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Influence of the geographical origin on substance concentrations in herring as basis for dietary exposure assessments

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Abstract

Previous investigations on agricultural products showed that geographical origin influences concentrations of selected undesirable substances and ultimately dietary exposure assessment. This could also be relevant for fish from different catching areas, as substance concentrations have been found to vary between catching areas. Herring was chosen as an example. Norwegian and German data on consumption and substance concentrations were considered. To investigate if concentrations of substances are different in Norway and Germany, monitoring data between 2012 and 2017 were used. Norway provided data of commercial catching areas from the Norwegian Spring Spawning (NSS) herring stock, while Germany had market data available. Concentrations of cadmium, mercury and selenium tended to be higher in herring from Norway, while lead concentrations were higher in Germany. Polychlorinated dibenzo-*p*-dioxins/polychlorinated dibenzofurans (PCDD/Fs), dioxin-like polychlorinated biphenyls (DL-PCBs) and non-dioxin-like PCBs (NDL-PCBs) tended to have higher concentrations in Germany, while perfluorinated alkylated substances (PFAS) were mostly below quantifiable levels in the two countries. These differences could be attributed to different herring stocks available on the market in Germany and Norway. Country-specific data on consumption and substance concentrations give a basis for a refined exposure assessment covering both the Norwegian and the German situation. This is of special importance if European risk assessments are carried out combining concentration data recorded in several countries without taking origin into account.

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Keywords: dietary exposure, fish, herring, geographical origin, catching area

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1. Introduction

Previous investigations on the agricultural products tomatoes, pineapples and kiwis showed effects of the geographical origin, such as country of origin, on concentrations of selected undesirable substances (Fechner et al., 2019). The performed dietary exposure assessment showed a possible refinement by integrating this information in the approach using assumptions on the origin-related consumption behaviour. Another study on dietary cadmium exposure from several food items showed influences on the exposure estimate depending on the use of pooled European concentration data in comparison to country-specific concentration data (Sand et al., 2013). The researchers concluded that both approaches lead to conservative estimates and a low aggregation level of food items is important for the estimation. Depending on the geographical origin of food items and investigated substances, the use of country-specific occurrence data could possibly refine exposure assessments, if there is a geographical variation in substance concentrations related to a country-specific food supply.

An effect of geographical origin on concentrations of selected substances could also apply to fillet of fish from different catching areas, as geographical variations in substance concentrations have been observed. Sunderland et al. (2018) studied geographical origins of seafood on the market in the United States and the concentration of methyl mercury, and showed that seafood was available from different catching areas and contributed to the methyl mercury exposure with different amounts. Several fish species caught in subareas of the Northeast Atlantic were investigated for methyl mercury and concentrations increased from north to south and by fish length (Azad et al., 2019). Another study for the same area showed decreasing concentrations of the brominated flame retardant (BFR) BDE-47 with increasing latitude for eight of 15 fish species investigated (Nøstbakken et al., 2018). For cod caught in the Barents Sea, the highest mercury concentrations were found in the southwest area for all length classes, whereas cod from the eastern area had higher arsenic concentrations (Julshamn et al., 2013). Several deep sea fish species, mainly tusk, ling and haddock, caught in Norwegian waters were analysed for mercury and other metals, polychlorinated dibenzo-*p*-dioxins/polychlorinated dibenzofurans (PCDD/Fs), dioxin-like polychlorinated biphenyls (DL-PCBs), non-dioxin-like PCBs (NDL-PCBs), BFRs and perfluorinated alkylated substances (PFAS) (Frantzen and Måge, 2016). Mercury concentrations in fillet varied geographically with an increasing trend from north to south and in some species from open sea to coast (Frantzen and Måge, 2016; Azad et al., 2019). For the organic contaminants, the concentrations were low in fillets but high concentrations were found in fish liver increasing from north to south and from open sea to fjords in the North Sea area (Frantzen and Måge, 2016). PFAS concentrations were mostly below the limit of quantification (LOQ) in fillet and liver, for perfluorooctanoic acid the LOQ was 2.4 ng/g and for perfluorooctanesulfonic acid 1.8 ng/g, which was below the cut-off values 10 ng/g and 14 ng/g used by EFSA for these two substances (Frantzen and Måge, 2016; EFSA CONTAM Panel, 2018a,b). A similar study was done for Atlantic halibut and concentrations of mercury and organic contaminants in lean and fatty fillet parts increased from north to south and with fish length and weight (Nilsen et al., 2016). Concentrations of PCDD/Fs and DL-PCBs in herring vary by catching area and fishing season (Karl et al., 2002; Frantzen et al., 2011; Karl and Lahrssen-Wiederholt, 2013) and concentrations in farmed salmon decrease if the feed composition is changed (Karl and Lahrssen-Wiederholt, 2013). Fish and fishery products like herring and salmon from the Baltic region contain higher amounts of PCDD/Fs and DL-PCBs than from other areas and therefore special recommendations for monitoring are given (European Commission 2016; EFSA CONTAM Panel, 2018a,b).

