Distribution of Radioactive Caesium from the Fukushima Dai-ichi Nuclear Power Plant in Seabed Sediment from Offshore Niigata Prefecture and Yamagata Prefecture

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Seabed sediments were collected off the coast of Niigata Prefecture and Yamagata Prefecture and radioactivity was measured to identify the migration pathway of radioactive caesium from the Fukushima Dai-ichi Nuclear Power Plant. 134Cs from the Fukushima Dai-ichi Nuclear Power Plant was detected in seabed sediment from offshore Sakata and Kamo (0.16±0.03 to 0.68±0.02 Bq/kg), but was not detected in seabed sediment from offshore Naoetsu. The results suggest that the potential source is the region northeast of Naoetsu to Sakata, including the Agano and Mogami Rivers.

Key Words: Fukushima Dai-ichi Nuclear Power Plant Accident, Japan Sea, radioactive caesium, migration pathway, Tsushima warm current

1. Introduction

After the Fukushima Dai-ichi Nuclear Power Plant (FDNPP) accident in March 2011, aerial radioactivity surveys performed by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) indicated that the Agano River Basin and the Mogami River Basin were polluted with radioactive materials.1 The government of Niigata Prefecture also performed a radioactivity survey to investigate pollution by radioactive materials in the Agano River basin. 134Cs was detected in seabed sediment offshore of the Agano River mouth by surveys in August 2011.2 In June 2011, the Japan Coast Guard detected 3.14 Bq/kg 137Cs in surface seawater in the southwestern Sea of Okhotsk, and this was 2.18 Bq/kg greater than that in the previous year.3, 4 These surveys suggest that radioactive caesium derived from the FDNPP spread over the Japan Sea and the Sea of Okhotsk.

Relatively few marine radioactivity surveys have focused on the Japan Sea5, 6 and the Sea of Okhotsk compared with the Fukushima coastal sea area and the western North Pacific. However, interesting temporal variations of the 137Cs concentrations in surface waters are reported in Japan Sea, i.e., radioactive caesium concentrations gradually increased during 2013–2016.5, 6 In addition, it is not clear whether the radioactive materials migrated via ocean currents in the Japan Sea and the Sea
It has been reported that just after the FDNPP accident radioactive caesium migrated to the Japan Sea via atmosphere.\cite{7} Our research suggests that radioactive caesium migrated from the Japan Sea to the Soya Strait and the Notsuke Strait,\cite{8,9} although transport processes of the radioactive caesium in these sea areas are still unknown.

In the present study, we conducted radioactivity surveys of offshore Sakata, Kamo, and Naoetsu to clarify the sources and migration pathway of radioactive caesium. We discuss the potential sources of radioactive caesium in the sediment collected in areas northeast of Naoetsu to Sakata, including the Agano and Mogami Rivers.

2. Sampling and Measurements

2.1 Sampling

Seabed sediment was collected at offshore of Sakata Port in July 2015 and from the offshore Naoetsu Port and Kamo Port in August 2016. Fig. 1 shows the sea survey area and sampling points. These sampling areas are along the route of the Tsushima warm current, and this route is shown in Fig. 2. The Agano River Basin has the region where the deposition density of radioactive caesium from the FDNPP is relatively high. Seabed sediments were collected (∼3 L) at each sampling point using a Smith-Mcintyre grab sampler. Stones and visible benthic organisms in the seabed sediments were removed. Seabed sediment was dried at 95°C for more than 24 h and passed through a 2-mm sieve. Seabed sediment was put in a 2-L Marinelli vessel and radioactivity was measured.

2.2 Measurement of radioactive caesium

A germanium semiconductor detector (GEM40-76-XLB-C; Seiko EG&G Co., Ltd., Tokyo, Japan) was used to measure the radioactivity of the sample. The γ-radioactivity of seabed sediments was measured for 80,000 s. The concentrations of radioactive caesium were calculated according to MEXT manual,\cite{10} and the radioactivity was decay-corrected to the sampling date. The spectral peaks at 605 and 662 keV were used for analyses of $^{134}$Cs and $^{137}$Cs.
respectively. The detection limit was 0.1 Bq/kg.

2.3 Measurement of the grain size distribution

After obtaining radioactivity measurements, the grain size distribution of the seabed sediment was determined using sieves (dry method). Portions of dried sediment (30 g) were separated using 850-, 250-, and 75-µm sieves, and the seabed sediments were classified as coarse sand, medium sand, fine sand, and clay-silt. Sample isolation, sieving, and weighing were performed in duplicate for each sample. The average values were obtained and the grain size distribution was determined.

