Niðurstöður sívirkrar vöktunar á óæskilegum efnum í sjávarfangi úr auðlindinni 2024

Undesirable substances in seafood – results from the Icelandic marine monitoring activities in the year 2024

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Skýrsla Matís nr. 1-25

January 2025
ISSN 1670-7192
DOI nr. 10.5281/zenodo.14621003

Skýrsluágrip Matís ohf
Matvælarannsóknir

Report Summary
Icelandic Food and Biotech R&D

ISSN 1670-7192

Titill / Title	**Niðurstöður sívirkrar vöktunar á óæskilegum efnum í sjávarfangi úr auðlindinni 2024 / Undesirable substances in seafood – results from the Icelandic marine monitoring activities in the year 2024**		
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Skýrsla / Report no.	01-25	*Útgáfudagur / Date:*	Janúar 2025
Verknr. / Project no.	62450		
Styrktaraðilar /Funding:	Matvælaráðuneytið / Ministry of Food, Agriculture and Fisheries		
Ágrip á íslensku:	Í þessari skýrslu eru teknar saman niðurstöður vöktunar á óæskilegum efnum í ætum hluta sjávarfangs 2024. Vöktunin hófst árið 2003 fyrir tilstuðlan þáverandi Sjávarútvegsráðuneytis, núverandi Matvælaráðuneytið, og sá Matís ohf. um að safna gögnum og útgáfu á skýrslum vegna þessarar kerfisbundnu vöktunar á tímabilinu 2003-2012. Vegna skorts á fjármagni í þetta vöktunarverkefni var gert hlé á þessari mikilvægu gagnasöfnun sem og útgáfu niðurstaðna á tímabilinu 2013-2016. Verkefnið hófst aftur í mars 2017 en vegna fjárskorts nær það nú eingöngu yfir vöktun á óæskilegum efnum í ætum hluta sjávarfangs úr auðlindinni sem ætlað er til manneldis, en ekki fiskimjöl og lýsi fyrir fóður. Af sömu ástæðu eru ekki lengur gerðar efnagreiningar á PAH og PBDE efnum. Markmiðið með verkefninu er að sýna fram á stöðu íslenskra sjávarafurða m.t.t. öryggi og heilnæmis og hægt að nýta gögnin við gerð áhættumats á matvælum til að tryggja hagsmuni neytenda og lýðheilsu. Verkefnið byggir upp þekkingargrunn um magn óæskilegra efna í efnahagslega mikilvægum tegundum og sjávarafurðum, það er skilgreint sem langtímaverkefni þar sem útvíkkun og endurskoðun er stöðugt nauðsynleg. Almennt voru niðurstöðurnar sem fengust 2024 í samræmi við fyrri niðurstöður frá árunum 2003 til 2012 sem og 2017 til 2023. Niðurstöðurnar sýndu að íslenskar sjávarafurðir innihalda óverulegt magn þrávirkra lífrænna efna s.s. díoxín, PCB og varnarefni. í þessari skýrslu voru hámarksgildi Evrópusambandsins (ESB) fyrir díoxín, díoxínlík PCB (DL-PCB) og ekki díoxínlík PCB (NDL-PCB) í matvælum samkvæmt reglugerð nr. 2023/915 notuð til að meta hvernig íslenskar sjávarafurðir standast kröfur ESB. Niðurstöður ársins 2024 sýna að öll sýni af sjávarafurðum til manneldis voru undir hámarksgildum ESB fyrir þrávirk lífræn efni og þungmálma. Þá reyndist styrkur svokallaðra ICES6-PCB efna vera lágur í ætum hluta sjávarfangs, miðað við hámarksgildi ESB samkvæmt reglugerð nr. 2023/915. Sömuleiðis sýndu niðurstöðurnar að styrkur þungmálma, t.d. kadmíum (Cd), blý (Pb) og kvikasilfur (Hg) í íslenskum sjávarafurðum var alltaf undir hámarksgildum ESB.		
	Sjávarfang, vöktun, Díoxín, díoxínlík PCB, PCB, varnarefni, þungmálmar, hámarksgildi, heilnæmi, lýðheilsa		

Summary in English:	This report summarises the results obtained in 2024 for the screening of various undesirable substances in the edible part of Icelandic marine catches. The main aim of this project is to gather data and evaluate the status of Icelandic seafood products in terms of undesirable substances and the data can be utilised to estimate the exposure of consumers to these substances from Icelandic seafood and risks related to public health. The surveillance programme began in 2003 and was carried out for ten consecutive years before it was interrupted in 2013. The project was revived in March 2017 to fill in knowledge gaps regarding the level of undesirable substances in economically important marine catches for Icelandic export. Due to financial limitations the monitoring now only covers screening for undesirable substances in the edible portion of marine catches for human consumption and not feed or feed components. The limited financial resources also required the analysis of PAHs and PBDEs to be excluded from the monitoring, providing somewhat more limited information than before. However, it is considered a long-term project where extension and revision are constantly necessary. In general, the results obtained in 2024 were in agreement with previous results on undesirable substances in the edible part of marine catches obtained in the monitoring years 2003 to 2012 and 2017 to 2023. In this report from the monitoring programme, the maximum levels for dioxins, dioxin-like PCBs and non-dioxin-like PCBs in foodstuffs (Commission Regulation 2023/915) were used to evaluate how Icelandic seafood products measure up to limits currently in effect. The results show that in regard to the maximum levels set in the regulation, the edible parts of Icelandic seafood products contain negligible amounts of dioxins, dioxin like and non-dioxin-like PCBs. In fact, all samples of seafood analysed in 2024 were below EC maximum levels. Furthermore, the concentration of ICES-6-PCBs was found to be low in the edible part of the marine catches, compared to the maximum limits set by the EU (Commission Regulation 2023/915). The results also revealed that the concentration of toxic trace elements, i.e., cadmium (Cd), lead (Pb) and mercury (Hg) in the edible part of marine catches were below the relevant maximum limits set by the EU in all samples.
English keywords:	*Marine catches, monitoring, dioxin, PCB, pesticides, heavy metals, maximum limits, human consumption, public health*

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1 Introduction

In 2003, the Icelandic Ministry of Fisheries, now the Ministry of Food, Agriculture and Fisheries, initiated a project aimed at screening for undesirable substances in the edible portion of marine catches from Icelandic waters, as well as in the fish meal and fish oil produced for feed. Matis was assigned the responsibility of carrying out the monitoring programme, which was on-going for ten consecutive years. In the period 2013-2016 this important collection of information and publication of the results was interrupted since Matis did not receive funding to work on this monitoring project. In March 2017 the monitoring programme was revived with funding from the Ministry of Industries and Innovation in Iceland to continue gathering data and evaluate the status of Icelandic seafood products regarding undesirable substances, however, the current funding only covers screening for undesirable substances in the edible portion of marine catches for human consumption and not feed or feed components. The project includes measurements on various undesirable substances in several economically important marine species from Icelandic fishing grounds to gather information and evaluate the status of Icelandic seafood products in terms of undesirable substances. This report summarises results from the screening programme in the year 2024. The substances investigated in this monitoring project are polychlorinated dibenzo dioxins and dibenzo furans (commonly called dioxins), dioxin-like polychlorinated biphenyls (PCBs), ICES-6 PCBs, and trace elements such as As, Cd, Hg and Pb.

The purpose of this work is:

1. To gather information and evaluate the status of Icelandic seafood products in terms of undesirable substances.
2. Provide scientific evidence that Icelandic seafood products conform to regulations on seafood safety. That is, to evaluate how products measure up to limits currently in effect for toxic trace elements and organic contaminants in the EU (Commission regulation (EC) No 2023/915).

3. Provide data gathered in this programme for that can be utilised for risk assessment and the setting of maximum values within EU & the European Economic Area (EEA) area, which are constantly being reviewed based on new data.
4. Provide independent scientific data on undesirable substances in Icelandic seafood for food authorities, fisheries authorities, industry, markets, and consumers.

In this report the maximum levels for dioxins, dioxin-like PCBs and non-dioxin-like PCBs in foodstuffs are used to evaluate how Icelandic seafood products measure up to European commission (EC) limits currently in effect. The results obtained in the years 2003 to 2012, as well as 2017 to 2023, have already been published and are accessible at the Matis website (http://www.matis.is: Auðunsson, 2004; Ásmundsdóttir et al., 2005; Ásmundsdóttir and Gunnlaugsdóttir, 2006; Ásmundsdóttir et al., 2008; Jörundsdóttir et al., 2009; Jörundsdóttir et al., 2010a; Jörundsdóttir et al., 2010b; Baldursdóttir et al., 2011; Jörundsdóttir et al., 2012; Jensen et al., 2013; Jensen et al., 2018; Jensen et al., 2019; Jensen et al., 2020; Jensen et al., 2021; Jensen et al., 2022; Jensen et al., 2023; Jensen et al., 2024). The above-mentioned EU regulation have been implemented in the Icelandic legal framework regarding undesirable substances in food (Regulation (EC) No 2023/915), which means that the maximum limits for undesirable substances in Icelandic seafood products are in line with the limits for these products in the EU member states.

2 Contaminants measured in the project

The following contaminants were measured in the edible parts of seafood and other seafood products for human consumption:

Dioxins, PCDD/Fs: Dioxins (dibenzo-p-dioxins) and dibenzofurans (17 congeners according to WHO): 2,3,7,8-Tetra-CDD; 1,2,3,7,8-Penta-CDD; 1,2,3,4,7,8-Hexa-CDD; 1,2,3,6,7,8-Hexa-CDD; 1,2,3,7,8,9-Hexa-CDD; 1,2,3,4,6,7,8-Hepta-CDD; OCDD; 2,3,7,8-Tetra-CDF; 1,2,3,7,8-Penta-CDF; 2,3,4,7,8-Penta-CDF; 1,2,3,4,7,8-Hexa-CDF; 1,2,3,6,7,8-Hexa-CDF; 1,2,3,7,8,9-Hexa-CDF; 2,3,4,6,7,8-Hexa-CDF; 1,2,3,4,6,7,8-Hepta-CDF; 1,2,3,4,7,8,9-Hepta-CDF and OCDF.

Dioxin-like PCBs: (12 congeners according to WHO): non-ortho (PCB-77, PCB-81, PCB-126, PCB-169) and mono-ortho (PCB-105, PCB-114, PCB-118, PCB-123, PCB-156, PCB-157, and PCB-167, PCB-189).

ICES-6-PCBs: (6 congeners): PCB-28, PCB-52, PCB-101, PCB-138, PCB-153, and PCB-180.