Risk benefit assessments of fish are carried out because next to negative effects from various contaminants contained in fish, positive effects are observed because of beneficial substances like omega-3 polyunsaturated fatty acids (VKM 2014). Depending on the catching area of fish and seafood, different environmental factors could influence the composition of substances. Therefore, it is important to investigate to what extent the geographical origin will impact the assessment approach. In this project, substance concentrations in herring from different catching areas and Norwegian and German consumption data were used to evaluate potential effects of herring origin on human exposure to certain substances. Country-specific data enable a comparison of herring as well as for different consumption behaviour as for substance concentrations and provide the basis for a refined dietary exposure assessment accounting for geographical food origin.

2. Description of work programme

2.1. Aims

The Norwegian Scientific Committee for Food and Environment (VKM), a scientifically independent and administrative unit of the Norwegian Institute of Public Health (NIPH), initiated the project 'Faster, better and stronger exposure assessment'. Fish was chosen as the targeted food group for this study. In cooperation with other Norwegian and German scientific institutes, the aim was to compare fish consumption, fish contamination and resulting dietary exposure estimates integrating the influence of fish origin and catching area to develop refined approaches and reduce uncertainties.

As a part of the project, data on selected substances should be prepared to expand the Norwegian food composition database, which is provided by the University of Oslo (UiO). This database also contains consumption data from different Norwegian surveys, data which were used in the project to perform exposure assessments. Parameters contributing to uncertainty in exposure calculations were identified and described.

2.2. Activities/methods

Herring was selected as a case study because it is a wild fish species, because Norwegians and Germans consume it, and because various substances are analysed in monitoring programmes in Germany and Norway. In this project the software IBM SPSS Statistics 25 was used for data analyses.

Data on the consumption of fish and seafood in total and herring in particular were extracted from two national consumption surveys. Both surveys recorded two 24-h recalls and participants who reported only one 24-h recall were excluded. The survey Norkost 3 was conducted during 2010–2011 in Norway (Totland et al., 2012), included 1,787 adults (925 women and 862 men) aged 18–70 years, who completed two 24-h recalls, and the data were provided by the UiO. The German National Nutrition Survey II (NVS II) was conducted during 2005–2006 by Max Rubner-Institut (MRI) (Brombach et al., 2006; Krems et al., 2006) and 13,926 participants (6,897 male and 7,029 female) aged between 14 and 80 years, who completed two 24-h recalls, were considered here. To derive consumption amounts of fish and seafood in total and herring in particular, a version with disaggregated household recipes was used for Germany. That means the amount of pure herring from household recipes consumed was available, while industrial products consumed remained aggregated and the derived consumption amount contained other ingredients next to herring. For Norway both, an aggregated and a disaggregated version for industrial and household recipes was used for herring to derive consumption amounts. Fish and seafood consumption was derived from aggregated data. The consumption of herring was used for dietary exposure assessment on an individual level, per kg body weight (BW) and as mean of the two 24-h recalls.

Concentration data for substances in herring, from national monitoring programmes between 2012 and 2017, were requested in Standard Sample Description format. Norwegian data on substances in herring from the Norwegian Spring Spawning (NSS) herring stock were provided by the Institute of Marine Research (IMR). The herring was sampled from commercial catches in fishery areas by fishermen on contract with the IMR. German data were taken from the authorities in the federal states on the German market. Data of all federal states were submitted to and organised by the Federal Office of Consumer Protection and Food Safety (BVL) and can be used by the German Federal Institute for Risk Assessment (BfR) for exposure assessments. Different codes for the identification of substances were used in Norway and Germany and had to be unified to identify substances investigated in both countries. The substances investigated in both countries were combined in one data file, and each substance was checked for equality of units and if concentrations were equally related to whole weight or fat weight in both countries. Units were equal for Norway and Germany and the concentrations were mostly related to whole weight. NDL-PCBs investigated in Germany in 2012 were reported in fat weight, to have all results in whole weight, the reported fat content in percent of each sample was used to relate results to whole weight. Nickel was investigated in both countries but excluded from further investigations as only two samples from Germany were available and the 50 samples from Norway were neither quantified, nor was a LOQ stated. For all other substances investigated in Norway and Germany lower bound concentrations were calculated replacing results below the limit of detection (LOD) or LOQ by zero. For upper bound concentrations, results below the LOD were replaced by the LOD and results below the LOQ were replaced by the LOQ. In case of missing LOQs and LODs, they were replaced by zero before. Every sample investigated for PCDD/Fs