3. Results and discussion

3.1 Geological features of seabed sediment and radioactivity

In the offshore Sakata sampling area, the depth was 8.2–55.9 m and the deepest points were stations (Sts.) 14 and 16. The seafloor topography of offshore Sakata is slanted from the shoreline to the northwest. The seabed sediment is mainly composed of sand at offshore Sakata but also contains shells and stones. In the offshore Kamo sampling area, the depth is 13.2–79.7 m and the deepest point is St. 44. The seabed sediment is mainly composed of sand, and the seafloor topography of offshore Kamo is sloped from the shoreline to the northwest. In the offshore Naoetsu sampling area, the depth is 6.8–99.7 m and the deepest point is St. 39. The seafloor topography of offshore Naoetsu is slanted from the shoreline to the northwest. The seabed sediment is composed of mud, sand, shells, and stones at offshore Naoetsu. 

$^{134}$Cs was detected in the seabed sediment at four sampling points of offshore Sakata and at two sampling points of offshore Kamo; $^{134}$Cs was not detected in the seabed sediment at sampling points of offshore Naoetsu (Table 1). Therefore, the radioactive materials from the FDNPP may have migrated to offshore Sakata and Kamo. However, the radioactive

| Survey areas       | No  | Latitude       | Longitude       | Depth [m] | Sampling day | $^{134}$Cs [Bq/kg] | $^{137}$Cs [Bq/kg] |
|--------------------|-----|----------------|-----------------|-----------|--------------|-------------------|-------------------|
| Offshore Sakata    | St.10 | 38° 59' 06"  | 139° 50' 12"  | 8.2       | 13-Jul-15    | N.D               | 0.28 ± 0.04       |
|                    | St.11 | 38° 59' 18"  | 139° 48' 30"  | 26.8      | 13-Jul-15    | 0.32 ± 0.04       | 1.5 ± 0.1         |
|                    | St.12 | 38° 59' 30"  | 139° 47' 00"  | 44.7      | 13-Jul-15    | 0.68 ± 0.02       | 4.0 ± 0.1         |
|                    | St.13 | 39° 00' 06"  | 139° 45' 12"  | 53.6      | 13-Jul-15    | 0.16 ± 0.03       | 0.75 ± 0.04       |
|                    | St.14 | 39° 00' 18"  | 139° 43' 28"  | 55.9      | 13-Jul-15    | N.D               | 0.43 ± 0.04       |
|                    | St.15 | 38° 59' 59"  | 139° 43' 31"  | 55.5      | 13-Jul-15    | N.D               | 0.52 ± 0.16       |
|                    | St.16 | 38° 58' 23"  | 139° 44' 24"  | 55.9      | 13-Jul-15    | N.D               | 0.86 ± 0.04       |
|                    | St.17 | 38° 58' 12"  | 139° 46' 18"  | 45.7      | 13-Jul-15    | 0.64 ± 0.05       | 3.8 ± 0.1         |
|                    | St.18 | 38° 58' 00"  | 139° 48' 14"  | 22.4      | 13-Jul-15    | N.D               | 2.5 ± 0.3         |
| Offshore Kamo      | St.40 | 38° 45' 46"  | 139° 43' 58"  | 13.2      | 6-Aug-16     | 0.61 ± 0.06       | 4.7 ± 0.1         |
|                    | St.41 | 38° 46' 22"  | 139° 43' 27"  | 17        | 6-Aug-16     | N.D               | 0.49 ± 0.04       |
|                    | St.42 | 38° 46' 55"  | 139° 41' 27"  | 39.6      | 6-Aug-16     | N.D               | 0.29 ± 0.03       |
|                    | St.43 | 38° 48' 02"  | 139° 37' 48"  | 59.6      | 6-Aug-16     | N.D               | 0.32 ± 0.04       |
|                    | St.44 | 38° 48' 32"  | 139° 36' 02"  | 79.7      | 6-Aug-16     | 0.33 ± 0.04       | 3.2 ± 0.1         |
| Offshore Naoetsu   | St.34 | 37° 14' 30"  | 138° 20' 01"  | 6.8       | 5-Aug-16     | N.D               | 0.13 ± 0.04       |
|                    | St.35 | 37° 15' 38"  | 138° 19' 16"  | 20.9      | 5-Aug-16     | N.D               | 0.19 ± 0.06       |
|                    | St.36 | 37° 15' 55"  | 138° 18' 18"  | 39.5      | 5-Aug-16     | N.D               | 0.52 ± 0.04       |
|                    | St.37 | 37° 17' 01"  | 138° 16' 53"  | 62.3      | 5-Aug-16     | N.D               | 0.97 ± 0.04       |
|                    | St.38 | 37° 17' 37"  | 138° 15' 54"  | 79.4      | 5-Aug-16     | N.D               | 1.1 ± 0.1         |
|                    | St.39 | 37° 18' 23"  | 138° 14' 42"  | 99.7      | 5-Aug-16     | N.D               | 0.96 ± 0.04       |

a) Radioactive caesium concentration was decay-corrected to the sampling date.