Pesticides: DDT-substances (6 congeners: pp-DDT, op-DDT, pp-DDD, op-DDD, pp-DDE and op-DDE), HCH-substances (5 isomers: α-, β-, γ-(Lindane), δ-, and ε-hexachlorocyclohexane), HCB, chlordanes (4 congeners and isomers: α- and γ-chlordane, oxychlordane and trans-nonachlor), toxaphenes (3 congeners, Parlar 26, 50 and 62), aldrin, dieldrin, endrin, endosulfan (α-endosulfan), heptachlor (3 congeners: heptachlor, cis-hepatchlorepoxide, trans-heptachlorepoxide) pentachlorobenzene, octachlorstyrene and mirex.

Trace elements: Hg (mercury), Cd (cadmium), Pb (lead), arsenic (As), chromium (Cr) and tin (Sn).

3 Sampling and analysis

3.1 Sampling

The collection of samples and the quality criteria for the analytical methods were in accordance with conditions set out by the EU for the information gathering campaign on dioxins and dioxin-like PCBs as well as for metals (Commission regulation 333/2007/EC, Commission regulation 2017/644/EC, Commission regulation EU 2022/1428). The fish samples were collected by the Marine and Freshwater Research Institute (MRI) in Iceland according to sampling protocols provided by Matis and the samples were kept frozen until preparation for analysis (see section 3.1.1). Blue mussels were provided by Þórishólmi ehf and both the lumpfish roe and capelin roe were supplied by Vignir G. Jónsson HF. Fishing grounds around Iceland are divided into five areas, as illustrated in Figure 1. Samples were identified and labelled with the fishing area where they were caught.

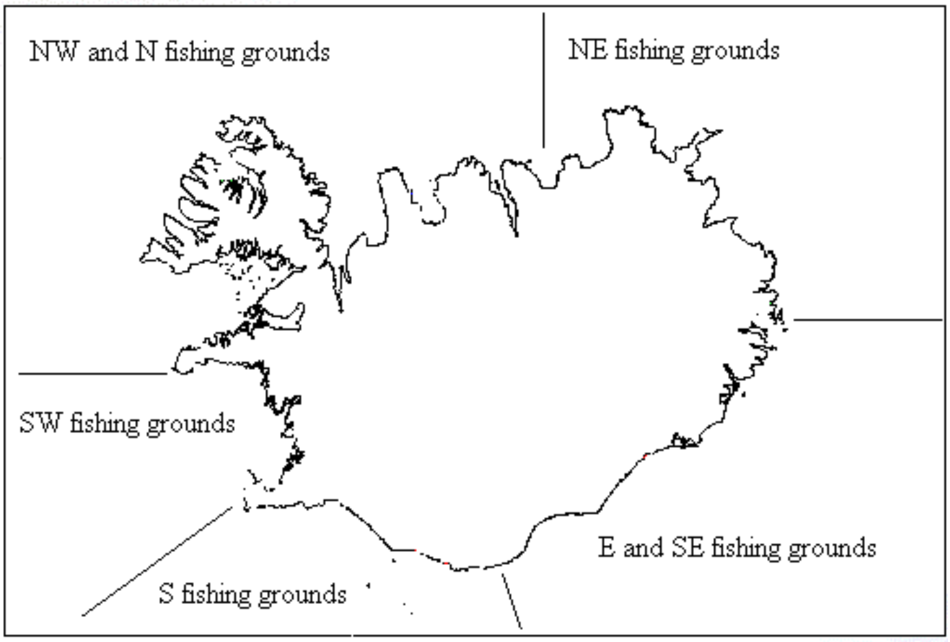

Figure 1. The division of the fishing grounds around Iceland used in this research.

3.2 Sample preparation

All analyses were performed on edible parts of the fish samples. Each fish sample consisted of a pool from at least ten individuals of a specific length distribution. For details on length distribution and fishing grounds of the samples see Appendices T1 and T2.

Prior to sample preparation each fish was defrosted, and the total weight and length of each individual fish recorded as well as gender, gut weight, and weight of fillets. The skinless fish fillets from the individuals were then pooled, homogenised and frozen again for analysis of organic contaminants or freeze-dried for trace element analysis. The ten cod livers, capelin, and lumpfish roes were pooled as individual samples, homogenised, and freeze-dried before analysis.

3.3 Analyses

The trace metal analysis of chromium, arsenic, tin, cadmium, mercury, and lead was carried out at Matís. The total element concentration in samples was determined by ICP-MS according to an accredited in-house method SV-25-02-SN in Matís Quality manual (modified NMKL 186 (2007) method). Matís is a National Reference Laboratory for trace element analysis in food and feed and has taken part in various international inter-laboratory studies for many years. The lipid content and organic contaminants were measured by Eurofins, Hamburg, Germany. Eurofins has participated in an international inter-laboratory quality control study organised by WHO and EU and uses accredited methods for analysing lipids, dioxins, WHO-PCBs, ICES-6-PCBs, and pesticides. All results are expressed as upper bound level, meaning that where the concentration of a substance is measured to be below limit of detection (LOD) or limit of quantification (LOQ) of the analytical method, the concentration is set as equal to the LOD/LOQ. In the case of dioxins and dioxin-like PCBs, the analytical data are converted to pg WHO-TEQ/g where the toxicity of each congener has been calculated using WHO-TEF (Toxic Equivalence Factor) based on the existing knowledge of its toxicity (Van den Berg et al., 1998). WHO-TEQ values have been adapted by the World Health Organization (WHO) in 1997 and by the EU in its legislations. In 2005 the WHO-TEF values were re-evaluated based on existing toxicological data (Van den Berg et al., 2005; Haws et al., 2006) and expert judgment. These new TEF values have been established as the WHO-2005-TEQs for human risk assessment of the concerned compounds and have been implemented in the current EU legislation i.e., Commission Regulation (EU) No 2023/915.

4 Results from monitoring of fish and fishery products in Iceland

All results for undesirable substances from the monitoring programme in 2024 are listed in Appendices T1-3. The sections below contain an overview of the results obtained in samples of fish collected as part of the monitoring activities 2024.

4.1 Dioxins (PCDD/Fs) and dioxin-like PCBs

All the samples analysed contained dioxin (PCDD/PCDFs) levels below the EU maximum limit of 3.5 pg WHO-TEQ/g (Figure 2), where the upper bound concentration in muscle tissues did not exceed 0.51 pg WHO-TEQ/g and the single sample of cod liver analysed contained 1.4 pg WHO-TEQ/g. The species that are known to accumulate fat in the muscle such as mackerel, herring and Greenland halibut (sample numbers 11, 12, 15 and 16) as well as the cod liver and spotted catfish (sample numbers 2 and 14) were the only samples with quantifiable levels of dioxins. The dioxin content in the cod liver was approximately four-fold higher than in the muscle tissue from the same individuals (sample numbers 1 and 2) as the liver is a target organ for toxicity for many persistent organic pollutants including dioxins and PCBs (Kennedy et al., 2014; Wahlang et al., 2019). This is similar to the results reported for the monitoring year 2022 (Jensen et al., 2023) but not the year 2023 (Jensen et al., 2024) where concentrations were similar throughout both tissue types.

In general, the level of dioxins in the edible part of the fish increases as the fat percentage in the muscle increases, but other variables such as age (size) and habitat may also play a role. Wild Greenland halibut may have a maximum lifespan of approximately 50 years (Brogan et al., 2021) which may contribute to the higher levels of dioxins and dioxin-like PCBs sometimes observed for this species, whilst mackerel and herring are high in fat content but do not become very old and therefore accumulate less dioxins over their whole life span (Appendix T1). Compared to results for Greenland halibut from Jensen et al., 2024, the fat content, the size of the fish and the dioxin levels of the samples were similar.

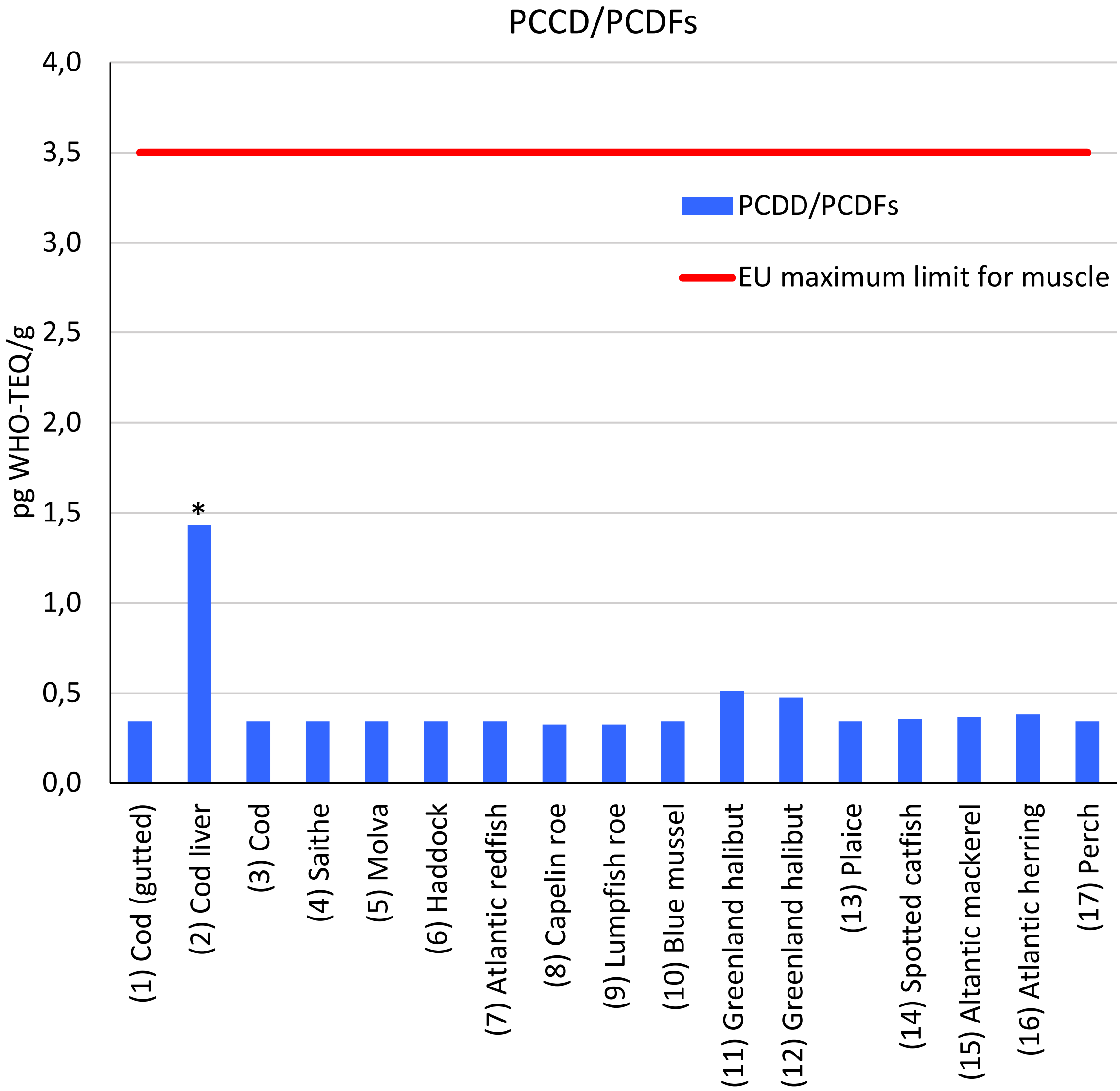

Figure 2. Dioxins (PCDD/PCDFs) in marine catches from Icelandic fishing grounds in 2024 in relation to the EU maximum limit in pg WHO-TEQ/g wet weight. The number within parenthesis is the sample number indicated in Appendix T1.

