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Full Length Research Paper

Total quantity of caesium radioisotopes in fish in the Fukushima-Ken Exclusive Economic Zone, Japan, in November 2012

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The Tokyo Electric Power Company Fukushima Dai-ichi nuclear power plant in Fukushima-Ken (Prefecture), Japan, was destroyed in March 2011 due to a massive earthquake (magnitude 9) centred offshore to the northeast of Honshu Island and the subsequent historic tsunami on 11 March 2011. Due to nuclear meltdown, damage to the buildings housing the reactors by hydrogen explosions, and the contamination of cooling water from the reactor cores, huge quantities of radioisotopes were emitted to the atmosphere and to the adjacent seawater. Fishing is currently prohibited off the coast of Fukushima-Ken because intermittent surveys have found that the majority of fishery products still contain radioisotope levels exceeding the Japanese Standard Value. However, the total amount of caesium radioisotopes in fish biomass in the Fukushima-Ken Exclusive Economic Zone (EEZ) has not yet been reported. The Tokyo University of Marine Science and Technology has measured radioisotope levels in fishery species off Iwaki-Shi (City), Fukushima-Ken (located south of the destroyed nuclear power plant), and these data can be used to estimate the total fish biomass and the quantity of caesium radioisotopes in fish in the Fukushima-Ken EEZ. On 22 to 23 November 2012, the estimated total fish biomass in the Fukushima-Ken EEZ was 91,150,218.79 kg and the estimated total quantities of Cs-134 and Cs-137 in fish were 4,879,259,657 Bq and 8,381,002,727 Bq, respectively.

Key words: Nuclear power plant, Exclusive Economic Zone (EEZ), radioisotope.

INTRODUCTION

The Tokyo Electric Power Company Fukushima Dai-ichi nuclear power plant, located in Futaba-Gun (County), Fukushima-Ken (Prefecture), Japan, was destroyed in March 2011 due to a massive earthquake (magnitude 9) centred offshore to the northeast of Honshu Island and the subsequent historic tsunami on 11 March, 2011. Due to the resulting nuclear meltdown, damage to the buildings housing the reactors by hydrogen explosions, and the contamination of cooling water from the reactor cores, huge quantities of radioisotopes were emitted to the atmosphere and to the adjacent seawater. Fishing is currently prohibited off the coast of Fukushima-Ken because intermittent surveys have found that the majority of fishery products still contain radioisotope levels exceeding the Japanese Standard Value. Therefore, the Japanese government has measured radioisotope levels in fishery species not only offshore near the destroyed reactors but also throughout the

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Japanese Exclusive Economic Zone (EEZ). The Japanese government has regularly released a subset of these measurements to the public, for example, via the internet (Japanese Governmental Off. Bull. On-Line, 2012; Ministry of Education, C., S., S. & T., 2011; NEMOTO et al., 2012; Ohnishi, 2012). To date, however, the total quantity of fishery resources and the estimated total quantity of caesium radioisotopes in fish biomass in the Fukushima-Ken EEZ after 11 March, 2011 have not been reported (Wan et al., 2012). This information is important not only to Japanese residents but also to residents of other countries. These data would make it possible to calculate overall contamination levels and to predict future trends. On 22 to 23 November, 2012, the Tokyo University of Marine Science and Technology performed an independent sampling measure radioisotope levels in fishery species off Iwaki-Shi (City), Fukushima-Ken (located south of the destroyed nuclear power plant). These data included detailed measurements of individual fish, such as weight, sex, length, and collection locality. Thus, this information could be used to estimate the fish biomass and the total quantity of caesium radioisotopes in fish in the Fukushima-Ken EEZ during November 2012. These estimates are reported here.

MATERIALS AND METHODS

Trawl (dragnet) fishing was performed on 22 November, 2012 off Yotsukura and Ena, Iwaki-Shi, Fukushima-Ken, Japan to sample the fish in the region. The total fishing areas were 9,450 and 9,775 square meter off Yotsukura and Ena, respectively (Atkins and Warren, 1953). Gill-net fishing was performed on 22 to 23 November, 2012 in the same locations. The total fishing areas were 28,900 and 50,141 square meter off Yotsukura and Ena, respectively (Buscaino et al., 2009). Subsequently, the edible portions of the fish were minced, and U-8 containers (100 mL) were filled with the minced fish flesh. The concentrations of the radioisotopes Cs-134 and Cs-137 in the fish biomass were measured by IDEA Consultants Inc. (Tokyo, Japan) using a germanium semiconductor detector (Seiko EG&G Co. model GEM20-70) (Inazu et al., 2011; Minatani et al., 2012).