b) N.D.: Not detected. Measurement time was 80,000 s.
materials from the FDNPP probably did not affect the offshore area of Naoetsu. $^{137}$Cs was detected in all seabed sediment at offshore Kamo, Sakata, and Naoetsu, and the concentration was 0.13–4.7 Bq/kg. The maximum $^{137}$Cs concentration was detected in the seabed sediment from St. 40 in offshore Kamo. $^{134}$Cs was not detected in the seabed sediment at sampling points of offshore Naoetsu, suggesting that the seabed sediment in this area rarely contains $^{137}$Cs derived from the FDNPP.

### 3.2 Grain size distribution of seabed sediment

The grain size distribution of seabed sediment was investigated to clarify the relationship between the spatial distribution of radioactive caesium and the mineralogical properties of the sediment. There was a significant difference in the clay-silt and medium sand ratios between Fig. 3 (a) and (b); in particular, the clay-silt was only 0.1–6.0% in Fig. 3 (a), showing areas where $^{134}$Cs was not detected, and was 1.2–33.7% in Fig. 3 (b), where $^{134}$Cs was detected. In addition, the medium sand proportion was lower in Fig. 3 (b) than in Fig. 3 (a). The $^{134}$Cs and $^{137}$Cs concentrations increased proportionally with increasing portion of clay-silt in Fig. 3 (d). $^{134}$Cs was not detected in seabed sediment with a low content of clay-silt, but was detected in seabed sediment that contained clay-silt. This difference suggests that the particle size of seabed sediment is an important factor in the adsorption of radioactive caesium from the seawater to seabed sediment. In a previous survey, in ponds around the periphery of the FDNPP, sediment with small particle sizes adsorbed a large amount of $^{137}$Cs.14) Furthermore, another study indicated that radioactive caesium was adsorbed by clay and silt in river sediment, and there was little adsorption in sand.15) Therefore, radioactive caesium is adsorbed by clay-silt selectively in both fresh water and seawater. However, $^{134}$Cs was not detected in seabed soil that contained more than 20% clay-silt at St. 38–39 (Fig. 2 (c)), suggesting that the adsorption of radioactive caesium to clay-silt and/or the supply of clay-silt particles including radioactive caesium oc-

![Fig. 3 Grain size distributions in dry seabed sediment. Error bars are shown at the top of the bar graphs. (a): Seabed sediment where $^{134}$Cs was not detected at offshore Sakata and Kamo. (b): Seabed sediment where $^{134}$Cs was detected at offshore Sakata and Kamo. (c): Seabed sediment at offshore Naoetsu ($^{134}$Cs was not detected). (d): Relations between $^{134}$Cs, $^{137}$Cs concentration and Clay-Silt ratio.](image-url)
occurred between Naoetsu and Sakata.

3.3 Contribution of global fallout

Fig. 4 shows the relationship between $^{134}\text{Cs}$ and $^{137}\text{Cs}$ concentrations in seabed sediment at offshore Sakata, Kamo, and Naoetsu. The radioactive caesium concentration was decay-corrected to March 11, 2011. The radioactive caesium was released into the environment from nuclear reactors 1–3 at the FDNPP after the Great East Japan Earthquake.

The $^{134}\text{Cs}/^{137}\text{Cs}$ activity ratio when the FDNPP accident occurred was almost 1.6 and was similar for all three reactors.16) If both of $^{134}\text{Cs}$ and $^{137}\text{Cs}$ in the sediments were originating from the FDNPP accident, therefore, all plots should be present along the broken line indicating a ratio of 1. However, the $^{137}\text{Cs}$–$^{134}\text{Cs}$ plots were below the broken line in Fig. 4.

