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(Contract Number: Fission-2010-3.5.1-269672)

DELIVERABLE (D-N°3.5)

Report on fluxes and trophic transfer of radiocaesium in marine ecosystems

Author(s): **Zofia Baumann, Daniel Madigan, Jun Nishikawa, Cuiyu Wang, Shelagh Zegers and Nicholas Fisher**

Editor: **Laureline Février**

Reporting period: 01/02/14 – 31/07/15

Date of issue of this report: 30/07/2015

Start date of project: 01/02/2011 Duration: 54 Months

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<tr><td colspan="3">Dissemination Level</td></tr>
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Executive Summary

An emergent trend of the Fukushima disaster has been the persistence of radionuclides, particularly ^{134}Cs and ^{137}Cs, in bottom-dwelling fish. Public health concerns regarding the continued release of radionuclides from the damaged Fukushima reactor into coastal waters are tied most prominently to radionuclide concentrations in seafood (not directly from water or sediment), and it is critical to understand both the concentrations of major radionuclides in key marine animals and the rates and routes of their bioaccumulation. Understanding the processes affecting the bioaccumulation should enable better management of key environmental regions and help guide the selection of seafood items for further monitoring. Recent studies in these waters have revealed that sediments are highly enriched in ^{134}Cs and ^{137}Cs. We hypothesized that contaminated sediments serve as an important source of Cs isotopes for benthic food chains in coastal waters off Fukushima. Testing this hypothesis requires an approach that integrates lab-based experiments with analyses of field-collected samples. This report describes results of laboratory experiments that address the extent to which contaminated sediments can serve as a source of radioactive caesium for benthic food webs. It also describes radiocaesium measurements of biota collected from several research cruises off Fukushima, focusing on benthic organisms, but also contrasting them with some pelagic organisms at the same sites. Experiments have generated trophic uptake and elimination parameters for Cs in key benthic animals. Our experimental results show (1) that Cs can desorb from contaminated sediments at rates influenced by bioturbation, (2) sediment can be a source of Cs for marine benthic fauna, and (3) efficient assimilation of Cs from prey can lead to its build-up in benthic food chains. Thus, the experimental findings help explain why bottom fish remain more contaminated by radiocaesium than pelagic fish. In addition, field-collected samples allowed for reconstruction of benthic and pelagic food web dynamics via gut content analysis, stable isotope analysis (SIA) and radioanalysis of biota and will be used to infer relationships between dietary inputs of Cs and activity levels in fish. These combined approaches provide a holistic picture of the factors governing the Cs transport through benthic ecosystems near Fukushima and also provide critical information to further assess public health implications of Cs fluxes in benthic regions off Fukushima. The findings may also be relevant to other coastal regions subject to Cs contamination, either from ongoing activities or future accidents.

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1 Background and Concepts

A major emergent trend of the Fukushima disaster has been the persistence of radionuclides, particularly ^{134}Cs and ^{137}Cs, in bottom-dwelling (benthic and demersal) fish (Buesseler 2012; Iwata et al. 2013; Fisher group unpubl.) (Fig. 1). This suggests a persistent source of radionuclides to bottom fish in coastal waters off Fukushima, which could present a serious concern for public health in the region. Recent studies in these waters have revealed that marine sediments are highly enriched in ^{134}Cs and ^{137}Cs (Kusakabe et al. 2013). We hypothesized that contaminated sediments serve as an important source of Cs isotopes for benthic food chains in coastal waters off Fukushima. Testing this hypothesis requires an approach that combines laboratory-based experiments with analyses of field-collected samples. Experiments generated trophic uptake and elimination parameters for radiocaesium, and field-collected samples allowed for reconstruction of benthic and pelagic food web dynamics via gut content analysis, stable isotope analysis (SIA) and radioanalysis of biota. Importantly, no study has thus far evaluated Cs transfer from sediment to deposit-feeding animals (e.g., polychaetes) and from these detritivores to their predators (such as crabs and flatfish that are common to the Fukushima benthos). These combined approaches provided a more holistic picture of the factors that govern radiocaesium transport through benthic ecosystems near Fukushima.

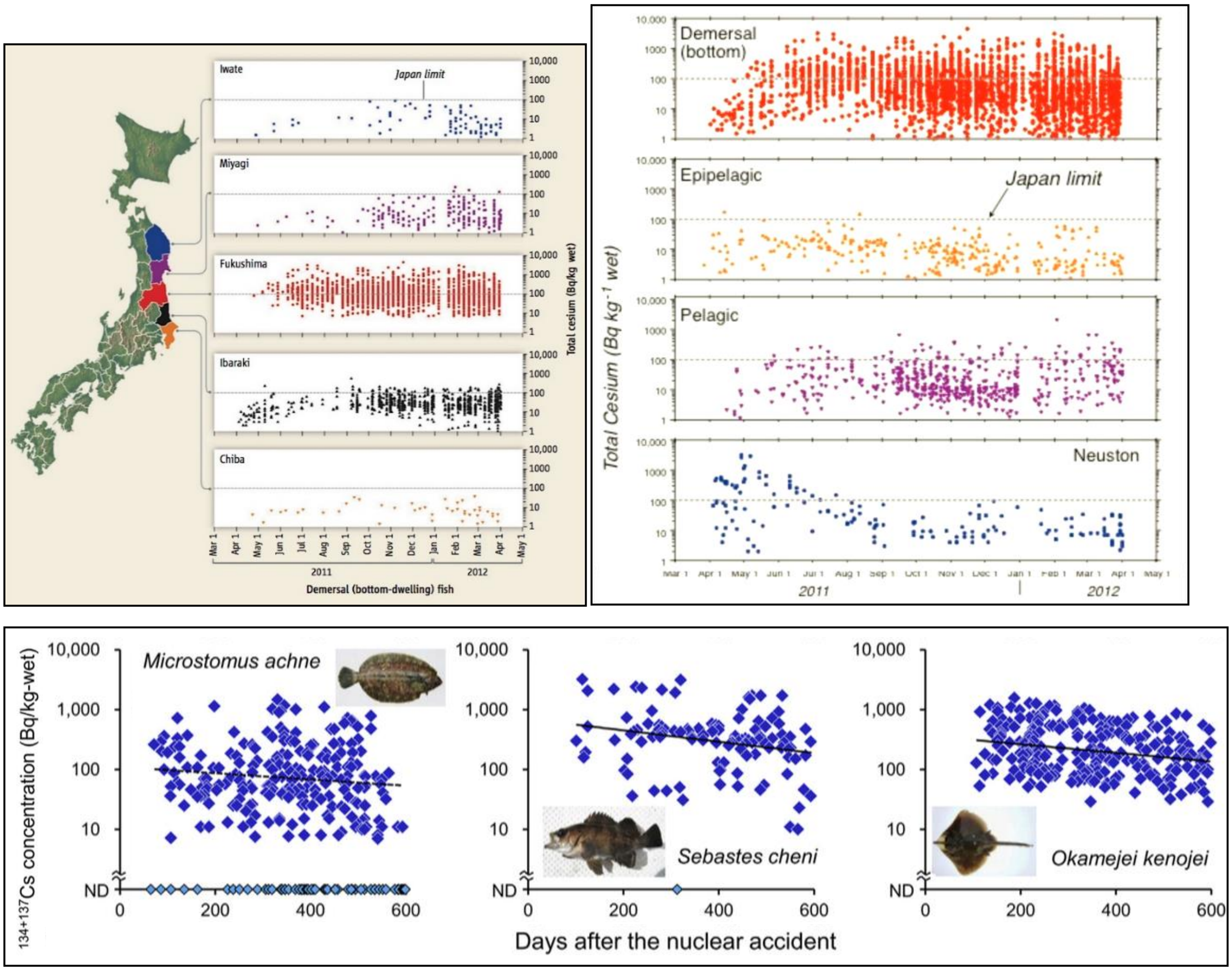

Fig. 1. After the tsunami and damage to the Fukushima nuclear power plant in March 2011, bottom fish caught off Fukushima have had higher radiocesium (^{134}Cs and ^{137}Cs) levels than those to the north and south (Fig. 1a) and higher levels than pelagic fish (Fig. 1b), with no clear decline during the first 2 years after the accident (Fig. 1c). Benthic invertebrates, many being prey items for bottom fish, show the same slow decrease in radiocesium as sediments, suggesting that contaminated sediment is a continuing source of radiocesium in these invertebrates and bottom fish.

This new work complements ongoing evaluation of field measurements of ^{134}Cs and ^{137}Cs in zooplankton, benthic invertebrates and fish. Some of this work has been performed with the collaboration of Japanese colleagues (J. Nishikawa, Tokyo University, and T. Ishimaru, Tokyo Univ. of Marine Science and Technology). Thus far, our research has revealed interesting trends of bioaccumulation of Fukushima radionuclides in pelagic marine animals (Buesseler et al. 2012; Madigan et al. 2012, 2013, 2014; Fisher et al. 2013). The fluxes of radiocaesium in the benthos were therefore evaluated within the context of ongoing research of biological interactions of Cs in the upper water column.

Elevated contaminant levels in bottom-dwelling animals are not unique to Fukushima, as other marine sites have shown contaminant buildup in benthic food webs. Although sediments have often been considered to be the final repositories of particle-reactive metals in marine systems, in recent years it has been recognized that some metals may be mobilized by and assimilated into benthic biota. In fact, contaminated sediments have been shown to be a dominant source of some metals for benthic animals (Luoma and Fisher 1997; Wang and Fisher 1999; Baumann and Fisher 2011). Contaminated sediments are of concern if the contaminants are in a bioavailable form; that is, if they can accumulate in biological tissue instead of being irreversibly bound to sediment under prevailing environmental conditions. Bioavailability of metals from sediments or other food can be quantified by measuring the assimilation efficiency (AE, or the percent of ingested metal that is assimilated into an organism's tissues). AEs can be used with experimentally determined efflux (loss) rates and influx (uptake) rates from water in simple, predictive bioaccumulation models that have been field-tested in diverse bodies of water for a variety of invertebrate and vertebrate marine animals (Wang et al. 1996; Luoma and Rainbow 2005; Baumann and Fisher 2011; Dutton and Fisher 2014) (Fig. 2).

