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Radioactive substances in Norwegian farmed Atlantic salmon (*Salmo salar*)

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Radioactive substances in Norwegian farmed Atlantic salmon (*Salmo salar*)

Forfatter(e):
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Sammendrag (norsk):
Nivåene av den menneskeskapte radionukliden cesium-137 (^{137}Cs) i norsk oppdrettslaks (*Salmo salar*) er svært lave, og langt under grenseverdien på 600 Bq/kg satt av norske myndigheter etter Tsjernobyl-ulykken. Nivåene av radioaktiv forurensning i fôr er tilsvarende lave. Sammenlignet med vill fisk fra norske havområder har norsk oppdrettslaks omtrent like eller lavere nivåer av både naturlige og menneskeskapte radionuklider. Det ble ikke funnet geografiske variasjoner i nivåene av ^{137}Cs i oppdrettslaks. Innholdet av radioaktiv forurensning i norsk oppdrettslaks er så lavt at det ikke medfører noen helserisiko for konsumenter.

Summary (English):
The levels of the anthropogenic radionuclide cesium-137 (^{137}Cs) in Norwegian farmed Atlantic salmon (*Salmo salar*) are about three orders of magnitude lower than the intervention level for radioactive cesium in food set by the Norwegian authorities after the Chernobyl accident. Levels of anthropogenic radionuclides in fish feed are likewise very low. The levels of anthropogenic and natural radionuclides found in farmed salmon in the present study are comparable to or lower than the levels found in other fish species in the North Atlantic Ocean. Any potential health risk caused by the levels of radionuclides found in farmed salmon in the present study will be very low and of no concern to the consumer.

Emneord (norsk):	**Subject heading (English):**
1. Radioaktiv forurensning	**1. Radioactive contamination**
2. Naturlige radionuklider	**2. Natural radionuclides**
3. Norsk oppdrettslaks (*Salmo salar*)	**3. Norwegian farmed Atlantic salmon**

Hilde Elise Heldal	Jarle Klungsøyr
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prosjektleder	faggruppeleder

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Radioactive substances in Norwegian farmed Atlantic salmon (*Salmo salar*)

Summary

In this report, we present the results of the first comprehensive survey of anthropogenic radionuclides (^{137}Cs, ^{90}Sr, ^{238}Pu, $^{239,240}Pu$ and ^{241}Am) in farmed Atlantic salmon (*Salmo salar*) and manufactured fish feed from Norway. The survey was conducted during 2016. Cesium-137 (^{137}Cs) was found in all samples of farmed salmon. The activity concentrations are, however, low, and range from 0.05 to 0.25 Bq/kg fresh weight. In comparison, the Norwegian authorities set a maximum permitted level for radioactive cesium in food of 600 Bq/kg fresh weight after the Chernobyl accident. No other anthropogenic radionuclides were detected in farmed salmon. Likewise, the only anthropogenic radionuclide detected in fish feed was ^{137}Cs, and the activity concentrations ranged from below the detection limit to 0.54 Bq/kg fresh weight. This report contributes to increased knowledge and better documentation of the levels of radioactive contamination in farmed salmon and fish feed from Norway.

The activity concentrations of the natural radionuclide potassium-40 (^{40}K) in farmed salmon and fish feed ranged from 87.6 to 142.5 and 167.7 to 303.9 Bq/kg fresh weight, respectively. The activity concentrations of radium-226 (^{226}Ra) and radium-228 (^{228}Ra) were below the detection limit in all samples of farmed salmon. Activity concentrations of ^{226}Ra in fish feed were also below the detection limit, while those of ^{228}Ra in fish feed varied from 1.7 to 6.9 Bq/kg fresh weight. Activity concentrations of lead-210 (^{210}Pb) and polonium-210 (^{210}Po) in farmed salmon ranged from 0.032 to 0.07 Bq/kg fresh weight and 0.003 to 0.023 Bq/kg fresh weight, respectively. The levels of anthropogenic and natural radionuclides found in farmed salmon in the present study are comparable to or lower than the levels found in other fish species in the North Atlantic Ocean.

It is important to keep all radiation exposure as low as possible, to minimise the risk of developing cancer. As the levels of radionuclides are comparable to or lower than in wild fish species, any potential health risk caused by the levels found in farmed salmon in this study will be very low and should be of no concern to the consumer.

1. Introduction

Norway produces more than half of all farmed Atlantic salmon (*Salmo salar*) worldwide, and exported salmon worth NOK 61.4 billion in 2016 (Norwegian Seafood Council). This is the highest export value of salmon ever recorded. Both Norwegian and foreign consumers are concerned about how safe the fish is, and request documentation of the levels of pollutants in farmed fish. Levels of heavy metals and organic pollutants in farmed Atlantic salmon from Norway are routinely investigated (Nøstbakken et al. 2015); however, a systematic and thorough survey of the levels of natural and anthropogenic radionuclides has never been performed.

Radioactive contamination was introduced to Norwegian marine areas more than 60 years ago. An updated overview of past and present sources is given in e.g. AMAP (2015). The main sources are:

- Global fallout following atmospheric nuclear weapons testing in the 1950s and 1960s
- Local fallout following nuclear weapons testing conducted at Novaya Zemlya in the same period
- Fallout from the Chernobyl accident in 1986
- Authorised discharges from the nuclear reprocessing facilities at Sellafield (UK) and Cap de la Hague (France)

Potential contamination sources include radioactive waste dumped in the fjords on the east coast of Novaya Zemlya and the sunken nuclear submarines “Komsomolets” in the Norwegian Sea and “K-159” in the Barents Sea. Figure 1 shows real and potential sources of radioactive contamination in Norwegian waters.

Experience from earlier events have shown that both national and international markets are sensitive even to rumours of radioactive contamination in fish and seafood, and this may cause negative economic impacts. Documentation of the levels of radioactive contamination in wild fish and seafood from Norwegian waters are therefore very important to the Norwegian authorities, the export industry and the population as a whole. Radioactive contamination in wild fish has been monitored for several decades (e.g. Gwynn et al. 2012; Heldal et al. 2015). In this report, we present the results of the first comprehensive survey of the anthropogenic radionuclides cesium-137 (^{137}Cs), strontium-90 (^{90}Sr), plutonium-238 (^{238}Pu), plutonium-239,240 (^{239,240}Pu) and americium-241 (^{241}Am) in farmed Atlantic salmon and manufactured fish feed from Norway.

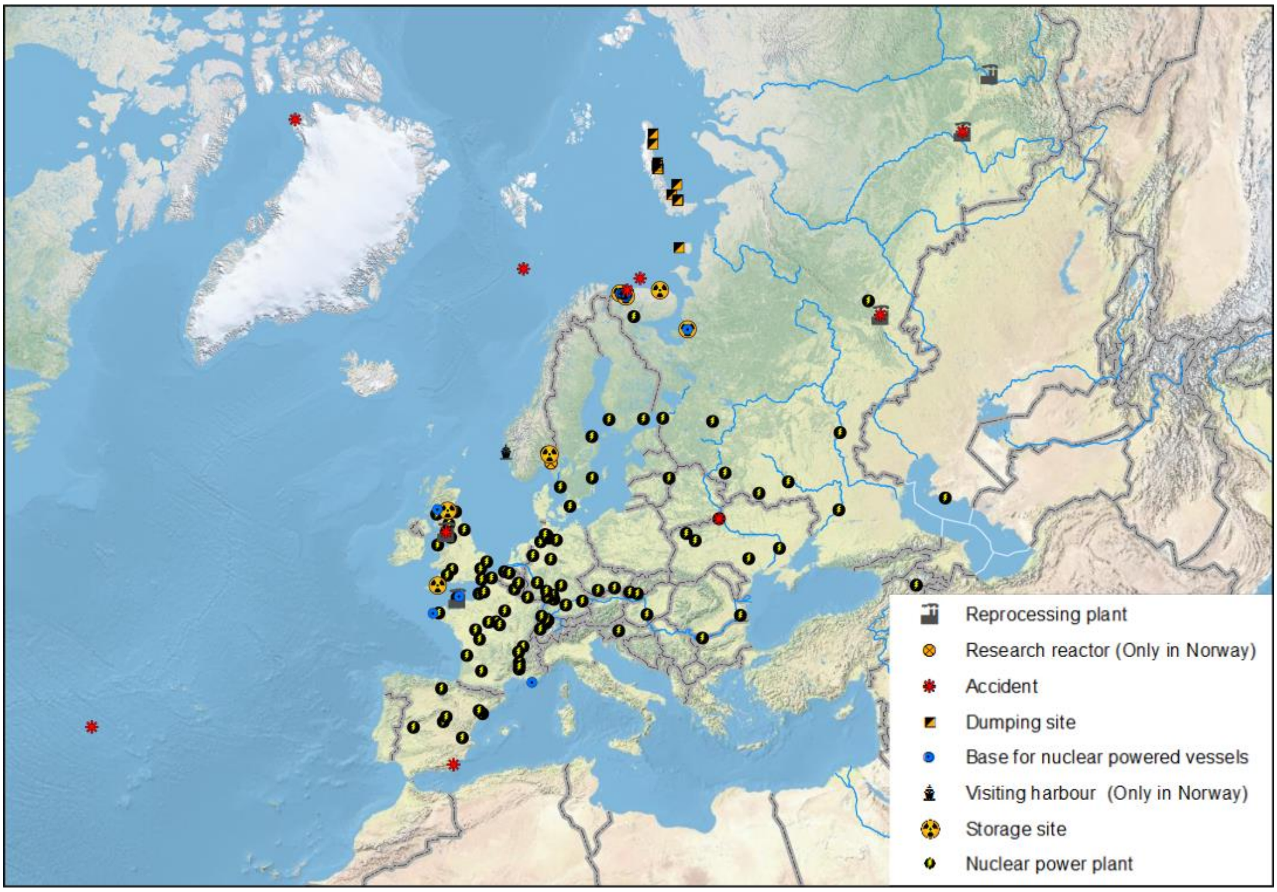

Figure 1. Real and potential sources of radioactive contamiation in Norwegian waters (source: Norwegian Radiation Protection Authority).

Seafood is the food that contributes with the largest dose from natural radioactivity in the Norwegian diet, particularly due to high concentrations of polonium-210 (^{210}Po) (Komperød et al. 2015). Concentrations may vary substantially between different species of fish and shellfish; therefore, it is essential that the data used for dose estimates represent the actual species consumed. This study examines the concentrations of the natural radionuclides potassium-40 (^{40}K), radium-226 (^{226}Ra), radium-228 (^{228}Ra), lead-210 (^{210}Pb) and polonium-210 (^{210}Po) in farmed salmon and manufactured fish feed. Farmed salmon constitutes approximately 25% of Norwegian fish consumption, and these new data provide important input to estimates of doses from food.

2. Materials and Methods

2.1. Sample collection

Official inspectors from the Norwegian Food Safety Authority collected samples of farmed Atlantic salmon at 100 processing plants between January and December 2016. Samples were collected from all fish-producing regions in Norway, covering most of the 100,915-km-long coastline, from the Boknafjord (Rogaland) in the southwest to the Varangerfjord (Finnmark) in the northeast (Figure 2). The sampling was randomised with regard to season and region. The samples are representative of fish sold on the open market. A standardised muscle sample (the Norwegian Quality Cut (NQC); Johnsen et al. 2011) was collected from each fish, frozen at -20°C and transported in a frozen state to the National Institute of Nutrition and Seafood Research (NIFES). A list of the sampling locations is given in Appendix 1.

