Fish in Scotland or from Scottish Vessels

Table A.1. Tonnage and value of landings by Scottish vessels into Scotland by main species

Species	Tonnage 2017	Tonnage 2018	Tonnage 2019	Tonnage 2020	Tonnage 2021	Value 2017 (1000s of £s)	Value 2018 (1000s of £s)	Value 2019 (1000s of £s)	Value 2020 (1000s of £s)	Value 2021 (1000s of £s)
Total demersal	89,419	99,649	90,819	80,244	73,020	167,408	187,115	180,695	141,340	141,043
Total pelagic	134,176	133,286	93,450	119,679	139,291	92,991	95,999	85,516	99,571	120,668
Total shellfish	48,658	41,583	47,089	34,126	42,245	152,656	147,459	162,165	98,926	130,997
Total landings	272,253	274,518	231,359	234,049	254,556	413,054	430,572	428,376	339,837	392,708

Table A.2. Tonnage and value of landings by rest of the UK vessels into Scotland by main species from 2017 to 2021 (IMPORT from UK)

Species	Tonnage 2017	Tonnage 2018	Tonnage 2019	Tonnage 2020	Tonnage 2021	Value 2017 (1000s of £s)	Value 2018 (1000s of £s)	Value 2019 (1000s of £s)	Value 2020 (1000s of £s)	Value 2021 (1000s of £s)
Total demersal	16,882	17,270	17,173	15,014	11,549	30,545	30,078	31,186	24,642	20,836
Total pelagic	6,144	7,661	6,340	5,821	2,802	4,110	5,024	5,279	4,655	2,929
Total shellfish	3,271	2,616	2,998	2,250	2,508	8,596	7,743	8,791	5,319	6,923
Total landings	26,298	27,548	26,511	23,085	16,859	43,252	42,846	45,256	34,615	30,688

Table A.3. Tonnage and value of landings by foreign vessels into Scotland by main species 2017 to 2021

Species	Tonnage 2017	Tonnage 2018	Tonnage 2019	Tonnage 2020	Tonnage 2021	Value 2017 (1000s of £s)	Value 2018 (1000s of £s)	Value 2019 (1000s of £s)	Value 2020 (1000s of £s)	Value 2021 (1000s of £s)
Total demersal	30,008	29,874	24,557	20,331	10,480	41,392	37,183	36,632	20,176	13,808
Total pelagic	10,958	15,363	16,433	9,321	610	9,795	13,374	12,766	9,697	745
Total shellfish	109	47	48	28	20	577	107	172	86	72
Total landings	41,075	45,283	41,038	29,680	11,110	51,764	50,664	49,570	29,959	14,625

Table B.4. Tonnage and value of landings by all vessels into Scotland by main species 2017 to 2021

