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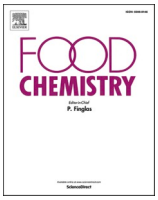

Sampling of Atlantic salmon using the Norwegian Quality cut (NQC) vs. Whole fillet; differences in contaminant and nutrient contents

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ABSTRACT

Risk- benefit assessments of seafood require high-quality food composition data. In accordance with EU regulations, Atlantic salmon (*Salmo salar*) has conventionally been sampled using the Norwegian Quality Cut (NQC), a sub-cut of the middle section of the fish, in Norwegian surveillance programs. By comparing the contents of nutrients and contaminants in 34 samples of farmed Atlantic salmon, we aimed to evaluate the representativeness of the NQC compared with the whole fillet. Of the 129 analytes evaluated, eight single analytes, in addition to 25 different fatty acids, showed significant differences between the cuts. Significant differences were evident for total fat, including eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), and sum PCB-6, but not for the sum of dioxins and dioxin-like PCBs. We further suggest that the NQC may still be used in large-scale sampling of Atlantic salmon, and that the whole fillet would be preferable when analysing the content of nutrients.

1. Introduction

Farmed Atlantic salmon (*Salmo salar*) has become a major part of the global aquaculture market due to its high economic and nutritional value (Asche, Roll, Sandvold, Sørvig, & Zhang, 2013; FAO, 2020). In 2020, close to 1.4 million metric tonnes of farmed Atlantic salmon were sold for human consumption (Fiskeridirektoratet [Directorate of Fisheries], 2021), amounting to 14 million meals of Norwegian farmed Atlantic salmon consumed around the world every single day (Sjømatråd, 2020). Although salmon contains nutrients that are beneficial for human health (Moxness Reksten et al., 2022; Nøstbakken et al., 2021), it also contains undesirable substances, such as persistent organic pollutants (POPs) and heavy metals (Nøstbakken et al., 2015). Therefore, to ensure proper food safety throughout the food chain, regular monitoring programs that include rigorous quality control systems and extensive sampling are key aspects.

In accordance with EU regulations, all sectors of food production must comply with general principles and requirements of food safety. Consequently, large-scale sampling with analysis of certain substances and their residues in food and feed is therefore mandatory. For aquaculture products, the EU council directive 96/23/EC specifies that the minimum number of samples to be collected each year must be at least 1 per 100 tonnes of annual production (Directive, 1996; The European Parliament and the Council of the European Union, 2017). Additionally, samples should be taken from at least 10% of the registered sites of production. Given that Norway currently has over 1000 registered production sites (Fiskeridirektoratet [Directorate of Fisheries], 2021), and that two thirds of the samples should be collected at slaughter, which for salmon is at a size of approximately 4–5 kg, approximately 60 tonnes of samples need to be collected from more than 100 different sampling locations annually, making the logistics of the sampling excessively challenging. It is recommended that for fish species of intermediate size (1–6 kg), the sample should be taken as a sub-cut of the middle part of the fish, extending from the backbone to the belly of the fish (The European Parliament and the Council of the European Union, 2017).

Previous analyses of quality and flesh characteristics of Atlantic salmon have used the Norwegian Quality Cut (NQC) as a representative sample of the whole fillet (Einen, Mørkøre, Rørå, & Thomassen, 1999; Johnsen, Hagen, & Bendiksen, 2011; Nøstbakken et al., 2021; Veliyulin, van der Zwaag, Burk, & Erikson, 2005). The NQC was created to ensure that the sampling of Norwegian farmed Atlantic salmon is performed in a structured and unambiguous manner, allowing analytical values to be directly comparable between samples (Norwegian standard 9401.E, N.

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S., 1996). Nevertheless, it is well-known that the fat content is not heterogeneously distributed in the whole of the salmon fillet (Zhu et al., 2014). This can affect the distribution of the marine omega-3 fatty acids, eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), which have been linked to many of the health benefits of consuming fatty fish such as salmon. Further, heterogeneously distributed fat may also affect the distribution of fat-soluble contaminants, such as dioxins and dioxin-like polychlorinated biphenyls (dl-PCBs) and fat-soluble vitamins. Thus, in this study, we aimed to assess whether the NQC can be used as a representative sample of the whole salmon fillet for sampling of a range of contaminants, as well as for selected nutrients.