Samples of fish feed were taken from ten different producers and/or different batches from the same producer. A list of the producers and names of feed is given in Appendix 2.

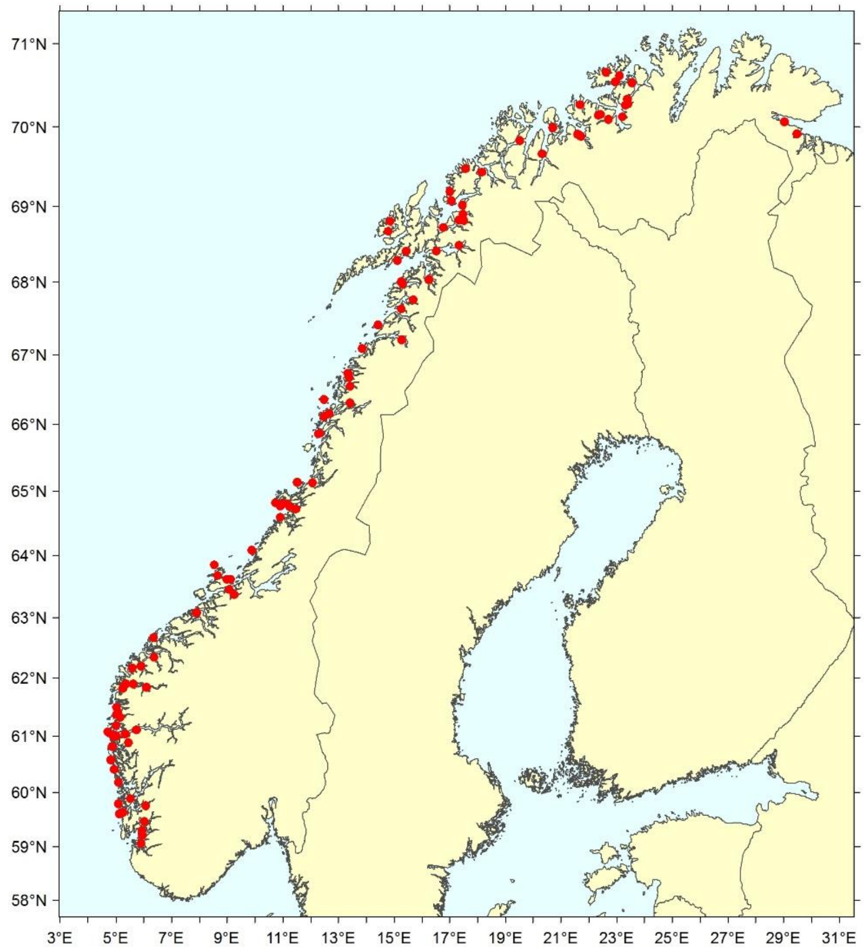

Figure 2. Sampling locations for farmed Atlantic salmon (*Salmo salar*).

2.2. Sample preparation

Upon arrival at NIFES, pooled samples of muscle from five fish from the same cage/farm were homogenised in a conventional food processor. Thereafter, the samples were freeze-dried (Labconco FreeZone), and the dry sample was homogenised again.

The fish feed samples were homogenised fresh (they were not dried prior to analysis) using a conventional food processor. The samples were transported to the Institute of Marine Research (IMR) and the Norwegian Radiation Protection Authority (NRPA) for analyses.

2.3. Sample analyses

All 100 samples of farmed salmon and ten samples of fish feed were analysed at IMR for gamma emitters (^{40}K, ^{137}Cs, ^{226}Ra and ^{228}Ra). A further seven samples of farmed salmon and three samples of fish feed were analysed for the beta emitter ^{90}Sr and the alpha emitters ^{238}Pu, ^{239,240}Pu, ^{241}Am, ^{210}Pb and ^{210}Po at NRPA. Farmed salmon samples were analysed dry, while fish feed samples were analysed fresh. A brief description of the analytical methods are given below.

2.3.1. Analyses of gamma emitters (^{40}K, ^{137}Cs, ^{226}Ra and ^{228}Ra)

The analytical method for measuring ^{137}Cs is accredited in accordance with the standard ISO 17025. The method is regularly verified by participation in laboratory proficiency tests and by analysing reference materials provided by the International Atomic Energy Agency (IAEA) and the National Physical Laboratory (NPL). The methods for determining ^{40}K, ^{226}Ra and ^{228}Ra are not accredited, but are verified by analysing a NIST traceable reference source.

The sample sizes varied from 158 to 491 g (Appendix 1). Depending on sample size, homogenised samples were measured either in a 500 ml Marinelli beaker or a 200 ml PP plastic beaker. Counting times varied from 48 to 72 hours. The ^{40}K, ^{137}Cs, ^{226}Ra and ^{228}Ra content was determined by gamma spectroscopy using ORTEC®-supplied coaxial high-purity germanium detectors (HPGe) with electric cryostat cooling systems, MCA computerised system and GammaVision® version 8 software. Relative efficiencies of the detectors at 1.33 MeV were 47% and 74%. The detectors are shielded from background radiation by approximately 10 cm of lead lined with a cadmium and copper layer on the inside. Analytical uncertainties are due to uncertainty in sample preparation, calibration standards, calibration methods, counting statistics and background correction.

Determination of ^{40}K

The ^{40}K content was determined with the same calibration curve as for ^{226}Ra and ^{228}Ra content, but using the 1460.8 keV gamma peak. The validity of the calibration curve for determining

^{40}K was confirmed by measuring KCl-salt (Merck, pro analysi) and 5.0 wt.% KCl in deionised water in relevant geometries. ^{40}K isotopic abundance of 0.0117% was assumed. The minimum detectable activity was dependent on the counting time and sample weight, but was typically in the range of 0.5-3.0 Bq/kg.

Determination of ^{137}Cs

The ^{137}Cs content was determined using a NIST traceable calibration source containing ^{137}Cs with its 661.7 keV gamma peak. The calibration source had the same geometry, similar density and was sealed in a similar way as the samples. The minimum detectable activity was dependent on the counting time and sample weight, but was typically in the range of 0.03-0.14 Bq/kg.

Determination of ^{228}Ra and ^{226}Ra

The ^{226}Ra activities were determined using gamma peaks of the decay products ^{214}Pb (295.2 keV and 351.9 keV) and ^{214}Bi (609.3 keV). This method is described by Kahn et al. (1990) and Köhler et al. (2002). The ^{228}Ra activities were determined using the 338.3 keV, 911.2 keV and 969.0 keV peaks of ^{228}Ac. To prevent loss of radon, the sample beakers were sealed airtight with aluminium foil and aluminium foil tape and stored for at least four weeks to achieve a secular equilibrium between radium and its decay products. The gamma detectors were calibrated with a NIST traceable calibration source with the same geometry, a similar density and sealed in a similar way as the samples. To correct for the cascade summing, the efficiency calibration was done using the TCC method of Gamma Vision® software (Keyser et al. 2001). The minimum detectable activity was dependent on the counting time and sample weight, but was in the range of 0.03-1.30 Bq/kg for both nuclides.

2.3.2. Analysis of the beta emitter ^{90}Sr

Strontium-90 is analysed according to the method described by Suomela et al. (1993). To determine the activity concentration of ^{90}Sr, the daughter nuclide yttrium-90 (^{90}Y) was separated chemically. For one measurement, 100 g of sample material was used. The sample was ashed before it was dissolved in hydrochloric acid. Yttrium-90 was then extracted by liquid-liquid extraction (10% HDEHP). Thereafter, ^{90}Y was precipitated as yttrium hydroxide, dissolved in nitric acid and transferred to a counting vial. The activity concentration of ^{90}Y was determined using liquid scintillation counting (Quantulus), detecting the Cerenkov radiation from ^{90}Y. The ^{90}Y activity concentration equals the ^{90}Sr activity concentration, assuming equilibrium between ^{90}Sr and ^{90}Y. To determine the chemical yield, the liquid was titrated with titriplex III, and compared with reference samples.

2.3.3. Analyses of alpha emitters (^{238}Pu, ^{239,240}Pu, ^{241}Am, ^{210}Pb and ^{210}Po)

Determination of ^{210}Po and ^{210}Pb

Polonium-210 and ^{210}Pb were analysed according to a slightly modified version of the method described by Chen et al. (2001). Polonium-209 tracer was added to a 10 g dried sample. After treating the sample several times using *aqua regia*, $NaNO_3$, H_2O_2, HCl and NH_2-HCl, the sample was deposited onto silver discs before being measured using a Canberra Alpha Analyst. The sample solution was then used to determine the ^{210}Pb activity. Adding ^{209}Po tracer once more, the sample was stored for six months before a new spontaneous deposition and measured using a Canberra Alpha Analyst.

Determination of ^{238}Pu, ^{239,240}Pu and ^{241}Am

Plutonium-238, ^{239,240}Pu and ^{241}Am were analysed by alpha spectrometry after radiochemical separation. The radiochemical separation of Pu and Am is similar to the procedure described in IAEA (1989). The samples were initially ashed (550 °C) over night before addition of yield determinants (^{242}Pu and ^{243}Am). The ash was then leached for several hours in *aqua regia* before Pu and Am was co-precipitated with $Fe(OH)_3$. Pu was then separated using ion-exchange (Eichrom anion 1x4 100-200 mesh; 8 M HNO_3 and eluated with 9 M HCl + 0.1 M NH_4I). Americium was separated by ion exchange (8 M HNO_3), co-precipitation with calcium oxalate followed by ion exchange to remove lanthanides, ^{210}Pb and ^{210}Po. The samples were then electrodeposited on stainless steel discs using the method described by Hallstadius (1984). Finally, the samples were analysed by alpha spectrometry using PIPS detectors (Canberra Alpha Analyst).

2.4. Statistical analysis of geographical variations in ^{137}Cs levels

The regional groupings Finnmark, Troms, Nordland, Trøndelag, Møre og Romsdal, Sogn og Fjordane, Hordaland and Rogaland were used to compare geographical variations of ^{137}Cs levels in Norwegian farmed Atlantic salmon. Statistical analysis was performed with XLSTAT software (Addinsoft, US) using one-way ANOVA and the Tukey-Kramer multiple comparison.

3. Results

3.1. Anthropogenic radionuclides in Norwegian farmed Atlantic salmon and fish feed

3.1.1. Cesium-137

The anthropogenic radionuclide ^{137}Cs was found in all 100 samples of farmed salmon collected from processing plants during 2016. The activity concentrations are very low, and range from 0.05 ±0.03 to 0.25 ±0.05 Bq/kg fresh weight. The lowest and highest activity concentrations were found in samples collected at Storvika in Nordland and Vågsøya in Sogn og Fjordane, respectively (Figure 3, Figures 4 a-h, Appendix 1). Cesium-134 was not detected in any of the samples (the detection limits ranged from 0.020 to 0.092 for farmed salmon and from 0.12 to 0.22 for fish feed).

