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Natural variation of radionuclide ^{137}Cs concentration in marine organisms with special reference to the effect of food habits and trophic level

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ABSTRACT: Although a number of measurements have been made on radiocesium concentrations in aquatic organisms, no clear agreement has been reached on the factors affecting accumulation of these radionuclides. Natural variations in the concentration of the long-lived artificial radionuclide ^{137}Cs in marine organisms and factors affecting variations in marine fishes were investigated through long-term and systematic measurements in coastal waters of Japan from 1984 to 1995. Concentrations of ^{137}Cs were measured in more than 30 species of crustaceans, cephalopods and teleosts considered representative of the marine biotic community. A clear positive correlation ($p < 0.05$) was found between mean weight and concentration of ^{137}Cs in 276 fish samples. However, different relationships between ^{137}Cs concentration and weight of fish were observed in different species. Within 16 studied species ^{137}Cs concentration increased with growth for 4 species, while no specific correlation was observed in the remaining species. These different patterns depended on a change of food habits with growth. Analysis of 6066 stomach contents of fish samples together with ^{137}Cs concentrations in the stomach contents demonstrated that ^{137}Cs concentration increased with rising trophic level and that the biomagnification factor (^{137}Cs in predator/^{137}Cs in prey) was 2.0 (95% confidence interval 1.8 to 2.2). From the yearly change of ^{137}Cs in 24 marine fish species, a mean effective environmental half-life of ^{137}Cs of 13 ± 3 yr (range 10 to 17 yr) was calculated.

KEY WORDS: Trophic level · Food habits · Marine organisms · Bioaccumulation · ^{137}Cs · Size-dependence · Environmental half-life

INTRODUCTION

The long-lived artificial radionuclide ^{137}Cs can be considered to be of great interest and importance as an indicator of radioactive pollution in the marine environment because of its relatively high radiotoxicity. Its major sources are the atmospheric deposition of debris from past nuclear explosions during 1954 to 1962 and 1980. The nuclear accident at the Chernobyl nuclear power station has renewed interest in this radionuclide.

The fate and cycling of radionuclides in ecosystems have long been a subject of major interest to applied ecologists and health physicists. Although many measurements have been made on radiocesium concentrations and their variations in aquatic organisms (e.g. Williams & Pickering 1961, Baptist & Price 1962, Hiyama & Shimizu 1964, King 1964, Morgan 1964, Hasanen et al. 1968, Kolehmainen et al. 1968, Jefferies & Hewett 1971, Pentreath & Jefferies 1971, Whicker et al. 1972, Pentreath 1973, Suzuki et al. 1973, Newman & Brisbin 1990, Tateda & Misonou 1991, Morgan et al. 1993, Cocchio et al. 1995), no agreement seems to have been reached on the factors affecting the accumulation of this radionuclide, and this lack of ecological understanding has hindered the development of a robust dose model (Rowan & Rasmussen 1994).

Furthermore, the bioaccumulation of radionuclides by aquatic organisms and the factors affecting the concentrations have been examined mainly under controlled conditions in aquaria. Such studies have been

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conducted on a limited range of marine species (generally species easy to rear in laboratory experiments) and performed under conditions that cannot be truly representative of the natural environment. There have been few direct and large-scale environmental studies on ^{137}Cs accumulation in marine organisms in the natural environment.

Although there is a general agreement that food is the major route of ^{137}Cs uptake by fish, some authors claim varying degrees of biomagnification (Gustafson 1967), some deny food-chain effects (Reichle et al. 1970, Thomann 1981), and some even claim that the radiocesium undergoes 'biodiminution' in aquatic food chains (Mailhot et al. 1988).

The Marine Ecology Research Institute, Tokyo, has been carrying out large-scale and systematic measurements of ^{137}Cs concentrations of sea water, sediments and marine edible organisms sampled from fishing grounds along the coast of Japan since 1984 as part of an extended marine environmental radioactive monitoring program sponsored by the Science and Technology Agency of Japan. This paper reports the variation of ^{137}Cs in edible marine organisms, with special reference to the factors affecting ^{137}Cs concentration, based on results from the long-term measurements at different locations around Japan over more than 10 yr (1984 to 1995).

MATERIALS AND METHODS

Sampling areas and samples. The locations of sampling sites are shown in Fig. 1. For the purpose of the monitoring program, marine organisms to be analyzed were selected from coastal species which have been abundantly caught by the coastal fisheries of Japan. Marine organism samples were taken on the continental shelf and shelf slope (between the sea surface and approximately 500 m depth) around Japan, through various fishing operations. These samples were provided twice a year by the local fisherman's union. Samples of marine organisms were frozen and transferred to the laboratory. More than 30 species (representing more than 20 families) of marine organisms were sampled. The samples consisted of teleosts, cephalopods and crustaceans. The species and samples measured during 1984 to 1995 are shown in Table 1. Sea water was sampled once a year using a Niskin type bottle, taking 80 l per sample.

Measurement. Samples of marine organisms (total wet weight about 20 kg) were transported to the Japan Chemical Analysis Center, where the major part of the analysis was carried out. Muscle tissues from each fish were dissected out and pooled. After being dried at 105°C, individual samples were ashed at 450°C for 24 h. Samples were analyzed using Gamma-spectrometry to determine ^{137}Cs (measuring for 20 h). Results were expressed as Bq kg^{-1} wet weight for ^{137}Cs.

^{137}Cs concentrations in sea water were measured from 50 l samples. Cesium was absorbed onto ammonium molybdophosphate precipitate under acidic conditions, and ^{137}Cs was separated by means of a cation exchange resin column method, fixed as cesium chloroplatinate and measured by Gamma-spectrometry (measuring for 20 h). Food habits of the studied fish species were investigated from their stomach contents. Stomach contents were expressed as a percentage of weight of each prey item against total weight of stomach contents.