**EU maximum limit applies only to fish muscle meat.*

As shown in Figure 3 and Appendix T1, the sum of dioxins and dioxin-like PCBs (DL-PCBs) in all samples analysed were below EU maximum limit of 6.5 pg WHO-TEQ/g. The sum of dioxins and DL-PCBs was highest in the sample of cod liver (sample number 2) – however the maximum level applies only to the muscle meat of fish.

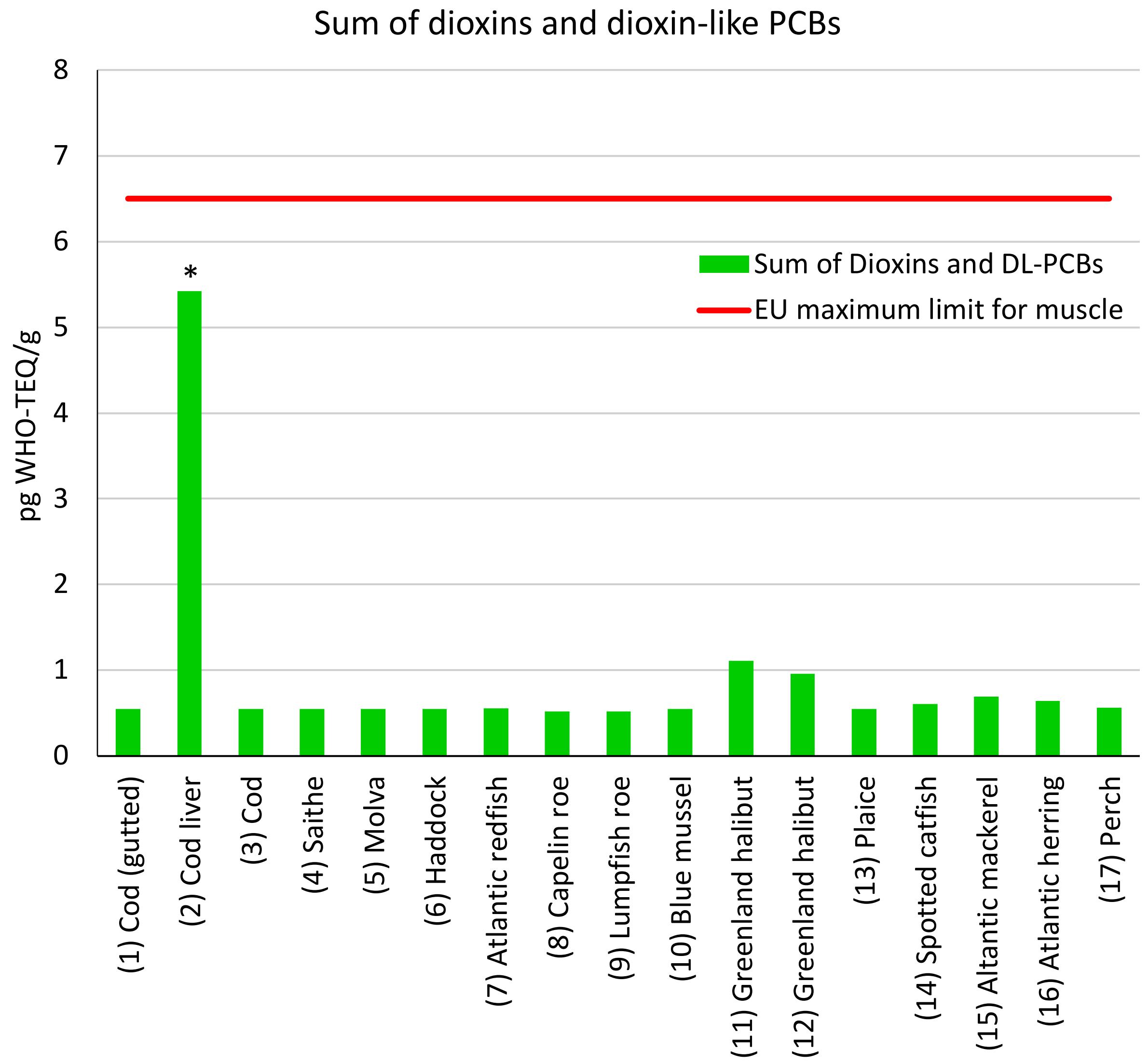

Figure 3. The sum of dioxins and dioxin-like PCBs in marine catches from Icelandic fishing grounds in 2024 in relation to the EU maximum limit in pg WHO-TEQ/g wet weight. The number within parenthesis is the s*a*mple number indicated in Appendix T1.

**EU maximum limit for fish liver is 20 pg WHO-TEQ/g wet weight.*

4.2 Marker PCBs

Marker PCBs are used as indicators of the total PCB content or body burden of environmental biota, food, and human tissue. The most frequent approach is to use either the total level of six or seven of the most commonly occurring PCBs. Nevertheless, the EU maximum limits are set for the sum concentration of ICES-6, i.e., PCB-28, -52, -101, -138, -153 and -180 (Commission Regulation (EU) No 2023/915). To enable comparison to earlier results, the sum of seven marker PCBs is presented in Appendix T1, while the ICES-6 maximum limits are presented in Figure 4 to evaluate how Icelandic seafood products measure up to EU maximum limits.

4.2.1 ICES-6 PCBs in fish and fishery products from Icelandic waters

The results obtained for all the samples analysed in 2024 were well below the maximum limits set for non-dioxin-like PCBs i.e., the ICES-6-PCBs (Figure 4). In this study, the highest total concentration for the sum of all six marker PCBs in the samples was measured in the cod liver and Greenland halibut (sample numbers 2, 11 and 12), where concentrations total of 34, 5.7 and 4.9 µg kg^{-1} wet weight, respectively. Beyond these samples, non-dioxin-like PCBs were detectable in only in the perch, spotted catfish, Atlantic herring and mackerel (sample numbers 14, 15, 16 and 17). With regards to individual congeners, PCB-153 was always the most abundant followed by PCB-138 – which is in line with what has been previously reported for wild caught fish in several areas of Europe (European Food Safety Authority, 2010; Corsolini et al., 2005). Similar to the dioxins and dioxin-like PCBs (Section 4.1.), the highest concentrations of the ICES-6 PCBs were found in samples with higher lipid contents. Further details can be found in Appendix T1.

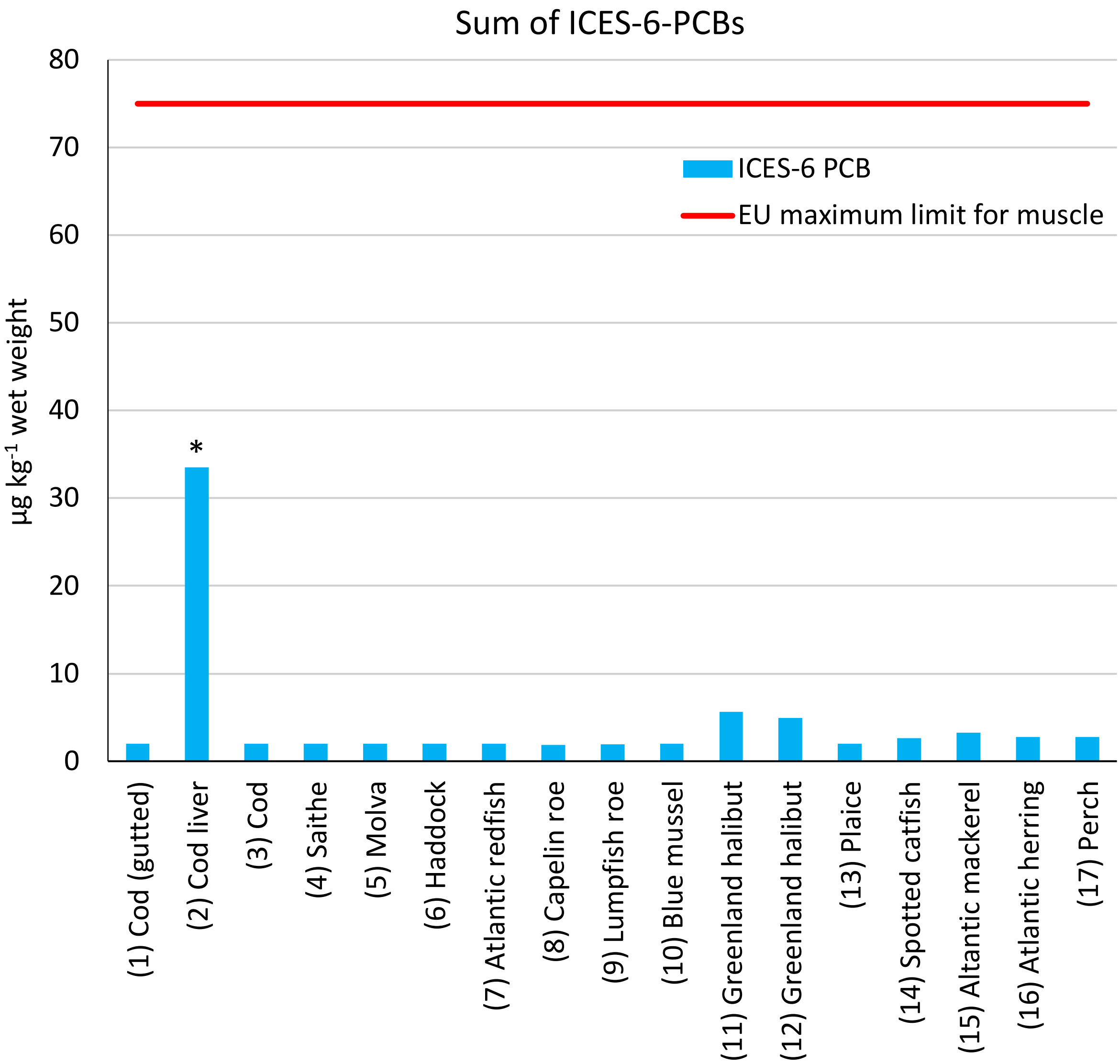

Figure 4. ICES-6 PCBs in marine catches from Icelandic fishing grounds in 2024 in relation to the maximum EU limit in µg kg^{-1} wet weight. The number within parenthesis is the sample number indicated in Appendix T1.

