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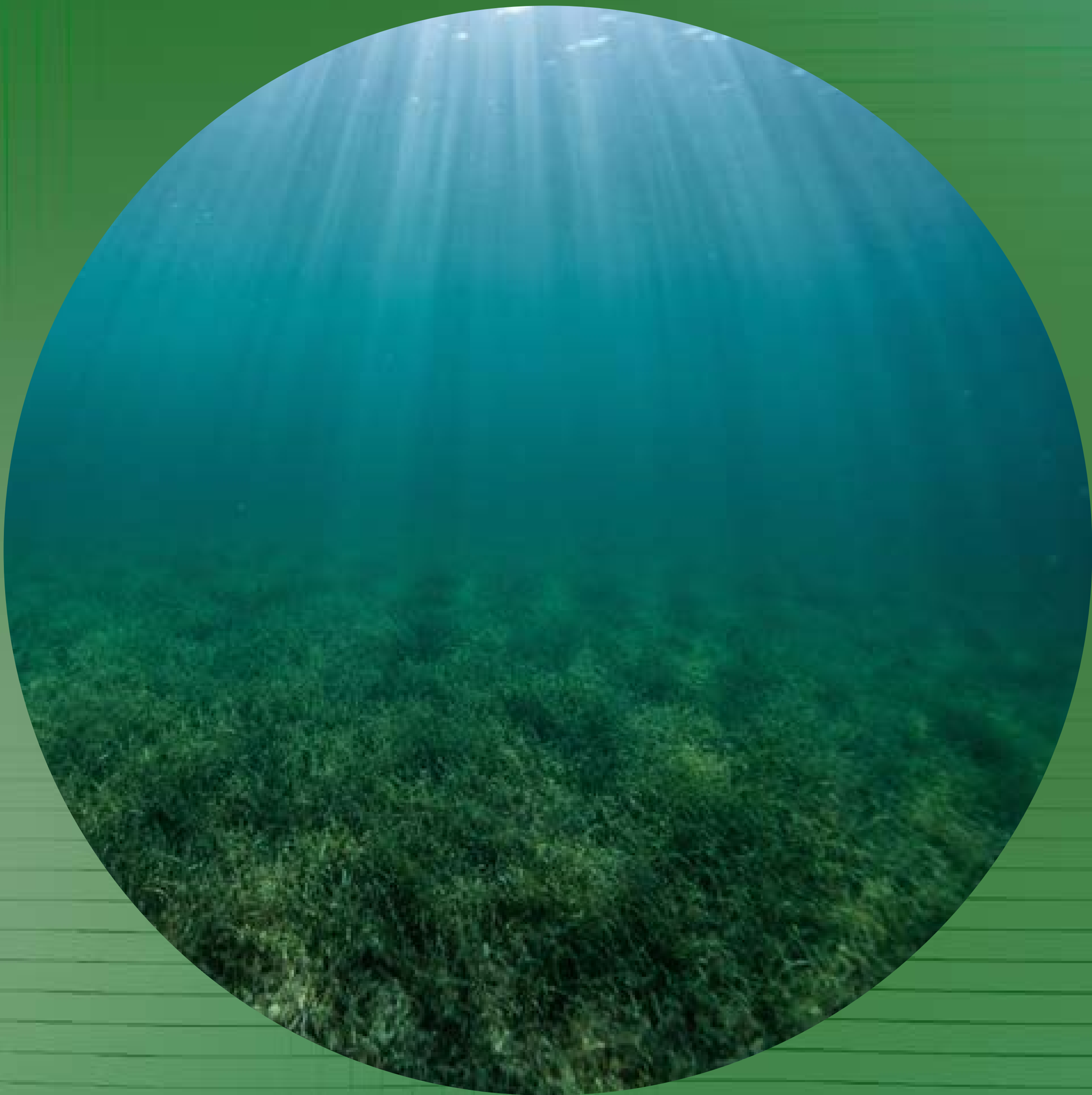
Radioactivity in the Marine Environment 2018, 2019 and 2020

Results from the Norwegian Marine Monitoring Programme RAME



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Resymé
Rapporten inneholder resultater fra overvåkningen av radioaktivitet i sjøvann, sedimenter og biota i norske havområder i 2018, 2019 og 2020.

Reference
Skjerdal H[1], Heldal HE[2], Rand A[3], Gwynn J[1], Jensen LK[1], Volynkin A[2], Haanes H[1], Møller B[1], Gäfvert T[1]. Radioactivity in the Marine Environment 2018, 2019 and 2020. Results from the Norwegian Marine Monitoring Programme RAME. DSA Report 2025:07. Østerås: Norwegian Radiation and Nuclear Safety Authority, 2025.
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Key words
Radioactivity, marine environment, RAME, monitoring, Norway.

Abstract
This report presents results of monitoring of radioactivity in sea water, sediment and biota collected in Norwegian waters in 2018, 2019 and 2020.

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1 Introduction

In 2018, 2019 and 2020 samples for monitoring radioactivity in the marine environment were collected in the Barents, the North and the Norwegian Seas, respectively, and at permanent coastal stations along the Norwegian coastline. Results from the analyses of these samples are presented in this report and a summary of the findings and the conclusions are given.

Information about the design of the monitoring programme, a detailed description of the radionuclides and analytical methods can be found in previous reports from the monitoring programme [e.g. 1, 2 and 3].

2 Sources

Radionuclides originating from nuclear weapons fallout, the Chernobyl accident, and current and historic discharges from the reprocessing of spent nuclear fuel are still the main contributors to anthropogenic radionuclides in Norwegian waters. Runoff from Chernobyl polluted areas is still contributing to the elevated levels of anthropogenic radionuclides along the coast and in fjords.

In addition, offshore oil and gas production in the North Sea and the Norwegian Sea results in the discharge of produced water containing elevated levels of naturally occurring radionuclides into the marine environment. In the North Sea, Norwegian and British offshore installations are the main contributors while only Norwegian operators are found in the Norwegian Sea [4, 5 and 6]. In 2018, the reported discharged activity of ^{226}Ra and ^{228}Ra from the Norwegian offshore oil and gas industry was 400 GBq and 360 GBq, respectively. For 2019, 430 GBq ^{226}Ra and 380 GBq ^{228}Ra were discharged and 400 GBq ^{226}Ra and 360 GBq ^{228}Ra were discharged in 2020. The discharges are at the same level as previous years, as shown in Figure 1. Total Norwegian discharges to the North Sea and the Norwegian Sea in 2018-2020 are shown in Figure 2, and discharges per installation in 2018, 2019 and 2020 are presented in Figures 3, 4 and 5, respectively.

Smaller Norwegian sources of anthropogenic radionuclides include discharges from the Institute for Energy Technology (IFE) and Norwegian hospitals which routinely discharge medical radionuclides into the marine environment, and the discharges are reported to DSA annually. Discharges from the Institute for Energy Technology are restricted by activity limits per nuclide, in line with their permit under the Pollution Control Act. In addition, the dose to a hypothetical critical group should not exceed 1 μSv per year. The annual dose from liquid discharges from IFE Kjeller was estimated to 0.051 μSv, 0.000035 μSv and 0.0032 μSv in 2018, 2019 and 2020, respectively.

Norwegian hospitals are permitted to use and discharge a range of medical radionuclides into the marine environment, under the Pollution Control Act. Unsealed radioactive substances used in medicine dominate the anthropogenic radioactive discharges to the sewage system. The medical radionuclides used for diagnostic and medical treatments are mainly short-lived. However, due to the amount used and subsequently discharged, the most important radionuclide concerning dose to the public after discharge is ^{131}I. Accumulation of iodine and other short-lived nuclides discharged from the hospital in Tromsø has been studied in [7]. The discharge of ^{131}I has been estimated according to instructions published by OSPAR. The discharges to the sewage system from the medical sector in 2018, 2019 and 2020 were 2.6 TBq, 1.20 TBq and 1.07 TBq ^{131}I, respectively.

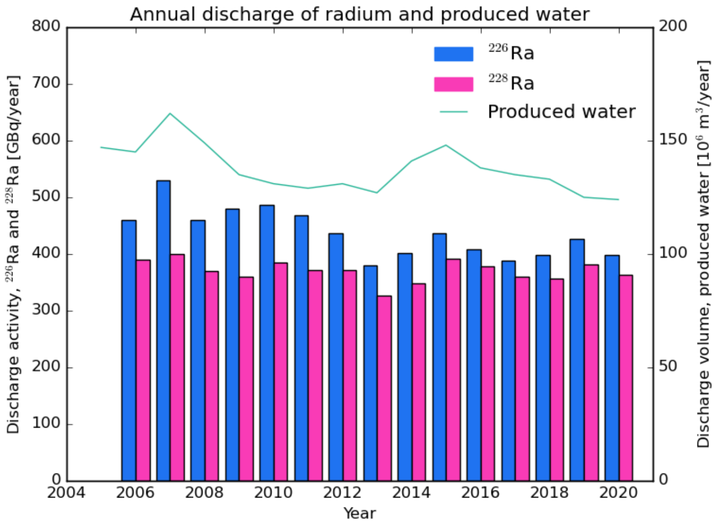

Figure 1: Annual discharge of ^{226}Ra and ^{228}Ra to the marine environment, via produced water, and discharged volume of produced water from the Norwegian offshore oil and gas industry in the period 2005 to 2020.

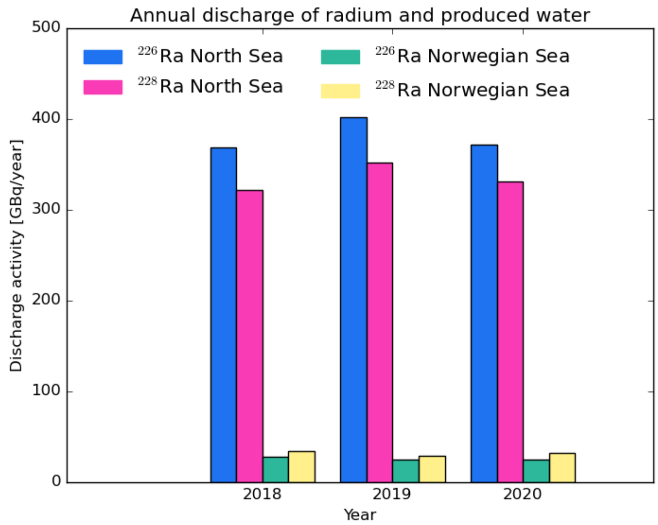

Figure 2: Discharge of ^{226}Ra and ^{228}Ra to the North Sea and the Norwegian Sea from the Norwegian offshore oil and gas industry.