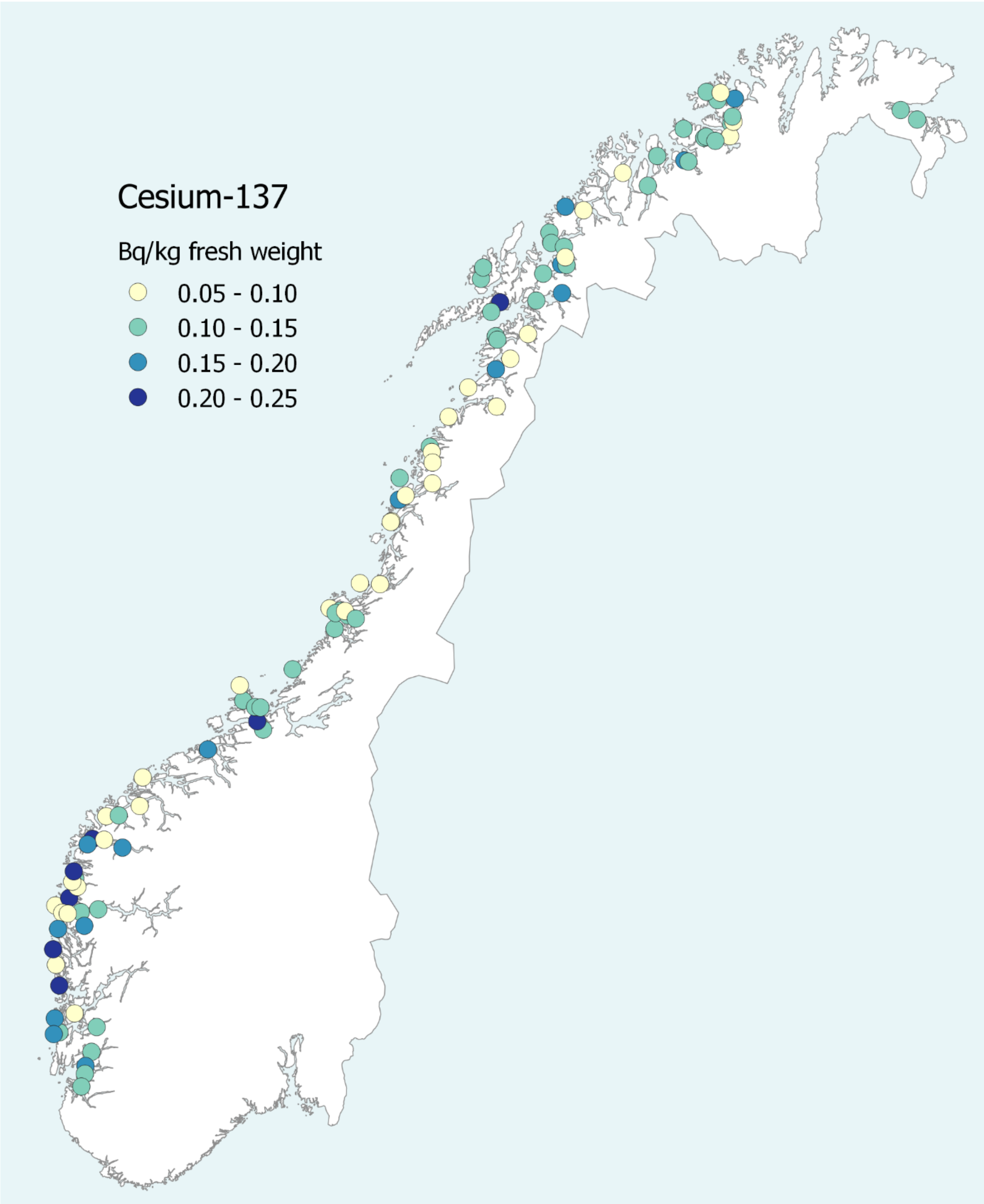

Figure 3. Levels of ^{137}Cs in farmed Atlantic salmon (*Salmo salar*) collected from Norwegian processing plants during 2016.

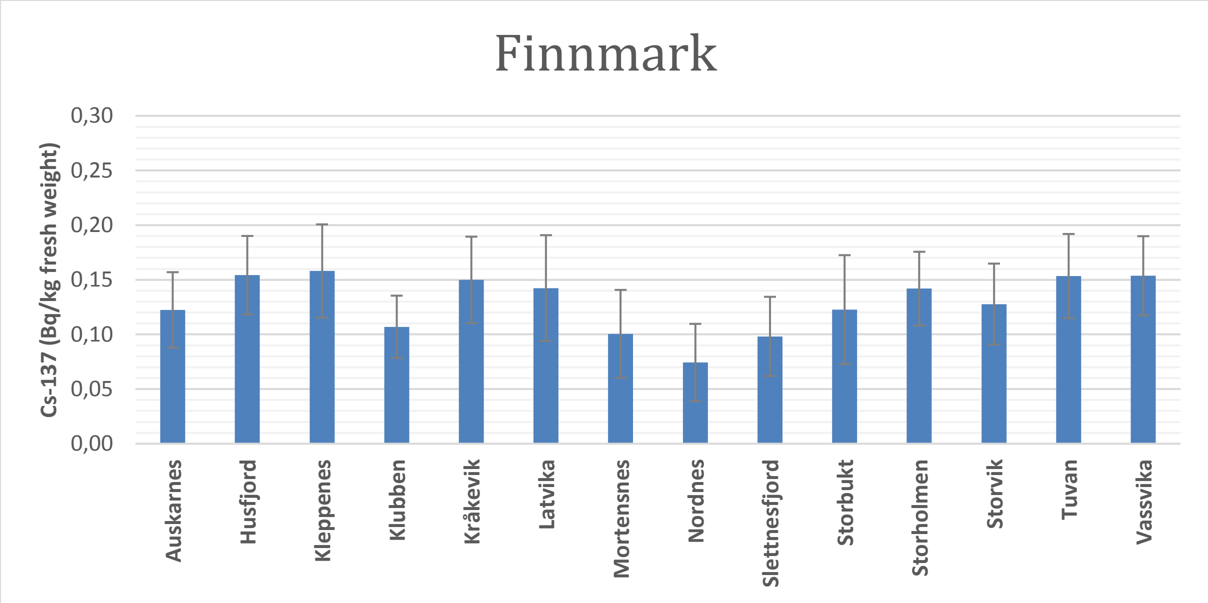

Figure 4a. Activity concentrations of ^{137}Cs in farmed Atlantic salmon (*Salmo salar*) collected from processing plants in Finnmark during 2016. Analytical uncertainties (2σ) in individual measurements are shown with error bars. Sampling locations are shown in alphabetical order.

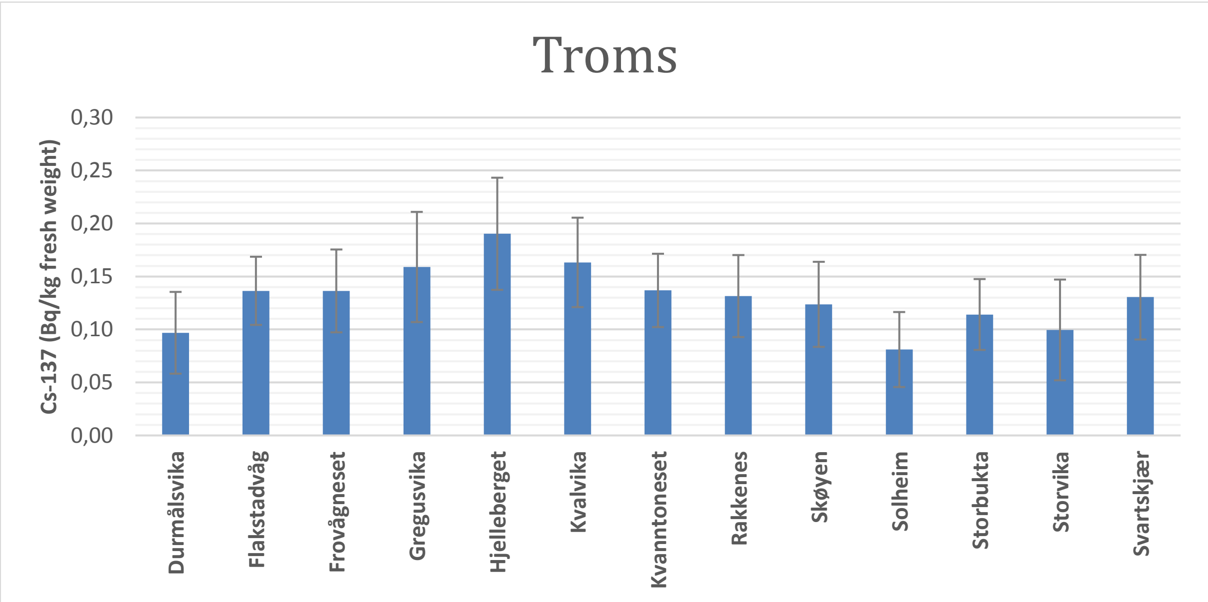

Figure 4b. Activity concentrations of ^{137}Cs in farmed Atlantic salmon (*Salmo salar*) collected from processing plants in Troms during 2016. Analytical uncertainties (2σ) in individual measurements are shown with error bars. Sampling locations are shown in alphabetical order.

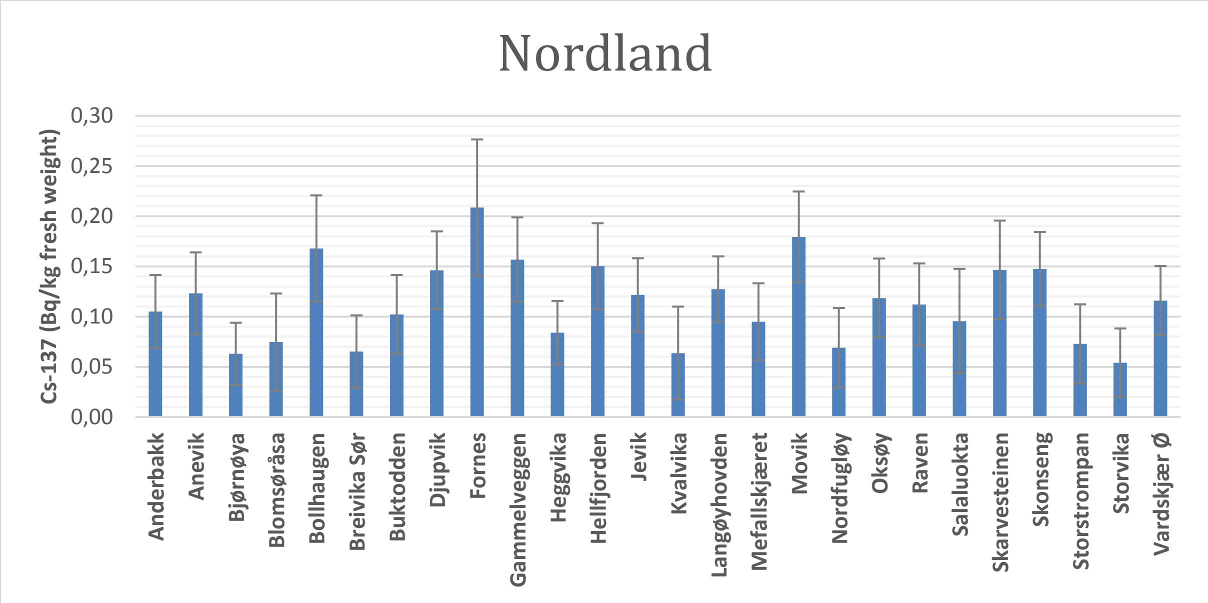

Figure 4c. Activity concentrations of ^{137}Cs in farmed Atlantic salmon (*Salmo salar*) collected from processing plants in Nordland during 2016. Analytical uncertainties (2σ) in individual measurements are shown with error bars. Sampling locations are shown in alphabetical order.

