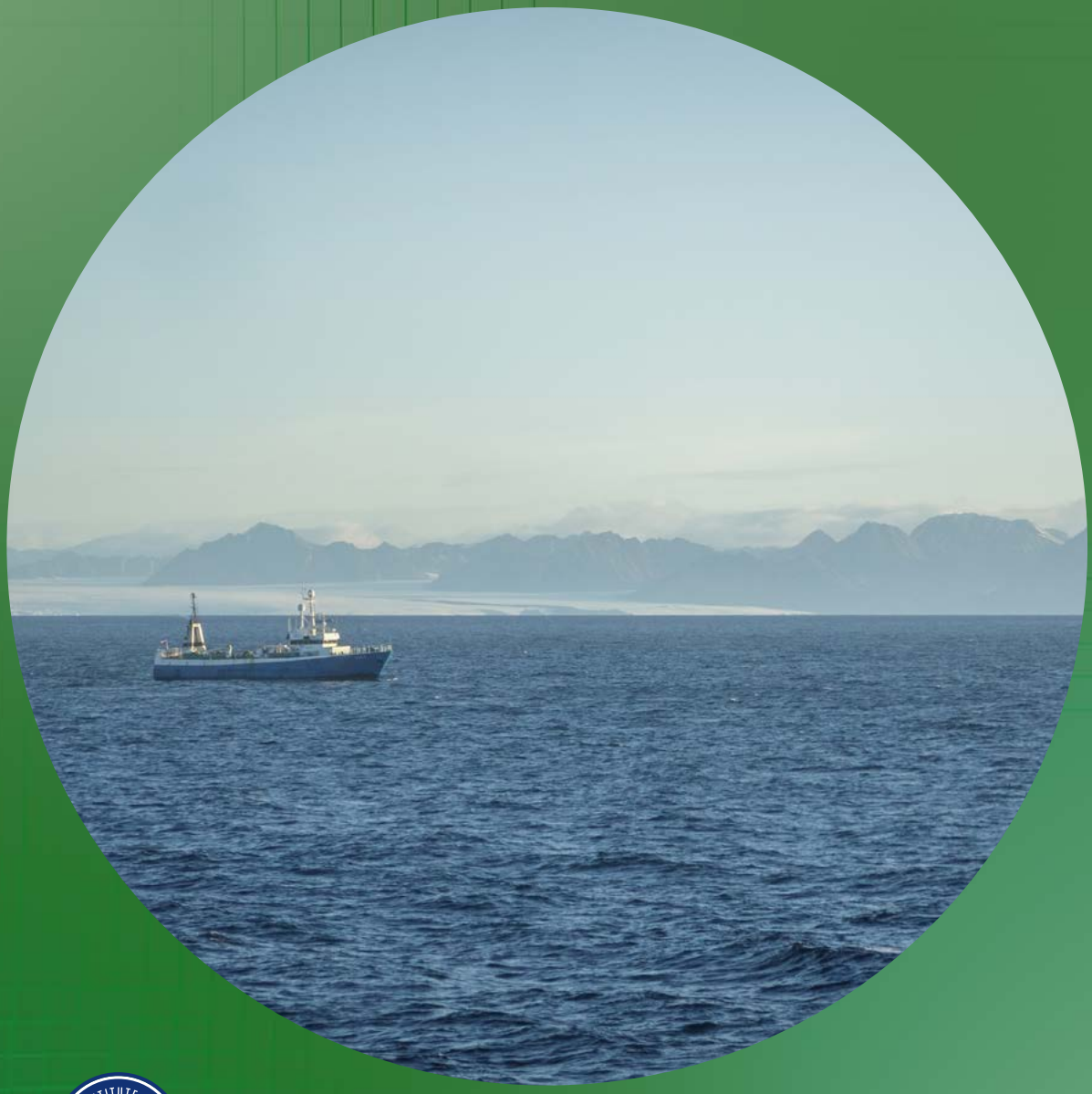
DSA Report
June 2020, Number 04

Radioactivity in the Marine Environment 2015, 2016 and 2017

Results from the Norwegian Marine Monitoring Programme RAME.



DSA

Norwegian Radiation and Nuclear Safety Authority

Reference
Skjerdal H1, Heldal HE2, Rand A3, Gwynn J1, Jensen LK1, Volynkin A2, Haanes H1, Møller B1, Liebig PL2, Gäfvert T1. Radioactivity in the Marine Environment 2015, 2016 and 2017. Results from the Norwegian Marine Monitoring Programme RAME. DSA Report 2020:04. Østerås: Norwegian Radiation and Nuclear Safety Authority, 2020.

Language: English.

1) Norwegian Radiation and Nuclear Safety Authority, 2) Institute for Marine Research, 3) Institute for Energy Technology

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 2015, 2016 and 2017.

Referanse
Skjerdal H1, Heldal HE2, Rand A3, Gwynn J1, Jensen LK1, Volynkin A2, Haanes H1, Møller B1, Liebig PL2, Gäfvert T1. Radioactivity in the Marine Environment 2015, 2016 and 2017. Results from the Norwegian Marine Monitoring Programme RAME. DSA-rapport 2020:04. Østerås, Direktoratet for strålevern og atomsikkerhet, 2020.

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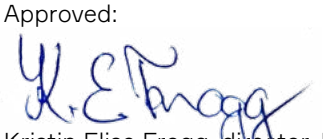
Emneord
Radioaktivitet, marint miljø, RAME, overvåkning, Norge.

Resymé
Rapporten inneholder resultater fra overvåkningen av radioaktivitet i sjøvann, sedimenter og biota i norske havområder i 2015, 2016 og 2017.

Head of project: Hilde Skjerdal.
Approved:



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Published 2020-08-10
Pages 34

Coverpage photo: Erlend A. Lorentzen/HI

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ISSN 2535-7379

DSA rapport Nummer 2020:04 **Publisert** aug 2020

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1 Introduction

In 2015, 2016 and 2017, 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

Long-range transport of radionuclides originating from nuclear weapons fallout, the Chernobyl accident, and from reprocessing of spent nuclear fuel are still the main contributors to anthropogenic radionuclides in Norwegian waters. In addition, water from the Baltic Sea containing ^{137}Cs from the Chernobyl accident and remobilisation of ^{137}Cs and plutonium isotopes from the contaminated Irish Sea sediments act as secondary sources of radionuclides to the Norwegian marine environment. Runoff from Chernobyl polluted areas are still contributing to the elevated levels of anthropogenic radionuclides along the coast and in fjords.

The petroleum industries in the North Sea and the Norwegian Sea are discharging produced water containing natural radionuclides into the marine environment. In the North Sea, the Norwegian and the British petroleum industry as the main contributors while only Norwegian operators are found in the Norwegian Sea [4, 5 and 6]. In 2015, the reported discharged activity of ^{226}Ra and ^{228}Ra from the Norwegian oil and gas industry was 440 GBq and 390 GBq, respectively. For 2016, 410 GBq ^{226}Ra and 380 GBq ^{228}Ra were discharged and 390 GBq ^{226}Ra and 360 GBq ^{228}Ra were discharged in 2017. 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 2015-2017 are shown in Figure 2, and discharges per installation in 2015, 2016 and 2017 are presented in Figures 3, 4 and 5, respectively.

Smaller Norwegian sources of anthropogenic radionuclides includes discharges from Institute for Energy Technology (IFE) and Norwegian hospitals which routinely discharge radionuclides into the marine environment. Discharges from Institute for Energy Technology (IFE) are restricted by activity limits per nuclide. 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 0.0084 µSv, 0.00018 µSv and 0.00008 µSv in 2015, 2016 and 2017, respectively. The annual dose from liquid discharges from IFE Halden in 2015, 2016 and 2017 was estimated to 0.0015 µSv, 0.0018 µSv and 0.00093 µSv, respectively.

In addition, Norwegian hospitals are discharging anthropogenic radionuclides into the marine environment. Unsealed radioactive substances used in medicine dominate the anthropogenic radioactive discharges to the sewage system. The radionuclides used in medical treatments and discharged from the hospitals are mainly short-lived and will not accumulate in the environment. However, due to the amount discharged, the most important radionuclide concerning dose to the public after discharge is ^{131}I. 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 2015, 2016 and 2017 were 1.22 TBq, 2.18 TBq and 0.97 TBq ^{131}I, respectively.

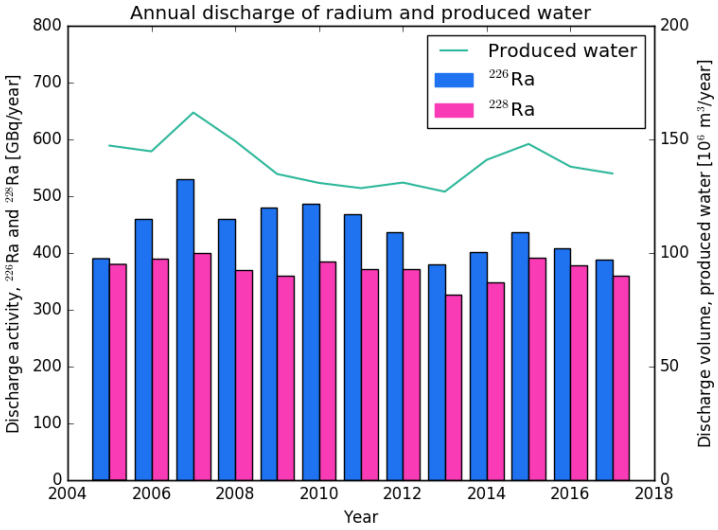

Figure 1: Annual discharge of ^{226}Ra and ^{228}Ra to the marine environment via produced water, and discharged volume of produced water from the Norwegian oil and gas industry in the period 2005 to 2017.

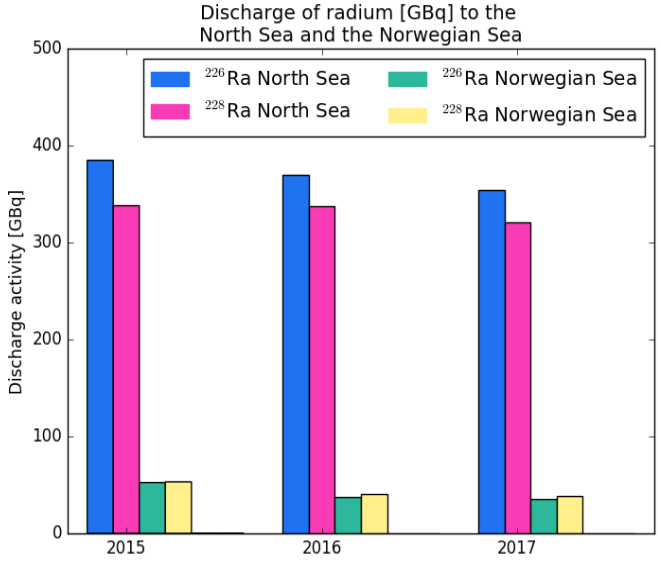

Figure 2: Discharge of ^{226}Ra and ^{228}Ra to the North Sea and the Norwegian Sea from the Norwegian oil and gas industry.