Table 2 shows the results for seabed sediment where $^{134}\text{Cs}$ was detected in the radioactivity survey. The sampling point at offshore Naoetsu is not listed because $^{134}\text{Cs}$ was not detected. The radioactive caesium concentration was decay-corrected to March 11, 2011. The $^{134}\text{Cs}/^{137}\text{Cs}$ ratios ranged from 0.56 to 0.83, as shown in Table 2, which are lower than the typical value (about 1) at the FDNPP. This can be explained by the $^{137}\text{Cs}$ from global fallout deposited on the seabed sediment in the survey sea area. The difference in the concentration between $^{137}\text{Cs}$ and $^{134}\text{Cs}$ ($^{137}\text{Cs}$–$^{134}\text{Cs}$) in Table 2 can be regarded as the estimated global fallout value. The differences between the $^{137}\text{Cs}$ concentration and the broken line at each data point are the estimated $^{137}\text{Cs}$ concentrations from global fallout, and were 0.14–1.60 Bq/kg.

In the radioactivity survey in 2010, the year before the Great East Japan Earthquake, the $^{137}\text{Cs}$ concentration in seabed sediment from global fallout was 0.6–5.6 Bq/kg in the sea near Japan,4) which is similar to the value obtained in the present study.

| Survey areas  | No. | $^{134}\text{Cs}$ [Bq/kg] | $^{137}\text{Cs}$ [Bq/kg] | $^{134}\text{Cs}/^{137}\text{Cs}$ [Bq/kg] | $^{137}\text{Cs}$–$^{134}\text{Cs}$ [Bq/kg] |
|---------------|-----|--------------------------|--------------------------|-----------------------------------|-----------------------------------|
| Offshore Sakata | St.11 | 1.37 ± 0.17 | 1.66 ± 0.05 | 0.83 ± 0.11 | 0.28 ± 0.17 |
|               | St.12 | 2.92 ± 0.18 | 4.42 ± 0.07 | 0.66 ± 0.04 | 1.50 ± 0.19 |
|               | St.13 | 0.69 ± 0.13 | 0.83 ± 0.04 | 0.83 ± 0.17 | 0.14 ± 0.14 |
|               | St.17 | 2.75 ± 0.19 | 4.20 ± 0.07 | 0.65 ± 0.05 | 1.45 ± 0.21 |
|               | St.40 | 3.75 ± 0.33 | 5.29 ± 0.11 | 0.71 ± 0.06 | 1.54 ± 0.34 |
| Offshore Kamo | St.44 | 2.03 ± 0.21 | 3.63 ± 0.06 | 0.56 ± 0.06 | 1.60 ± 0.22 |

a) The concentration of radioactive caesium was decay-corrected to March 11, 2011.
Seabed sediments at St. 11 and 13 were low in clay-silt, and the $^{134}$Cs and $^{137}$Cs concentrations were low. In contrast, the seabed sediments at St. 12, 17, 40, and 44 were mud and the $^{134}$Cs concentrations were higher than those at St. 11 and 13. The seabed sediment with small grain sizes also adsorbed a larger amount of the global fallout.

3.4 Migration of radioactive caesium from the FDNPP to the Japan Sea and offshore Sakata

Fig. 5 shows the relationship between the distance from the Agano River mouth to the sampling point and the radioactive caesium concentration in the seabed sediment for each sea area. The $^{134}$Cs and $^{137}$Cs concentrations were decay-corrected to the value on March 11, 2011. $^{134}$Cs concentrations of 3.75 and 2.92 Bq/kg were detected at the offshore Kamo (K) and offshore Sakata (S) sites, respectively. However, $^{134}$Cs was not detected at the offshore Naoetsu (N) site. Thus, the radioactive caesium from the FDNPP may not have reached offshore Naoetsu. The Niigata Prefecture government performed a radioactivity survey of seabed sediment at the offshore Agano River mouth in August 2011. The $^{134}$Cs concentration was 194 Bq/kg (decay-corrected to the value on March 11, 2011), which was greater than those of the offshore Kamo and Sakata sites. The $^{134}$Cs concentration in seabed sediment decreased in the order of offshore Kamo, offshore Sakata, and Ishikari Bay, which indicated that it decreased with increasing migration distance, assuming that $^{134}$Cs in seabed sediment of Agano river mouth was a source in the Japan Sea coastal areas of the East Honshu Island.