RESULTS

Variation of ^{137}Cs concentrations in marine organisms

Table 1 shows details of the marine organisms analyzed from 1984 to 1995, together with their concentrations of ^{137}Cs and mean concentration factors (CF; concentration in organism/concentration in sea water) of ^{137}Cs during the years 1992 to 1995. Tables 2 & 3 shows

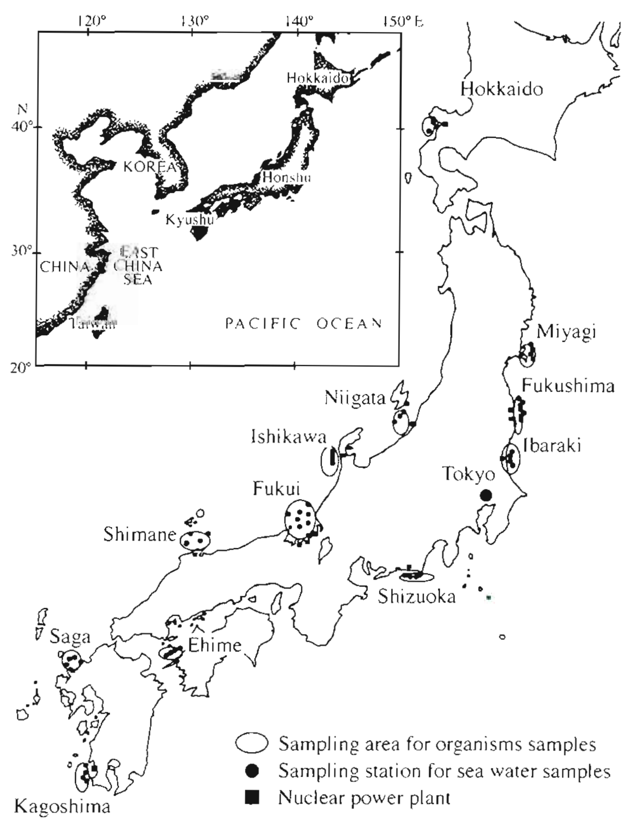

Fig. 1. Sampling sites in Japan

Table 1. Length, wet weight and concentration of ^{137}Cs in marine organisms measured during 1984 to 1995. CF: concentration factor (concentration in organism/concentration in sea water). ND: not detected; concentration less than 3 times the analysis errors

Species	No. of samples	Mean length (cm) Max.	Min.	Mean wet weight (g) Max.	Min.	Concentration (Bq kg^{-1} fresh) Max.	Min.	Mean CF ± SD 1992–95
Chondrichthyes								
Order Rajiformes								
Family Dasyatididae								
Stingrays	19	74	29	6890	1181	0.48	0.23	94 ± 13
Osteichthyes								
Order Anguiliformes								
Family Congridae								
Common Japanese conger	31	78	38	898	87	0.21	0.05	38 ± 9
Order Salmoniformes								
Family Argentinidae								
Deep-sea smelt	17	24	13	80	12	0.58	0.2	78 ± 9
Order Gadiformes								
Family Moridae								
Morid cod	12	43	29	1016	243	0.42	0.03	51 ± 3
Family Gadidae								
Pacific cod	50	98	19	9537	43	0.74	0.13	76 ± 23
Walleye pollack	37	56	38	1499	359	0.54	0.26	94 ± 9
Order Scorpaeniformes								
Family Scorpaenidae								
Scorpion fish	25	40	15	1099	59	0.29	0.12	57 ± 9
Black rockfish	16	27	21	375	156	0.37	0.16	79 ± 5
Family Platycephalidae								
Bertail flathead	19	57	34	1370	316	0.27	0.11	54 ± 10
Family Hexagrammidae								
Atka mackerel	41	39	29	598	219	0.5	0.18	80 ± 15
Greenling	6	35	28	595	227	0.25	0.11	45 ± 10
Order Perciformes								
Family Percichthyidae								
Japanese sea bass	57	82	47	4851	964	0.62	0.22	94 ± 11
Family Carangidae								
Jacks	21	31	15	356	34	0.39	0.17	66 ± 11
Family Sparidae								
Red sea bream	34	48	16	1544	62	0.36	0.12	50 ± 5
Crimson sea bream	25	28	17	401	102	0.49	0.12	51 ± 10
Yellow sea bream	6	27	15	392	66	0.32	0.2	–
Family Sciaenidae								
White croaker	18	27	21	243	131	0.31	0.12	46 ± 4
Black mouth croak	6	39	24	605	165	0.33	0.17	–
Family Girellidae								
Rudder fish	24	34	18	850	129	0.26	0.1	40 ± 6
Family Trichodontidae								
Japanese sandfish	22	22	17	94	36	0.18	0.06	33 ± 8
Order Pleuronectiforms								
Family Paralichthyidae								
Bastard halibut	53	72	28	4477	223	0.5	0.11	70 ± 12
Family Pleuronectidae								
Flathead flounder	50	39	23	640	40	0.27	0.09	42 ± 9
Pointhead flounder	8	32	26	293	158	0.28	0.17	58 ± 3
Shothole halibut	24	33	19	435	58	0.28	0.14	50 ± 10
Stone flounder	24	51	21	1798	95	0.4	0.09	59 ± 22
Brown sole	19	30	22	2367	123	0.22	0.06	27 ± 5
Marbled sole	19	43	21	1156	102	0.42	0.09	
Rikuzen sole	7	26	15	222	33	0.18	0.05	31 ± 15
Family Cynoglossidae								
Black tonguefish	25	32	22	200	68	0.19	0.07	30 ± 2
Red tonguefish	14	32	23	203	64	0.19	0.1	37 ± 3
Cephalopods								
Family Decapoda	53	29	9	1691	42	0.09	ND	8 ± 8
Family Octopoda	89	92	6	18466	285	0.09	ND	5 ± 5
Crustacea								
Family Decapoda	31	14	6	15	1	0.19	0.04	26 ± 10

mean concentrations of ^{137}Cs in sea water (0 to 200 m depth) during the period 1984 to 1995 (14 sites with 56 stations) and ^{137}Cs in sea water by depth (1992 to 1995), respectively.

Concentration of ^{137}Cs in fishes ranged from 0.05 to 0.74 Bq kg^{-1} fresh wt (n = 746) during 1984 to 1995 and the 1992-95 overall mean concentration factor was 59 ± 24 (n = 276). Concentration of ^{137}Cs in squids varied from ND (not detected) to 0.09 Bq kg^{-1} fresh wt (n = 53), and that of octopus from ND to 0.09 Bq kg^{-1} fresh wt (n = 89). Concentration of ^{137}Cs in shrimps (Crustacea Decapoda) ranged from 0.04 to 0.19 Bq kg^{-1} fresh wt (n = 23) with 1992-1995 mean CF of 26 ± 10 (n = 31).