2. Materials and methods

2.1. Sampling procedure and methodology

Thirty-four farmed Atlantic salmon (*Salmo salar*) were collected in June 2017 from Sekkingstad AS, a Norwegian salmon and trout slaughterhouse and distributor located outside of Bergen, Norway. The salmon was slaughtered at the slaughterhouse and were collected after slaughter. The salmon were farmed at Erko Seafood AS, a Norwegian salmon producer also located outside of Bergen. Mean length was 68 ± 7 cm and mean weight was 3723 ± 1370 g, with a mean K-factor (condition factor; a numerical value reflective of a salmonid's condition) of 1.1 ± 0.2. The fish were slaughtered and transported in isoprene boxes containing freezing elements to the Institute of Marine Research (IMR) where for each fish, a NQC was taken from one side of the fish, whereas the whole fillet was sampled from the other side of the fish (Fig. 1). The NQC is a standardised cross section of the fish extending from posterior of the dorsal fin to the anterior of the anal fin (Norwegian standard 9401.E, N. S., 1996). The fillet cut includes the whole side of the fish and is collected by making a diagonal cut behind the pectoral fin towards the head and leading the knife along the backbone of the fish down to the tail. Both cuts included discarding of the spine, bones, and skin, and inclusion of the subcutaneous fat. The samples were homogenised and analysed for a range of different nutrients and contaminants (Table 1). Methods used are accredited according to NS-EN ISO/IEC 17,025 (2017), and the laboratory regularly take part in international proficiency tests. The analytical methodology used for this study has been described previously (Lundebye et al., 2017; Moxness Reksten et al., 2020; Valdersnes, Nilsen, Breivik, Borge, & Maage, 2017). A summary of the methods can be found in supplement (Table S1).

Data are presented per wet weight due to relevance for legislation, and since this is most relevant for estimation of food safety.

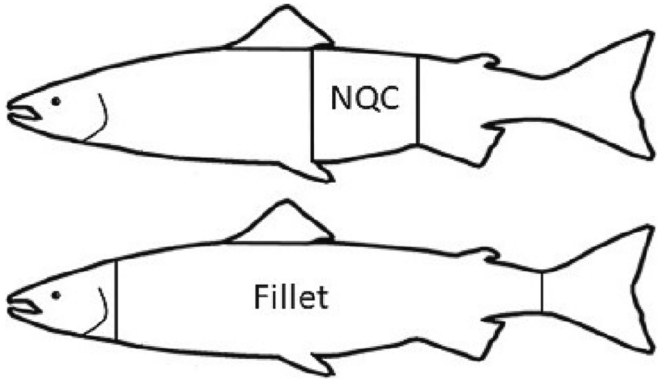

Fig. 1. Schematic of the cuts used. One side of the fish was cut using the Norwegian Quality Cut (NQC), and on the other side of the fish, the whole fillet was cut. Both cuts were homogenised and analysed. Picture was collected and modified from the publication of Johnsen et al. (2011).

2.2. Statistics

Most of the data passed the normality tests (Kolmogorov-Smirnov test and visual inspection of histograms and Q-Q plots) and the test for homogeneity of variance (Levene's test) in the software Statistica version 13.4.0.14 (TIBCO Software Inc., Palo Alto, CA, USA). Therefore, these data have been treated using the parametric Student's T-test for comparison between the NQC and whole fillet with a significance level of $p < 0.05$. Four of the individual fatty acids (17:0, 18:1n-7, 18:2n-6, and 22:5n-6) and two of the sums of fatty acids (sum 18:1 and sum n-6) did not pass Levene's test, so for these the non-parametric Wilcoxon-Mann-Whitney test was used. All values are presented as means ± standard deviations (SD). Figures were made, and basic statistics were also assessed, using GraphPad Prism® 8 (GraphPad Software Inc., La Jolla, CA, USA). For results below the limit of quantification (LOQ), an upper bound (UB) approach was used, where contents below the LOQ are set equal to the LOQ value. However, for analytes where < 50% of the results were below the LOQ, no values are presented.