RESULTS AND DISCUSSION

(1) The total fish-collection area on 22 to 23 November, 2012 was as follows (Table 1):

9,450 + 28,900 +9,775 +50,141 = 98,266 square meter.

The total area of the Fukushima-Ken EEZ is 33,300,000,000 square meter.

(33,300,000,000 / 98,266) = 338,876.1118

Thus, the estimated biomass of all fish species in the Fukushima-Ken EEZ in November 2012 can be calculated by multiplying 338,876.1118 times the total weight of the collected fish, and the total quantity of caesium radioisotopes (Cs-134 and Cs-137) in the fish biomass can be estimated using the following equations:

[ETFW] = Estimated total fish weight in the Fukushima-Ken EEZ [kg]

[ACS134] = Average Cs-134 level in fish biomass in the Fukushima-Ken EEZ in November 2012 [Bq/kg]

[Estimated Total Cs-134 in Fish] = Estimated total quantity of Cs-134 in fish biomass in the Fukushima-Ken EEZ in November 2012 [Bq]

[ACS137] = Average Cs-137 level in fish biomass in the Fukushima-Ken EEZ in November 2012 [Bq/kg]

[Estimated Total Cs-137 in Fish] = Estimated total quantity of Cs-137 in fish biomass in the Fukushima-Ken EEZ in November 2012 [Bq]

[Estimated Total Cs-134 in Fish] = [ETFW] X [ACS134]
[Estimated Total Cs-137 in Fish] = [ETFW] X [ACS137]

Table 2 shows the resulting estimates. The estimated total fish weight in the Fukushima-Ken EEZ on 22 to 23 November, 2012 was 91,150,218.79 kg; the estimated total quantity of Cs-134 in all fish in the Fukushima-Ken EEZ was 4,879,259,657 Bq; and the estimated total quantity of Cs-137 in all fish in the Fukushima-Ken EEZ was 8,381,002,727 Bq.

[2] Some scholars and other professionals do not agree with this estimation method because the range of a particular fish species depends on environmental conditions, and they believe that it is not meaningful to extrapolate from fish sampled off the coast of Fukushima-Ken to the total area of the Fukushima-Ken EEZ. On the other hand, not only Japanese residents but also residents of other countries, especially those living in Pacific coastal areas, are strongly interested in the total quantity of radioisotopes in fish biomass in the Fukushima-Ken EEZ. This information is critical to an overall perspective and future prediction of radioactive contamination in Pacific fisheries. One way to address this contradiction is to examine historical accidents at nuclear power plants, such as those at the Three Mile Island Nuclear Generating Station in Pennsylvania, U.S.A. (1979) and at the Chernobyl Nuclear Power Plant in Ukraine, former U.S.S.R. (1986) (Macdonald et al., 1987; Asmolov et al. 1987). However, these accidents did not occur along marine coastlines. On the other hand, governments conducted frequent atmospheric nuclear tests prior to the effective date of the Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and Under Water [often abbreviated as the Partial Test Ban Treaty (PTBT), Limited Test Ban Treaty (LTBT), or Nuclear Test Ban Treaty (NTBT)] in October 1963 (Scherb and Voigt, 2011; Lown and Pastore, 1985). Some atmospheric nuclear tests were conducted in the ocean, and reported estimates of the total Amounts

Table 1. Total fish-collection area on 22 to 23 November, 2012.

Location	YOTSUKURA	YOTSUKURA	ENA	ENA (Land Side)			
Way of sampling	Trawl (Net) [Dragneta Trawlnet] (HIKIAMI)	Gill Net (SASHIAMI)	Trawl (Net) [Dragneta Trawlnet] (HIKIAMI) (2 Times)	Gill Net (SASHIAMI)			
Sampling date for weight of fishes	22- NOV-2012	22 to 23 NOV-2012	22- NOV-2012	22 to 23 NOV-2012	Total fish collecting area in 22 to 23 NOV-2012 [m^2] = [TFCA]	Total area of FUKUSHIMA-KEN EEZ [m^2] = [TAFEEZ]	[TAFEEZ] / [TFCA]
Area [m^2]	9450	28900	9775	50141	98266	33300000000	338876.1118

Table 2. Amount of fishery resources and the estimated total amount of cesium radioisotopes in fish bodies in offshore Fukushima-Ken, Japan in November 2012.