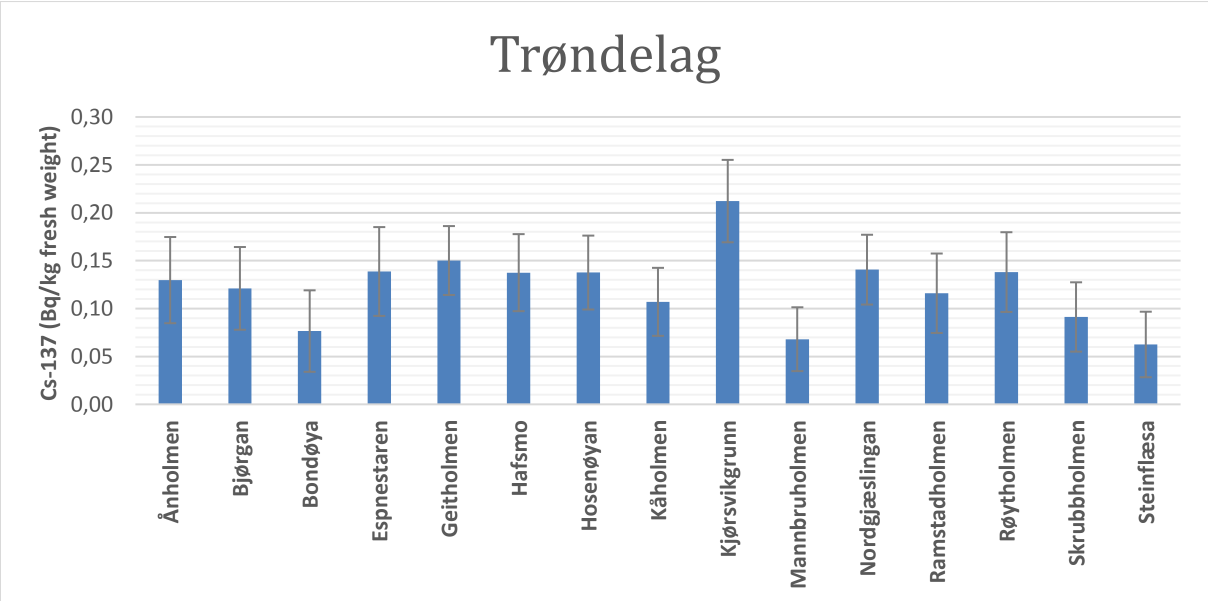

Figure 4d. Activity concentrations of ^{137}Cs in farmed Atlantic salmon (*Salmo salar*) collected from processing plants in Sør-Trøndelag and Nord-Trøndelag during 2016. Analytical uncertainties (2σ) in individual measurements are shown with error bars. Sampling locations are shown in alphabetical order.

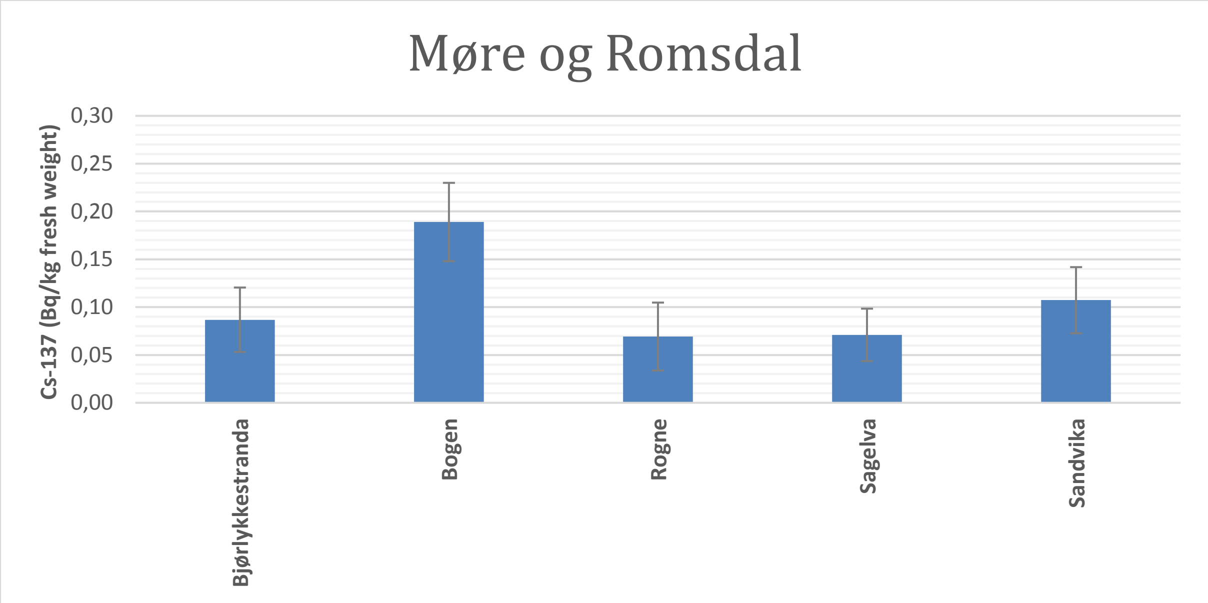

Figure 4e. Activity concentrations of ^{137}Cs in farmed Atlantic salmon (*Salmo salar*) collected from processing plants in Møre og Romsdal during 2016. Analytical uncertainties (2σ) in individual measurements are shown with error bars. Sampling locations are shown in alphabetical order.

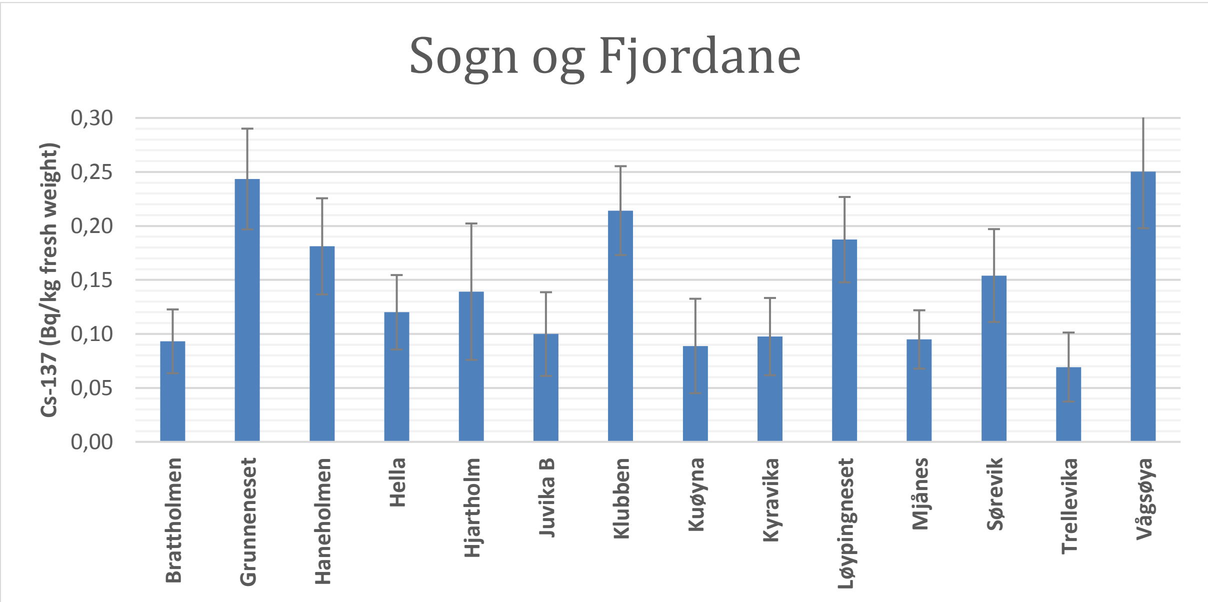

Figure 4f. Activity concentrations of ^{137}Cs in farmed Atlantic salmon (*Salmo salar*) collected from processing plants in Sogn og Fjordane during 2016. Analytical uncertainties (2σ) in individual measurements are shown with error bars. Sampling locations are shown in alphabetical order.

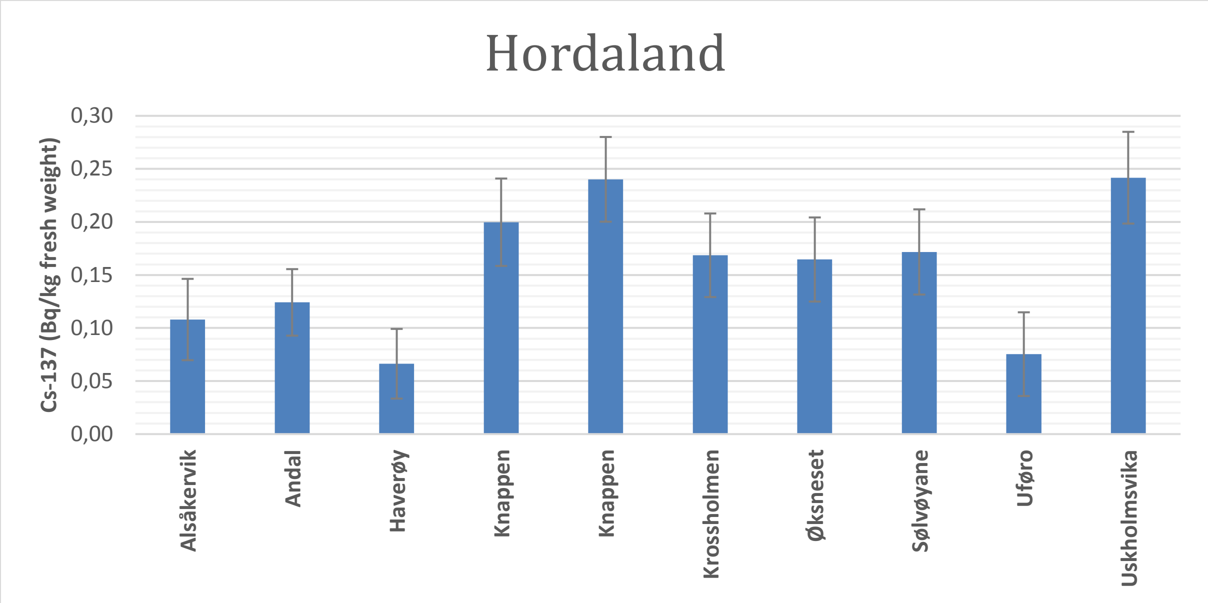

Figure 4g. Activity concentrations of ^{137}Cs in farmed Atlantic salmon (*Salmo salar*) collected from processing plants in Hordaland during 2016. Analytical uncertainties (2σ) in individual measurements are shown with error bars. Sampling locations are shown in alphabetical order.

