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ECOLOGICAL IMPLICATIONS OF FALLOUT RADIOACTIVITY

ACCUMULATED BY ESTUARINE FISHES AND MOLLUSKS¹

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ABSTRACT

Fallout radioactivity accumulated by estuarine organisms near Beaufort, North Carolina, was measured from October 1963 to October 1966. Sixteen species of fish were analyzed for fallout radioactivity. These fish were separated into four groups based on the predominant radioisotopes accumulated in the environment. One group contained ^{137}Cs , another group ^{54}Mn , another group ^{137}Cs and ^{54}Mn , and a fourth group contained little or no measurable quantity of either radioisotope. Nektonic feeders comprised the group that contained ^{137}Cs and benthic feeders contained ^{54}Mn . The results of these measurements suggest that the radioactivity accumulated by mollusks and fish reflects different ecological niches. Seven radionuclides were identified in the soft parts of hard clams, *Mercenaria mercenaria*; marsh mussels, *Modiolus demissus*; American oyster, *Crassostrea virginica*; and bay scallops, *Argopecten irradians*. Clams, mussels and oysters accumulated relatively large amounts of ^{144}Ce and ^{106}Ru . The radioisotope present in greatest concentrations in oysters was ^{65}Zn and in bay scallops was ^{54}Mn . Laboratory experiments on the accumulation of ^{65}Zn and ^{54}Mn confirmed these results.

INTRODUCTION

The ubiquitous distribution in the biosphere of fallout radioactivity from atmospheric testing provided ecologists with the opportunity to study the accumulation of these materials by organisms under natural conditions. Quantities present in the environment were small so radionuclides could be measured conveniently by us only in organisms that concentrated radionuclides. Furthermore, our studies were not initiated until late in 1963 or until most of the short-lived nuclides produced from nuclear testing in 1962 had decayed to undetectable levels. Our study, therefore, was restricted to naturally occurring K-40 (1.3×10^9 -year half-life), Ru-106 (fission product, 1.0-year half-life), Cs-137 (fission product, 30-year half-life), Mn-54 (neutron activation product, 310-day half-life) and Zn-65 (neutron activation product, 245-day half-life). Samples also contained two additional fission products, Ce-144 (285-day half-life) and Zr-95 - Nb-95 (65-day - 35-day half-lives), but these radionuclides are not reported in our study.

Radioactivity can be measured with greater sensitivity in organisms than in water because most radionuclides present originally in the water are concentrated in organisms. In addition, organisms reflect previous environmental conditions because they accumulate and retain radioactivity for a finite time from quantities in water that may vary greatly, may be undetectable, or detectable only occasionally. To know which organisms accumulate relatively large amounts of radioactivity facilitates environmental surveys because, in such cases, environmental radioactivity can be determined from a few organisms instead of monitoring entire communities. Such organisms have been referred to previously as biological indicators (Schelske 1966). Others have applied the concept of "biological monitoring" of radioactivity released from atomic energy facilities (Harvey 1965, Glaser 1963).

Radioactivity may be accumulated through food chains in the natural environment. Phosphorus 32 added to a stream ecosystem was used to define pathways of energy flow and to distinguish trophic relationships (Ball and Hooper 1963). Radioactivity in marine organisms was related to their trophic level (Osterberg et al. 1964). In the Columbia River, radionuclides were accumulated by the biota of the river through food chains (Davis and Foster 1958); 98.5% of the radionuclides in fish were ingested. Flounder in laboratory experiments accumulated Zn-65 more readily from food than from water (Hoss 1964). Concentrations of Cs-137 and Cs-137/K ratios increased with higher trophic levels in freshwater fish (Gustafson 1969). A tracer experiment with Zn-65 was used to study the zinc cycle in a salt marsh estuarine system in Georgia (Pomeroy, Johannes, Odum, and Roffman 1969). The roles of zinc (Rice 1963a) and manganese (Wangersky 1963) and the relationship of cesium to potassium (Davis 1963) in ecology have been reviewed.

In our study we measured fallout radioactivity in fish and mollusks and have discussed the ecological implications of these results. Feeding habits were related to accumulation of different radionuclides among the species of fish. Differential accumulation by fish was not too surprising since our samples represented a broad range of feeding habits, including planktonic, nektonic, and benthic feeders. That differential accumulation of radionuclides occurred among the species of filter feeding mollusks might have been expected also since mollusks are known to feed selectively (Jørgensen 1955; Loosanoff 1949).