Scientific Name	Japanese Name	Weight [g] at YOTSUKURA by Trawl (Net)	Weight % at YOTSUKURA by Trawl (Net)	Weight [g] at YOTSUKURA by Gill Net	Weight % at YOTSUKURA by Gill Net	Weight [g] at ENA by Trawl (Net) (2 Times)	Weight % at ENA by Trawl (Net) (2 Times)	Weight [g] at ENA (Land Side) by Gill Net	Weight % at ENA (Land Side) by Gill Net	Weight [g] at ENA (Offshore Side) by Gill Net	Weight % at ENA (Offshore Side) by Gill Net	Grand Fish Weight Toatl [g]	Grand Fish Weight %	Estimated Total Fish Weight in FUKUSHIMA-KEN EEZ [g]	Estimated Total Fish Weight in FUKUSHIMA-KEN EEZ [kg]	Average Cs-134 in Fish in NOV-2012 in FUKUSHIMA-KEN EEZ [becquerel]/[kg]	Estimated Total Cs-134 in Fish Body in NOV-2012 in FUKUSHIMA-KEN EEZ [becquerel] = [Estimated Total Cs-134 in Fish]	([Estimated Cs-134 in Fish] / [Estimated Total Cs-134 in Fish]) x 100 [%]	Average Cs-137 in Fish in in NOV-2012 FUKUSHIMA-KEN EEZ [becquerel]/[kg]	Estimated Total Cs-137 in Fish Body in NOV-2012 in FUKUSHIMA-KEN EEZ [becquerel] = [Estimated Total Cs-137 in Fish]	([Estimated Cs-137 in Fish] / [Estimated Total Cs-137 in Fish]) x 100 [%]
sAcanthopagrus schlegeli	KURODAI	2000	1.456261195	0	0	0	0	0	0	0	0	2000	0.743555235	677752223.6	677752.2236	0	0	0	0	0	0
Chelidonichthys spinosus	HOUBOU	0	0	1170	3.549757282	0	0	0	0	0	0	1170	0.434979812	396485050.8	396485.0508	7.015	2781342.631	0.057003374	10.085	3998551.737	0.047709706
Clupea pallasii Vakenciennes	NISHIN	23	0.016747004	0	0	0	0	0	0	0	0	23	0.008550885	7794150.571	7794.150571	0	0	0	0	0	0
Cynoglossus joyneri	AKASHITA BIRAME	600	0.436878359	0	0	1810	4.815110402	300	2.284843869	0	0	2710	1.007517343	918354262.9	918354.2629	14.1	12948795.11	0.265384423	22.25	20433382.35	0.243805938
Ditrema temminkii	UMI TANAGO	0	0	0	0	0		210	1.599390708	2960	6.171809842	3170	1.178535047	1074237274	1074237.274	12.445	13368882.88	0.273994086	22.3	23955491.22	0.285830849
Engraulis japonica	KATAKUCHI IWASHI	88	0.064075493	0	0	0	0	0	0	0	0	88	0.03271643	29821097.84	29821.09784	0	0	0	0	0	0
Hexagrammos otakii	AINAME	0	0	2130	6.462378641		0	1060	8.073115004	1810	3.773978315	5000	1.858888088	1694380559	1694380.559	52.19230769	88433631.48	1.812439544	88.01538462	149131556.6	1.779399929
Hexagrammos stelleri	EZO ISO AINAME	0	0	0	0	0	0	330	2.513328256	940	1.959966639	1270	0.472157574	430372662	430372.662	21.9	9425161.297	0.193167857	37.36666667	16081591.8	0.191881477
Kareius bicoloratus	ISHI GAREI	0	0	750	2.275485437	920	2.447459431	0	0	0	0	1670	0.620868621	565923106.7	565923.1067	130	73570003.87	1.507810796	213	120541621.7	1.438272074
Lateolabrax japonicus	SUZUKI	0	0	0	0	1300	3.458366587	0	0	0	0	1300	0.483310903	440538945.3	440538.9453	53.9	23745049.15	0.486652706	98.6	43437140.01	0.518280944
Lepidotrigla microptena Gunther	KANA GASHIRA	280	0.203876567	0	0	0	0	0	0	0	0	280	0.104097733	94885311.3	94885.3113	0	0	0	0	0	0
Liparis tanakai	KUSAUO	310	0.225720485	0	0	0	0	0	0	0	0	310	0.115251061	105051594.7	105051.5947	0	0	0	0	0	0
Mlicrostomus achn	BABA GAREI	0	0	2600	7.888349515	0	0	0	0	850	1.772310259	3450	1.28263278	1169122586	1169122.586	107.8333333	126070385.5	2.583801526	187.3333333	219015631	2.61323899
Mustelus manazo	HOSHI ZAME	50500	36.77059517	0	0	11100	29.52913009	0	0	0	0	61600	22.90150124	20874768486	20874768.49	0	0	0	0	0	0
Nibea mitsukurii	NIBE	0	0	0	0	0	0	1140	8.682406702	1040	2.168473728	2180	0.810475206	738749923.7	738749.9237	16.66	12307573.73	0.252242647	29.9	22088622.72	0.263555847
Okamejei kenojei	KOMON KASUBE	56900	41.430631	1390	4.21723301	13480	35.86060122	0	0	0	0	71770	26.68247961	24321138542	24321138.54	98.95	2406576659	49.32257817	173.95	4230662049	50.47918713
Oncorhynchus keta	SAKE	0	0	0	0	0	0	0	0	500	1.042535446	500	0.185888809	169438055.9	169438.0559	0	0	0	0	0	0
Oplegnathus punctatus	ISHIGAKI DAI	0	0	640	1.941747573	0	0	0	0	0	0	640	0.237937675	216880711.5	216880.7115	0	0	0	0	0	0

