AN INVESTIGATION INTO THE REASONS FOR A LACK OF A TROPHIC LEVEL EFFECT FOR ^{137}Cs IN FUNDULUS HETEROCLITUS AND ITS FOOD IN THE HUDSON RIVER ESTUARY

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Abstract

A detailed investigation into the behavior of radiocesium in the food chain of one species of fish (*Fundulus heteroclitus*) in the Hudson River Estuary revealed the probable reasons for the lack of a trophic level effect for ^{137}Cs in the food chain of *Fundulus* and perhaps that of most fish in the Hudson River Estuary.

A series of laboratory experiments revealed that the elimination rate of ^{137}Cs was 1/5 that of potassium in *Fundulus*, thereby creating the potential for the trophic level effect. However, since the fish were not in equilibrium with their source of ^{137}Cs and the ability of the fish to assimilate ^{137}Cs relative to that of potassium was markedly reduced due to the presence of sediment in the ingested foods, the trophic level effect did not occur.

Introduction

Radiocesium has been shown to be the critical radionuclide in the liquid effluent of one light water reactor located on an estuary and the ingestion of fish has been shown to be the critical pathway of exposure to man.[1] It is reasonable to believe that radiocesium may be the critical nuclide (in the sense of ICRP 7) for many light water reactors because of the high escape rate coefficient in relation to other radionuclides such as ^{90}Sr.[2] Accordingly, a thorough understanding of the ecological behavior of radiocesium in aquatic ecosystems is needed in order to predictively assess the dose to man due to a given release of radiocesium to a given aquatic environment.

Many investigators have observed a systematic threefold increase in the concentration of radiocesium between successive trophic levels of aquatic food chains in freshwater environments.[3-8] If this trophic level effect were observed to occur under all or most circumstances, it would make the accurate prediction of the concentration of radiocesium in aquatic biota a relatively trivial matter. Some other investigators have not always observed such a trophic level effect. In particular, Nelson studying the accumulation of ^{137}Cs in fish in the Clinch River, has noted that threefold trophic level enrichment of the $^{137}Cs/K$ ratio did not occur.[9] Studies of radiocesium and potassium performed in the Hudson River Estuary showed that biota in this ecosystem did not

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exhibit a trophic level effect.[1,10] This paper presents the results of investigations into the accumulation of radiocesium and potassium in the food chain of one species of fish, Fundulus heteroclitus, in the Hudson River Estuary, and the results are used to explain the reasons for the lack of a trophic level effect.

Based on our review of the literature, we conclude that the following set of conditions must exist in an ecosystem in order for a trophic level effect to exist:

1) The fish must obtain essentially all of its radiocesium and potassium from its food organisms.

2) The activity of radiocesium and potassium in the fish must be in equilibrium with that in the fish's food organisms.

3) The fractional assimilation of radiocesium and potassium by the fish from its food organisms must be the same.

4) The elimination rate of radiocesium from the fish must be 1/3 that of potassium.

5) The potassium concentration of all organisms of the fish's food chain must be similar.

A series of field and laboratory studies conducted during 1971 and 1972 were performed in order to determine which among the above conditions were responsible for the observed lack of a trophic level effect in Fundulus heteroclitus in the Hudson River Estuary.

Materials and Methods

Field Studies

Fundulus heteroclitus, aquatic plants, invertebrates, sediment and water were collected on a biweekly basis from the shore area at site 11W1 (see Fig. 1) from the Hudson River Estuary during the growing seasons of 1971 and 1972. The samples were reduced in volume and analyzed for ^{40}K and ^{137}Cs by gamma spectrometric analysis described elsewhere.[1]

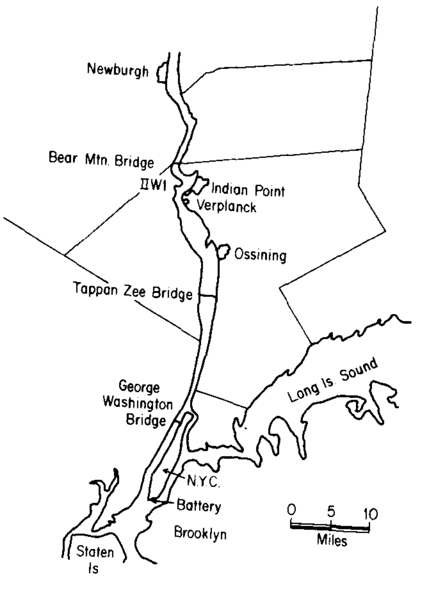

Fig. 1 The Lower Hudson River Estuary

Prior to analysis, the stomachs of the fish were removed and the contents weighed and identified in order to determine the feeding habits of the fish.

Laboratory Studies

Stomach Clearance Rate

Well-fed Fundulus held in the laboratory and also Fundulus obtained from the river were held unfed in the laboratory. The fish were then periodically sacrificed and the stomach content weight determined. This yielded a stomach clearance rate which was used, along with the stomach content analysis, to determine the daily feeding rate of Fundulus in the Hudson River Estuary.