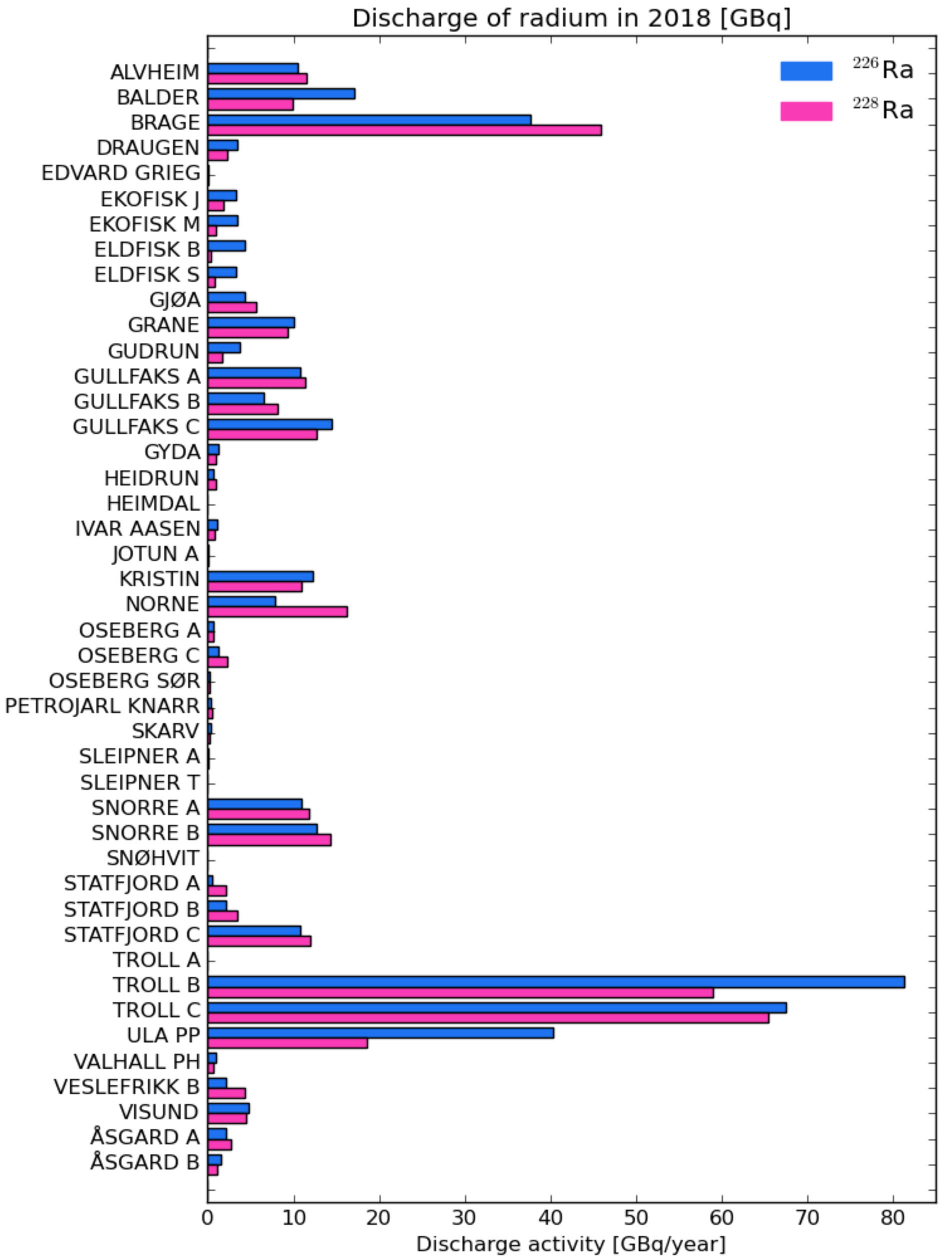

Figure 3: Discharged activity of ^{226}Ra and ^{228}Ra from Norwegian oil and gas fields in 2018.

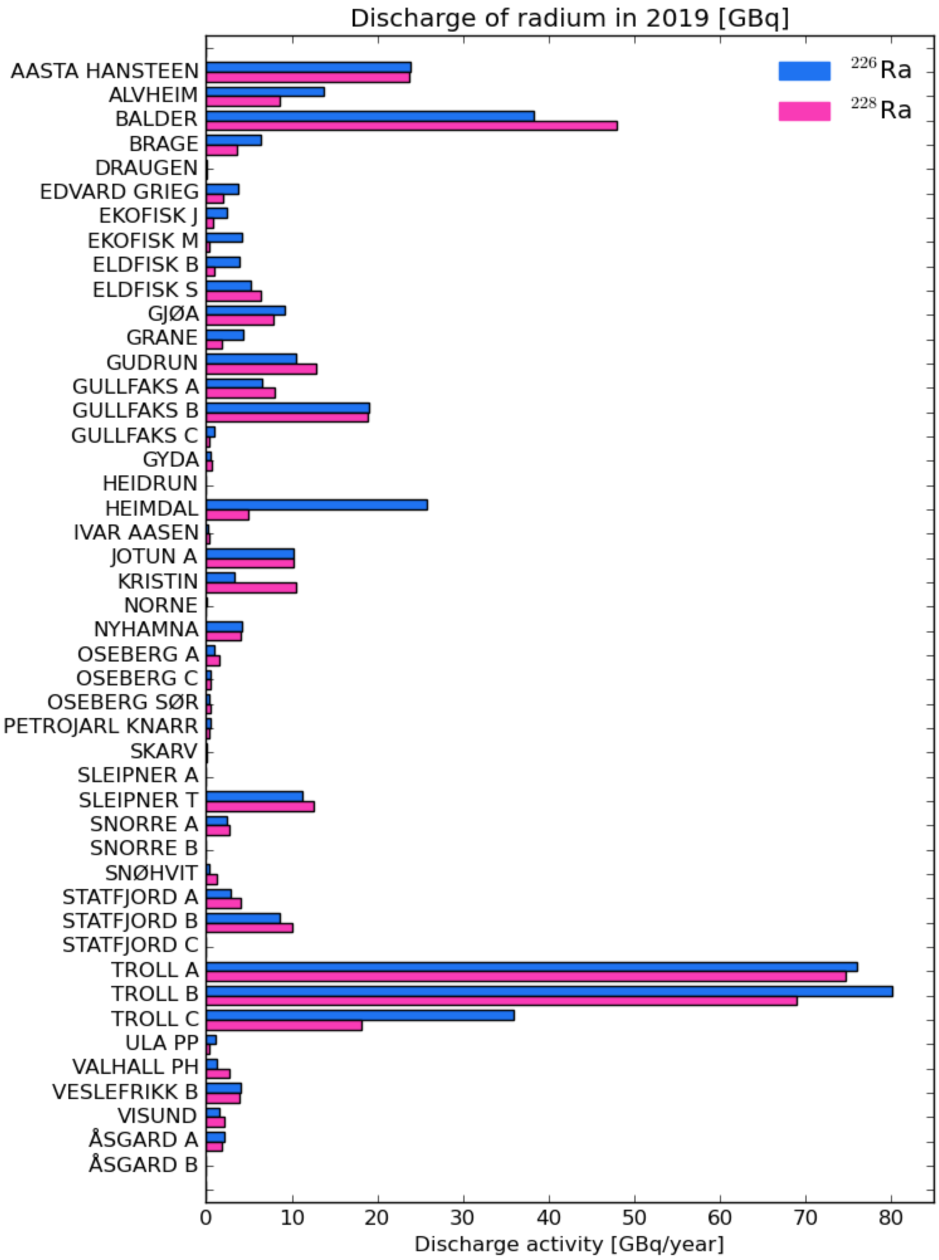

Figure 4: Discharged activity of ^{226}Ra and ^{228}Ra from Norwegian oil and gas fields in 2019.

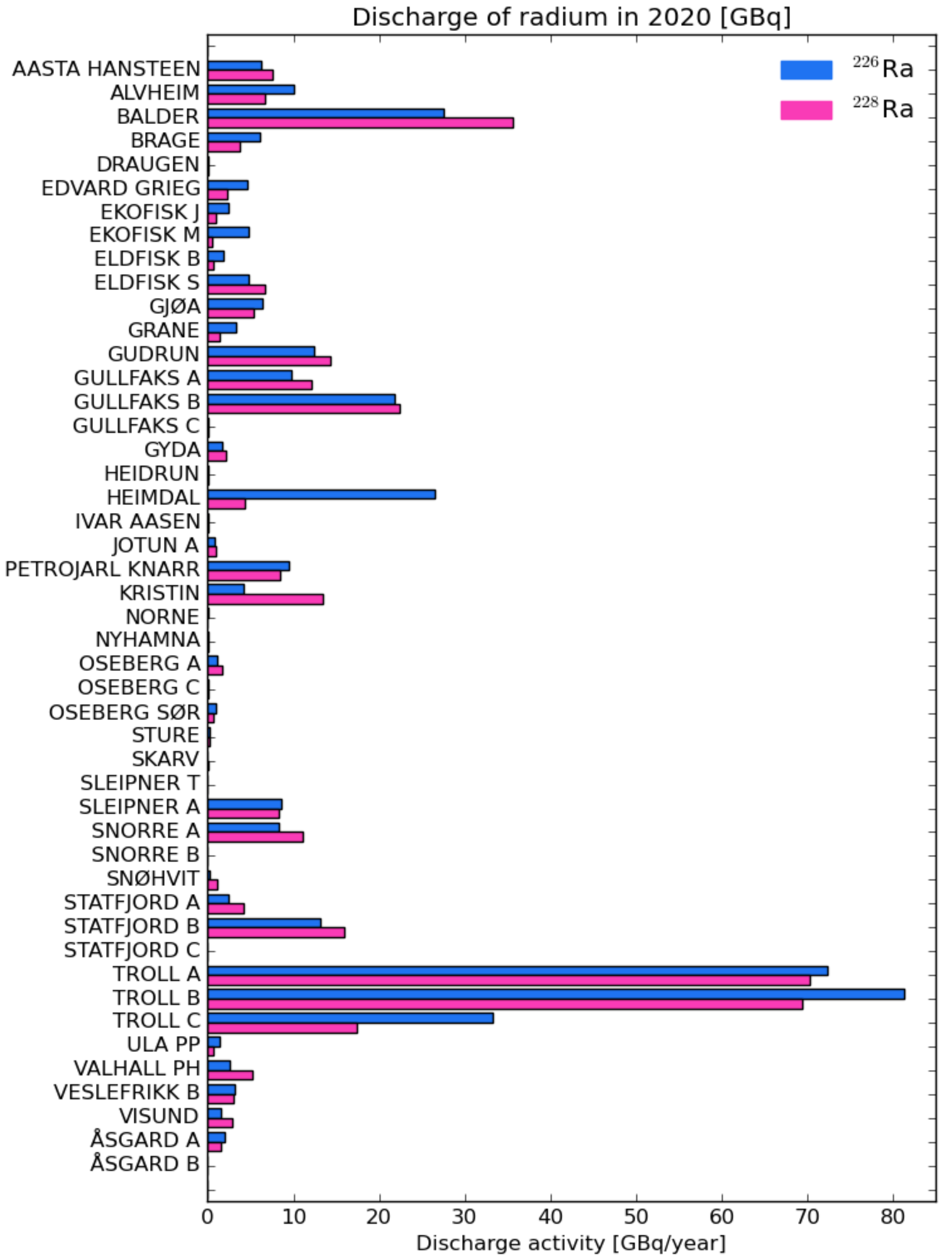

Figure 5: Discharged activity of ^{226}Ra and ^{228}Ra from Norwegian oil and gas fields in 2020.

3 Collection of samples

A broad range of samples were collected on cruises to the Barents Sea (2018), in the North Sea (2019) and to the Norwegian Sea (2020). In addition, annual sediment and water samples were collected around the sunken nuclear submarine Komsomolets in the Norwegian Sea. A dedicated research cruise to Komsomolets in 2019 carried out more detailed investigations, and the results are available in [8]. Annual samples of cod were obtained from Bjørnøya and the coast of Finnmark. Selected fjords were sampled for seawater and sediments each year, while seawater was sampled annually from the Skagerrak. Permanent coastal sampling stations along the Norwegian coast were sampled annually or monthly for seaweed and/or seawater. A geographic overview of the sampling areas and coastal stations covered by the marine monitoring programme is shown in Figure 6.