**EU maximum limit for fish liver is 200 µg kg^{-1} wet weight.*

4.3 Polycyclic aromatic hydrocarbons (PAHs)

PAHs are not included in the regulation for fresh fish. PAHs were not analysed in the samples this year. Results on PAHs in Icelandic seafood have been published in previous reports (Jörundsdóttir et al., 2010; Jensen et al., 2013).

4.4 Brominated flame retardants (BFRs)

BFRs are not included in the regulation for fresh fish. BFRs have been accumulating in the environment over the last decade as their use in industry has increased. BFRs were not analysed in the samples this year. Results on BFRs in Icelandic seafood have been published in a previous report (Jensen et al., 2013).

4.5 Organochlorine pesticides

In total 12 different pesticides or groups of pesticides were measured in the monitoring programme. In this section, the results for these different classes of pesticides are discussed. Results are shown in Appendix T2. There are currently no EU maximum limits regarding the levels of pesticides in seafood.

DDT (dichloro diphenyl trichloroethane) is one of the most well-known insecticides. The technical product DDT is fundamentally composed of p,p'-DDT (80%) (Buser, 1995). DDT breaks down in nature, mostly to DDE but also to DDD. The concentration of DDT presented in this report is the sum of p,p'-DDT, o,p´-DDT, p,p'-DDE, o,p´-DDE, p,p´-DDD and o,p´-DDD.

HCH (hexachlorocyclohexane) is an insecticide which has been used since 1949. It is still produced and used in numerous countries, although it has been banned in many countries since the 1970s. Technical-grade HCH is a mixture of mainly five isomers: α-, β-, γ-(Lindane), δ-, and ε-HCH. Of these, only Lindane is an active substance comprising approximately 15% of the total mixture, while α-HCH is 60-70% of the mixture. The Food and Agriculture Organization of the UN (FAO) has prohibited the use of the HCH mixture since in the 1980s, after that it was only allowed to use 99% pure Lindane. In this report the concentration α-, β-, γ-(Lindane), and δ-, and ε -HCH in the samples are reported.

HCB (hexachlorobenzene) is a fungicide, but it has also been used for industrial purpose and was e.g., produced in Germany until 1993. Today, HCB is mainly a by-product in different industrial processes such as production of pesticides but also from waste incineration and energy production from fossil fuels.

Chlordanes is a group of compounds and isomers where α- and γ-chlordane, oxychlordane and *trans*-nonachlor are the most common, but over 140 different chlordanes were produced from 1946 until 1988 when the production was banned. Chlordanes have been widely used all over the world as insecticides. In this report the concentration of chlordanes is reported as the upper bound sum of α-chlordane, γ-chlordane and oxychlordane. *Trans*-nonachlor is reported separately.

The **Toxaphenes** measured in the samples are the parlar 26, 50 and 62 congeners. Toxaphene was used as an insecticide after the use of DDT was discontinued. Toxaphenes use was widespread, and the toxaphene congeners are numerous. Several hundred have been analysed but they are thought to be tens of thousands. The substances measured, i.e., the parlar 26, 50 and 62, are the most common toxaphenes (about 25% of the total amount in nature) and these are used as indicators of toxaphene pollution. In this report the concentration of toxaphenes is reported as the upper bound sum of toxaphene 26, 50 and 62.

Aldrin and **Dieldrin** are widely used insecticides, but in plants and animals aldrin is transformed to dieldrin. Hence, the concentration of aldrin was below LOD in all the samples measured, while dieldrin was in some samples above LOD. The results are presented as the upper bound sum of these two.

One **Endosulfan** was measured, α--endosulfan. Endosulfans are not as persistent as the other insecticides measured in this project. Other pesticides measured were **Endrin**, the sum of **Heptachlores** (cis-heptachlorepoxide, trans-heptachlorepoxide and heptachlor), **Pentachlorobenzene**, **Mirex** and **Octachlorostyren**e.

4.5.1 DDT in fish and fishery products from Icelandic waters

As previously mentioned, there are no maximum limits for the concentration of organochlorine pesticides in fishery products. The upper bound concentrations for the sum of **DDT** and its associated degradation products ranged from 0.6-8.9 µg kg^{-1} for all muscle meat and samples, where Greenland halibut had the highest levels (5.2-8.9 µg kg^{-1}) and was 38 µg kg^{-1} for the cod liver (sample number 2). These results (Figure 5 and Appendix T2) are extremely similar to those from the monitoring during previous year 2023 (Jensen et al., 2024), where the highest concentrations of total DDT were also found in the cod liver and Greenland halibut samples. Again, this can likely be attributed to the high lipid content of these samples (Appendix T2) as DDT is highly fat soluble. The most frequently detected and abundant compound was p,p'-DDE which was detected in 11 out of 17 samples. This compound is the major degradation product of p,p'-DDT.

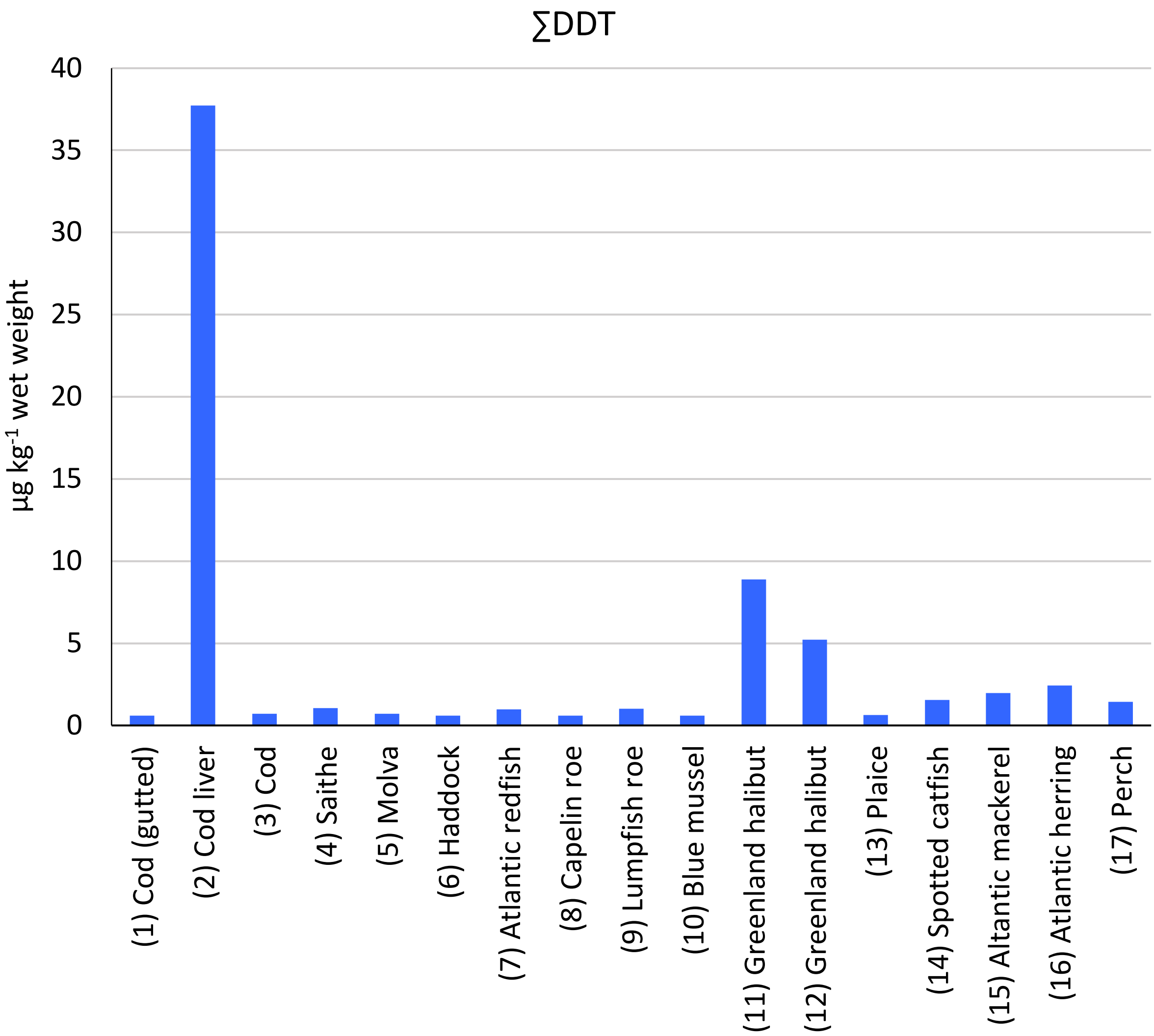

Figure 5. The ∑DDT and degradation products in marine catches from Icelandic fishing grounds in 2024 in µg kg^{-1} wet weight.

4.5.2 HCB in fish and fishery products from Icelandic waters

The upper bound concentrations of **HCB** ranged from 0.50-15 µg kg^{-1} (Figure 6) where again the cod liver and Greenland halibut (sample numbers 2, 11 and 12) contained the highest levels (15 µg kg^{-1} and 2.4-3.8 µg kg^{-1} respectively). As before, the higher levels of HCB however found in these samples is likely correlated to the lipid content. The lumpfish roe, Atlantic mackerel and herring (sample numbers 9, 15 and 16) were the only other samples with detectable HCB concentrations, Appendix T2.