Table 2. Mean concentrations of ^{137}Cs in the coastal surface sea water (0 to 200 m depth)

Year	^{137}Cs (mBq l^{-1})	SD	No. of samples	Sampling period
1984	4.3	0.5	104	Mar-Dec
1985	4.1	0.4	91	Jun-Aug
1986	4.3	0.7	88	May-Jul
1987	4.1	0.6	88	May-Aug
1988	4.0	0.2	98	May-Jul
1989	3.8	0.2	96	May-Jul
1990	3.8	0.2	97	May-Jul
1991	3.7	0.2	99	May-Jul
1992	3.5	0.2	100	May-Jul
1993	3.2	0.2	99	May-Jun
1994	3.1	0.2	99	May-Jul
1995	2.9	0.2	100	May-Jul

Table 3. Mean concentrations of ^{137}Cs of sea water by depth in coastal waters during 1992 to 1995

Depth (m)	^{137}Cs (mBq l^{-1})	SD	No. of samples
0-200	3.15	0.35	416
200-300	2.75	0.57	34
300-400	2.42	0.40	24
400-520	1.90	0.33	23

Effect of area on ^{137}Cs concentration

The possible effect of area of origin on the concentrations of ^{137}Cs was investigated by comparing concentrations by areas and by species (Table 4).

There were no significant differences in the concentrations between areas except in 2 species, Atka mackerel *Pleurogrammus azonus* and common Japanese conger *Conger myriaster*. There was no difference in the depth of habitats and the ^{137}Cs concentrations of the sea waters between the areas (Kasamatsu & Inatom 1997). In the case of the common Japanese conger, however, a large difference in size between areas was noted. The concentration of ^{137}Cs in this species is size-dependent (as discussed in the following section). A possible reason for the difference in ^{137}Cs concentration in Atka mackerel between areas is also explained in the 'Discussion'.

Table 4. Mean concentration factors of ^{137}Cs in 7 species from different areas. CF: concentration factor

Species	Sampling area	^{137}Cs CF ± SD	No. of samples	Mean weight ± SD (g)
Walleye pollack	Hokkaido	96 ± 11	4	481 ± 41
	Niigata	95 ± 7	8	747 ± 260
Japanese sea bass	Fukushima	97 ± 11	8	2925 ± 826*
	Fukui	95 ± 6	4	1437 ± 304*
	Saga	91 ± 12	8	2359 ± 1101
Bastard halibut	Hokkaido	62 ± 3	4	693 ± 205*
	Ibaraki	69 ± 12	7	2716 ± 1581*
	Fukui	70 ± 17	4	707 ± 366*
	Shimane	73 ± 8	8	968 ± 290*
Atka mackerel	Hokkaido	92 ± 10**	8	449 ± 55
	Niigata	67 ± 7**	8	448 ± 97
Japanese common conger	Miyagi	32 ± 7**	8	237 ± 66**
	Fukui	46 ± 7**	7	657 ± 118**
Red sea bream	Shimane	50 ± 4	8	566 ± 102*
	Fukui	50 ± 7	4	337 ± 616*
Pacific cod	Miyagi	68 ± 5	5	3848 ± 1318
	Fukushima	76 ± 16	8	3776 ± 842

*Significantly different at 5% level, **at 1% level

Effect of fish size on ^{137}Cs concentration

Fig. 2 shows the relationship between mean CF of ^{137}Cs and the mean total length and the mean body weight for 28 fish species (147 samples) obtained during 1992 to 1995. There was a clear positive correlation (the slopes are significantly different from zero at 5% level). This demonstrates that the heavier and bigger species in the marine fish community apparently have the higher concentration factor of ^{137}Cs.

Fig. 3 shows the relationship between mean CF of ^{137}Cs and mean body weight for the 14 major fish species studied. Within these 14 spe-

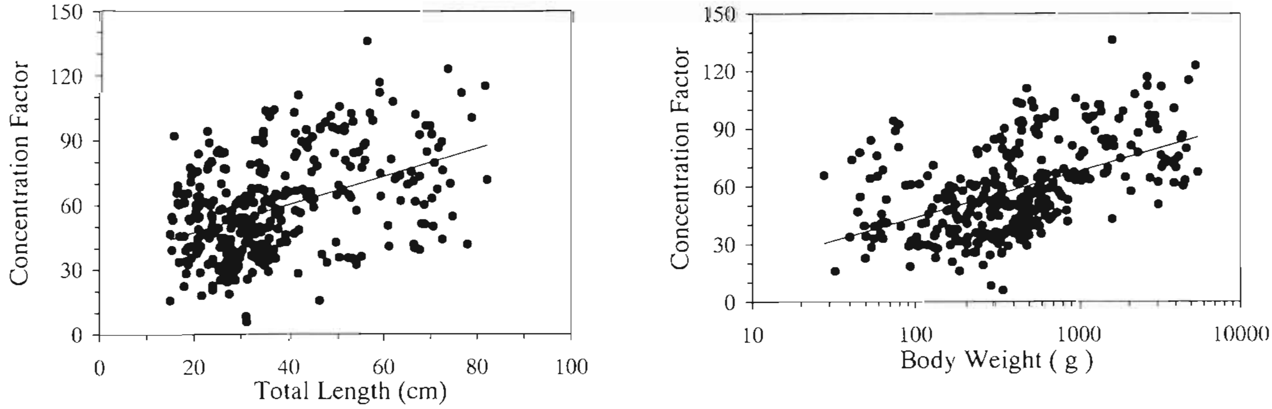

Fig. 2. Relationships between mean concentration factors of ^{137}Cs and mean total length and body weight of 147 fish samples during 1992–1995. Lines are least squares fits to the data

cies, a significant positive correlation ($p < 0.01$) was observed for the common Japanese conger, Pacific cod *Gadus macrocephalus*, bertail flathead *Platycephalus indicus* and stone flounder *Kareius bicoloratus*. No increase of ^{137}Cs concentration with increase of weight was observed for the black rockfish *Sebastes inermis*, rudder fish *Girella punctata*, flathead founder *Hippoglossoides dubius*, and brown sole *Limanda herzensteini*. No specific correlation was identified in the remaining species.