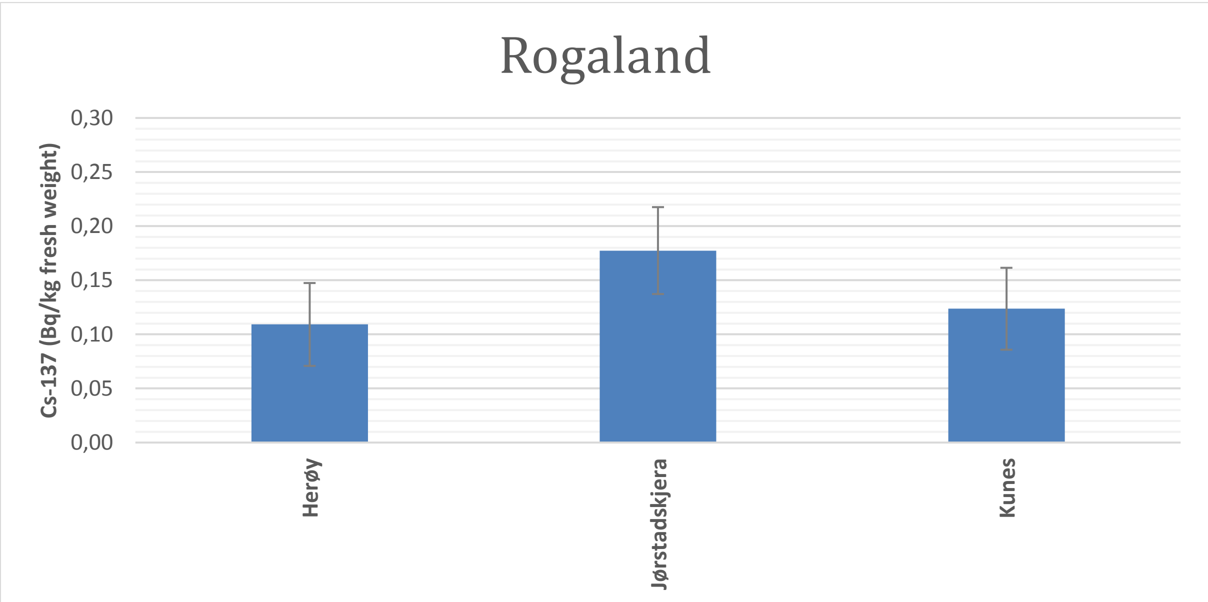

Figure 4h. Activity concentrations of ^{137}Cs in farmed Atlantic salmon (*Salmo salar*) collected from processing plants in Rogaland during 2016. Analytical uncertainties (2σ) in individual measurements are shown with error bars. Sampling locations are shown in alphabetical order.

The ^{137}Cs levels do not vary much between the different Norwegian counties (Figure 5). There are indications of slightly higher ^{137}Cs levels in Sogn og Fjordane and Hordaland compared to other counties. Comparisons with the southernmost county Rogaland should be made with care, as there are only three measurements in this group. The difference in ^{137}Cs levels between the eight different counties was not statistically significant (ANOVA, P=0.16).

The activity concentrations of ^{137}Cs in ten samples of fish feed range from below the detection limit (< 0.14 Bq/kg fresh weight) to 0.54 ±0.17 Bq/kg fresh weight (Appendix 2). Five samples had ^{137}Cs levels below the detection limit.

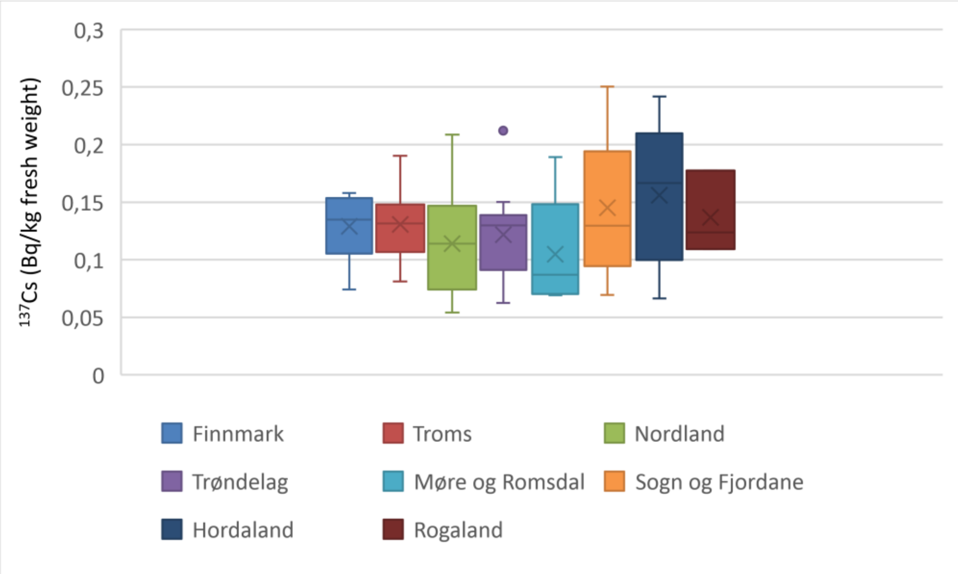

Figure 5. Box and whiskers plot of ^{137}Cs in farmed Atlantic salmon (*Salmo salar*) in different Norwegian counties. Finnmark: n=14; Troms: n=13; Nordland: n=26; Trøndelag: n=15; Møre og Romsdal: n=5; Sogn og Fjordane: n=14; Hordaland: n=10; Rogaland: n=3. The flat lines are averages, the crosses are medians, boxes are interquartile ranges and whiskers are depicting ranges. One measurement in the group "Trøndelag" is considered an outlier (shown as a dot).

3.1.2. Strontium-90

The activity concentrations of ^{90}Sr were below the detection limit for all samples of farmed salmon and fish feed (Appendices 3 and 4).

3.1.3. Plutonium-238, plutonium-239,240 and americium-241

The activity concentrations of ^{238}Pu, $^{239,240}Pu$ and ^{241}Am were below the detection limit for all samples of farmed salmon and fish feed (Appendices 3 and 4).

3.2. Natural radionuclides in Norwegian farmed Atlantic salmon and fish feed

3.2.1. Potassium-40, radium-226 and radium-228

The activity concentrations of ^{40}K in farmed salmon ranged from 87.6 ±5.6 to 142.5 ±8.4 Bq/kg fresh weight (Figure 6 and Appendix 1). Activity concentrations of ^{40}K in fish feed varied from 167.7 ±8.1 to 303.9 ±12.9 Bq/kg fresh weight (Appendix 2).

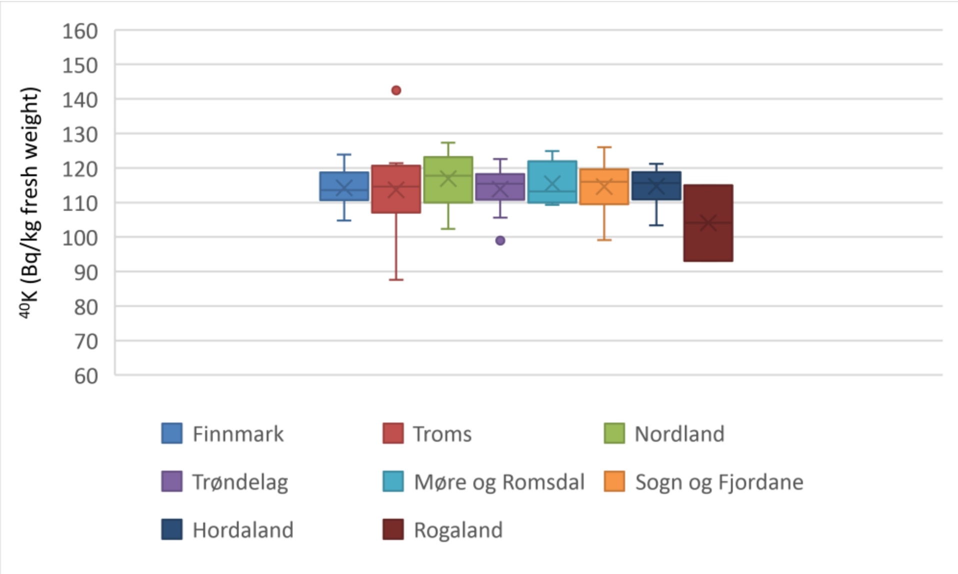

Figure 6. Box and whiskers plot of ^{40}K in farmed Atlantic salmon (*Salmo salar*) in different Norwegian counties. Finnmark: n=14; Troms: n=13; Nordland: n=26; Trøndelag: n=15; Møre og Romsdal: n=5; Sogn og Fjordane: n=14; Hordaland: n=10; Rogaland: n=3. The flat lines are averages, the crosses are medians, boxes are interquartile ranges and whiskers are depicting ranges. One measurement in the group "Troms" and one measurement in the group "Trøndelag" are considered outliers (shown as a dots).

The activity concentrations of ^{226}Ra and ^{228}Ra in farmed salmon were below the detection limit in all 100 samples (Appendix 1). Activity concentrations of ^{226}Ra in fish feed were also below the detection limit, while the activity concentrations of ^{228}Ra in fish feed varied from 1.7 ±0.7 to 6.9 ±0.8 Bq/kg fresh weight (Appendix 2).

3.2.2. Lead-210 and polonium-210

Activity concentrations of ^{210}Pb and ^{210}Po in farmed salmon ranged from 0.032 ±0.007 to 0.07 ±0.02 Bq/kg fresh weight and 0.003 ±0.001 to 0.023 ±0.008 Bq/kg fresh weight, respectively (Figure 7, 8 and Appendix 3).

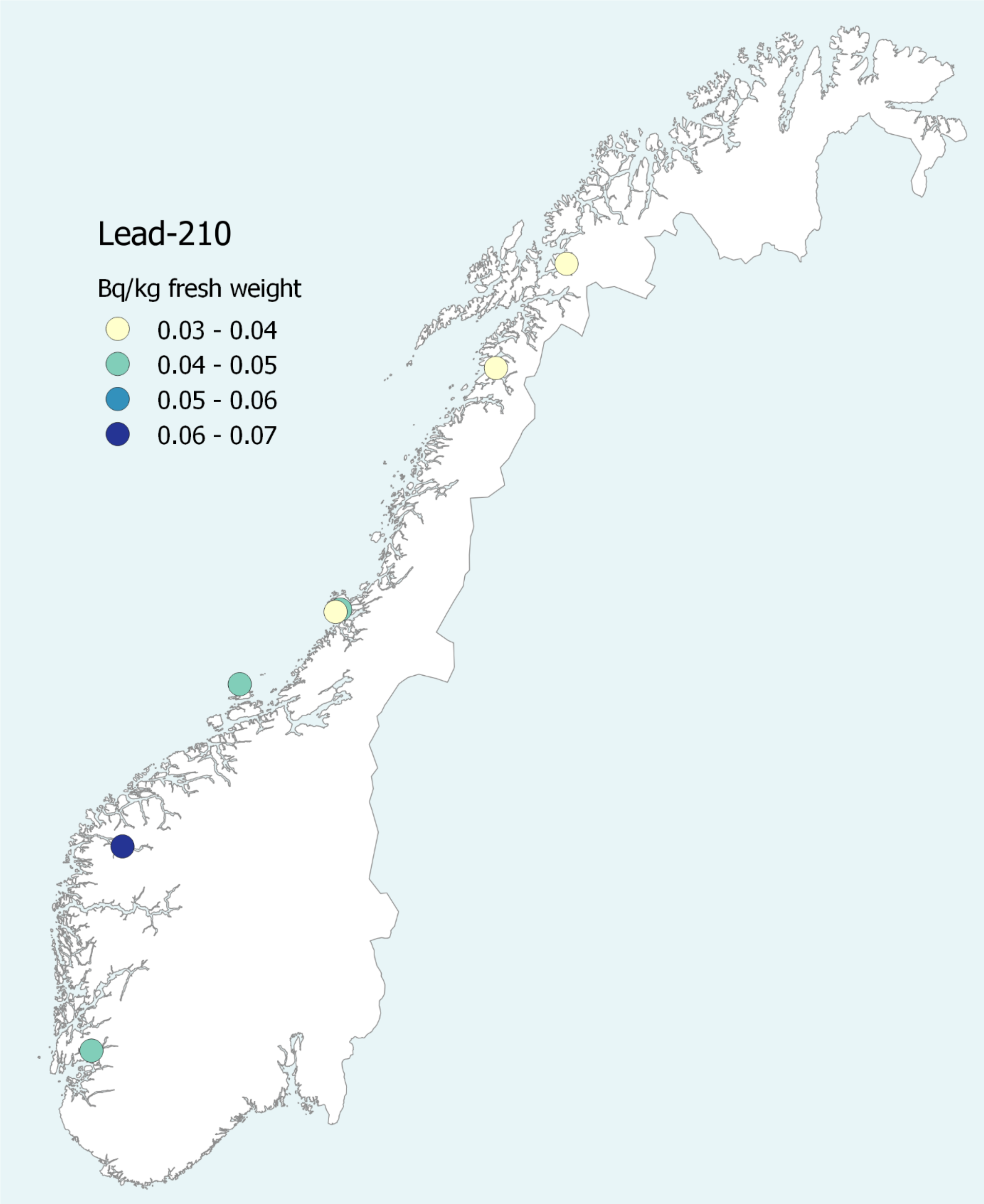

Figure 7. Levels of ^{210}Pb in farmed Atlantic salmon (*Salmo salar*) collected from Norwegian processing plants during 2016.