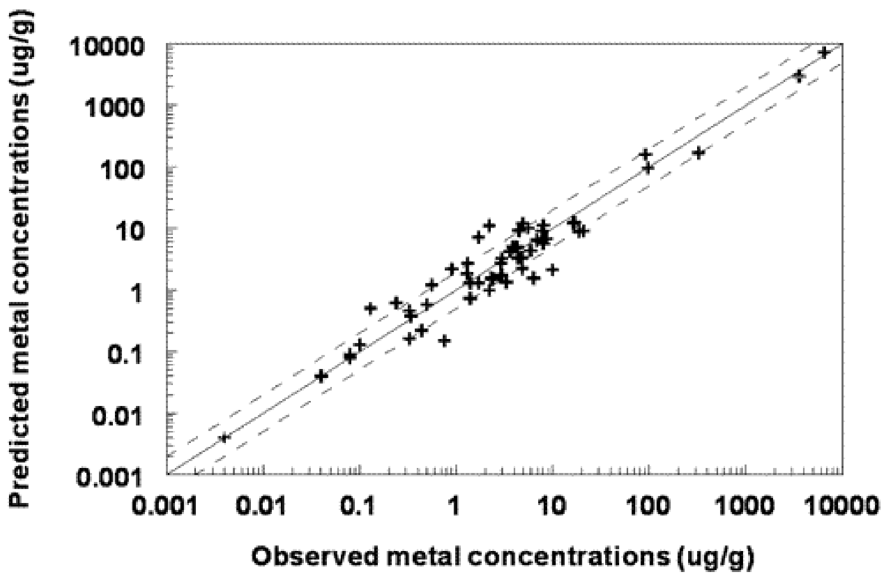

Fig. 2. Relationship between modeled and field measurements of metals in marine animals (from Luoma and Rainbow 2005).

Public health concerns regarding the continued release of radionuclides from the damaged Fukushima reactor into coastal waters are tied most prominently to radionuclide concentrations in seafood (not water or sediment), and it is critical to understand both the concentrations of major radionuclides in key marine animals and the rates and routes of their bioaccumulation. Understanding the processes underlying the bioaccumulation therefore enables better management of key environmental regions and guiding the selection of seafood items for further monitoring.

2 Objective

The key objective of the proposed work was to determine the extent to which contaminated sediment in Japanese coastal regions can serve as a source of radiocaesium for benthic food chains, leading to primary (detritivores), secondary (small fish and crabs), and tertiary consumers (large fish) and eventually to humans. This study integrated laboratory and field measurements to quantify the extent to which trophic Cs transfer from sediments to polychaete worms, benthic invertebrates, and fish can account for the elevated radioactivity in bottom fish. As noted above, the underlying hypothesis is that sediments can serve as a significant source of Cs for benthic food chains. The proposed work is relevant not just to Fukushima but also to other coastal regions that are subject to radiocaesium contamination, either from ongoing activities or from future accidents.

NOTE: This document includes the data analysis report (MS 3.12).

3 Laboratory experiments

To assess the release of Cs from Fukushima sediments, non-radioactive seawater was added to overlay ^{137}Cs-labeled sediment (worms were added in bioturbation experiments); overlying seawater was sampled periodically to determine ^{137}Cs release from sediments (Figs. 3, 4). ^{137}Cs desorption from the sediment and diffusion in overlying seawater reached equilibrium in four days (Fig. 3). The differences of ^{137}Cs flux in the 3 sediment depths were not significant. Bioturbation by polychaete worms clearly enhanced the initial release rate of ^{137}Cs from sediments to overlying water, and was in part dependent on the worm density (Fig. 4). The ^{137}Cs K_d values were 44±1.5 ml g^{-1}, 60±4.9 ml g^{-1} and 53±2.1 ml g^{-1} for the 3mm, 10mm, and 30mm treatments, respectively, almost 2 orders of magnitude lower than Cs K_d value (3×10^3 ml g^{-1}) for coastal sediments (IAEA 2004), possibly due to the large grain size (sand) of the sediments.

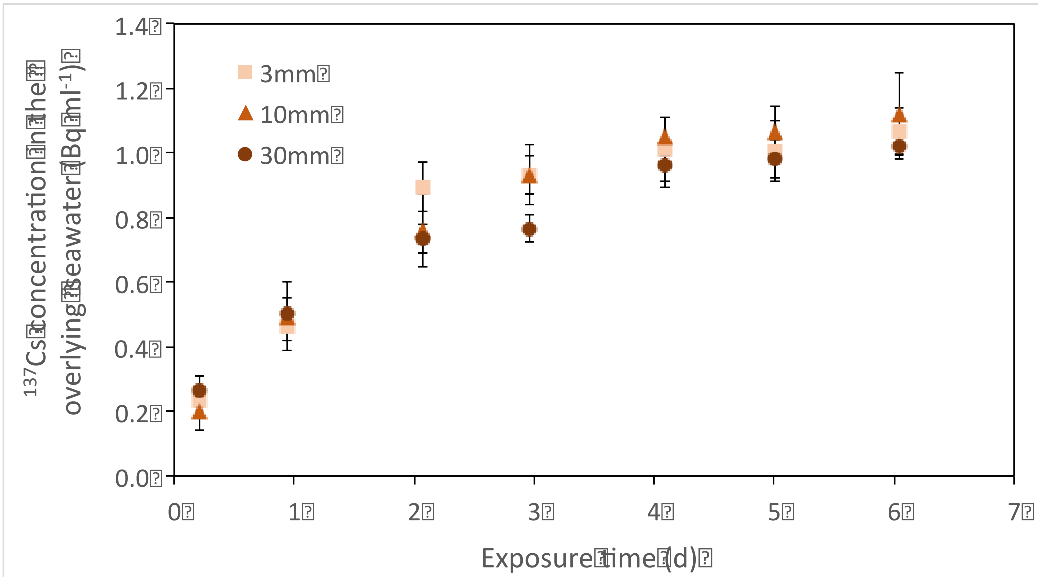

Fig. 3. Release of ^{137}Cs from contaminated sediment to overlying seawater.

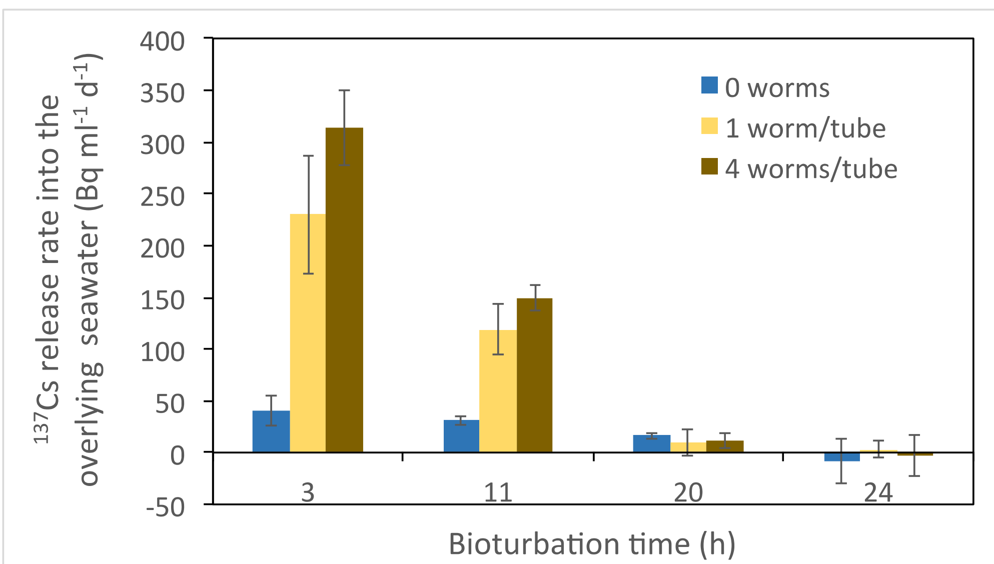

Fig. 4. Influence of polychaete bioturbation on release of ^{137}Cs from sediments into overlying seawater.

To evaluate the bioavailability of ^{137}Cs, the polychaete *Neries succinea*, the Asian shore crab *Hemigrapsus sanguineus*, and the killifish *Fundulus heteroclitus* were fed with ^{137}Cs labeled food (sediment for polychaetes, polychaetes for crabs, California black worms for killifish) or exposed to ^{137}Cs-labeled seawater to determine assimilation and retention of dietary and aqueous

^{137}Cs in the animals (Figs. 5-9). These parameters are critical for modeling radionuclide bioaccumulation. For dietary ^{137}Cs, the assimilation efficiency (AE) was highest in killifish, followed by the Asian shore crab, and lowest in the polychaetes, while loss rate constants (k_e) were highest in the polychaetes and lowest in killifish (Table 1). Both the AE and k_e of ^{137}Cs in killifish were similar to 3 other predator fishes, *P. maxima; S. auratus; S. canicula* (Mathews *et al*., 2008). For aqueous ^{137}Cs, the uptake and k_e from the animals were highest in polychaetes, followed by the Asian shore crab, and lowest in killifish (Table 2).