Effect of food habits on ^{137}Cs concentration

The effect of food habits on the ^{137}Cs concentration in fishes was investigated during 1993 to 1995. Stomach contents were examined in 6066 individuals from 25 species. The samples represented 5 seasons: 3 autumns and 2 springs. The prey items in the stomach contents were classified into the following categories: large fish (>15 cm total length), small fish (<15 cm), decapod crustaceans, cephalopods, zooplankton and macro-benthos (mainly Polychaeta). Concentrations of ^{137}Cs in these prey groups collected directly from the stomach were also measured (Table 5). Fig. 4 shows the stomach content composition of the major 20 species together with mean concentrations of ^{137}Cs. In general, high concentrations

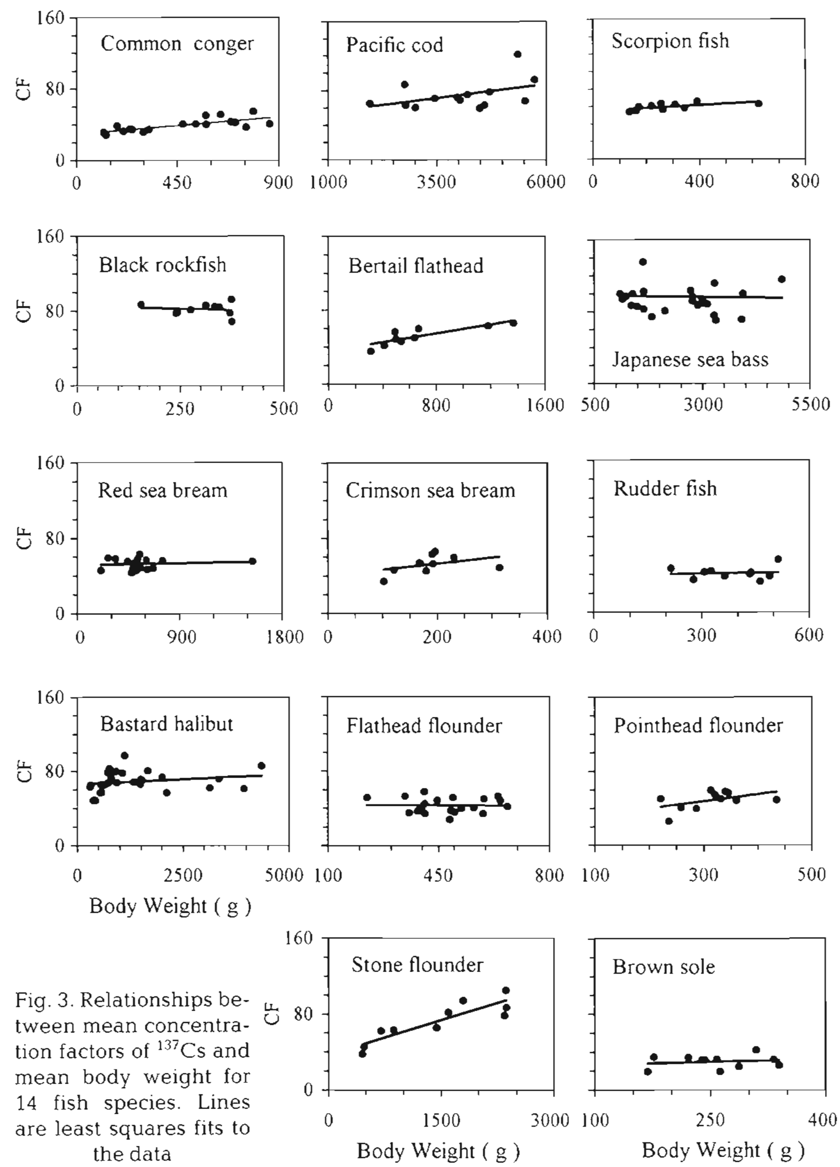

Fig. 3. Relationships between mean concentration factors of ^{137}Cs and mean body weight for 14 fish species. Lines are least squares fits to the data

Table 5. ^{137}Cs concentrations in stomach contents. CF: concentration factor

Stomach contents	$^{137}Cs^{a}$ (CF) (Bq kg^{-1})	Major contents	^{137}Cs CF from literature^{b}
Fish (large size)	0.15 ± 0.01 (48)	Horse mackerel etc.	56 ± 24 (this work)
Fish (small size)	0.10 ± 0.01 (32)	Sandlance, anchovy, etc.	30 ± 6 (i), (this work)
Fish (combined)	0.12 ± 0.01 (38)		34 ± 13 (i), (this work)
Crustacean Decapoda	0.11 ± 0.01 (35)	Prawn, shrimp	26 ± 10 (this work)
Cephalopoda	0.03 ± 0.01 (10)	Squid	17 ± 13 (iii)
Benthos	–	Polychaetes	4 ± 2 (ii)
Zooplankton	0.08 ± 0.02 (26)	Euphausiacea	8 ± 5, 15 (i, iii)

[a] Values are shown ± analysis error
[b] Literature:
(i) Ibaraki Environmental Pollution Research Center (1993, 1994, 1995); (ii) Pentreath & Jefferies (1971); (iii) Gomez et al. (1991)