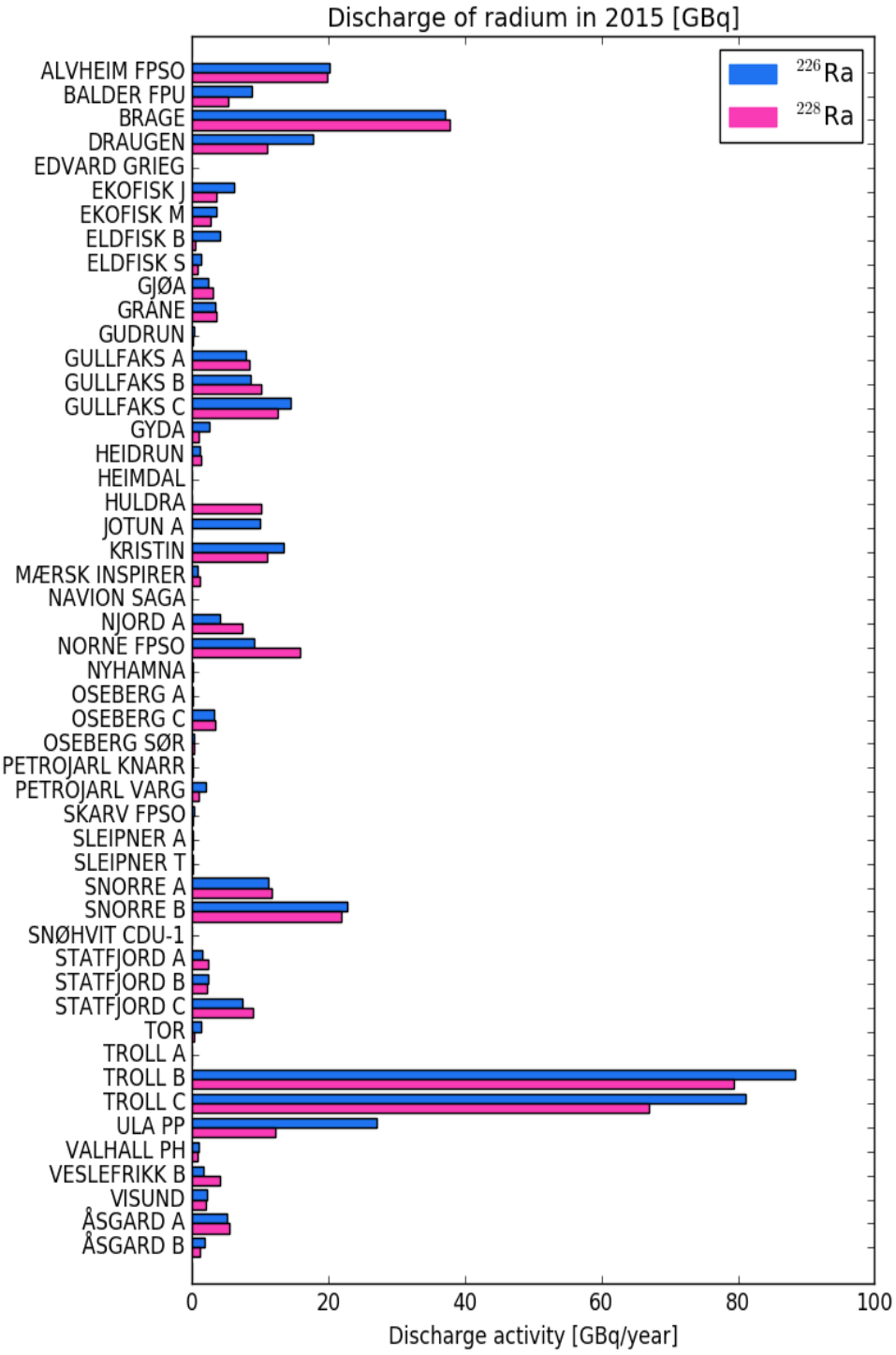

Figure 3: Discharged activity of ^{226}Ra and ^{228}Ra from Norwegian oil and gas fields in 2015.

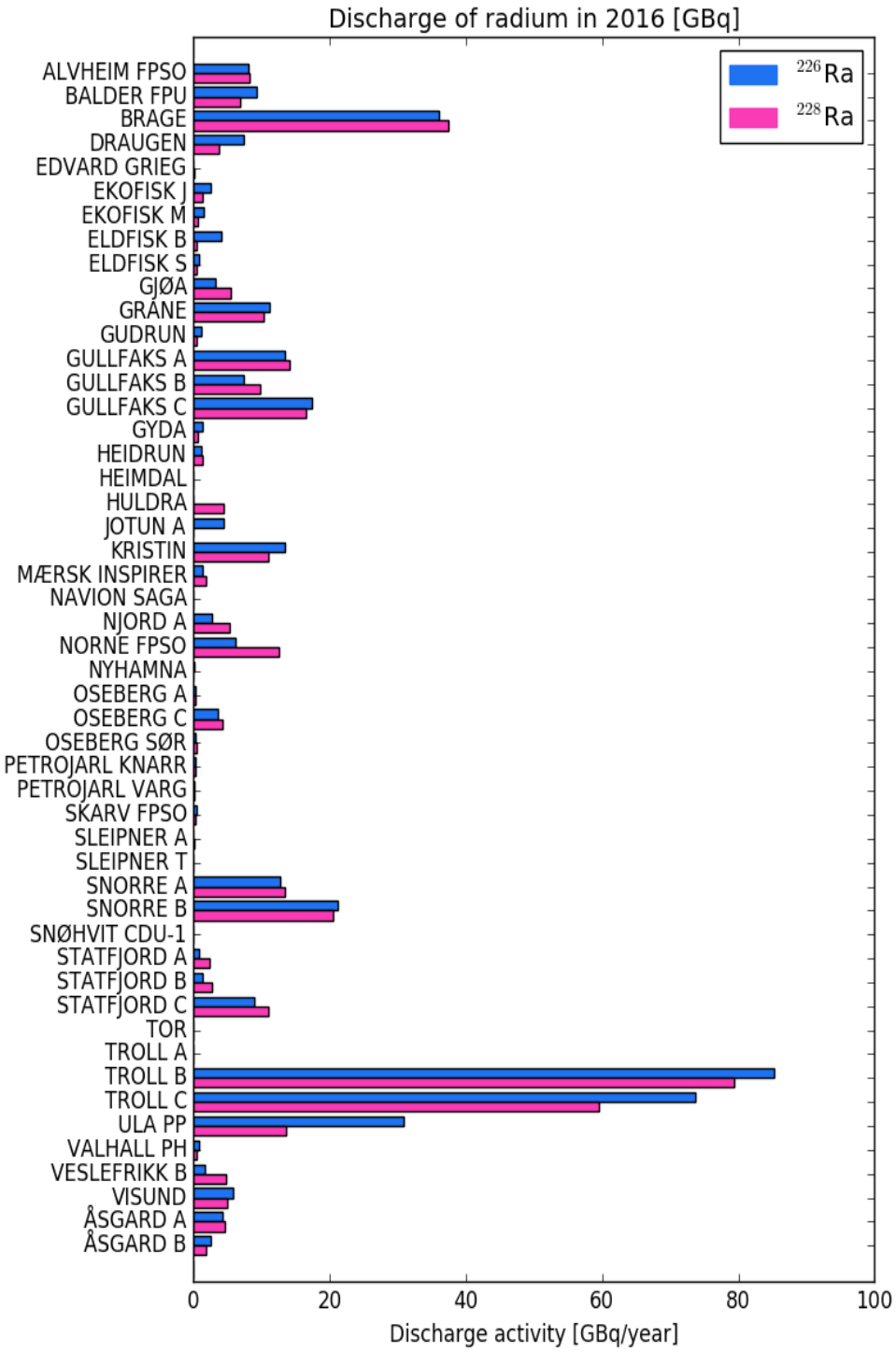

Figure 4: Discharged activity of ^{226}Ra and ^{228}Ra from Norwegian oil and gas fields in 2016.

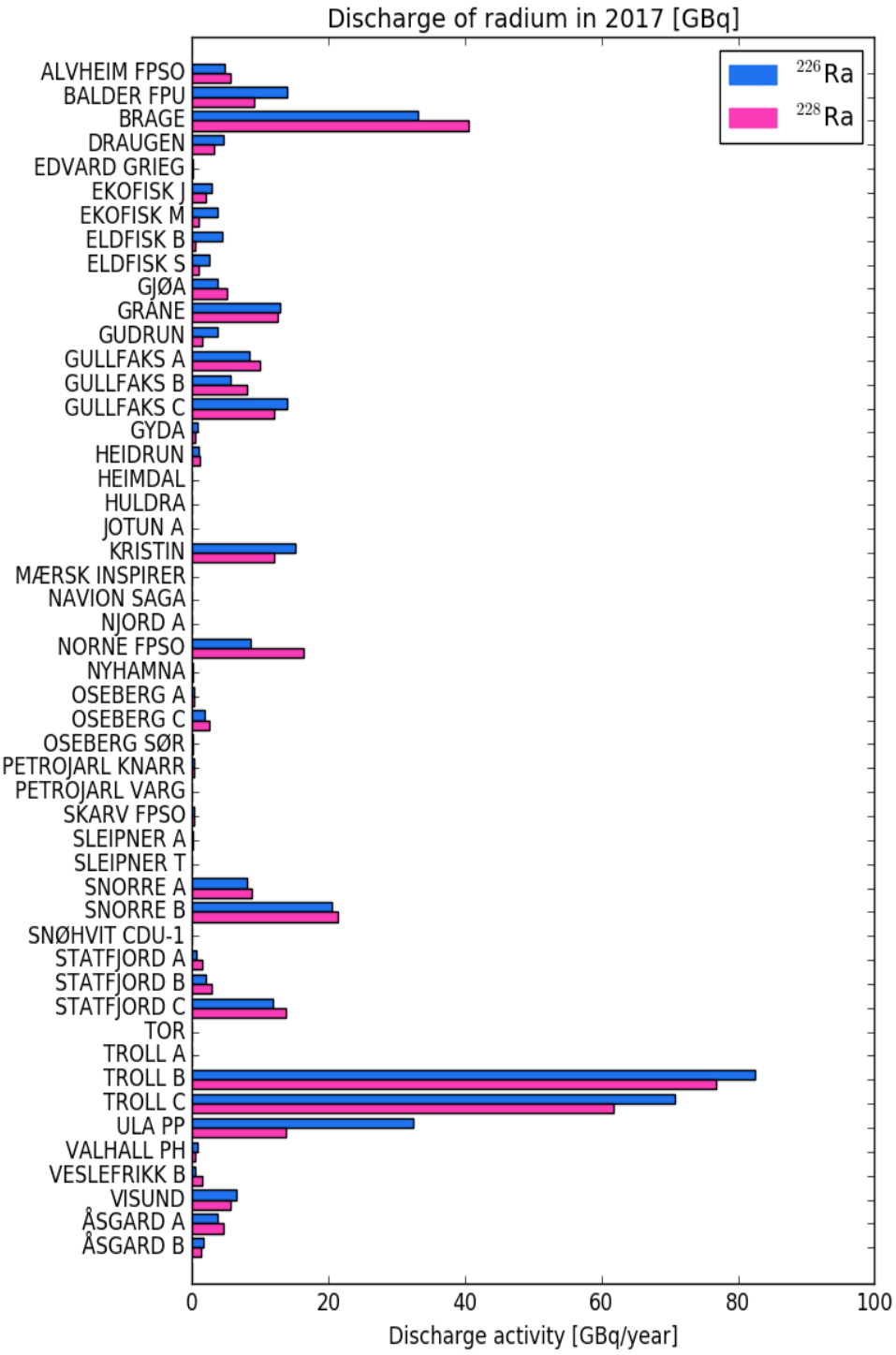

Figure 5: Discharged activity of ^{226}Ra and ^{228}Ra from Norwegian oil and gas fields in 2017.

3 Collection of samples

A board range of samples were collected on cruises to the Barents Sea (2015), in the North Sea (2016) and to the Norwegian Sea (2017), In addition, annual sediment and water samples are acquired from Komsomolets in the Norwegian Sea and annual samples of cod are obtained from Bjørnøya and the coast of Finnmark. Selected fjords are visited for seawater and sediment sampling once a year, and seawater from Skagerrak is sampled annually. Permanent coastal stations are sampled annually or monthly for seaweed and selected stations also for seawater. A geographic overview of the sampling area covered by the marine monitoring programme, with the fixed coastal stations marked, is shown in Figure 6.