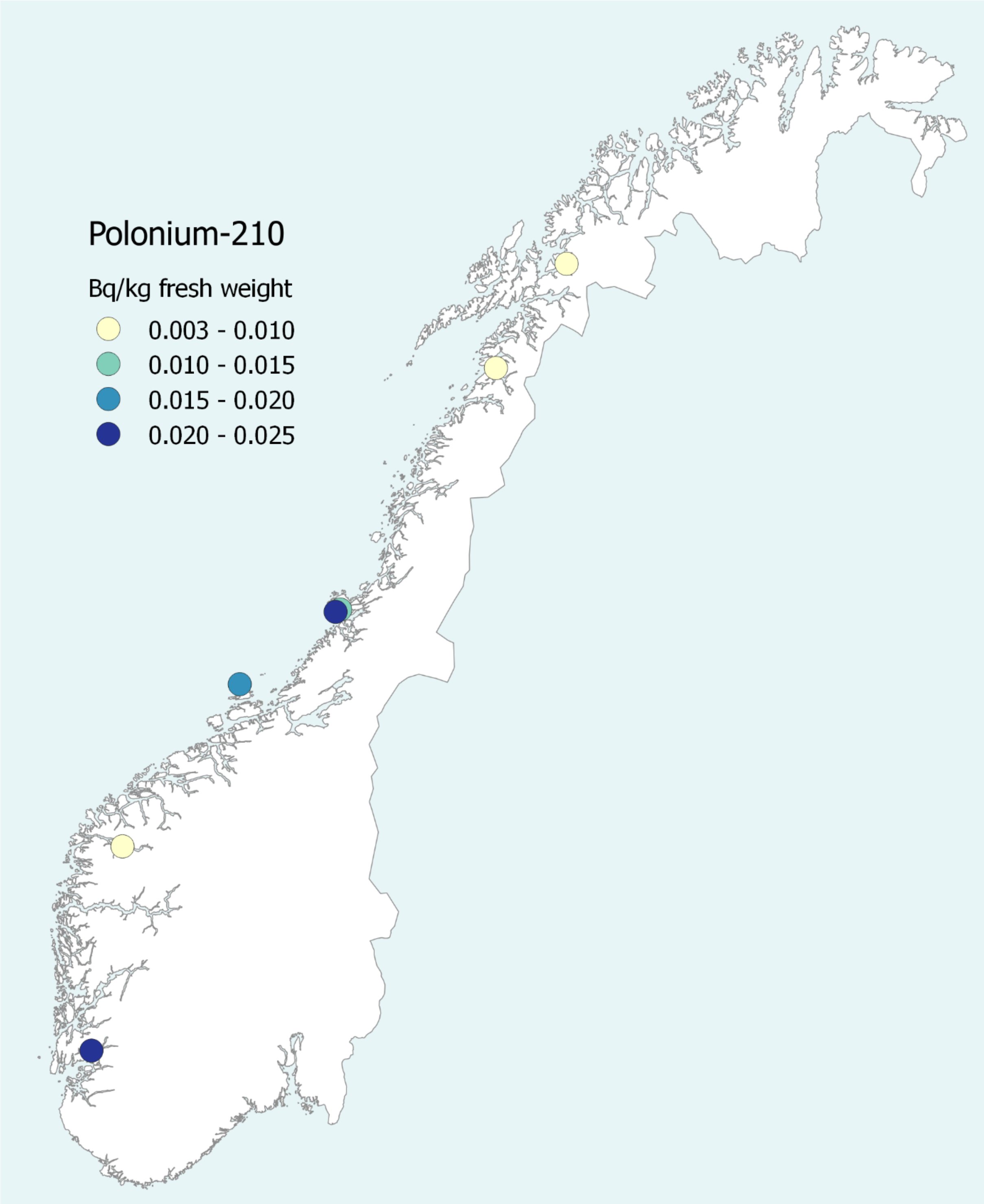

Figure 8. Levels of ^{210}Po in farmed Atlantic salmon (*Salmo salar*) collected from Norwegian processing plants during 2016.

4. Discussion

4.1. Anthropogenic radionuclides

The levels of the anthropogenic radionuclide ^{137}Cs in farmed salmon collected at processing plants along the Norwegian coast during 2016 (0.05–0.25 Bq/kg fresh weight) are similar to levels found in wild fish caught in open Norwegian waters (Table 1). The results of the present study are also in agreement with the results of measurements of ^{137}Cs in Norwegian farmed Atlantic salmon during the period 1994–2010 (Table 1). The levels are very low compared with the maximum permitted level for radioactive cesium in food set by the Norwegian authorities after the Chernobyl accident (600 Bq/kg fresh weight). The levels are also very low compared to the concentrations found in terrestrial animal products (Komperød et al. 2015).

Food is the major source of ^{137}Cs uptake by fish (e.g. Rowan and Rasmussen, 1994), but ambient levels of ^{137}Cs in seawater and salinity levels also affect the levels in fish (e.g. Harbitz and Skuterud, 1999). The levels of ^{137}Cs in seawater differ along the coast of Norway due to distances from point sources, such as Sellafield and the outflow from the Baltic Sea, which still contains significant amounts of ^{137}Cs originating from the Chernobyl accident (e.g. NRPA, 2011). The geographic variations in ^{137}Cs levels in seawater are generally reflected in the ^{137}Cs levels in fish (and their prey). For example, higher levels are measured in cod caught in the Skagerrak and the North Sea compared to the Barents Sea (e.g. NRPA, 2011). The lack of geographical variation in the ^{137}Cs levels in farmed salmon is probably due to salmon being fed with fish feed, which has no geographical variation.

Following the Fukushima-Daiichi nuclear accident and radioactive contamination of the Pacific Ocean, the public became concerned about the safety of fish and seafood, not only in Japan, but also in countries like Canada, which has a large commercial fishing industry. The levels of ^{137}Cs in Japanese fish have not exceeded 100 Bq/fresh weight since the second quarter of 2015 (Fisheries Agency of Japan, Ministry of Agriculture, Forestry and Fisheries (http://www.jfa.maff.go.jp/e/). The ^{137}Cs levels in fish caught along the west coast of Canada during 2013 were below the detection limit of ~ 2 Bq/kg fresh weight, i.e. comparable to the levels along the Norwegian coast (Chen et al. 2014). It is unlikely that we will be able to detect radioactive contamination originating from the Fukushima-Daiichi nuclear accident in Norwegian fish and seafood.

During the nuclear weapons testing at Novaya Zemlya in the 1950s and 1960s, different species of fish from the Barents Sea were analysed for "total mean beta activity minus potassium-40 (^{40}K)" during the 1960s (Figure 9). Although not directly comparable to current measurements, these levels of radioactive contamination in Norwegian fish and seafood are the highest measured to date. In recent decades, there has been a slow decrease in the activity concentrations of most anthropogenic radionuclides in fish and seafood as a result of decreasing discharges from European reprocessing plants for spent nuclear fuel, the reduced impact of fallout from the Chernobyl accident, radioactive decay of the different radionuclides and dilution of radionuclides in the water masses.

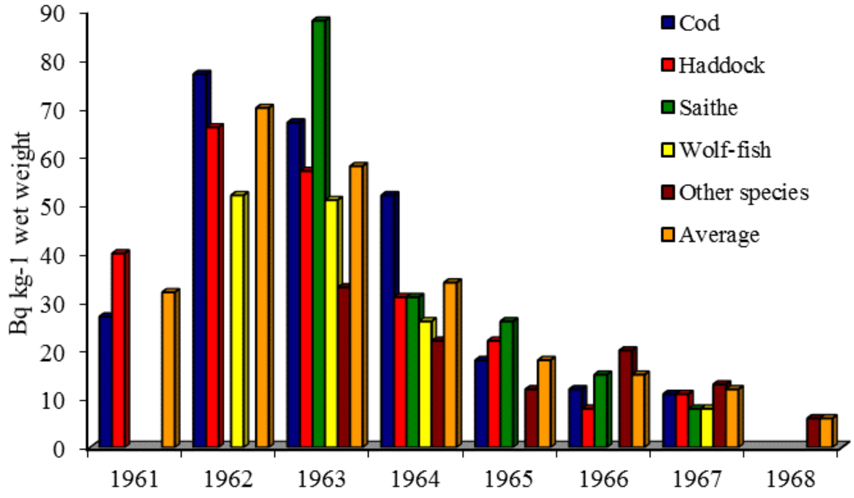

Figure 9. Total mean beta activity minus the natural radionuclide potassium-40 (^{40}K) in different fish species in the Barents Sea during the 1960s (Føyn et al. 1999). Cesium-137 accounts for a large part of this beta activity. (^{137}Cs is a beta emitter, but is determined using the gamma radiation emitted when an excited state of ^{137}Ba is de-excited to the ground state of ^{137}Ba. The details of this process are outside the scope of this report.)

The levels of the radionuclides ^{90}Sr, ^{238}Pu, $^{239,240}Pu$, and ^{241}Am in seawater and biota from Norwegian waters are monitored annually, but to a much lesser extent than ^{137}Cs. In the present study, measurements of these radionuclides were restricted to the edible parts/muscle of farmed salmon, and all measurements were below the detection limits. The chemical properties of all these radionuclides cause them to accumulate in the bones and liver, and to a lesser extent in the muscle (Harbitz and Skuterud, 1999). For example, ^{90}Sr has biochemical behaviour similar to calcium, which is important for skeletal development. The findings in the present study are thus not surprising, and the levels in farmed salmon are comparable to levels found in other species of fish from Norwegian waters (Table 1).

Table 1. Activity concentrations of ^{137}Cs, ^{90}Sr, ^{238}Pu, $^{239,240}Pu$, and ^{241}Am (Bq/kg fresh weight) in muscle from farmed salmon, cod and haddock from Norwegian waters during the period 1991–2011 compared with the levels found in farmed salmon in the present study.