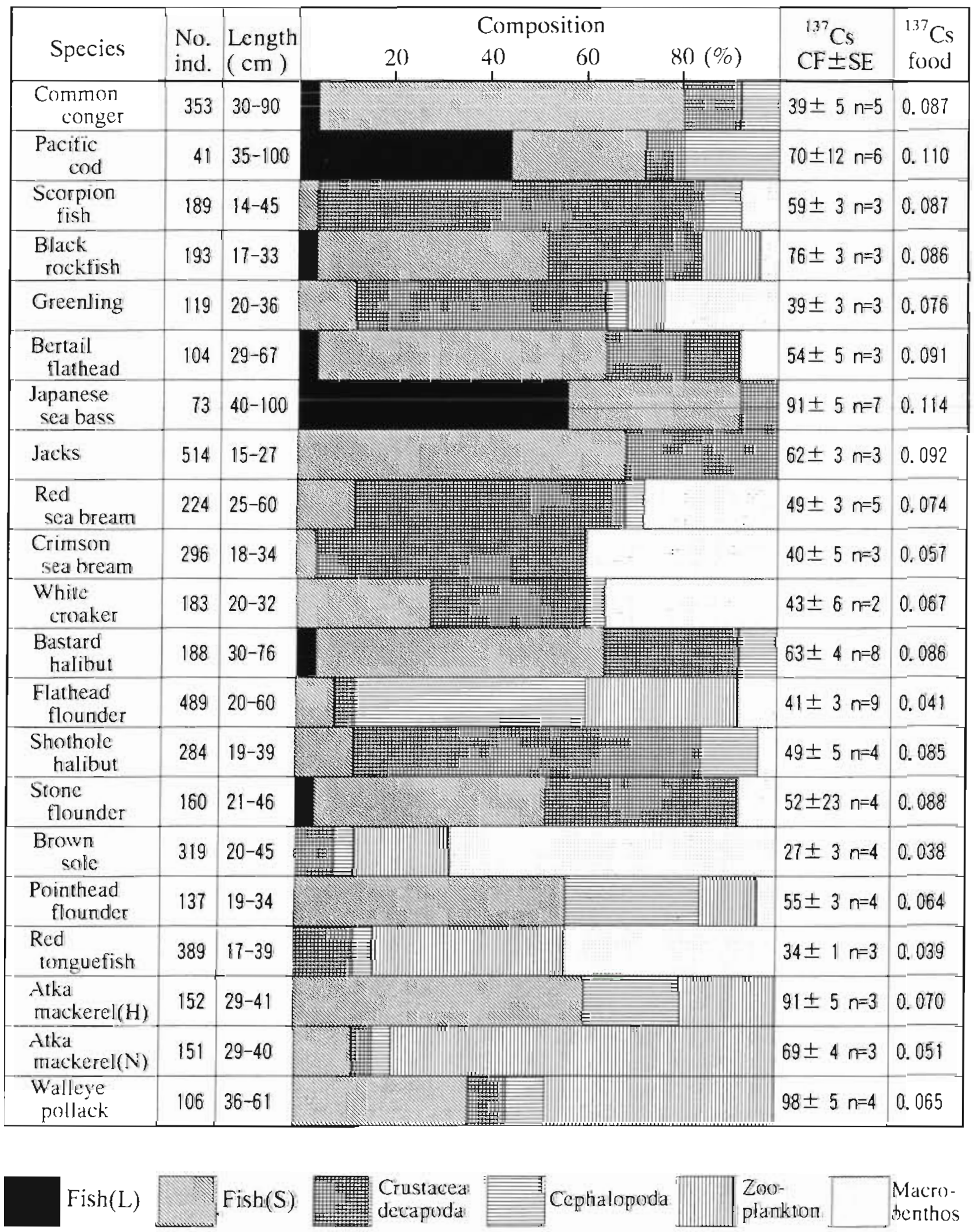

Fig. 4. Stomach contents and ^{137}Cs concentrations of 20 fish species. (H) Hokkaido; (N) Niigata; (L) large; (S) small

were observed in fish species whose prey was large-size fishes (e.g. Japanese sea bass and Pacific cod) and low concentrations were observed in fish species whose prey was mainly macro-benthos (e.g. brown sole and red tonguefish). It was, however, noted that relatively high concentrations were observed in Atka mackerel, walleye pollack and deep-sea smelt *Glossanodon semifasciata* and that the food of these fishes was not from the high trophic levels.

Fig. 5 shows stomach contents in relation to body size (at different growth stages) for 9 major fish species. With increase of body size (with growth) Pacific cod, stone flounder, Japanese common conger and bertail flathead apparently change their prey from that of low trophic level to that of high trophic level. ^{137}Cs in these species tends to increase with increase in size. In contrast, within the examined range of weight, flathead flounder, brown sole, Japanese sea bass and red sea bream do not change their food habits. These observations suggested that the size-dependent concentration of ^{137}Cs is mainly due to change of food habit.

A quantitative examination of the relationship between the concentration of ^{137}Cs in food and in fish was carried out. ^{137}Cs in the intake-food (I) is here expressed as follows:

$$I = b_i \cdot d_i \cdot f_i$$

where b_i is the absorption percentage of ^{137}Cs for the ith food item, d_i is the concentration of ^{137}Cs in the ith food item (Table 5), and f_i is the proportion of the ith food item in the diet of fish (Reichle 1969, Kolehmainen 1974). An absorption of 90% was assumed. Fig. 6 shows the relationship between ^{137}Cs in the intake-food and ^{137}Cs in the fishes that inhabit surface layers (above approximately 150 m depth, closed circles in Fig. 6). A significant positive relationship ($r = 0.79$, $p < 0.001$) was observed, suggesting food habits to be the major factor affecting concentration of ^{137}Cs in fishes, and the biomagnification factor (^{137}Cs in predator/^{137}Cs in prey) was estimated at 2.0 (95% confidence interval 1.8 to 2.2).