Table 2. Contd.

Scientific Name	Japanese Name	Weight [g] at YOTSUKURA by Trawl (Net)	Weight % at YOTSUKURA by Trawl (Net)	Weight [g] at YOTSUKURA by Gill Net	Weight % at YOTSUKURA by Gill Net	Weight [g] at ENA by Trawl (Net) (2 Times)	Weight % at ENA by Trawl (Net) (2 Times)	Weight [g] at ENA (Land Side) by Gill Net	Weight % at ENA (Land Side) by Gill Net	Weight [g] at ENA (Offshore Side) by Gill Net	Weight % at ENA (Offshore Side) by Gill Net	Grand Fish Weight Toatl [g]	Grand Fish Weight %	Estimated Total Fish Weight in FUKUSHIMA-KEN EEZ [g]	Estimated Total Fish Weight in FUKUSHIMA-KEN EEZ [kg]	Average Cs-134 in Fish in NOV-2012 in FUKUSHIMA-KEN EEZ [becquerel]/[kg]	Estimated Total Cs-134 in Fish Body in NOV-2012 in FUKUSHIMA-KEN EEZ [becquerel] = [Estimated Total Cs-134 in Fish]	([Estimated Cs-134 in Fish] / [Estimated Total Cs-134 in Fish]) x 100 [%]	Average Cs-137 in Fish in NOV-2012 FUKUSHIMA-KEN EEZ [becquerel]/[kg]	Estimated Total Cs-137 in Fish Body in NOV-2012 in FUKUSHIMA-KEN EEZ [becquerel] = [Estimated Total Cs-137 in Fish]	([Estimated Cs-137 in Fish] / [Estimated Total Cs-137 in Fish]) x 100 [%]
Pagrus major	MADAI	0	0	0	0	0	0	0	0	290	0.604670559	290	0.107815509	98274072.42	98274.07242	0	0	0		0	0
Pagrus major (Fry)	MADAI (CHIGYO)	322	0.234458052	0	0	0	0	0	0	0	0	322	0.119712393	109118108	109118.108	0	0	0	0	0	0
Paralichthys olivaceus	HIRAME	1600	1.165008956	6280	19.05339806	5340	14.20590583	0	0	2500	5.212677231	15720	5.844344147	5327132477	5327132.477	14.98	79800444.51	1.635503132	25.74727273	137159132.7	1.636548003
Paralichthys olivaceus (Fry)	HIRAME (CHIGYO)	34	0.02475644	0	0	0	0	0	0	0	0	34	0.012640439	11521787.8	11521.7878	0	0	0	0	0	0
Platycephalus sp.2	MAGOCHI	580	0.422315747	0	0	450	1.197126895	0	0	0	0	1030	0.382930946	349042395.1	349042.3951	0	0	0	0	0	0
Platycephalus sp.2 (fry)	MAGOCHI (CHIGYO)	10	0.007281306	0	0	0	0	0	0	0	0	10	0.003717776	3388761.118	3388.761118	0	0	0	0	0	0
Scyliorhinus torazame	TORA ZAME	5200	3.786279107	250	0.758495146	3190	8.486299548		0	0	0	8640	3.212158615	2927889606	2927889.606	27.00583333	79070098.71	1.620534759	47.58	139308987.4	1.662199524
Sebastes cheni	SHIRO MEBARU	0	0	200	0.606796117	0	0	8890	67.70753998	27760	57.88156797	36850	13.7000052	12487584719	12487584.72	129.0857143	1611968793	33.03715945	213.2857143	2663423427	31.77929316
Sebastes inermis	AKA MEBARU	0	0	0	0	0	0	0	0	1020	2.12677231	1020	0.37921317	345653634	345653.634	96.175	33243238.25	0.681317261	160.15	55356429.49	0.660498884