and DL-PCBs was analysed for all congeners and in this way no sample exclusion was needed for the calculation of sums (EFSA CONTAM Panel, 2018a,b). To weigh the concentrations of the individual congeners according to their different toxicity and to convert the given unit to Toxic Equivalents (TEQ), PCDD/F and DL-PCB lower and upper bound concentrations were multiplied with Toxic Equivalency Factors (TEF) (European Commission 2011) established by the World Health Organization (WHO) in 2005. Afterwards, sums for PCDD/Fs, DL-PCBs and PCDD/Fs and DL-PCBs were calculated. Tables with statistical parameters for country-specific concentrations of all substances investigated in both countries were prepared using the CTABLES command. On this basis, country-specific substance concentrations could be compared and we could also pay attention to the different catching areas. Norwegian parameters on substance concentrations were used to expand the Norwegian food composition database.

The project progress was presented at two conferences as part of the poster sessions; the 'International Conference on Uncertainty in Risk Analysis' 20–22.2.2019 hosted by BfR in Berlin, Germany, and 'The Science of Food Safety – What's our Future?' 21–22.8.2019 hosted by the Food Safety Authority of Ireland in Dublin, Ireland. Further investigations and the dietary exposure assessment were based on data of selected metals as well as PCDD/Fs and DL-PCBs using country-specific scenarios to account for uncertainties in exposure assessments related to the use of pooled concentration data.

3. Data for dietary exposure assessment

3.1. Consumption of herring

Country-specific consumption data of Norway and Germany enabled the comparison of the consumption of fish and seafood in total and herring in particular between the countries and provided the basis for the dietary exposure assessment. Table 1 shows the German and Norwegian fish and seafood consumption and the herring consumption calculated from NVS II and Norkost 3. In Germany, there were 13,926 participants, 3,455 (i.e. 24.8%) of them consumed fish and seafood and 596 (i.e. 4.3%) of them consumed herring. In Norway, there were 1,787 participants, while 1158 (i.e. 64.8 %) of them consumed fish and seafood and 99 (i.e. 5.5%) of them were consumers of herring. For Norway, the consumption of herring calculated from aggregated data included other ingredients from industrial products and household recipes, whereas the consumption calculated from disaggregated data was pure herring. Norwegian consumers of herring had a mean herring consumption of 0.31 g/day per kg BW from disaggregated data and 0.41 g/day per kg BW from aggregated data. This difference shows one of the uncertainties in the model. On one hand, factors used to calculate the disaggregated herring consumption may vary between different industrial and household recipes; on the other hand, the aggregated herring consumption contains more ingredients than herring. Which data version to use in dietary exposure assessment depended on model assumptions and in the current case also on the available German consumption data. For Germany, the disaggregated herring consumption included the herring amount from household recipes and industrial products with herring, which were aggregated containing other ingredients as well. German consumers of herring had a mean herring consumption of 0.88 g/day per kg BW, which was higher than in Norway (aggregated and disaggregated). In contrast, the mean fish and seafood consumption of all participants and of consumers was higher in Norway (0.89 g/day per kg BW and 1.37 g/day per kg BW) than in Germany (0.23 g/day per kg BW and 0.92 g/day per kg BW).

3.2. Substance concentrations in herring

For some substances, concentrations vary with geographical food origin. In these cases, country-specific concentration data could help to refine dietary exposure estimates and to see differences related to the origin of consumed food. This is already highlighted by the European Food Safety Authority (EFSA), because Baltic herring is supposed to have higher PCDD/F and DL-PCB concentrations than herring from other catching areas and for the consumption there could be a country-specific focus on certain catching areas (EFSA CONTAM Panel, 2018a,b). Different substance concentrations in herring for Norway and Germany could be due to different geographical origins, named 'catching areas' for fish.

For the substance group PCDD/Fs and DL-PCBs, the German herring samples were from the Baltic Sea and sampled on the German market during 2016 whereas Norwegian herring samples were from the Norwegian Sea and sampled January and February 2014 and 2017. Table 2 shows higher concentrations based on German data compared to Norwegian data for the sum of DL-PCBs, the sum

of PCDD/Fs and the total sum of PCDD/Fs and DL-PCBs. The concentrations for individual PCDD/F and DL-PCB congeners used to calculate the sums shown in Table 2 are described in Appendix A, Table A.1. German mean LOQs were below Norwegian mean LOQs for all congeners. For most of the congeners, German lower and upper bound mean and percentile 95 (P95) concentrations were higher than corresponding Norwegian data except for PCB-123 showing higher lower and upper bound mean and P95 concentrations for Norway. For congeners with only one or two samples quantified in Norway, upper bound mean and P95 concentrations were mostly higher than for Germany, while lower bound concentrations were higher for Germany. This shows the influence of higher LOQs in Norway used in upper bound calculations in comparison with lower quantified concentrations from Germany and represents uncertainty in estimations.