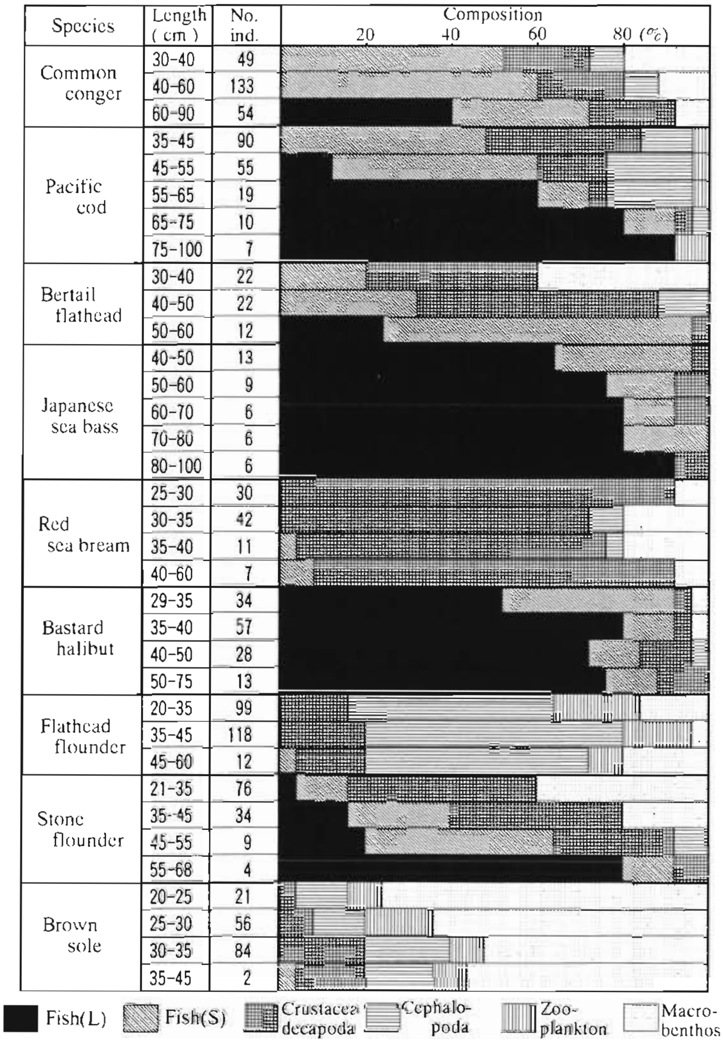

Fig. 5. Stomach contents of different body size ranges for the major 9 species

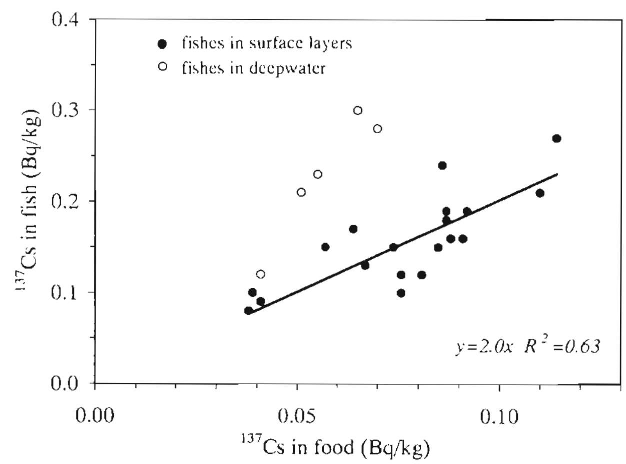

Fig. 6. Relationship of ^{137}Cs concentration between foods and fishes. (●) Fishes in surface layers, (○) fishes in deep-sea waters (walleye pollack, Atka mackerel and deep-sea smelt)

Effect of habitat on concentration

Fig. 7 shows depths of habitats and ^{137}Cs concentrations of 21 fish species samples. From the observations presented in Figs. 6 & 7, it is noted that walleye pollack, Atka mackerel and deep-sea smelt that inhabit a depth of 150 to 400 m with lower sea temperature have high concentrations of ^{137}Cs despite low concentra-

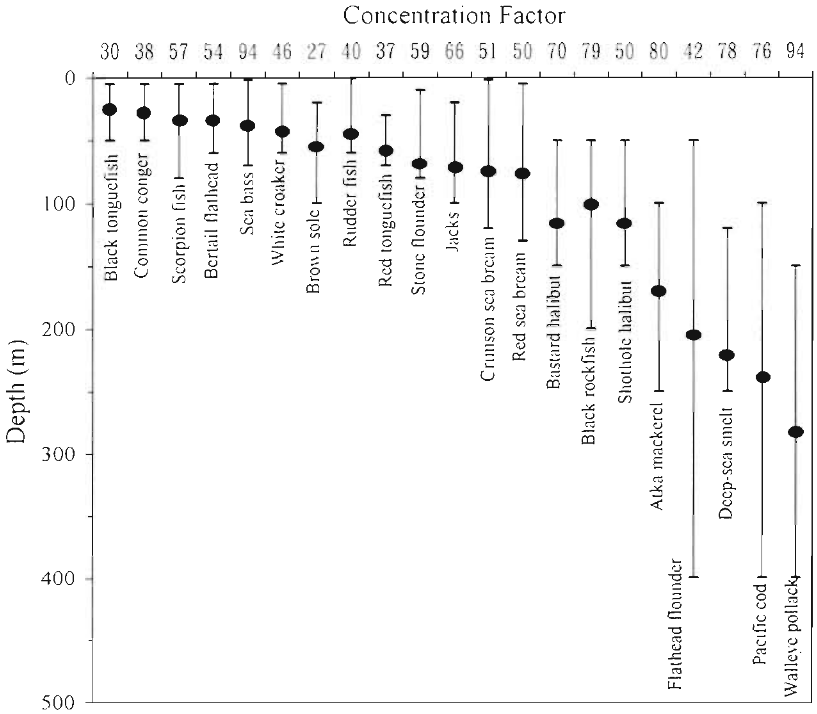

Fig. 7. Depth of capture and ^{137}Cs concentration factors of the 21 fish species studied. Closed circles show depth of capture and vertical lines show range of depth from the literature. Depths of captures were provided from interviews with fishermen conducted during 1994

tions in their food and in environmental sea water (see Table 3).

Concentration factors along trophic level

Our investigations indicated that food habit was one of the most important factors affecting concentrations of ^{137}Cs in marine fishes, and Fig. 8 shows the relationship between the ^{137}Cs concentration factor and the oceanic food chains. A clear increase in the concentration factor was observed with increase in trophic level. Nevertheless, most food relationships are not simple food chains but are more often complex as a result of opportunistic feeding ^{137}Cs could be a good indicator and/or a research tool for studies on food habits and trophic levels of the marine biota.

Temporal variation: effective environmental half-life

Fig. 9 shows the annual variation of ^{137}Cs in 24 fish species after the Chernobyl accident (1987 to 1995). The effective environmental half-lives were calculated and the results are shown in Table 6. Species having positive or negative annual trends in their mean body weight or having a large yearly variation in mean body weight were excluded to avoid size-dependent effects. The effective environmental half-lives range from 10 to 17 yr with a mean of 13 ± 3 yr (Table 6). These half-lives were slightly lower than those determined in surface layers of sea water (16 to 18 yr; Kasamatsu & Inatomi 1997) but not significantly different.