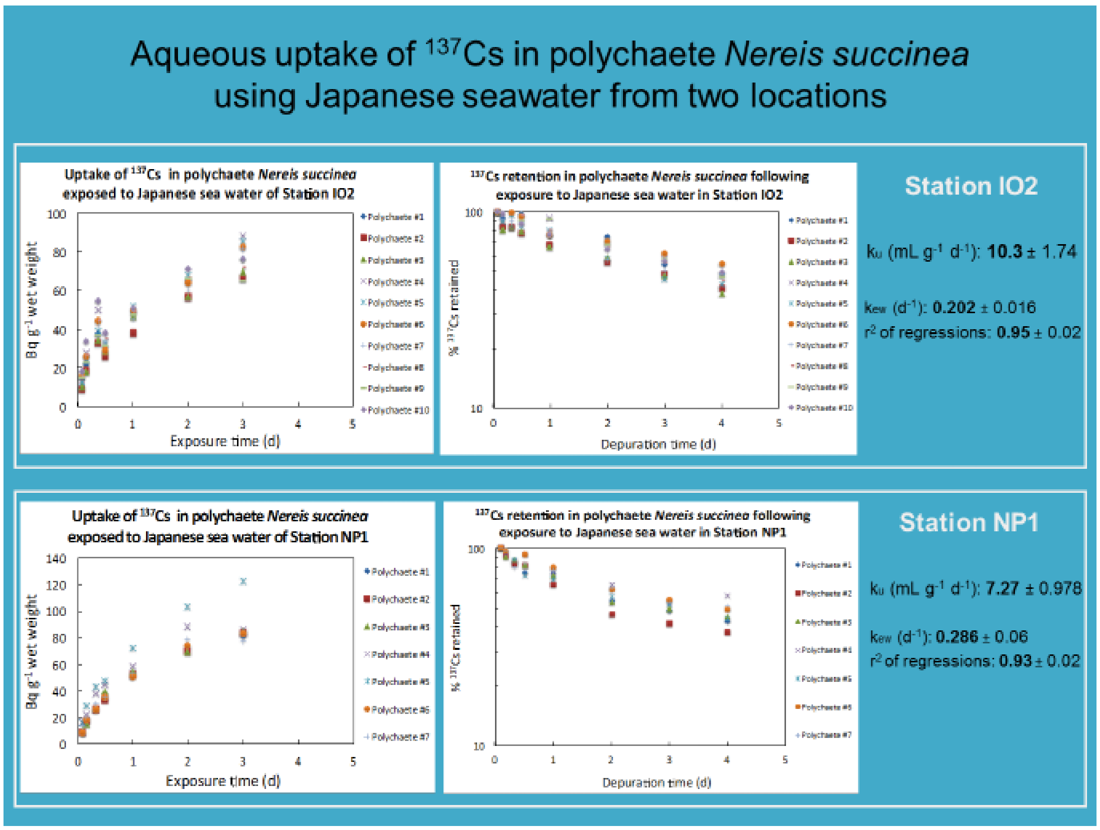

Fig. 5. Uptake and retention patterns of ^{137}Cs from the aqueous phase in the polychaete *Nereis succinea*

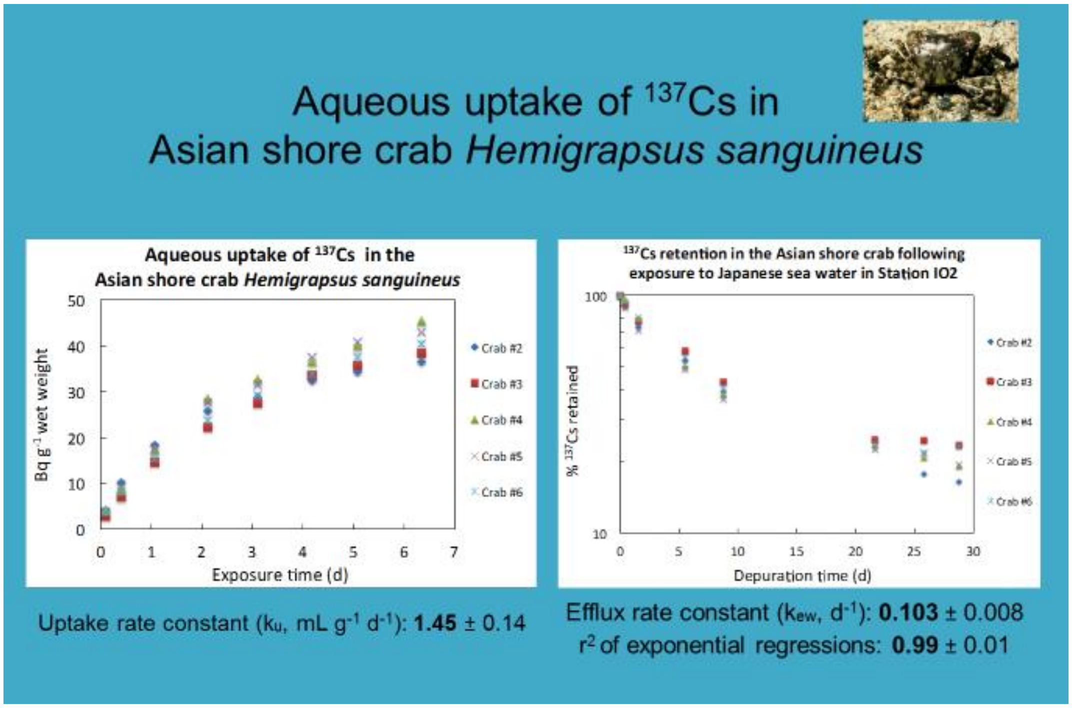

Fig. 6. Uptake and retention patterns of ^{137}Cs from the aqueous phase in the Asian shore crab *Hemigrapsus sanguineus*

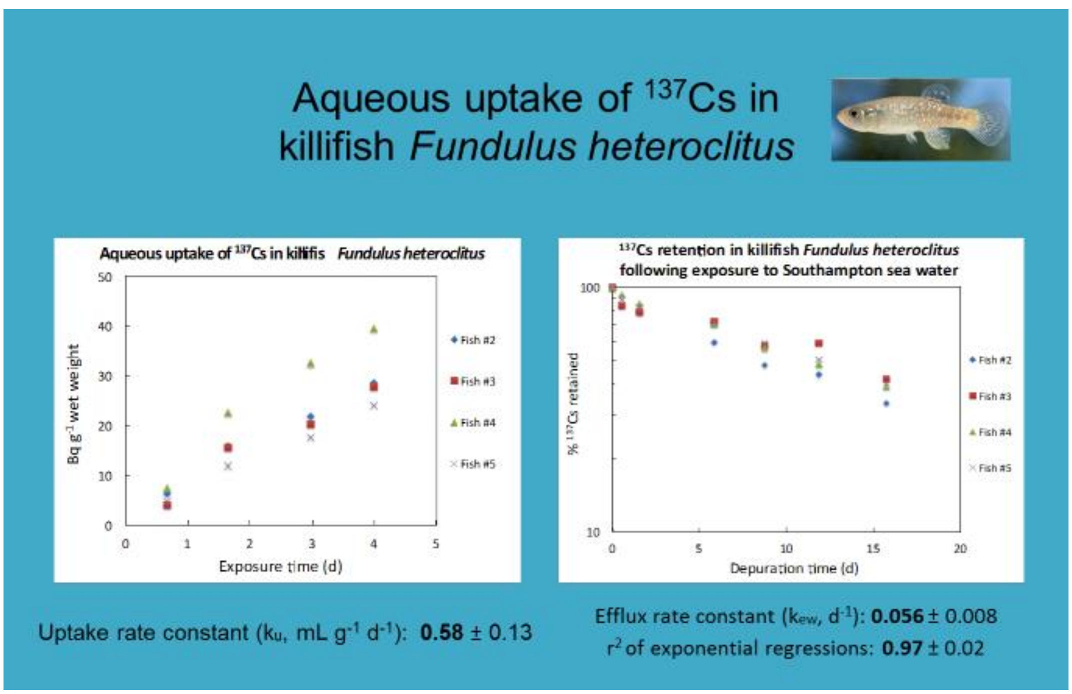

Fig. 7. Uptake and retention patterns of ^{137}Cs from the aqueous phase in the killifish *Fundulus heteroclitus*

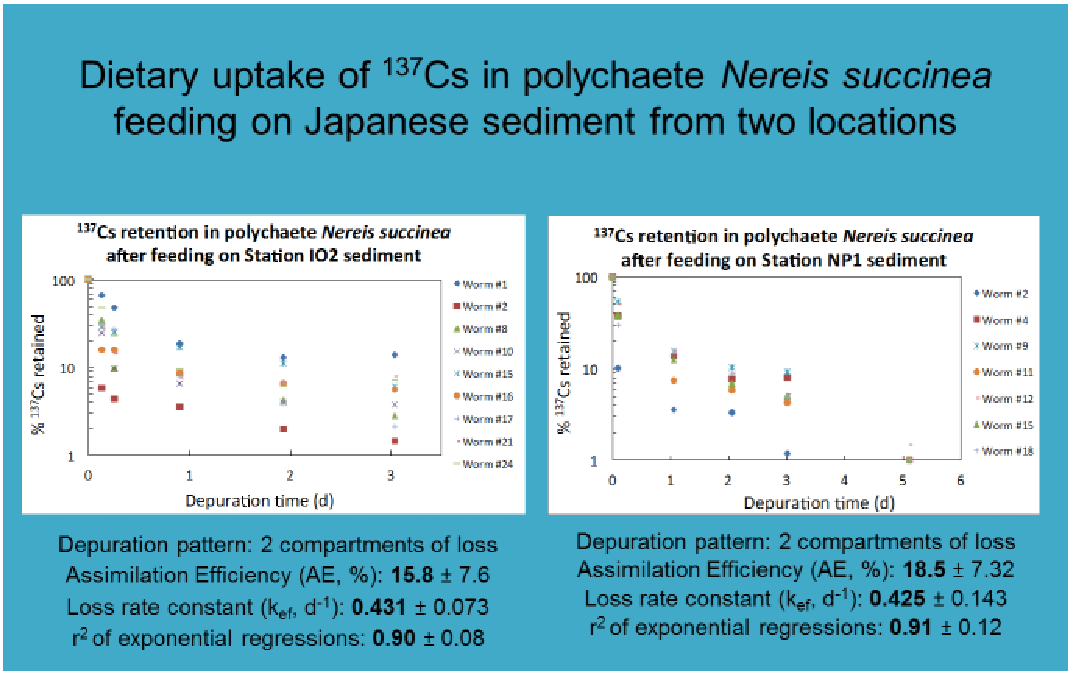

Fig. 8. Accumulation and retention of ^{137}Cs in the deposit-feeding polychaete *Nereis succinea* that fed on ^{137}Cs-contaminated Fukushima sediment.