EFSA evaluated PCDD/F and DL-PCB concentrations using pooled European data mostly from Germany, France, Norway and Denmark between 2010 and 2016, and catching areas were not reported and might be mixed (EFSA CONTAM Panel, 2018a,b). For most of the congeners, lower and upper bound mean and P95 concentrations from EFSA (2018) were higher than calculations using German Baltic Sea data. Only for four PCDD/Fs, 1,2,3,4,6,7,8-HpCDD, 1,2,3,4,7,8-HxCDD, 1,2,3,7,8,9-HxCDD and 1,2,3,4,6,7,8-HpCDF, most of the concentration parameters used by EFSA were lower than the German concentrations.

Further substances investigated in herring in Germany and Norway are displayed in Table 3. For Germany, metals were investigated in 2012 and 2017 and Baltic Sea, North Sea, Norwegian Sea and Atlantic were the catching areas reported, while ND-L-PCBs were investigated in herring in 2012 in samples from Baltic Sea, North Sea and Atlantic and in 2016 from Baltic Sea. German data for BFR and PFAS were derived from the Atlantic in 2012. For Norway, all substances displayed in Table 3 were investigated in 2014 and 2017 and sampled in the Norwegian Sea. Norwegian mean and percentile 50 (P50) LOQs were below German mean and P50 LOQs for all substances. While the concentrations of the metals arsenic, copper and zinc were similar, the concentrations of cadmium, mercury and selenium tended to be higher in Norway, and lead concentrations were higher in Germany. For BDE-47, a BFR investigated in both countries, only 11 samples including two quantifications were available from Germany. Lower bound concentrations from Norway were higher than Germany, and German upper bound concentrations were higher than the Norwegian and influenced by the higher German LOQs, which represents an uncertainty. For the substance group ND-L-PCBs, the German concentrations were higher or concentrations from Norway and Germany were similar. For PFAS, only one sample from Germany was quantified for perfluorooctane sulfonate, whereas the other samples had no quantifiable concentrations for PFAS.

3.3. Requirements for dietary exposure assessment and uncertainties

To investigate a potential relationship between catching areas and substance concentrations in herring, the concentrations were grouped by sampling country and reported catching areas were taken into account instead of pooling all concentration data. In combination with country-specific consumption data, a refined country-specific dietary exposure assessment is possible.

All data for dietary exposure assessments introduce uncertainty to the result of the exposure estimate, e.g. the consumption surveys used in the project were conducted years ago and therefore the current consumption might not be appropriately depicted (e.g. frequencies and amounts might have changed, new food items might be on the market). Additionally, underreporting or misreporting could occur, errors due to measured or self-reported body weights are possible, and the determination of food portion sizes has limitations. The consumption surveys used covered only 2 days, which do not give the full picture of the long-term food consumption. Furthermore, the aggregation level of food consumption might be different in different surveys, influencing the accuracy of derived consumption amounts. In German and Norwegian data, aggregated food items containing other ingredients than herring were included, causing an overestimation of herring consumption. Factors to derive the herring content out of composite foods may be different for various recipes but are unified for a recipe (e.g. amount of fish in different canned fish products). Substance concentration data used were derived from national monitoring programmes, where the LOQs were oriented towards maximum levels and not to the most sensitive analyses. Therefore, concentrations of some substances were below the LOQ and the real concentrations were not known. This effect was visible in the data used, as there were some PCDD/F and DL-PCB congeners with only a few quantified samples for Norway, which resulted in higher upper bound concentrations because of the calculation using the LOQ (Appendix A, Table A.1). Samples from single previous years were taken and might not represent current substance concentrations and

measuring errors appear. Furthermore, the sampling strategy was not representative for all available catching areas and finally consumed processed food items on the German and Norwegian markets, because special catching areas were sampled in Germany and Norway or the catching area was not relevant in the sampling plan in other cases in Germany, which might not depict the current situation properly. Fish length and weight also affect substance concentrations in herring (Frantzen et al., 2011, 2015), but this was not provided in the German data as ready-to-eat fillets might be sampled from the market. In exposure scenarios assumptions are used for calculations referring to average (P50) and high (P95) consumption as well as concentrations. This might not depict the real situation and causes uncertainties in the model, which could be different using distributions of consumption and concentration. Furthermore, factors of food processing were not part of our model and different food aggregation levels in consumption and concentration data were combined.