	Bq/kg (fresh weight)				
Species	^{137}Cs	^{90}Sr	^{238}Pu	$^{239,240}Pu$	^{241}Am
Farmed salmon (*Salmo salar*)	0.05–0.25[a] <0.10–2.3[b]	<0.04[a]	<0.002[a]	<0.004[a]	<0.0037[a]
Cod (*Gadus morhua*)	<0.10–3.20[b]	0.006–0.28[b]	<det. limit – 0.0001[b]	<0.0002–0.005[b]	–
Haddock (*Melangogrammus aeglefinus*)	<0.10–0.84[b]	<0.007[b]	–	–	–

[a]The present study; [b]Heldal et al. 2015

4.2. Naturally occurring radionuclides

Marine animals generally contain lower levels of anthropogenic radionuclides, but higher levels of naturally occurring radionuclides, than most terrestrial animals, including freshwater fish (Komperød et al. 2015).

Activity concentrations of ^{210}Po and ^{210}Pb in different species of saltwater fish are known to vary considerably (Carvalho 2011; Carvalho et al. 2011; Pearson et al. 2016; Pollard et al. 1998). Polonium-210 is mainly transferred to fish via diet. The ecological niche and diet of the fish determine in large part its ^{210}Po content. In general, fish that are lower in the food chain contain higher levels (Carvalho 2011; Carvalho et al. 2011). Polonium-210 concentrations found in other wild-caught fish species in the Norwegian monitoring programme RAME (Radioactivity in the Marine Environment) are shown in Table 2. These levels are higher than those observed in farmed salmon in the present study. A likely reason for this is that the fish feed, which consists of a large proportion of plant-based ingredients, contains significantly less ^{210}Po than the marine organisms consumed by the wild-caught fish.

Table 2. Activity concentrations of ^{210}Po and ^{210}Pb (Bq/kg fresh weight) in muscle from farmed salmon from the present study compared with levels found in wild-caught fish from Norwegian waters during the period 2002–2011.

	^{210}Po	^{210}Pb
Farmed Atlantic salmon (*Salmo salar*)	0.003–0.023[a]	0.03–0.07 [a]
Cod (*Gadus morhua*)	0.09–2.8[b]	0.02-0.07[c]
Haddock (*Melangogrammus aeglefinus*)	1.1–1.8[b]	–
Saithe (*Pollachius virens*)	0.7–1.0[b]	–
Redfish (*Sebastes marinus*)	0.16[b]	–
Herring (*Clupea harengus*)	0.6–8.5[b]	0.06[c]
Mackerel (*Scomber scombrus*)	1.3-5.4[b]	0.06[c]

[a]The present study; [b]Heldal et al. 2015; [c]Unpublished data, RAME 2015

An additional result of the analyses was that uranium was detected in the fish feed samples. However, uranium was not found in farmed salmon.

As for most types of food, naturally occurring radionuclides contribute far more to the radiation dose from farmed salmon than anthropogenic radionuclides. Potassium-40 is present in all types of food and makes up a specific fraction of all potassium. Potassium is an essential nutrient that is homeostatically regulated in the body, and any excess will be excreted. The dose from ^{40}K is therefore more or less constant and not affected by intake.

Apart from the constant contribution of ^{40}K from all foods, naturally occurring radioactivity in seafood has been estimated to be the largest single contributing factor to the total ingestion dose in Norway, mainly due to the relatively high content of ^{210}Po found in marine organisms (Komperød et al. 2015). However, previous dose calculations of fish have been based on the concentrations found in wild-caught fish. As a substantial portion of the seafood consumed in Norway consists of farmed salmon, and this study shows that farmed salmon contain less ^{210}Po than wild-caught fish, new dose calculations should be conducted that include the new data found in this study.

5. Conclusions

The present study is the most comprehensive study of anthropogenic and natural radionuclides in farmed Atlantic salmon (*Salmo salar*) and manufactured fish feed from Norway. The results will improve the Norwegian authorities' documentation of contamination levels in farmed salmon, and will provide important input to estimates of doses from food.

The levels of the anthropogenic radionuclide ^{137}Cs in farmed salmon are about three orders of magnitude lower than the maximum permitted level for radioactive cesium in food set by the Norwegian authorities after the Chernobyl accident. Levels of anthropogenic radionuclides in fish feed are likewise very low. The levels of anthropogenic and natural radionuclides found in farmed salmon in the present study are comparable to or lower than the levels found in other fish species in the North Atlantic Ocean. Any potential health risk caused by the levels of radionuclides found in farmed salmon in the present study will be very low and should be of no concern to the consumer.

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Appendix 1

Sampling locations, sample weights, % dry weights and activity concentrations of gamma-emitters (potassium-40 (^{40}K), cesium-137 (^{137}Cs), radium-226 (^{226}Ra) and radium-228 (^{228}Ra)) in farmed salmon (*Salmo salar*). Cesium-137 is a man-made radionuclide, while ^{40}K, ^{226}Ra and ^{228}Ra are naturally occurring radionuclides.

County	Location	Bq/kg (fresh weight) ^{40}K			^{137}Cs			^{226}Ra	^{228}Ra	Sample weight (dry) (g)	Dry weight % (g/100 g)
Finnmark	Auskarnes	104.8	±	6.1	0.12	±	0.03	< 0.04	< 0.08	281.8	38.13
Finnmark	Husfjord	113.8	±	6.7	0.15	±	0.04	< 0.04	< 0.08	407.2	40.86
Finnmark	Kleppenes	112.6	±	6.6	0.16	±	0.04	< 0.05	< 0.10	264.7	37.39
Finnmark	Klubben	117.4	±	6.8	0.11	±	0.03	< 0.04	< 0.07	342.9	38.63
Finnmark	Kråkevik	123.9	±	7.3	0.15	±	0.04	< 0.05	< 0.09	287.2	37.46
Finnmark	Latvika	108.0	±	7.0	0.14	±	0.05	< 0.06	< 0.12	335.1	40.10
Finnmark	Mortensnes	120.5	±	7.1	0.10	±	0.04	< 0.05	< 0.10	271.1	34.12
Finnmark	Nordnes	108.1	±	6.9	0.07	±	0.04	< 0.05	< 0.09	345.2	40.54
Finnmark	Slettnesfjord	111.5	±	6.6	0.10	±	0.04	< 0.05	< 0.09	333.2	39.53
Finnmark	Storbukt	113.4	±	7.3	0.12	±	0.05	< 0.06	< 0.12	256.9	35.72
Finnmark	Storholmen	111.9	±	6.5	0.14	±	0.03	< 0.04	< 0.07	316.4	38.73
Finnmark	Storvik	114.7	±	6.7	0.13	±	0.04	< 0.05	< 0.09	330.4	39.89
Finnmark	Tuvan	118.3	±	6.9	0.15	±	0.04	< 0.04	< 0.34	354.4	38.77
Finnmark	Vassvika	119.7	±	7.0	0.15	±	0.04	< 0.04	< 0.09	403.2	38.75
Troms	Durmålsvika	87.6	±	5.6	0.10	±	0.04	< 0.05	< 0.09	338.8	33.61
Troms	Flakstadvåg	95.4	±	5.6	0.14	±	0.03	< 0.04	< 0.07	450.4	41.81
Troms	Frovågneset	113.8	±	6.7	0.14	±	0.04	< 0.05	< 0.09	330.7	37.87
Troms	Gregusvika	142.5	±	8.4	0.16	±	0.05	< 0.07	< 0.13	268.4	47.37
Troms	Hjelleberget	120.6	±	7.7	0.19	±	0.05	< 0.06	< 0.13	214.5	37.32
Troms	Kvalvika	118.8	±	7.0	0.16	±	0.04	< 0.05	< 0.09	300.5	38.27
Troms	Kvanntoneset	120.7	±	7.0	0.14	±	0.03	< 0.04	< 0.07	287.0	32.96
Troms	Rakkenes	111.6	±	6.5	0.13	±	0.04	< 0.04	< 0.08	323.7	38.56
Troms	Skøyen	116.7	±	7.4	0.12	±	0.04	< 0.05	< 0.11	342.1	40.25
Troms	Solheim	107.3	±	6.3	0.08	±	0.04	< 0.05	< 0.09	317.5	37.25
Troms	Storbukta	114.6	±	6.7	0.11	±	0.03	< 0.04	< 0.07	312.5	38.71
Troms	Storvika	121.4	±	7.2	0.10	±	0.05	< 0.06	< 0.11	248.8	37.58
Troms	Svartskjær	106.8	±	6.8	0.13	±	0.04	< 0.05	< 0.10	391.0	40.37
Nordland	Anderbakk	116.9	±	6.8	0.10	±	0.04	< 0.05	< 0.08	247.1	36.32
Nordland	Anevik	118.5	±	7.0	0.12	±	0.04	< 0.05	< 0.09	272.8	36.90
Nordland	Bjørnøya	108.2	±	6.3	0.06	±	0.03	< 0.04	< 0.08	347.3	38.31
Nordland	Blomsøråsa	118.2	±	7.6	0.07	±	0.05	< 0.07	< 0.13	298.4	38.95
Nordland	Bollhaugen	127.3	±	8.2	0.17	±	0.05	< 0.07	< 0.13	221.9	36.84
Nordland	Breivika Sør	116.6	±	6.8	0.07	±	0.04	< 0.05	< 0.39	309.0	38.98
Nordland	Buktodden	105.3	±	6.2	0.10	±	0.04	< 0.05	< 0.09	344.5	44.63
Nordland	Djupvik	102.3	±	6.0	0.15	±	0.04	< 0.05	< 0.08	358.2	44.29
Nordland	Fornes	124.8	±	7.4	0.21	±	0.07	< 0.09	< 0.15	165.6*	35.77
Nordland	Gammelveggen	121.9	±	7.1	0.16	±	0.04	< 0.05	< 0.08	298.9	35.08
Nordland	Heggvika	106.7	±	6.2	0.08	±	0.03	< 0.04	< 0.07	359.6	42.67
Nordland	Hellfjorden	126.9	±	7.4	0.15	±	0.04	< 0.05	< 0.08	204.4	31.30
Nordland	Jevik	120.9	±	7.1	0.12	±	0.04	< 0.05	< 0.08	329.8	34.75
Nordland	Kvalvika	122.6	±	7.3	0.06	±	0.05	< 0.07	< 0.12	237.1	40.21
Nordland	Langøyhovden	116.1	±	7.3	0.13	±	0.03	< 0.18	< 0.08	491.4	37.14
Nordland	Mefallskjæret	123.0	±	7.2	0.09	±	0.04	< 0.05	< 0.10	249.5	35.90
Nordland	Movik	117.3	±	6.9	0.18	±	0.05	< 0.05	< 0.09	274.7	35.77
Nordland	Nordfugløy	127.3	±	7.5	0.07	±	0.04	< 0.06	< 0.10	240.5	36.63
Nordland	Oksøy	121.0	±	7.7	0.12	±	0.04	< 0.04	< 0.10	396.0	35.74
Nordland	Raven	123.4	±	7.2	0.11	±	0.04	< 0.05	< 0.10	236.9	37.62
Nordland	Salaluokta	115.6	±	7.4	0.10	±	0.05	< 0.07	< 0.13	281.1	38.56
Nordland	Skarvesteinen	113.0	±	7.3	0.15	±	0.05	< 0.06	< 0.12	235.0	39.58

