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Monitoring ^{137}Cs and ^{134}Cs at marine coasts in Indonesia between 2011 and 2013

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ABSTRACT

Environmental samples (seawater, sediments and biota) were collected along the eastern and western Indonesian coasts between 2011 and 2013 to anticipate the possible impacts of the Fukushima radioactive releases in Indonesia. On the eastern coasts (south and north Sulawesi), the ^{137}Cs concentrations in the seawater and sediments were 0.12–0.32 Bq m^{-3} and 0.10–1.03 Bq kg^{-1}, respectively. On the western coasts (West Sumatra, Bangka Island, North Java, South Java and Madura island), the ^{137}Cs concentrations in the seawater and sediments were 0.12–0.66 Bq m^{-3} and 0.19–1.64 Bq kg^{-1}, respectively. In general, the ^{137}Cs concentrations in the fish from several Indonesian coasts were <MDA – 109.75 mBq kg^{-1}. In contrast, the ^{137}Cs concentrations in mollusk, crab and prawn were 10.65–38.78, 4.02 and 6.16 mBq kg^{-1}, respectively. ^{134}Cs was not detected in the seawater, sediments or biota. Thus, it was concluded that ^{137}Cs on the eastern and western Indonesian coasts originated from global fallout.

1. Introduction

Following the Eastern Japanese Earthquake and following the tsunami that occurred on March 11, 2011, the Fukushima Dai-ichi Nuclear Power Plant (1F NPP) of the Tokyo Electric Power Company (TEPCO) was damaged and released ^{137}Cs and ^{134}Cs radionuclides into the surrounding areas (Maderich et al., 2013). The total amounts of ^{137}Cs that were directly released into the sea were estimated to equal up to 27 ± 15 PBq (Bailly du Bois et al., 2011). Tsumune et al. (2012) estimated that 160 PBq 131I and 15 PBq of ^{137}Cs were discharged into the atmosphere from the 1F NPP reactors (No. 1, No. 2 and No. 3). Steinhauser et al. (2014) estimated that more than 80% of the atmospherically released ^{137}Cs entered the atmosphere offshore from Fukushima, followed by deposition in the Pacific Ocean.

Due to their chemical properties, the ^{137}Cs radionuclides can be soluble in seawater, which allows them to spread over long distances by marine currents and dissipate throughout the oceanic water masses (Povinec et al., 2004). Oceanic currents (e.g., the Oyashio and Kuroshio currents) will transport radionuclides quickly from the western North Pacific Coast off Japan and undergo advection and mixing (Bu et al., 2013). Pacific water that is transferred into the Indian Ocean through this association is well known as Indonesian Through Flow (ITF) (Sprintall et al., 2009). Thus, the ^{137}Cs and ^{134}Cs radionuclides potentially entered the Indonesian sea from Fukushima through ITF.

In response to the Japan Fukushima Daiichi nuclear accident, the Indonesia National Nuclear Energy Agency (BATAN) conducted an intensified marine environmental radioactivity-monitoring program. Between 2011 and 2013, monitoring was conducted in some Indonesian estuaries and coastal waters to anticipate the possible impacts of the Fukushima radioactive releases on the Indonesian coastal area. In contrast, Indonesia has followed the IAEA RAS/7/021 Project on the marine benchmark study regarding the possible impacts of the Fukushima radioactive release on Asian Pacific regions. ^{137}Cs data must be obtained for the Indonesian marine environment to evaluate the extent and possible impacts in Asian Pacific Regions. Several samples, including surface coastal water, sediments and local biota (fish, mollusk and crustacean) samples, were collected between 2011 and 2013.

2. Methods

2.1. Study area

In the present study, sediment samples were collected from various sites of the some Indonesian coastal areas, including West Sumatra, Bangka Island, North and South Java, Madura Island, and north and south Sulawesi. Biota samples were only collected from

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Bangka Island Padang and the Java Sea. The sampling locations are shown in Fig. 1. Surface water and sediment samples were collected at points that were approximately 1 km off the coast.