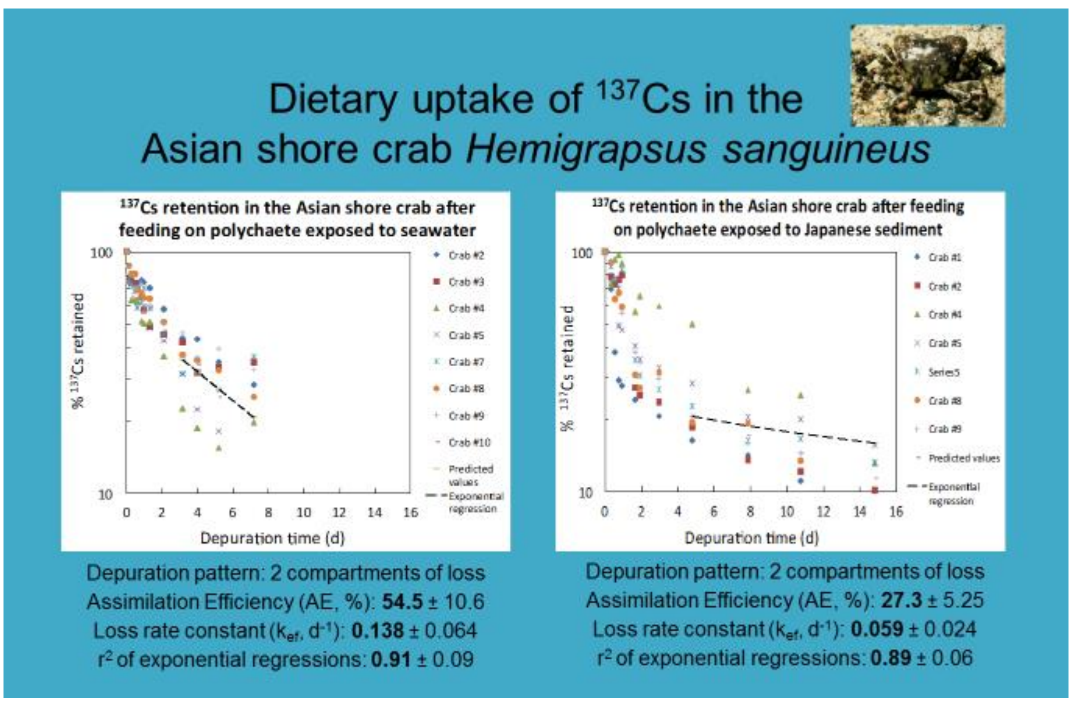

Fig. 9. Accumulation and retention of ^{137}Cs in the Asian shore crab *Hemigrapsus sanguineus* that fed on ^{137}Cs-contaminated worms

Table 1. Assimilation efficiencies and subsequent loss rates of ingested ^{137}Cs in worms, crabs, and fish

Comparison of dietary uptake parameters



Organism	Diet	Assimilation Efficiency (%)	Efflux rate constant k_{ef} (d^{-1})
Polychaete *Nereis succinea*	Japanese sediments	15.8 ± 7.6	0.4 ± 0.07
Asian shore crab *Hemigrapsus sanguineus*	Polychaete exposed to seawater	54.5 ± 10.6	0.1 ± 0.06
	Polychaete exposed to sediment	27.3 ± 5.3	0.06 ± 0.02
Killifish *Fundulus heteroclitus*	California black worm	78.5 ± 7.2	0.05 ± 0.01

The assimilation efficiency is the highest in killifish, followed by the Asian shore crab, and lowest in the polychaetes, while loss rate constant is highest in the polychaetes and lowest in killifish.

Polychaetes feeding on IO2 sediment have similar assimilation efficiencies and loss rate constant of ingested Cs as those feeding on NP1 sediment.

Both the assimilation efficiency and loss rate constant of killifish are similar as of other three predator fishes, *P. maxima*; *S. auratus*; *S. canicula* (*Mathews et al*, 2008).

Table 2. Comparison of dietary and aqueous uptake parameters of ^{137}Cs in benthic animals

Organism	Dietary Cs			Aqueous Cs	
	Diet	Assimilation Efficiency (%)	Efflux rate constant k_{ef} (d^{-1})	Uptake rate constant k_u (mL g^{-1} d^{-1})	Efflux rate constant k_{ew} (d^{-1})
Polychaete *Nereis succinea*	Japanese sediment	15.8 ± 7.6	0.4 ± 0.07	10.3 ± 1.7	0.2 ± 0.01
Asian shore crab *Hemigrapsus sanguineus*	Polychaete exposed to seawater	54.5 ± 10.6	0.1 ± 0.06	1.5 ± 0.1	0.1 ± 0.01
	Polychaete exposed to sediment	27.3 ± 5.3	0.06 ± 0.02		
Killifish *Fundulus heteroclitus*	California black worm	78.5 ± 7.2	0.05 ± 0.01	0.6 ± 0.1	0.06 ± 0.008

These experiments provide quantitative information on the mechanism and extent to which radiocesium in sediments becomes biologically available for benthic food webs. Specifically, our results suggest that ^{137}Cs can desorb from contaminated sediments at rates influenced by bioturbation and sediment can be a source of ^{137}Cs for marine benthic fauna. Further, efficient assimilation of ^{137}Cs from prey can lead to its build-up in benthic food chains. Our findings help explain why bottom fish remain more contaminated by radiocesium than pelagic fish.

4 Radioanalysis of Fukushima biota

Sampling was conducted during three cruises off Fukushima in June 2011 onboard US-based R/V Ka'imikai-o-Kanaloa, May 2013 onboard Japanese R/V Umitaka Maru, and September 2013 onboard Japanese R/V Dai-San Kaiyo Maru. Biota of multiple trophic levels from both pelagic and benthic food webs were sampled. At all sampling stations phytoplankton and/or zooplankton were collected by MTD, Bongo (June 2011 cruise) and ORI (May and September 2013 cruises) nets, or IKMT trawls (June 2011 and September 2013 cruise) for small forage fish (myctophids, anchovies) and squids. Hook and line collections also included pelagic, benthic, and demersal predatory fish, as well as large ommastrephid squid. Predatory fish species included dolphinfish and mackerels (pelagic), olive flounder, stone flounder, and gurnards (benthic), and Pacific cod, hammerhead shark, and croakers (demersal). Predator gut contents were also used to collect prey samples for analysis. Intact, recently consumed prey were removed, rinsed, and frozen for subsequent Cs and SI analyses. Prey items sampled from predator stomach contents included squid, crabs, shrimp, sand lances, flying fish, and other small forage fish.

Thus far, samples have been analyzed using high purity germanium detectors to determine activity concentrations of radiocesium. Most analyses have been completed, but a few more samples remain to be analysed (these are underway at the time of writing). Thus far, it appears that trophic transfer factors are low in both pelagic and benthic food webs at their base (TTFs: 0.003-3) and become elevated at the final link of the benthic food web as well as at the link between the large demersal fish and their prey items (TTFs: 22-150). Gamma radioanalysis was performed for freeze-dried and homogenized biota samples that were collected during 3 cruises off Japan. Spectra interpretation resulted in activities of 134Cs, 137Cs, both of which were Fukushima-released and 40K, a naturally occurring radionuclide. 40K was used for data quality control and to put the artificial radionuclide activities into context relative to natural radionuclide activities. Without this context, the public commonly shows alarm when presented artificial radioactivity measurements in marine samples (Fisher et al. 2015). Results are shown in Table 3. In September 2013 phytoplankton, small zooplankton and large zooplankton were collected from 13 different locations. The largest variation between sampling locations for radioactive isotopes of Cs was found for phytoplankton (e.g. 134Cs: from <DL to 411 Bq kg-1 dry wt.), followed by small zooplankton (e.g. 134Cs: from <DL to 297 Bq kg-1 dry wt.), and larger zooplankton (e.g. 134Cs: from <DL to 52 Bq kg-1 dry wt.) (Table 4). While 137Cs was detectable in all biota samples, 134Cs in many of the samples was below detection (e.g., squid and myctophid fish). Other pelagic fish such as Pacific mackerel had on average a very low level of 134Cs (0.4 Bq kg-1 dry wt.) (Table 3). Benthic flatfish had the highest levels of radiocesium (mean 134Cs: 36.6 Bq kg-1 dry wt.; Table 3). For samples which had detectable levels of 134Cs, the 134Cs: 137Cs ratios were 0.34 ± 0.08.

Table 3. All radioactive data for biological samples collected off Japan.