DISCUSSION

Radiocesium ^{137}Cs falls to earth in a readily soluble form following atomic bomb detonations and is thus available to human beings through concentration and transfer up the food chain. Identification of factors affecting or controlling accumulations of ^{137}Cs in edible marine organisms is critically necessary to identify pathways of radiocesium accumulation from a surface input.

Factors affecting accumulation of ^{137}Cs in fishes have been the subject of previous investigations (Bryan 1963,

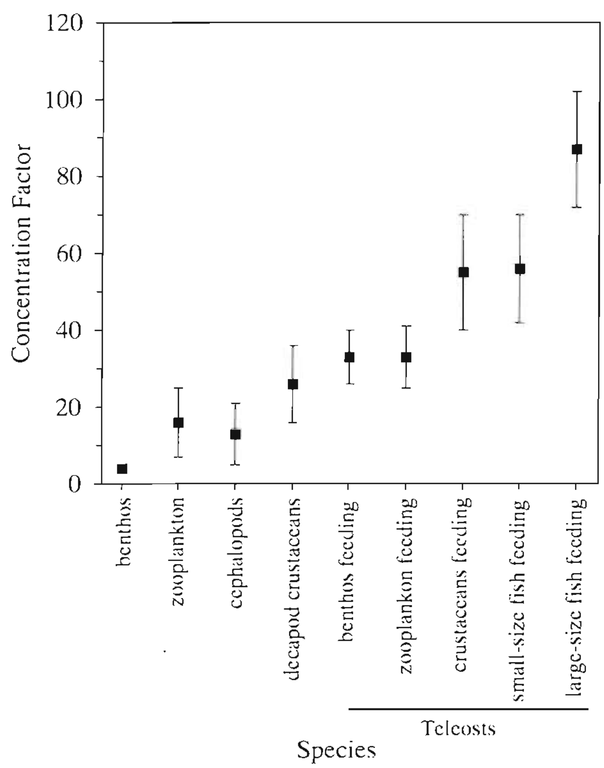

Fig. 8. Food habits and mean ^{137}Cs concentration factors for marine organisms. Vertical lines show standard deviation

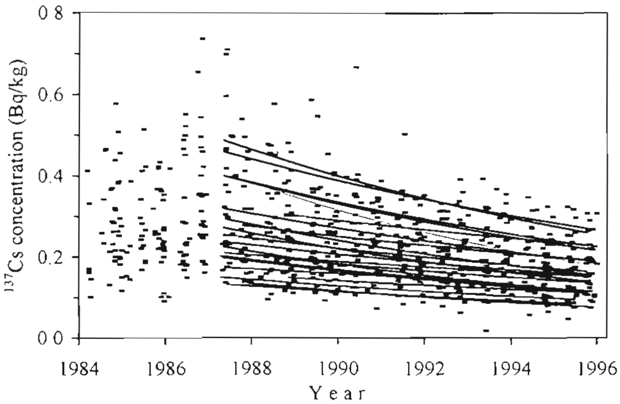

Fig. 9. Yearly changes of mean concentrations of ^{137}Cs in 24 fish species. Lines are least squares fits to the data

1965, King 1964, Morgan 1964, Pendleton et al. 1965, Hasanen et al. 1968, Kolehmainen et al. 1968, Pentreath 1973, Kasamatsu 1996). Morgan (1964), Hiyama & Shimizu (1964), Morita (1980) and Yoshida (1992) suggested a positive correlation between body size and radiocesium concentration in fishes, while Hasanen & Miettinen (1963), Kimura (1984), Newman & Brisbin (1990), and Ishikawa et al. (1995) observed neither a positive nor any other clear correlation between ^{137}Cs and size (or age) of fishes. However, the reason for this discrepancy has not been clearly identified. We also found both size-dependence and no size-dependence of ^{137}Cs concentration in different fish species. Our analysis demonstrated that those different patterns were due to changes of food habits with growth. The ^{137}Cs concentration in the fish increased clearly when the food habit changed from low trophic level to high trophic level with growth, but it did not increase when the fish did not change their prey. These results suggest that food habit is one of the most important factors affecting concentrations of ^{137}Cs in marine fishes.

The effect of food habits on ^{137}Cs concentration could explain the difference in ^{137}Cs concentration in different areas (see Table 4). It has been suggested that the difference of food of Atka mackerel from Hokkaido (mainly fishes) and Niigata (mainly zooplankton) might cause the difference in ^{137}Cs concentration between areas, because zooplankton has a much lower concentration of ^{137}Cs than fishes (Kasamatsu 1996). In the case of common Japanese conger, size-dependent concentration of ^{137}Cs (Fig. 3) resulted in a high concentration in larger size fish (Fukui area) and a low concentration in smaller size fish (Miyagi area). The yearly variation of ^{137}Cs in stone flounders (Fig. 10) before 1992 was well explained by the yearly variation

Table 6. Annual trends of ^{137}Cs concentration in major fish species during 1987–1995

Species	Slope[a]	Half-life (yr)	Corr. coeff.[b]	No. of samples	CV of body wt[c]	Trend body wt[d]
Stingrays	−0.045	15.4	0.57*	17	0.49	No
Common Japanese conger (Miyagi)	−0.017	40.7	0.35	9	0.42	No
Common Japanese conger (Fukui)	−0.049	14.1	0.39	18	0.19	No
Deep-sea smelt	−0.041	16.9	0.6	11	0.29	No
Pacific cod	−0.092	7.5	0.55**	35	0.51	No
Walleye pollack (Hokkaido)	−0.063	11.0	0.87*	16	0.41	No
Scorpion fish	−0.053	13.6	0.70**	21	0.36	No
Black rockfish	−0.068	10.2	0.95**	15	0.21	No
Bertail flathead	−0.052	13.8	0.47	15	0.47	No
Atka mackerel (Hokkaido)	−0.064	10.8	0.79**	11	0.18	Positive
Japanese sea bass	−0.075	9.2	0.72**	46	0.40	No
Jacks	−0.037	18.7	0.57*	15	0.31	Negative
Red sea bream	−0.079	8.8	0.88**	27	0.49	No
Crimson sea bream	−0.042	16.5	0.56*	18	0.30	No
White croaker	−0.052	13.3	0.86**	11	0.21	No
Rudder fish	−0.081	8.6	0.82**	18	0.36	No
Japanese sandfish	−0.055	12.6	0.62**	16	0.26	Positive
Bastard halibut	−0.061	11.3	0.63**	49	0.85	No
Flathead flounder	−0.063	11.0	0.67**	41	0.32	No
Shothole halibut	−0.041	16.9	0.47*	18	0.19	No
Stone flounder	−0.078	8.9	0.52	18	0.73	No
Brown sole	−0.072	9.6	0.70**	17	0.27	No
Black tonguefish	−0.057	12.2	0.62**	18	0.23	Positive
Red tonguefish	−0.063	11.0	0.67**	12	0.25	No