4. Conclusions

For some substances, there were distinct differences in the Norwegian and German concentrations. This supports the use of country-specific concentrations paying attention to catching areas in dietary exposure assessment.

To evaluate if there are origin-related differences in substance concentrations, information on catching areas is needed. Depending on the fish supply per country, fish from different catching areas could be available on the country-specific markets. Concentration data used for the current project provided much information on substances in herring and catching areas but the sampling was not related to catching areas available on the country markets. To investigate which substance concentrations vary geographically, a representative sampling for catching areas would be necessary.

However, differences in concentrations may be due to other reasons than catching areas, e.g. season-related. Therefore, seasonal sampling and sampling over several years is needed to evaluate the influence on the substance concentrations. Additionally, information like fish weight and length are important to investigate further influences.

Nevertheless, using the available country-specific concentration data in combination with country-specific consumption data, a first insight in origin-related exposure estimates was possible. This shows the need of country-specific data, if substance concentrations are origin-related, in case of fish, related to different catching areas available.

Because of the globalised markets in Europe, geographical food origin might not be relevant for all foods distributed within the European Member States. Even if there are different levels in fish from different catching areas, this will only affect exposure assessment, if there is a realistic chance for individuals to consume long-term fish from the same catching area.

Depending on the request of the consumer and the substance, it might be more appropriate to do the exposure assessment using country-specific concentrations or in other cases to use information on geographical food origin independent from the place of sampling. However, for EFSA it will be important to ask in calls for data also for information on geographical food origin to be able to consider this in exposure assessment.

Table 1: Consumption of fish and seafood in total and herring in particular in Germany and Norway according to 24-h recalls in the surveys NVS II and Norkost 3

Participants ^(a) (N)	Food item	Consumption (g/day per kg BW)					
		Mean		P50		P95	
		GER	NOR	GER	NOR	GER	NOR
All participants GER: 13926 NOR: 1787	Fish and seafood	0.23	0.89	0.00	0.42	1.39	3.15
	Herring aggregated	–	0.02	–	0.00	–	0.15
	Herring disaggregated	0.04	0.02	0.00	0.00	0.00	0.09
Consumers of fish and sea food/herring GER: 3455/596 NOR: 1158/99	Fish and seafood	0.92	1.37	0.77	1.10	2.21	3.53
	Herring aggregated	–	0.41	–	0.26	–	1.37
	Herring disaggregated	0.88	0.31	0.72	0.19	2.15	1.17

N: sample number; BW: body weight; P50: percentile 50; P95: percentile 95; GER: Germany; NOR: Norway; –: no data.

(a): Two 24-h recalls were recorded and an individual mean consumption was calculated. Participants, who reported only one day, were excluded.

Table 2: Sums of PCDD/Fs (dioxins) and DL-PCBs in herring investigated in monitoring programmes in Germany and Norway

Substance sum	Sampling country	Valid N	Substance concentration lower bound (pg WHO ₂₀₀₅ -TEQ/g) ^(a)				Substance concentration upper bound (pg WHO ₂₀₀₅ -TEQ/g) ^(a)			
			Mean	SD	P50	P95	Mean	SD	P50	P95
DL-PCBs	GER	47	0.92	0.33	0.92	1.37	0.92	0.33	0.92	1.37
	NOR	100	0.43	0.17	0.40	0.74	0.43	0.17	0.40	0.74
PCDD/Fs	GER	47	0.84	0.34	0.87	1.30	0.85	0.33	0.87	1.30
	NOR	100	0.36	0.17	0.34	0.65	0.47	0.15	0.46	0.71
PCDD/Fs and DL-PCBs	GER	47	1.76	0.61	1.68	2.65	1.77	0.61	1.68	2.65
	NOR	100	0.79	0.32	0.75	1.34	0.90	0.31	0.85	1.43

N: sample number; SD: standard deviation; P50: percentile 50; P95: percentile 95; PCDDs: polychlorinated dibenzo-*p*-dioxins; PCDFs: polychlorinated dibenzofurans; DL-PCBs: dioxin-like polychlorinated biphenyls; WHO World Health Organization; TEQ: Toxic Equivalents; GER: Germany; NOR: Norway.

(a): All concentrations are given in whole weight of herring.