2.3. Assessment of differences in concentrations of PRI, MOE, and ML

To assess potential severity of differences between the the NQC and the whole fillet used in this study, we evaluated the nutrients that showed statistically significant differences between the two cuts in the context of the dietary reference values (DRVs) as stated by the European Safety Authority (EFSA). For EPA and DHA, an adequate intake (AI) of 250 mg/day was used as DRV (EFSA Panel on Dietetic Products N., Allergies Scientific Opinion on Dietary Reference Values for fats, including saturated fatty acids, polyunsaturated fatty acids, monounsaturated fatty acids, trans fatty acids, and cholesterol EFSA Journal 8 3 2010, 2010). For thiamine and iron, population reference intake (PRI) values of 0.4 mg/1000 kcal (assuming a standard diet of 2500 kcal/day = 1 mg thiamine/day) (EFSA Panel on Dietetic Products, Nutrition and Allergies, Turck, D., Bresson, J.-L., Burlingame, B., Dean, T., … Neuhäuser-Berthold, M. (2016), 2016) and 11 mg/day (EFSA Panel on Dietetic Products, 2015), were used as DRVs, respectively. Given the general European recommendation of one serving of fatty fish per week (European Commission, n.d; we estimated the contribution of one weekly serving of a standard salmon portion size of 175 g (Østerhold Østerhold Dalane, Martinsen Bergvatn, Kielland, & Carlsen, 2015). We further evaluated contaminants showing statistical differences between the NQC and the whole fillet using maximum limits (ML) as set by the EU, or MOE set by EFSA. The MOE was calculated using one serving of 175 g salmon for an adult of 70 kg for PBDE 153, as described in (EFSA Panel on Contaminants in the Food Chain, 2011; Nøstbakken et al., 2018), whereas the more legislatively relevant MLs set by the EU were used for PCB-6 (Regulation (EU), 2011).

3. Results

In this study, a range of nutrients and contaminants were analysed in both NQC and whole fillet of farmed Atlantic salmon (Table 1). Of the 84 single compounds analysed, 41 analytes had more than 50% of the measurements above the LOQ making it possible to compare the two sampling methods. Of these, only eight compounds showed a significant difference between the NQC and the whole fillet (Fig. 3). Out of these eight compounds, only one of the analytes showed higher concentrations in the NQC compared to whole fillet, whereas the other seven analytes were higher in the fillet than in the NQC. Fatty acids and sums of fatty acids are presented in the supplement (Table S2). Of these, 13 of the 45 different fatty acids analysed had greater than 50% of the measurements below the LOQ and are thus not presented.

NQCs from Atlantic salmon showed a significantly lower content of total fat (15.5 ± 2.7 g/100 g) than whole fillet (18.0 ± 3.4 g/100 g, $p = 0.002$). Correspondingly, the content of the marine long-chain omega-3 polyunsaturated fatty acids (n-3 LC-PUFA), EPA + DHA, were also

Table 1
Differences between NQC and fillet for a range of nutrients and contaminants. Significant differences ($p < 0.05$) are highlighted in red. If more than 50% of the values for each analyte were below the LOQ, no value is presented.