Biota samples (fish, shellfish, and crustacean) were bought directly from fish market landings at local harborsides and were stored frozen (−20 °C) after pooling several specimens into one sample. Before the radioactivity measurement, each biota sample (wet weights ranged from 1 to 5 kg, or less in the case of benthos) was prepared by drying in a laboratory oven for 2 days at 110 °C. The samples were ashed in a large furnace with a maximum temperature of 400 °C. After cooling, the ash was transferred to a 7 cm polyethylene container. The activities of the cesium radionuclides (^{134}Cs and ^{137}Cs) were determined using a gamma spectrometer.

Sediment samples were collected with a grab sampler. The samples were dried, homogenized and transferred to plastic containers. Approximately 200 l of the marine water samples were taken from each station before placing into a PVC container. Nearly 10 g of copper(II) nitrate salt was added to the marine water sample and the mixture was stirred until it was homogeneous. Next, 10 g of potassium hexacyanoferrates(II) trihydrate was added and the solution was stirred until red-brownish complexes of copper hexacyanoferrates(II) appeared. The adsorption of cesium onto copper hexacyanoferrates(II) was completed by using sufficient stirring. Next, the precipitate was allowed to settle for 24 h. Then, the precipitate was separated from the marine water sample before washing twice or three times with distilled water and decanting the supernatant solution following centrifugation. The precipitate was dried in a laboratory oven for 1–2 days at 60 °C. This water preparation method was conducted according to the procedures described by Wo and Ahmad (2004), with minor modifications.

Radiocesium (^{137}Cs and ^{134}Cs) was measured using gamma counting at photopeaks of 661 keV and 953.8 keV, respectively. We used 3 HPGe detectors with counting efficiencies of 20–25% and FWHM 1.8 keV for a peak ^{60}Co of 1332 keV. The measurement time for each sample was 259,200–345,600 s. Canberra type GX 2018, Canberra type GC 2020 and Ortex type GMX 25P4-76 gamma spectrometers were used. The measurement method included detector calibration, the determination of the detector counting efficiency, the cumulative counts of the samples and background at regular intervals, smoothing of the photopeak and linear regression. MDA (Bq/kg) is commonly used to evaluate the measurement sensitivity and limit detection concentrations of radiocesium, MDA (Bq/kg). The MDA calculation is derived from the following formula

$$\mathrm{MDA} = \frac{2.71 + 4.65\sqrt{B}}{tmEY}, \tag{1}$$

where B is background count at the peak energy of interest, t is the counting time (s), m is the sample mass, E is the detector efficiency at the energy and geometry of interest, and Y is the effective yield at the energy. All reported activities were decay-corrected to the year 2012 using a half-life of 30.07 years.

3. Results and discussion

Atmospheric and coastal waters of the NW Pacific Ocean received large quantities of radioactive materials that were released from the nuclear accident at the Fukushima Dai-ichi nuclear power plant (NPP). Furthermore, the contaminated water that was directly discharged into the marine environment resulted in significantly elevated radionuclide concentrations in the coastal seawater (Povinec et al., 2013). The dissolved radionuclides, such as radiocesium (^{137}Cs or ^{134}Cs) can be transported by tidal currents, wind-driven or by dispersion. Most of the radiocesium remains in the surface or near-surface layers and its concentration decreases considerably with depth beginning at approximately 1000 m (Duran et al., 2004). Seawater that contains radioactive materials was transported by the Kuroshio current from the eastern coast of Japan to the north and entered the Pacific Ocean (Maderich et al., 2013). You et al. (2005) explained that the Kuroshio branch within the East/Japan sea transports North Pacific Intermediate Water (NPIW). Therefore, the global ocean circulation is affected by the Mindanao Current and the Indonesian Through Flow (ITF). The upper thermocline of the North Pacific water is a major part of the ITF that is transported from the Mindanao Current into the Indonesian Sea through the Makassar Strait (Ding et al., 2013; Sprintall et al., 2009). Seawater from ITF that enters into Indonesian marine water area could distribute ^{137}Cs from the Fukushima release.