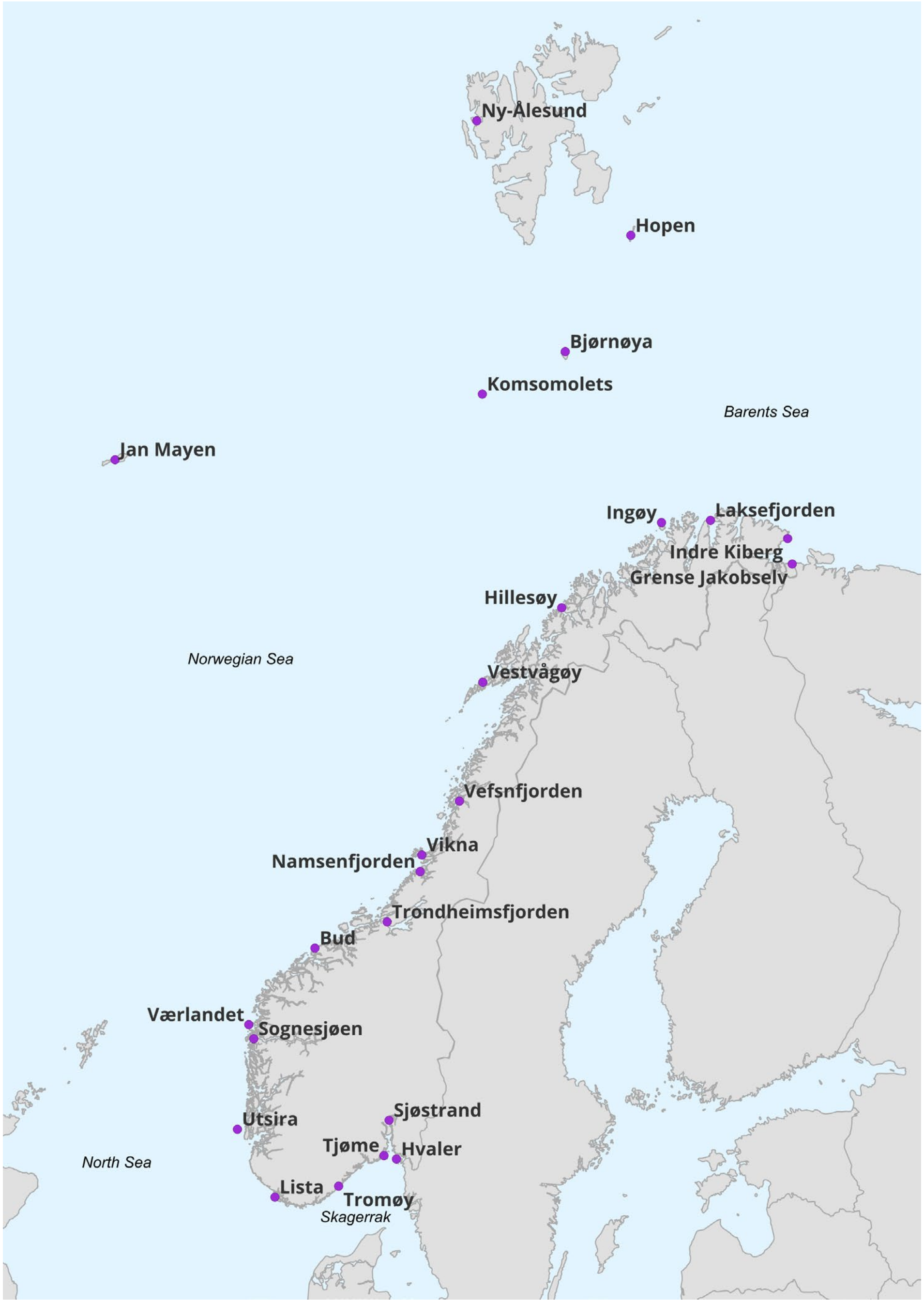

Figure 6: Geographic overview of the sampling areas and coastal sampling stations covered by the marine monitoring programme.

Sampling and analyses were carried out by the Institute of Marine Research (IMR), the Institute for Energy Technology (IFE) and the Norwegian Radiation and Nuclear Safety Authority (DSA).

Samples from the Barents Sea were collected in August and September 2018, from the North Sea in July 2019 and from the Norwegian Sea in May 2020. Sampling was performed by IMR and DSA on board the research vessels R/V "G. O. Sars" and R/V "Johan Hjort" (Figure 7 and 8). Samples of surface seawater collected onboard these research vessels were analysed for ^{137}Cs, ^{226}Ra, ^{241}Am and plutonium isotopes. The samples are also analysed for ^{40}Ka and ^{228}Ra, but the results are not included in this report. ^{90}Sr in seawater will be reported in the next report on radioactivity in the marine environment. Sediment samples and various samples of marine biota were analysed for ^{137}Cs.

For over two decades, coastal samples of seawater and seaweed at different locations have been collected for the analysis of technetium-99 (^{99}Tc) as a result of the discharge of this radionuclide from Sellafield. In recent years, the activity concentrations of ^{99}Tc in seawater have been decreasing and are now often the below the analytical detection limit. Certain brown seaweeds can accumulate high levels of ^{99}Tc, and this allows us to continue to follow the levels of this radionuclide in the marine environment. As a consequence, the monitoring of ^{99}Tc in seawater has been reduced, but the monitoring in seaweeds continues.

Samples of the brown seaweed *Fucus vesiculosus* from the Norwegian coastline were collected by IFE and the DSA (sampling stations are shown in Figure 6). At most costal stations, sampling is performed annually. More frequent seaweed sampling is performed at Utsira and Hillesøy. Additionally, IMR sample different species of brown seaweed as well as lobster (and seawater) annually at Værlandet for the analysis of ^{99}Tc.

Samples of cod (*Gadus morhua*) were collected annually from the Barents Sea by the IMR's reference fleet, a small group of Norwegian fishing vessels that provide IMR with detailed information about their fishing activity and catches on a regular basis.

Figure 7: Research vessel R/V "G. O. Sars". Photo: Erlend A. Lorentzen / Institute of Marine Research.

Figure 8: Research vessel R/V "Johan Hjort". Photo: Institute of Marine Research.

4 Radioactivity in seawater and sediments

4.1 Caesium-137 in seawater and sediment

Levels of ^{137}Cs in Norwegian waters in 2018-2020 are shown in Figure 9 and 10. The activity concentrations in surface water ranged from 0.6 to 13.6 Bq/m^3, with analytical uncertainties on individual measurements ranging from approximately 10 to 50% (2 sigma). The highest levels were found in the Skagerrak.

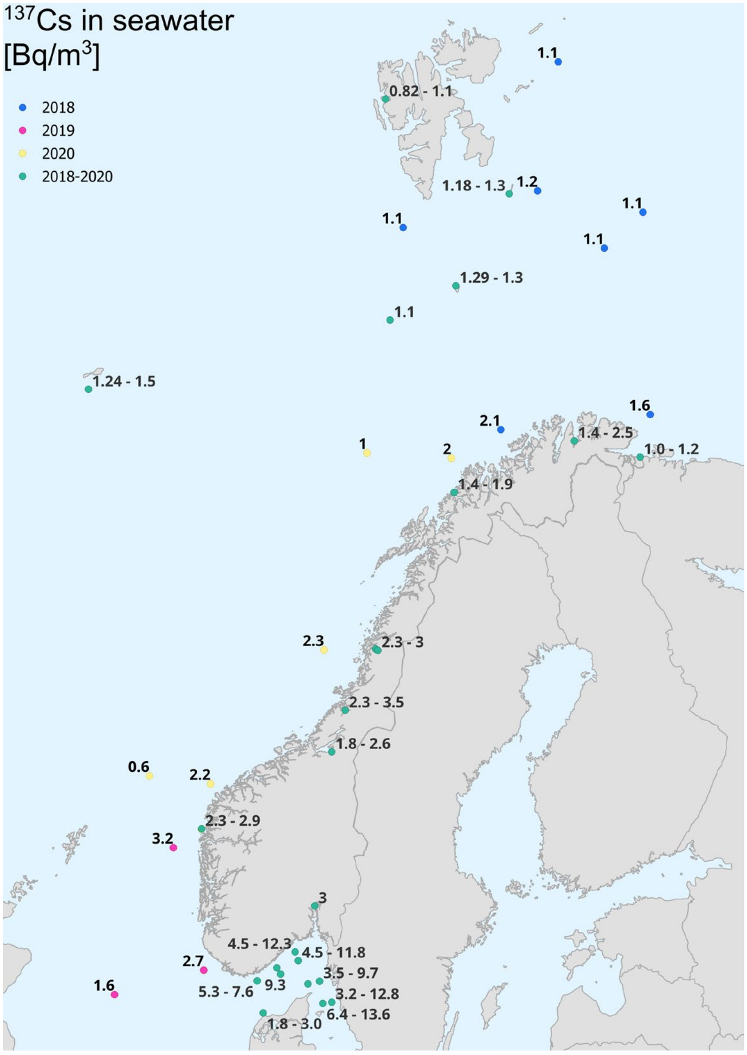

Figure 9: Activity concentrations (Bq m^{-3}) of ^{137}Cs in surface seawater collected in the Norwegian waters in 2018-2020. For locations with more than one measurement, the range is shown.

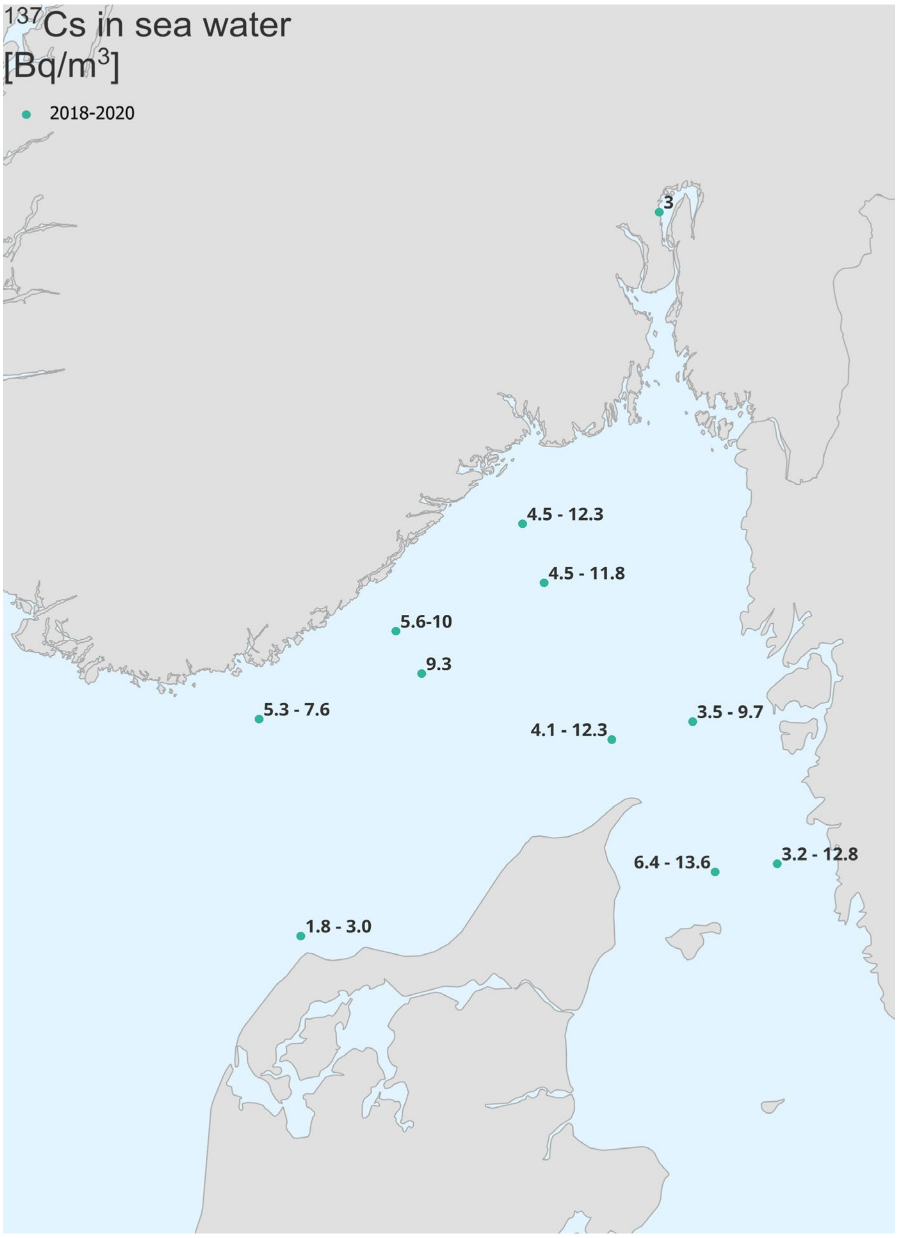

Figure 10: Range of activity concentrations (Bq m^{-3}) of ^{137}Cs in surface seawater collected in the Skagerrak in 2018, 2019 and 2020.

Data from Hillesøy (2002-2020) and Grense Jakobselv (2005-2020) (Figure 11) showed that the levels of ^{137}Cs in the Norwegian coastal current are slowly decreasing.