Figure 6: Geographic overview of the coastal sampling stations and the sampling area 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).

Cruise samples from the Barents Sea were collected in August and September 2015, from the North Sea in July and August 2016 and from the Norwegian Sea in May 2017. 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). During the cruises, samples of surface seawater were collected and results for ^{137}Cs, ^{226}Ra, ^{241}Am and plutonium isotopes will be presented in this report. Due to contaminated tracer, the ^{137}Cs-samples from 2017 was rejected. The analyses of the ^{90}Sr-samples are delayed and will be reported later. Sediment and various samples of marine biota were also collected and later analysed for ^{137}Cs.

Annually, coastal samples of seawater and seaweed have been acquired for the analyses of technetium-99 (^{99}Tc) to trace the development in the discharges from Sellafield. In recent years, the activity concentrations of technetium-99 in seawater have been decreasing and are now often the below detection limits. However, seaweed is a useful bioindicator for ^{99}Tc and it was decided to reduce the sampling of ^{99}Tc in seawater but continue the seaweed sampling.

Samples of the brown seaweed *Fucus vesiculosus* were collected from the Norwegian coastline are collected by IFE and DSA (sampling stations are shown in Figure 6). At most costal stations, sampling is performed once a year. More frequent seaweed sampling is performed at Utsira and Hillesøy. IMR are sampling different species of brown seaweed, lobster and seawater at Værlandet once a year.

In addition, samples of cod (Gadus morhua) are collected yearly 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 2015-2016 are shown in Figure 9 and 10. The activity concentration in surface water ranged from 0.9 to 13.5 Bq/m^3, where the highest levels were found in the Skagerrak.

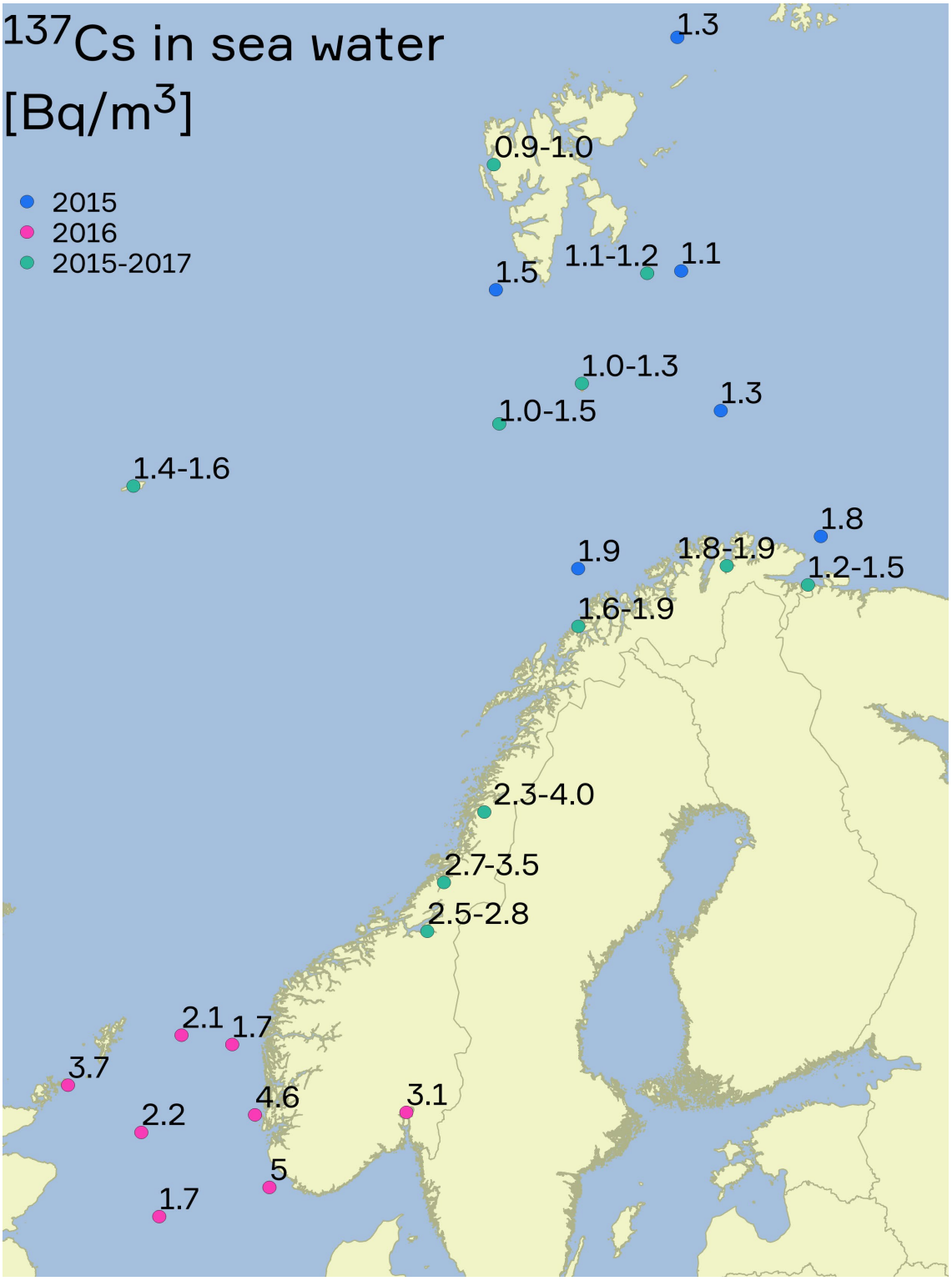

Figure 9: Activity concentration (Bq m^{-3}) of ^{137}Cs in surface seawater collected in the Norwegian waters in 2015-2017. For locations with more than one measurement, the range is shown. Samples from the British part of the North Sea are shown as well.

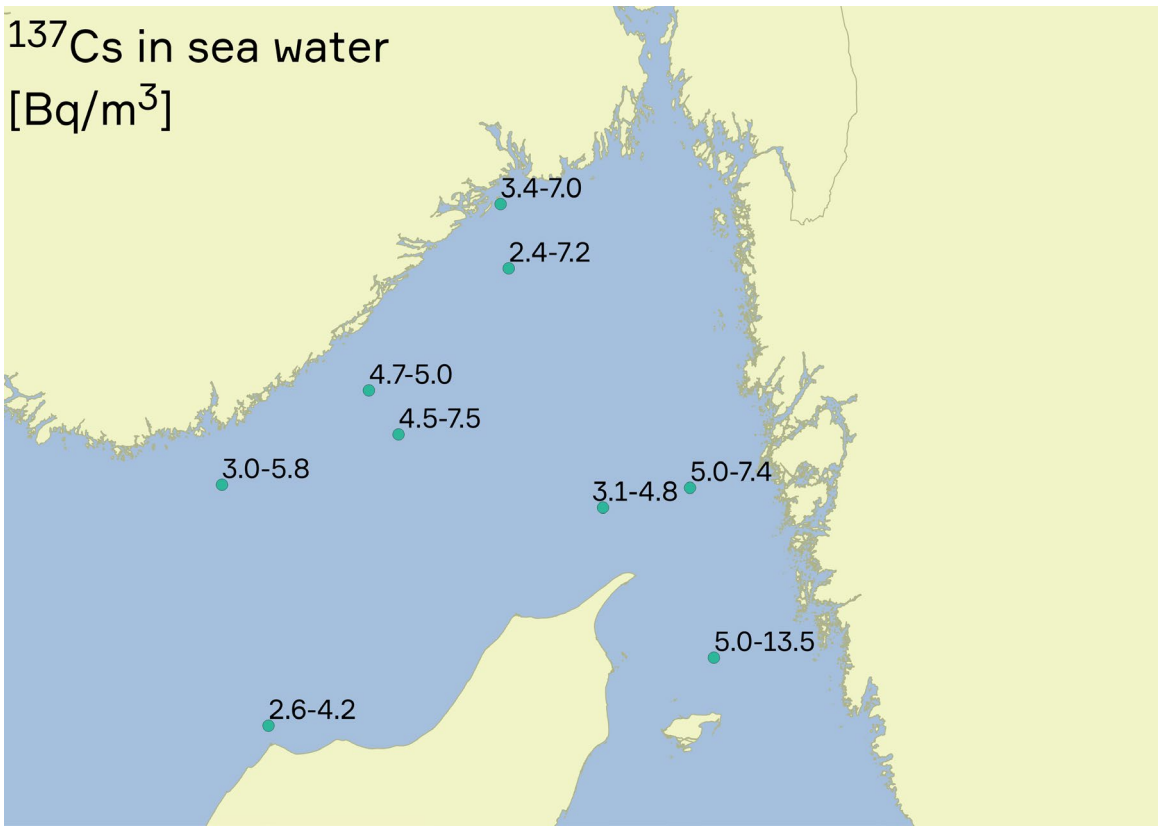

Figure 10: Range of activity concentration (Bq m^{-3}) of ^{137}Cs in surface seawater collected in the Skagerrak in 2015, 2016 and 2017.

Data from Hillesøy (2002-2017) and Grense Jakobselv (2005-2017) (Figure 11) show that the levels of ^{137}Cs in the Norwegian coastal current are slowly decreasing. The effective half-life of ^{137}Cs in the Baltic Sea, which is one of the main sources of ^{137}Cs to the Norwegian coastal current, has been estimated to 10 years [7].

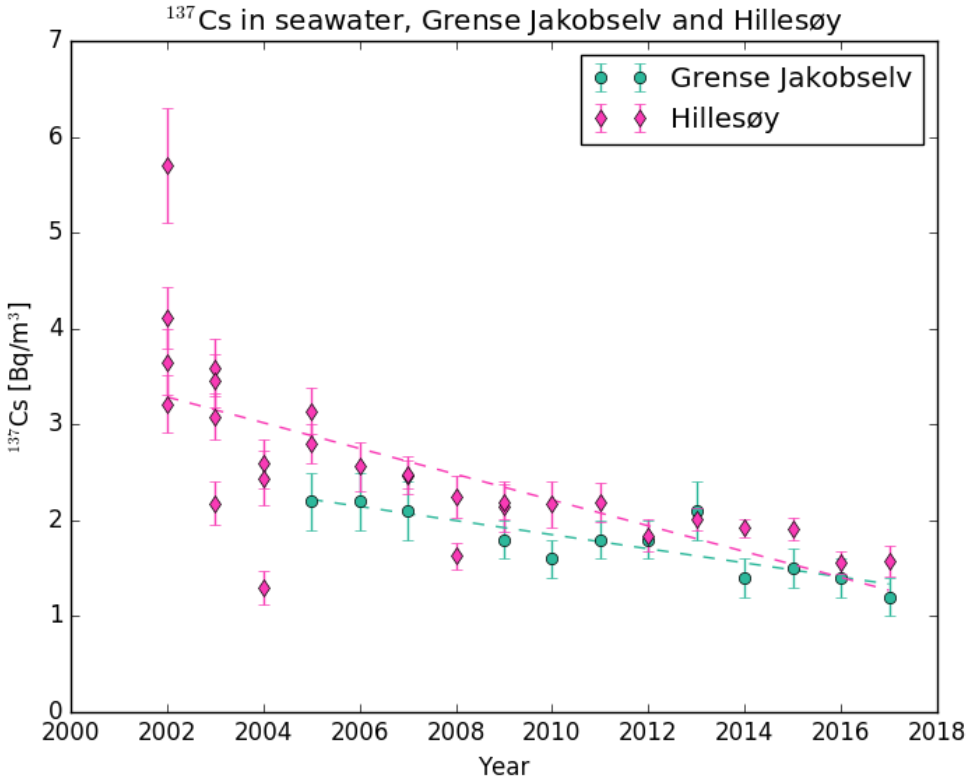

Figure 11: Activity concentration (Bq/m^3) of ^{137}Cs in seawater at Hillesøy and Grense Jakobselv in the period 2002/2005-2017.