The ^{137}Cs concentrations that were observed in the surface waters and sediments on some Indonesian coasts that have been monitored in the west and east are presented in Table 1. As

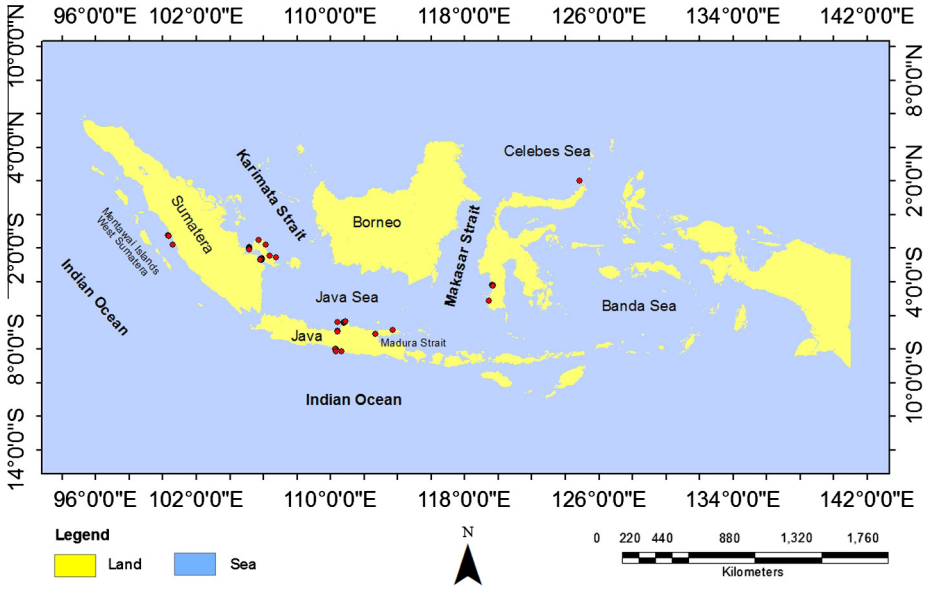

Fig. 1. Sampling locations.

Table 1
The concentration of ^{137}Cs in marine surface water and marine sediment at some Indonesia coastal (western to eastern).