METHODS AND MATERIALS

Eighteen species of fish were collected during this study. More than 40 samples were collected from April 1965 until September 1966 with the exception

of two samples that were collected in September 1964 (Table 1). Due to our inability to obtain fish samples consistently by other means, we relied on the catches brought by commercial fisherman to Beaufort, North Carolina, as a major source of samples. Exact locations of these catches are not known other than being in the general vicinity of Beaufort. Locations of the five stations that we sampled are indicated in Table 1. Common and scientific names and the systematic classification of fishes collected are listed in Table 2. Common names or a shortened form of the common name, if there is no possibility of ambiguity among our species, are used throughout the text (American Fish. Society 1960).

Four species of lamellibranch mollusks were used in our study and samples were collected near Beaufort from October 1963 to January 1964. The four species were: hard clams, *Mercenaria mercenaria* (Linnaeus); marsh mussels, *Modiolus demissus* (Dillwyn); American oyster, *Crassostrea virginica* (Gmelin); and bay scallops, *Argopecten irradians* (Lamarck).

Gamma-emitting radionuclides were measured with a low-background counting system consisting of a 512-channel analyzer, a 10 x 10-cm NaI(Tl) crystal mounted on a 7.5-cm phototube, and a large shield (inside dimensions .6 x .6 x .9 m high) constructed of steel sides 15 cm thick lined with 6 mm of lead and 1.6 mm of stainless steel. The 512-channel analyzer was equipped with an oscilloscope, IBM typewriter, and paper punch for readout and with data reduction capabilities for background subtraction. Samples were counted with 127 channels of the analyzer calibrated at 20 kev/channel.

Only gamma emitters were studied because existing quantities of radioactivity in estuarine organisms were small making it difficult and time

consuming to prepare samples for analysis of alpha or beta radioactivity. Prior to measurement of radioactivity, soft parts of mollusks were separated from shells and the shells were discarded. Fishes were selected according to arbitrary size groups depending on availability and the average total length was recorded. Either whole fish or major parts of the fish were used for analyses. Samples of fish and mollusks were weighed to determine the wet weight, dried at 100°C, ashed at 450-500°C, and weighed to determine the ash weight. Sample sizes usually ranged from 0.5-2.5 kg. Ashed samples with a known geometry were prepared for counting in plastic containers. Samples of mollusks were counted for 40 or 80 minutes. Samples of fish were counted for 80-200 minutes. Longer counting times were required for fish because levels of radioactivity had declined in the two-year period between the collection of mollusk and fish samples.

Counts were corrected for background with the computer portion of the analyzer. Resulting data were printed out with the IBM typewriter and plotted to obtain the gamma spectra of each sample (Fig. 1). A stripping program based on the spectra of standards for K-40, Zn-65, Mn-54, Zr-95 - Nb-95, Cs-137, Ru-106, and Ce-144 was used to determine the net counts in the photopeaks for each radionuclide. The presence of radionuclides other than the above seven introduces error into the analyses of the spectrum. Errors associated with stripping were evaluated from a composite spectrum composed of the stripped spectra for some samples relative to the spectrum prior to stripping. The above radionuclides accounted for 90-95% of the original spectra. Other fallout and naturally occurring radioisotopes, with the exception of Ce-144, did not comprise a significant part of the gamma spectra since the composite spectra were in close agreement with the original spectra. Values of Ce-144 were not reported due to variability among samples and to the error associated with stripping. Levels of

Zr-95 - Nb-95 were usually low and were not considered in this report. Sample No. 1675, butterfish, was an exception; it contained 782 pCi Zr-95 - Nb-95/100 g wet weight.

Net counts for each radionuclide were corrected for decay to the collection date and were converted with an efficiency factor to pCi per sample and then to pCi/100 g wet weight. Relative counting errors in terms of pCi/100 g wet weight were based on the standard deviation (SD) of total counts composed of the background and net counts for each photopeak.

$$SD = \sqrt{2 \times \text{Background} + \text{Net Counts}} .$$

Results are presented only for those analyses where net counts exceeded $1.96 \times$ SD. For low counts, this arbitrarily selected detection limit is approximately twice that represented by $\sqrt{3 \times \text{Background}}$.

Concentrations of iron and manganese in the samples were determined by dissolving known quantities of the ash in a known volume of HCl and running the analyses with atomic absorption spectrometry against standards of known concentration.

