Statens strålevern
Norwegian Radiation Protection Authority

HAVFORSKNINGSINSTITUTTET
INSTITUTE OF MARINE RESEARCH

StrålevernRapport 2017:13

Radioactivity in the Marine Environment 2012, 2013 and 2014

Results from the Norwegian Marine Monitoring Programme (RAME)

Reference:
Skjerdal H[1], Heldal HE[2], Gwynn J[1], Strålberg E[3], Møller B[1], Liebig PL[2], Sværen I[2], Rand A[3], Gäfvert T[1], Haanes H[1]. NRPA. Radioactivity in the marine environment 2012, 2013 and 2014. Results from the Norwegian National Monitoring Programme (RAME).
StrålevernRapport 2017:13. Østerås: Norwegian Radiation Protection Authority, 2017.
1)Norwegian Radiation Protection Authority, 2)Insitute 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 2012, 2013 and 2014.

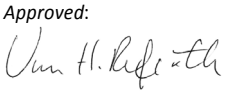
Referanse:
Skjerdal H[1], Heldal HE[2], Gwynn J[1], Strålberg E[3], Møller B[1], Liebig PL[2], Sværen I[2], Rand A[3], Gäfvert T[1], Haanes H[1]. NRPA. Radioactivity in the marine environment 2012, 2013 and 2014. Results from the Norwegian National Monitoring Programme (RAME).
StrålevernRapport 2017:13. Østerås: Norwegian Radiation Protection Authority, 2017.

Language: Norwegian.
1)Statens strålevern, 2)Havforskningsinstituttet, 3)Institutt for Energiteknikk

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

Resymé:
Rapporten inneholder resultater fra overvåkningen av radioaktivitet i sjøvann, sedimenter og biota i norske havområder i 2012,2013 og 2014.

Head of project: Hilde Skjerdal
Approved:



Unn Hilde Refseth, director, Department of Monitoring and Research

37 pages.
Published 2017-11-15.
Printed number ?? (17-06).
Printed by 07 Media.
Cover photo: Hilde Skjerdal, NRPA.

Norwegian Radiation Protection Authority, P.O. Box 55, N-1332 Østerås, Norway.
Telephone +47 67 16 25 00
E-mail: nrpa@nrpa.no
www.nrpa.no
ISSN 0804-4910 (print)
ISSN 1891-5205 (online)

StrålevernRapport 2017:13

Radioactivity in the Marine Environment 2012, 2013 and 2014

Results from the Norwegian Marine Monitoring Programme (RAME)

Skjerdal H, Heldal HE, Gwynn J, Strålberg E, Møller B,
Liebig PL, Sværen I, Rand A, Gäfvert T, Haanes H

Havforskningsinstituttet
Insitute for
Marine Research

Statens strålevern
Norwegian Radiation
Protection Authority
Østerås, 2017

Innhold/Contents

1 Introduction

In 2012, 2013 and 2014, samples for monitoring radioactivity in the marine environment were collected in the Barents Sea, the North Sea and the Norwegian Sea, 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 is given.

Information about the monitoring programme, a detailed description of the radionuclides and analytical methods are not included, but 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 found in Norwegian waters. In addition to direct discharges from reprocessing, water from the Baltic Sea and remobilisation of ^{137}Cs and plutonium from contaminated Irish Sea sediments act as secondary sources of radionuclides to the Norwegian marine environment.

European petroleum industries in the North Sea are discharging natural radionuclides into the marine environment, with the Norwegian and the British petroleum industry as the main contributors [4, 5 and 6]. In addition, Norwegian hospitals and Institute for Energy Technology (IFE) are discharging anthropogenic radionuclides into the marine environment. Runoff from Chernobyl polluted areas are still contributing to the elevated levels of anthropogenic radionuclides along the coast and fjords.

Discharges from IFE Kjeller and IFE Halden 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 0.0074 µSv and 0.00012 µSv in 2013 and 2014, respectively. There was no liquid discharge in 2012. The annual dose from liquid discharges from IFE Halden in 2012, 2013 and 2014 was estimated to 0.0081 µSv, 0.0046 µSv and 0.0020 µSv, respectively.

Unsealed radioactive substances used in medicine dominate the anthropogenic radioactive discharges to the sewage system. 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 2012, 2013 and 2014 were 1.22 TBq ^{131}I, 1.10 TBq ^{131}I and 1.07 TBq ^{131}I, respectively.

In 2012, the reported discharged activity of ^{226}Ra and ^{228}Ra from the Norwegian oil and gas industry was to 437 GBq and 372 GBq, respectively. For 2013, 380 GBq ^{226}Ra and 326 GBq ^{228}Ra were discharged and 402 GBq ^{226}Ra and 349 GBq ^{228}Ra were discharged in 2014. The discharges are at the same level as previous years, as shown in Figure 2-1. Discharges to the North Sea and the Norwegian Sea in 2012-2014 are shown in Figure 2-2, and discharges per installation in 2012, 2013 and 2014 are presented in Figures 2-3, 2-4 and 2-5, respectively.

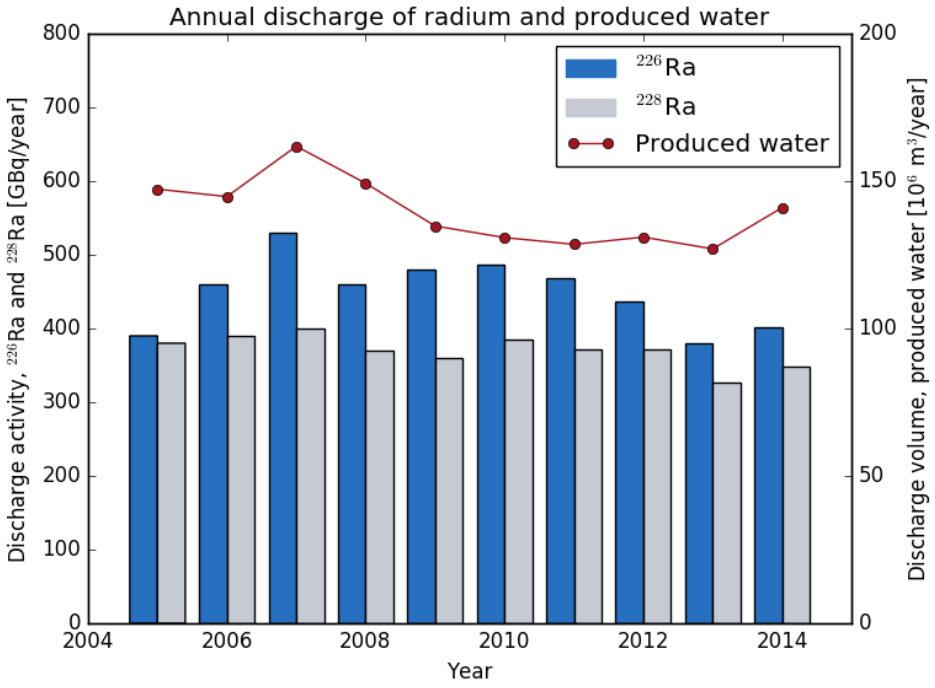


Figure 2-1 Annual discharge of ^{226}Ra and ^{228}Ra to the marine environment via produced water, and discharged volume of produced water from the Norwegian oil and gas industry in the period 2005 to 2014.

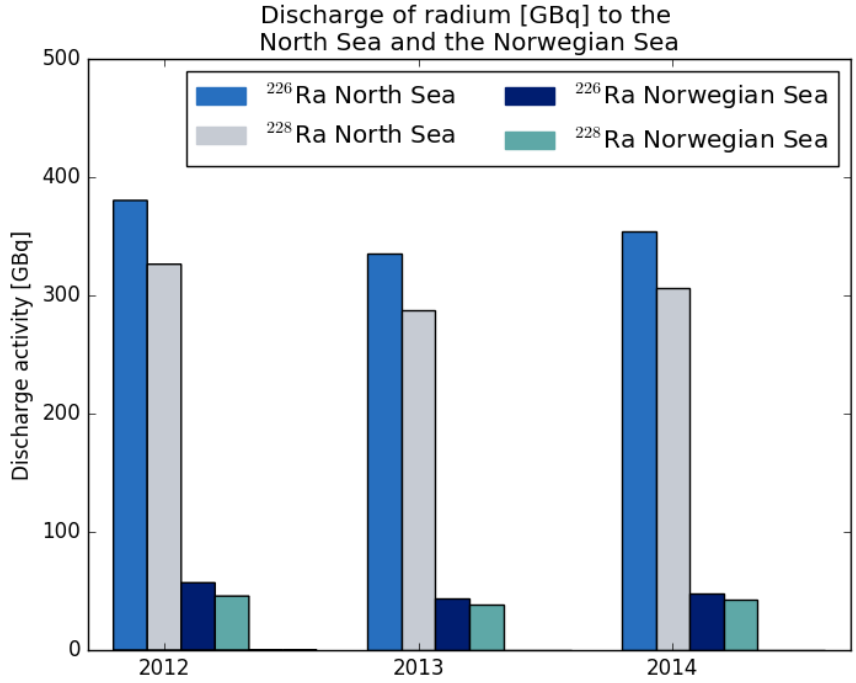


Figure 2-2 Discharge of ^{226}Ra and ^{228}Ra to the North Sea and the Norwegian Sea from the Norwegian oil and gas industry.

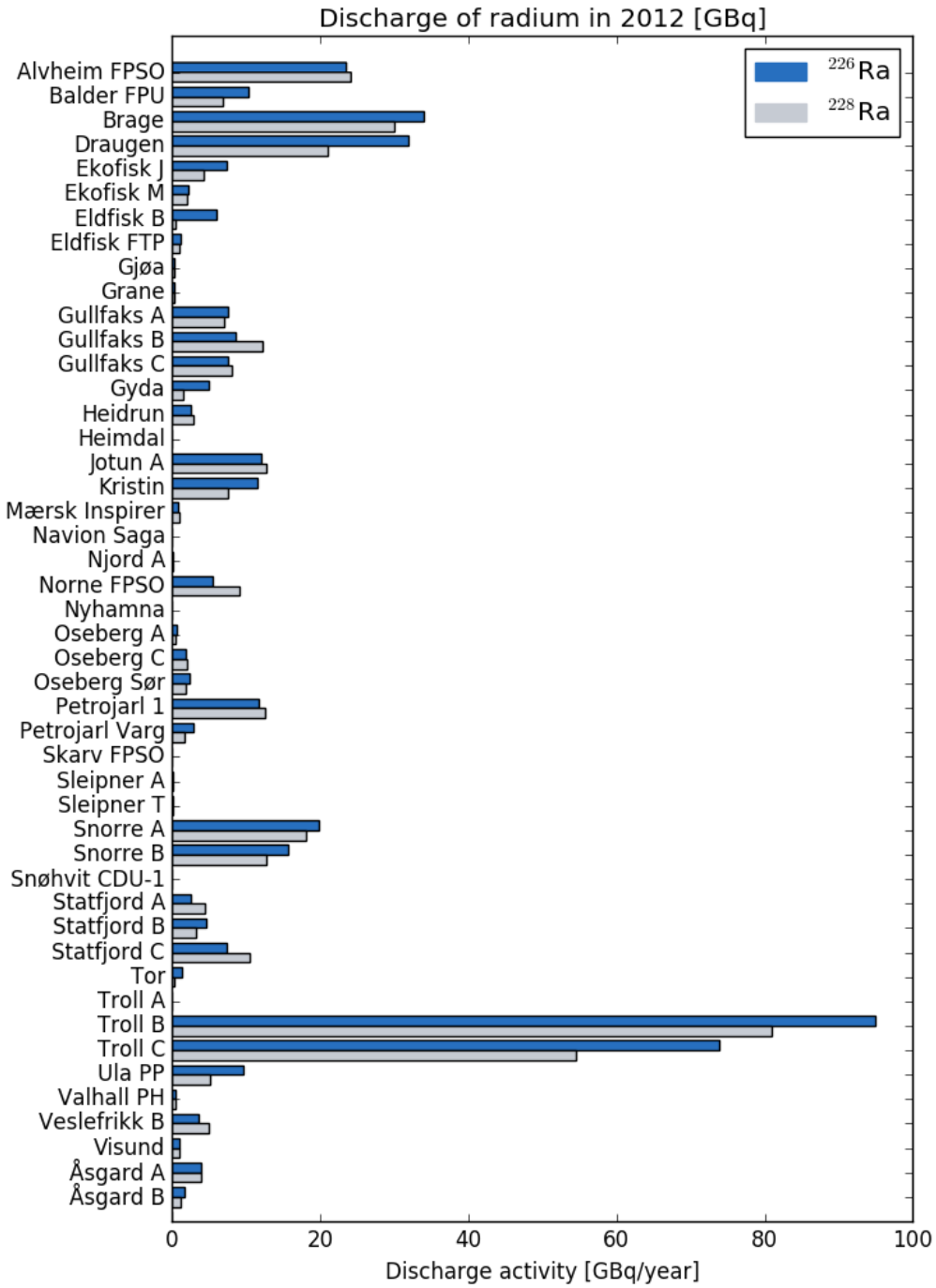


Figure 2-3 Discharged activity of ^{226}Ra and ^{228}Ra from Norwegian oil and gas fields in 2012.