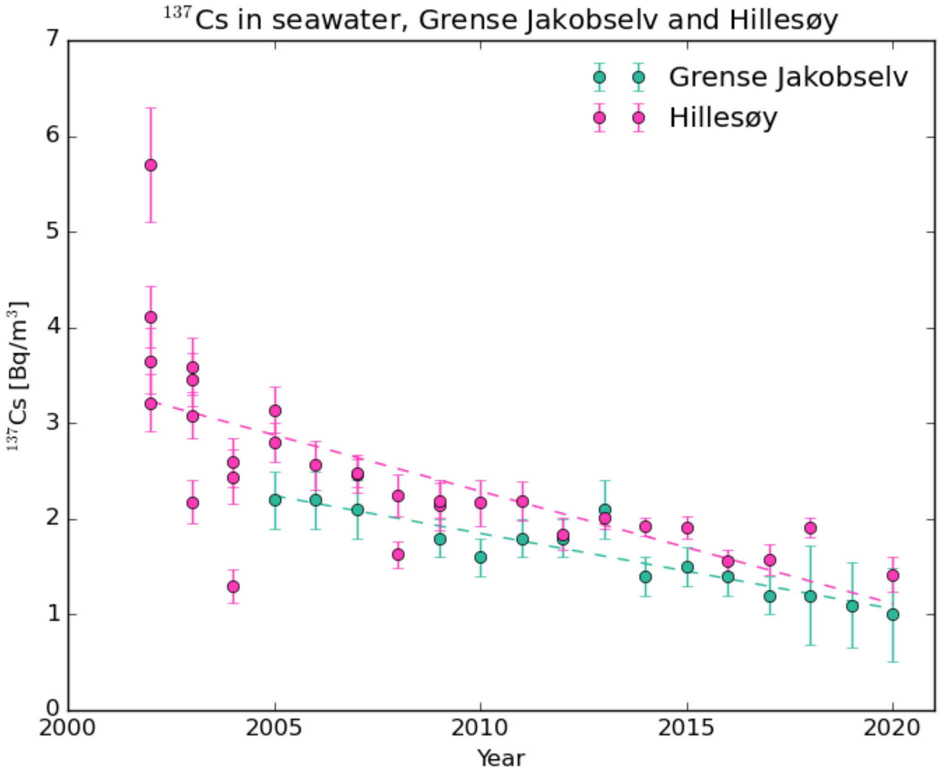

Figure 11: Activity concentrations (Bq/m^3) of ^{137}Cs in seawater at Hillesøy and Grense Jakobselv in the period 2002/2005-2020.

Caesium-137 has also been analysed in surface sediments (upper 2 cm layer) from the different marine areas, selected fjords and close to the sunken nuclear submarine "Komsomolets" in the Norwegian Sea. The results are presented in Figure 12, 13 and 14, respectively. The ^{137}Cs activity concentrations in sediments from open waters range from <0.19 Bq/kg (d.w.) to 6.8 Bq/kg (d.w.) with analytical uncertainties on individual measurements ranging from approximately 10 to 50% (2 sigma).

The activity concentration of ^{137}Cs in sediments sampled in the fjords ranged from 4.0 Bq/kg (d.w.), measured in the Laksefjord in 2020, to 191 Bq/kg (d.w.), measured in the Vefsnfjord in 2018. The fjords are subject to runoff from land and thereby to terrestrial derived ^{137}Cs from global fallout and fallout from Chernobyl. The areas in mid-Norway received the highest fallout from Chernobyl which explains the higher activity concentrations of ^{137}Cs found in the Vefsnfjord.

At Komsomolets, the levels of ^{137}Cs in surface sediments were within the range of values for surface sediments from other open water sampling stations.

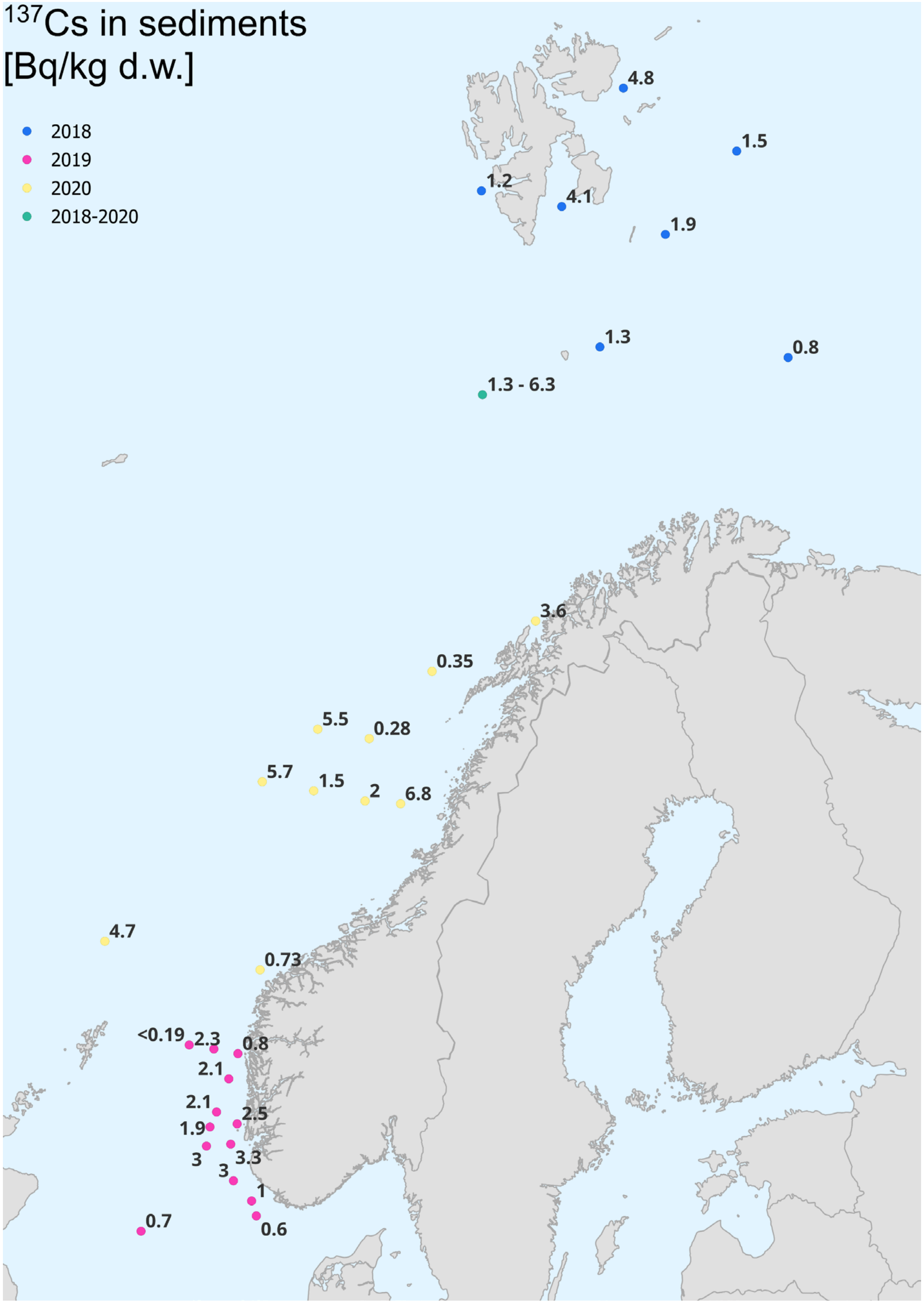

Figure 12: Activity concentrations (Bq/kg d.w.) of ^{137}Cs in surface sediments in 2018, 2019 and 2020. For locations with more than one measurement, the range is shown. The samples southwest of Bjørnøya were collected close to the sunken submarine Komsomolets.

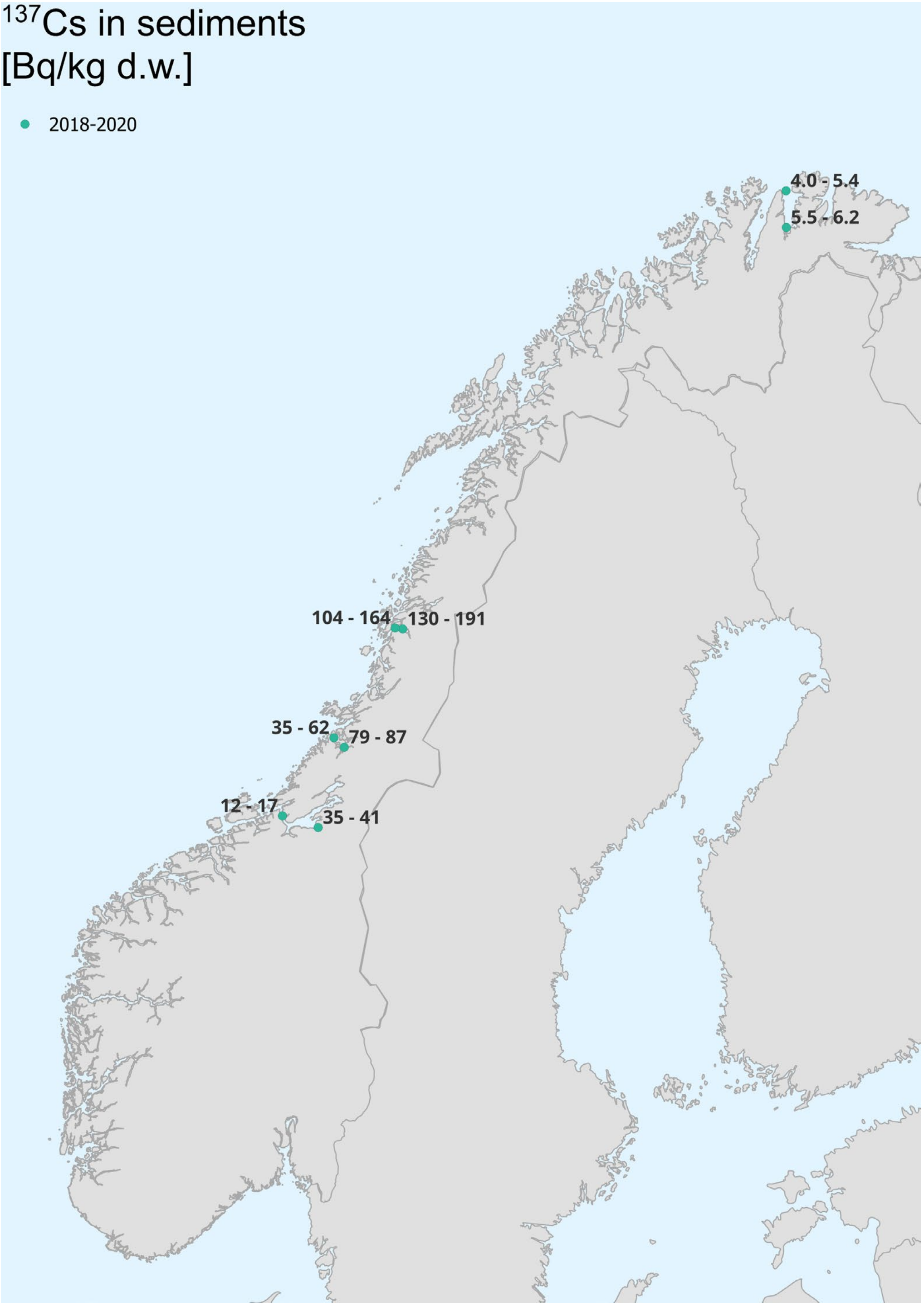

Figure 13: Range of activity concentrations (Bq/kg d.w.) of ^{137}Cs in surface sediment in Laksefjorden, Vefsnfjorden, Namsenfjorden and Trondheimsfjorden in 2018, 2019 and 2020.