Sample code	Station	Sampling month&year	species	^{134}Cs Bq kg^{-1} dry wt.	±	^{137}Cs Bq kg^{-1} dry wt.	±	^{40}K Bq kg^{-1} dry wt	±	^{134}Cs:^{137}Cs
KK 13 -5 GM PRED 1-3 FO1D	F01	May-13	giant myctophiids pred 1-3	0.00	0.00	1.54	0.14	313.0	4.8	Bd
KK 13 -5 IKMT MYCTOPHIIDS FO1	FO1	May-13	myctophiids	0.00	0.00	0.76	0.11	395.4	5.7	Bd
KK 13 -5 IKMT MYCTOPHIIDS FO1D	FO1	May-13	myctophiids	0.00	0.00	2.38	0.38	376.9	12.2	Bd
KK 13 -5, PHYTO+ZOO, >300UM, st. F01	FO1	May-13	phyto +zooplankton	0.00	0.00	11.69	164.54	3120.5	43.1	Bd
KK 13 -5, PHYTO 100-300UM, st. FO1	FO1	May-13	phytoplankton	0.00	0.00	9.75	1.38	2896.5	39.4	Bd
KK 13 -5 ORI NOT DEEP FO1	FO1	May-13	zooplankton	0.00	0.00	2.21	0.20	129.3	3.4	Bd
KK 13 -5 ORI DEEP FO1	FO1	May-13	zooplankton	0.41	0.14	1.27	0.15	402.7	6.0	0.32
KK 13 -5 st. MAHI, DOR2	Mahi	May-13	dorado	0.00	0.00	0.91	0.08	760.1	5.4	Bd
KK 13 -5 st. MAHI, DOR3	Mahi	May-13	dorado	0.00	0.00	1.04	0.14	950.0	12.3	Bd
KK 13 -5 st. MAHI, DOR1	Mahi	May-13	dorado	0.00	0.06	1.52	0.08	663.8	4.9	Bd

KK 13 -5, PHYTO+ZOO, >300UM, st. N01	NO1	May-13	phyto +zooplankton	0.00	0.00	0.00	0.00	346.2	5.6	Bd
KK 13 -5 ORI N01	NO1	May-13	zooplankton	1.32	0.11	4.56	0.18	229.0	2.9	0.29
KK 13 -5, PHYTO+ZOO, >300UM, st. N02	NO2	May-13	phyto +zooplankton	1.14	0.51	6.27	0.61	1098.7	14.4	0.18
KK 13 -5, PHYTO 100-300UM, st. NO2	NO2	May-13	phytoplankton	0.00	0.00	5.57	1.87	461.6	18.4	Bd
KK 13 -5 st. NO2, squid A	NO2	May-13	squid	0.00	0.00	0.00	0.00	578.1	9.0	Bd
KK 13 -5 st. NO2, squid B	NO2	May-13	squid	0.00	0.00	0.65	0.06	577.0	3.9	Bd
KK 13 -5 st. NO2, squid C	NO2	May-13	squid	0.00	0.00	0.40	0.05	649.3	4.0	Bd
KK 13 -5 st. NO2, squid D	NO2	May-13	squid	0.00	0.00	0.00	0.00	1052.6	10.3	Bd
KK 13 -5 ORI N02	NO2	May-13	zooplankton	3.90	0.34	10.92	0.47	329.8	9.0	0.36
KK 13 -5, PHYTO+ZOO, >300UM, st. N03	NO3	May-13	phyto +zooplankton	0.00	0.00	0.00	0.00	502.7	16.7	Bd
KK 13 -5, PHYTO 100-300UM, st. NO3	NO3	May-13	phytoplankton	0.00	0.00	18.49	1.46	494.3	8.5	Bd

KK 13 -5 ORI N03	NO3	May-13	zooplankton	0.39	0.11	1.60	0.13	275.7	3.4	0.24
KK 13 -5 ORI??? NO4	NO4	May-13	large shrimp	0.00	0.00	0.52	0.09	454.1	4.6	Bd
KK 13 -5 IKMT MYCTOPHIIDS N04	NO4	May-13	myctophiids	0.00	0.00	0.79	0.09	310.1	4.1	Bd
KK 13 -5 ORI N04	NO4	May-13	zooplankton	0.82	0.14	2.38	0.19	310.0	5.0	0.35
KK 13 -5, PHYTO+ZOO, >300UM, st. NP0	NP0	May-13	phyto +zooplankton	296.82	6.11	727.38	9.82	569.8	25.8	0.41
KK 13 -5 ORI NPO	NP0	May-13	zooplankton	52.42	1.21	127.30	1.96	222.8	9.6	0.41
KK 13 -5 st. NP1, JM1+JM2	NP1	May-13	jack mackarel	1.95	0.31	6.66	0.46	801.9	17.1	0.29
KK 13 -5 st. NP1, JM3+JM4	NP1	May-13	jack mackarel	3.61	0.30	9.62	0.39	752.4	12.7	0.38
KK 13 -5 st. NP1, HALIBUT 1	NP1	May-13	Olive flounder	8.56	0.36	20.43	0.54	733.1	13.2	0.42
KK 13 -5 st. NP1, PM6+PM7	NP1	May-13	pacific mackarel	0.31	0.08	1.12	0.11	588.4	5.6	0.28
KK 13 -5 st. NP1, PM4+PM5	NP1	May-13	pacific mackarel	0.39	0.08	1.35	0.10	533.9	5.4	0.29
KK 13 -5, PHYTO+ZOO, >300UM, st. NP1	NP1	May-13	phyto +zooplankton	0.00	0.00	0.00	0.00	551.8	18.1	Bd

KK 13 -5, PHYTO 100-300UM, st. NP1	NP1	May-13	phytoplankton	0.00	0.00	0.00	0.00	815.2	36.8	Bd
KK 13 -5 ORI NP1 amphipods removed	NP1	May-13	zooplankton	1.35	0.22	3.89	0.28	362.7	7.5	0.35
KK 13 -5 ORI NP1	NP1	May-13	zooplankton	1.43	0.26	3.64	0.35	184.5	6.4	0.39
KK 13 -5 st. NP2, HH1	NP2	May-13	hammerhead shark	6.75	0.51	18.22	0.79	635.0	19.4	0.37
KK 13 -5, PHYTO+ZOO, >300UM, st. NP2	NP2	May-13	phyto +zooplankton	9.60	1.16	25.01	1.59	868.2	29.0	0.38
KK 13 -5 ORI NP2	NP2	May-13	zooplankton	1.18	0.19	3.27	0.22	194.6	4.7	0.36
KK 13 -5, PHYTO+ZOO, >300UM, st. NP3	NP3	May-13	phyto +zooplankton	0.00	0.00	8.44	0.79	475.0	8.6	Bd
KK 13 -5, PHYTO 100-300UM, st. NP3	NP3	May-13	phytoplankton	0.00	0.00	16.26	1.99	453.5	10.8	Bd
KK 13 -5 ORI NP3	NP3	May-13	zooplankton	2.16	0.38	6.30	0.46	380.8	10.7	0.34
KK 13 -5, JM4+JM5+JM6, wm, NPE1	NPE1	May-13	jack mackarel	10.13	1.07	26.47	1.68	834.8	38.1	0.38
KK 13 -5, JM1+JM2+JM3, wm, NPE1	NPE1	May-13	jack mackarel	7.15	0.57	18.24	0.80	835.7	20.6	0.39

KK 13 -5 PACIFIC MACKAREL, 31 cm, wm, NPE1	NPE1	May-13	pacific mackarel	0.00	0.00	2.32	0.30	676.9	11.2	Bd
KK 13 -5 PACIFIC MACKAREL, 29cm, wm, NPE1	NPE1	May-13	pacific mackarel	1.15	0.22	2.89	0.29	1010.1	12.5	0.40
KK 13 -5 st. NPE1, PM3	NPE1	May-13	pacific mackarel	0.00	0.00	2.87	0.45	884.2	16.0	Bd
KK 13 -5, PHYTO+ZOO, >300UM, st. NPE1	NPE1	May-13	phyto +zooplankton	63.34	2.36	164.88	3.51	420.5	16.9	0.38
KK 13 -5, PHYTO 100-300UM, st. NPE1	NPE1	May-13	phytoplankton	5.92	1.05	13.99	1.25	1493.5	24.5	0.42
KK 13 -5 ORI NPE1	NPE1	May-13	zooplankton	1.93	0.28	4.27	0.38	211.3	7.4	0.45
KK 13 -5 st. NPE2, HALIBUT 2	NPE2	May-13	Olive flounder	64.59	0.96	155.63	1.54	708.5	14.6	0.42
KK 13 -5, PHYTO+ZOO, >300UM, st. NPE2	NPE2	May-13	phyto +zooplankton	78.05	4.91	218.48	7.89	615.9	42.6	0.36
KK 13 -5, PHYTO 100-300UM, st. NPE2	NPE2	May-13	phytoplankton	75.54	2.92	202.31	4.47	524.6	22.1	0.37
KK 13 -5 ORI NPE2	NPE2	May-13	zooplankton	46.53	1.48	111.45	2.35	246.7	13.2	0.42
KK 13 -5, PHYTO 100-300UM, st. NP0	NPO	May-13	phytoplankton	411.14	4.77	1015.12	7.71	562.8	21.1	0.41

KK 13 -5 sea robin, wm, RA3	RA3	May-13	sea robin	2.54	0.25	7.85	0.43	530.7	12.1	0.32
KK 13 -5 st. RA4, DOR2	RA4	May-13	dorado	0.00	0.00	0.70	0.06	582.8	4.1	Bd
KK 13 -5 st. RA4, DOR1	RA4	May-13	dorado	0.32	0.05	1.35	0.09	636.8	4.7	0.24
KK 13 -5, croaker 2, Sendai	Sendai	May-13	croaker	3.08	0.36	8.78	0.53	260.8	11.2	0.35
KK 13 -5, croaker 1, Sendai	Sendai	May-13	croaker	10.48	0.70	25.96	0.99	891.4	21.1	0.40
JCJ14 NPE2B	NPE2	Sep-14	zooplankton	51.92	1.92	128.42	2.14	393.6	9.0	0.40
JCJ14 FO1	FO1	Sep-14	zooplankton	bd		3.65	0.59	763.5	14.4	Bd
JCJ14 NO3A	NO3	Sep-14	zooplankton	bd		7.15	0.68	282.0	5.9	Bd
JCJ14 NO3B	NO3	Sep-14	zooplankton	bd		0.09	0.01	242.8	4.4	Bd
KS1406 126	?	Sep-14	Pacific Cod	5.51	0.38	14.48	0.39	642.0	8.5	0.38
KS1406 131	?	Sep-14	Pacific Cod	1.70	0.30	7.44	0.34	706.6	9.5	0.23
KS1406 42	?	Sep-14	Pacific Cod	8.05	0.37	21.22	0.46	576.4	9.2	0.38