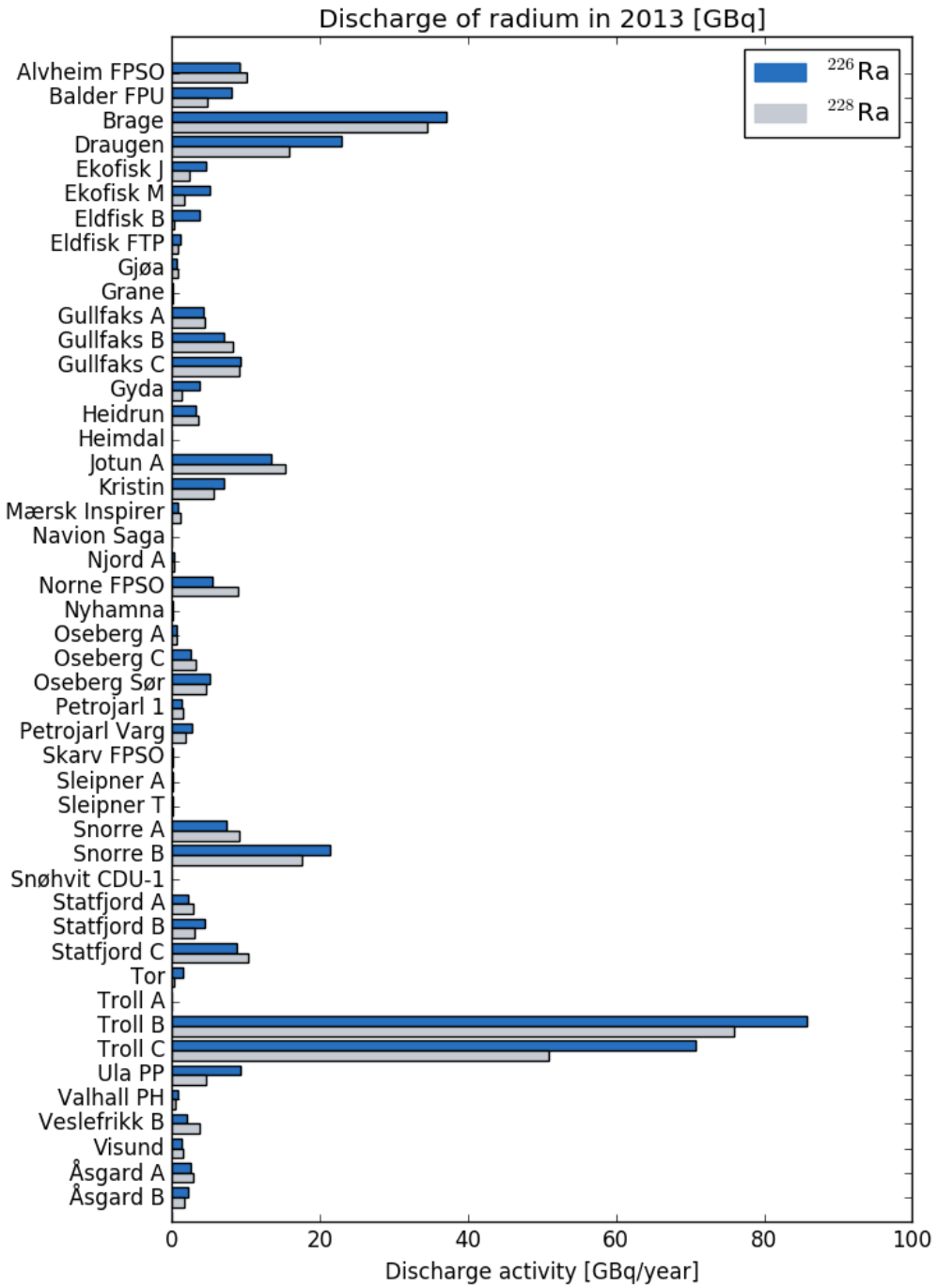


Figure 2-4 Discharged activity of ^{226}Ra and ^{228}Ra from Norwegian oil and gas fields in 2013.

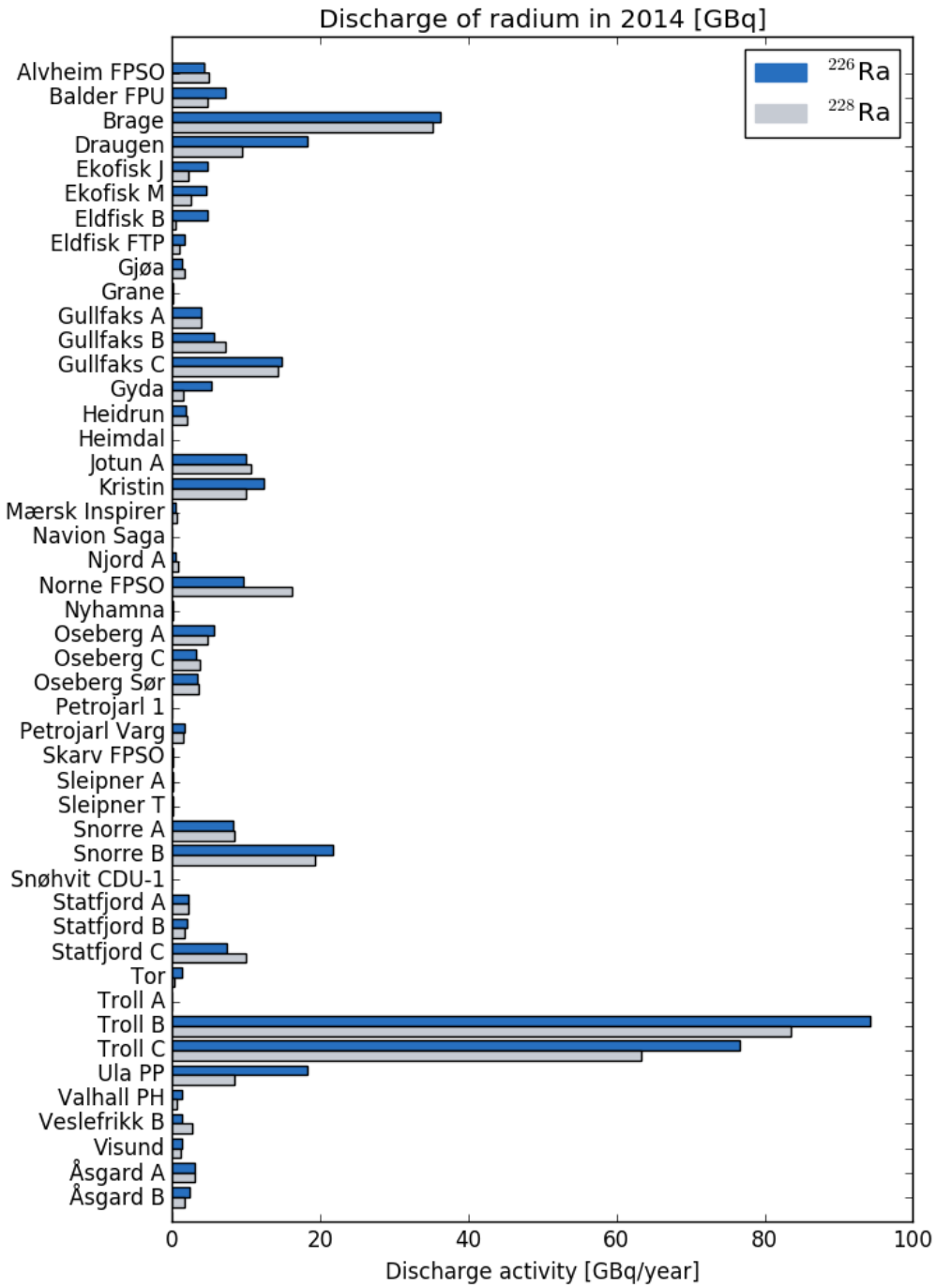


Figure 2-5 Discharged activity of ^{226}Ra and ^{228}Ra from Norwegian oil and gas fields in 2014.

3 Collection of samples

In 2012, 2013 and 2014, samples were collected in the Skagerrak, the North Sea, the Norwegian Sea, the Barents Sea and in selected fjords, and also at permanent coastal stations. A geographic overview of the sampling area covered by the marine monitoring programme, with the fixed coastal stations marked, is shown in Figure 3-1.

Figure 3-1 Geographic overview of the coastal sampling stations and the sampling area covered by the marine monitoring programme.

Sampling and analysis were carried out by the Norwegian Radiation Protection Authority (NRPA), the Institute of Marine Research (IMR), and the Institute for Energy Technology (IFE).

Samples from the Barents Sea were mostly collected in September 2012, from the North Sea in July 2013 and from the Norwegian Sea in June 2014. Sampling was performed by IMR and NRPA on board the research vessels R/V "G. O. Sars" and R/V "Johan Hjort" (Figure 3-2). During the cruises, samples of surface seawater were collected and later analysed for ^{99}Tc, ^{137}Cs, ^{90}Sr, ^{241}Am, ^{226}Ra and plutonium isotopes. Sediment was also collected and later analysed for ^{137}Cs. Samples of fish and other marine biota were collected and analysed for ^{137}Cs. In addition, samples of cod (*Gadus morhua*) are collected yearly from the Barents Sea by the Norwegian 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 3-2 Research vessels R/V "G. O. Sars" and R/V "Johan Hjort".

Seaweed samples from the Norwegian coastline are collected by IFE and NRPA. At most costal stations, sampling is performed once a year. More frequent seaweed sampling is performed at Utsira and Hillesøy. IMR are sampling seaweed, lobster and seawater at Værlandet once a year.

4 Radioactivity in seawater and sediments

4.1 Technetium-99 in seawater

Seawater samples were collected during research cruises and at the costal stations Utsira, Hillesøy and costal station at Svalbard, Bjørnøya, Hopen and Jan Mayen. The results are presented in Figure 4.1. The activity concentrations ranged from below detection limit to 0.56 Bq m^{-3} (presented as mean value 0.52 Bq m^{-3} in Figure 4-1).

The activity concentrations found in 2012-2014 are generally lower than, or at the same level as, previous observations [1–3]. The reason for the decreasing concentrations is the reduced discharge of ^{99}Tc from Sellafield.

Monthly samples have also been collected at Hillesøy (Figure 4.2). The results show that the activity concentration of ^{99}Tc in seawater continues to slowly decrease since the peak concentrations in 1998/1999.

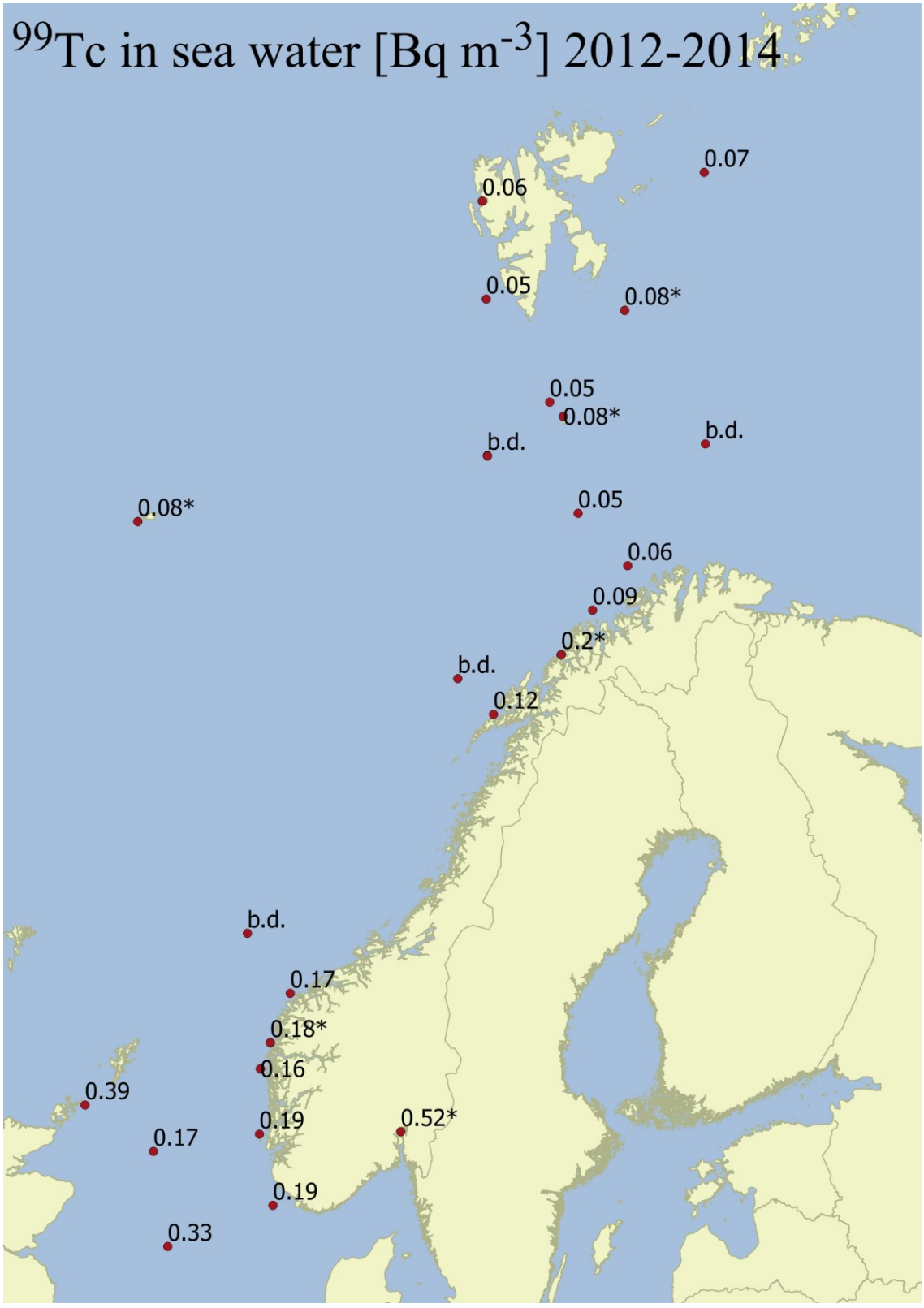


*Figure 4-1 Activity concentration (Bq m^{-3}) of ^{99}Tc in seawater samples collected in 2012-2014. Mean values are marked with *, and b.d. marks measurements below the detection limit.*