Sampling date	Location	Coordinate	Concentration ^{137}Cs	
			Seawater (Bq m^{-3})	Sediment (Bq kg^{-1})
20 June 2011	West Bangka	105°07.325′E 02°03.991′S	0.15 ± 0.02	0.45 ± 0.10
20 June 2011	West Bangka	105°07.040′E 01°57.369′S	0.60 ± 0.04	0.30 ± 0.09
20 June 2011	West Bangka	105°06.334′E 02°00.508′S	0.49 ± 0.05	0.30 ± 0.08
20 June 2011	West Bangka	105°06.425′E 02°02.402′S	0.57 ± 0.06	0.48 ± 0.12
20 June 2011	West Bangka	105°07.696′E 02°05.159′S	0.66 ± 0.08	1.33 ± 0.41
19 August 2011	South Bangka	105°53.600′E 02°39.600′S	0.13 ± 0.02	0.19 ± 0.06
19 August 2011	South Bangka	105°42.300′E 01°31.700′S	0.26 ± 0.02	0.92 ± 0.28
19 August 2011	South Bangka	106°06.900′E 01°47.900′S	0.24 ± 0.05	0.24 + 0.07
19 August 2011	South Bangka	105°53.000′E 02°39.300′S	0.11 ± 0.02	0.66 ± 0.09
2 March 2012	South Bangka	106°42.500′E 02°32.300′S	0.13 ± 0.02	0.32 ± 0.09
2 March 2012	South Bangka	106°20.000′E 02°26.000′S	0.16 ± 0.02	0.36 ± 0.10
2 November 2011	Parepare, South Sulawesi	119°36.9′E 04°11.533′S	0.13 ± 0.02	0.72 ± 0.11
2 November 2011	Parepare, South Sulawesi	119°37.000′E 04°11.167′S	0.22 ± 0.02	0.81 ± 0.13
2 November 2011	Parepare, South Sulawesi	119°36.533′E 04°16.533′S	0.32 ± 0.03	1.03 ± 0.15
22 March 2012	West Sumatra	100°25.590′E 01°14.529′S	0.12 ± 0.02	0.35 ± 0.07
22 March 2012	West Sumatra	100°26.333′E 01°15.424′S	0.12 ± 0.02	0.35 ± 0.08
22 March 2012	West Sumatra	100°45.214′E 01°46.666′S	0.12 ± 0.02	0.26 ± 0.07
22 March 2012	West Sumatra	100°26.333′E 01°15.424′S	0.12 ± 0.02	0.35 ± 0.08
9 March 2012	Makassar, South Sulawesi	119°24.300′E 05°08.900′S	0.18 ± 0.02	0.58 ± 0.11
9 March 2012	Makassar, South Sulawesi	119°24.300′E 05°08.800′S	0.27 ± 0.03	0.59 ± 0.10
2 June 2012	Semarang, Java sea	110°23.67′E 06°56.76′S	0.11 ± 0.02	0.65 ± 0.24
2 June 2012	Semarang, Java sea	110°23.4′E 06°56.46′S	0.12 ± 0.02	0.69 ± 0.23
2 June 2012	Semarang, Java sea	110°23.56′E 06°56.65′S	0.14 ± 0.02	1.10 ± 0.23
2 June 2012	Semarang, Java sea	110°23.3′E 06°56.25′S	0.12 ± 0.02	0.72 ± 0.27
7 June 2012	Madura Java sea	113°39.75′E 06°53′S	0.11 ± 0.02	1.21 ± 0.32
7 June 2012	Madura Java sea	113°39.9′E 06°53′S	0.11 ± 0.02	0.66 ± 0.15
7 June 2012	Madura Java sea	113°40.16′E 06°52.96′S	0.11 ± 0.02	1.75 ± 0.27
3 September 2012	Manado, North Sulawesi	124°50.09′E 01°29.28′N	0.31 ± 0.03	0.23 ± 0.05
3 September 2012	Manado, North Sulawesi	124°50.371′E 01°29.986′N	0.18 ± 0.02	0.10 ± 0.02
3 September 2012	Manado, North Sulawesi	124°50.514′E 01°30.428′N	0.14 ± 0.02	0.16 ± 0.06
3 September 2012	Manado, North Sulawesi	124°48.186′E 01°27.618′N	0.12 ± 0.02	0.21 ± 0.02
17 April 2013	South Bangka	105°53.66′E 02°36.81′S	0.27 ± 0.02	0.32 ± 0.02
17 April 2013	South Bangka	105°53.10′E 02°35.68′S	0.18 ± 0.02	0.20 ± 0.02
17 April 2013	South Bangka	105°52.69′E 02°36.24′S	0.17 ± 0.02	NA
17 April 2013	South Bangka	105°52.32′E 02°38.33′S	0.25 ± 0.02	NA
17 April 2013	South Bangka	105°50.24′E 02°38.4′S	0.20 ± 0.02	NA
17 April 2013	South Bangka	105°49.20′E 02°39.14′S	0.11 ± 0.02	NA
17 April 2013	South Bangka	105°48.35′E 02°39.9′ LS	0.48 ± 0.05	NA
17 April 2013	South Bangka	105°47.94′E 02°40.37′S	0.52 ± 0.06	NA
17 April 2013	South Bangka	105°47.17′E 02°40.8′S	0.27 ± 0.02	0.53 ± 0.07
17 April 2013	South Bangka	105°47.27′E 02°41.29′S	0.15 ± 0.02	0.22 ± 0.03
17 April 2013	South Bangka	105°48.06′E 02°41.64′S	0.24 ± 0.02	0.25 ± 0.03
17 April 2013	Jepara, Java Sea	110°45.00′E 06°25.48′S	0.21 ± 0.02	1.45 ± 0.15
17 April 2013	Jepara, Java Sea	110°46.00′E 06°23.37′S	0.25 ± 0.02	1.60 ± 0.16
17 April 2013	Jepara, Java Sea	110°47.00′E 06°23.06′S	0.22 ± 0.02	1.50 ± 0.15
17 April 2013	Jepara, Java Sea	110°48.00′E 06°23.01′S	0.19 ± 0.02	1.64 ± 0.17
17 April 2013	Jepara, Java Sea	110°49.00′E 06°23.19′S	0.20 ± 0.02	1.58 ± 0.16
17 April 2013	Jepara, Java Sea	110°51.07′E 06°22.59′S	0.23 ± 0.02	1.52 ± 0.16
28 June 2013	Jogjakarta, Indian ocean	110°17′ 34.1″E 8°0′49.4″S	0.12 ± 0.02	0.84 ± 0.05
28 June 2013	Jogjakarta, Indian ocean	110°15′ 56.1″E 8°0′14″S	0.12 ± 0.02	0.63 ± 0.03
28 June 2013	Jogjakarta, Indian ocean	110°36′ 44.1″E 8°8′1.22″S	0.13 ± 0.04	1.05 ± 0.09
28 June 2013	Jogjakarta, Indian ocean	110°17′ 34.1″E 8°9′1.22″S	0.14 ± 0.02	0.78 ± 0.06