	Unit	Fillet mean	NQC mean	P-value	SD fillet	SD NQC	Diff %[1]
Total fat	g/100 g	18.0	15.5	0.002	3	3	− 14
20:5n-3 (EPA)	g/100 g	0.410	0.369	0.029	0.09	0.07	− 10
22:6n-3 (DHA)	g/100 g	0.801	0.739	0.034	0.1	0.1	− 8
Sum EPA + DHA	g/100 g	1.21	1.11	0.028	0.2	0.2	− 9
Vitamin A_1	µg/100 g	3.21	2.98	0.161	0.7	0.7	
Vitamin A_2	µg/100 g	11.1	9.88	0.153	3	4	
Thiamine (B_1)	mg/100 g	0.21	0.16	0.004	0.08	0.06	− 25
Cobalamin (B_{12})	µg/100 g	2.3	2.2	0.769	0.5	0.5	
Vitamin D_3	µg/100 g	11	10	0.471	4	4	
Silver (Ag)							
Arsenic (As)	mg/kg	0.538	0.508	0.224	0.1	0.1	
Cadmium (Cd)							
Cobalt (Co)							
Chromium (Cr)							
Copper (Cu)	mg/100 g	0.038	0.037	0.800	0.02	0.004	
Iron (Fe)	mg/100 g	0.29	0.33	0.003	0.05	0.06	14
Mercury (Hg)	mg/kg	0.012	0.011	0.654	0.002	0.001	
Iodine (I)	µg/100 g	6.2	6.1	0.674	1	1	
Manganese (Mn)	mg/100 g	0.0082	0.0066	0.055	0.004	0.002	
Molybdenum (Mo)							
Nickel (Ni)							
Lead (Pb)							
Selenium (Se)	µg/100 g	8.9	8.9	0.670	0.9	0.8	
Vanadium (V)	mg/100 g	0.00064	0.00063	0.905	0.0003	0.0005	
Zinc (Zn)	mg/100 g	0.38	0.39	0.400	0.04	0.05	
2378-TCDD							
12378-PeCDD							
123478-HxCDD							
123678-HxCDD							
123789-HxCDD							
1234678-HpCDD							
OCDD							
Sum PCDD	pg TEQ/g	0.17	0.17	0.493	0.05	0.05	
2378-TCDF	pg TEQ/g	0.0400	0.0400	0.972	0.005	0.008	
12378-PeCDF							
23478-PeCDF	pg TEQ/g	0.042	0.045	0.377	0.008	0.02	
123478-HxCDF							
123678-HxCDF							
123789-HxCDF							
234678-HxCDF							
1234678-HpCDF							
1234789-HpCDF							
OCDF							
Sum PCDF	pg TEQ/g	0.10	0.11	0.287	0.01	0.03	
PCB-77	pg TEQ/g	0.0020	0.0010	0.457	0.0002	0.0003	
PCB-81	pg TEQ/g	0.00018	0.00016	0.036	0.00006	0.00003	− 13
PCB-126	pg TEQ/g	0.41	0.41	0.634	0.05	0.08	
PCB-169	pg TEQ/g	0.029	0.028	0.375	0.004	0.006	
Sum non-ortho PCB	pg TEQ/g	0.44	0.44	0.609	0.05	0.09	
PCB-105	pg TEQ/g	0.0072	0.0070	0.329	0.001	0.001	
PCB-114							
PCB-118	pg TEQ/g	0.027	0.026	0.302	0.003	0.004	
PCB-123							
PCB-156	pg TEQ/g	0.0037	0.0026	0.286	0.006	0.0004	
PCB-157	pg TEQ/g	0.00090	0.0070	0.185	0.0009	0.0001	
PCB-167	pg TEQ/g	0.0019	0.0018	0.191	0.0006	0.0003	
PCB-189							
Sum mono-ortho PCB	pg TEQ/g	0.042	0.039	0.163	0.009	0.006	
Sum dioxins	pg TEQ/g	0.26	0.28	0.332	0.06	0.06	
Sum PCBs	pg TEQ/g	0.49	0.47	0.519	0.05	0.09	
Sum dioxins and dl-PCBs	pg TEQ/g	0.75	0.75	0.930	0.09	0.1	
PCB-101	ng/g	1.3	1.2	0.041	0.2	0.2	− 8
PCB-138	ng/g	1.6	1.5	0.151	0.2	0.3	
PCB-153	ng/g	3.2	2.8	0.085	1.2	0.5	
PCB-180	ng/g	0.56	0.55	0.480	0.1	0.1	
PCB-28	ng/g	0.17	0.16	0.070	0.03	0.03	
PCB-52	ng/g	0.57	0.51	0.008	0.08	0.1	− 11
Sum PCB-6	ng/g	7.5	6.8	0.020	1	1	− 9
PBDE 28	ng/g	0.017	0.017	0.447	0.002	0.002	
PBDE 47	ng/g	0.31	0.29	0.060	0.03	0.04	
PBDE 49	ng/g	0.11	0.10	0.556	0.02	0.03	
PBDE 66	ng/g	0.012	0.012	0.743	0.002	0.003	

(*continued on next page*)

Table 1 (*continued*)

	Unit	Fillet mean	NQC mean	P-value	SD fillet	SD NQC	Diff %[1]
PBDE 99	ng/g	0.047	0.047	0.842	0.005	0.006	
PBDE 100	ng/g	0.075	0.072	0.177	0.008	0.01	
PBDE 119	ng/g	0.0048	0.0038	0.014	0.002	0.002	− 21
PBDE 138							
PBDE 153	ng/g	0.010	0.0090	0.030	0.001	0.001	− 7
PBDE 154	ng/g	0.040	0.039	0.318	0.004	0.006	
PBDE 183							
PBDE 7 (UB)	ng/g	0.52	0.50	0.108	0.05	0.06	
PFBA							
PFBS							
PFDA							
PFDoDA							
PFDS							
PFHpA							
PFHxA							
PFHxS							
PFNA							
PFOA							
PFOS							
PFOSA							
PFTeDA							
PFTrDA							
PFUdA							

[1]Difference in percentage between the content of the analyte in the NQC compared with the fillet.
Abbreviations: Diff: difference; NQC: Norwegian quality cut; SD: standard deviation; TEQ: dioxin toxicity equivalence.