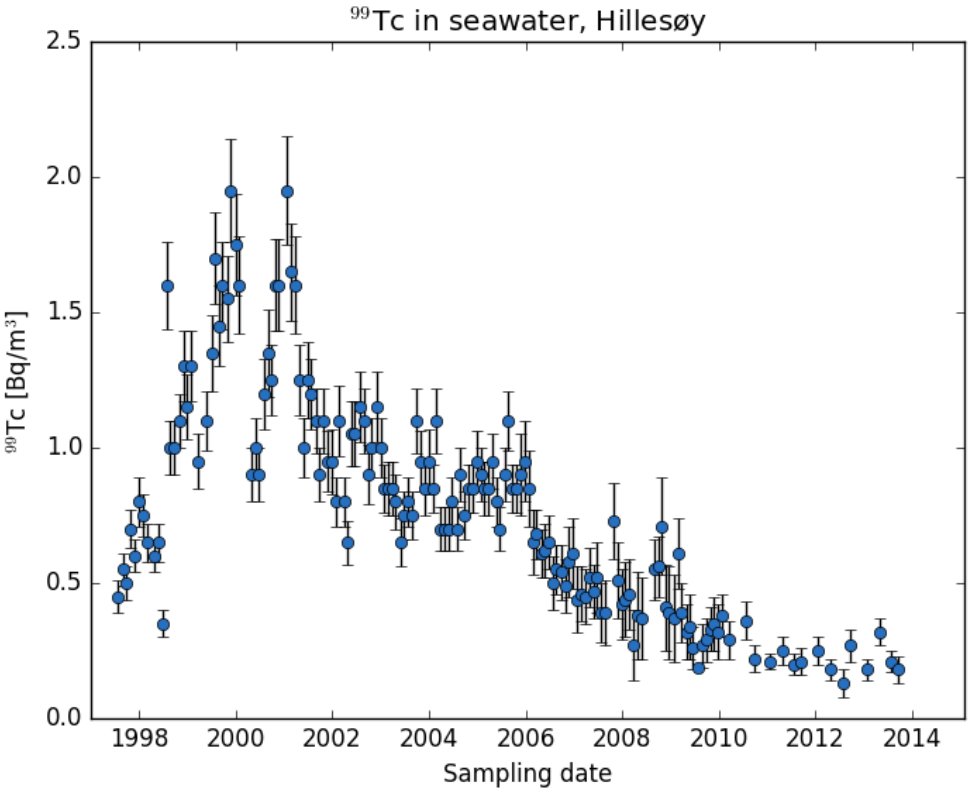


Figure 4-2 Activity concentration (Bq m^{-3}) of ^{99}Tc in seawater at Hillesøy.

4.2 Strontium-90 in seawater

The activity concentration of ^{90}Sr in seawater in the Norwegian coastal current is slowly decreasing, results from 2012-2014 are presented in Figure 4-3. Explanations for this are the reduced discharges from Sellafield over the last 10 years and the physical decay of ^{90}Sr from global fallout. The ^{90}Sr in seawater time series at Hillesøy and Grense Jakobselv (Figure 4-4) are showing a decreasing trend.

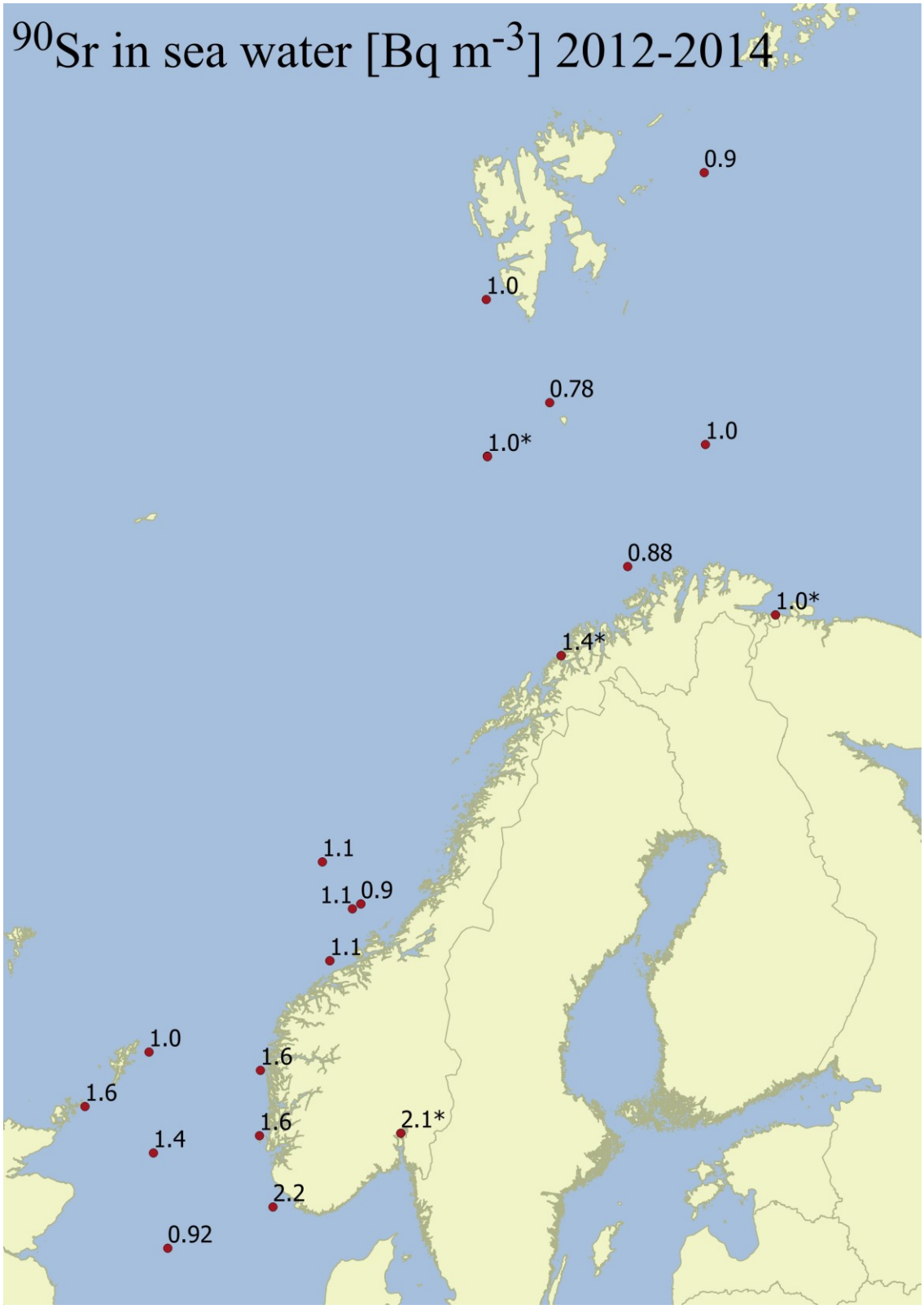


*Figure 4-3 Activity concentration (Bq m^{-3}) of ^{90}Sr in surface seawater samples collected in the Norwegian Sea in 2012-2014. * Mean value 2012-2014.*

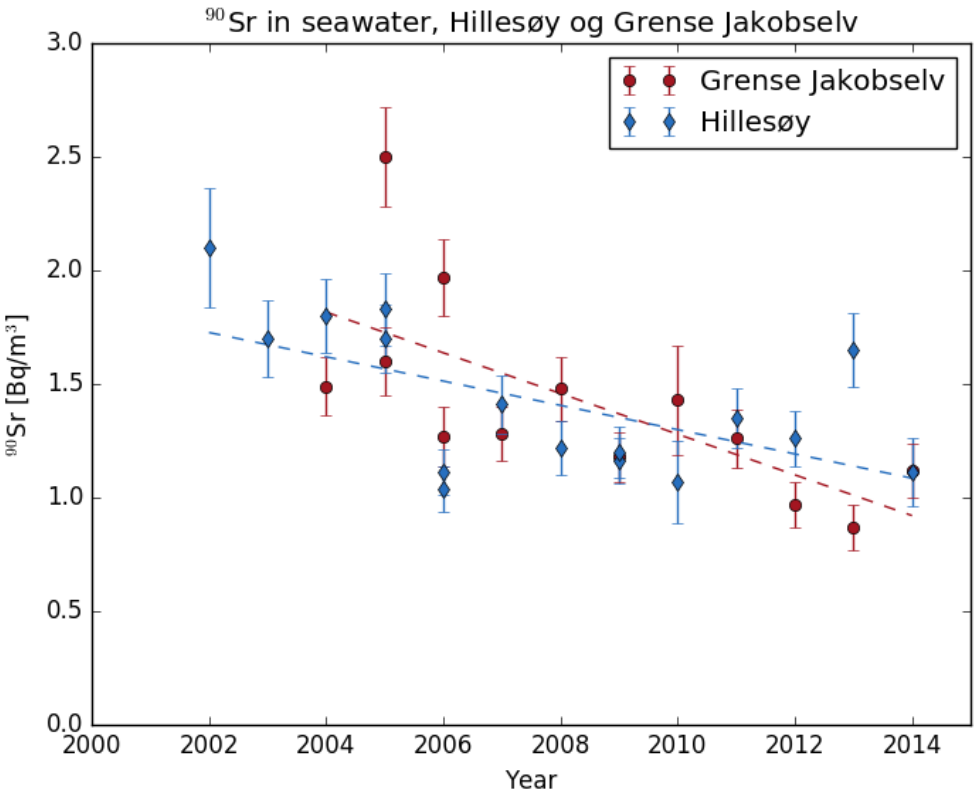


Figure 4-4 Activity concentration (Bq m^{-3}) of ^{90}Sr in seawater at Hillesøy (2002-2014) and Grense Jakobselv (2004-2014).

4.3 Caesium-137 in seawater and sediment

Levels of ^{137}Cs in Norwegian waters are shown in Figure 4-5. The activity concentration in surface water ranged from 1 to 20 Bq m^{-3}, where the highest levels were found in the Skagerrak. Observed levels of ^{137}Cs in the Skagerrak in 2012-2014 are shown in Figure 4-6.

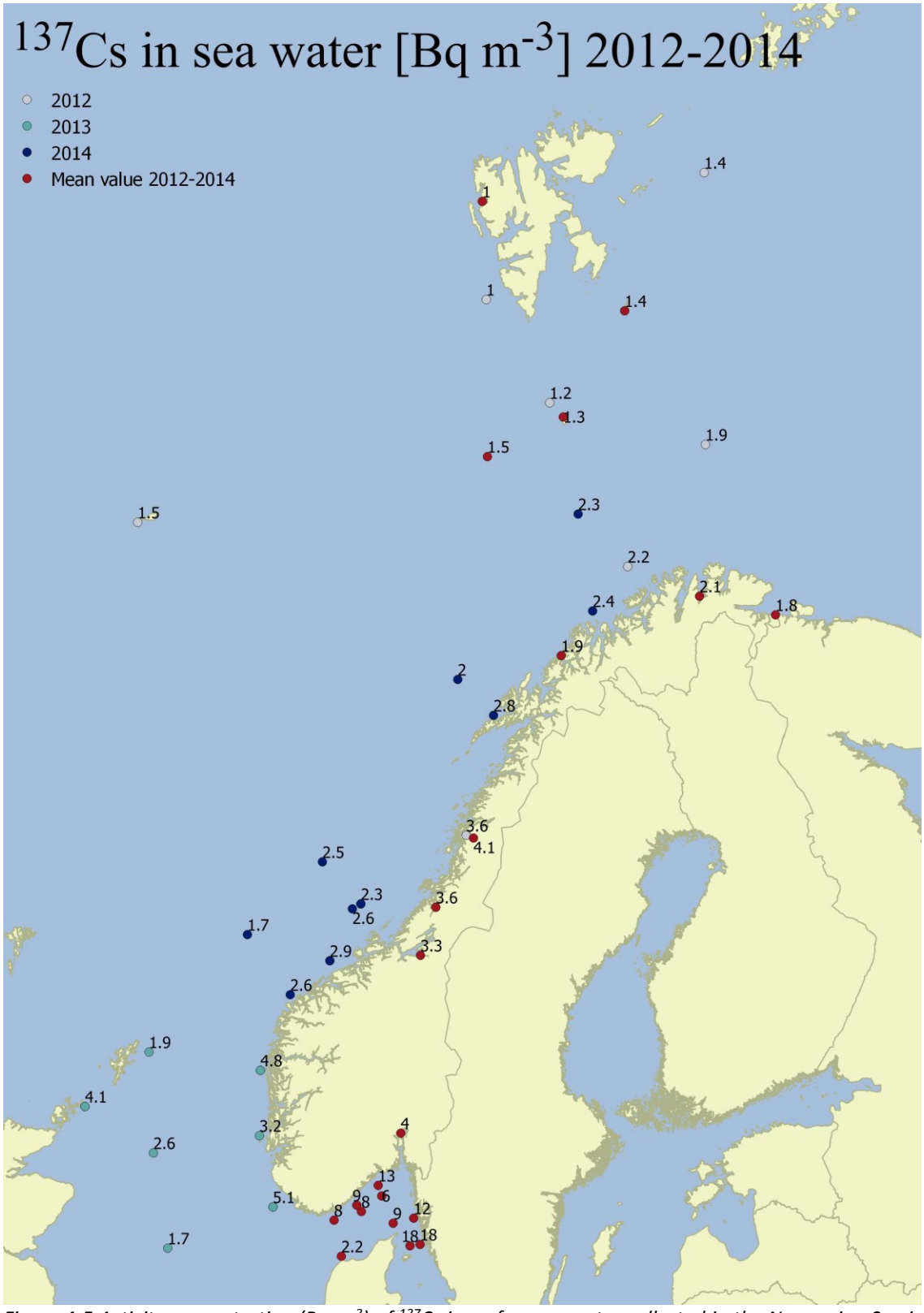


Figure 4-5 Activity concentration (Bq m^{-3}) of ^{137}Cs in surface seawater collected in the Norwegian Sea in 2012-2014.