KS1406 56	?	Sep-14	Flounder	7.10	0.33	18.69	0.38	710.4	8.7	0.38
KS1406 57	?	Sep-14	Flounder	13.17	0.37	33.50	0.44	601.6	7.5	0.39
KS1406 69	?	Sep-14	Pacific Cod	1.59	0.21	4.96	0.21	769.3	8.2	0.32
JCJ14 NPE2A	NPE2	Sep-14	zooplankton	134.98	3.08	345.63	3.80	2163.1	30.7	0.39
JCJ14 NP0	NP0	Sep-14	zooplankton	110.70	5.04	387.65	7.40	414.6	12.0	0.29
KS1406 122	?	Sep-14	Pacific Cod	bd		3.44	0.22	718.0	9.5	Bd
KS1406 125	?	Sep-14	Pacific Cod	8.59	0.36	20.28	0.40	928.4	9.7	0.42
JCJ14 NO4	NO4	Sep-14	zooplankton	bd		2.10	0.47	710.5	13.0	Bd
JCJ14 NP2A	NP2	Sep-14	zooplankton	12.68	0.92	34.29	0.97	373.6	8.6	0.37
JCJ14 NP2B	NP2	Sep-14	zooplankton	27.83	1.22	72.63	1.44	489.9	12.3	0.38
JCJ14 NP3A	NP3	Sep-14	zooplankton	bd		4.86	0.68	681.4	14.8	Bd
JCJ14 NP3B	NP3	Sep-14	zooplankton	bd		3.42	0.65	818.9	13.9	Bd

JCJ14 NPE2C	NPE2	Sep-14	zooplankton	21.32	1.09	56.95	1.20	843.3	14.7	0.37
KS1406 93	?	Sep-14	Pacific Cod	1.31	0.22	4.20	0.20	842.2	8.4	0.31
KS 1406 101	?	Sep-14	Greenling	7.54	0.97	21.53	1.09	739.6	22.0	0.35
KS1406 105	?	Sep-14	Flounder	12.87	1.05	31.32	1.10	912.3	22.0	0.41
KS1406 48	?	Sep-14	Pacific Cod	0.79	0.13	2.74	0.15	679.8	6.6	0.29

Table 4. A summary for radiocesium in planktonic biota off Fukushima in September 2013.

Organism	^{134}Cs Bg kg^{-1} dry wt			^{137}Cs Bg kg^{-1} dry wt			^{134}Cs:^{137}Cs		
	min	max	mean	min	max	mean	min	max	mean
phytoplankton (mesh opening 100-300 µm)	<DL	411	62	0.0	1015	160		0.42	0.15
phyto & zooplankton (mesh opening >300 µm)	<DL	297	45	0.0	727	116		0.41	0.17
zooplankton	<DL	52	8.8	1.3	127	22		0.45	0.33
large shrimp	<DL	<DL	<DL	0.5	0.5	0.5			
squid	<DL	<DL	<DL	<DL	0.6	0.3			
giant myctophids pred 1-3	<DL	<DL	<DL	1.5	1.5	1.5			
myctophiids	<DL	<DL	<DL	0.8	2.4	1.3			
Pacific mackerel	<DL	1.1	0.4	1.1	2.9	2.1		0.40	0.19
jack mackerel	2.0	10.1	5.7	6.7	26.5	15.2	0.29	0.39	0.36
croaker	3.1	10.5	6.8	8.8	26.0	17.4	0.35	0.40	0.38
sea robin	2.5	2.5	2.5	7.8	7.8	7.8	0.32	0.32	0.32
hammerhead shark	6.8	6.8	6.8	18.2	18.2	18.2	0.37	0.37	0.37
dorado	<DL	0.3	0.1	0.7	1.5	1.1		0.24	0.05
olive flounder	8.6	64.6	36.6	20.4	155.6	88.0	0.42	0.42	0.42

5 Stable isotope analysis of Fukushima biota

SIA is a tool increasingly used by ecologists to model food webs and to examine nutrient flow within or across ecosystems (e.g., Cabana and Rasmussen 1994; Madigan et al. 2012b). Carbon, nitrogen, and sulfur isotope ratio values ($\delta^{13}C$, $\delta^{15}N$, and $\delta^{34}S$) vary depending on the base of local food webs (*i.e.*, coastal versus pelagic). These isotope ratios, particularly $\delta^{34}S$, have been useful in determining the relative proportion of benthic inputs to consumer diets (e.g., Fry 1988). All predator species collected off Fukushima, particularly demersal predators which move between the benthos and the water column, may have variable inputs of benthic and pelagic food sources. Quantification of the relative importance of these dietary inputs allows the examination of trophic transfer of Cs as the dominant mechanism by which benthic and demersal fish off Fukushima acquire and retain high concentrations of Cs in their muscle tissue.

We have thus far sampled and analyzed for stable isotope analysis (SIA) 270 samples for $\delta^{13}C$ and $\delta^{15}N$. Samples include benthic and pelagic crustaceans, bivalves, cephalopods, fishes, and elasmobranchs (see Table 5). The primary objective of the SIA component of this project is to quantitatively assess the relative proportional inputs of benthic and/or pelagic prey sources to predator diets. This requires that benthic and pelagic prey items are discrete as characterized by $\delta^{13}C$ and $\delta^{15}N$ values. Based on the data we have generated, this is indeed the case. Benthic organisms are more enriched (higher values) in both $\delta^{13}C$ and $\delta^{15}N$ than analogous pelagic organisms. Bayesian mixing model estimates will thus be highly informative. Bayesian mixing models can be applied to these data to assess the relative inputs of pelagic and benthic prey for predators that theoretically feed on both (predators characterized as 'mixed' in Table 5), using only the $\delta^{13}C$ and $\delta^{15}N$ values presented here. However, SIA of sulfur ($\delta^{34}S$) is extremely useful in differentiating organisms that feed within benthic versus pelagic food webs. In addition, adding an additional isotopic marker ($\delta^{34}S$) to $\delta^{13}C$ and $\delta^{15}N$ greatly increases the reliability and precision of mixing model estimates. SIA of $\delta^{34}S$ is currently underway at the Stable Isotope Biogeochemistry Laboratory at Indiana University-Purdue University Indianapolis using a Delta V isotope mass spectrometer. Once SIA of $\delta^{34}S$ is completed, ratios of $\delta^{13}C$, $\delta^{15}N$, and $\delta^{34}S$ will be used to reconstruct benthic and pelagic food webs using MixSir Version 4.0. As proposed, these values will be compared to radiocaesium measurements in both prey and predators to quantitatively assess the role of diet in radiocaesium uptake in predators inhabiting waters near the failed Fukushima plant.

Table 5. Results from stable isotope analyses

Sample code	Organism	pelagic or benthic	mass	$\delta^{15}N$ ‰	$\delta^{13}C$	C:N
HAL1	olive flounder	benthic	0.4765	12.0	-17.8	3.2
CR1	crab	benthic	0.5175	11.3	-17.0	3.4
CR2	crab	benthic	0.4611	11.6	-17.3	3.4
CR3	crab	benthic	0.4988	9.9	-18.4	4.3
CR4	crab	benthic	0.4806	9.9	-18.9	4.9
SHR1	shrimp	benthic	0.5080	10.7	-17.0	3.4
FLF1	flatfish (tiny)	benthic	0.5167	10.1	-19.0	3.8
EEL1	eel	benthic	0.4500	11.7	-17.8	3.4
ST NP1 UMI FISH 4	small flounder	benthic	0.4604	10.7	-17.6	3.6
UMIAN6 SEAWEED 2	seaweed	benthic	0.5431		-17.3	n/a
UMIAN6 SEAWEED	seaweed	benthic	0.555		-19.1	n/a
KKSENDAI CROAKER 2	croaker	benthic	0.4814	13.7	-17.2	3.2
KKRA3 SEAROBIN	sea robin	benthic	0.5628	13.2	-17.6	3.7
KKRA3 SEAROBIN	sea robin	benthic	0.5054	13	-17.7	3.7
KKSENPAI CROAKER 1	croaker	benthic	0.514	13.9	-16.9	3.2
ZOO+PHYTO	zooplankton + phyto	pelagic	0.4749	6.0	-21.1	4.0
PHYTO	phytoplankton	pelagic	0.5308	5.6	-21.6	4.5
ZOO+PHYTO	zooplankton + phyto	pelagic	0.4889	7.0	-21.5	3.9
SQA	squid	pelagic	0.5240	9.1	-20.9	3.8
PHYTO	phytoplankton	pelagic	0.4740	5.6	-21.9	4.1
PM6+PM7	pacific mackerel	pelagic	0.4651	10.5	-19.8	3.8
PHYTO	phytoplankton	pelagic	0.4697	5.5	-21.7	4.3
DOR1	dolphinfish	pelagic	0.5491	11.5	-18.9	3.3
DOR2	dolphinfish	pelagic	0.5030	11.3	-18.2	3.2
ANCH1	anchovy	pelagic	0.4945	8.6	-21.2	3.9
JELLY1	jellyfish	pelagic	0.5288		-20.5	4.3
SL1	sand lance	pelagic	0.4747	10.1	-19.7	4.5
SL2	sand lance	pelagic	0.4534	9.7	-18.9	3.7
SL3	sand lance	pelagic	0.5302	9.7	-20.0	4.4
SL4	sand lance	pelagic	0.5480	10.0	-19.6	3.9
SL5	sand lance	pelagic	0.4757	10.2	-19.5	4.2
SL6	sand lance	pelagic	0.5199	10.3	-19.7	4.2
SL7	sand lance	pelagic	0.5104	9.9	-19.7	4.4
SL8	sand lance	pelagic	0.5466	9.9	-19.9	4.5
SL9	sand lance	pelagic	0.5292	10.3	-18.6	3.9
SL10	sand lance	pelagic	0.5088	10.3	-19.5	4.2