RADIOACTIVITY IN FISH

Five radionuclides were identified in samples of fish (Table 3) and all of these except K-40 originated from fallout. Thirteen of the eighteen species we studied were analyzed for gamma radioactivity originating from fallout. The other five species were not analyzed quantitatively since inspection of the gamma spectrum of each showed relatively small amounts of radioactivity compared to the other species.

Potassium-40

The highest concentrations of K-40 were found in samples of false albacore and Spanish mackerel (Table 3). Butterfish also had a high value, but only one sample was collected. The lowest concentrations of K-40 were found in burrfish and filefish, puffer had low concentrations of K-40 also. These three species with small concentrations of K-40 relative to the other fish have thick integuments, which coupled with their relatively small size may explain the low concentrations. The average concentration was more than a factor of two greater in the Spanish mackerel than in the burrfish.

Cesium-137

There was a large range in the concentrations of Cs-137 among the different species (Table 3) and smaller but large variations among some species. The largest concentrations were found in Spanish mackerel. Two samples of Spanish mackerel were separated into visceral mass and body less the visceral mass. No Cs-137 was detected in the samples of visceral mass, indicating that Cs-137 in these tissues was not in equilibrium with the remainder of the body even though the K-40 concentrations were similar. There is no apparent explanation for the order of magnitude difference in sample 1591 compared to the other samples of Spanish mackerel. Likewise there is no apparent reason for the large amount of variation among the samples of spot and croaker.

Our data indicate that four species, Spanish mackerel, weakfish, mullet, and false albacore, contained greater concentrations of Cs-137 than the other species. Conversely burrfish and filefish contained smaller amounts of Cs-137 than the other species.

Zinc-65

The most obvious feature of zinc-65 measurements is the lack of measurable quantities in a large number of samples (Table 3). No zinc-65 was measurable in Spanish mackerel which had the highest concentrations of Cs-137 and it was measurable in only two of the six samples of spot. Relatively large concentrations were found in burrfish and filefish, species which had relatively small amounts of Cs-137, and in our two samples of anchovy.

Manganese-54

Like zinc-65, Mn-54 was not measurable in some species, but unlike Zn-65, there was a large range of values in the different samples (Table 3). No Mn-54 was detectable in Spanish mackerel and false albacore and Mn-54 was present in relatively small concentrations in weakfish and mullet. Filefish contained the

largest concentrations of Mn-54, approximately a tenfold greater concentration than most of the other species. Puffer, burrfish, and pinfish also contained more Mn-54 than the other species.

Ruthenium-106

Concentrations of Ru-106 in our samples were highly variable among the different species that were sampled and also among the samples within individual species. Four species, with the exception of sample number 1176, contained no measurable amounts of Ru-106 (Table 3). The four species were false albacore, Spanish mackerel, weakfish, and anchovy and the exception was a sample of visceral mass from Spanish mackerel which contained the largest concentration of Ru-106 measured in any of our samples. Because the large amount of Ru-106 was found in only one sample, we assumed that it was due either to sample contamination or to material in the digestive tract that would have been egested and not assimilated. Filefish and possibly burrfish were the only species in which Ru-106 was found consistently. The highest concentration in filefish (sample number 713) was from the only sample collected and analyzed in 1964 (Table 1), indicating that amounts of Ru-106 in fish may have been greater in 1964 than in 1965 and 1966. It is also possible that Ru-106 was removed at a faster rate from the pathways leading to fish in the environment than Zn-65, Mn-54, and Cs-137, or that fish do not assimilate Ru-106.

CONCENTRATIONS OF IRON AND MANGANESE IN FISH

Iron and manganese were analyzed so the ratios of iron to manganese could be determined since these elements have a similar chemical behavior in the environment. In addition, data on the concentration of stable manganese enabled us to determine the specific activity of fallout Mn-54 and, therefore, to determine if the two isotopes of manganese were concentrated differentially by fish

in the natural environment. Differences in specific activities among species would indicate that fallout Mn-54 did not act as a tracer for stable manganese in the environment but that it was accumulated by some selective mechanism.

Iron

Concentrations of iron were different among the species and between parts of fish when the visceral mass was separated from the remainder of the carcass (Table 4). Viscera of Spanish mackerel, puffer, and spiny dogfish contained larger concentrations of iron than the remainder of the body, indicating that iron was concentrated more in the visceral tissues relative to the other parts of the body or that most of the iron was in the digestive tract and would not have been absorbed but would have been egested. Filefish had the largest iron concentrations and the data indicate that croaker, spot, pinfish, and burrfish also had larger iron concentrations than other species. Data are quite variable among species making it difficult to draw conclusions about differences between species.