Table 3: Substances in herring included in monitoring programmes in both Germany and Norway

Substance group	Substance	Sampling country	Valid N	Quantified N	Mean LOQ ^(a)	P50 LOQ ^(a)	Substance concentration lower bound ^(b)				Substance concentration upper bound ^(b)			
							Mean	SD	P50	P95	Mean	SD	P50	P95
Metals (mg/kg)	Total Arsenic (As)	GER	140	139	0.02	0.02	1.53	0.43	1.52	2.20	1.53	0.43	1.52	2.20
		NOR	100	100	0.00	0.00	1.50	0.37	1.45	2.10	1.50	0.37	1.45	2.10
	Cadmium (Cd)	GER	140	67	0.01	0.00	0.00	0.01	0.00	0.02	0.01	0.01	0.01	0.02
		NOR	100	100	0.00	0.00	0.02	0.01	0.02	0.04	0.02	0.01	0.02	0.04
	Copper (Cu)	GER	135	112	0.41	0.20	0.67	0.35	0.78	1.06	0.84	0.19	0.87	1.06
		NOR	100	100	0.03	0.03	0.82	0.11	0.80	1.00	0.82	0.11	0.80	1.00
	Total Mercury (Hg)	GER	140	139	0.01	0.01	0.05	0.02	0.05	0.09	0.05	0.02	0.05	0.09
		NOR	100	97	0.00	0.00	0.07	0.03	0.06	0.11	0.07	0.03	0.06	0.11
	Lead (Pb)	GER	140	49	0.01	0.02	0.01	0.01	0.00	0.03	0.01	0.01	0.01	0.04
		NOR	100	20	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.01
Selenium (Se)	GER	135	129	0.03	0.03	0.34	0.15	0.33	0.59	0.34	0.15	0.33	0.59	
	NOR	100	100	0.02	0.02	0.42	0.09	0.41	0.60	0.42	0.09	0.41	0.60	
Zinc (Zn)	GER	135	134	1.10	1.00	7.25	2.61	7.04	11.90	7.26	2.60	7.04	11.90	
	NOR	100	100	0.15	0.15	7.23	1.74	7.00	10.50	7.23	1.74	7.00	10.50	
BFR (mg/kg)	BDE-47	GER	11	2	0.96	0.97	0.16	0.38	0.00	1.20	3.89	1.91	5.00	5.00
		NOR	112	112	0.01	0.00	0.38	0.18	0.36	0.70	0.38	0.18	0.36	0.70
NDL-PCBs (ng/g)	PCB-101	GER	58	44	0.42	0.40	1.52	1.29	1.45	3.20	1.65	1.15	1.45	3.20
		NOR	100	100	0.02	0.02	1.35	0.60	1.30	2.40	1.35	0.60	1.30	2.40
	PCB-138	GER	58	58	0.42	0.40	3.60	1.68	3.70	6.60	3.60	1.68	3.70	6.60
		NOR	100	100	0.02	0.02	1.39	0.69	1.30	2.50	1.39	0.69	1.30	2.50
PCB-153	GER	58	56	0.42	0.40	4.18	1.88	4.10	7.70	4.20	1.84	4.10	7.70	
	NOR	100	100	0.02	0.02	2.10	1.00	2.00	3.70	2.10	1.00	2.00	3.70	
NDL-PCBs (ng/g)	PCB-180	GER	58	45	0.42	0.40	1.14	1.25	0.69	2.90	1.25	1.17	0.70	2.90
		NOR	100	100	0.02	0.02	0.40	0.22	0.36	0.70	0.40	0.22	0.36	0.70
	PCB-28	GER	57	28	0.43	0.50	0.37	0.93	0.00	1.30	0.60	0.87	0.50	1.30
		NOR	100	100	0.02	0.02	0.41	0.24	0.40	0.80	0.41	0.24	0.40	0.80
	PCB-52	GER	58	35	0.42	0.40	0.59	0.94	0.47	1.69	0.81	0.84	0.55	1.69
		NOR	100	100	0.02	0.02	0.79	0.34	0.75	1.30	0.79	0.34	0.75	1.30