Elimination Rate of Radiocesium

Fundulus were fed various food items which were labeled with ^{137}Cs. Immediately after labeling, the fish were live counted and placed into aquaria. These fish were then periodically live counted yielding the fractional assimilation of radiocesium by Fundulus from its various food items and also the biological half life of ^{137}Cs in the fish. (The procedure followed was identical to that described in detail by Kevern.)[4]

Elimination Rate of Potassium by Fundulus

Fundulus were force fed ^{40}K and then individually placed into aquaria. Periodically the aquaria water was removed and the ^{40}K in it, due to excretion by the fish, was collected on ion exchange resins. The resins were then analyzed for ^{40}K by gamma spectrometry. This yielded the biological half time of potassium in Fundulus. (This procedure is described in detail by Kolehmainen.)[6]

The Uptake Rate of ^{137}Cs by Fundulus from Direct Sorption from Water

Fundulus were held unfed in Hudson River water of various salinities and containing 1 μCi/l of ^{137}Cs. The fish were periodically washed and then live counted yielding the uptake rate of radiocesium by direct sorption from water.

The above series of experiments quantified the uptake and elimination rates of ^{137}Cs in Fundulus, thereby enabling one to identify the causes for any lack of a trophic level effect which might be found to occur.

Results and Discussion

Table 1 presents the ^{137}Cs and ^{40}K activity observed in Fundulus heteroclitus and its food organisms collected from the Hudson River in 1971 and 1972.

Table 1. The Concentration of ^{40}K and ^{137}Cs in Fundulus heteroclitus and its Food Organisms During 1971 and 1972 pCi/g Ash Weight

	Fundulus heteroclitus				Gammarus			
	K-40	Cs-137	Cs-137 / K-40	# of Samples	K-40	Cs-137	Cs-137 / K-40	# of Samples
1971	33.9±5.0	4.2	.13	10	-	7.4	-	2
1972	32.2±6.8	3.1	.09	6	25	3.2	.13	3
	Filamentous Algae				Higher Plants			
1971	40±12	22.6	.56	3	60±36	11.4	.13	6
1972	75±16	6.3	.08	8	77±35	4.2	.05	13

There is an obvious lack of a trophic level effect. The following results reveal which among the 6 conditions presented in the introduction were responsible for the absence of a trophic level effect.

Condition 1

The fish can obtain radiocesium from its foods, from the ingestion of sediment, and from direct sorption from water. The uptake rate from food is the product of the mass of food eaten per day, the ^{137}Cs activity of the food and the fractional assimilation of ^{137}Cs from the food by the fish.

Stomach content analyses performed on fish which were collected during the months of May through September revealed that the fish ingested 14% of its body weight per day, that 52% of the ingested food was filamentous algae, 29% was Gammarus, 8% was higher plants and less than 1% was sediment. Table 2 presents the average activity observed in these items during 1971 and 1972 and the fractional assimilation of ^{137}Cs by Fundulus from these items. The assimilation of ^{137}Cs was markedly reduced due to the presence of sediment along with the ingested material.

The results of the series of laboratory experiments where Fundulus obtained ^{137}Cs solely via direct sorption from water revealed that among 12 fish ranging in size from 2 to 12 grams and held in water ranging in salinity from 1 to 140 ppm potassium the uptake rate was .057±.027 of the concentration in the water per day.

Table 3 summarizes the above studies showing the rate of uptake of radiocesium by Fundulus from its various sources during 1971. Almost all of the radiocesium in Fundulus was from the ingestion of food organisms and very little was from the direct sorption from water or the ingestion of sediment. It is also believed that the potassium content of fish originated from the fish's food items.[11] Therefore, Condition 1 for the existence of a trophic level effect is fulfilled in Fundulus in the Hudson River Estuary.

Table 2. The Average Activity of ^{137}Cs Observed in Water and Food Items of Fundulus heteroclitus Taken from the Hudson River Estuary During 1971 and 1972 and the Fractional Assimilation of ^{137}Cs by Fundulus from These Items

	1971		1972		
Item	pCi/Kg Wet Wt.	# of Samples	pCi/Kg Wet. Wt.	# of Samples	Fractional Assimilation
Filamentous					.084±.058*
Algae	616	3	218	8	.79±16
Higher Plants	340	6	131	13	.084±.058
Gammarus	70	2	36	3	.834±.077
Sediment	11452	5	10322	11	.031±.017
Water	.78	5	.30	17	-

*This value is the assimilation of ^{137}Cs by Fundulus from labeled filamentous algae had sediment associated with it.