Caesium-137 has also been analysed in surface sediments (upper 2 cm layer) from the Norwegian waters, 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 range from <0.2 Bq/kg (d.w.) to 8.7 Bq/kg (d.w.) in open waters. The activity concentration of ^{137}Cs in sediments sampled in the fjords ranged from 4.9 Bq/kg (d.w.), measured in Ytre Laksefjord in 2015, to 268 Bq/kg (d.w.), measured in the Vefsnfjord in 2016. The fjords are subjected 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 fjords here. At Komsomolets, the activities are within the range of the activities at open water stations.

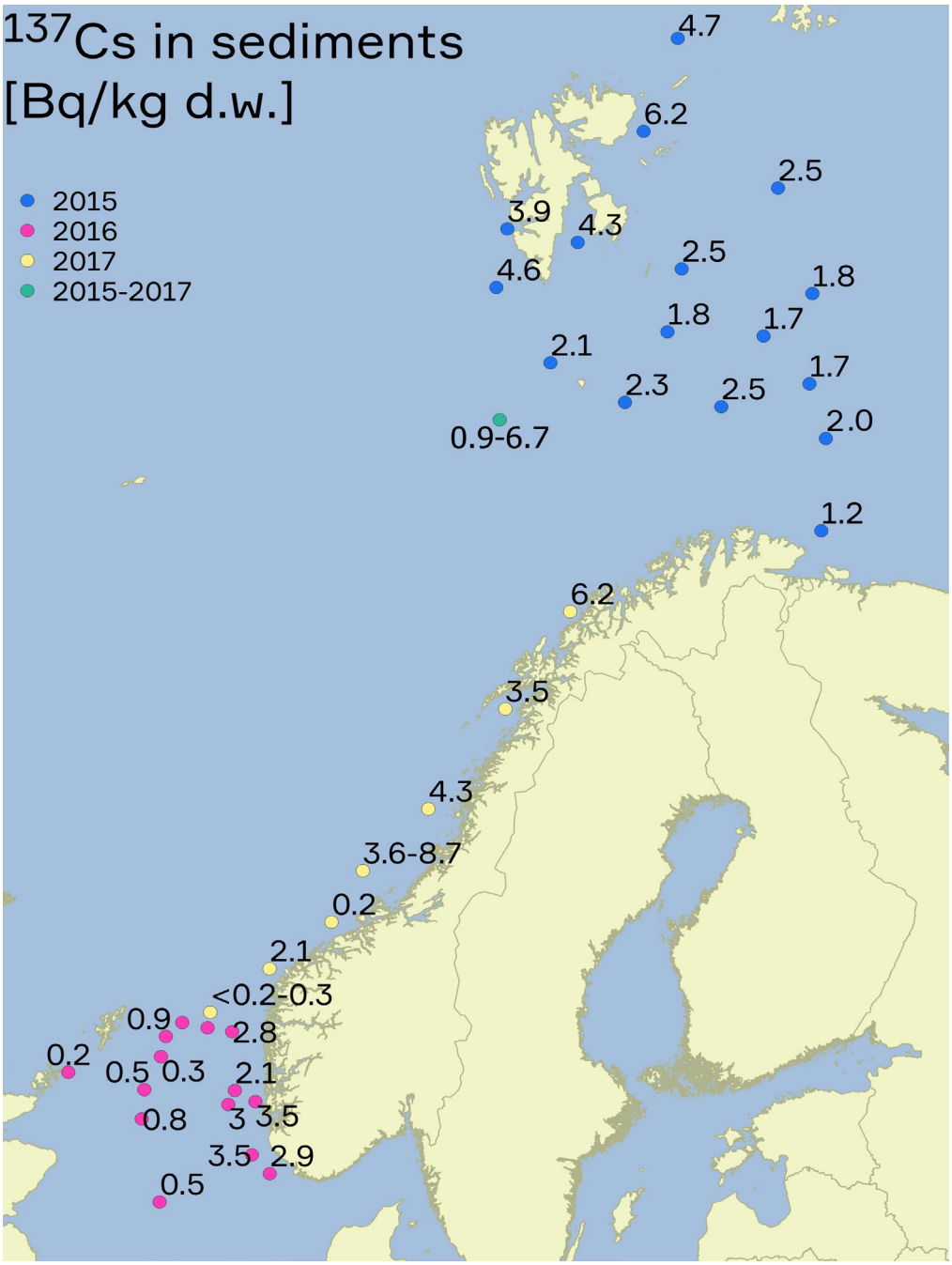

Figure 12: Activity concentration (Bq/kg d.w.) of ^{137}Cs in surface sediment in 2015, 2016 and 2017. For locations with more than one measurement, the range is shown. The sample southwest of Bjørnøya has been collected close to the sunken submarine Komsomolets.

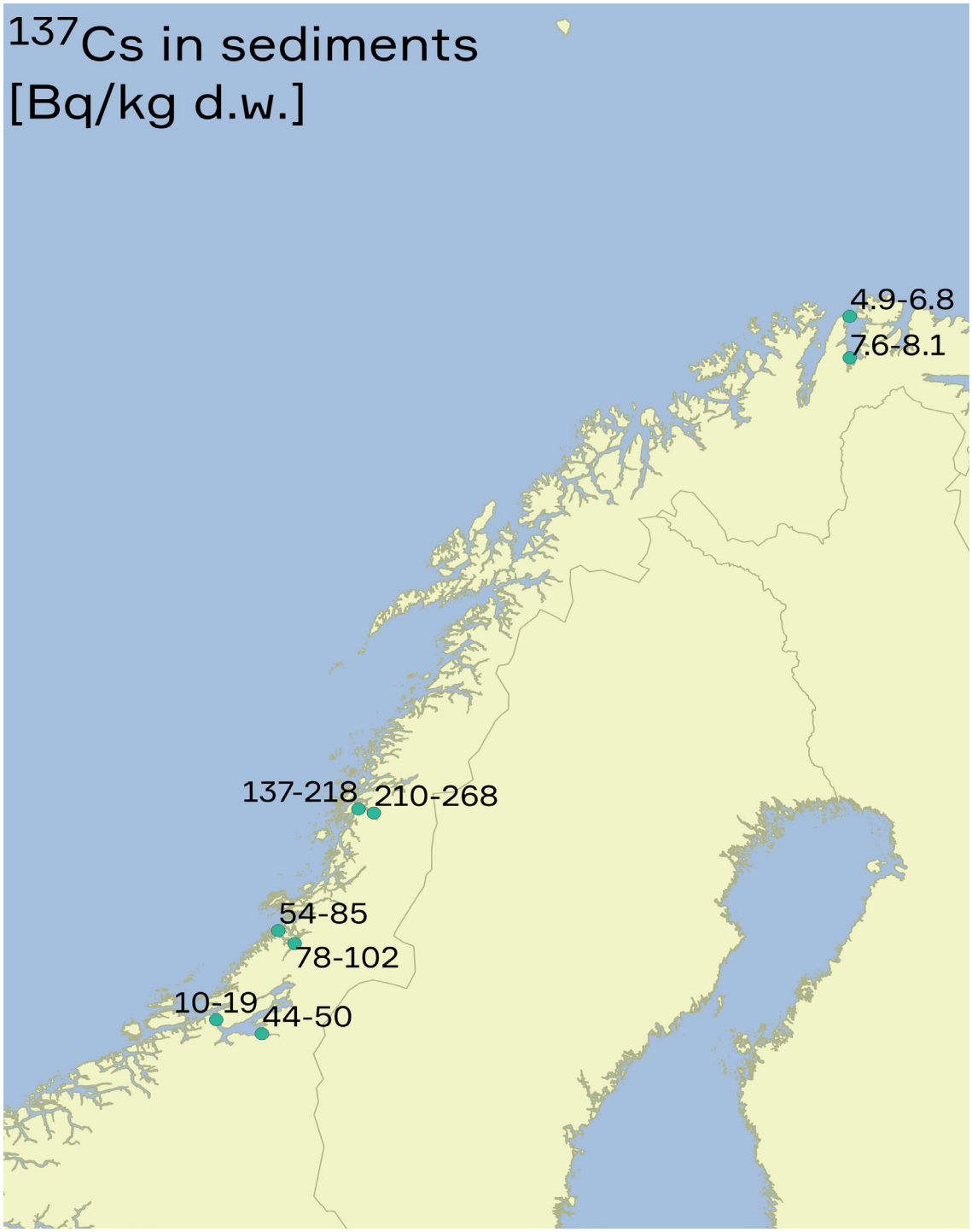

Figure 13: Range of activity concentration (Bq/kg d.w.) of ^{137}Cs in surface sediment in Laksefjorden, Vefsnfjorden, Namsenfjorden and Trondheimsfjorden in 2015, 2016 and 2017.

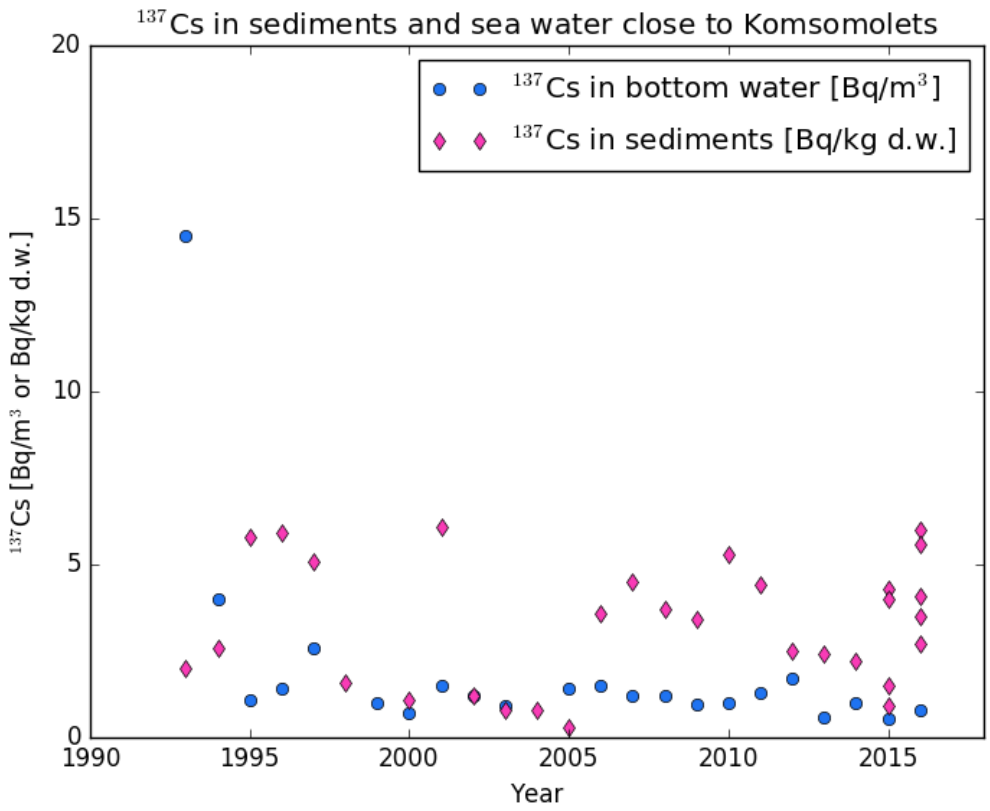

Figure 14: ^{137}Cs in samples close to the position of the sunken nuclear submarine “Komsomolets”.