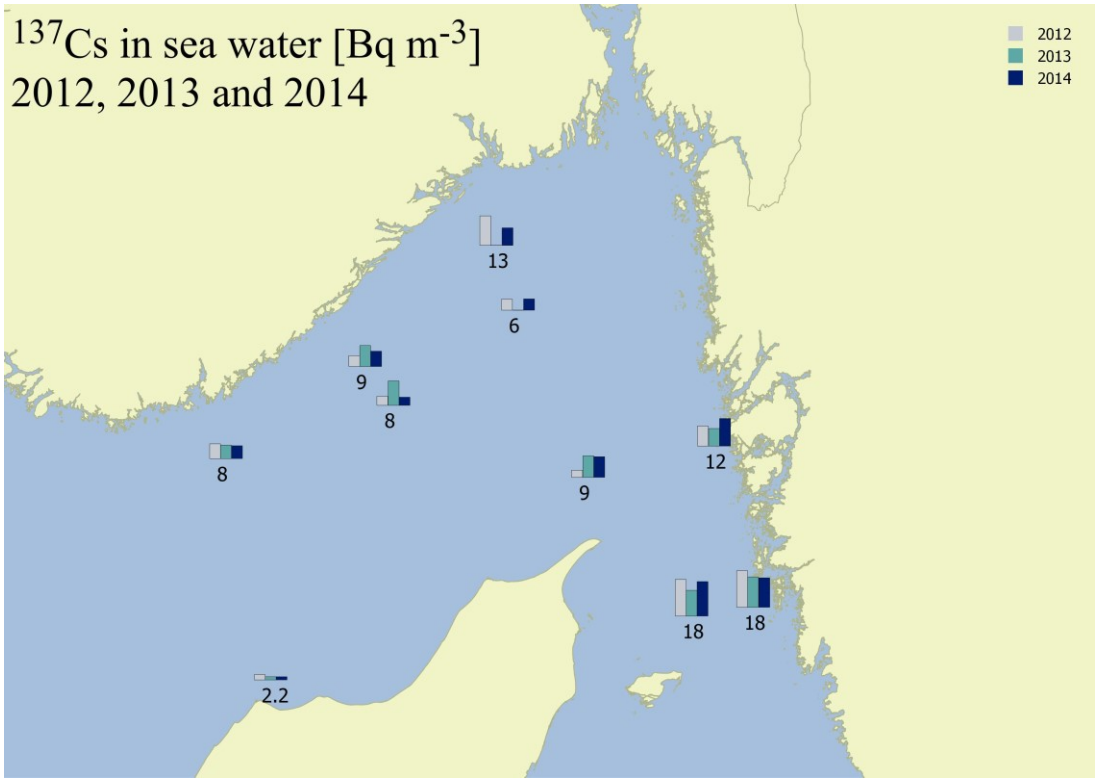


Figure 4-6 Activity concentration (Bq m^{-3}) of ^{137}Cs in surface seawater collected in the Skagerrak in 2012, 2013 and 2014. Mean values for the different sampling stations are shown under the histograms.

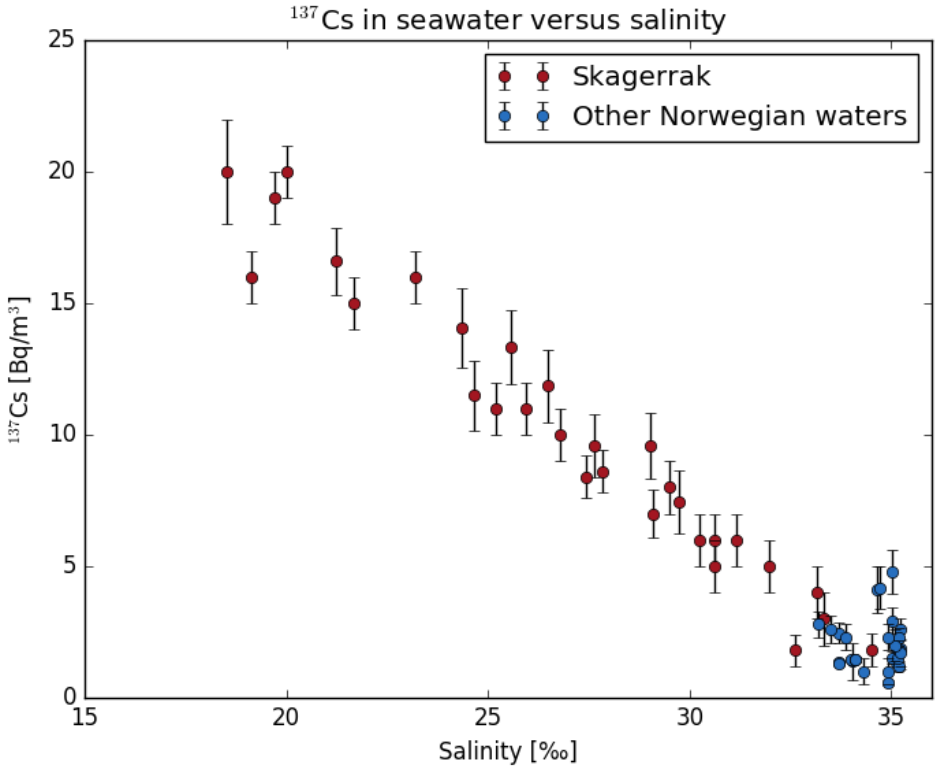


Figure 4-7 Due to the outflow of contaminated, brackish water from the Baltic Sea, levels of ^{137}Cs are elevated in the Skagerrak.

Data from Hillesøy (2002-2014) and Grense Jakobselv (2005-2014) (Figure 4.8) 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 in this region, has been estimated to 10 years [7].

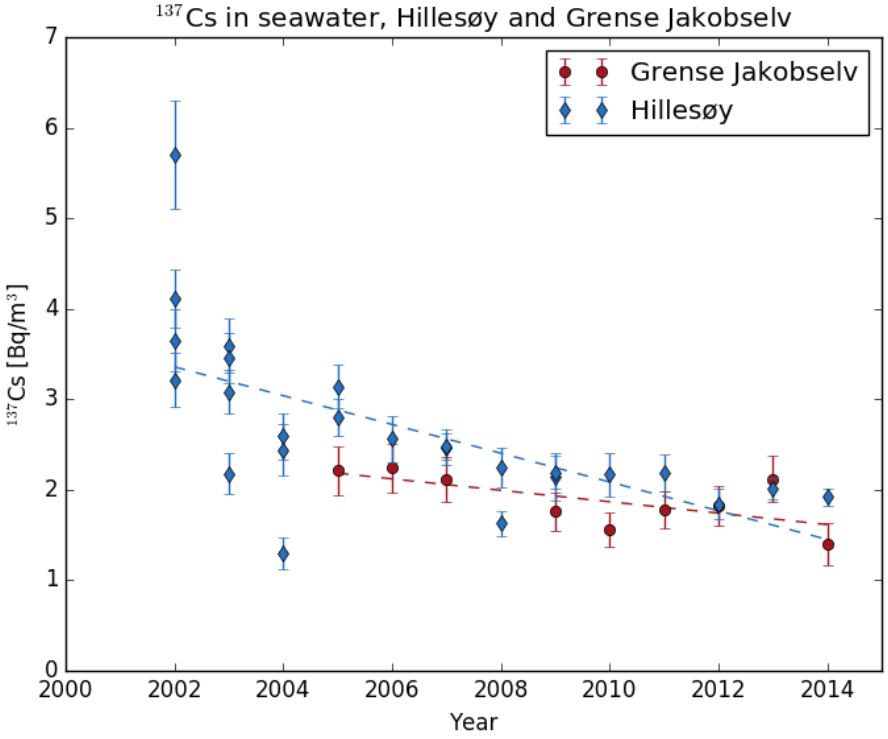


Figure 4-8 Activity concentration (Bq m^{-3}) of ^{137}Cs in seawater at Hillesøy and Grense Jakobselv in the period 2002-2014.

Caesium-137 has also been analysed in surface sediments (upper 2 cm layer) from the Norwegian waters, selected fjords and close to the position of the sunken nuclear submarine "Komsomolets". The results are presented in Figure 4-9 and 4-10, and range from <0.3 Bq kg^{-1} (d.w) to 10 Bq kg^{-1} (d.w) in open waters. The activity concentration of ^{137}Cs in sediments sampled in the fjords ranged from 1.7 Bq kg^{-1} (d.w.) (Ytre Laksefjord in 2013) to 256 Bq kg^{-1} (d.w.). The highest activity concentration was found in the Vefsnfjord in 2014.

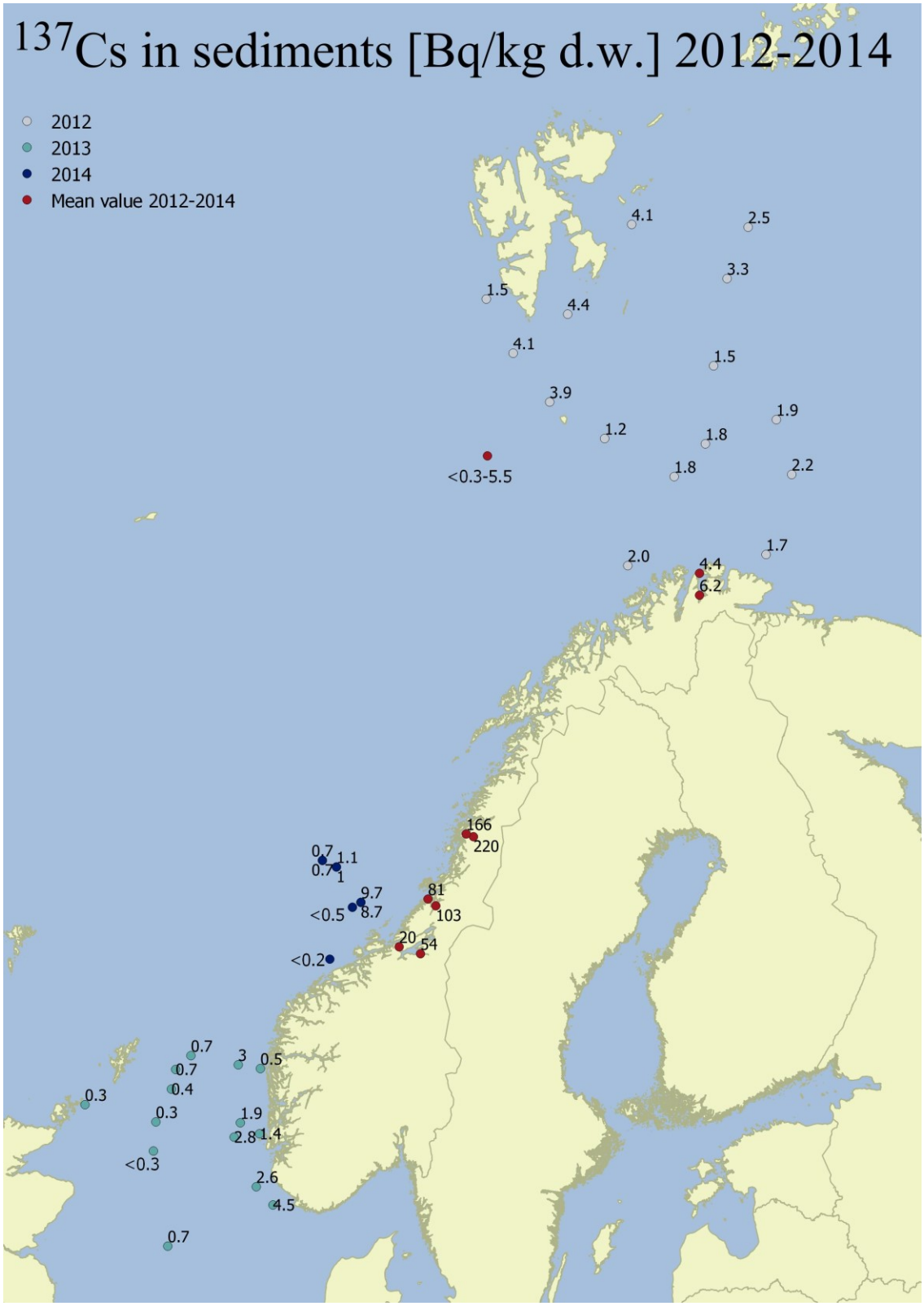


Figure 4-9 Activity concentration (Bq kg^{-1} d.w.) of ^{137}Cs in surface sediment in 2012, 2013 and 2014. Mean values are shown for stations with annual sampling. The sample southwest of Bjørnøya has been collected close to the position of the sunken submarine Komsomolets, and minimum and maximum values for the period is shown.

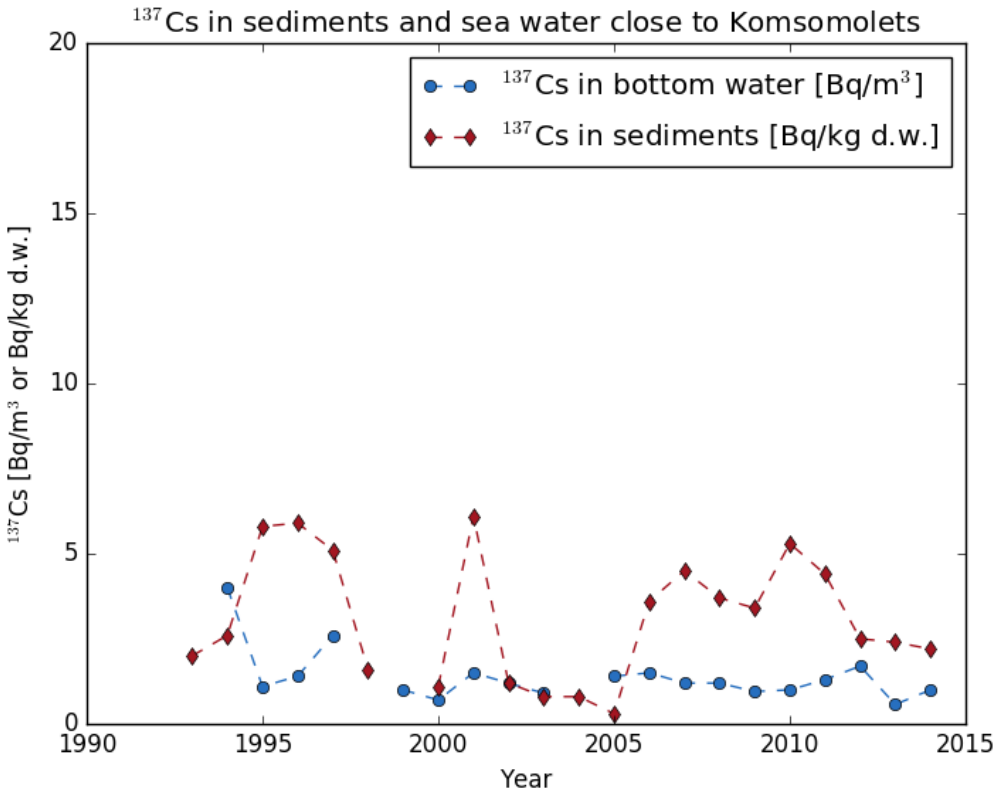


Figure 4-10 ^{137}Cs in samples close to the position of the sunken nuclear submarine "Komsomolets". There is no indication of leakage from the submarine.