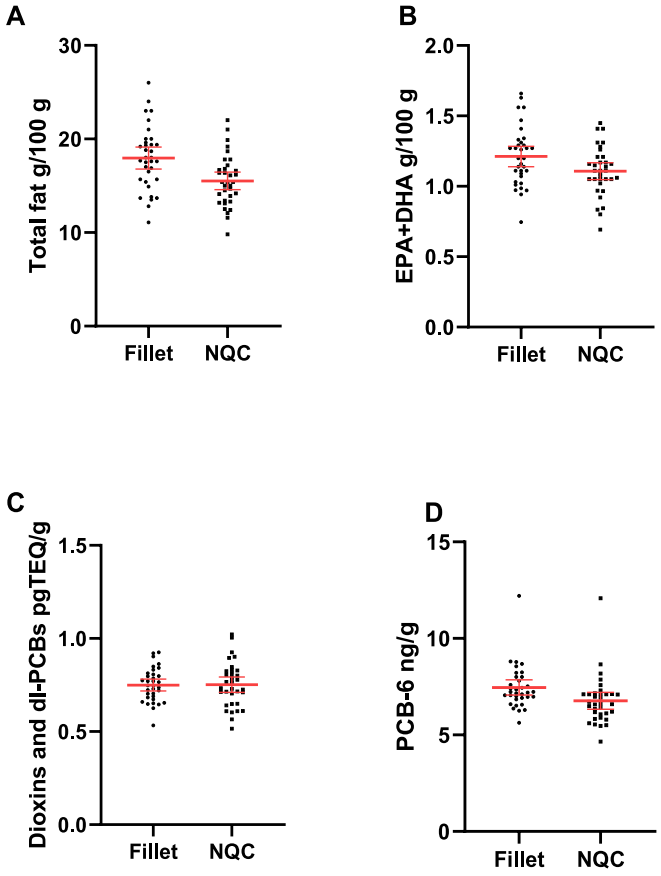

Fig. 2. Distribution of the contents of selected compounds between whole fillet and the Norwegian Quality Cut (NQC). A) Total fat, B) eicosapentaenoic acid (EPA) + docosahexaenoic acid (DHA), C) dioxins and dioxin-like polychlorinated biphenyls (dl-PCBs), D) PCB-6. The concentrations of total fat, EPA + DHA, and PCB-6 in the fillets were significantly higher than in the NQC ($p < 0.05$) following a Student's T-test. Dioxins and dl-PCBs showed no significant differences.

significantly lower in the NQC ($p = 0.028$) compared with the whole fillet (Fig. 2). Overall, 25 of the 32 fatty acids that had more than 50% of the values above the LOQ were significantly different in the NQC compared with the whole fillet (Table 1, appendix). Of these, all were found in the highest amounts in the whole fillet. The thiamine content was 25% higher in the fillet compared with the NQC, making this the largest percent difference of any of the analytes. A significantly higher content of iron was found in the NQC (0.33 ± 0.055 mg/100 g) compared with the fillet (0.29 ± 0.054 mg/100 g), making it the only analyte presenting a significantly higher content in the NQC. No significant differences were found for the concentrations of the fat-soluble vitamins, vitamin A and vitamin D, nor for vitamin B_{12} or the minerals iodine, selenium, and zinc.

Only 11 of 29 congeners of dioxins and dl-PCBs had measurement with more than 50% of the values above the LOQ. The content of neither