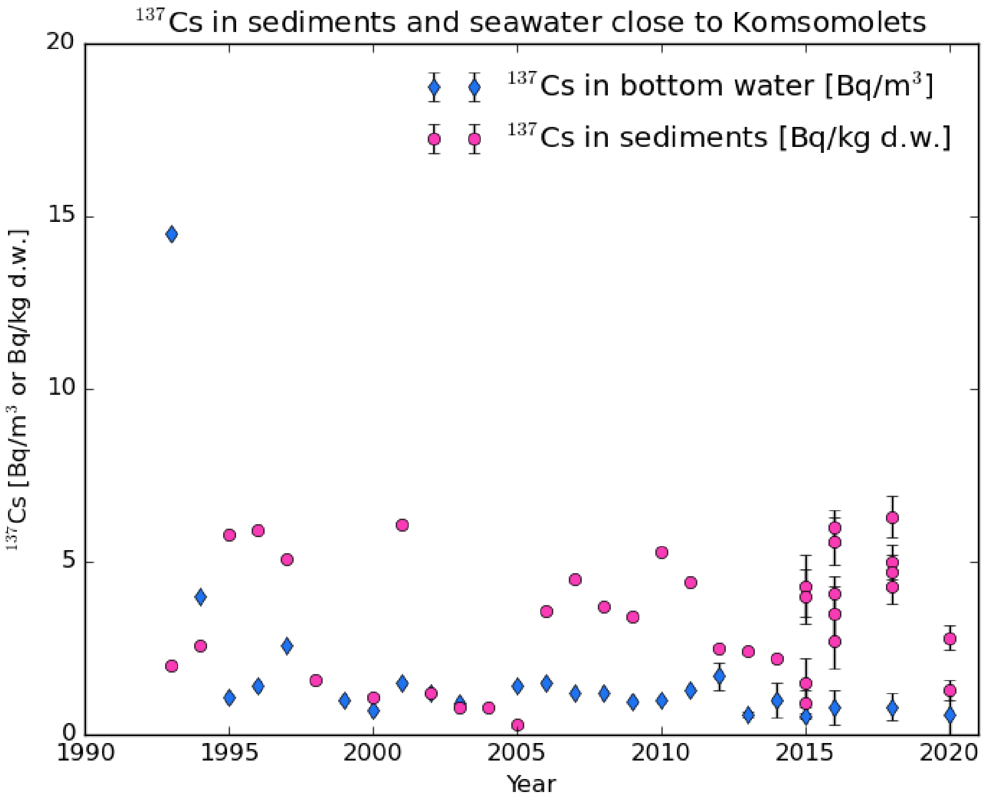

Figure 14: ^{137}Cs in samples collected close to the sunken nuclear submarine "Komsomolets". The bars are showing measurements uncertainties (2 sigma).

4.2 Plutonium-239 and plutonium-240 $^{239,240}Pu$ in seawater

The observed activity concentrations of plutonium-239,240 in 2018 and 2019 were low and ranged from 2.3 to 14.3 mBq/m³ (Figure 15), with analytical uncertainties on individual measurements ranging from approximately 20 to 50% (2 sigma). The levels are comparable to the levels presented in previous reports [9, 10], but the levels of $^{239,240}Pu$ at Grense Jakobselv are somewhat higher than previous years.

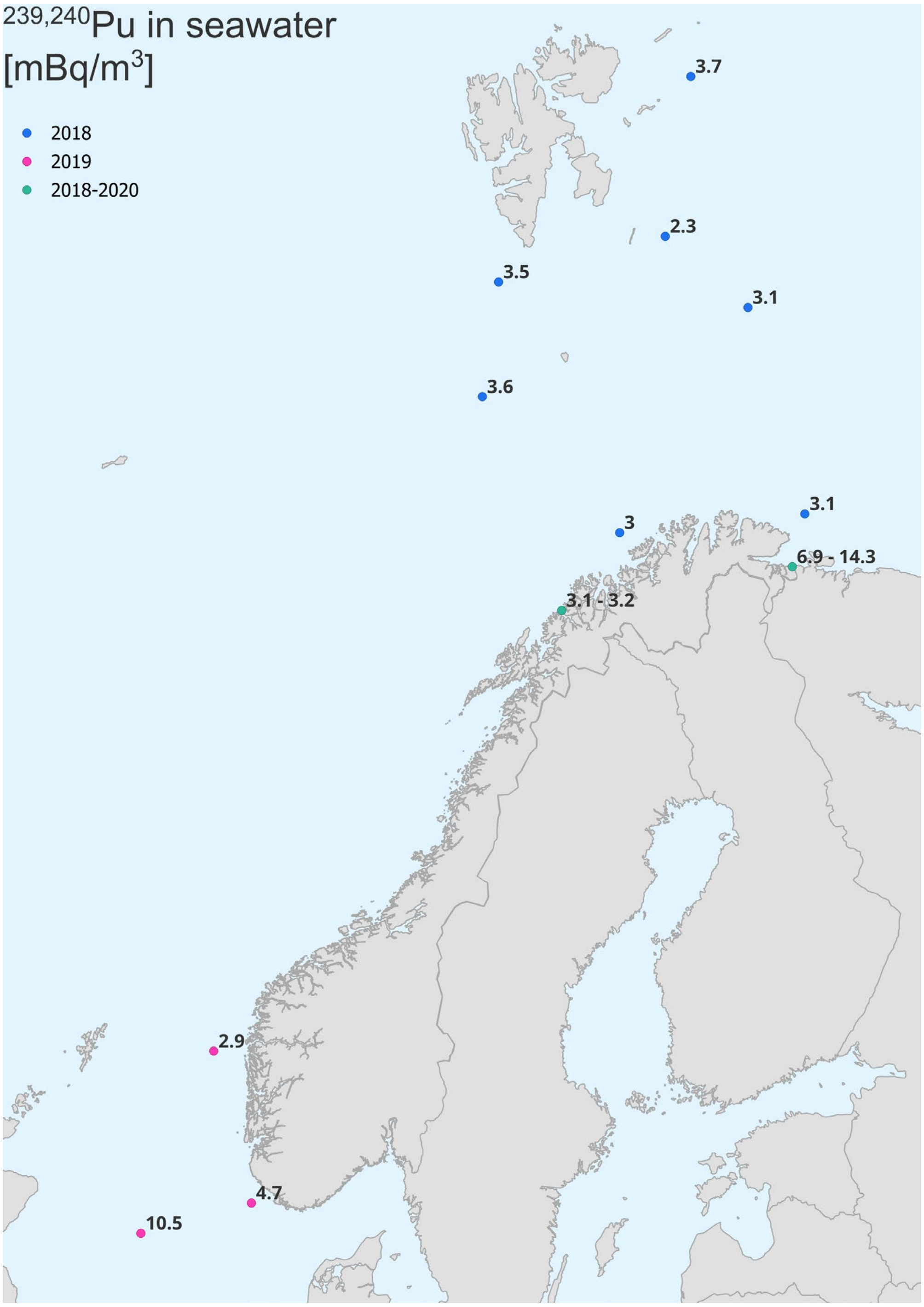

Figure 15: Activity concentrations (mBq/m³) of $^{239,240}Pu$ in surface seawater samples collected in 2018 and 2019. For locations with more than one measurement, the range is shown.

4.3 Americium-241 in seawater

The observed activity concentrations of ^{241}Am in 2018 and 2019 were low and ranged from <0.2 to 2.1 mBq/m^3 (Figure 16), and were comparable to the levels presented in previous reports [e.g. 9 and 10]. The measurements are close to the detection limit, and analytical uncertainties on individual measurements above detection limit ranging from approximately 50 % to 100 % (2 sigma).

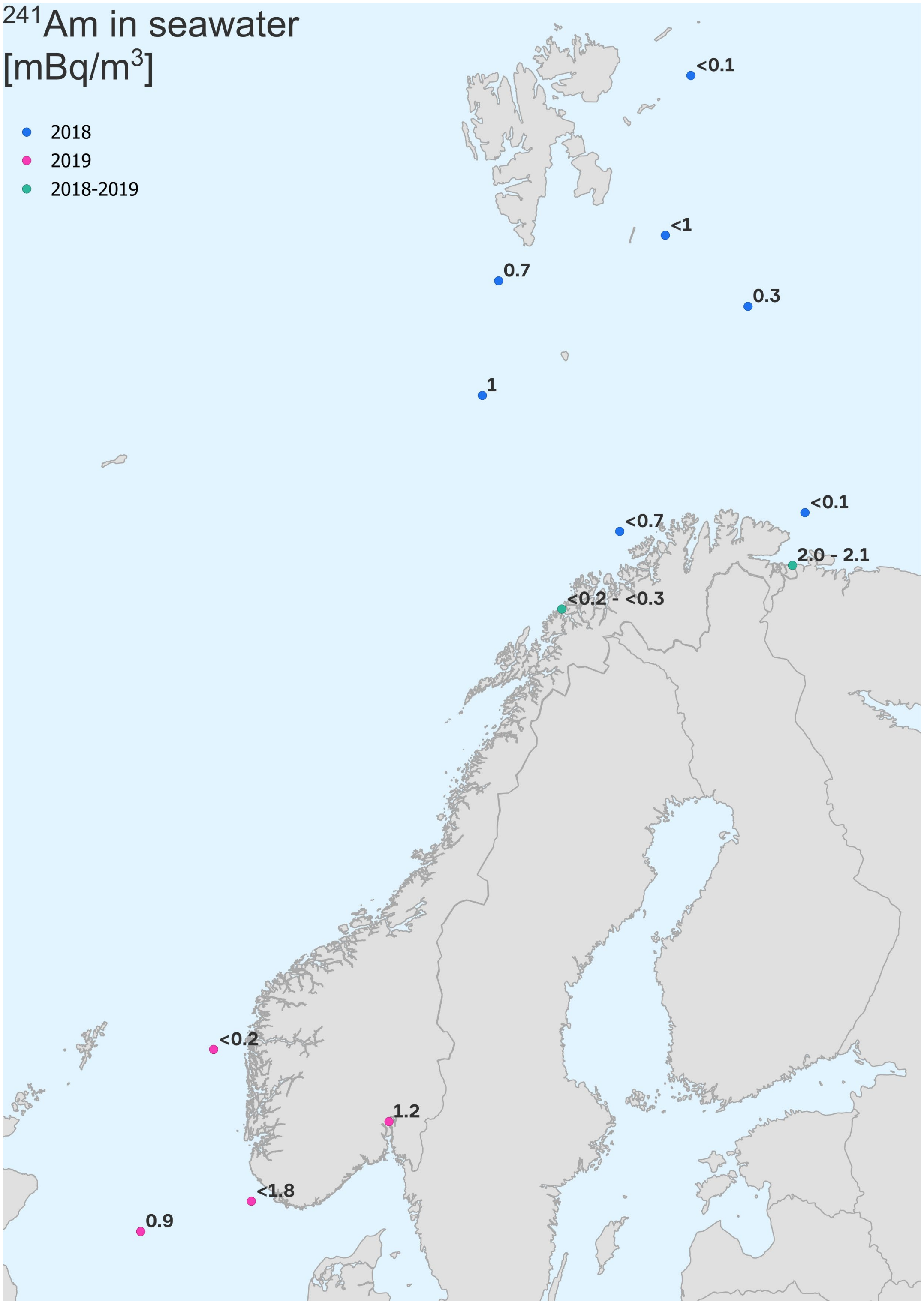

Figure 16: Activity concentrations (mBq/m^3) of ^{241}Am in seawater in 2018 and 2019. For locations with more than one measurement, the range is shown.

4.4 Radium-226 in seawater

The activity concentration of ^{226}Ra observed in Norwegian waters in 2018, 2019 and 2020 were in the range of 1.3 to 2.1 Bq/m³ (Figure 17), with analytical uncertainties on individual measurements ranging from approximately 10 to 30% (2 sigma), and comparable to previously observed levels [e.g. 9, 10]. In addition to sources of ^{226}Ra from discharges of produced water, ^{226}Ra enters the marine environment naturally through rivers, run-off and groundwater. Based on the available data, there are no obvious geographical differences in the levels of ^{226}Ra in Norwegian waters.