4.4 Plutonium-238 and plutonium-239 and -240 in seawater

Observed levels of plutonium-239,-240 in 2012 to 2014 are presented in Figure 4-11 and range from 1.7 mBq m^{-3} to 6 mBq m^{-3}. In addition, 39 mBq m^{-3} is measured outside Scotland. The levels of $^{239,240}Pu$ in Norwegian waters are similar to the levels observed in 2008, 2009, 2010 and 2011 [1–3].

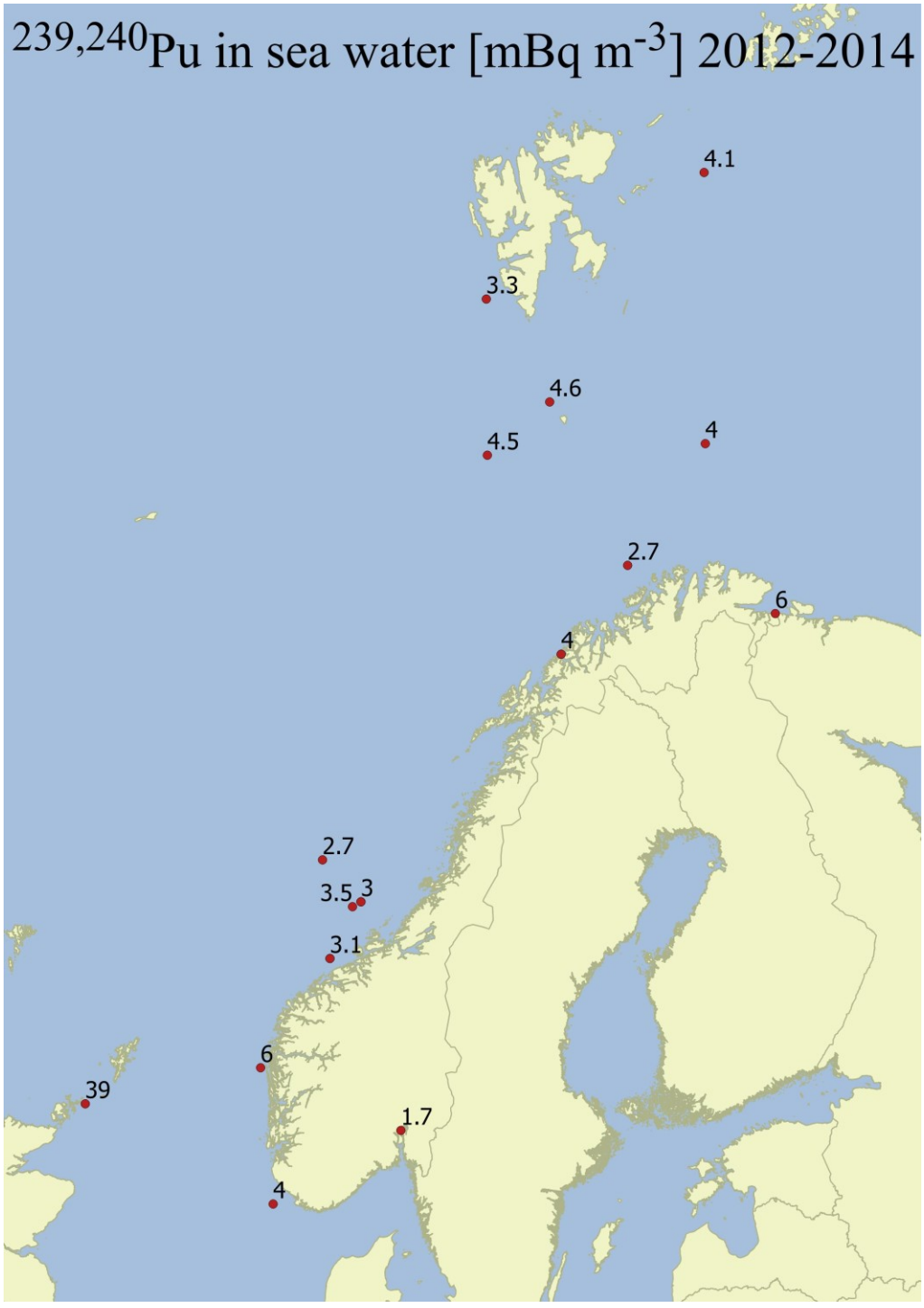


Figure 4-11 Activity concentration (mBq m^{-3}) of $^{239,240}Pu$ in surface seawater samples collected in 2012, 2013 and 2014.

Observed levels of plutonium-238 in 2012 to 2014 are presented in Figure 4-12 and range from below detection limit to 4.3 mBq m^{-3}. In addition, 6 mBq m^{-3} is measured outside Scotland.

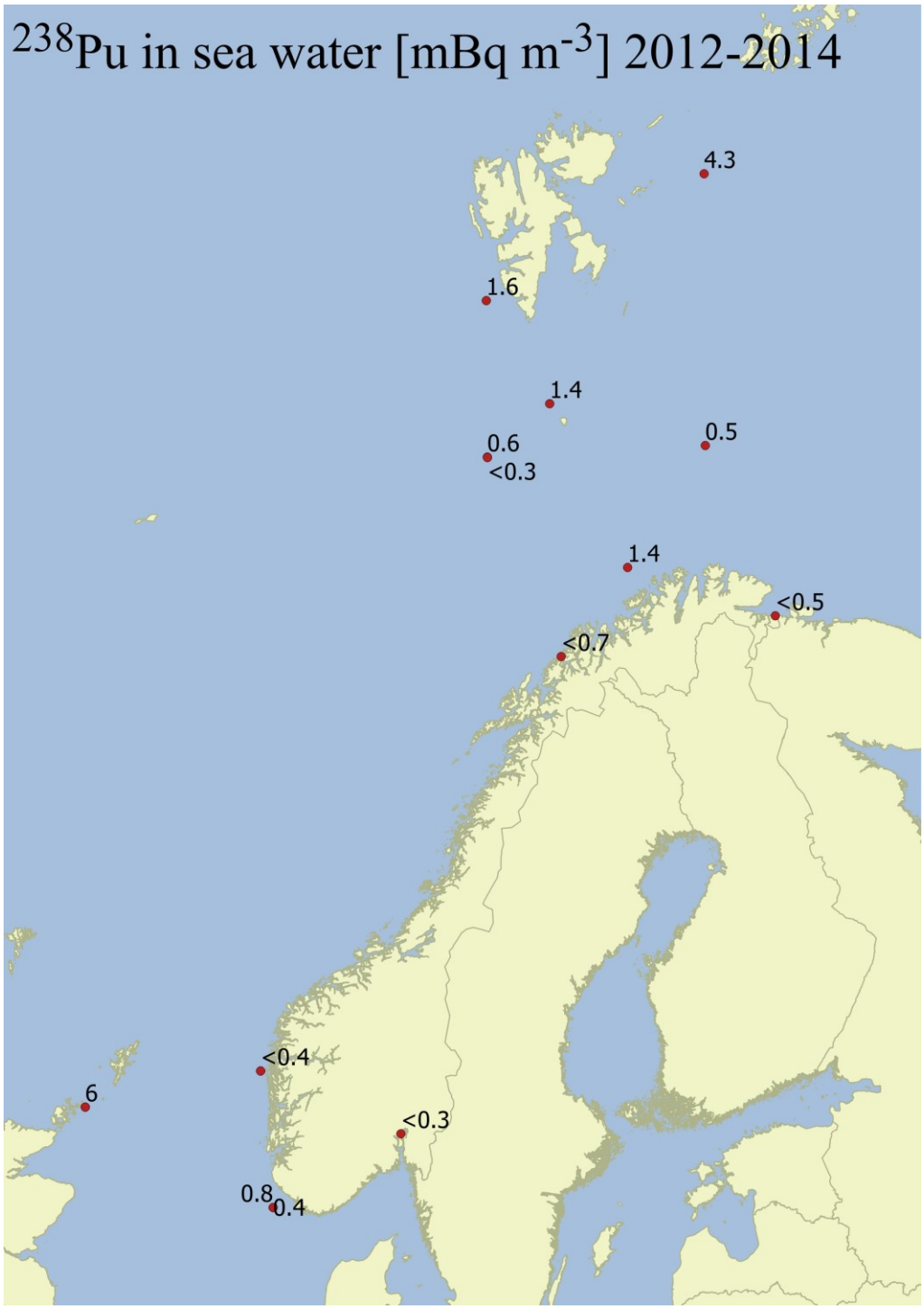


Figure 4-12 Activity concentration (mBq m^{-3}) of ^{238}Pu in surface water samples collected in 2012, 2013 and 2014.

4.5 Americium-241 in seawater

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

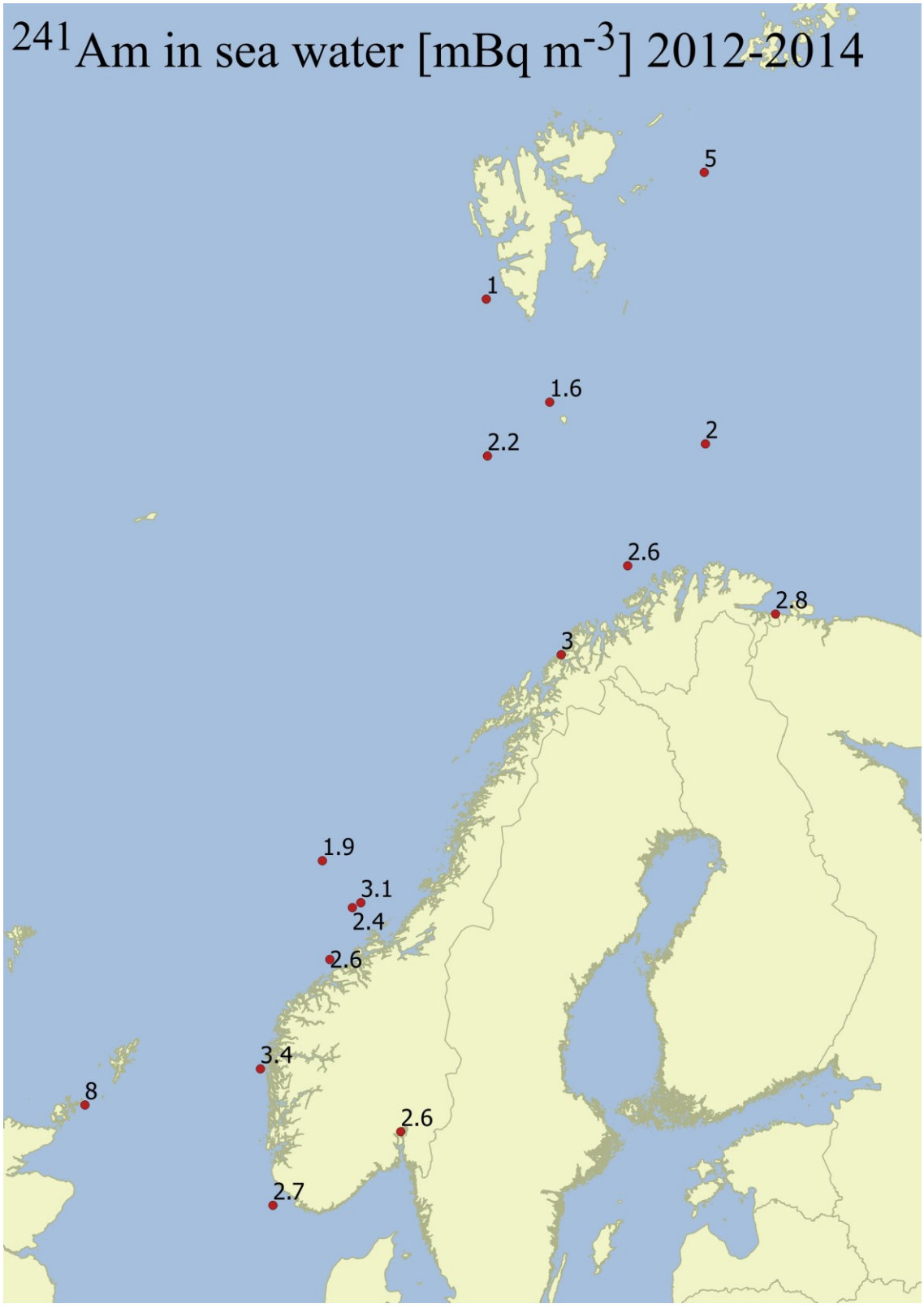


Figure 4-13 Activity concentration (mBq m^{-3}) of ^{241}Am in seawater in 2012, 2013 and 2014.

4.6 Radium-226 in seawater

The activity concentration of ^{226}Ra observed in Norwegian waters in 2012, 2013 and 2014 were in the range of 0.29 to 2.8 Bq m^{-3} (Figure 4.14) and comparable to previously observed concentrations [e.g. 1, 9 and 10].