SL11	sand lance	pelagic	0.5173	10.2	-18.3	3.6
SL12	sand lance	pelagic	0.4860	10.0	-18.8	3.8
SL13	sand lance	pelagic	0.4930	10.0	-19.3	4.2
SL14	sand lance	pelagic	0.5023	10.3	-18.5	3.4
T. JAP	tigriopus copepod	pelagic	0.5429	7.2	-20.0	4.9
COPES ORI	copepods	pelagic	0.4691	8.1	-22.3	4.4
SHR ORI	shrimp	pelagic	0.4719	6.6	-20.3	4.0
ZOOPL BULK	bulk zooplankton	pelagic	0.4851	6.7	-25.1	5.1
AMPHS ORI	amphipods	pelagic	0.4973	6.6	-21.6	5.1
T. JAP	tigriopus copepod	pelagic	0.5303	7.2	-20.7	4.9
SQ1	squid	pelagic	0.5281	10.5	-18.4	3.5
AMPHS	amphipods	pelagic	0.5370	7.4	-20.3	4.6
CRAB LARV	crab larvae	pelagic	0.5447	6.8	-20.5	4.7
JELLY1	jellyfish	pelagic	0.5485		-20.2	4.1
JELLY2	jellyfish	pelagic	0.5175		-20.7	4.2
KKNP2 FLY FISH	flying fish	pelagic	0.4503	8.4	-18.7	3.0
KKNP2 FLY FISH	flying fish	pelagic	0.5871	8.3	-18.7	3.1
KKNO2 BULK ZOOP	bulk zooplankton	pelagic	0.4956	6.9	-21.4	4.0
KKNO2 BULK ZOOP	bulk zooplankton	pelagic	0.5295	6.6	-21.1	4.0
KKNPI PMI	pacific mackerel	pelagic	0.5721	11.6	-19.5	3.8
KKNPI PMI	pacific mackerel	pelagic	0.5061	11.5	-20.2	4.3
KKNPE2 BULK ZOOP	bulk zooplankton	pelagic	0.5453	8.2	-19.7	4.8
KKNO2 SQUID D	squid	pelagic	0.5427	9.8	-20.4	3.8
KKNO2 SQUID D	squid	pelagic	0.5646	9.7	-20.2	3.6
KKNP3 BULK ZOOP	bulk zooplankton	pelagic	0.4405	5.7	-21.2	4.1
KKNPO PHYTO+ZOO	zooplankton + phyto	pelagic	0.4931	7.3	-20.1	4.3
KKNPO PHYTO+ZOO	zooplankton + phyto	pelagic	0.4682	6.5	-20.2	4.2
KKNPZ1 PM1WM	pacific mackerel	pelagic	0.5156	11.2	-19.4	3.3
KKNP2 BILK ZOOP	bulk zooplankton	pelagic	0.5585	7.2	-20.9	4.2
KK MAHI DOR3	dolphinfish	pelagic	0.5732	11.1	-18.4	3.2
KKNO3 BULK ZOOP	bulk zooplankton	pelagic	0.5393	6.5	-21.5	4.0
KKNO3 BULK ZOOP	bulk zooplankton	pelagic	0.4868	6.5	-21.2	3.9
KKNPE1 PM3	pacific mackerel	pelagic	0.5285	10.4	-19	3.3
KKFO1 HYCTOPHIDS A	myctophid	pelagic	0.4648	8.7	-22.9	6.0
KKFO1 HYCTOPHIDS A	myctophid	pelagic	0.5628	9.1	-21.6	4.9
KKNO2 SQUID C	squid	pelagic	0.5251	9.6	-20.6	3.9

KKNO2 SQUID C	squid	pelagic	0.458	8.9	-20.1	3.8
KKNPE1 ZOO+PHYTO	zooplankton + phyto	pelagic	0.4548	5.8	-21.3	4.0
KKNPE1 PHYTO	phytoplankton	pelagic	0.5114	5.6	-21.6	4.4
KKNO1 PHYTO+ZOO	zooplankton + phyto	pelagic	0.5594	6.3	-21.3	3.8
KKFOID MYCTS	myctophid	pelagic	0.432	8.9	-22.8	6.0
KKFOID MYCTS	myctophid	pelagic	0.5409	9	-22.4	5.4
KKNP1 PHYTO	phytoplankton	pelagic	0.5016	5.4	-21.5	4.2
KKNO4 MYCTS	myctophid	pelagic	0.4847	9.3	-23.8	9.9
KKNPE1 PM2	pacific mackerel	pelagic	0.5219	10.4	-19	3.2
KKNPO BULK ZOOP	bulk zooplankton	pelagic	0.541	7.3	-19.9	4.5
KK MAHI DOR2	dolphinfish	pelagic	0.5319	11.3	-18.9	3.1
KKNO3 ZOO+PHYTO	zooplankton + phyto	pelagic	0.5336	6.2	-21.8	3.9
KK MAHI DOR1	dolphinfish	pelagic	0.4932	11.2	-19.1	3.7
KKNP3 PHYTO	phytoplankton	pelagic	0.5375	5.2	-21.7	4.3
KKFO1 PHYTO	phytoplankton	pelagic	0.5482	5.5	-21.8	4.4
KKNP3 PALMACK	pacific mackerel	pelagic	0.4936	10.9	-20.5	4.2
KKNP3 PHYTO+ZOO	zooplankton + phyto	pelagic	0.4753	5.7	-21.2	3.8
KKNO2 PHYTO	phytoplankton	pelagic	0.508	6.2	-21.9	4.4
KKNP1 PHYTO+ZOO	zooplankton + phyto	pelagic	0.5241	6.7	-21.1	3.9
KKNP1 PM4+PM5	pacific mackerel	pelagic	0.5985	10.9	-19.6	3.6
KKFOID GMPRED1-3	mycts, deep preds	pelagic	0.4666	11.5	-22.7	5.8
KKFOID GMPRED1-3	mycts, deep preds	pelagic	0.4372	11.3	-22.8	5.9
KKNP2 PHYTO+ZOO	zooplankton + phyto	pelagic	0.5381	5.3	-21	3.8
KKFO1 BULK ZOOP	bulk zooplankton	pelagic	0.5485	6.1	-21.1	4.2
KKNO4 BULK ZOOP	bulk zooplankton	pelagic	0.5789	8.7	-22.1	4.3
KKNO1 BULK ZOOP	bulk zooplankton	pelagic	0.4769	7.2	-21.1	4.2
KKNO2 SQUID B	squid	pelagic	0.5229	9.4	-20.1	3.5
KKNO2 SQUID B	squid	pelagic	0.5047	8.7	-19.3	3.4
KKNP1 BULK ZOOP	bulk zooplankton	pelagic	0.5606	6.3	-20.9	4.1
KKNEP1 BULK ZOOP	bulk zooplankton	pelagic	0.5218	6	-20.1	4.0
KKNP1 PM3+PM2	pacific mackerel	pelagic	0.5753	10.8	-18.8	3.2
UMIFO1 BULK ZOOP	bulk zooplankton	pelagic	0.5177	7.8	-22.8	6.3
UMIFO1 BULK ZOOP	bulk zooplankton	pelagic	0.5482	8.1	-22.9	6.2

UMINOP1 ZOOPL	zooplankton	pelagic	0.5032	7	-22.7	4.7
JM1+JM2	jack mackerel	mixed	0.4923	12.2	-18.4	3.3
HH1	hammerhead shark	mixed	0.4700	12.1	-17.4	2.7
HAL2	olive flounder	mixed	0.4750	12.1	-17.8	3.1
ST A UMI FISH 5	cod	mixed	0.5515	11.6	-18.8	3.2
ST A UMI FISH 1	cod	mixed	0.5399	11.3	-18.7	3.2
ST NP1 UMI FISH 3	cod	mixed	0.5653	13.8	-17.7	3.2
ST NP1 UMI FISH 2	cod	mixed	0.4642	11.6	-18.8	3.1
ST A UMI FISH 4	cod	mixed	0.5769	11.7	-18.1	3.2
ST A UMI FISH 3	cod	mixed	0.4648			#DIV/0!
ST A UMI FISH 2	cod	mixed	0.5055	11.5	-18.9	3.2
ST NP1 UMI FISH 1	cod	mixed	0.47	12.4	-18.3	3.1
UMINO2 MTD7300u		mixed	0.4656	6.4	-26.3	6.3
KKNPI JM3+JM4	jack mackerel	mixed	0.5633	12.7	-18.2	3.2
KKNPI JM3+JM4	jack mackerel	mixed	0.5048	12.7	-18.3	3.3
KKNPE1 JM4+JM5+JM6	jack mackerel	mixed	0.5547	12.6	-18.1	3.4
KKNO4 SHRIMP	shrimp	benthic	0.44	8.9	-22.5	5.3
KKNO4 SHRIMP	shrimp	benthic	0.5725	9.1	-22.7	5.6
KKPIPE1 JM1+JM2+JM3	jack mackerel	mixed	0.4786	12.2	-17.6	3.4
86	rat tail	benthic	0.4775	15.6	-19.8	3.1
72	unknown fish	mixed	0.5373	15.4	-20.2	3.2
72-45	unknown fish	mixed	0.5297	15.3	-19	3.1
72	unknown fish	mixed	0.4613	15.2	-18.7	3.1
8	conger eel	benthic	0.5427	15.1	-18.2	3.2
12	conger eel	benthic	0.5043	15	-18.2	3.2
98	rat tail	benthic	0.5714	14.9	-18.9	3.1
13	rockfish	mixed	0.523	14.6	-19.1	3.5
96	hermit crab	benthic	0.5798	14.6	-17.5	3.3
14	rockfish	mixed	0.5409	14.3	-19.2	3.4
STAR2	starfish	benthic	0.4887	14.2	-17.9	4.7
7	conger eel	benthic	0.5979	14.1	-19.3	3.2
72-71b	unknown fish	mixed	0.5361	14.1	-20.2	3.2
2	rat fish	benthic	0.4693	14	-17.3	2.8
4	rockfish	mixed	0.5664	13.9	-20.3	4.2
STAR1	starfish	benthic	0.5057	13.7	-17.5	4.6
72	unknown fish	mixed	0.5178	13.6	-20.2	3.2
15	rockfish	mixed	0.5177	13.5	-18.9	3.2
21b	conger eel	benthic	0.4973	13.5	-18.9	3.2
101	greenling	mixed	0.4498	13.5	-16.6	3.2