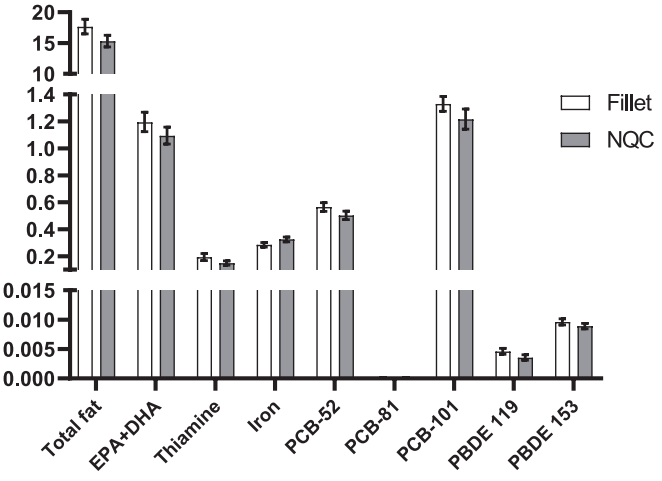

Fig. 3. Differences in contents of the analytes that showed significant differences between the Norwegian Quality Cut (NQC) and whole fillet following a Student's T-test ($p < 0.05$). The analytes are presented in different units: total fat (g/100 g), eicosapentaenoic acid (EPA) + docosahexaenoic acid (DHA) (g/100 g), thiamine (mg/100 g), iron (mg/100 g), polychlorinated biphenyls-52 (PCB-52) (ng/g), PCB-81 (pg/g), PCB-101 (ng/g), polybrominated diphenyl ethers 119 (PBDE 119) (ng/g), and PBDE 153 (ng/g).

the sum of dioxins and dl-PCBs, nor the sum of dioxins alone were significantly different between the NQC and whole fillet. For individual congeners, only the non-ortho PCB-81 showed a significant difference ($p = 0.036$) between the NQC (0.00016 ± 0.00003 pg TEQ/g) and whole fillet (0.00018 ± 0.00006 pg TEQ/g). For PCB-6, there were significant differences between the cuts for PCB-52, PCB-101, and sum PCB-6, with 11, 8 and, 9% higher concentrations in the fillet than in the NQC, respectively. None of the heavy metals, nor the metalloid arsenic (As), showed significant differences between the two cuts. However, for both cadmium (Cd) and lead (Pb), more than 50% of the measurements were below the LOQ. For the polybrominated diphenyl ethers (PBDEs), only PBDE 119 and 153 were significantly different between the cuts, with 21 and 7% higher contents in the fillet, respectively. None of the per- and polyfluoroalkyl substances (PFAs) had more than 50% of the measurements above the LOQ.

When the concentrations of sum dioxins and dl-PCBs, PCB-6, and EPA + DHA were assessed per lipid-weight instead of per wet weight, the sum of dioxins and dl-PCBs and EPA + DHA were significantly higher in the NQC (5.0 pg TEQ/g lipid and 0.072 g/g lipid, respectively) than in the fillet (4.3 pg TEQ/g lipid and 0.067 g/g lipid, respectively). However, PCB-6 per lipid weight was not significantly different between the cuts (Fig. 2, appendix).

An evaluation of the analytes presenting statistically significant differences was performed in the context of PRI, MOE, and ML, in order to illustrate the impact of using the whole fillet or the NQC in risk–benefit assessments of seafood where salmon is included (Fig. 4). Overall, the differences between the two cuts were small. One serving of farmed Atlantic salmon, using either NQC or fillet, exceeded the AI for EPA + DHA by 7–8 times, meeting 777 and 847% of the AI, respectively. For thiamine, which salmon generally has not been considered a major source of, one portion of the NQC and fillet was able to meet 28 and 37% of the PRI, respectively. For iron, the differences were even smaller, with both cuts meeting approximately 5% of the PRI. For PBDE 153, one serving of salmon using whole fillet would amount to a MOE of 384, whereas for the NQC, it amounted to a MOE of 427. For PCB-6, the concentration in the fillet was 7.5 ng/g, comprising 10% of the ML of 75 ng/g, whereas the concentration in the NQC was 6.8 ng/g, comprising 9% of the ML.