4.2 Plutonium-239, -240 in seawater

Observed levels of plutonium-239, -240 in 2015 to 2017 are presented in Figure 15 and range from below detection limit (<0.8 mBq/m^3) to 9 mBq/m^3. In addition, 37 mBq/m^3 is measured outside Scotland. The levels of ^{239,240}Pu in Norwegian waters are similar to the levels observed and presented in previous reports [1–3, 8].

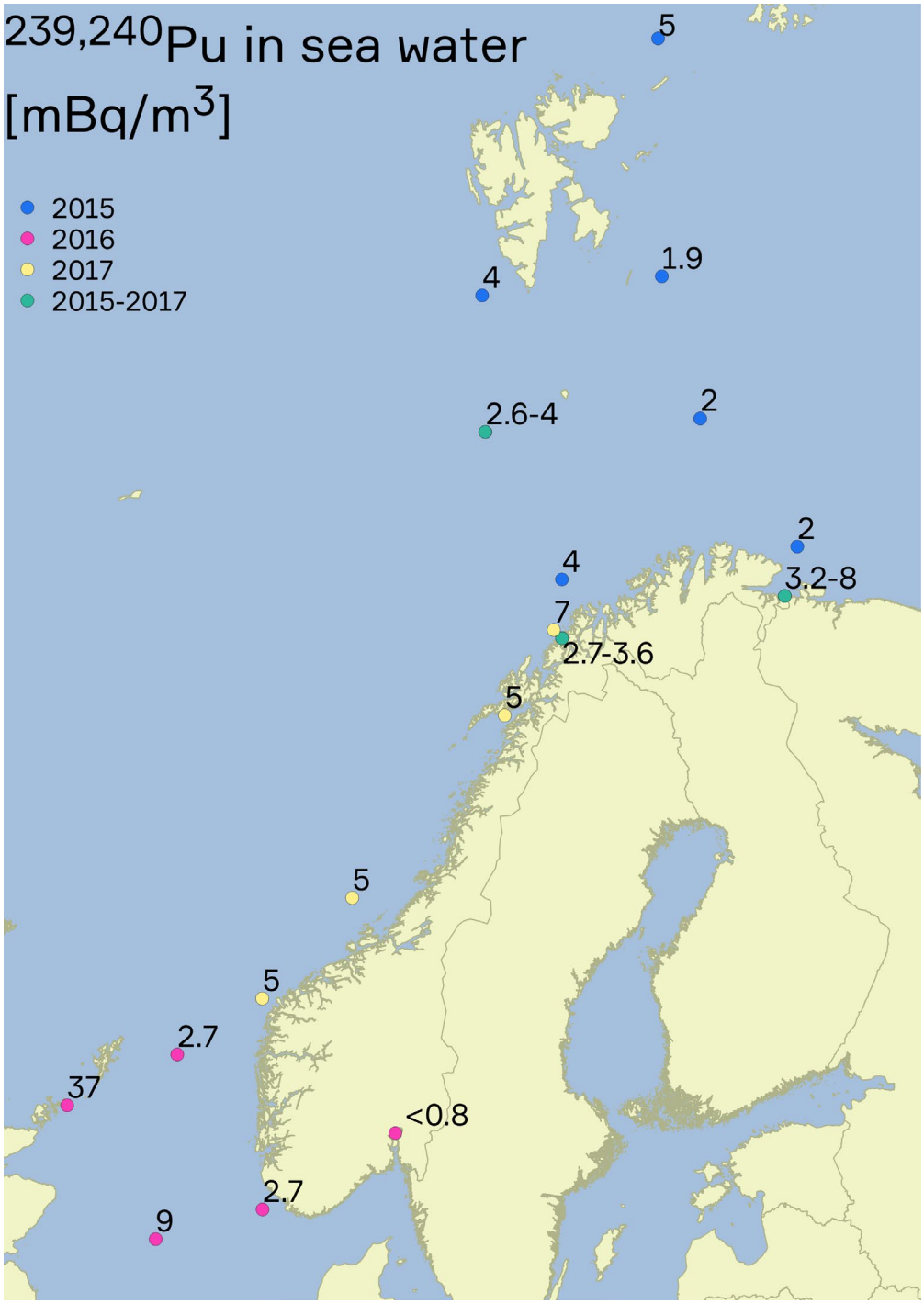

Figure 15: Activity concentration (mBq/m³) of ^{239,240}Pu in surface seawater samples collected in 2015, 2016 and 2017. For locations with more than one measurement, the range is shown.

4.3 Americium-241 in seawater

The observed levels of ^{241}Am (Figure 16) are low and comparable to previously observed concentrations [e.g. 3 and 8].

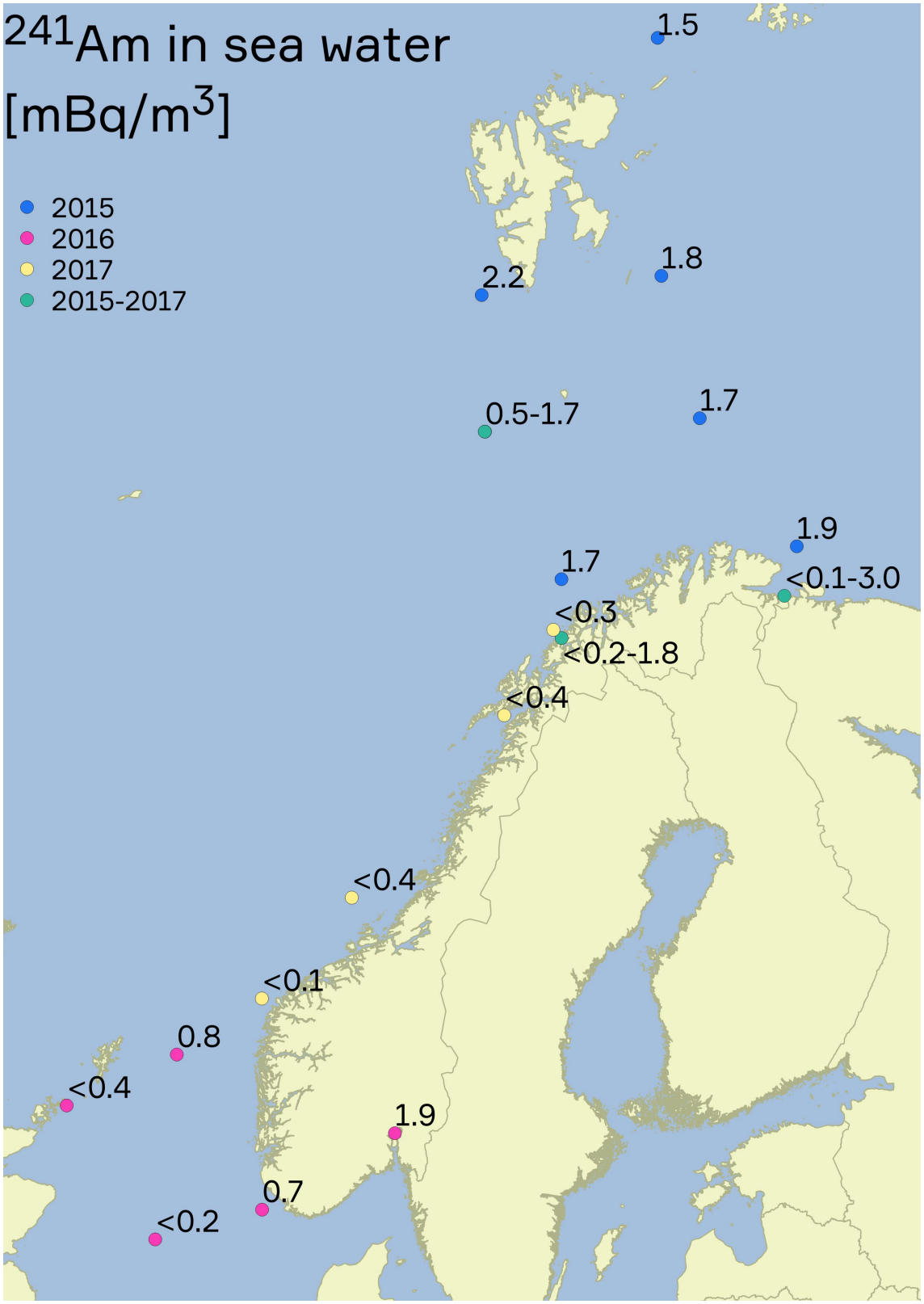

Figure 16: Activity concentration (mBq/m³) of ^{241}Am in seawater in 2015, 2016 and 2017. For locations with more than one measurement, the range is shown.

4.4 Radium-226 in seawater

The activity concentration of ^{226}Ra observed in Norwegian waters in 2015, 2016 and 2017 were in the range of 0.9 to 2.5 Bq/m³ (Figure 17) and comparable to previously observed concentrations [e.g. 8]. The sources

of ^{226}Ra to seawater may be both terrestrial runoff and the aforementioned and known discharges from the petroleum sector. However, no geographical differences are obvious, and we may not from the current data conclude on any impact of known sources.

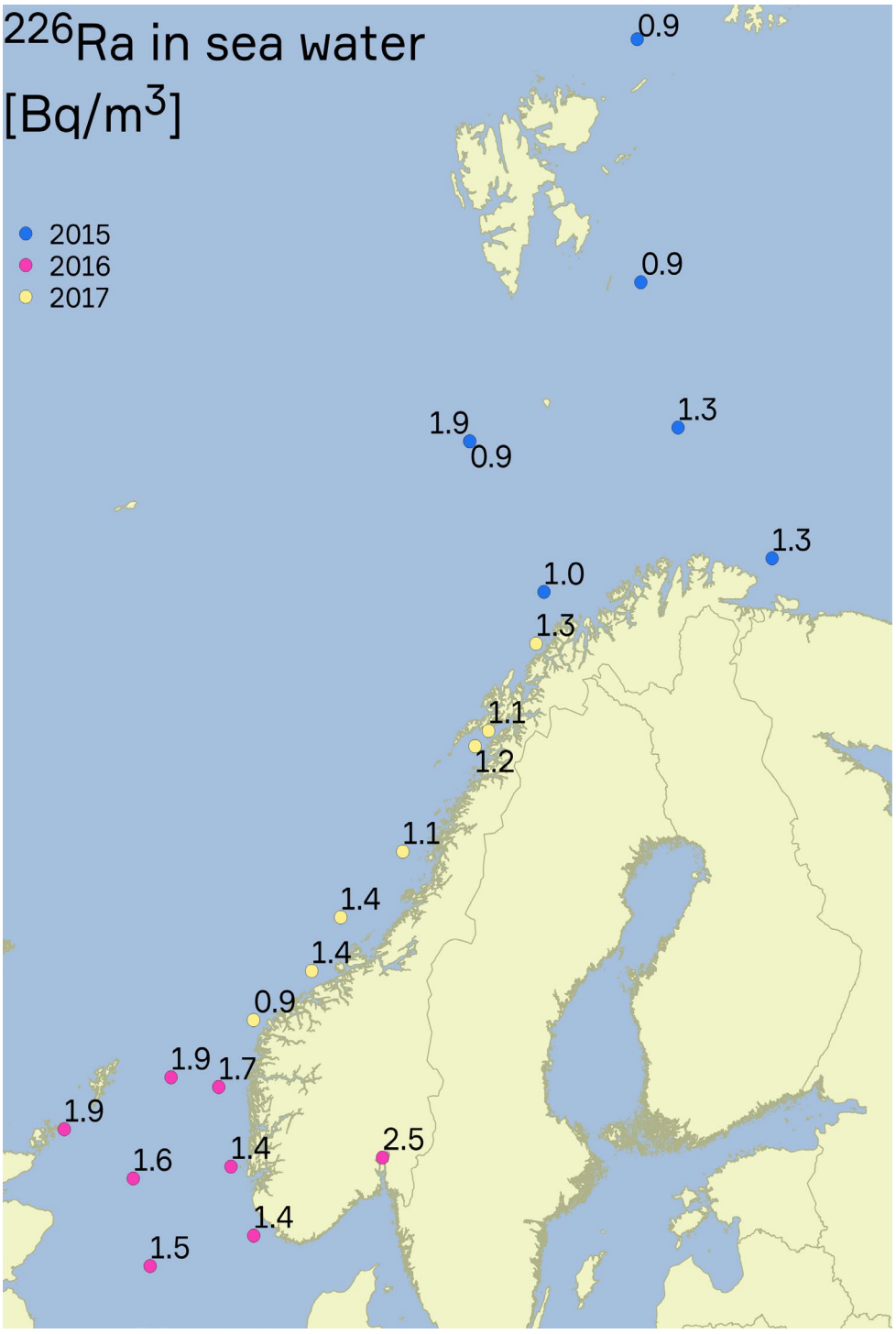

Figure 171: Activity concentration (Bq/m^3) of ^{226}Ra in seawater in 2015, 2016 and 2017.