Substance group	Substance	Sampling country	Valid N	Quantified N	Mean LOQ ^(a)	P50 LOQ ^(a)	Substance concentration lower bound ^(b)				Substance concentration upper bound ^(b)			
							Mean	SD	P50	P95	Mean	SD	P50	P95
PFAS (ng/g)	Perfluorobutane sulfonate	GER	21	0	1.00	1.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00	1.00
		NOR	99	0	0.56	0.38	0.00	0.00	0.00	0.00	0.56	0.24	0.38	0.80
	Perfluorohexane sulfonate	GER	21	0	1.00	1.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00	1.00
		NOR	99	0	0.56	0.38	0.00	0.00	0.00	0.00	0.56	0.24	0.38	0.80
	Perfluorooctane sulfonate	GER	40	1	1.28	1.00	0.10	0.60	0.00	0.00	0.97	0.55	1.00	1.00
		NOR	99	0	0.51	0.25	0.00	0.00	0.00	0.00	0.51	0.29	0.25	0.80
	Perfluorohexanoic acid	GER	21	0	1.00	1.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00	1.00
		NOR	99	0	0.56	0.25	0.00	0.00	0.00	0.00	0.56	0.34	0.25	0.90
	Perfluorooctanoic acid	GER	40	0	1.28	1.00	0.00	0.00	0.00	0.00	0.90	0.30	1.00	1.00
		NOR	99	0	0.76	0.25	0.00	0.00	0.00	0.00	0.76	0.54	0.25	1.30
	Perfluorononanoic acid	GER	21	0	1.00	1.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00	1.00
		NOR	99	0	0.56	0.25	0.00	0.00	0.00	0.00	0.56	0.34	0.25	0.90
	Perfluorodecanoic acid	GER	21	0	1.00	1.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00	1.00
		NOR	99	0	0.36	0.25	0.00	0.00	0.00	0.00	0.36	0.14	0.25	0.50
	Perfluoropentanoic acid	GER	21	0	1.00	1.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00	1.00
		NOR	50	0	0.22	0.22	0.00	0.00	0.00	0.00	0.22	0.01	0.22	0.25

N: sample number; LOQ: limit of quantification; SD: standard deviation; P50: percentile 50; P95: percentile 95; BFR: brominated flame retardants; NDLCBs: non-dioxin-like polychlorinated biphenyls; PFAS: perfluorinated alkylated substances; GER: Germany; NOR: Norway.

(a): Missing values were replaced by 0.

(b): All concentrations are given in whole weight of herring.

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Abbreviations

BfR	German Federal Institute for Risk Assessment (Bundesinstitut für Risikobewertung)
BFR	brominated flame retardant
BVL	Federal Office of Consumer Protection and Food Safety (Bundesamt für Verbraucherschutz und Lebensmittelsicherheit)
DL-PCBs	dioxin-like polychlorinated biphenyls
GER	Germany
IMR	Institute of Marine Research (Havforskningsinstituttet)
LOD	limit of detection
LOQ	limit of quantification
MRI	Max Rubner-Institut
N	sample number
NDL-PCBs	non-dioxin-like polychlorinated biphenyls
NIPH	Norwegian Institute of Public Health (Folkehelseinstituttet)
NOR	Norway
NSS	Norwegian Spring Spawning (herring stock)
P50	percentile 50
P95	percentile 95
PCDDs	polychlorinated dibenzo- <i>p</i> -dioxins
PCDFs	polychlorinated dibenzofurans
PFAS	perfluorinated alkylated substances
SD	standard deviation
TEF	Toxic Equivalency Factor
TEQ	Toxic Equivalent
UiO	University of Oslo
VKM	Norwegian Scientific Committee for Food and Environment (Vitenskapskomiteen for mat og miljø)
WHO	World Health Organization

Appendix A – Additional information on PCDD/Fs (dioxins) and DL-PCBs in herring investigated in monitoring programmes in Germany and Norway

Table A.1: Individual congeners of PCDD/Fs (dioxins) and DL-PCBs in herring investigated in monitoring programmes in Germany and Norway