Table 3. The Rate of Uptake of ^{137}Cs by Fundulus heteroclitus from its Various Sources During 1971

Source	Uptake Rate (pCi/Kg-day)	% of Total
Filamentous algae	2.4	61
Higher plants	.2	5
Gammarus	1.2	29
Sediment	.13	3
Water	.04	1.2

Condition 2

The data on the observed concentrations of ^{137}Cs in Fundulus, filamentous algae, Gammarus, and water taken at a single site in the Hudson River during 1971 and 1972 are shown in Fig. 2. It can be seen that the variation of radiocesium with time is much less in Fundulus than in any of the other media. This is reasonable in view of the relatively long half-life of ^{137}Cs in Fundulus, equivalent to about 250 days as determined from elimination rate experiments. Others have shown that filamentous algae come into equilibrium with water in days and that Gammarus equilibrates in a period of weeks.[12-14] In this location, ^{137}Cs in water was a result of the addition of runoff into the watershed from the accumulated ^{137}Cs in soil from fallout and from the ^{137}Cs introduced from the Indian Point power plant across the river. By the time releases from Indian Point had diffused across the river, several tidal cycles normally would have occurred and, accordingly, fluctuations in the water over any several-day period would not be too great. However, from Fig. 2 one can see that the fluctuations in water were simply greater than those observed in Fundulus. The water samples are the results of grab samples taken biweekly during this period. Because the river is tidal and the flushing time is in excess of one month at this location during the late summer, the grab samples are believed to represent a reasonable average over a period of some days. It is, accordingly, reasonable to conclude, from the data presented in Fig. 2, that the food organisms upon which Fundulus feed reached equilibrium with the activity in the water relatively rapidly. On the other hand, it was clear that Fundulus had not reached an equilibrium activity because of its continued increase in activity during the months of August and September of 1971 when ^{137}Cs concentrations in water were relatively constant. It is, therefore, clear that Fundulus had not reached equilibrium with its environment and, moreover, the environment itself was fluctuating, the water and the food at different rates, but all generally much more rapidly than the radiocesium content of Fundulus. Accordingly, Condition 2, which requires that the fish be subsisting on food which is at equilibrium with water and that equilibrium conditions be obtained in the fish, was not satisfied in this environment. Because of the seasonal fluctuations of freshwater flow in the Hudson, and the variability of reactor releases with time, it is unlikely that a constant radiocesium level in water will ever be obtained over time periods exceeding 2 half lives (or about a year) in Fundulus, so that equilibrium conditions never exist in this system.

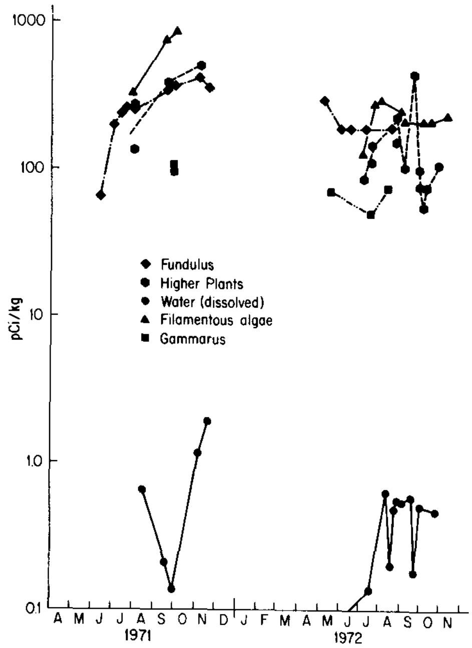

Fig. 2 ^{137}Cs Activity of samples collected during 1971 & 1972 from site 11W1 on the Hudson River Estuary.

Condition 3

The fractional assimilation of radiocesium by Fundulus from plants has been found to be markedly reduced (perhaps 10-fold) due to the association of sediment with the ingested material (see Table 2). Perhaps due to the high potassium content of the sediment, the presence of sediment with the ingested plants does not reduce the assimilation of potassium from the plants. Therefore, the relative assimilation of ^{137}Cs and potassium by Fundulus from its various foods is markedly different and, accordingly, Condition 3 is not fulfilled.

Condition 4

Laboratory experiments revealed that the biological half life of ^{137}Cs among 9 Fundulus ranging in weight from 2 to 12 grams and held in water containing 20 ppm potassium (salinity = 2 ppt) at a temperature of 20°C was 265 ± 45* days. Under similar conditions, the biological half life of potassium in 12 Fundulus was 50 ± 18 days. Therefore, the rate of elimination of potassium is about 5 times greater than that of cesium. Accordingly, Condition 4 is fulfilled, although the relative elimination rates differ somewhat from that assumed in the current "dogma".

*± 1 standard deviation.

Condition 5

The fifth condition for existence of the trophic level effect is that the potassium concentration in the major food organisms of fish should be similar. Table 1 lists the concentrations of potassium observed in Fundulus and its major food items and in view of the fact that there exists only a two-fold difference among them, it is considered that this condition is satisfied.

Conclusions

Although the elimination rate of ^{137}Cs was 1/5 that of potassium in Fundulus heteroclitus, the ^{137}Cs was not consistent with that which would have been predicted by postulating a "trophic level effect" for the following reasons:

1) The ^{137}Cs activity in Fundulus was not at equilibrium with that in its food organisms.

2) The assimilation of ^{137}Cs from much of its food was markedly reduced relative to that of potassium. This was most likely due to the association of sediment with ingested plants which was effective in inhibiting uptake of radiocesium but not of potassium.

Clearly, the one phenomenon which was largely responsible for the lack of a trophic level effect in Fundulus in the Hudson River Estuary was the large reduction in the assimilation of ^{137}Cs relative to that of potassium due to the association of sediment with ingested material.

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