5 Radioactivity in biota

5.1 Technetium-99 in seaweed

Seaweed is a useful bioindicator for ^{99}Tc in the marine environment. It readily accumulates ^{99}Tc from seawater and is easily accessible in most coastal areas. In 2015, 2016 and 2017, bladderwrack (*Fucus vesiculosus*) was collected at the permanent coastal sampling stations along the Norwegian coastline and analysed for ^{99}Tc.

At Hillesøy, sampling was performed monthly in 2015, 2016 and 2017, and sampling was performed six times in 2015, nine times in 2016 and seven times in 2017 at Utsira. At the other sites, sampling was conducted in August or September. The results range from 10 to 42 Bq/kg (d.w.), where the highest activity concentration was found in the sample collected at Lista in 2015 (Figure 18). Compared with the results from 1999-2001 [9 and 10], the levels of ^{99}Tc have decreased at most 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.

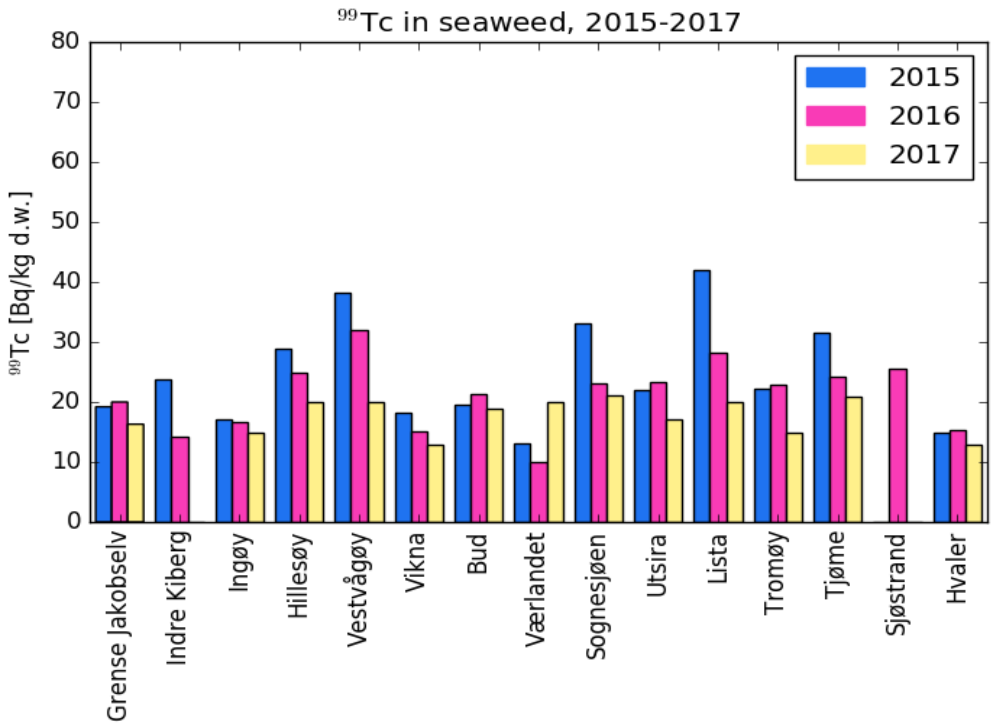

Figure 18: Levels of ^{99}Tc in *Fucus vesiculosus* sampled along the Norwegian coastline in 2015, 2016 and 2017. Mean values for Hillesøy and Utsira.

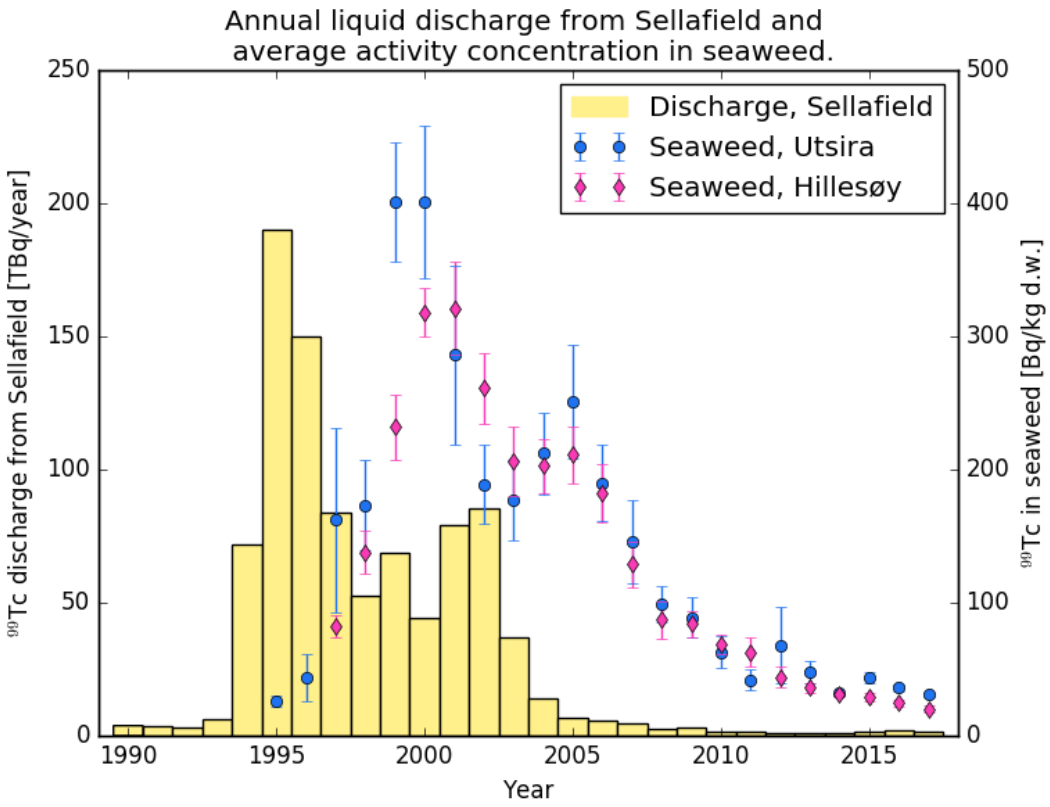

Figure 19: Annual liquid discharge of ^{99}Tc from Sellafield and annual average (with 95 % confidence limits) ^{99}Tc activity concentration in bladderwrack *(Fucus vesiculosus)* sampled at Utsira (data provided by IFE) in the period 1995-2017 and Hillesøy in the period 1997-2017.

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 2017 are presented in Figure 20. The activity concentrations in these samples were in the range from below detection limit to 201 mBq/kg, with relatively large fluctuations from year to year. A slowly decreasing trend in the activity concentration of ^{239,240}Pu in the seaweed samples collected in the period from 1980 to 2017 is observed.

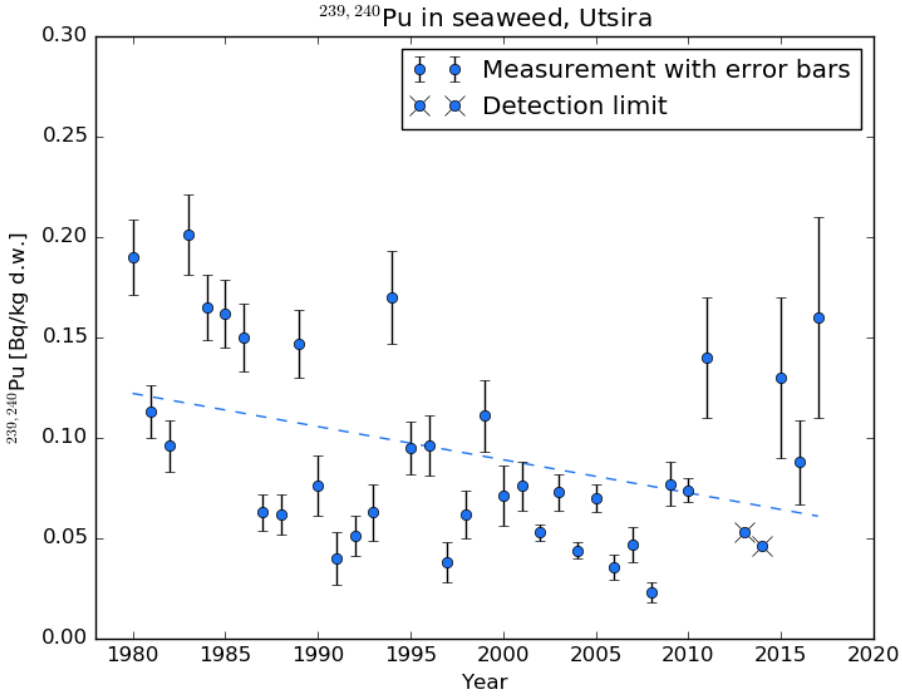

Figure 20: ^{239,240}Pu levels (Bq/kg d.w.) in *Fucus vesiculosus* at Utsira in the period 1980 to 2017 (data provided by IFE). Results are reported biannually. No sampling in 2012, measurements in 2013 and 2014 are below the detection limit.

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 [11].

In 2015, 2016 and 2017, samples of *F. vesiculosus* from the permanent coastal stations were analysed with respect to ^{137}Cs. The results are presented in Figure 21 and range from below detection limit to 2.1 Bq/kg (d.w.). Detection limits are shown with hatched bars.