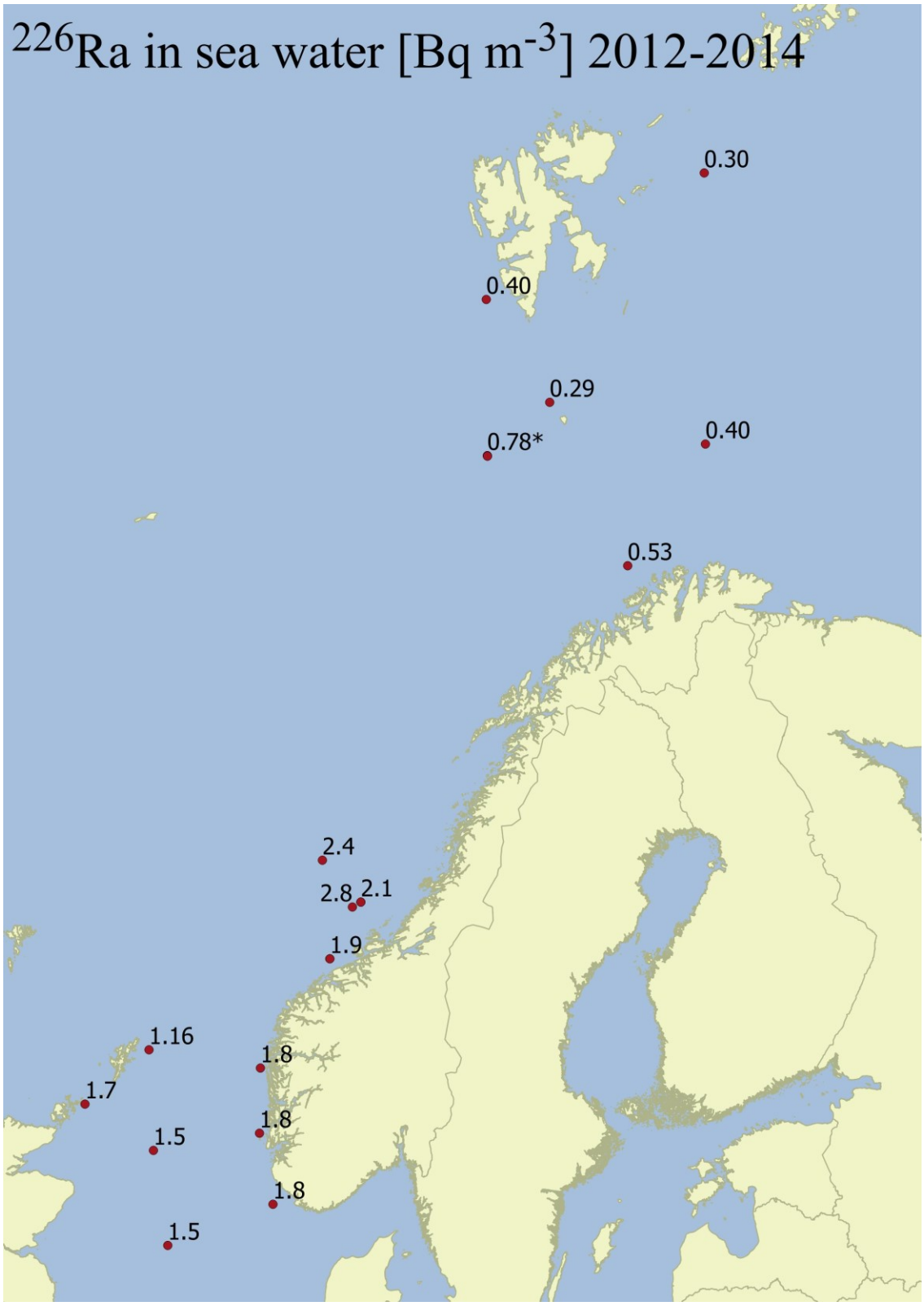


Figure 4-14 Activity concentration (Bq m^{-3}) of ^{226}Ra in seawater in 2012, 2013 and 2014.

5 Radioactivity in biota

5.1 Technetium-99 in seaweed

Seaweed is a useful bioindicator for ^{99}Tc in the marine environment. It has a high ability to concentrate ^{99}Tc from seawater and is easily accessible in most coastal areas. In 2012, 2013 and 2014, seaweed (*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 2012, 2013 and 2014, and sampling was performed every month in 2012, six times in 2013 and five times in 2014 at Utsira. At the other sites, sampling was conducted in August or September. The results of the analyses are presented in Figure 5-1 and range from 14 to 64 Bq kg^{-1} (d.w.), where the highest activity concentration was found in one of the monthly samples collected at Utsira (mean value 64 Bq kg^{-1} d.w., range 27-196 Bq kg^{-1} d.w. at Utsira in 2012). Compared with the results from 1999-2001 [11 and 12], 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 5-2, which shows the annual average activity concentration of ^{99}Tc in *Fucus vesiculosus* at Utsira and Hillesøy, together with the annual discharge of ^{99}Tc from Sellafield.

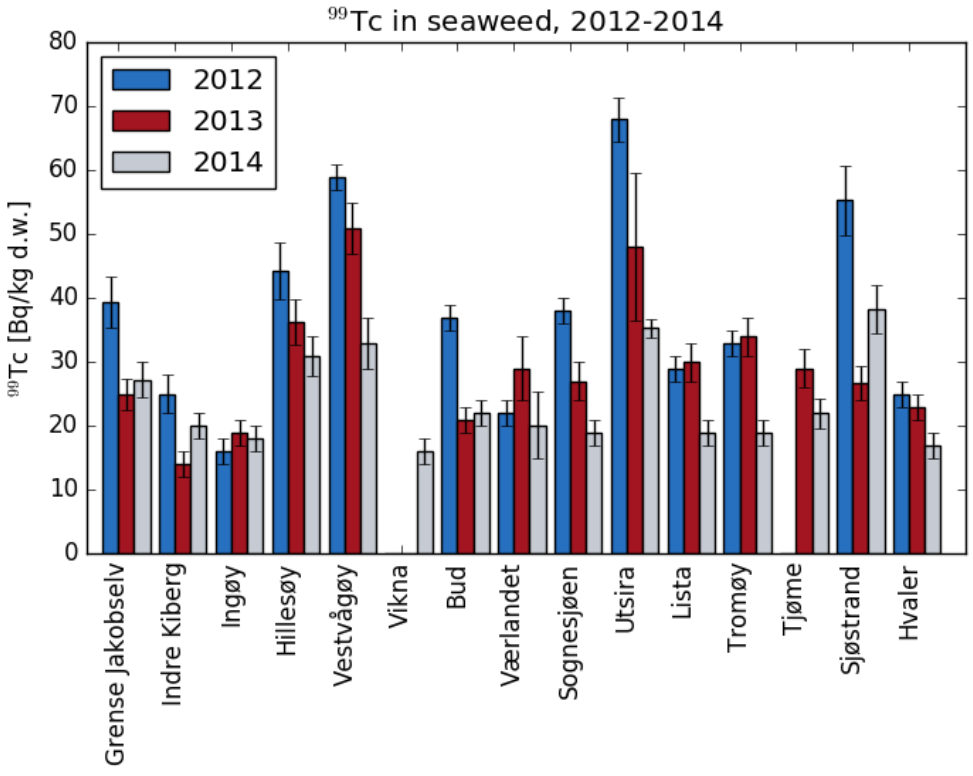


Figure 5-1 Levels of ^{99}Tc in Fucus vesiculosus sampled along the Norwegian coastline in 2012, 2013 and 2014. Mean values for Hillesøy and Utsira.

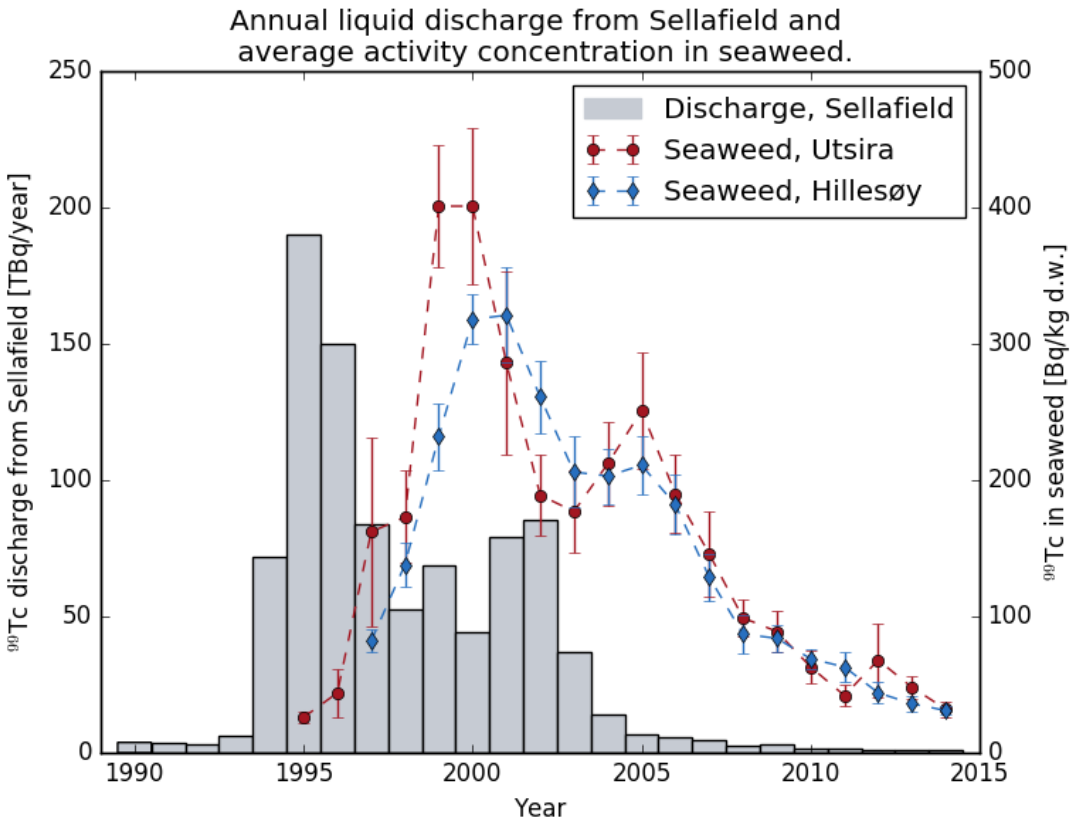


Figure 5-2 Annual liquid discharge of ^{99}Tc from Sellafield and annual average (with 95 % confidence limits) ^{99}Tc activity concentration in brown algae (Fucus vesiculosus) sampled at Utsira (data provided by IFE) in the period 1995-2014 and Hillesøy in the period 1997-2014.

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 2014 are presented in Figure 5-3. The activity concentrations in these samples were in the range from below detection limit to 201 mBq kg^{-1}, 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 2014 is observed. The measurements from 2013 and 2014 are below the detection limit.

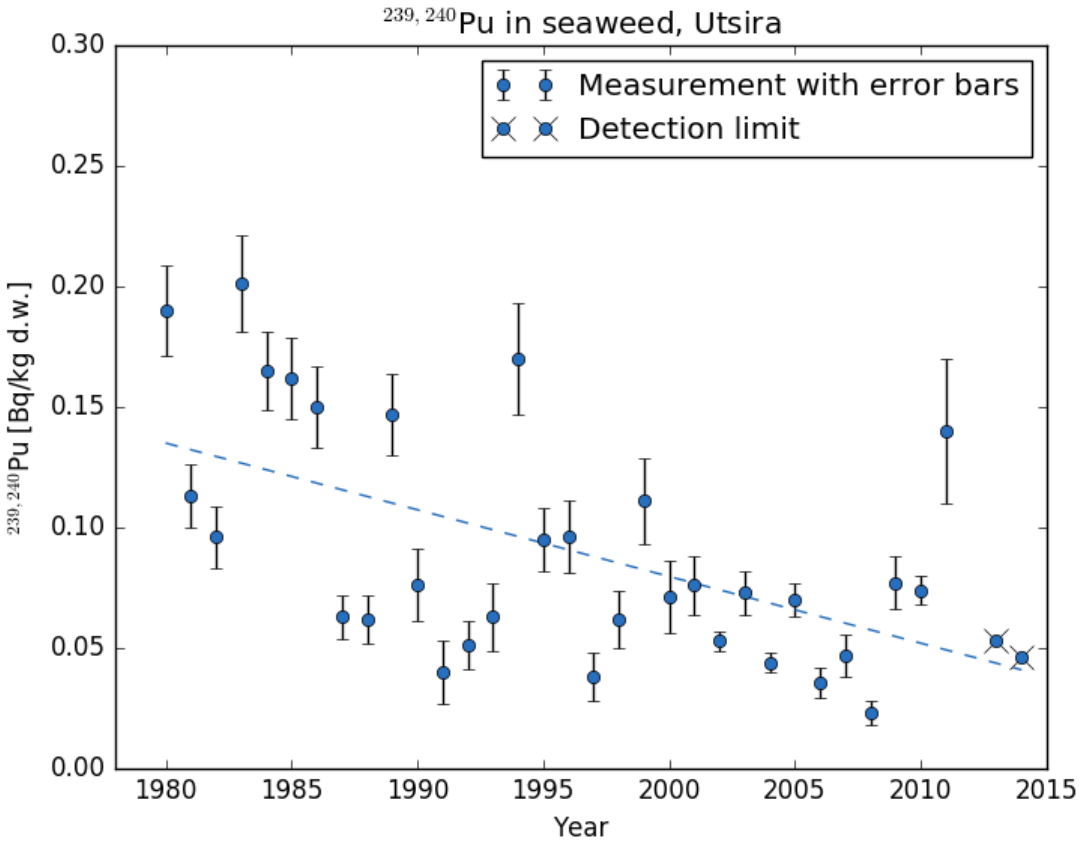


Figure 5-3 $^{239+240}$Pu levels (Bq kg^{-1} d.w.) in Fucus vesiculosus at Utsira in the period 1980 to 2014 (data provided by IFE). No sampling in 2012, measurements in 2013 and 2014 are below the detection limit.

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 brown algae 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 [13].

In 2012, 2013 and 2014, samples of *Fucus vesiculosus* from the permanent coastal stations were analysed with respect to ^{137}Cs. The results are presented in Figure 5-4, and ranged from 0.17 Bq kg^{-1} (d.w.) to 3.2 Bq kg^{-1} (d.w.).