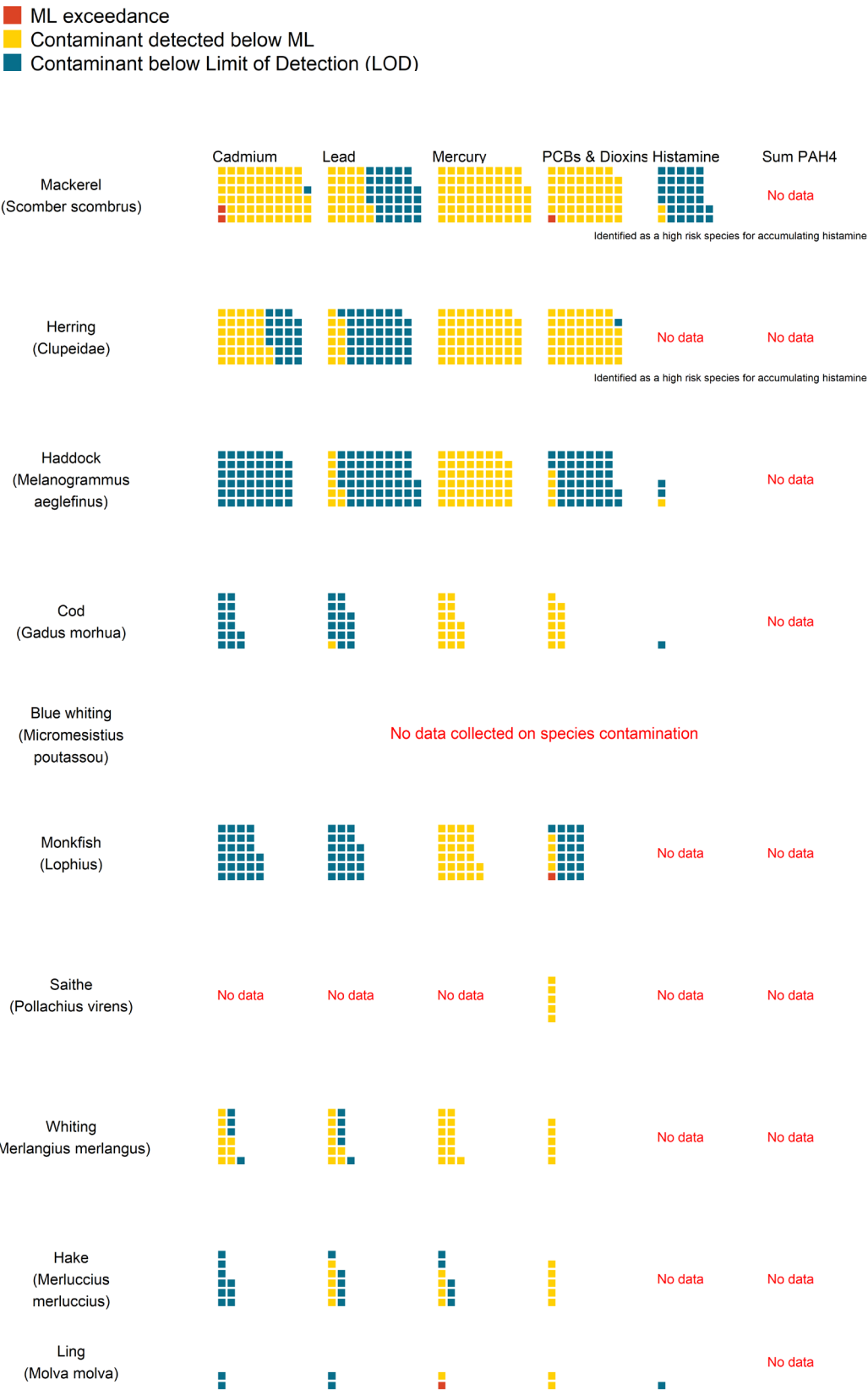
Species	Tonnage 2017	Tonnage 2018	Tonnage 2019	Tonnage 2020	Tonnage 2021	Value 2017 (1000s of £s)	Value 2018 (1000s of £s)	Value 2019 (1000s of £s)	Value 2020 (1000s of £s)	Value 2021 (1000s of £s)
Total demersal	136,310	146,793	132,550	115,589	95,049	239,345	254,376	248,513	186,158	175,688
Total pelagic	151,278	156,310	116,223	134,821	142,703	106,896	114,397	103,561	113,923	124,342
Total shellfish	52,038	44,246	50,135	36,404	44,773	161,829	155,309	171,128	104,331	137,991
Total landings	339,625	347,349	298,908	286,815	282,524	508,070	524,082	523,202	404,412	438,021

Table A.5. Tonnage and value of landings by Scottish vessels into the rest of the UK by main species 2017 to 2021

Species	Tonnage 2017	Tonnage 2018	Tonnage 2019	Tonnage 2020	Tonnage 2021	Value 2017 (1000s of £s)	Value 2018 (1000s of £s)	Value 2019 (1000s of £s)	Value 2020 (1000s of £s)	Value 2021 (1000s of £s)
Total demersal	797	580	405	234	234	1,411	1,047	822	488	562
Total pelagic	2	1	33	5	0	1	1	9	6	1
Total shellfish	12,662	10,815	12,536	10,836	12,018	28,189	25,116	28,826	18,241	19,396
Total landings	13,460	11,396	12,975	11,076	12,252	29,601	26,165	29,658	18,734	19,959

Annex B: Waffle plots of occurrence of chemical contaminant in fish and fishery products

Figure 14. Waffle plot of chemical contaminants in fish and shellfish – collated data from surveys