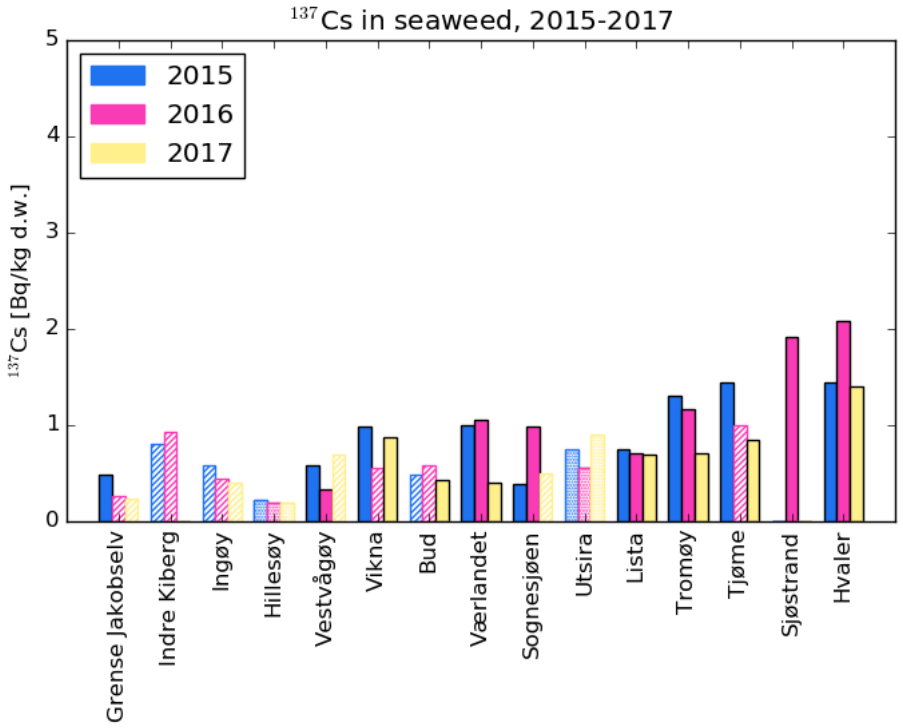

Figure 21: Levels of ^{137}Cs (Bq/kg d.w.) in Fucus vesiculosus sampled along the Norwegian coastline in 2015-2017. Mean values are presented for Hillesøy and Utsira, detection limits are used for measurements below level of detection. Detection limit is shown with hatched bars for measurements below level of detection. The figure shows the stations along the coast from north east to south east, see Figure 6.

A reason for the higher activity concentration in *F. vesiculosus* in the southern part (stations on the right side of Figure 21) of Norway is due to a 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) show that the activity concentration of ^{137}Cs has been slowly decreasing in bladderwrack. This is in agreement with the reported temporal trend of ^{137}Cs in Baltic Sea seawater [7].

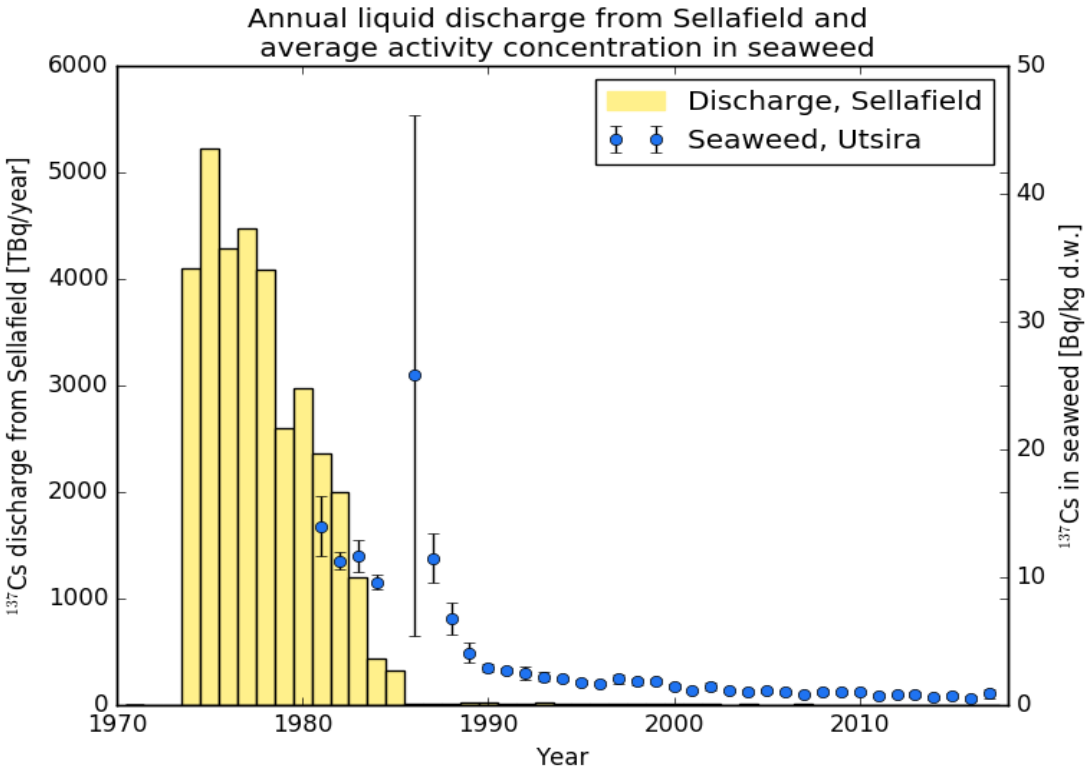

Figure 22: Annual liquid discharge of ^{137}Cs from Sellafield and average activity concentration (Bq kg^{-1} d.w.) from monthly sampling of bladderwrack *(Fucus vesiculosus)* from Utsira in the period 1980-2017 (data from IFE). The large variability in 1986 is due to the Chernobyl accident.

5.4 Caesium-137 in fish and crustaceans

Samples of cod (*Gadus morhua*) from the Barents Sea have been analysed for ^{137}Cs since the early 1990s. In Figure 23, the activity concentration of ^{137}Cs in muscle tissue from cod caught in the Bjørnøya-area in the Barents Sea is shown, and in Figure 24, levels of ^{137}Cs in cod caught off the coast of Finnmark is shown. All samples from recent years are below 0.5 Bq/kg (w.w.). The results show a slightly decreasing trend in the period 1992-2017. This is as expected, and comparable to levels found in recent years [e.g. 8 and 12].

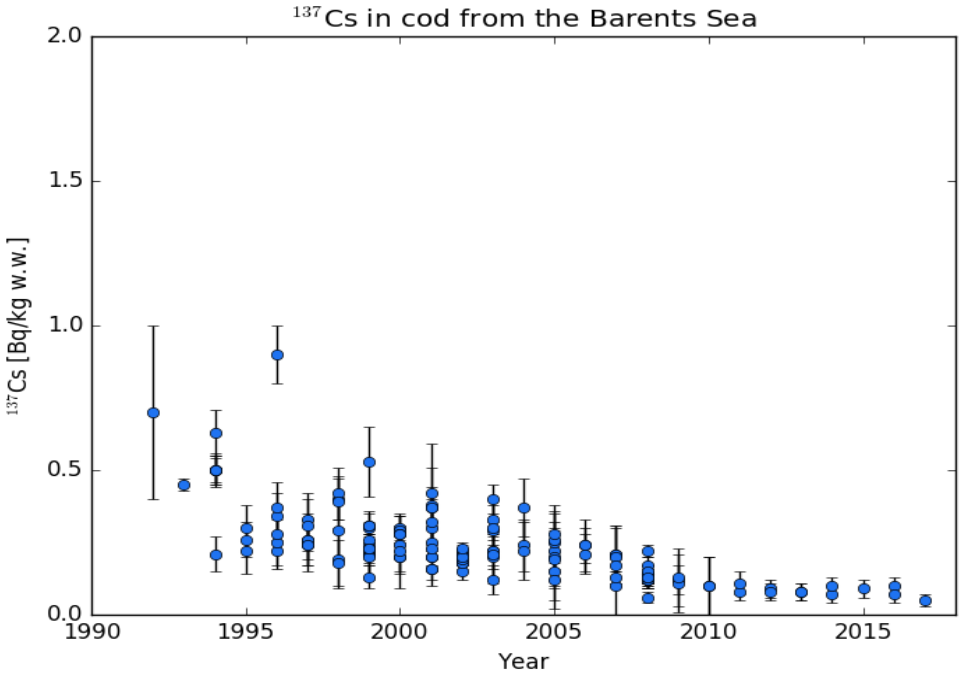

Figure 23: Activity concentration of ^{137}Cs (Bq kg^{-1} w.w.) in cod from the Barents Sea (the area around Bjørnøya) sampled in the period 1992 to 2017.

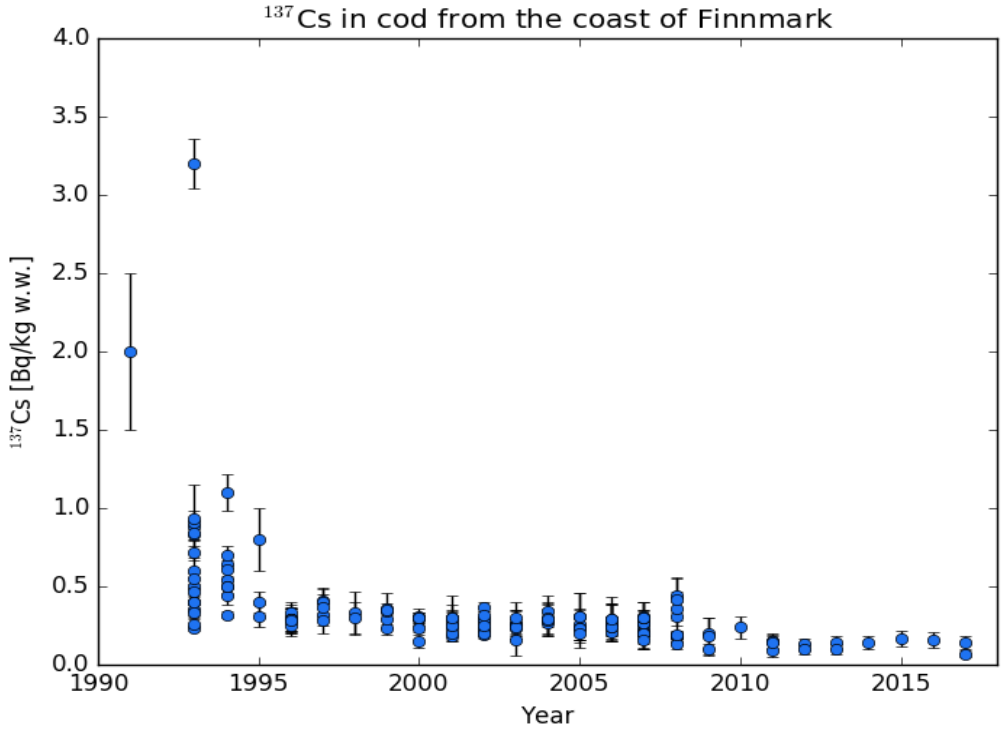

Figure 24: Activity concentration of ^{137}Cs (Bq kg^{-1} w.w.) in cod from the coast of Finnmark sampled in the period 1992 to 2017.

Caesium-137 levels in fish species and crustaceans caught in Norwegian waters in 2015, 2016 and 2017 are shown in Table 1. All obtained results were below 1 Bq/kg (w.w.), with 0.73 ± 0.17 Bq/kg (w.w.) as the maximum value.

Table 1: Activity concentrations (Bq/kg w.w.) of ^{137}Cs in fish and crustaceans caught in the Barents Sea, the Norwegian Sea, the North Sea and in the Skagerrak in 2015-2017. Samples from fjords are marked with *. Values are presented with measurement uncertainties.