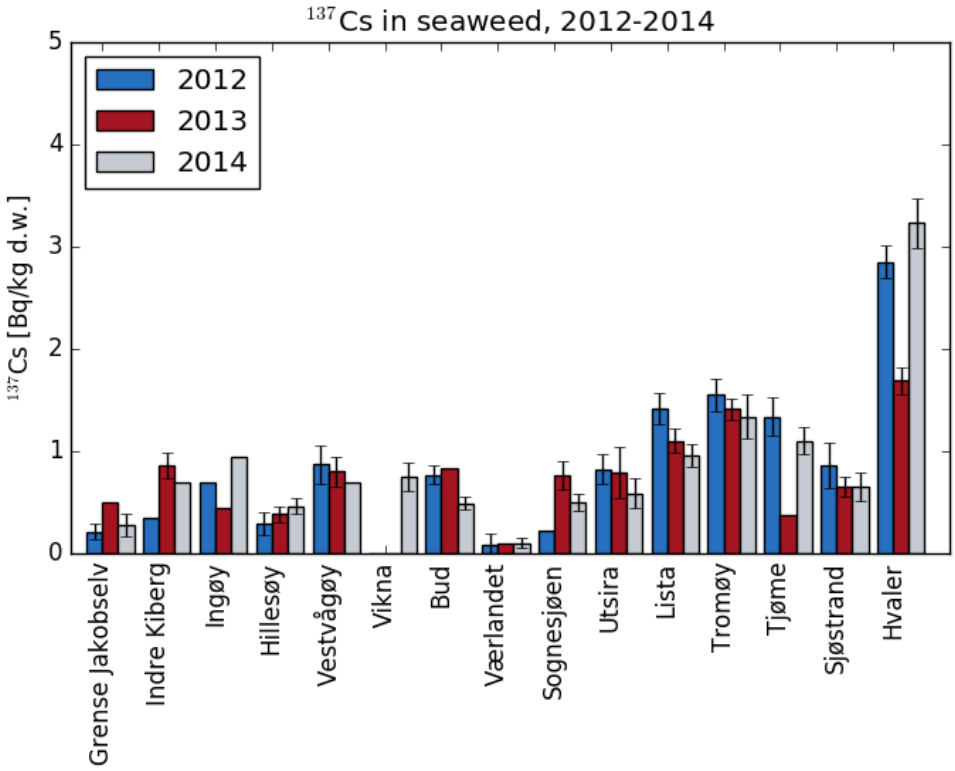


Figure 5-4 Levels of ^{137}Cs (Bq kg^{-1} d.w.) in Fucus vesiculosus sampled along the Norwegian coastline in 2012-2014. Detection limit is shown for measurements below level of detection, without errorbars. Mean values are presented for Hillesøy and Utsira.

A reason for the higher activity concentration in *Fucus vesiculosus* in the southern part of Norway is due to a higher activity concentration of ^{137}Cs in the outflowing Baltic seawater contaminated by the Chernobyl accident.

Comparing the results with the levels found at the coastal sampling stations in the period 2000-2010, the activity concentration of ^{137}Cs in *Fucus vesiculosus* has been relatively stable in recent years. However, data from frequent sampling at Utsira (Figure 5-5) show that the activity concentration of ^{137}Cs has been slowly decreasing in seaweed. This is in agreement with the reported temporal trend of ^{137}Cs in Baltic Sea seawater [7].

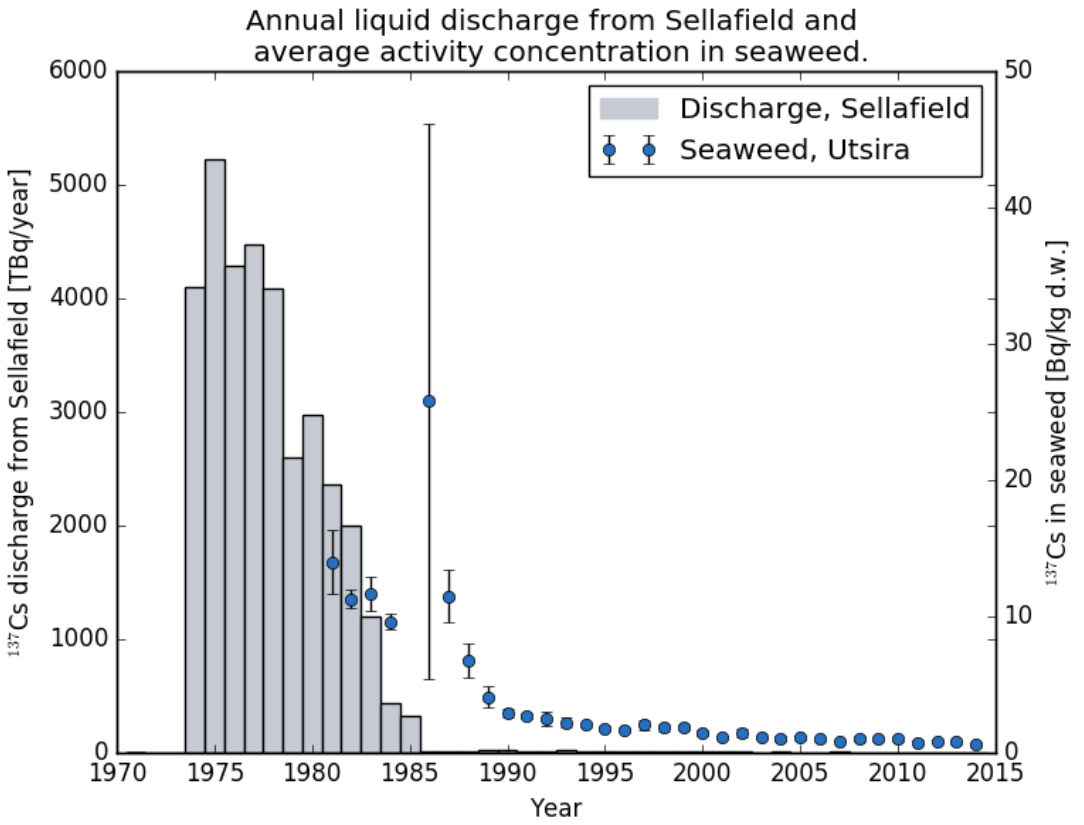


Figure 5-5 Annual liquid discharge of ^{137}Cs from Sellafield and average activity concentration (Bq kg^{-1} d.w.) from monthly sampling of seaweed (Fucus vesiculosus) from Utsira in the period 1980-2014 (data from IFE). The large variability in 1986 is due to the Chernobyl accident.

5.4 Caesium-137 in fish and crustaceans

Samples of cod from the Barents Sea have been analysed for ^{137}Cs since the early 1990s. In Figure 5-6, the activity concentration of ^{137}Cs in muscle tissue from cod caught in the Barents Sea is shown, and in Figure 5-7, levels of ^{137}Cs in cod caught off the coast of Finnmark is shown. All samples are below 1 Bq kg^{-1} (w.w.), and in recent years below 0.5 Bq kg^{-1} (w.w.). The results show a slightly decreasing trend in the period 1992-2014. This is as expected, and comparable to levels found in recent years [e.g. 1 and 8].

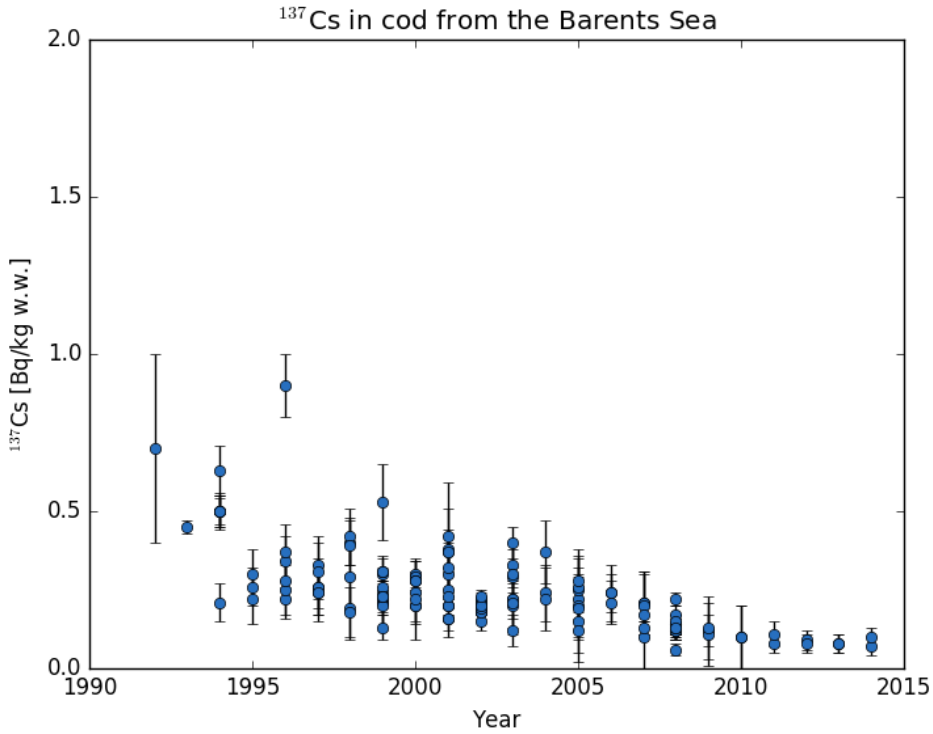


Figure 5-6 Activity concentration of 137Cs (Bq kg-1 w.w.) in cod from the Barents Sea (the area around Bjørnøya) sampled in the period 1992 to 2014.

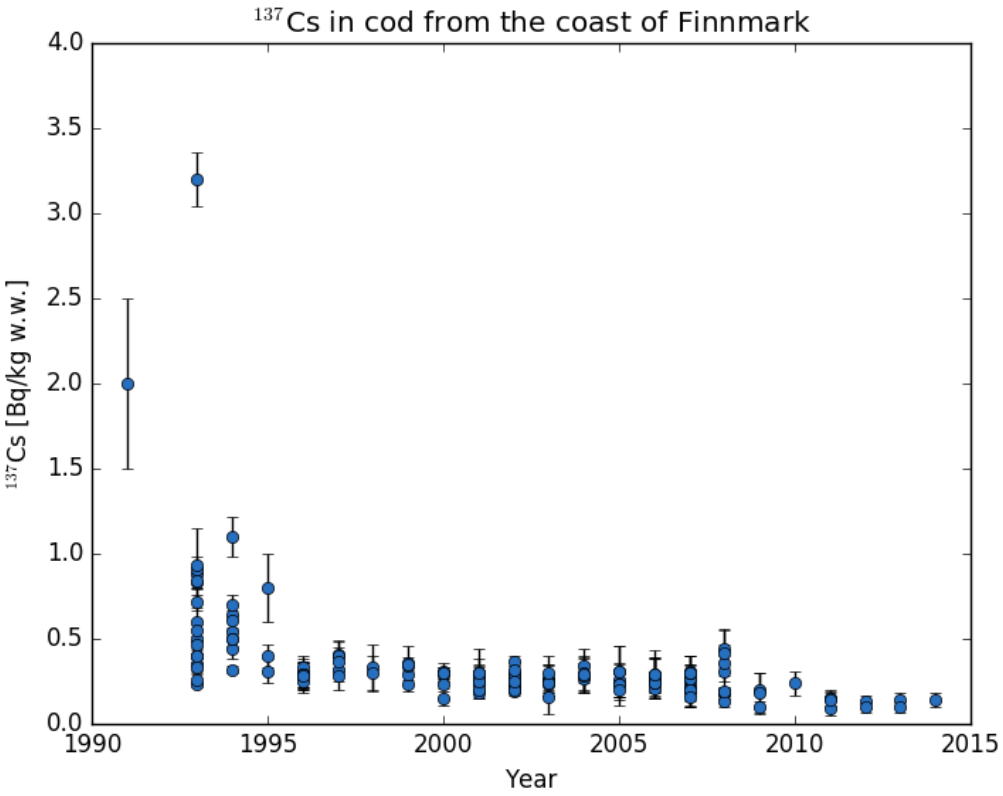


Figure 5-7 Activity concentration of 137Cs (Bq kg-1 w.w.) in cod from the coast of Finnmark sampled in the period 1992 to 2014.

Caesium-137 levels in fish species and crustaceans caught in Norwegian waters in 2012, 2013 and 2014 are shown in Table 5.1. All obtained results were below 1.3 ± 0.3 Bq kg^{-1} (w.w.).