NA: Not analysis.

observed from Table 1, the western and eastern coasts of Indonesia have been monitored in South and North Sulawesi. These monitoring areas are part of the Makassar Strait. Sampling at the Parepare coast in southern Sulawesi (119°E) was performed on November 2011. The ^{137}Cs concentrations in the seawater and sediments in these areas were 0.13–0.32 Bq m^{-3} and 0.72–1.03 Bq kg^{-1}, respectively. Sampling at Makasar-South Sulawesi (119°E) and Manado in northern Sulawesi (124°E) was performed in March 2012. The ^{137}Cs concentrations in the seawater and sediments in these areas were 0.12–0.31 Bq m^{-3} and 0.10–0.59 Bq kg^{-1}, respectively. In contrast, the MDA of both ^{137}Cs and ^{134}Cs were 0.03 Bq m^{-3}. All monitoring activities (November 2011 and March 2012) in these study areas were performed during a period of northwest monsoons, when the wind pushes down the warm seawater from the Pacific Ocean to the Indian Ocean. Sprintall et al. (2009) described that the Makassar strait received upper thermocline through surface waters from the western route of the North Pacific that passed through the Sulawesi Sea. There are 680 m deep Dewakang sills within the Makassar strait that only allow the upper thermocline water to enter the Banda sea via the eastward flow of the Flores sea, or flows to the shallow (300 m) Lombok Strait before exiting the Indian Ocean. At the "eastern" route, smaller contributions of the North Pacific surface water flow to the Maluku Sea and over the deeper (1940 m) sill of the Lifamatola Strait before entering the Banda Sea (Sprintall et al., 2009). Fukushima-derived radiocesium can be estimated by the presence of ^{134}Cs because this radionuclide provides information that can be used to estimate the Fukushima-derived radiocesium (Povinec et al., 2013). In this case, ^{134}Cs was not detected in the seawater or sediments in these areas.

As shown in Table 1, monitoring in western Indonesia covered West Sumatra (100°E), Bangka Island (105°E), North Java