Naoetsu Port is approximately 240 km southwest from Sakata Port. In this area, there are several rivers, including the Agano and Mogami Rivers. In river sediments at the Agano river mouth, $^{134}$Cs of 50 Bq/kg was detected in May 2012. Additionally, 24 Bq/kg $^{134}$Cs in river sediment at the Mogami River mouth was detected in August 2012. From August to September 2011, MEXT performed aerial radioactivity surveys in Niigata Prefecture and found that the surface soil in Niigata Prefecture contained radioactive caesium from the FDNPP. The FDNPP-derived radioactive caesium dispersed in East Honshu Island and dominantly deposited in forest areas by rainfall. The deposited radioactive caesium migrated into river by rainwater. Radioactive caesium exists as dissolved and suspended forms in river water, and some of radioactive caesium in suspended matter may change dissolved form in the river mouth and the neighboring sea area. The radioactive caesium dissolved in seawater is transported by ocean currents, adsorbed by mineral particles, and settles to the seabed sediment and/or river suspended materials are transported by ocean currents.

Fig. 2 shows the Tsushima warm current and the Soya warm current. The Tsushima warm current flows north along the northwest coast to offshore Sakata from offshore Naoetsu. Radioactive caesium from the FDNPP was detected in seabed sediment at
the offshore Kamo and offshore Sakata sites, but was not detected in seabed sediment offshore Naoetsu. The results suggested that radioactive caesium is distributed from the FDNPP from northeast of Naoetsu to Sakata, including the Agano and Mogami Rivers, although we do not have concentration data in the Tsushima warm current. However, because elevated $^{134}$Cs was detected in surface seawater offshore Fukushima prefecture since 2013, we should also consider other pathways of $^{134}$Cs, i.e., effect of $^{134}$Cs advected by the Tsushima Current to seabed sediment.

4. Conclusion

We performed radioactivity surveys in seabed sediment from offshore Sakata, Kamo, and Naoetsu to identify the source and the migration pathway of radioactive caesium from the FDNPP in these offshore areas. $^{134}$Cs was detected in seabed sediment containing mud and sand at offshore Sakata and Kamo, which contained 1.2–33.7% clay-silt. There was a proportional relationship between the clay-silt proportion and radioactive caesium concentration. This result suggested that the particle size of the seabed sediment is an important determinant of the adsorption of radioactive caesium in seabed sediment. $^{134}$Cs was not detected in seabed sediment from offshore Naoetsu, even though seabed sediments contained more than 20% clay-silt, showing that the radioactive caesium from the FDNPP did not migrate to this area. The $^{134}$Cs concentration in seabed sediment decreased in the order of offshore Kamo, offshore Sakata, and Ishikari Bay. $^{137}$Cs from global fallout was detected at all sampling points in this survey, in which the concentrations were estimated to be 0.28–1.6 Bq/kg. Radioactive caesium from the FDNPP was detected in seabed sediment from offshore Kamo and Sakata, whereas it was not detected in seabed sediment from offshore Naoetsu. The present results suggest that a potential source of the FDNPP accident-derived radioactive caesium is located between the Naoetsu and Kamo/Sakata coastal areas. Major rivers flowing into these areas, such as the Agano and Mogami Rivers, are among the most likely sources.

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References

1) Nuclear Regulation Authority HP. http://radioactivity.nsr.go.jp/en/contents/4000/3179/24/1270_1216.pdf (Accessed Jan 4, 2017)
2) Habuki, H., Ishiyama, H., Yoko, T., Ono, T., et al., Research of radioactive caesium distribution around agano river downstream due to Fukushima Daiichi Nuclear Power Plant Accident, Radioisotopes, 62, 649–658 (2013)
3) Guard, J. C., Report of Radioactivity Surveys Results of Surveys in 2011, pp. 1–17, Japan Coast Guard, Tokyo (2013)
4) Guard, J. C., Report of Radioactivity Surveys Results of Surveys in 2010, pp. 1–16, Japan Coast Guard, Tokyo (2012)
5) Inoue, M., Shirotani, Y., Yamashita, T., Takata, H., et al., Temporal and spatial variations of $^{134}$Cs and $^{137}$Cs levels in the Sea of Japan and Pacific coastal region: Implications for dispersion of FDNPP-derived radiocesium, J. Environ. Radioact., 182, 142–150 (2018)
6) Takata, H., Kusakabe, M., Inatomi, N. and Ikenoue, T., Appearance of Fukushima Daiichi Nuclear Power Plant-Derived $^{137}$Cs in coastal waters around Japan: Results from marine monitoring off nuclear power plants and facilities, 1983–2016, Environ. Sci. Technol., 52, 2629–2637 (2018)
7) Inoue, M., Kofuji, H., Oikawa, S., Murakami, T., et al., Spatial variations of low levels of $^{134}$Cs and $^{137}$Cs in seawaters within the Japan Sea after the Fukushima Daiichi Nuclear Power Plant accident, Appl. Radiat. Isot., 81, 340–343 (2013)
8) Nabae, Y., Miyashita, S. and Nakashima, S., Observation of radiocaesium in seabed soil at the Notsuke Strait of the southern Okhotsk Sea derived from the Fukushima Daiichi Nuclear Power Plant, *Radiation Safety Management*, **15**, 9–15 (2016)