*Table 5-1 Activity concentrations (Bq kg^{-1} 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 2012-2014. Samples from fjords are marked with *. Values are presented with measurement uncertainties.*

Species	**Latin name**	**^{137}Cs in muscle tissue (Bq/ kg w.w.) minimum**	**^{137}Cs in muscle tissue (Bq/ kg w.w.) maximum**	**Samples (total no. of individuals)**	**Location**
Blackmouth catshark	*Galeus melastomus*		0.4 ± 0.1	1(10)	North Sea
Blue whiting	*Micromesistius poutassou*		0.10 ± 0.03	1(25)	
Cod	*Gadus morhua*	0.2 ± 0.1	0.27 ± 0.08	4(82)	
Common dab	*Limanda limanda*		0.09 ± 0.03	1(25)	
Haddock	*Melanogrammus aeglefinus*	0.09 ± 0.03	0.12 ± 0.07	4(100)	

Herring	*Clupea harengus L.*	0.10 ± 0.11	0.19 ± 0.05	3(25)	
Mackerel	*Scomber scombrus*	0.09 ± 0.04	0.15 ± 0.04	3(75)	
Norway pout	*Trisopterus esmarkii*	<0.06	0.10 ± 0.07	2(50)	
Saithe	*Pollachius virens*	0.20 ± 0.10	0.28 ± 0.08	3(73)	
Spiny dogfish	*Squalus acanthias*		0.5 ± 0.1	1(7)	
Blackmouth catshark	*Galeus melastomus*		0.25 ± 0.09*	1(1)	Norwegian Sea
Blue whiting	*Micromesistius poutassou*	0.05 ± 0.03	0.14 ± 0.09	9(214)	
Cod	*Gadus morhua*	<0.2	1.0 ± 0.3*	9(127)	
Common ling	*Molva molva*		0.3 ± 0.1	1(2)	
Cusk	*Brosme brosme*	0.17 ±0.05	0.27 ± 0.07	6(163)	
European sprat	*Sprattus sprattus*		0.3 ± 0.1*	1(24)	
Greater forkbeard	*Phycis blennoides*		0.23 ± 0.09	1(25)	
Greenland halibut	*Reinhardtius hippoglossoides*	0.1 ±0.1	0.25 ± 0.09	17(250)	
Haddock	*Melanogrammus aeglefinus*	0.07 ± 0.05	0.6 ± 0.2*	4(57)	
Herring smelt	*Argentina sphyraena*		0.23 ± 0.06*	1(52)	
Mackerel	*Scomber scombrus*	0.11 ± 0.03	0.4 ± 0.1*	2(26)	
Norway redfish	*Sebastes viviparus*		0.10 ±0.06	1(25)	
Rabbit fish	*Chimaera monstrosa*		<0.04*	1(1)	
Redfish	*Sebastes norvegicus*	0.15 ±0.04	0.5 ± 0.2*	3(65)	
Saithe	*Pollachius virens*	0.19 ±0.05	0.24 ± 0.07	3(62)	
Shrimp	*Pandalus borealis*	0.1 ±0.1	0.2 ± 0.2*	4	
Velvet belly lanternshark	*Etmopterus spinax*		0.1 ± 0.1*	1(2)	
Whiting	*Merlangius merlangus*	0.3 ±0.1*	1.2 ± 0.3*	2(6)	

Witch flounder	*Glyptocephalus cynoglossus*	0.3 ±0.1*	1.3 ± 0.3*	3(14)	
American Plaice	*Hippoglossoides platessoides*	0.1 ±0.1	0.1 ± 0.1	2(48)	Barents Sea
Capelin	*Mallotus villosu*	0.03 ±0.02	0.1 ± 0.1	4	
Cod	*Gadus morhua*	0.07 ± 0.03	0.2 ± 0.1	18 (1318)	
Deepwater Redfish	*Sebastes mentella*		0.1 ± 0.1	1(25)	
Greenland Halibut	*Reinhardtius hippoglossoides*	0.1 ±0.1	0.14 ± 0.04	4(68)	
Haddock	*Melanogrammus aeglefinus*	0.1±0.1	0.2 ± 0.1	5(81)	
Herring	*Clupea harengus L.*	0.1 ±0.1	0.14 ± 0.03	2(49)	
Polar Cod	*Boreogadus saida*		<0.1	1	
Redfish	*Sebastes norvegicus*	<0.1	0.1 ± 0.1	3	
Saithe	*Pollachius virens*		0.2 ± 0.1	1(21)	
Shrimp	*Pandalus borealis*	0.02 ±0.03	<0.1	5	

Technetium-99 has been analysed in lobster (*Hommarus gammarus*) (muscle from tail and claws) from Værlandet since 2002. In the period from 2002 to 2014 the levels of ^{99}Tc in lobster have decreased due to the reduced discharge of ^{99}Tc from Sellafield.

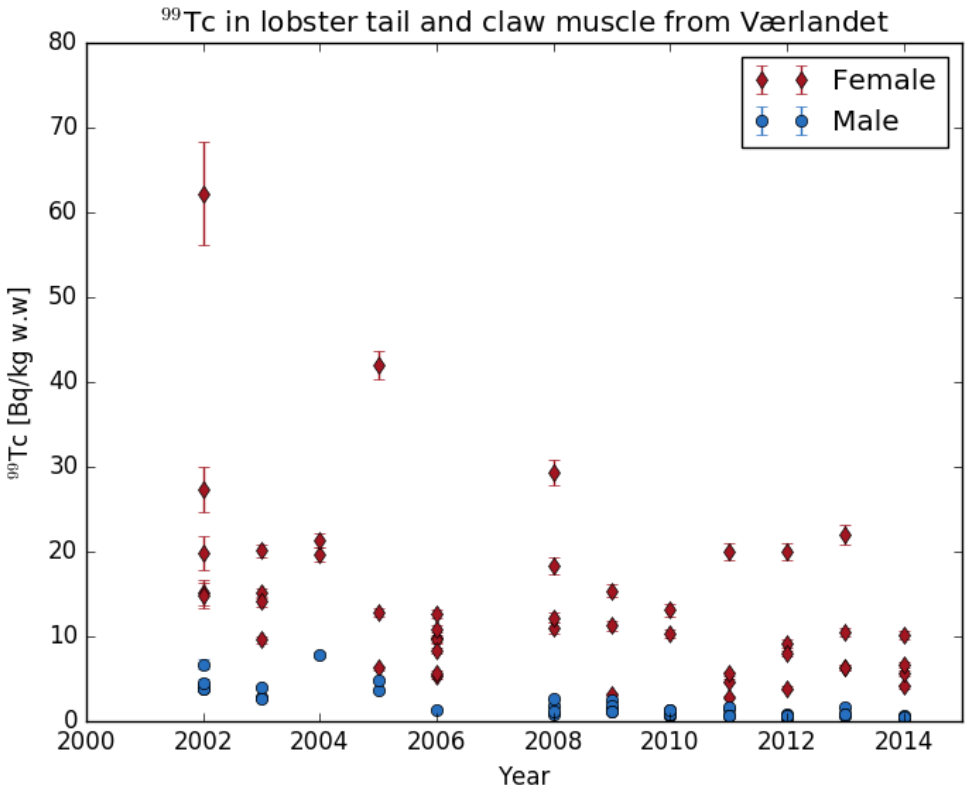


Figure 5-8 Technetium-99 concentration in lobster (Hommarus gammarus) from Værlandet (2002-2014).

6 Summary and conclusions

In 2012, 2013 and 2014, samples of seawater, sediment, and biota were collected in Norwegian waters, and at a number of 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 0.0074 µSv and 0.00012 µSv in 2013 and 2014, respectively, there was no liquid discharge in 2012. The annual dose from liquid discharges from IFE Halden was estimated to 0.0081 µSv, 0.0046 µSv and 0.0020 µSv in 2012, 2013 and 2014, 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 2012, 2013 and 2014 were 1.22 TBq ^{131}I, 1.10 TBq ^{131}I and 1.07 TBq ^{131}I, respectively.

Produced water from offshore oil production may contain enhanced levels of naturally occurring radium isotopes. In 2012 the discharged activity of ^{226}Ra and ^{228}Ra from the Norwegian oil and gas industry were reported to 437 GBq and 372 GBq, respectively. For 2013, 380 GBq ^{226}Ra and 326 GBq ^{228}Ra were discharged, and 402 GBq ^{226}Ra and 349 GBq ^{228}Ra were discharged in 2014.

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 contaminated Irish Sea sediments act as secondary sources of radionuclides to the Norwegian marine environment.

6.2 Radioactivity in seawater and sediment

In 2012, 2013 and 2014, samples of seawater and sediment were collected in Norwegian waters and analysed with respect to ^{137}Cs, ^{99}Tc, ^{90}Sr, ^{238}Pu, ^{239,240}Pu, ^{241}Am and ^{226}Ra. 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 Technetium-99 in seawater

Levels of ^{99}Tc in surface seawater ranged from below the detection limit to 0.56 Bq m^{-3}. The activity concentrations are significantly lower than the peak values observed in 1999/2000. The concentration of ^{99}Tc is approaching the same level as before the increase in discharges in 1994/1995.

6.2.2 Strontium-90 in seawater

The activity concentration in surface seawater sampled in Norwegian waters in 2012-2014 range from 0.78 Bq m^{-3} to 2.2 Bq m^{-3}. Data from Hillesøy and from Grense Jakobselv in the period 2002/2005 to 2014 indicates that the levels of ^{90}Sr are slowly decreasing in the Norwegian coastal current.

6.2.3 Caesium-137 in seawater

Observed levels of ^{137}Cs in surface seawater in Norwegian waters in 2012-2014 ranged from 1 Bq m^{-3} to 20 Bq m^{-3}. The highest levels were found in the Skagerrak. This is generally similar to previously observed concentrations. Data from Hillesøy and Grense Jakobselv also show that the levels of ^{137}Cs are slowly decreasing in the Norwegian coastal current.

6.2.4 Plutonium-238, plutonium-239, -240 and americium-241 in seawater

Levels of ^{239,240}Pu in the Norwegian waters in 2012-2014 ranged from 1.7 mBq m^{-} to 6 mBq m^{-3}, for plutonium-238 from below detection limit to 4.3 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 are low and comparable to previously observed levels.

6.2.5 Radium-226 in seawater

The activity concentration of ^{226}Ra observed in Norwegian waters in 2012, 2013 and 2014 were in the range of 0.29 to 2.8 Bq m^{-3} and comparable to previously observed concentrations.

6.3 Radioactivity in biota

6.3.1 Technetium-99 in seaweed

Samples of *Fucus vesiculosus* collected at the permanent coastal stations showed activity concentrations in the range 14 Bq kg^{-1} (d.w.) to 196 Bq kg^{-1} (d.w.). For most stations the levels were lower in 2014 compared to observed levels in the period 2002-2007. The levels in 2014 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 2012-2014 were in the range of 0.17 Bq kg^{-1} (d.w.) to 3.2 Bq kg^{-1} (d.w.), where the highest levels were found in the Skagerrak. 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

Different species of fish and crustaceans, commercially important and others, have been sampled in the Barents Sea, the Norwegian Sea and the North Sea. The activity concentration of ^{137}Cs in fish from Norwegian marine waters is generally low. All analysed samples were below 1.3 ± 0.3 Bq kg^{-1} (w.w.).

Samples of cod from the Barents Sea have been analysed for ^{137}Cs since the early 1990s. These results suggests a slightly decreasing trend of ^{137}Cs in this period.

7 References

1. NRPA. Radioactivity in the marine environment 2008 and 2009. Results from the Norwegian National Monitoring Programme (RAME). StrålevernRapport 2011:4. Østerås: Norwegian Radiation Protection Authority, 2011.
2. NRPA. Radioactivity in the marine environment 2010. Results from the Norwegian National Monitoring Programme (RAME). StrålevernRapport 2012:12. Østerås: Norwegian Radiation Protection Authority, 2012.
3. NRPA. Radioactivity in the marine environment 2011. Results from the Norwegian National Monitoring Programme (RAME). StrålevernRapport 2015:3. Østerås: Norwegian Radiation Protection Authority, 2015.
4. Discharges of Radionuclides from the Non-nuclear Sectors in 2012. OSPAR Commission. Publication Number: 637/2014
5. Discharges of Radionuclides from the Non-nuclear Sectors in 2013. OSPAR Commission. Publication Number: 661/2015
6. Annual report on discharges of radioactive substances from the non-nuclear sector in 2014. OSPAR Commission. Publication Number: 686/2016.
7. Ikäheimonen TK *et al*. Radioactivity in the Baltic Sea: inventories and temporal trends of ^{137}Cs and ^{90}Sr in water and sediments. Journal of Radioanalytical and Nuclear Chemistry. Vol. 282, No. 2, pp 419-425.
8. Gwynn et al. Radiological status of the marine environment in the Barents Sea. Journal of Environmental Radioactivity, 2012; 113: 155–162
9. NRPA. Radioactivity in the marine environment 2005. Results from the Norwegian National Monitoring Programme (RAME). StrålevernRapport 2007:10. Østerås: Norwegian Radiation Protection Authority, 2007.
10. NRPA. Radioactivity in the marine environment 2006. Results from the Norwegian National Monitoring Programme (RAME). StrålevernRapport 2008:14. Østerås: Norwegian Radiation Protection Authority, 2008.
11. Rudjord AL, Føyn L, Brungot AL, Kolstad AK, Heldal HE, Brown J, Iosjpe M, Christensen G. Radioactivity in the marine environment 1999. StrålevernRapport 2001:9. Østerås: Norwegian Radiation Protection Authority, 2001.
12. Gäfvert T, Føyn L, Brungot A L, Kolstad A K, Lind B, Christensen G C, Strålberg E, Drefvelin J, Rudjord A L. Radioactivity in the Marine Environment 2000 and 2001. Results from the Norwegian National Monitoring Programme (RAME). StrålevernRapport 2003:8. Østerås: Norwegian Radiation Protection Authority, 2003.
13. Carlsson L, Erlandsson B. Effects of salinity on the uptake of radionuclides by *Fucus vesiculosus* L. Journal of Environmental Radioactivity 1991; 13: 309-322.

Statens strålevern
Norwegian Radiation Protection Authority

2017

StrålevernRapport 2017:1
Årsrapport 2016

StrålevernRapport 2017:2
Ionising radiation metrology infrastructure in Europe

StrålevernRapport 2017:3
Radon i nye boliger

StrålevernRapport 2017:4
Stråledoser til øyelinsen for intervensjons-personell

StrålevernRapport 2017:5
Persondosimetritjenesten ved Statens strålevern

StrålevernRapport 2017:6
Faglige anbefalinger for strålebehandling ved ikke-småcellet lungekreft

StrålevernRapport 2017:7
Faglige anbefalinger for kurativ stråle-behandling ved småcellet lungecancer

StrålevernRapport 2017:8
Faglige anbefalinger for lindrende stråle-behandling ved lungecancer

StrålevernRapport 2017:9
Environmental Impact Assessment Of The Removal of Spent Nuclear Fuel (SNF) From Andreeva Bay

StrålevernRapport 2017:10
Radioaktivitet i norsk mat

StrålevernRapport 2017:11
Radioaktivitet i utmarksbeitende dyr 2016

StrålevernRapport 2017:12
Environmental modelling and radiological impact assessment associated with hypothetical accident scenarios for the Russian nuclear submarine K-159

StrålevernRapport 2017:13
Radioactivity in the Marine Environment 2012, 2013 and 2014

ISSN 1891-5191 (online)
ISSN 0804-4910 (print)