(Semarang, Jepara, 110°E), the coast of the Indian Ocean – South Java (Yogyakarta, 110°E) and Madura (113°E). We choose these locations because they were all potentially impacted by the Fukushima Accident. Within the North Pacific, Kuroshio is the main western boundary current that flows into the Luzon Strait to the east and connects with the South China Sea (SCS) water. The Karimata, Gaspar and Bangka Straits and the Java Sea are connected with the SCS in the south (You et al., 2005). In contrast, West Sumatra and South Java are part of the Indian ocean. Along the southern shorelines of Java and Sumatra, currents are guided by the Indian Ocean waves. In addition, along the west coasts of New Guinea and Australia, the currents are guided by the Pacific Ocean waves. These processes are evident when considering the continuous regions with high correlations between the upper layer and the total transport (Potemra, 2005). Furthermore, Java seawater is originally transported from the west (South China Sea) and east (oceanic). Seasonal mass water movement in the Java Sea is related to the adjacent waters, such as the Flores Sea, South China Sea and Karimata Strait. The southeast monsoon water, with lower temperatures and more saline water, flows from the Flores Sea to the Java Sea. This saline water continuously passes through the Java Sea and the lower salinity water is not completely replaced by the current. Consequently, the higher density mass water will penetrate the Java Sea during this period. During the northwest monsoon, these phenomena are reverse and the less saline water from the West Java Sea is transported to the east. The salinity and density in the Java Sea are relatively lower (Sprintall et al., 2009; Duran et al., 2004; Qu et al., 2005).

Sampling at West Sumatra (100°E) was performed in March 2012. The results of this analysis indicated that the ^{137}Cs concentrations in the seawater and sediments were 0.12 Bq m^{-3} and 0.26–0.35 Bq kg^{-1}, respectively. In contrast, hand sampling at South Java (110°E) was performed on June 2013, and the result of the analysis indicated that the concentrations were 0.12–0.14 Bq m^{-3} (sea water) and 0.63–1.05 Bq kg^{-1}. The data from South Java and West Sumatra were comparable and ^{134}Cs was not detected at either location.

First, sampling at Bangka Strait was performed in June 2011 (West Bangka) and August 2011 (South Bangka). Sampling was conducted during the period of the southeast monsoon. The ^{137}Cs concentrations in the seawater and sediments on the coast of the West Bangka Strait were 0.15–0.66 Bq m^{-3} and 0.19–1.33 Bq kg^{-1}, respectively. On other hand, in South Bangka, the ^{137}Cs concentrations in the seawater and sediments were 0.11–0.26 Bq m^{-3} and 0.19–0.92 Bq kg^{-1}, respectively. The second sampling was performed in March 2012 in South Bangka. This sampling time occurred during the period of the northwest monsoon. The ^{137}Cs concentration in the seawater and sediments along the coast of the South Bangka Strait were 0.13–0.16 Bq m^{-3} and 0.32–0.36 Bq kg^{-1}, respectively. The third sampling was performed in April 2013 at South Bangka. This sampling was conducted during the period of the transition monsoon. The ^{137}Cs concentrations in the seawater and sediments on the coast of the South Bangka Strait were 0.16–0.27 Bq m^{-3} and 0.22–0.36 Bq kg^{-1}, respectively. All of the data from the monsoon period were comparable, and ^{134}Cs was not detected in either the seawater or sediments. The Java Sea (north of Java Island, 110°E) was monitored in June 2012 and April 2013. Both of these sampling periods occurred during the period of the southeast monsoon. The ^{137}Cs concentrations in the seawater and sediments were 0.11–0.25 Bq m^{-3} and 0.65–1.64 Bq kg^{-1}, respectively.