English name	Latin name	Norwegian name	^{137}Cs minimum Bq/kg w.w.	^{137}Cs maximum Bq/kg w.w.	Samples (individuals)
		Barents Sea			
American plaice	*Hippoglossoides platessoides*	Gapeflyndre	0.07 ± 0.06	0.17 ± 0.06	4 (72)
Atlantic argentine	*Argentina silus*	Vassild		0.07 ± 0.03	1 (15)
Atlantic wolffish	*Anarhichas lupus*	Gråsteinbit		0.05 ± 0.03	1 (7)
Blue whiting	*Micromesistius poutassou*	Kolmule	0.06 ± 0.03	0.12 ± 0.06	2 (>25)

Capelin	*Mallotus villosus*	Lodde	0.04 ±	0.03	0.12 ±	0.07	6 (>600)
Cod	*Gadus morhua*	Torsk	0.05 ±	0.02	0.25 ±	0.06	22 (668)
Deepwater Redfish	*Sebastes mentella*	Snabeluer			0.12 ±	0.05	2 (50)
Greenland Halibut	*Reinhardtius hippoglossoides*	Blåkveite	0.11 ±	0.05	0.18 ±	0.05	6 (>85)
Haddock	*Melanogrammus aeglefinus*	Hyse	0.07 ±	0.03	0.11 ±	0.05	3 (>48)
Herring	*Clupea harengus*	Sild	0.09 ±	0.03	<0.13		2 (50)
Krill	*Meganyctiphanes norvegica*	Krill			<0.15		1
Krill	*Thysanoessa inermis*	Krill			<0.02		1 (2 kg)
Lumpfish	*Cyclopterus lumpus*	Rognkjeks			<0.03		1 (9)
Mackerel	*Scomber scombrus*	Makrell			<0.14		1 (15)
Polar Cod	*Boreogadus saida*	Polartorsk	0.05 ±	0.03	0.06 ±	0.06	2 (129)
Redfish	*Sebastes norvegicus*	Uer/Vanlig uer			0.23 ±	0.07	1 (1)
Saithe	*Pollachius virens*	Sei	0.15 ±	0.04	0.25 ±	0.03	11 (35)
Shrimp	*Pandalus borealis*	Reker			0.06 ±	0.06	1 (1 kg)
Snake blenny	*Lumpenus lampretaeformis*	Langhalet langebarn			0.04 ±	0.03	1 (50)
Spotted wolffish	*Anarhichas minor*	Flekksteinbit			<0.13		
Vahl's eelpout	*Lycodes vahlii*	Ålebrosme			0.05 ±	0.05	1 (11)
Sandeel	*Ammodytes marinus*	Tobis			0.17 ±	0.03	1
		Norwegian Sea					
Atlantic argentine	*Argentina silus*	Vassild	0.02 ±	0.02	0.06 ±	0.02	4 (70)
Blue whiting	*Micromesistius poutassou*	Kolmule	0.09 ±	0.04	0.12 ±	0.04	2 (36)
Cod	*Gadus morhua*	Torsk	0.15 ±	0.05	0.39 ±	0.12	9 (49)
Deepwater redfish	*Sebastes mentella*	Snabeluer			0.17 ±	0.07	1 (12)
Greenland halibut	*Reinhardtius hippoglossoides*	Blåkveite	0.14 ±	0.04	0.18 ±	0.04	6 (149)
Haddock	*Melanogrammus aeglefinus*	Hyse	0.10 ±	0.03	0.15 ±	0.07	4 (76)
Herring	*Clupea harengus*	Sild			0.11 ±	0.03	1 (25)
Lesser argentine	*Argentina sphyraena*	Strømsild			0.48 ±	0.13 *	1 (10)

Norway pout	*Trisopterus esmarkii*	Øyepål	0.07 ±	0.03	0.25 ±	0.08 *	3 (125)
Poor cod	*Trisopterus minutus*	Sypike			0.73 ±	0.17 *	1 (13)
Redfish	*Sebastes norvegicus*	Uer/Vanlig uer			0.17 ±	0.08	1 (4)
Saithe	*Pollachius virens*	Sei	0.17 ±	0.05	0.22 ±	0.06	5 (125)
Shrimp	*Pandalus borealis*	Reker	0.05 ±	0.04	0.08 ±	0.05	3
Whiting	*Merlangius merlangus*	Hvitting			0.25 ±	0.08	1 (20)
		North Sea					
American Plaice	*Hippoglossoides platessoides*	Gapeflyndre			0.06 ±	0.03	1 (50)
Blue whiting	*Micromesistius poutassou*	Kolmule	0.10 ±	0.03	0.12 ±	0.07	2 (37)
Cod	*Gadus morhua*	Torsk	0.14 ±	0.04	0.17 ±	0.05	3 (75)
Common dab	*Limanda limanda*	Sandflyndre			0.04 ±	0.03	2 (50)
Common ling	*Molva molva*	Lange	0.25 ±	0.07	0.29 ±	0.11	3 (42)
European hake	*Merluccius merluccius*	Lysing	0.18 ±	0.05	0.40 ±	0.12	2 (25)
European plaice	*Pleuronectes platessa*	Rødspette	0.08 ±	0.05	0.12 ±	0.07	2 (25)
Greater sandeel	*Hyperoplus lanceolatus*	Storsil (Tobis)			0.17 ±	0.05	1 (25)
Grey gurnard	*Eutrigla gurnardus*	Knurr			0.17 ±	0.04	1 (25)
Haddock	*Melanogrammus aeglefinus*	Hyse	0.06 ±	0.03	0.08 ±	0.03	3 (74)
Herring	*Clupea harengus*	Sild	0.08 ±	0.03	0.11 ±	0.03	2 (50)
Mackerel	*Scomber scombrus*	Makrell	0.12 ±	0.03	0.13 ±	0.04	2 (50)
Norway pout	*Trisopterus esmarkii*	Øyepål	<0.06		0.07 ±	0.04	2 (50)
Saithe	*Pollachius virens*	Sei	0.19 ±	0.05	0.35 ±	0.09	3 (75)
Silvery cod	*Gaidropsarus argenteus*	Sølvtorsk			0.05 ±	0.02	1
Whiting	*Merlangius merlangus*	Hvitting			0.19 ±	0.05	1 (10)

Technetium-99 has been analysed in lobster (*Hommarus gammarus*) (muscle from tail and claws) from Værlandet since 2002. In the period from 2002 to 2017 the levels of ^{99}Tc in lobster (Figure 25) have decreased due to the reduced discharge of ^{99}Tc from Sellafield.

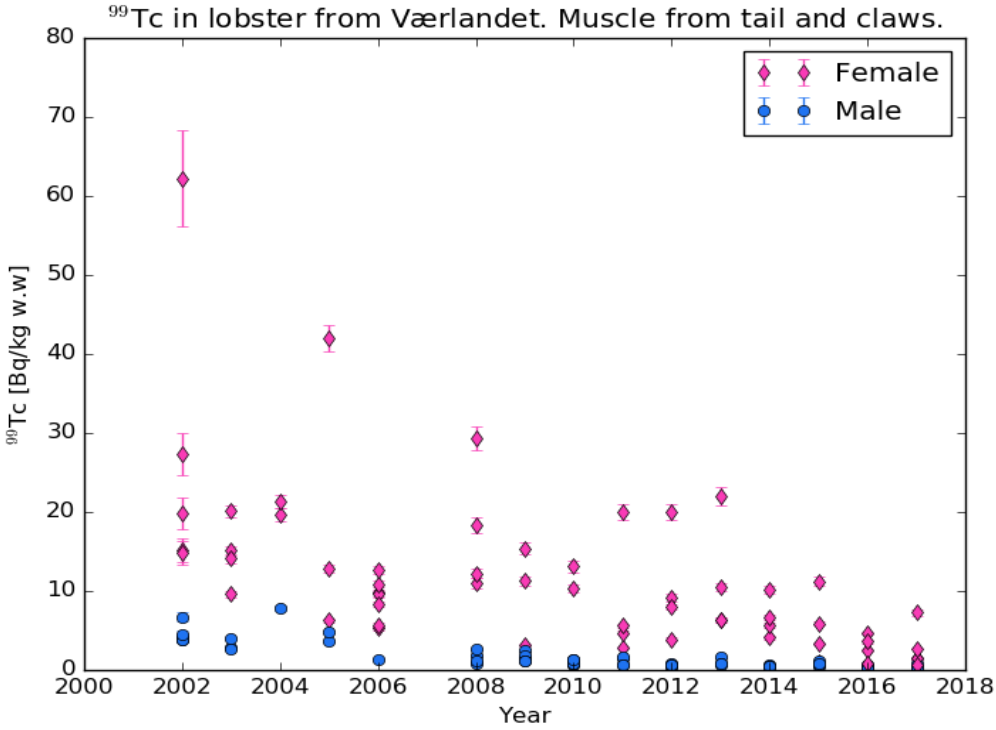

Figure 25: Technetium-99 concentration in lobster *(Hommarus gammarus)* from Værlandet (2002-2017).

6 Summary and conclusions

In 2015, 2016 and 2017, 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 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 0.0084 µSv, 0.00018 and 0.00008 µSv in 2015, 2016 and 2017, respectively. The annual dose from liquid discharges from IFE Halden was estimated to 0.0015 µSv, 0.0018 µSv and 0.00093 µSv in 2015, 2016 and 2017, 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 2015, 2016 and 2017 were 1.22 TBq ^{131}I, 2.18 TBq ^{131}I and 0.97 TBq ^{131}I, respectively.

Produced water from offshore oil production may contain enhanced levels of naturally occurring radium isotopes. In 2015 the discharged activity of ^{226}Ra and ^{228}Ra from the Norwegian oil and gas industry were reported to 440 GBq and 390 GBq, respectively. For 2016, 410 GBq ^{226}Ra and 380 GBq ^{228}Ra were discharged, and 390 GBq ^{226}Ra and 360 GBq ^{228}Ra were discharged in 2017. Thus, there is a slight decreasing trend in the reported discharges during these three years.

The long-range transports of radionuclides originating from nuclear weapons fallout, the Chernobyl accident, and from reprocessing of spent nuclear fuel are still the main contributors to anthropogenic radionuclides found in Norwegian waters. In addition to direct discharges from reprocessing, water from the Baltic Sea and remobilisation of ^{137}Cs and plutonium from the contaminated Irish Sea sediments act as secondary sources of radionuclides to the Norwegian marine environment.

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

Observed levels of ^{137}Cs in surface seawater in Norwegian waters in 2015-2017 ranged from 0.9 Bq/m^3 to 13.5 Bq/m^3. The highest levels were, as expected, found in the Skagerrak and the levels are generally similar to previously observed activity concentrations in the open sea areas. However, data from Hillesøy and Grense Jakobselv show that the levels of ^{137}Cs are slowly decreasing in the Norwegian coastal current.

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

Levels of ^{239,240}Pu in the Norwegian waters in 2015-2017 ranged from below detection limit to 9 mBq/m^3. This is generally similar to levels observed in the same area previous years. The activity concentration of ^{241}Am in seawater from Norwegian waters ranged from below detection limit to 2.2 mBq/m^3 and are comparable to previously observed levels.

6.2.3 Radium-226 in seawater

The activity concentrations of ^{226}Ra observed in Norwegian waters in 2015, 2016 and 2017 were in the range of 0.9 to 2.5 Bq/m^3 and are comparable to previously observed concentrations.

6.3 Radioactivity in biota

6.3.1 Technetium-99 in seaweed

Samples of bladderwrack collected at the permanent coastal stations showed activity concentrations in the range 10 Bq/kg (d.w.) to 42 Bq/kg (d.w.). For most stations the levels were lower in 2015-2017 compared to observed levels in the period 2002-2007. The levels in 2015-2017 are significantly lower than the peak values observed in the period 1999-2001. Monthly sampling 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 concentrations of ^{137}Cs in *Fucus vesiculosus* sampled at the coastal stations in 2015-2017 were in the range from below detection limit to 2.1 Bq/kg (d.w.), where the highest levels were found at Hvaler. Data from monthly sampling at Utsira indicates that the levels of ^{137}Cs in seaweed are slowly decreasing and have been relatively stable the last years.

6.3.3 Caesium-137 in fish and crustaceans

The activity concentration of ^{137}Cs in fish from Norwegian marine waters is generally low. All analysed samples were below 1 Bq/kg (w.w.), which is far below the maximum permitted levels of 600 Bq/kg in food, and in general lower than in foods from the terrestrial environment and freshwater systems.

Samples of cod from the Barents Sea have been analysed for ^{137}Cs since the early 1990s. These results suggest a slightly decreasing trend of ^{137}Cs in this period, and low levels of radioactive contamination in cod.

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ISSN 2535-7379

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