Sebastes pachycephalus pachycephalus	MURASOI	0	0	0	0	0	0	330	2.513328256	1760	3.669724771	2090	0.777015221	708251073.6	708251.0736	40.175	28453986.88	0.583161973	70.65	50037938.35	0.597039996
Sebastes vulpes	KITSUNE MEBARU	0	0	1260	3.822815534	0	0	590	4.493526276	6530	13.61551293	8380	3.115496435	2839781817	2839781.817	32.4	92008930.86	1.885714992	59.068	167740232.3	2.001433931
Sebastiscus marmoratus	KASAGO	0	0	0	0	0	0	280	2.132520944	0	0	280	0.104097733	94885311.3	94885.3113	38.3	3634107.423	0.074480714	67.1	6366804.388	0.075967096
Seriola quinqueradiata	BURI	0	0	1670	5.066747573	0	0	0	0	0	0	1670	0.620868621	565923106.7	565923.1067	4.03	2280670.12	0.046742135	5.09	2880548.613	0.034369976
Takifugu poecilonotus	KOMON FUGU	70	0.050969142	0	0	0	0	0	0	0	0	70	0.026024433	23721327.82	23721.32782	0	0	0	0	0	0
Takifugu rubipes	TORA FUGU	1610	1.172290262	0	0	0	0	0	0	0	0	1610	0.598561964	545590540	545590.54	83.9	45775046.3	0.938155571	135	73654722.89	0.878829483
Takifugu snyderi	SHOUSAI FUGU	16200	11.79571568	0	0	0	0	0	0	0	0	16200	6.022797404	5489793011	5489793.011	0	0	0	0	0	0
Takifugu stictonotus	GOMA FUGU	120	0.087375672	0	0	0	0	0	0	0	0	120	0.044613314	40665133.41	40665.13341	0	0	0	0	0	0
Trachurus japonicus	MA AJI	887	0.64585184	0	0	0	0	0	0	0	0	887	0.329766747	300583111.1	300583.1111	0	0	0	0	0	0
Triakis scyllium	DOCHI ZAME	0	0	14620	44.35679612	0	0	0	0	0	0	14620	5.435388768	4954368754	4954368.754	27.00583333	133796856.8	2.742154881	47.58	235728865.3	2.812657065
Zeus faber Linnaeus	MATOU DAI	4	0.002912522	0	0	0	0	0	0	0	0	4	0.00148711	1355504.447	1355.504447	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Estimated Total Cs-134 in All Fish in FUKUSHIMA-KEN EEZ [becquerel] = [Estimated Total Cs-134 in Fish]	4879259657	0	Estimated Total Cs-137 in All Fish in FUKUSHIMA-KEN EEZ [becquerel]	8381002727	0
0	Total fish weight	137338	0	32960	0	37590	0	13130	0	47960	0	268978	0	0	91150218.79	0	0	0	0	0	0

quantity of radioisotopes in fish biomass cover broad ranges extending from offshore to the boundaries of designated areas, such as EEZs (Moiseev and Kardashev, 1964).

Conclusion

(1) The estimated total fish biomass in the Fukushima-Ken EEZ on 22 to 23 November, 2012 was 91,150,218.79 kg.
(2) The estimated total quantities of Cs-134 and Cs-137 in all fish in the Fukushima-Ken EEZ on 22 to 22 November, 2012 were 4,879,259,657 Bq and 8,381,002,727 Bq, respectively.

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