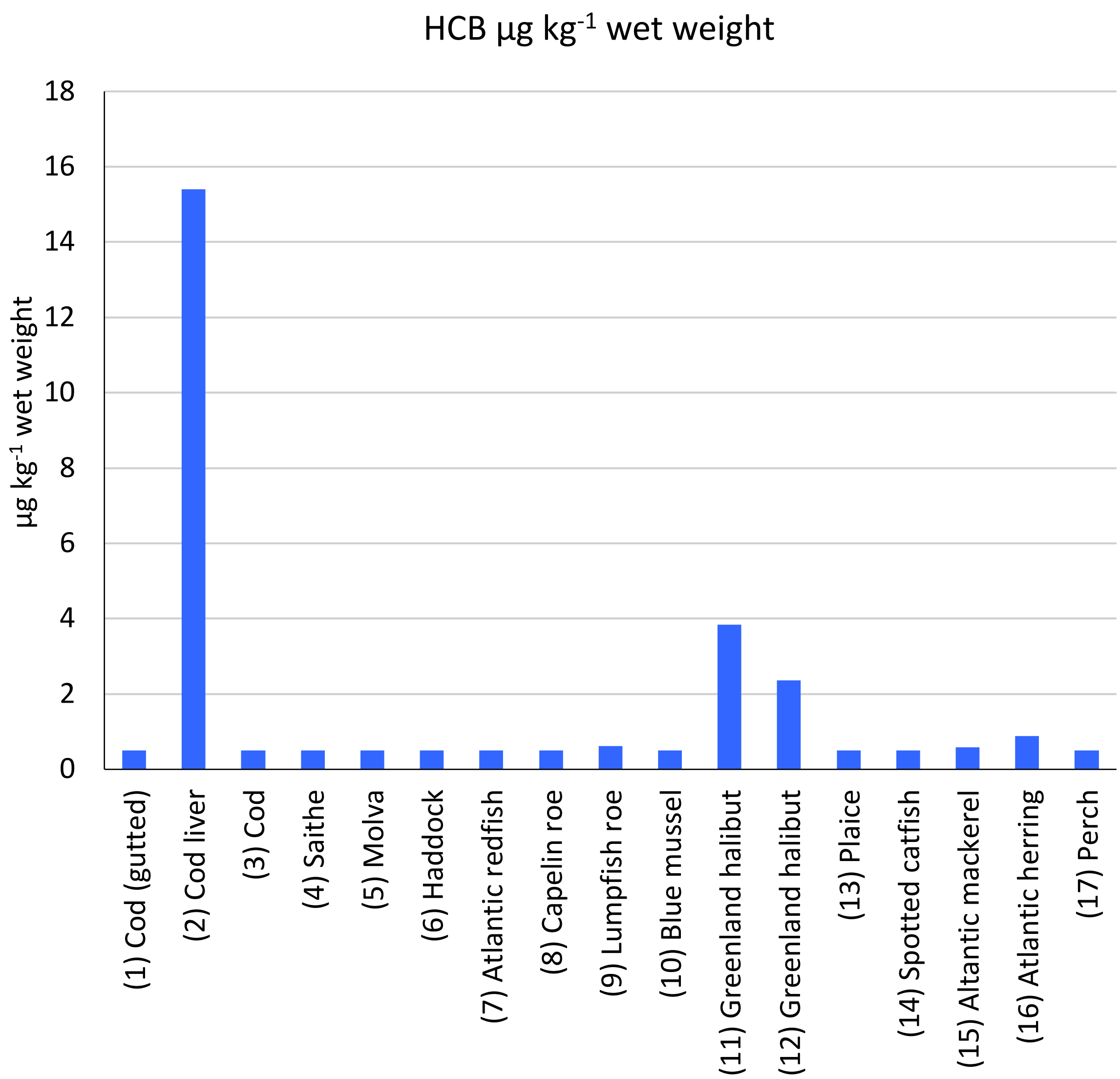

Figure 6. HCB in marine catches from Icelandic fishing grounds in 2024 in µg kg^{-1} wet weight.

4.5.3 Other organochlorine pesticides in fish and fishery products from Icelandic waters

Other organochlorine pesticides were most commonly detected in the cod liver and samples of Greenland halibut (sample numbers 2, 11 and 12) as shown in Appendix T2. **HCH** (α-HCH) and **octachlorstyrene** were only found in the cod liver (sample number 2). **Endrin** was detected in cod liver and both greenland halibut where concentrations in these samples ranged from 0.33-1.8 µg kg^{-1}. **Aldrin** was not detected in any sample, but the degradation product **dieldrin** was detected in 8 samples with concentrations above the detection limit ranging from 0.35-16 µg kg^{-1}. **Toxaphenes** were detected in 7 samples which had sum upper bound concentrations ranging from 2.0-48 µg kg^{-1} with the largest contribution from the parlar 50 congener.

Cis-heptachlorepoxide was the only **Heptachlors** compound detected and was found in 4 samples. **Chlordanes** were detected in 9 samples, with cis-chlordane being either the most abundant or only chlordane compound detected. **Trans-nonchlor** was also detected in 8 samples. **Mirex** was detected in only the cod liver and one sample of Greenland halibut (sample numbers 2 and 11), whilst **pentachlorobenzene** was only detected in the cod liver (sample number 2). **α-endosulfan** was not detected in any sample.

4.6 Trace elements

The total concentrations of trace elements Hg (mercury), Cd (cadmium), Pb (lead), As (arsenic), Sn (tin) and Cr (chromium) were analysed in all samples from the year 2024. As previously described, the results are expressed as upper bound concentrations and are therefore likely to be an overestimation of actual concentrations. The results for trace elements in all samples are reported in Appendix T3.

4.6.1 Chromium and tin in fish and fishery products from Icelandic waters

Concentrations of chromium (Cr) and tin (Sn) were low in all samples analysed in 2024. As shown in Appendix T3, only the blue mussel (sample number 10) contained concentrations of Cr and Sn above quantification limits, where concentrations were 0.069 mg kg^{-1} and 0.013 mg kg^{-1} respectively. Maximum limits set by the EU (Commission regulation 2023/915) for tin (Sn) apply only to canned food products and no maximum limits exist in the EU for tin (Sn) in fish or fishery products, and there are no current regulations for levels of chromium.

4.6.2 Cadmium in fish and fishery products from Icelandic waters

The concentration of cadmium (Cd) in each sample was below the applicable EU maximum limit for all fish species analysed, as shown in Figure 7 and Appendix T3. The blue mussel (sample number 10) contained the highest level of Cd (0.24 mg kg^{-1}) but was still below the EU limit of 1 mg kg^{-1} wet weight set for bivalve molluscs. Filter-feeding organisms such as mussels may accumulate high levels of Cd if grown in contaminated waters and as such are often used as bio-monitors of pollution (Gomez-Delgado et al., 2023). The cod liver contained 0.17 mg kg^{-1} of Cd and was magnitudes higher than in the muscle tissue taken from the same fish (sample numbers 1 and 2) as Cd is a potent hepatotoxin (Genchi et al., 2020).

This is similar to the results for cod from 2023 (Jensen et al., 2024), however, the current EU maximum limits apply only to the muscle tissue of fish.

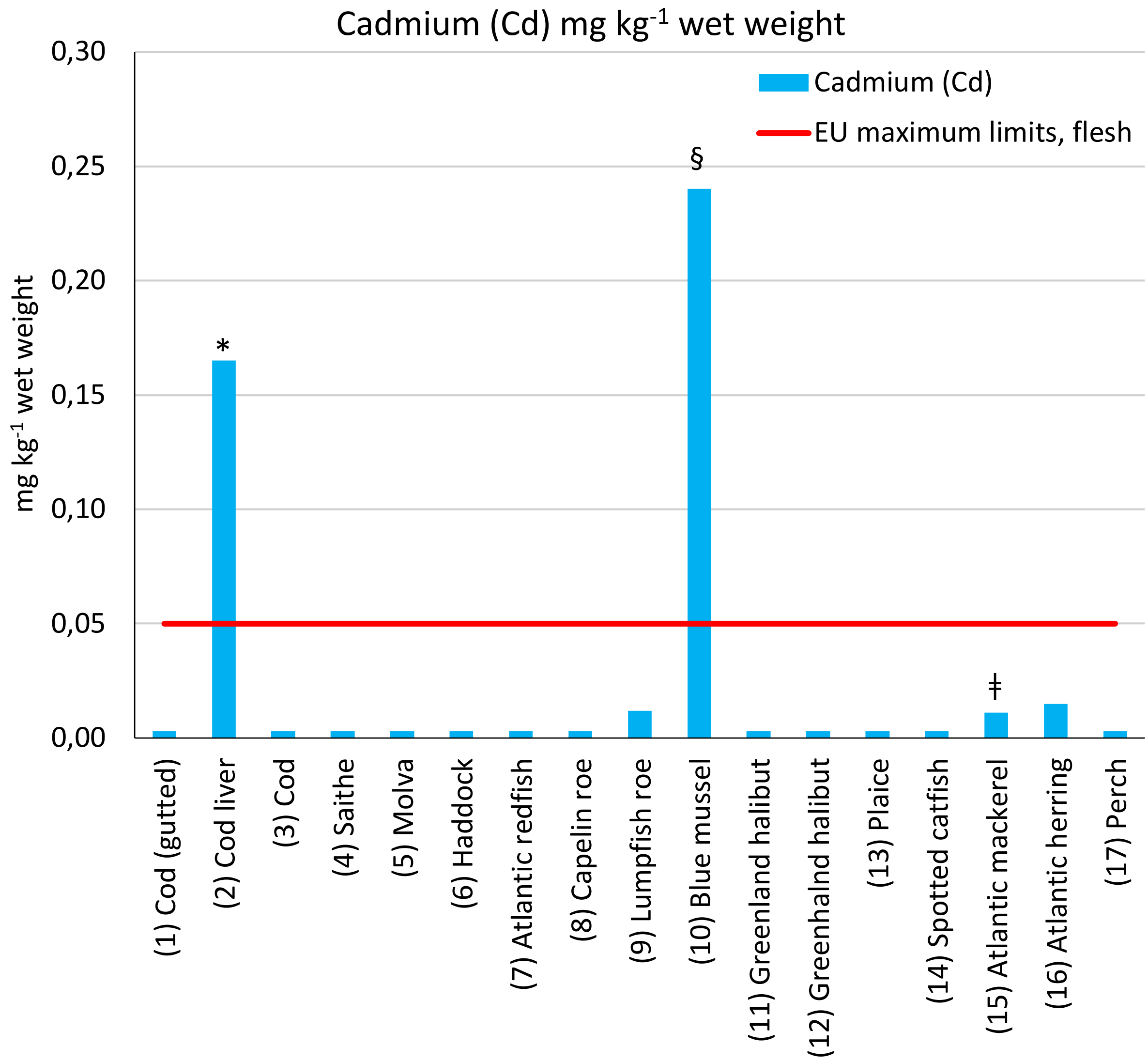

Figure 7. *Cadmium (Cd) in marine catches from Icelandic fishing grounds in 2024 in mg kg^{-1} wet weight.*
**EU maximum limit only applies to muscle meat of fish.*
§EU maximum limit for Cd in blue mussel is 1.0 mg kg^{-1} wet weight.
ǂEU maximum limit for Cd in mackerel is 0.1 mg kg^{-1} wet weight.