Substance group	Substance	Sampling country	Valid N	Quantified N	Mean LOQ ^(a)	Substance concentration ^(b)			
						Mean lower bound	Mean upper bound	P95 lower bound	P95 upper bound
						pg WHO ₂₀₀₅ -TEQ/g			
PCDDs	1,2,3,4,6,7,8-HpCDD	GER	47	38	0.000	0.008	0.008	0.004	0.004
		NOR	100	18	0.000	0.000	0.000	0.001	0.001
	1,2,3,4,7,8-HxCDD	GER	47	40	0.001	0.004	0.005	0.013	0.013
		NOR	100	1	0.005	0.000	0.005	0.000	0.009
	1,2,3,6,7,8-HxCDD	GER	47	40	0.001	0.014	0.015	0.027	0.027
		NOR	100	61	0.006	0.005	0.008	0.017	0.017
	1,2,3,7,8,9-HxCDD	GER	47	37	0.001	0.003	0.004	0.010	0.010
		NOR	100	2	0.005	0.000	0.006	0.000	0.010
	1,2,3,7,8-PeCDD	GER	47	45	0.012	0.223	0.224	0.340	0.340
		NOR	100	60	0.074	0.062	0.098	0.180	0.195
	2,3,7,8-TCDD	GER	47	43	0.005	0.084	0.084	0.140	0.140
		NOR	100	6	0.048	0.002	0.048	0.029	0.078
OCDD	GER	47	27	0.000	0.000	0.000	0.000	0.000	
	NOR	100	7	0.000	0.000	0.000	0.000	0.000	
PCDFs	1,2,3,4,6,7,8-HpCDF	GER	47	40	0.000	0.001	0.001	0.004	0.004
		NOR	100	5	0.000	0.000	0.000	0.000	0.001
	1,2,3,4,7,8,9-HpCDF	GER	47	10	0.000	0.000	0.000	0.000	0.000
		NOR	100	2	0.000	0.000	0.000	0.000	0.001
	1,2,3,4,7,8-HxCDF	GER	47	43	0.001	0.010	0.010	0.021	0.021
		NOR	100	26	0.004	0.001	0.004	0.006	0.007
	1,2,3,6,7,8-HxCDF	GER	47	43	0.001	0.010	0.010	0.017	0.017
		NOR	100	70	0.004	0.004	0.005	0.010	0.010
	1,2,3,7,8,9-HxCDF	GER	47	10	0.001	0.001	0.002	0.009	0.009
		NOR	100	1	0.005	0.000	0.005	0.000	0.011
	1,2,3,7,8-PeCDF	GER	47	45	0.000	0.008	0.008	0.013	0.013
		NOR	100	89	0.003	0.004	0.005	0.009	0.009
	2,3,4,6,7,8-HxCDF	GER	47	43	0.001	0.011	0.012	0.023	0.023
		NOR	100	74	0.004	0.005	0.006	0.010	0.010
	2,3,4,7,8-PeCDF	GER	47	47	0.003	0.308	0.308	0.480	0.480
		NOR	100	100	0.028	0.180	0.180	0.300	0.300
	2,3,7,8-TCDF	GER	47	47	0.001	0.158	0.158	0.270	0.270
		NOR	100	100	0.011	0.098	0.098	0.200	0.200
PCDFs	OCDF	GER	47	24	0.000	0.000	0.000	0.000	0.000
		NOR	100	1	0.000	0.000	0.000	0.000	0.000

Substance group	Substance	Sampling country	Valid N	Quantified N	Mean LOQ ^(a)	Substance concentration ^(b)			
						Mean lower bound	Mean upper bound	P95 lower bound	P95 upper bound
						pg WHO ₂₀₀₅ -TEQ/g			
Non-ortho DL-PCBs	PCB-77	GER	47	45	0.000	0.002	0.002	0.003	0.003
		NOR	100	100	0.000	0.001	0.001	0.001	0.001
	PCB-81	GER	47	45	0.000	0.000	0.000	0.000	0.000
		NOR	100	2	0.000	0.000	0.000	0.000	0.000
	PCB-126	GER	47	47	0.002	0.781	0.781	1.200	1.200
		NOR	100	100	0.043	0.334	0.334	0.550	0.550
PCB-169	GER	47	47	0.000	0.081	0.081	0.117	0.117	
	NOR	100	100	0.008	0.054	0.054	0.104	0.104	
Mono-ortho DL-PCBs	PCB-105	GER	47	47	0.000	0.010	0.010	0.016	0.016
		NOR	100	100	0.000	0.009	0.009	0.015	0.015
	PCB-114	GER	47	45	0.000	0.001	0.001	0.001	0.001
		NOR	100	79	0.000	0.001	0.001	0.001	0.001
	PCB-118	GER	47	47	0.000	0.037	0.037	0.055	0.055
		NOR	100	100	0.000	0.029	0.029	0.050	0.050
	PCB-123	GER	47	45	0.000	0.000	0.000	0.001	0.001
		NOR	100	89	0.000	0.001	0.001	0.002	0.002
	PCB-156	GER	47	46	0.000	0.004	0.004	0.006	0.006
		NOR	100	99	0.000	0.002	0.002	0.003	0.003
	PCB-157	GER	47	45	0.000	0.001	0.001	0.002	0.002
		NOR	100	81	0.000	0.001	0.001	0.001	0.001
	PCB-167	GER	47	45	0.000	0.003	0.003	0.004	0.004
		NOR	100	97	0.000	0.001	0.001	0.002	0.002
	PCB-189	GER	47	45	0.000	0.000	0.000	0.001	0.001
		NOR	100	9	0.000	0.000	0.000	0.000	0.001

N: sample number; LOQ: limit of quantification; P95: percentile 95; PCDDs: polychlorinated dibenzo-*p*-dioxins; PCDFs: polychlorinated dibenzofurans; DL-PCBs: dioxin-like polychlorinated biphenyls; WHO World Health Organization; TEQ: Toxic Equivalents; GER: Germany; NOR: Norway.

(a): Missing values were replaced by 0.

(b): All concentrations are given in whole weight of herring.