Generally the ^{137}Cs concentrations on the Indonesian coast (100°–124°E) were not directly affected by the Fukushima accident because ^{134}Cs was not detected in all of the sampling areas. Indonesian marine water originates from the Pacific Ocean. On other hand, the highest deposition of global fallout radionuclides into the ocean occurred in the Pacific Ocean (Povinec et al., 2013). Therefore, the radiocesium in the seawater will be detected for many years in this area. In addition, the ^{137}Cs concentration in the surface seawater of the Pacific Ocean was 1–2 Bq m^{-3} just before the FNPP1 accident, which is now incorporated with the Fukushima-derived ^{137}Cs (Bailly du Bois et al., 2011; Kumamoto et al., 2013). Similar quantities of ^{134}Cs were released from Fukushima and behave as ^{137}Cs. Therefore, this ^{134}Cs can be used as an indicator of late contamination (Steinhauser et al., 2014). The radioactive decay half times of ^{137}Cs and ^{134}Cs are different (20 and 30 years, respectively), and could be used to quantify the involvement of the Fukushima releases in the North Pacific surface waters by time labeling according to the water masses (Bailly du Bois et al., 2011). Water penetration in the North Pacific before June 2011 had an activity ratio of ^{134}Cs/^{137}Cs in the seawater samples that were close to 1, which undoubtedly indicated that the source of these radionuclides was the Fukushima accident (Povinec et al., 2013). Inoue et al. (2012) reported that the seawater that was taken from the southwestern Okhotsk Sea in Japan and the eastern region of the East China Sea have a ^{134}Cs/^{137}Cs activity ratio of approximately 1. The same result was reported by Kaeriyama et al. (2013), who indicated that most surface seawaters in the western and central portions of the North Pacific had ^{134}Cs/^{137}Cs activity ratios of approximately 1 after the Fukushima accident.

Relative to the data in South and East Asia, the result from Wo and Ahmad (2004) indicated that the ^{137}Cs concentrations in Malaysia were uniformly distributed from 2.33 to 5.00 Bq m^{-3} and from 1.76 to 4.76 Bq m^{-3} in the South China Sea and the Malacca Strait, respectively. The decay correction in 2014 indicated that the ^{137}Cs concentrations in the Malaysian marine area remain greater than our measurements. Kameník et al. (2013) reported that the average ^{137}Cs concentration on Aloha Hawaii after the Fukushima accident was 1.46 ± 0.06 Bq m^{-3}. Furthermore, the ^{137}Cs concentration in the Hawaii surface water (depth 24 m) was 1.53 ± 0.08 Bq m^{-3}. Sartandel et al. (2011) reported that the ^{137}Cs concentrations in the Coastal Marine environment of the Arabian sea were 0.71–0.91 Bq m^{-3}. Compared with the Hawaiian and Arabian Seas, the ^{137}Cs concentrations in the Indonesian coastal waters were very low. Unfortunately, no recent adequate ^{137}Cs data are available for Indonesia's marine environment before the Fukushima accident. Suseno and Umbara (2006) reported that the ^{137}Cs concentration in the marine surface water from Muria Peninsula Jepara was 1.34 Bq m^{-3}.

Radionuclides can accumulate in marine biota through aqueous and dietary exposure routes. Fish are a major source of nutrition and protein and are a potential carrier of radionuclides from aquatic environments to humans. Radiocesium can be concentrated in skeletal muscle; therefore fish from contaminated areas are an important pathway for human exposure (Malek et al., 2004). Some bivalve species, such as *Anadara granosa* (blood cockle), Asian moon scallop, and mud clam, are consumed as seafood in Indonesia. In addition, hand bivalves can accumulate multifarious contaminant and are resistant to contamination (O'Connor, 2002).

The radiocesium concentrations in marine organisms from the Indonesian coast are presented in Table 2. The safety of the seafood is a prime concern for the public worldwide, including Indonesia. Fish function as an integral element in the natural food web and in commercial food production for humans. Therefore, information regarding the radioactive contents of fish tissue is important for estimating the impacts and hazards of ionizing radiation (Zalewska and Suplin'ska, 2012). Cesium is present in the marine environment in the form of cations (Cs^+), and in fish, cesium is mainly accumulated in muscle tissues. Among the radiocesium, only ^{137}Cs was detected. However, the concentrations were not significantly different between the 4 sampling areas. The ^{137}Cs

Table 2
Concentration ^{137}Cs in marine biota.