4.6.2 Lead in fish and fishery products from Icelandic waters

The concentration of lead (Pb) in all samples from 2024 was below the EU maximum limit of 0.3 mg kg^{-1} (wet weight) for fish flesh, Figure 8. Moreover, all fish species analysed contained <0.08 mg kg^{-1} of Pb (Appendix T3).

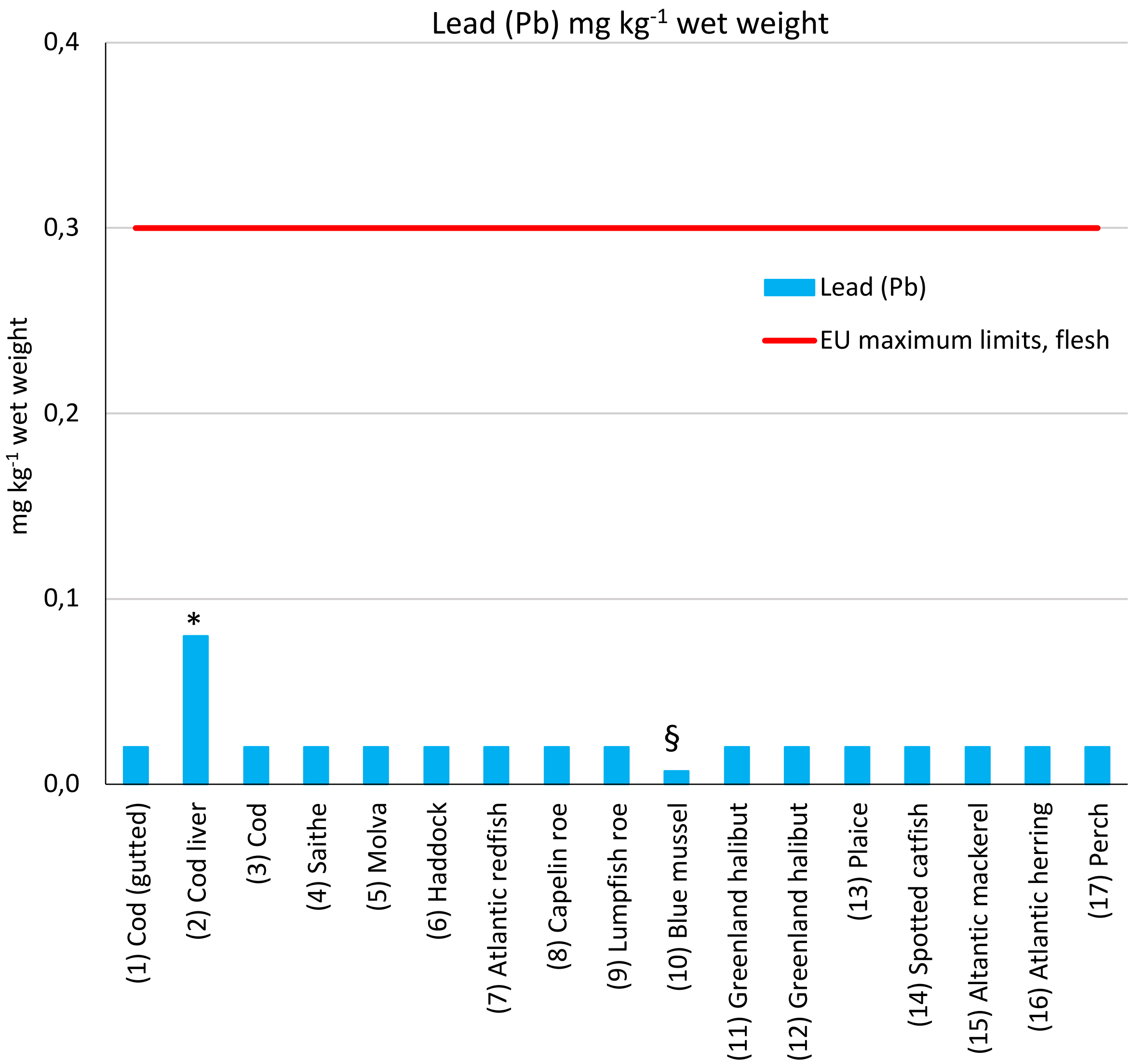

Figure 8. Lead (Pb) in marine catches from Icelandic fishing grounds in 2024 in mg kg^{-1} wet weight.
**EU maximum limit applies only to muscle meat of fish.*
§EU maximum limit for Pb in blue mussel is 1.5 mg kg^{-1} wet weight.

4.6.2 Mercury in fish and fishery products from Icelandic waters

No sample exceeded the applicable EU maximum limit for mercury (Hg), Figure 9, where all concentrations were ≤0.25 mg kg^{-1} (wet weight). The highest levels were found in the perch, spotted catfish and one sample of Greenland halibut (sample numbers 17, 14 and 11).

This can likely be attributed to age and mass, as the body burden of Hg increases over the lifetime of the fish (Dang and Wang, 2012). For example, when comparing the two samples of Greenland halibut, the specimens from sample number 11 had an average body weight of 2.6 kg, whilst those from sample 12 had an average weight of only 0.9 kg. The Hg concentrations were below detection limits in the cod liver, capelin roe and lumpfish roe (sample numbers 2, 8 and 9).

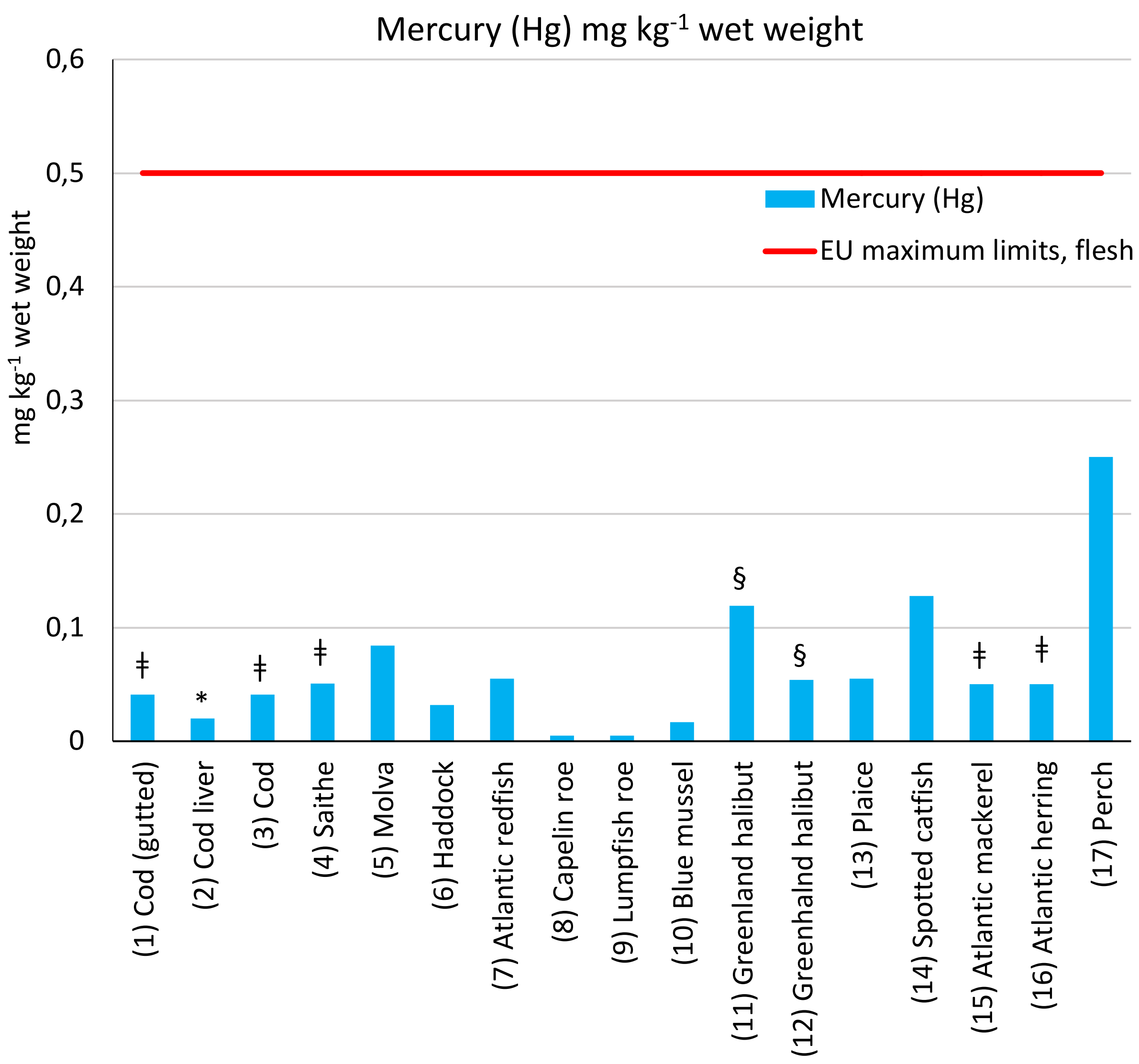

Figure 9. Mercury (Hg) in marine catches from Icelandic fishing grounds in 2024 in mg kg^{-1} wet weight.

**EU maximum limit applies only to muscle meat of fish.*

§EU maximum limit for Hg in Greenland halibut is set to 1 mg kg^{-1} wet weight.

ǂEU maximum limit for Hg in cod, saithe, mackerel, and herring is set to 0.3 mg kg^{-1} wet weight.