	Cadmium	Lead	Mercury	PCBs & Dioxins	Histamine	Sum PAH4
Megrim (<i>Lepidorhombus whiffiagonis</i>)					No data	No data
Plaice (<i>Pleuronectes platessa</i>)					No data	No data
Lemon sole (<i>Microstomus kitt</i>)					No data	No data
Skates and rays (<i>Rajidae</i> , <i>Leucoraja naevus</i> , <i>Raja montagui</i> , <i>Raja clavata</i>)					No data	No data
Gurnards (<i>Eutrigla gurnardus</i> and <i>Chelidonichthys lucerna</i>)					No data	No data
Blue ling (<i>Molva dypterygia</i>)					No data	No data
Pollock (<i>Pollachius</i>)	No data collected on species contamination					
Horse mackerel (<i>Trachurus trachurus</i>)					No data	No data
	Identified as a high risk species for accumulating histamine					
Turbot (<i>Scophthalmus maximus</i>)					No data	No data
Wrass (<i>Labridae</i>)	No data collected on species contamination					
	Cadmium	Lead	Mercury	PCBs & Dioxins	Histamine	Sum PAH4
Brill (<i>Scophthalmus rhombus</i>)	No data	No data	No data	No data	No data	No data

Cuttlefish (Sepiida)					No data	No data
Sole (Solea solea)	No data collected on species contamination					
Sea Bass (Dicentrarchus labrax)						No data
Pilchards (Sardina pilchardus)					 Identified as a high risk species for accumulating histamine	No data
Tuna (Thunnini)	No data	No data	No data	No data	 Identified as a high risk species for accumulating histamine	No data
Monks and anglers (Thunnini)					No data	No data
Atlantic catfish (Anarhichas lupus)	No data collected on species contamination					
Halibut (Hippoglossus hippoglossus)					No data	No data
Dog fish (Hippoglossus hippoglossus)					No data	No data
Rose fish (Sebastes marinus)	Cadmium No data	Lead No data	Mercury No data	PCBs & Dioxins No data	Histamine No data	Sum PAH4 No data
Witch Flounder (Glyptocephalus cynoglossus)					No data	No data