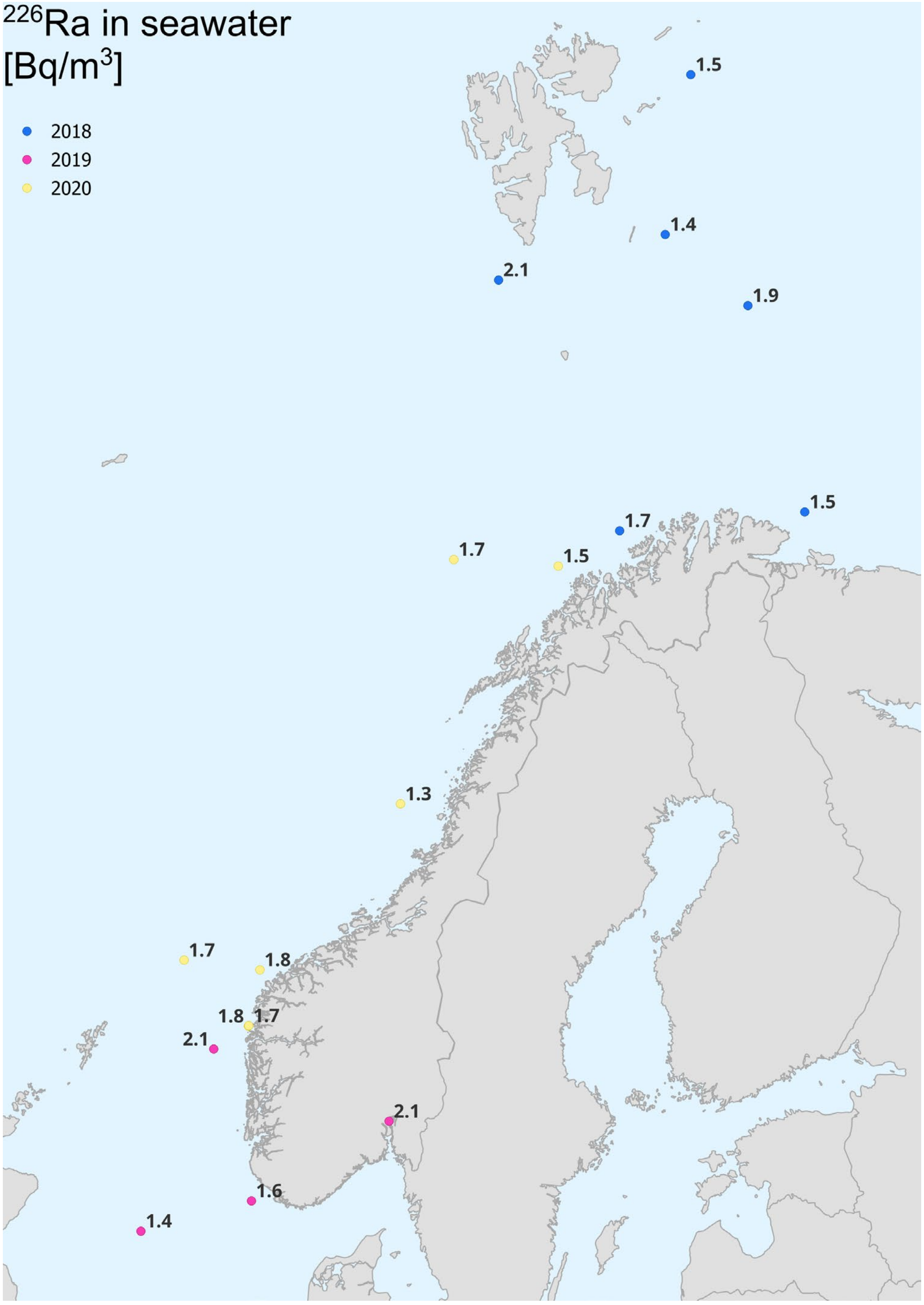

Figure 17: Activity concentrations (Bq/m³) of ^{226}Ra in seawater in 2018, 2019 and 2020.

5 Radioactivity in biota

5.1 Technetium-99 in seaweed

Brown seaweeds are a useful bioindicator for ^{99}Tc in the marine environment, as they readily accumulate ^{99}Tc from seawater and is easily accessible in most coastal areas. In 2018, 2019 and 2020, bladderwrack (*Fucus vesiculosus*) was collected at five coastal sampling stations along the Norwegian coastline and analysed for ^{99}Tc.

At Hillesøy, sampling was carried out monthly in 2018, 2019 and 2020, while at Utsira, sampling was carried out four times in 2018, twice in 2019 and six times in 2020. At other sites, sampling was carried out in August or September. Overall, the results range from 10 to 23 Bq/kg (d.w.), where the highest activity concentration was found in the sample collected at Utsira in November 2020 (Figure 18). Compared with the results from 1999-2001 [11 and 12], the levels of ^{99}Tc in *F. vesiculosus* have decreased at all sampling sites, due to the reduced discharge of ^{99}Tc from Sellafield. The trend can also be seen in Figure 19, which shows the annual average activity concentration of ^{99}Tc in *F. vesiculosus* at Utsira and Hillesøy, together with the annual discharge of ^{99}Tc from Sellafield.

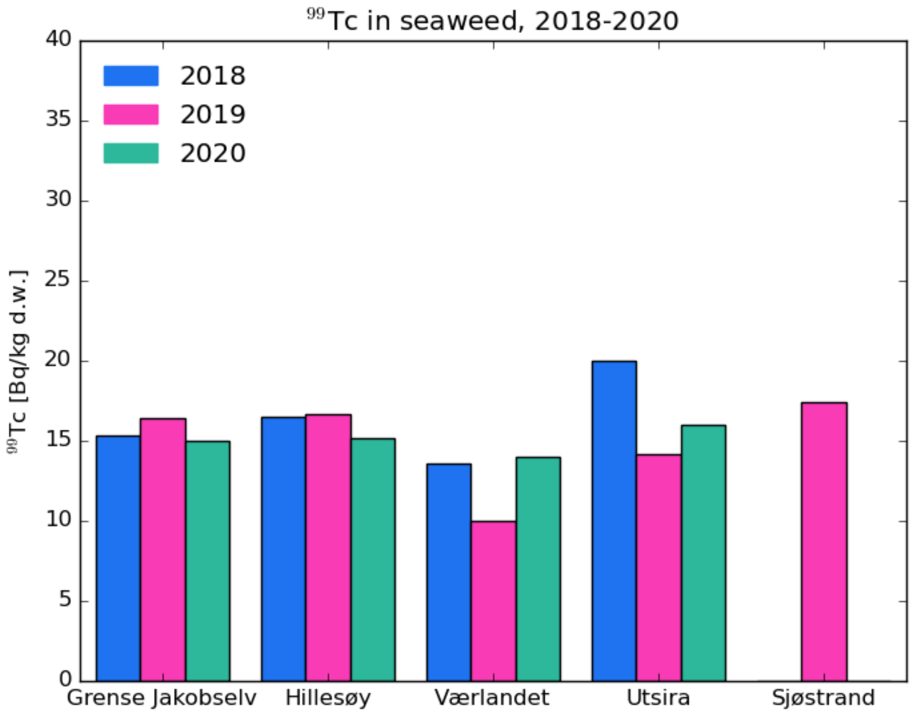

Figure 18: Activity concentrations of ^{99}Tc (Bq/kg d.w.) in *Fucus vesiculosus* sampled along the Norwegian coastline in 2018, 2019 and 2020. Mean values for Hillesøy and Utsira.

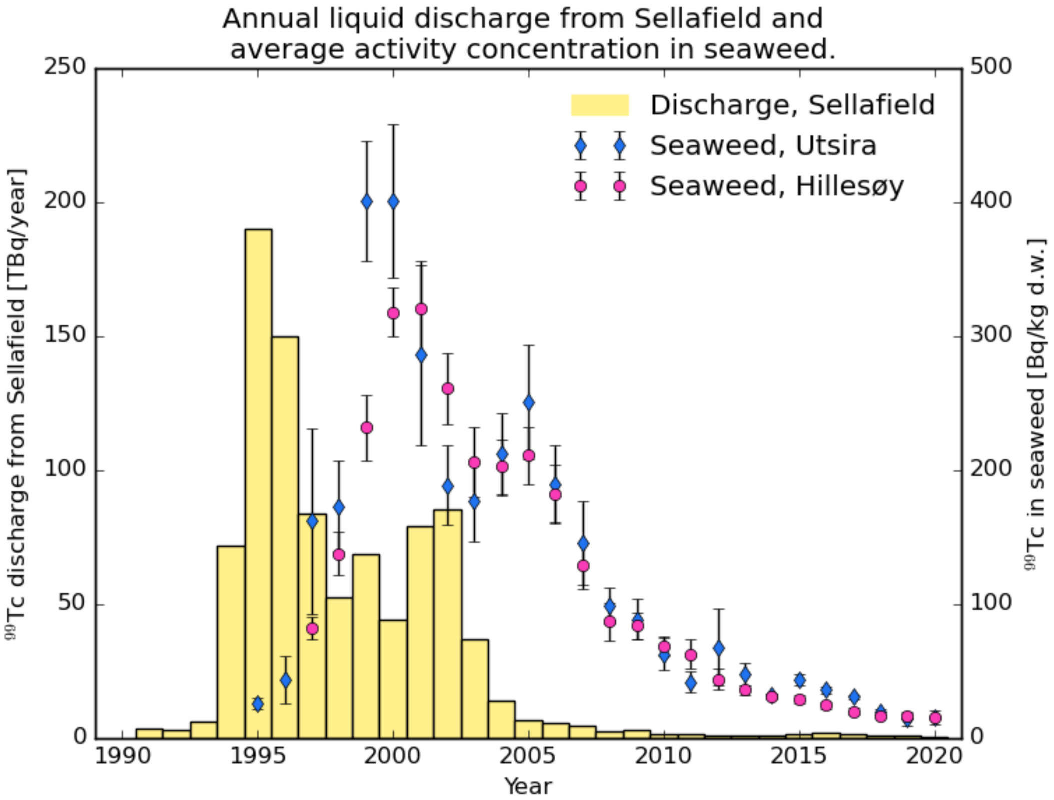

Figure 19: Annual liquid discharge of ^{99}Tc from Sellafield [13] and annual average (with 95 % confidence limits) ^{99}Tc activity concentration in bladderwrack *(Fucus vesiculosus)* sampled at Utsira (data provided by IFE) in the period 1995-2020 and Hillesøy in the period 1997-2020.

5.2 Plutonium-239,240 in seaweed

Fucus vesiculosus has been collected and analysed for $^{239,240}Pu$ at Utsira since 1980. The results from the period 1980 to 2020 (Figure 20) show a slowly decreasing trend in the activity concentration of $^{239,240}Pu$ in seaweed over time.

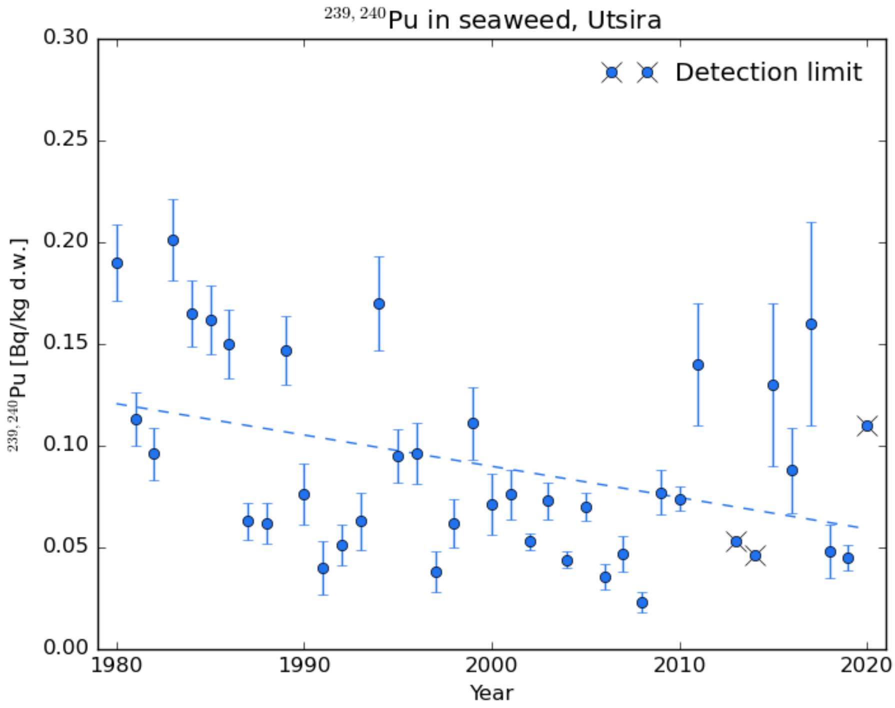

Figure 20: $^{239,240}Pu$ levels (Bq/kg d.w.) in *Fucus vesiculosus* (with measurement uncertainty) at Utsira in the period 1980 to 2020 (data provided by IFE). Results are reported biannually. No sampling in 2012, measurements in 2013, 2014 and 2020 are below the detection limit.