10	conger eel	benthic	0.5229	13.4	-19.4	3.2
21a	conger eel	benthic	0.4735	13.4	-18.7	3.1
3	shark unkown b	mixed	0.4757	13.3	-18.9	2.7
75	ray	benthic	0.5765	13.2	-19.1	2.8
85	conger eel	benthic	0.5607	13.1	-22.3	5.6
STAR3	starfish	benthic	0.4698	13.1	-13.2	4.6
79	ray	benthic	0.5206	13	-19.1	2.6
5	rockfish	mixed	0.547	12.9	-19.5	3.2
21C	conger eel	benthic	0.4915	12.9	-18.8	3.2
39	sea robin	benthic	0.5051	12.9	-18.4	3.3
48	cod	mixed	0.5294	12.9	-18.7	3.2
125	cod	mixed	0.4524	12.8	-18	3.1
126	cod	mixed	0.4554	12.8	-18.9	3.1
ROCKFISH 11b	rockfish	mixed	0.4803	12.7	-19.2	3.2
PRAWN	prawn	benthic	0.4782	12.7	-16.6	3.0
47-70	conger eel	benthic	0.4963	12.6	-22.9	5.7
65	bonefish	mixed	0.5566	12.6	-20	4.3
87	rat tail	benthic	0.5081	12.6	-20.5	3.1
122	cod	mixed	0.5457	12.6	-18.8	3.2
47-55b	conger eel	benthic	0.5171	12.5	-21.2	5.0
103	conger eel	benthic	0.593	12.5	-20.9	4.1
123	sea robin	benthic	0.4989	12.5	-17.3	3.1
42	cod	mixed	0.4361	12.4	-18.4	3.2
47-55a	conger eel	benthic	0.5659	12.4	-20.6	3.9
47-78	conger eel	benthic	0.641	12.4	-24.6	8.8
80	conger eel	benthic	0.4961	12.4	-20.3	3.8
131	cod	mixed	0.5405	12.4	-18.6	3.2
OCTOPUS	octopus	benthic	0.4673	12.4	-18.1	3.4
47-56	conger eel	benthic	0.4777	12.3	-21.2	4.2
83	conger eel	benthic	0.5437	12.3	-22.2	6.2
93	cod	mixed	0.5743	12.3	-18.9	3.1
STAR5	starfish	benthic	0.5886	12.3	-10	14.1
62	dark sleeper	benthic	0.5482	12.2	-17.6	3.2
92	flounder	benthic	0.5466	12.2	-16.2	3.2
34	cod	mixed	0.5253	12.1	-19.1	3.1
SL-90	myctophids	pelagic	0.5989	12.1	-24.3	8.5
109	shark A	mixed	0.5537	12	-17.5	2.6
132	rat tail	benthic	0.5145	12	-19.9	3.1
SL-75b	myctophids	pelagic	0.5734	12	-23.9	7.5
37	cod	mixed	0.4801	11.9	-19.4	3.2
38	cod	mixed	0.4483	11.9	-19.1	3.1

55	dark sleeper	benthic	0.5334	11.9	-19.2	3.2
67	cod	mixed	0.4897	11.9	-18.9	3.1
69	cod	mixed	0.4883	11.9	-19.1	3.1
77	clams	benthic	0.4235	11.9	-18.2	4.1
116	flounder	benthic	0.4956	11.9	-16.6	3.2
121	cod	mixed	0.5257	11.9	-18.9	3.2
SL-75a	myctophids	pelagic	0.5329	11.9	-25.3	13.0
ROCKFISH 11a	rockfish	mixed	0.5188	11.8	-24.2	6.0
82	rat tail	benthic	0.5491	11.8	-19.4	3.1
105	flounder	benthic	0.5599	11.8	-17.1	3.2
SL-65a	myctophids	pelagic	0.487	11.8	-23	10.2
77	clams - WM	benthic	0.5278	11.7	-18.3	4.3
127	gonatid squid	pelagic	0.5027	11.7	-21	3.2
SL-70	myctophids	pelagic	0.5788	11.7	-22.7	7.5
SL-65b	myctophids	pelagic	0.5862	11.7	-22.5	8.9
52	dark sleeper	benthic	0.4689	11.6	-19.4	3.2
74	rat tail	benthic	0.4539	11.6	-20.5	3.2
106	flounder	benthic	0.5362	11.6	-16.6	3.2
111	shark A	mixed	0.4791	11.6	-17.5	2.6
44	squid	pelagic	0.453	11.5	-18.8	3.4
49	cod	mixed	0.4864	11.5	-18.7	3.1
112	shark A	mixed	0.4515	11.5	-17.7	2.7
SL-65C	myctophids	pelagic	0.5113	11.5	-23.4	10.3
110	shark A	mixed	0.5067	11.4	-17.8	2.7
73	dark sleeper	benthic	0.5004	11.3	-19.1	3.2
88D	unknown fish	mixed	0.5207	11.3	-18.1	3.3
113	flounder	benthic	0.4814	11.3	-17.1	3.2
CLINGFISH	cling fish	benthic	0.5674	11.2	-16.8	3.2
88B	unknown fish	mixed	0.5038	11.1	-18.2	3.3
104 SHRA	shrimp	benthic	0.4552	11.1	-19.4	3.5
108	shark A	benthic	0.5154	11.1	-17.5	2.6
64	dark sleeper	benthic	0.5083	11	-18.8	3.2
104	shrimp	benthic	0.5786	11	-19.1	3.3
104 SHRB	shrimp	benthic	0.5412	11	-24.4	9.9
107	flounder	benthic	0.4249	11	-17.1	3.3
STAR4	starfish	benthic	0.5195	11	-10.7	9.2
24	scomber	pelagic	0.4536	10.9	-19.2	3.2
SL-45	myctophids	pelagic	0.4917	10.9	-22.9	6.8
SL-60a	myctophids	pelagic	0.6164	10.9	-23.4	8.9
SL-55	myctophids	pelagic	0.4494	10.9	-24.7	7.6
SL-56A	myctophids	pelagic	0.5577	10.9	-26	11.1

88	unknown fish	mixed	0.5282	10.8	-18.1	3.3
SL60b	myctophids	pelagic	0.4944	10.7	-24.5	8.9
88C	unknown fish	mixed	dup	10.6	-17.5	3.2
SMCR5	small crabs	benthic	0.5282	10.6	-16.9	4.9
SL-75c	myctophids	pelagic	0.4302	10.5	-25.2	10.3
56	flounder	benthic	0.5061	10.4	-19	3.3
57	flounder	benthic	0.5034	10.4	-19.1	3.2
SMCR2	small crabs	benthic	0.5269	10.4	-14.2	6.0
SMCR4	small crabs	benthic	0.5381	10.4	-15.4	5.8
97	rat tail	benthic	0.5611	10.1	-19.5	3.2
59	unknown squid	pelagic	0.5258	10	-20	3.5
100	rat tail	benthic	0.4393	10	-19.3	3.2
102	rat tail	benthic	0.5012	10	-19.6	3.2
SMCR3	small crabs	benthic	0.5369	10	-15.6	5.9
SMCR 1	small crabs	benthic	0.5066	10	-15.1	5.0
78	rat tail	benthic	0.4686	9.8	-19.1	3.2
SL-50	myctophids	pelagic	0.4715	9.8	-23.2	5.7
RATTAIL 11	rattail	benthic	0.4974	9.8	-19.3	3.2
RATTAIL 10	rattail	benthic	0.5464	9.8	-18.9	3.3
RATTAIL 11.5	rattail	benthic	0.4895	9.8	-19.5	3.2
130	squid	pelagic	0.5249	9.7	-20.1	3.9
SL-50b	myctophids	pelagic	0.4884	9.7	-23	4.6
SL-52	myctophids	pelagic	0.4597	9.5	-22.1	5.2
rat tail 13	rattail	benthic	0.5077	9.5	-19	3.2
	NPE2A plnk	pelagic	0.5526	9.4	-20.3	4.1
ANCHOVY	anchovy	pelagic	0.5715	9.3	-19.5	3.3
51	unknown squid	pelagic	0.4969	9.2	-20.2	3.5
BRST4	brittle stars	benthic	0.4802	8.9	-10.2	6.9
BRST5	brittle stars	benthic	0.5433	8.8	-10.7	6.5
	NP2A plnk	pelagic	0.5043	8.7	-21.7	4.0
54	unknown squid	pelagic	0.5129	8.5	-20.1	3.5
BRST2	brittle stars	benthic	0.52	8.4	-10.3	6.5
58	hatchet fish	pelagic	0.585	7.8	-20.5	3.3
	NP0 plnk	pelagic	0.4493	7.8	-21.1	5.0
	NP3B plnk	pelagic	0.5692	7.8	-21.4	4.5
BRST3	brittle stars	benthic	0.4906	7.7	-11	5.8
61	snipe eel	pelagic	0.55	7.6	-20.2	3.2
53	unknown myctophid b	pelagic	0.5175	7.2	-20.3	3.7
BRST 1	brittle stars	benthic	0.4609	6.4	-6.5	10.7
AT1	"algae soup"	pelagic	0.449	6.4	-19.7	5.2
AT3	"algae soup"	pelagic	0.4847	6.4	-20.1	5.4

AT4	"algae soup"	pelagic	0.5483	6.1	-19.8	4.9
AT2	"algae soup"	pelagic	0.4294	6	-19.7	4.8

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