Date	Location	Biota	^{137}Cs (mBq kg^{-1})
20 June 2011	West Bangka (105°E)	*Cat fish* (*Arius thalassinus*)	14.15 ± 1.51
20 June 2011	West Bangka (105°E)	Giant seaperch (*Lates calcarifer*)	62.09 ± 7.44
20 June 2011	West Bangka (105°E)	Narrow-barred Spanish mackerel (*Scomberomorus commerson*)	109.75 ± 15.32
20 June 2011	West Bangka (105°E)	Black crab (*Scylla sp*)	4.02 ± 0.37
20 June 2011	West Bangka (105°E)	Striped eel catfish (*Plotosus lineatus*)	36.53 ± 4.05
20 June 2011	West Bangka (105°E)	*Pawns* (*Penaeus merguiensis*)	6.16 ± 0.59
20 June 2011	West Bangka (105°E)	Redbelly Fusilier (*Caesio erythrogaster*)	8.95 ± 9.30
20 June 2011	West Bangka (105°E)	Blood cockle (*Anadara granosa*)	10.65 ± 1.12
20 June 2011	West Bangka (105°E)	Smallhead catfish (*Euristhmus microceps*)	4.68 ± 0.60
2 June 2012	Java sea (110°E)	Little tunny (*Euthynnus alletteratus*)	10 ± 1.11
2 June 2012	Java sea (110°E)	Blood cockle *Anadara granosa*	20 ± 1.92
22 March 2012	Padang (100°E)	Little tunny (*Euthynnus allecterates*)	55.84 ± 9.30
13 April 2013	South Bangka (105°E)	Spotted sicklefish (*Drepane punctata*)	53.67 ± 8.8
13 April 2013	South Bangka (105°E)	Bluespotted Stingray (*Dusyatis kuhlii*)	99.22 ± 12.1
13 April 2013	South Bangka (105°E)	Mud clam (*Polymeosda erosa*)	38.78 ± 8.5
13 April 2013	South Bangka (105°E)	Annularis Angelfish (*Pomacanthus annularis*)	86.52 ± 9.30
13 April 2013	South Bangka (105°E)	Asian moon scallop (*Amusium pleuronectes*)	<MDA

concentrations were very low, which indicated limited accumulation in the species studied. However, the ^{137}Cs appeared to be more available to *Scomberomorus commerson*, *Dasyatis kuhlii* and *Pomacanthus annularis*, with mean concentrations of 109.75, 99.22 and 86.52 mBq kg^{-1}, respectively. Generally, the ^{137}Cs concentrations that were found in fish from some Indonesian coasts were <MDA – 109.75 mBq kg^{-1}. On other hand, the ^{137}Cs concentrations found in mollusk, crab and prawn were 10.65–38.78, 4.02 and 6.16 mBq kg^{-1}, respectively.

4. Conclusions

On the eastern coasts of South and North Sulawesi, the ^{137}Cs concentrations in the seawater and sediments were 0.12–0.32 Bq m^{-3} and 0.10–1.03 Bq kg^{-1}, respectively. On the western coasts of West Sumatra, Bangka Island, North Java, South Java and Madura Island, the ^{137}Cs concentrations in the seawater and sediments were 0.12–0.66 Bq m^{-3} and 0.19–1.64 Bq kg^{-1}, respectively. In general, the ^{137}Cs concentrations that were found in fish from some Indonesia coasts were <MDA – 109.75 Bq kg^{-1}. In contrast, the ^{137}Cs concentrations in mollusk, crab and prawn were 10.65–38.78, 4.02 and 6.16 mBq kg^{-1} respectively. Furthermore, ^{134}Cs was not detected in the seawater, sediment or biota samples. Compared with other Asia Pacific regions, such as Hawaii and India, the concentrations of ^{137}Cs in the Indonesian coastal waters were very low. The Indonesian marine waters originated from the Pacific Ocean. Consequently, the ratio of ^{134}Cs/^{137}Cs should be the same as that of the Pacific Ocean. Soon after the F1-NPP accident, no ^{134}Cs was detected in samples that were collected from two locations in Hawaii (Pacific Ocean) between March 2011 and February 2013 (Kameník et al., 2013). Furthermore, the ratios of ^{134}Cs/^{137}Cs in the seawater from Japan and Hawaii were >1, which indicated these areas were influenced by global fallout. Based on these data, the ^{137}Cs on the eastern and western Indonesian coasts originated from global fallout.

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