5.3 Caesium-137 in seaweed

Fucus vesiculosus has also been widely used as a bioindicator for ^{137}Cs. The accumulation of ^{137}Cs in bladder wrack is, however, not as pronounced as for ^{99}Tc. The uptake of ^{137}Cs also depends on the salinity of the surrounding seawater, with higher uptake at lower salinities [14].

In 2018, 2019 and 2020, samples of *F. vesiculosus* from the permanent coastal stations were analysed with respect to ^{137}Cs (Figure 21). Activity concentrations of ^{137}Cs in seaweed ranged from below the detection limit to 2.1 Bq/kg (d.w.).

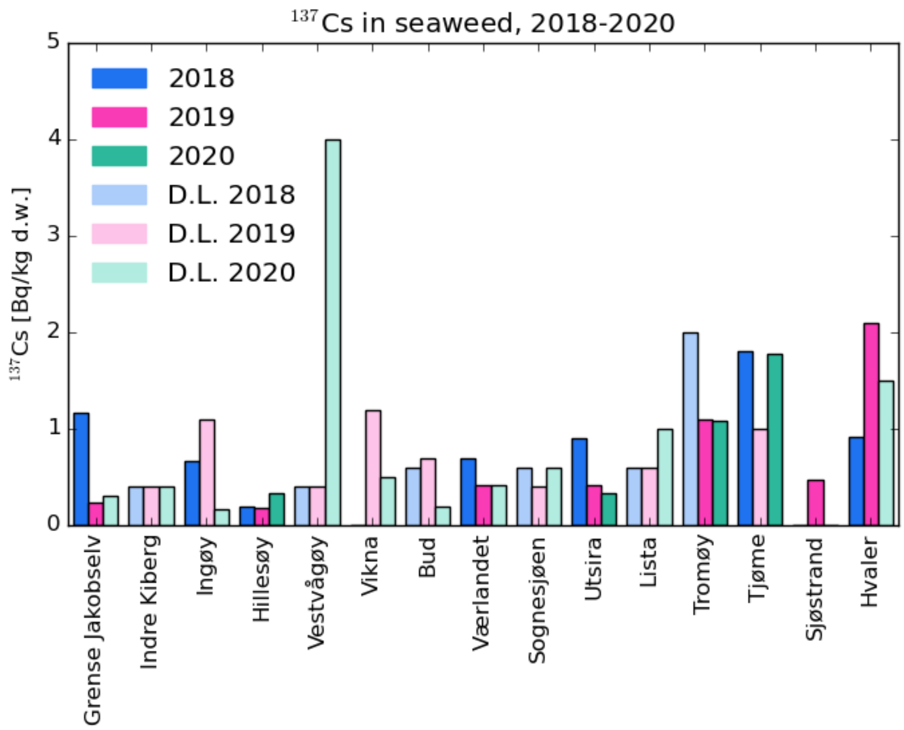

Figure 21: Levels of ^{137}Cs (Bq/kg d.w.) in Fucus vesiculosus sampled along the Norwegian coastline in 2018-2020. Mean values are presented for Hillesøy and Utsira, detection limits are plotted for measurements below level of detection. Results below the detection limits are shown with a lighter shaded bar. The figure shows the stations along the coast from northeast to southeast, see Figure 6.

The higher activity concentration of ^{137}Cs in *F. vesiculosus* in the southern part of Norway (stations on the right side of Figure 21) is due to the higher activity concentration of ^{137}Cs in the outflowing Baltic seawater contaminated by the Chernobyl accident.

The activity concentration of ^{137}Cs in *F. vesiculosus* has been relatively stable in recent years. However, data from frequent sampling at Utsira (Figure 22) shows that the activity concentration of ^{137}Cs has been slowly decreasing in this seaweed. This is in agreement with the reported temporal trend of ^{137}Cs in Baltic Sea seawater [15].

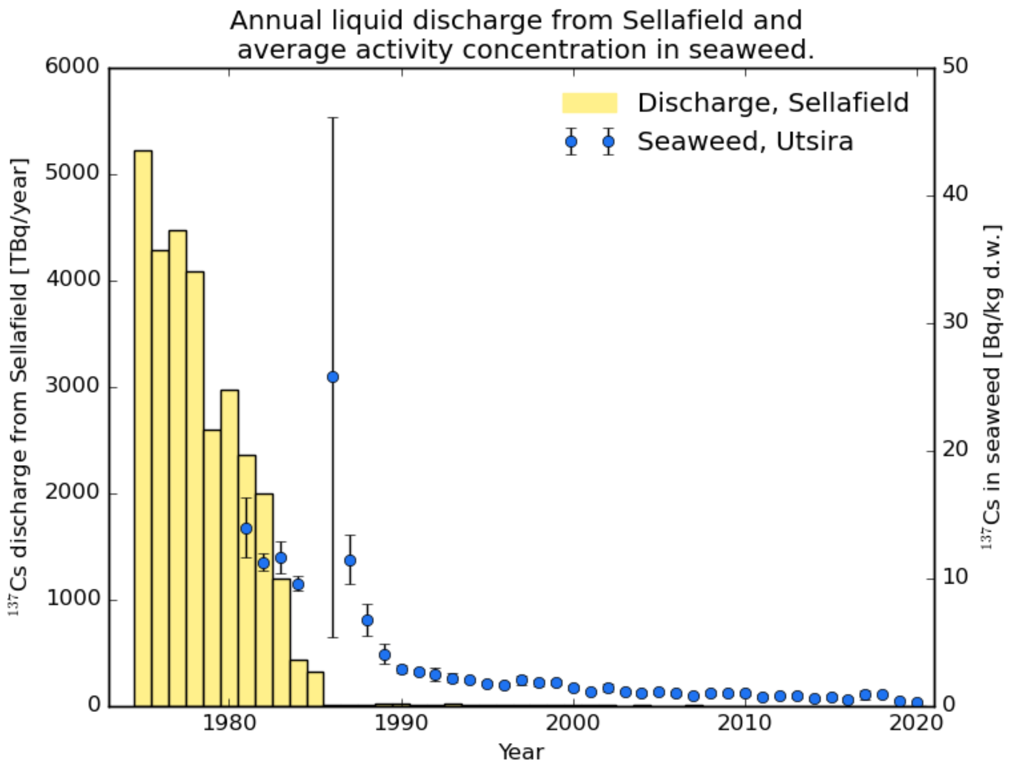

Figure 22: Annual liquid discharge of ^{137}Cs from Sellafield [13] and average activity concentration (Bq kg^{-1} d.w.) from monthly sampling of bladderwrack *(Fucus vesiculosus)* from Utsira in the period 1980-2020 (data from IFE). The large variability in 1986 is due to the Chernobyl accident.

5.4 Caesium-137 in fish and crustaceans

Samples of cod (*Gadus morhua*) from the Barents Sea caught either in the Bjørnøya-area or off the coast of Finnmark have been analysed for ^{137}Cs since the early 1990s (Figure 23 and 24). All samples of cod from 2018, 2019 and 2020 showed low activity concentrations of ^{137}Cs (below 0.5 Bq/kg (f.w.)), which were comparable to levels found in previous years [e.g. 9 and 16]. Overall, the results show a slightly decreasing trend in the levels of ^{137}Cs in cod since 1992.

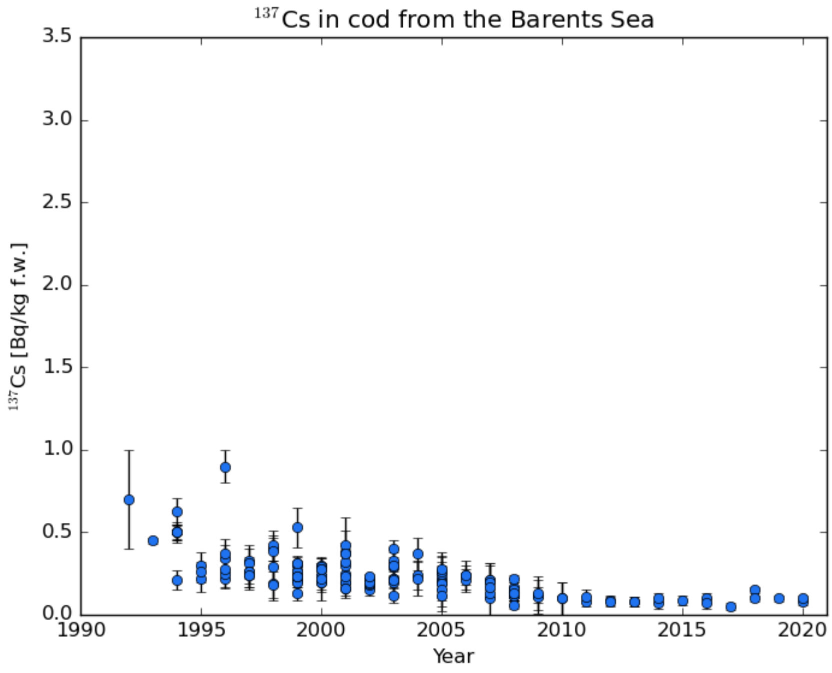

Figure 23: Activity concentration of ^{137}Cs (Bq kg^{-1} f.w.) in cod from the Barents Sea (the area around Bjørnøya) sampled in the period 1992 to 2020.

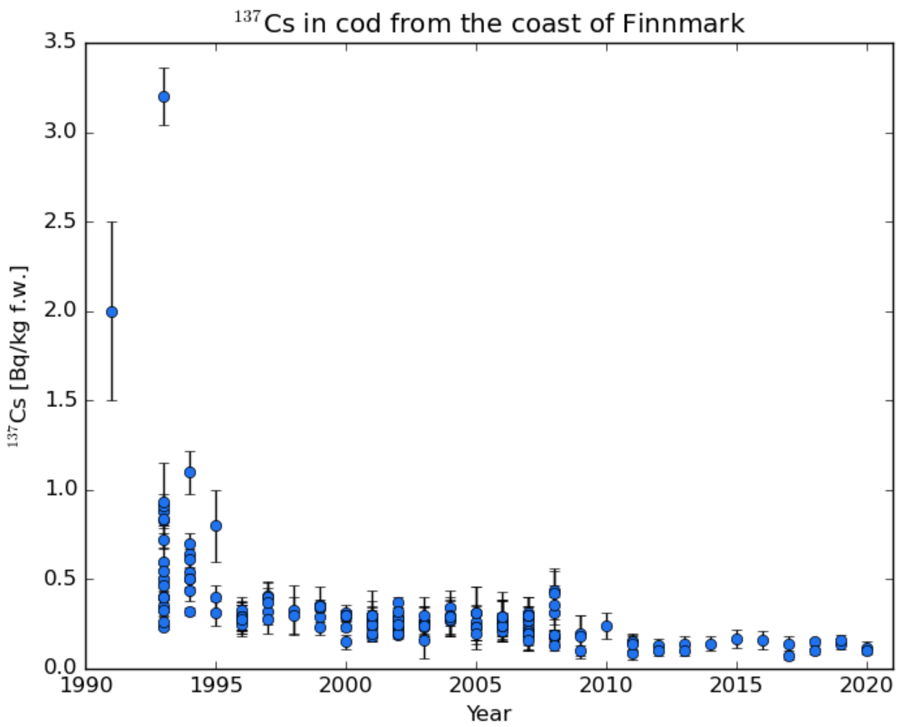

Figure 24: Activity concentration of ^{137}Cs (Bq kg^{-1} f.w.) in cod from the coast of Finnmark sampled in the period 1992 to 2020.