4.6.4 Arsenic in fish and fishery products from Icelandic waters

There are currently no maximum limits for the concentration of arsenic in seafood, but results from the monitoring in 2024 (Figure 10) were mostly in agreement with measurements from previous years (Auðunsson, 2004; Ásmundsdóttir et al. 2005; Ásmundsdóttir and Gunnlaugsdóttir, 2006; Jörundsdóttir et al., 2009; Baldursdóttir et al, 2011; Jörundsdóttir et al., 2012; Jensen et al., 2013; Jensen et al., 2018; Jensen et al., 2019; Jensen et al., 2020; Jensen et al., 2021; Jensen, et al. 2022; Jensen, et al. 2023; Jensen et al., 2024). The highest levels of As (21, 12 and 6.4 mg kg^{-1}) were found in plaice, haddock and spotted catfish samples (sample numbers 13, 6 and 14). This is similar to the results from 2023 (Jensen, et al. 2024) where haddock and plaice samples also contained some of the highest levels of arsenic. Haddock and plaice are demersal species, which feed and live in proximity to the sediment where arsenic may settle (Saei-Dehkordi et al., 2010). Only the total arsenic concentration was measured in the samples, however, this does not provide an accurate estimation of the potential risk as the toxicity of arsenic is highly dependent on chemical form. The arsenic present could be in the form of inorganic compounds (arsenite and arsenate) which are confirmed carcinogens (Cohen et al., 2013) but currently unregulated in marine catches, or the organic compound arsenobetaine which is considered non-toxic to humans. Therefore, there is a need to include the measurement of individual compounds in future analyses to determine the risk posed by arsenic in edible fish tissues.

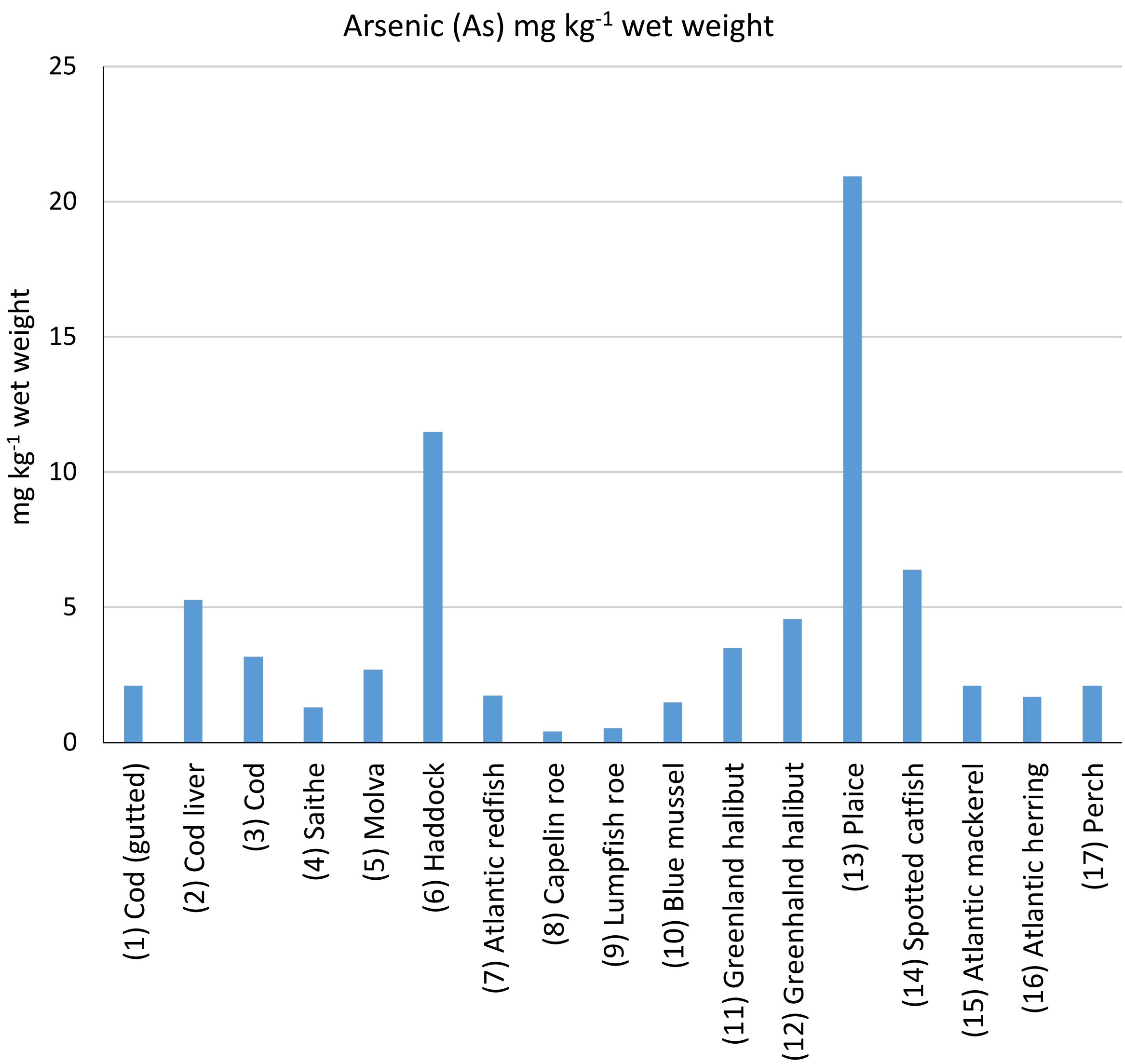

Figure 10. Arsenic (As) in marine catches from Icelandic fishing grounds in 2024 in mg kg^{-1} wet weight.

4.7 Perfluoroalkyl substances (PFAS)

The concentration of PFAS (sum of PFOS, PFOA, PFNA and PFHxS) in fresh fish was reported previously in the year 2023 (Jensen, et al. 2024). All samples were below the EU maximum limit for muscle tissue (2.0 μg kg^{-1}), however one sample of cod roe exceeded this (2.63 μg kg^{-1}). Recent studies have also demonstrated vast differences in PFAS accumulation between fish species, tissue type, and habitat (Chen et al., 2021; Hedgespeth et al., 2023), and there is the potential for marine organisms at all trophic levels to be severely impacted due to the diverse chemical properties of this class of compounds (Adeogun et al., 2024; Banyoi et al., 2022).

The current EU legislation (2023/915) is limited to four compounds (PFOS, PFOA, PFNA and PFHxS) in fish muscle meat, and does not cover other edible tissues (i.e. roe or liver), fish-based oils or fishmeal used as livestock feed. With the latter in particular, there is a risk of unintentionally introducing PFAS to other food systems – for example, a recent study in Denmark has shown that the inclusion of fishmeal in laying hen feed was found to contaminate organic eggs (Granby et al., 2024). Thus, there is a future need to investigate a wider selection of these analytes in more tissue types and fishery products to fully assess the risk to consumers.

5 Acknowledgements

The Icelandic marine and freshwater research institute (MFRI) are thanked for the sampling of specimens. Vignir G. Jónsson HF are thanked for providing the capelin and lumpfish roe and Þórishólmi ehf are thanked for providing the blue mussel samples.

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Commission Regulation (EC) No 333/2007 laying down the methods of sampling and analysis for the official control of the levels of lead, cadmium, mercury, inorganic tin, 3-MCPD and benzo(a)pyrene in foodstuffs.

Commission Regulation (EC) No 2017/644 laying down methods of sampling and analysis for the control of levels of dioxins, dioxin-like PCBs and non-dioxin-like PCBs in certain foodstuffs.

Commission Regulation (EC) No 2022/1428 laying down methods of sampling and analysis for the control of perfluoroalkyl substances in certain foodstuffs.

Commission Regulation (EC) No 2023/915 on maximum levels for certain contaminants in food and repealing Regulation (EC) No 1881/2006.

7 Appendix

Appendix T1. The upper bound concentration of dioxins and PCBs in fish and fishery product samples in wet weight

Sample code	Fish sample no.	Sample name	Latin name	Fishing ground	Size [cm]	Lipid content %	PCDD/PCDFs pg WHO-TEQ/g	Dioxin like PCBs pg WHO-TEQ/g	Sum of Dioxins and DL-PCBs pg WHO-TEQ/g	Marker PCBs µg kg^{-1}	ICES-6 PCBs µg kg^{-1}
R2400747-1	1	Cod (gutted)	*Gadus morhua*	*NW*	60-70	0.5	0.343	0.206	0.55	2.05	2.00
R2400747-2	2	Cod liver	*Gadus morhua*	*NW*		63.5	1.430	3.99	5.42	39.7	33.5
R2400747-3	3	Cod	*Gadus morhua*	*E*	50-60	<0.1	0.340	0.2	0.55	2.05	2.00
R2400747-4	4	Saithe	*Pollachius virens*	*E*	60-70	1.3	0.343	0.208	0.55	2.08	2.00
R2400747-5	5	Molva	*Gadus molva*	*W*	60-90	0.4	0.343	0.206	0.55	2.05	2.00
R2400747-6	6	Haddock	*Melanogrammus aeglefinus*	*N*	50-60	0.8	0.343	0.206	0.55	2.05	2.00
R2400747-7	7	Atlantic Redfish	*Sebastes mentella*	*N*	30-40	2.9	0.343	0.209	0.55	2.13	2.00
R2400747-8	8	Capelin roe	*Mallotus villosus*	*NW*		6.38	0.325	0.195	0.52	1.93	1.89
R2400747-12	9	Lumpfish roe	*Cyclopterus lumpus*	*SW*		4.22	0.326	0.197	0.52	1.96	1.90
R2400747-13	10	Blue mussel	*Mytilus edulis*	*NW*		0.79	0.340	0.206	0.55	2.05	2.00
R24002807-1	11	Greenland halibut	*Reinhardtius hippoglossoides*	*W*	60-80	13.8	0.512	0.601	1.11	6.55	5.66
R24002807-2	12	Greenland halibut	*Reinhardtius hippoglossoides*	*N*	40-50	10.6	0.476	0.481	0.96	5.63	4.91
R24002807-3	13	Plaice	*Pleuronectes platessa*	*W*	40-50	1.91	0.340	0.206	0.55	2.05	2.00
R24002807-4	14	Spotted catfish	*Anarchichas minor*	*NW*	60-80	3.5	0.358	0.247	0.61	2.87	2.64
R24002807-5	15	Atlantic mackerel	*Scomber scombrus*	*NE*	~40	18.7	0.366	0.330	0.70	3.64	3.27
R24002807-6	16	Atlantic herring	*Clupea harengus*	*NE*	30-40	12.3	0.382	0.263	0.65	3.16	2.80
R24002807-7	17	Perch	*Sebastes norvegicus*	*SW*	30-40	1.33	0.343	0.218	0.56	3.10	2.78
		EU maximum limits‡					3.5	*	6.5	*	75

*No maximum limits exist in the EU for the substances

PCDD/PCDFs are 2,3,7,5,8-PCDDs and PCDFs.