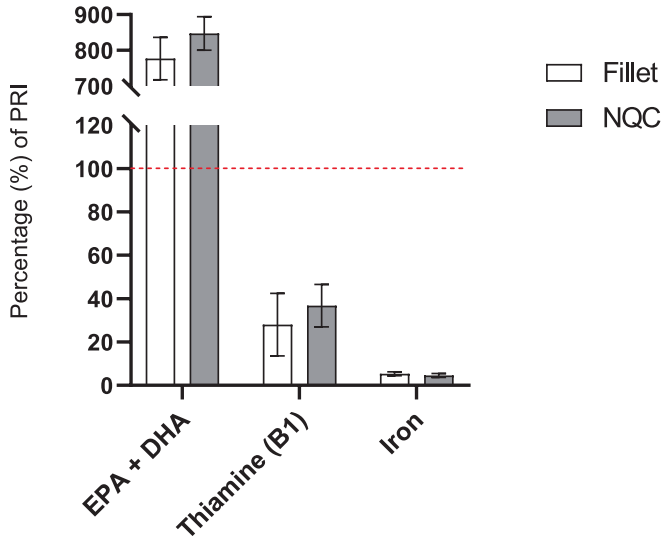

Fig. 4. One portion of farmed Atlantic salmon (175 g) was compared with the population reference intake (PRI) values as set by the European Food Safety Authority (EFSA), for analytes presenting statistically significant differences between whole fillet and the Norwegian Quality Cut (NQC). The red line illustrates 100% of the PRI. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

4. Discussion

This study compared the contents of a range of nutrients and contaminants in two different cuts of farmed Atlantic salmon, namely the NQC and the whole fillet. Although the fat content was lower in the NQC, few significant differences were identified between the cuts for contaminants with regulatory limits, such as mercury (Hg) or the sum of dioxins and dl-PCBs. However, PCB-6 was shown to be 9% lower in the NQC compared with the whole fillet. Nevertheless, since both the difference between the cuts and the relative contribution of PCB-6 to the ML are small, the advantage of continuing the standardised sampling with a time-series monitoring the development of contaminants in farmed salmon should outweigh the disadvantages of underestimating PCB-6 with 9%. Furthermore, of the 129 analytes evaluated, 25 individual fatty acids and eight other analytes in total, showed significant differences between the cuts. Of the 29 contaminants with greater than 50% of the values above the LOQ, only five individual compounds were significantly different.

Our study is the first to compare the fat content in NQC and whole fillet and found that the total fat content was significantly lower in the NQC compared with the whole fillet of the salmon. Fat is known to be heterogeneously distributed throughout the salmon fillet, with increasing contents from the tail region towards the head and decreasing contents from ventral to dorsal (Zhu et al., 2014). Lipophilic environmental contaminants, such as organochlorine contaminants, can be expected to accumulate in the fat, and the fat content is therefore of importance when assessing contaminant concentrations. We observed a 14% lower fat content in the NQC compared with the whole fillet in this study, which was not sufficient to cause significant differences in the contents of sum dioxins and dl-PCBs between the two cuts. However, the content of PCB-6 was significantly higher in the fillet than in the NQC. Notably, if the contents of sum dioxins and dl-PCBs were quantified per lipid content instead of per wet weight, the contents in the NQC were significantly higher than in the fillet. The same was observed for EPA + DHA. However, the concentration of PCB-6 adjusted per lipid weight was shown to be equal between the two cuts. One factor which may explain the differences in fat content between the cuts is the proportion of the belly flap included in the NQC. The belly flap does not only contain more total fat, but it also differs in the class of lipids present. The belly flap from salmon has previously been shown to consist of substantially more triacylglycerols, whereas the loin consists of more phospholipids (Nanton et al., 2007). It can be hypothesised that this may affect the accumulation of contaminants and nutrients in the different parts. However, this have not been assessed in the design of this study and can therefore not be established.

Further, the lack of difference between the two cuts concerning dioxins and dl-PCBs may also be due to the many congeners with values below the LOQ, making the analytical limitations more pertinent than the different sampling cuts. PCB-81, which is a dl-PCB, did show a significantly higher concentration in the fillet than in the NQC. However, PCB-81 constitutes < 0.03% of the total TEQ of the sum of dioxins and dl-PCBs and thus will not substantially impact food safety assessments as the TWI is based on the sum TEQ of all 29 congeners.

All measured concentrations have an analytical uncertainty. The measurement uncertainty varies for the different methods used (Moxness Reksten et al., 2020). For total fat, there is a 5–8% measurement uncertainty depending on the amount of fat present in the matrix, whereas for several of the contaminants, the measurement uncertainty is around 30–40% for concentrations close to the LOQ. The measurement uncertainty of mercury can be as high as 70% for concentrations below 0.05 mg/kg, which most of the values in this study were below. However, although a high measurement uncertainty will affect the single analytical results, the impact it will have on the mean value will be reduced with the number of samples analysed. Nevertheless, analytical

uncertainty and high LOQs seemed to have a greater impact on the variance in our data than the chosen cut (Nøstbakken et al., 2021). However, as analytical methods improve, the choice of matrix analysed may turn out to be a greater source of variance in the future.