Caesium-137 levels in fish species and crustaceans caught in Norwegian waters in 2018, 2019 and 2020 are shown in Table 1. All results were below 1 Bq/kg (f.w.), with 0.51 ± 0.07 Bq/kg (f.w.) as the highest value. The latter was found in a sample of herring caught in the North Sea.

Table 1: Activity concentrations (Bq/kg f.w.) of ^{137}Cs in fish and crustaceans caught in the Barents Sea, the Norwegian Sea, the North Sea and in the Skagerrak in 2018-2020. Samples from fjords are marked with *. Values are presented with measurement uncertainties (2 sigma).

English name	Latin name	Norwegian name	^{137}Cs minimum Bq/kg f.w.	^{137}Cs maximum Bq/kg f.w.	Samples (Individuals)
		Barents Sea			
Arctic cod	*Boreogadus saida*	Polartorsk		0.05 ± 0.02	1 (50)
Blue whiting	*Micromesistius poutassou*	Kolmule		0.09 ± 0.02	1 (25)
Capelin	*Mallotus villosus*	Lodde	0.05 ± 0.02	0.05 ± 0.02	2 (6 kg)
Cod	*Gadus morhua*	Torsk	0.08 ± 0.02	0.17 ± 0.03	12 (780)
Golden redfish	*Sebastes norvegicus*	Uer		0.12 ± 0.02	1 (50)
Haddock	*Melanogrammus aeglefinus*	Hyse	0.08 ± 0.02	0.11 ± 0.02	3 (75)
Halibut	*Reinhardtius hippoglossoides*	Blåkveite	0.12 ± 0.03	0.16 ± 0.02	3 (59)
Herring	*Clupea harengus*	Sild		0.10 ± 0.02	1 (75)
Long rough dab	*Hippoglossoides platessoides*	Gapeflyndre	0.11 ± 0.02	0.12 ± 0.04	2 (50)
Saithe	*Pollachius virens*	Sei	0.14 ± 0.03	0.23 ± 0.09	2 (28)
Shrimp	*Pandalus borealis*	Reker	0.04 ± 0.02	0.05 ± 0.02	3 (9kg)
Snow crab	*Chionoecetes opilio*	Snøkrabbe		<0.06	1 (10)
		Norwegian Sea			
Blue whiting	*Micromesistius poutassou*	Kolmule	0.08 ± 0.02	0.11 ± 0.02	2 (25 + 3.3 kg)
Cod	*Gadus morhua*	Torsk	0.022± 0.06	0.25 ± 0.05	3 (30)
Deepwater redfish	*Sebastes mentella*	Snabeluer		<0.44	1 (2)
Golden redfish	*Sebastes norvegicus*	Uer	0.15 ± 0.03	0.16± 0.03	2 (50)

Greater argentine	*Argentina silus*	Vassild*		0.19 ± 0.03 *	
Haddock	*Melanogrammus aeglefinus*	Hyse	0.11 ± 0.05	0.12 ± 0.06	3 (75)
Herring	*Clupea harengus*	Sild	0.07 ± 0.02	0.12 ± 0.04	3 (75)
Mackerel	*Scomber scombrus*	Makrell		0.10 ± 0.03	1 (25)
Northern bluefin tuna	*Thunnus thynnus*	Makrellstørje		0.20 ± 0.03	1 (1)
Saithe	*Pollachius virens*	Sei	0.16 ± 0.07	0.22 ± 0.03	3 (75)
Shrimp	*Pandalus borealis*	Reker		0.77 ± 0.08 *	
Tusk	*Brosme brosme*	Brosme	0.16 ± 0.03	0.19 ± 0.04	3 (58)
			North Sea		
Blue mussel	*Mytilus edulis*	Blåskjell		<0.17	
Blue whiting	*Micromesistius poutassou*	Kolmule	0.09 ± 0.03	0.13 ± 0.03	3 (75)
Cod	*Gadus morhua*	Torsk	0.18 ± 0.03	0.23 ± 0.07	3 (27)
Haddock	*Melanogrammus aeglefinus*	Hyse	0.07 ± 0.02	0.11 ± 0.02	3 (73)
Herring	*Clupea harengus*	Sild	0.15 ± 0.08	0.51 ± 0.07	3 (75)
Mackerel	*Scomber scombrus*	Makrell	0.05 ± 0.02	0.19 ± 0.03	3 (75)
Northern bluefin tuna	*Thunnus thynnus*	Makrellstørje		0.19 ± 0.03	1 (1)
Norway pout	*Trisopterus esmarkii*	Øyepål	0.04 ± 0.02	0.10 ± 0.06	3 (>261)
Saithe	*Pollachius virens*	Sei	0.20 ± 0.03	0.22 ± 0.03	3 (75)
Silvery cod	*Gadiculus argenteus thori*	Sølvtorsk	0.04 ± 0.02	0.16 ± 0.05	3 (>495)
Whiting	*Merlangius merlangus*	Hvitting	0.22 ± 0.07	0.25 ± 0.08	3 (67)

Lobsters (*Hommarus gammarus*), like brown seaweeds, can also accumulate levels of ^{99}Tc. Technetium-99 has been analysed in lobster muscle from tails and claws collected from Værlandet since 2002. In the period from 2002 to 2020 the activity concentrations of ^{99}Tc in lobster (Figure 25) have decreased due to the reduced discharge of ^{99}Tc from Sellafield.

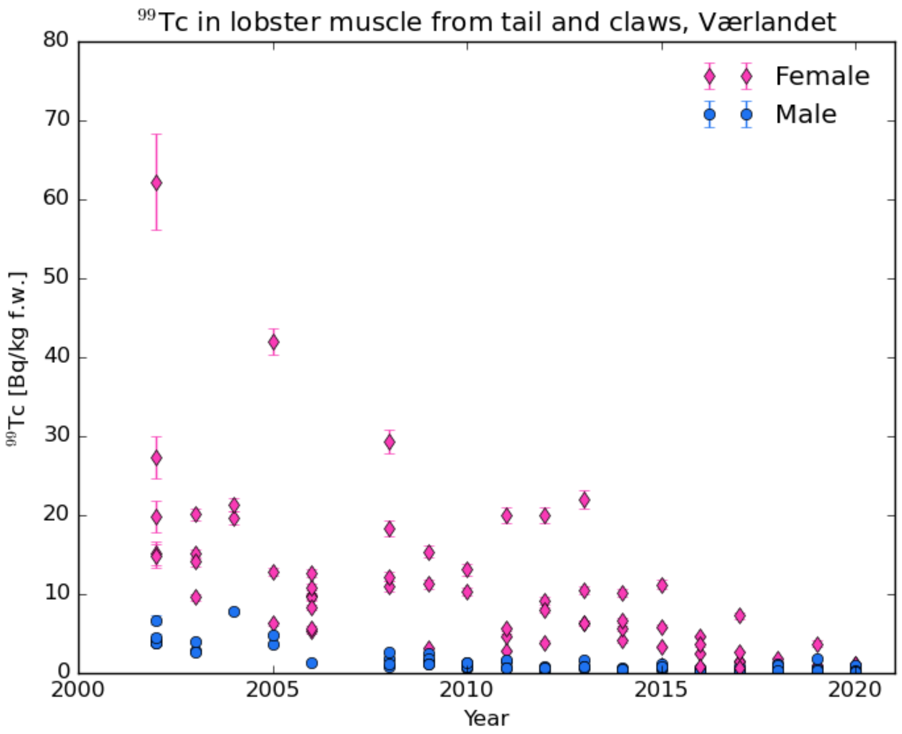

Figure 25: Activity concentrations of ^{99}Tc (Bq/kg (f.w.)) in lobster *(Hommarus gammarus)* from Værlandet (2002-2020).

6 Summary and conclusions

In 2018, 2019 and 2020, samples of seawater, sediment, and biota were collected in Norwegian waters, and at several coastal stations and fjords. Data on radioactivity levels and trends in these areas are summarised in this report.

6.1 Sources

The discharges of anthropogenic radionuclides from Norwegian sources such as hospitals and Institute for Energy Technology (IFE) are only detectable in the environment close to each discharge point and has no significant impact on the large-scale distribution of these radionuclides in the marine environment. The annual dose from liquid discharges from IFE Kjeller was estimated to 0.0051 μSv, 0.000035 and 0.0032 μSv in 2018, 2019 and 2020, respectively.

The discharge of ^{131}I has been estimated according to instructions published by OSPAR. The discharges to the sewage system from the medical sector in 2018, 2019 and 2020 were 2.6 TBq ^{131}I, 1.20 TBq ^{131}I and 1.07 TBq ^{131}I, respectively.

Produced water from offshore oil and gas production may contain enhanced levels of naturally occurring radionuclides. In 2018 the discharged activity of ^{226}Ra and ^{228}Ra from the Norwegian oil and gas industry were reported to 400 GBq and 360 GBq, respectively. For 2019, 430 GBq ^{226}Ra and 380 GBq ^{228}Ra were discharged, and 400 GBq ^{226}Ra and 360 GBq ^{228}Ra were discharged in 2020. The reported discharges are comparable to previous discharge figures.

Radionuclides originating from nuclear weapon test fallout, the Chernobyl accident, and from current and historic discharges from the reprocessing of spent nuclear fuel are still the main contributors to anthropogenic radionuclides found in Norwegian waters.

6.2 Radioactivity in seawater and sediment

A general trend seen in most samples is that the levels of radioactivity are similar to or slightly lower than have been observed in recent years. This can be explained by reduced discharges, radioactive decay, and other processes such as sedimentation and dilution. Discharge of produced water is at the same level as previous years.

6.2.1 Caesium-137 in seawater

Activity concentrations of ^{137}Cs in surface seawater in Norwegian waters in 2018-2020 were low and comparable to previously observed levels in open sea areas with highest values in the Skagerrak. Time trends from Hillesøy and Grense Jakobselv show that the levels of ^{137}Cs in seawater are slowly decreasing in the Norwegian coastal current over time.

6.2.2 Plutonium-239,240 and americium-241 in seawater

Activity concentrations of $^{239,240}Pu$ and ^{241}Am in Norwegian waters in 2018 and 2019 were low and comparable to previously observed levels in open sea areas.

6.2.3 Radium-226 in seawater

Activity concentrations of ^{226}Ra observed in Norwegian waters in 2018, 2019 and 2020 were comparable to previously observed levels and showed no particular geographic distribution.

6.3 Radioactivity in biota

6.3.1 Technetium-99 in seaweed

Activity concentrations of ^{99}Tc in seaweed in Norwegian waters in 2018, 2019 and 2020 were low. For most stations, the activity concentrations of ^{99}Tc were lower in 2018-2020 compared to observed levels in the period 2002-2007. The levels in 2018-2020 were significantly lower than the peak values that were observed in the period 1999-2001. Time trends at Hillesøy and Utsira show that the levels of ^{99}Tc in seaweed have decreased since 2005 due to the reduced discharge of ^{99}Tc from Sellafield.

6.3.2 Caesium-137 in seaweed

The activity concentration of ^{137}Cs in seaweed sampled at coastal stations in 2018-2020 were low, with highest levels from the sampling station at Hvaler. The time trend at Utsira indicates that the levels of ^{137}Cs in seaweed are slowly decreasing over time.

6.3.3 Caesium-137 in fish and crustaceans

Activity concentration of ^{137}Cs in fish from Norwegian marine waters in 2018, 2019 and 2020 were low. All analysed samples were below 1 Bq/kg (f.w.). This is in general lower than in foods from the terrestrial environment and freshwater systems. The time trends of ^{137}Cs in cod from the Barents Sea show that levels are slowly decreasing over time.

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