9) Nabae, Y., Miyashita, S. and Nakashima, S., Observation of radioactive caesium in seabed soil at the Soya Strait derived from the Fukushima Daiichi Nuclear Power Plant, *Radiation Safety Management*, **16**, 8–12 (2016)

10) Japan Chemical Analysis Center HP. http://www.kankyo-hoshano.go.jp/series/main_pdf_series_7.html (Accessed Nov 27, 2016)

11) Tsujimoto, M., Miyashita, S. and Nakashima, S., Acorrelation between the transfer factor of radioactive caesium from soil into rice plants and the grain size distribution of paddy soil in Fukushima, *Radiation Safety Management*, **15**, 1–8 (2016)

12) Japan Coast Guard, Nautical Chart W145 NIGATA KO TO OGA HANTO, Japan Coast Guard, Tokyo (2011)

13) Japan Coast Guard, Nautical Chart W1180 SADO KAIYOK AND APPROACHES, Japan Coast Guard, Tokyo (2015)

14) Yoshimura, K., Onda, Y. and Fukushima, T., Sediment particle size and initial radiocaesium accumulation in ponds following the Fukushima DNPP accident, *Sci. Rep.*, **4**, 4514 (2014)

15) Tabayashi, Y. and Yamamura, M., Relationship between particle size and the radioactive caesium concentration in sediments from rivers flowing into Lake Kasumigaura Japanese, *J. Limnol.*, **74**, 183–189 (2013), in Japanese

16) Komori, M., Shozugawa, K., Nogawa, N. and Mat-suo, M., Evaluation of radioactive contamination caused by each plant of Fukushima Dai-ichi Nuclear Power Station using $^{134}\text{Cs}/^{137}\text{Cs}$ activity ratio as an index, *Bunseki Kagaku*, **62**, 475–483 (2013), in Japanese

17) Iijima, K., Status of the researches on the behavior in the environment of radioactive caesium transported from forests to river systems, *Geochemistry*, **49**, 203–215 (2015)

18) Tagami, K. and Uchida, S., Sediment-seawater distribution coefficient for radionuclides and estimation of radionuclide desorption ratio from soil in seawater, *Bunseki Kagaku*, **62**, 527–533 (2013), in Japanese

19) Honda, M., Observational study of artificial radionuclides emitted from the nuclear power plant accident by using time-series sediment trap, *Geochemistry*, **49**, 227–238 (2015), in Japanese

20) Inoue, M., Uemura, H., Kofuji, H., Fujimoto, K., et al., Spatial variation in low-level $^{134}$Cs in the coastal sediments off central Honshu in the Sea of Japan: implications for delivery, migration, and redistribution patterns., *J. Oceanogr.*, **73**, 571–584 (2017)

21) Tsuruta, T., Harada, H., Misonou, T. and Matsuoka, T., Hodotsuka, Horizontal and vertical distributions of $^{137}$Cs in seabed sediments around the river mouth near Fukushima Daiichi Nuclear Power Plant., *J. Oceanogr.*, **73**, 547–558 (2017)

22) Guard, J. C., Sailing Directions for South and East Coasts of Honshu, pp. 6–9, Japan Hydrographic Association, Tokyo (2015)

23) Guard, J. C., Report of Radioactivity Surveys Results of Surveys in 2012, pp. 15–22, Japan Coast Guard, Tokyo (2014)
要　旨

新潟および山形県沖における福島第一原子力発電所に由来する海底土中の放射性セシウムの分布

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福島第一原子力発電所（FDNPP）からの放射性セシウムの移行経路を同定するため、新潟及び山形県の沖合において海底土を採取し、放射能を測定した。福島第一原子力発電所に由来する$^{134}$Csは酒田沖及び加茂沖の海底土から検出（0.16±0.03 – 0.68±0.02 Bq/kg）されたが、直江津沖の海底土からは検出されなかった。これらの結果より、FDNPP事故由来の放射性セシウムの流出源が直江津の北東地域から阿賀野、最上川を含む酒田までの地域である可能性が示唆された。