[a]Exponential coefficient. [b]Correlation coefficient (*significant at 5% and **at 1% level). [c]Coefficient of variation of yearly change of mean body weight. [d]Trend of yearly body weight

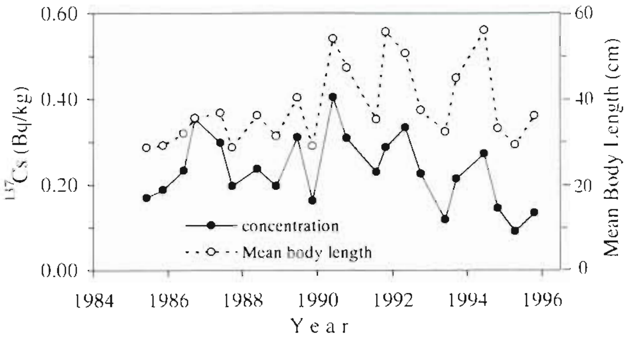

Fig. 10. *Kareius bicoloratus*. Yearly change of ^{137}Cs concentration and mean body length of stone flounders

of size together with the size-dependent concentration in this species (caused by change of food habits with growth, Figs. 3 & 5).

Through our investigations of food habits it is possible to describe most of the concentration levels of ^{137}Cs in surface fishes (those that inhabit the surface layers with a sea temperature of approximately 10 to 25°C); however, we identified another group of fishes having relatively high concentration levels of ^{137}Cs despite a low concentration in their food (e.g. walleye pollack, Atka mackerel, and deep-sea smelt, all of which inhabit deep-sea areas with a water temperature of less than 3 to 5°C), indicating that concentrations of ^{137}Cs in these fishes could not be explained only through their food habits. Kolehmainen et al. (1968) and Cocchio et al. (1995) suggested a decrease of excretion rate (increased biological half-lives) when the difference of environmental temperature is more than 10°C. Because there is no information on the absorption rate of ^{137}Cs at low temperatures or in changing temperatures, it is not possible at this stage to make conclusions about factors affecting accumulation of ^{137}Cs in deep-sea fishes. However, it is reasonable to suggest that environmental conditions (e.g. sea temperature) together with biological conditions (e.g low food availability) may affect accumulation of ^{137}Cs in these fishes. Since there is little information on the effect of depth of habitat (effect of temperature, difference of food or availability of food, etc.) on accumulation of radionuclides, especially for ^{137}Cs, this is a topic that should be investigated further.

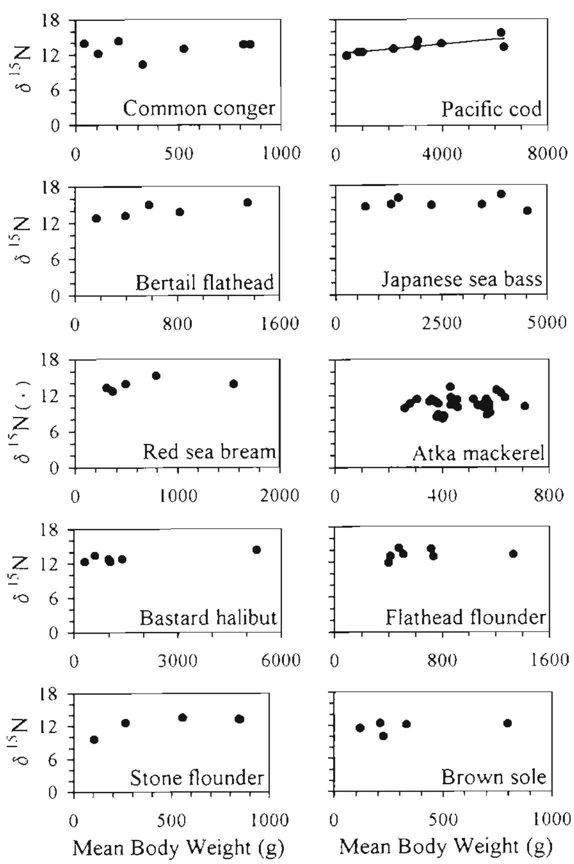

Fig 11 Relationship between weight of fish and $\delta^{15}N$ (from Kasamatsu et al. unpubl.). Muscle samples for $\delta^{15}N$ were frozen and $\delta^{15}N$ was measured using a Finnigan MAT Model delta E, following the method described in Minagawa & Wada (1984)

The natural variation of $\delta^{15}N$, which has recently been used to identify the trophic level of animals in relation to their food habits or trophic levels (Owens 1987, Wada et al. 1987, Fry 1988), was examined and its behavior compared in relation to food habits to that of ^{137}Cs. Fig. 11 shows the relationship between body weight and $\delta^{15}N$ in 10 fish species in which the ^{137}Cs concentration was also measured. In common Japanese conger, Pacific cod, bartail flathead and stone flounder, which shift their food habits to a higher trophic level with growth, ^{137}Cs concentration shows good agreement with the change of food habits according to growth (Figs. 2 & 3) but $\delta^{15}N$ does not show a significant change with growth except Pacific cod. Because the biological half-life of ^{137}Cs is relatively short (approximately 100 d; Gomez et al. 1991), concentration of ^{137}Cs in fishes may well reflect minor changes in prey species or variation of food quantity better than $\delta^{15}N$.

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