County	Location	Bq/kg (fresh weight)								Sample weight (dry) (g)	Dry weight % (g/100 g)
		^{40}K			^{137}Cs			^{226}Ra	^{228}Ra		
Nordland	Skonseng	107.5	±	6.3	0.15	±	0.04	< 0.05	< 0.09	313.6	39.71
Nordland	Storstrompan	123.9	±	7.3	0.07	±	0.04	< 0.11	< 0.10	250.4	34.10
Nordland	Storvika	110.5	±	6.5	0.05	±	0.03	< 0.05	< 0.09	285.4	39.38
Nordland	Vardskjær Ø	104.4	±	6.1	0.12	±	0.03	< 0.04	< 0.07	430.1	44.82
Nord-Trøndelag	Ånholmen	117.8	±	7.0	0.13	±	0.04	< 0.06	< 0.10	241.0	34.97
Nord-Trøndelag	Bondøya	109.7	±	7.0	0.08	±	0.04	< 0.06	< 0.12	294.3	33.05
Sør-Trøndelag	Espnestaren	99.0	±	6.4	0.14	±	0.05	< 0.06	< 0.12	220.4	34.91
Nord-Trøndelag	Geitholmen	119.4	±	7.0	0.15	±	0.04	< 0.04	< 0.07	305.5	35.96
Sør-Trøndelag	Hafsmo	115.4	±	6.8	0.14	±	0.04	< 0.05	< 0.09	341.3	38.54
Sør-Trøndelag	Hosenøyan	115.4	±	6.8	0.14	±	0.04	< 0.04	< 0.09	319.2	37.20
Sør-Trøndelag	Kåholmen	117.3	±	6.9	0.11	±	0.04	< 0.04	< 0.08	250.9	35.67
Sør-Trøndelag	Kjørsvikgrunn	111.2	±	6.5	0.21	±	0.04	< 0.04	< 0.08	274.3	37.38
Sør-Trøndelag	Mannbruholmen	112.5	±	6.6	0.07	±	0.03	< 0.04	< 0.08	336.0	40.65
Nord-Trøndelag	Nordgjæslingan	122.6	±	7.1	0.14	±	0.04	< 0.04	< 0.07	291.0	35.97
Nord-Trøndelag	Ramstadholmen	116.3	±	6.9	0.12	±	0.04	< 0.06	< 0.11	254.2	36.74
Sør-Trøndelag	Røytholmen	119.9	±	7.0	0.14	±	0.04	< 0.05	< 0.09	219.4	33.66
Nord-Trøndelag	Skrubbholmen	111.6	±	6.6	0.09	±	0.04	< 0.05	< 0.09	284.6	37.62
Nord-Trøndelag	Steinflæsa	105.6	±	6.2	0.06	±	0.03	< 0.05	< 0.08	325.2	37.96
Møre og Romsdal	Bjørlykkestranda	124.9	±	7.3	0.09	±	0.03	< 0.04	< 0.08	234.2	31.30
Møre og Romsdal	Bogen	119.0	±	6.9	0.19	±	0.04	< 0.04	< 0.08	274.0	36.84
Møre og Romsdal	Rogne	109.3	±	6.4	0.07	±	0.04	< 0.05	< 0.09	314.2	37.38
Møre og Romsdal	Sagelva	110.6	±	6.5	0.07	±	0.03	< 0.04	< 0.07	336.2	37.30
Møre og Romsdal	Sandvika	113.2	±	6.6	0.11	±	0.03	< 0.04	< 0.08	320.9	37.07
Sogn og Fjordane	Brattholmen	116.5	±	6.8	0.09	±	0.03	< 0.04	< 0.06	310.8	36.99
Sogn og Fjordane	Grunneneset	120.7	±	7.1	0.24	±	0.05	< 0.05	< 0.39	364.9	37.46
Sogn og Fjordane	Haneholmen	117.4	±	6.9	0.18	±	0.04	< 0.05	< 0.09	305.7	37.67
Sogn og Fjordane	Hella	99.1	±	5.8	0.12	±	0.03	< 0.04	< 0.08	358.9	40.83
Sogn og Fjordane	Hjartholm	126.0	±	5.3	0.14	±	0.06	< 0.09	< 0.14	169.7	39.79
Sogn og Fjordane	Juvika B	116.2	±	6.8	0.10	±	0.04	< 0.05	< 0.09	300.2	37.41
Sogn og Fjordane	Klubben	113.9	±	6.7	0.21	±	0.04	< 0.04	< 0.07	409.8	38.81
Sogn og Fjordane	Kuøyna	108.2	±	6.9	0.09	±	0.04	< 0.06	< 0.12	336.0	38.32
Sogn og Fjordane	Kyravika	114.0	±	6.7	0.10	±	0.04	< 0.04	< 0.08	354.2	36.71
Sogn og Fjordane	Løypingneset	119.2	±	7.0	0.19	±	0.04	< 0.04	< 0.08	285.0	37.75
Sogn og Fjordane	Mjånes	105.0	±	6.1	0.09	±	0.03	< 0.03	< 0.06	402.4	41.31
Sogn og Fjordane	Sørevik	122.7	±	7.2	0.15	±	0.04	< 0.05	< 0.10	290.1	36.86
Sogn og Fjordane	Trellevika	109.9	±	6.4	0.07	±	0.03	< 0.04	< 0.08	274.6	39.44
Sogn og Fjordane	Vågsøya	115.8	±	6.8	0.25	±	0.05	< 0.05	< 0.09	270.9	35.82
Hordaland	Alsåkervik	115.9	±	6.8	0.11	±	0.04	< 0.05	< 0.10	312.8	35.71
Hordaland	Andal	116.2	±	6.8	0.12	±	0.03	< 0.04	< 0.07	331.8	37.51
Hordaland	Haverøy	121.2	±	7.1	0.07	±	0.03	< 0.04	< 0.08	315.4	34.94
Hordaland	Knappen	120.3	±	7.0	0.20	±	0.04	< 0.04	< 0.07	291.0	33.17
Hordaland	Knappen	110.7	±	6.5	0.24	±	0.04	< 0.04	< 0.07	425.1	42.31
Hordaland	Krossholmen	114.9	±	6.7	0.17	±	0.04	< 0.04	< 0.08	273.6	38.47
Hordaland	Øksneset	115.3	±	6.7	0.16	±	0.04	< 0.05	< 0.08	261.0	39.27
Hordaland	Sølvøyane	118.3	±	6.9	0.17	±	0.04	< 0.04	< 0.08	292.0	36.03
Hordaland	Uføro	103.4	±	6.1	0.08	±	0.04	< 0.06	< 0.10	332.7	40.78
Hordaland	Uskholmsvika	110.9	±	6.5	0.24	±	0.04	< 0.03	< 0.06	313.4	35.61
Rogaland	Herøy	115.0	±	6.7	0.11	±	0.04	< 0.05	< 0.09	296.1	38.47
Rogaland	Jørstadskjera	93.1	±	5.5	0.18	±	0.04	< 0.04	< 0.08	293.8	35.90
Rogaland	Kunes	104.1	±	6.1	0.12	±	0.04	< 0.05	< 0.08	270.3	40.02

*Measured in a 200 ml PP plastic beaker. Other samples were measured in 500 ml Marinelli beakers.

Appendix 2

Sample weights and activity concentrations (Bq/kg fresh weight) of the man-made gamma-emitter cesium-137 (^{137}Cs) and the naturally occurring gamma-emitters potassium-40 (^{40}K), radium-226 (^{226}Ra) and radium-228 (^{228}Ra) in manufactured fish feed from different producers.

Feed Producer	Name of feed	Bq/kg (fresh weight)				Sample weight fresh (g)
		^{40}K	^{137}Cs	^{226}Ra	^{228}Ra	
Biomar Myre	Energy X 2500 ICE 70mg pan Q 2304630	207.7 ± 9.5	<0.14 ± -	<0.3	2.0 ± 0.7	183.7
Skretting Stokmarknes	Optiline S 2500 50A 12 mm	291.1 ± 12.4	<0.14 ± -	<1.2	5.1 ± 0.9	192.7
Ewos Halsa	Rapid HP 1000	203.7 ± 9.5	0.21 ± 0.19	<1.1	2.7 ± 0.8	181.2
Skretting Averøy	Premium L 1200	285.7 ± 12.2	0.16 ± 0.17	<1.0	4.0 ± 1.0	169.2
Skretting Averøy	Shield LHH 600-50A 7	279.3 ± 12.1	<0.14 ± -	<0.3	4.5 ± 1.0	158.4
Marine Harvest Bjugn	Marine Harvest Fish Feed,200133 MH 2500Feb	148.5 ± 7.3	<0.14 ± -	<0.3	2.1 ± 1.0	179.9
Ewos Florø	Rapid CC1 HP 1000	237.2 ± 10.2	0.41 ± 0.14	<1.3	2.4 ± 0.6	197.9
Ewos Florø	Extra CC 1 HP 1000 50A 500	265.7 ± 11.6	0.19 ± 0.18	<1.0	6.9 ± 0.8	173.5
Biomar Karmøy	51023650 Power 2500	167.7 ± 8.1	<0.14 ± -	<0.8	1.7 ± 0.7	189.2
Skretting Stavanger	React Pan 2500-70A 9	303.9 ± 12.9	0.54 ± 0.17	<1.2	3.2 ± 0.9	166.3

Appendix 3

Activity concentrations of the man-made beta-emitter strontium-90 (^{90}Sr), the man-made alpha-emitters plutonium-238 (^{238}Pu), plutonium-239,240 (^{239,240}Pu) and americium-241 (^{241}Am) and the naturally occurring alpha-emitters lead-210 (^{210}Pb) and polonium-210 (^{210}Po) in farmed salmon (*Salmo salar*).

County	Location	Bq/kg (fresh weight)					
		^{90}Sr	**^{238}Pu**	**^{39,240}Pu**	**^{241}Am**	**^{210}Pb**	**^{210}Po**
Troms	Kvanntoneset	<0.03	<0.001	<0.003	<0.0011	0.033 ± 0.007	0.003 ± 0.001
Nordland	Movik	<0.04	<0.001	<0.004	<0.0037	0.032 ± 0.007	0.004 ± 0.001
Nord-Trøndelag	Geitholmen	<0.04	<0.001	<0.002	<0.0005	0.05 ± 0.01	0.013 ± 0.003
Sør-Trøndelag	Mannbruholmen	<0.04	<0.001	<0.002	<0.0009	0.045 ± 0.008	0.020 ± 0.008
Nord-Trøndelag	Nordgjæslingan	<0.04	<0.001	<0.002	<0.0013	0.032 ± 0.007	0.022 ± 0.007
Sogn og Fjordane	Haneholmen	<0.04	<0.002	<0.002	<0.0010	0.07 ± 0.02	0.008 ± 0.002
Rogaland	Herøy	<0.04	<0.001	<0.002	<0.0009	0.046 ± 0.008	0.023 ± 0.008

Appendix 4

Activity concentrations of the man-made beta-emitter strontium-90 (^{90}Sr), the man-made alpha-emitters plutonium-238 (^{238}Pu), plutonium-239,240 ($^{239,240}Pu$) and americium-241 (^{241}Am) and the naturally occurring alpha-emitters lead-210 (^{210}Pb) and polonium-210 (^{210}Po) in manufactured fish feed from different producers.

Feed producer	**Name of feed**	**Bq/kg (fresh weight)**					
		^{90}Sr	**^{238}Pu**	**^{239,240}Pu**	**^{241}Am**	**^{210}Pb**	**^{210}Po**
Ewos Halsa	Rapid HP 1000	<0.1	<0.002	<0.004	<0.004	0.76 ± 0.12	3.6 ± 0.4
Ewos Florø	Rapid CC1 HP 1000	<0.1	<0.003	<0.004	<0.002	0.61 ± 0.12	5.2 ± 0.5
Biomar Karmøy	51023650 Power 2500	<0.1	<0.003	<0.006	<0.002	0.64 ± 0.12	1.5 ± 0.2