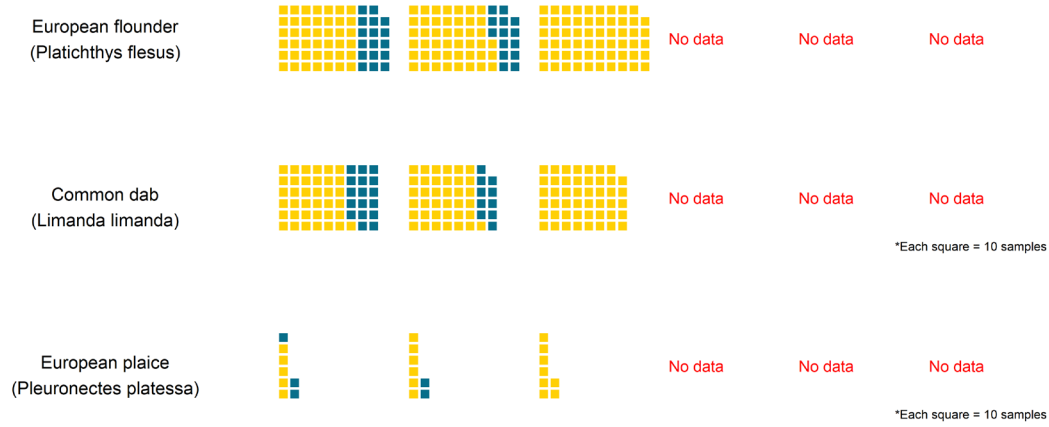
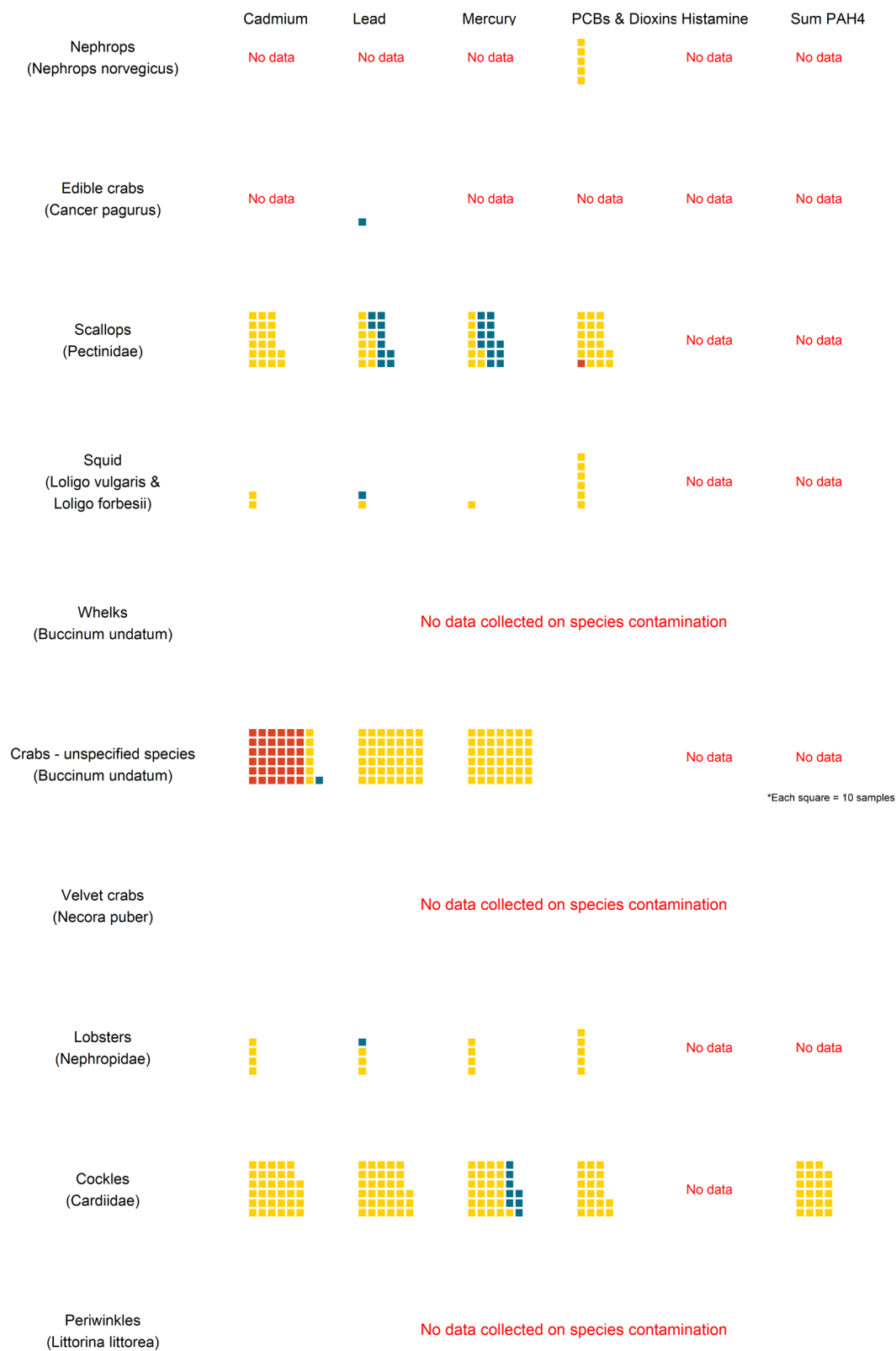


Figure 15. Waffle plots of occurrence of sum PAH4 in smoked fish and fishery products



Smoked coley	No data	No data	No data	No data	No data	
Smoked mussels	No data	No data	No data	No data	No data	

Figure 16. Waffle plots of chemical contaminants in Live Bivalve Molluscs – summarised results Official Control Monitoring



	Cadmium	Lead	Mercury	PCBs & Dioxins	Histamine	Sum PAH4
Pacific oysters (<i>Magallana gigas</i>)					No data	 *Each square = 10 samples
Carpet clams (<i>Tapes philippinarum</i>)					No data	
Common mussels (<i>Mytilus edulis</i>)					No data	 *Each square = 10 samples
Razor clams (<i>Tagelus plebeius</i>)					No data	 *Each square = 10 samples
Surf clams (<i>Spisula solidus</i>)					No data	No data
Atlantic surf clams (<i>Spisula solidissima</i>)				No data	No data	No data
Common cockles (<i>Cerastoderma edule</i>)					No data	No data
European oysters (<i>Ostrea edulis</i>)			No data	No data	No data	No data
Pullet carpet shells (<i>Venerupis senegalensis</i>)					No data	No data

Figure 17. Waffle plots of inorganic arsenic and PFAS results from Wild caught fish survey 2023.





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