Although the NQC is widely used in the literature, very few studies have previously evaluated whether there are any differences between the NQC and the whole salmon fillet in terms of nutrients and contaminants. Forsberg and Guttormsen (2006) reported that the content of astaxanthin, a carotenoid responsible for the characteristic red colour of salmon fillets, is significantly higher in the NQC compared with the whole fillet. Like the distribution of fat, astaxanthin is not distributed evenly within the fillet, with higher concentrations deposited in the tail and lower concentrations towards the anterior of the fish. As the NQC is located at the posterior part of the fish, this was not surprising (Forsberg & Guttormsen, 2006).

To visualise the differences between using the NQC and the whole fillet in risk–benefit assessments of seafood, we assessed the analytes presenting significant differences in view of the PRI, MOE, and ML. Use of the NQC rather than the whole fillet would have the greatest impact on EPA + DHA intakes, where a difference of 70 percentage points was estimated between the NQC and the whole fillet. However, since one portion of farmed salmon contributes with approximately 8 times the AI of EPA + DHA, we argue that this difference will not be of great importance in the broader view. Most health authorities recommend an EPA and DHA intake of between 200 and 500 mg/day (Global Organization for EPA and DHA Omega-3 Organization (2014)), and whether one portion of farmed salmon is able to provide 777 or 847% of the AI does not substantially impact risk–benefit assessments considering that farmed Atlantic salmon already is a major source of EPA and DHA. Regarding the contaminants measured, the concentrations in the different cuts did not affect the risk assessment considerably enough to cause any risk, mainly since there was no significant difference for dioxins and dl-PCBs, which is the most critical contaminants in regard to risk assessment of fatty fish. Furthermore, for the contaminants that significantly differed, and for which a MOE or ML are established, the levels in both NQC and whole fillet were well below the critical point due to small differences between the cuts and low concentrations of contaminants. Furthermore, when conducting risk-benefits assessments of seafood, other factors inherent within the assessment, such as the limitations and uncertainties associated with collecting dietary intake data and uncertainties related to analytical measurements, may play a greater role. Additionally, even within the same fish species, reared at the same facility and fed the same feed, there is still a high degree of intra-species variability for most nutrients and contaminants present between each individual fish, as evidenced by the minimum and maximum EPA + DHA values of 0.693 and 1.45 g/100 g for NQC, and 0.746 and 1.66 g/100 g for whole fillet, respectively (see Fig. 2). This illustrates that in either case, the calculations of possible health benefits associated with fish consumption is going to be based on estimated averages showing a high degree of variance, and that using data based on the NQC is not necessarily the largest source of variation.

5. Conclusions

In conclusion, the NQC differed from the whole fillet in terms of eight out of the 84 single compounds analysed, not including sums and individual fatty acids. We did not find any significant differences between the sum of dioxins and dl-PCBs, nor the sum of dioxins alone, between the NQC and the fillet. This indicates that the NQC is a representative cut of the whole salmon fillet in terms of the most important contaminant contents, and for practical reasons, we suggest that the NQC may still be used in large scale surveillance of contaminants in farmed Atlantic salmon. However, analysts should be aware of the difference between the cuts for PCB-6. For nutrients, significant differences were found for total fat and for most of the analysed fatty acids, as well as for thiamine and iron contents. Salmon is not considered a considerable source of thiamine and iron; however, it is considered a major source of n-3 LC-PUFA, EPA and DHA. This suggests that the whole fillet would be preferable when analysing the contents of various nutrients in farmed Atlantic salmon. Analysts should be aware of these differences, particularly in fat content, and acknowledge that whole fillet will provide the best representative sample and take this into account when assessing risk–benefit assessments of seafood where salmon is included.

CRediT authorship contribution statement

Ole Jakob Nøstbakken: Conceptualization, Formal analysis, Project administration, Methodology, Validation, Investigation, Writing – review & editing. **Amalie Moxness Reksten:** Formal analysis, Visualization, Writing – original draft, Writing – review & editing. **Rita Hannisdal:** Conceptualization, Methodology, Validation, Investigation, Writing – review & editing. **Lisbeth Dahl:** Resources, Writing – review & editing, Funding acquisition. **Arne Duinker:** Conceptualization, Project administration, Methodology, Investigation, Writing – review & editing.

Declaration of Competing Interest

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

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

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