DL-PCBs are PCB-77, -81, -126, -169, -105, -114, -118, -123, -156, -157, -167 and -189

Marker PCBs are PCB-28, -52, -101, -118, -138, -153 and -180

ICES-6 PCBs are marker PCBs excluding PCB-118

‡ Applies to muscle meat of fish and fishery products and products thereof

Appendix T2. Pesticides in fish and fishery product samples in wet weight.

Sample code	Fish sample no.	Sample name	Latin name	Fishing ground	Size [cm]	Lipid content %	alpha-HCH µg kg-1	beta-HCH µg kg-1	delta-HCH µg kg-1	gamma-HCH µg kg-1	epsilon-HCH µg kg-1	Σ DDT µg kg-1	Pentachlor benzene µg kg-1	HCB µg kg-1	Σ Heptachlores µg kg-1
R2400747-1	1	Cod (gutted)	*Gadus morhua*	*NW*	60-70	0.5	<0.250	<0.250	<0.250	<0.250	<0.250	0.60	<0.500	<0.500	0.550
R2400747-2	2	Cod liver	*Gadus morhua*	*NW*		63.5	0.75	<0.625	<0.625	<0.625	<0.625	37.7	1.67	15.4	2.210
R2400747-3	3	Cod	*Gadus morhua*	*E*	50-60	<0.1	<0.250	<0.250	<0.250	<0.250	<0.250	0.700	<0.500	<0.500	0.550
R2400747-4	4	Saithe	*Pollachius virens*	*E*	60-70	1.3	<0.250	<0.250	<0.250	<0.250	<0.250	1.06	<0.500	<0.500	0.550
R2400747-5	5	Molva	*Gadus molva*	*W*	60-90	0.4	<0.250	<0.250	<0.250	<0.250	<0.250	0.700	<0.500	<0.500	0.550
R2400747-6	6	Haddock	*Melanogrammus aeglefinus*	*N*	50-60	0.8	<0.250	<0.250	<0.250	<0.250	<0.250	0.600	<0.500	<0.500	0.550
R2400747-7	7	Atlantic Redfish	*Sebastes mentella*	*N*	30-40	2.9	<0.250	<0.250	<0.250	<0.250	<0.250	0.960	<0.500	<0.500	0.550
R2400747-8	8	Capelin roe	*Mallotus villosus*	*NW*		6.38	<0.250	<0.250	<0.250	<0.250	<0.250	0.600	<0.500	<0.500	0.550
R2400747-12	9	Lumpfish roe	*Cyclopterus lumpus*	*SW*		4.22	<0.250	<0.250	<0.250	<0.250	<0.250	1.02	<0.500	0.625	0.550
R2400747-13	10	Blue mussel	*Mytilus edulis*	*NW*		0.79	<0.250	<0.250	<0.250	<0.250	<0.250	0.600	<0.500	<0.500	0.550
R24002807-1	11	Greenland halibut	*Reinhardtius hippoglossoides*	*W*	60-80	13.8	<0.250	<0.250	<0.250	<0.250	<0.250	8.89	<0.500	3.84	0.634
R24002807-2	12	Greenland halibut	*Reinhardtius hippoglossoides*	*N*	40-50	10.6	<0.250	<0.250	<0.250	<0.250	<0.250	5.21	<0.500	2.36	0.648
R24002807-3	13	Plaice	*Pleuronectes platessa*	*W*	40-50	1.91	<0.250	<0.250	<0.250	<0.250	<0.250	0.635	<0.500	<0.500	0.550
R24002807-4	14	Spotted catfish	*Anarchichas minor*	*NW*	60-80	3.5	<0.250	<0.250	<0.250	<0.250	<0.250	1.56	<0.500	<0.500	0.550
R24002807-5	15	Atlantic mackerel	*Scomber scombrus*	*NE*	~40	18.7	<0.250	<0.250	<0.250	<0.250	<0.250	1.98	<0.500	0.592	0.603
R24002807-6	16	Atlantic herring	*Clupea harengus*	*NE*	30-40	12.3	<0.250	<0.250	<0.250	<0.250	<0.250	2.41	<0.500	0.877	0.550
R24002807-7	17	Perch	*Sebastes norvegicus*	*SW*	30-40	1.33	<0.250	<0.250	<0.250	<0.250	<0.250	1.43	<0.500	<0.500	0.550

Appendix T2 (cont). Pesticides in fish and fishery product samples in wet weight.

Sample code	Fish sample no.	Sample name	Latin name	Fishing ground	Size [cm]	Lipid content %	Aldrin/ dieldrin µg kg-1	Toxaphene µg kg-1	Octachloro-styrene µg kg-1	Endrin µg kg-1	alpha-endosulfane µg kg-1	Σ Chlordanes µg kg-1	*trans*-Nonachlor µg kg-1	Mirex µg kg-1
R2400747-1	1	Cod (gutted)	*Gadus morhua*	*NW*	60-70	0.5	0.250	2.00	<0.100	<0.300	<0.500	0.700	<0.100	<0.100
R2400747-2	2	Cod liver	*Gadus morhua*	*NW*		63.5	16.4	47.6	0.393	1.76	<1.25	10.6	16.0	0.422
R2400747-3	3	Cod	*Gadus morhua*	*E*	50-60	<0.1	0.250	2.00	<0.100	<0.300	<0.500	0.700	<0.100	<0.100
R2400747-4	4	Saithe	*Pollachius virens*	*E*	60-70	1.3	0.269	2.00	<0.100	<0.300	<0.500	0.797	0.255	<0.100
R2400747-5	5	Molva	*Gadus molva*	*W*	60-90	0.4	0.250	2.00	<0.100	<0.300	<0.500	0.700	<0.100	<0.100
R2400747-6	6	Haddock	*Melanogrammus aeglefinus*	*N*	50-60	0.8	0.250	2.00	<0.100	<0.300	<0.500	0.700	<0.100	<0.100
R2400747-7	7	Atlantic Redfish	*Sebastes mentella*	*N*	30-40	2.9	0.446	2.01	<0.100	<0.300	<0.500	0.758	0.224	<0.100
R2400747-8	8	Capelin roe	*Mallotus villosus*	*NW*		6.38	0.250	2.00	<0.100	<0.300	<0.500	0.700	<0.100	<0.100
R2400747-12	9	Lumpfish roe	*Cyclopterus lumpus*	*SW*		4.22	0.701	2.00	<0.100	<0.300	<0.500	0.719	<0.100	<0.100
R2400747-13	10	Blue mussel	*Mytilus edulis*	*NW*		0.79	0.250	2.00	<0.100	<0.300	<0.500	0.700	<0.100	<0.100
R24002807-1	11	Greenland halibut	*Reinhardtius hippoglossoides*	*W*	60-80	13.8	3.20	11.9	<0.100	0.462	<0.500	2.35	1.51	0.185
R24002807-2	12	Greenland halibut	*Reinhardtius hippoglossoides*	*N*	40-50	10.6	2.03	6.34	<0.100	0.334	<0.500	2.05	2.16	<0.100
R24002807-3	13	Plaice	*Pleuronectes platessa*	*W*	40-50	1.91	0.250	2.00	<0.100	<0.300	<0.500	0.700	<0.100	<0.100
R24002807-4	14	Spotted catfish	*Anarchichas minor*	*NW*	60-80	3.5	1.12	2.87	<0.100	<0.300	<0.500	0.884	0.596	<0.100
R24002807-5	15	Atlantic mackerel	*Scomber scombrus*	*NE*	~40	18.7	1.09	2.81	<0.100	<0.300	<0.500	0.980	0.651	<0.100
R24002807-6	16	Atlantic herring	*Clupea harengus*	*NE*	30-40	12.3	1.23	4.05	<0.100	<0.300	<0.500	1.13	0.733	<0.100
R24002807-7	17	Perch	*Sebastes norvegicus*	*SW*	30-40	1.33	0.250	2.00	<0.100	<0.300	<0.500	0.700	<0.123	<0.100

Appendix T3. Total trace element concentrations in fish and fishery product samples in mg kg^{-1} wet weight

Sample code	Fish sample no.	Sample name	Latin name	Cr mg kg^{-1}	As mg kg^{-1}	Cd mg kg^{-1}	Sn mg kg^{-1}	Hg mg kg^{-1}	Pb mg kg^{-1}
R24-747-1	1	Cod (gutted)	*Gadus morhua*	<0.01	2.10	<0.003	<0.01	0.041	<0.02
R24-747-2	2	Cod liver	*Gadus morhua*	<0.01	5.27	0.165	<0.01	<0.02	<0.08
R24-747-3	3	Cod	*Gadus morhua*	<0.01	3.19	<0.003	<0.01	0.041	<0.02
R24-747-4	4	Saithe	*Pollachius virens*	<0.01	1.32	<0.003	<0.01	0.051	<0.02
R24-747-5	5	Molva	*Gadus molva*	<0.01	2.71	<0.003	<0.01	0.084	<0.02
R24-747-6	6	Haddock	*Melanogrammus aeglefinus*	<0.01	11.5	<0.003	<0.01	0.032	<0.02
R24-747-7	7	Atlantic Redfish	*Sebastes mentella*	<0.01	1.75	<0.003	<0.01	0.055	<0.02
R24-747-8	8	Capelin roe	*Mallotus villosus*	<0.01	0.41	0.003	<0.01	<0.005	<0.02
R24-747-9	9	Lumpfish roe	*Cyclopterus lumpus*	<0.01	0.53	0.012	<0.01	<0.005	<0.02
R24-747-10	10	Blue mussel	*Mytilus edulis*	0.069	1.50	0.240	0.013	0.017	0.007
R24-2807-1	11	Greenland halibut	*Reinhardtius hippoglossoides*	<0.01	3.51	<0.003	<0.01	0.119	<0.02
R24-2807-2	12	Greenland halibut	*Reinhardtius hippoglossoides*	<0.01	4.58	<0.003	<0.01	0.054	<0.02
R24-2807-3	13	Plaice	*Pleuronectes platessa*	<0.01	20.9	<0.003	<0.01	0.055	<0.02
R24-2807-4	14	Spotted Catfish	*Anarchichas minor*	<0.01	6.40	<0.003	<0.01	0.128	<0.02
R24-2807-5	15	Atlantic mackerel	*Scomber scombrus*	<0.01	2.10	0.011	<0.01	0.049	<0.02
R24-2807-6	16	Atlantic herring	*Clupea harengus*	<0.01	1.70	0.015	<0.01	0.046	<0.02
R24-2807-7	17	Perch	*Sebastes norvegicus*	<0.01	2.10	<0.003	<0.01	0.250	<0.02