Manganese

Concentrations of manganese were lower than concentrations of iron particularly in samples that did not include the viscera of the fish (Table 4). Samples of false albacore, Spanish mackerel, and spiny dogfish without the viscera contained less than 0.1 mg Mn/100 g wet weight. False albacore, Spanish mackerel, weakfish, butterfish, anchovy, cutlass fish, sea mullet, and clearnose skate contained smaller amounts of manganese than other species, less than 1.0 mg Mn/100 g wet weight. Puffer, burrfish, and filefish contained more manganese than other species. The large range in the concentrations of manganese relative to iron was due to the small concentrations of manganese in Spanish mackerel, false albacore, and spiny dogfish (excluding the liver).

Ratio of Iron to Manganese

Iron/manganese ratios ranged from about 1.0 to more than 40 (Table 4), most

of the values were less than 10. Ratios were largest for false albacore, Spanish mackerel, spiny dogfish, and clearnose skate. Visceral samples of Spanish mackerel and puffer had larger ratios than the samples of the same fish with the viscera removed. Ratios were lowest for puffer (excluding the sample of viscera) and burrfish. With the exception of one sample, filefish also had low ratios of iron/manganese.

Specific Activity of Mn-54

Specific activity of Mn-54 in $\text{pCi } ^{54}\text{Mn/mg Mn}$ was determined from the ratios of concentrations of Mn-54 (Table 3) to stable Mn (Table 4). All ratios could not be calculated because our samples of false albacore and Spanish mackerel contained amounts of Mn-54 too small to be measured with our methods (Table 3). Specific activities that could be calculated, however, ranged from 2.0 or 3.0 to more than 20 for some samples of filefish (Table 4). The range might be much greater if data were available on the small Mn-54 concentrations in false albacore and Spanish mackerel, but one cannot conclude the ratios were smaller because the concentration of stable manganese was lower by a factor of two or three in these species than in the other species.

Filefish obviously had the largest specific activity of any species that was sampled (Table 4). No consistent pattern is apparent for the data from the other species with specific activities that have a range of less than 3 except for two samples of pinfish.

RATIOS OF RADIOISOTOPES IN FISH

If different fallout radioisotopes were concentrated selectively among the species of fish sampled, it should be evident from the ratios of the concentrations of the radioisotopes that were measured (Table 3). Because concentrations of Ru-106 were so variable among our samples (Table 3), this radioisotopes was

not used in the calculations of ratios.

Cs-137/Mn-54

Selective accumulation of Cs-137 and Mn-54 is apparent from the nearly hundred-fold range in the ratios of these radioisotopes (Table 4). An even greater range would have been found if we had been able to determine the concentrations of Mn-54 in false albacore and Spanish mackerel. Our data indicate that the concentrations were no greater than $0.2 \text{ pCi } ^{54}\text{Mn}/100 \text{ g wet weight}$ so the ratios for false albacore and Spanish mackerel may be 100 or greater. Ratios were smallest for filefish which had the largest concentrations of Mn-54 (Table 3). Other small ratios of less than 1.0 were found for banded drum, puffer, burrfish, and pinfish.

Cs-137/K-40

Cesium and potassium are similar chemically. Consequently, Cs-137 and K-40 might be expected to have ratios that do not differ greatly among the components of the environment. Apparently this is the case because most species have ratios that do not differ greatly from 0.01 (Table 4). Exceptions to this generalization were found for Spanish mackerel, weakfish, mullet, and one sample of croaker. In these exceptions we conclude that fallout cesium-137 was concentrated selectively by these species over stable cesium or potassium, that the ratio of cesium-137 to potassium was not constant in the environment sampled or that some combination of these factors was operative.

Mn-54/K-40

This ratio as would be expected from the data in Table 3 varied greatly among the species of fish. The ratio varied by a factor of 100 for the available data (Table 4) and would have varied more if data had been obtained on the concentration of Mn-54 in false albacore and Spanish mackerel, because Mn-54 was present in smaller concentrations in these species than in the other species. The ratio was possibly as small as 0.0006 for Spanish mackerel. The large range in values for this ratio among different species (Table 4) shows that species that

concentrated Mn-54 did not concentrate Cs-137 and conversely (Table 3).

Mn-54/Zn-65

Few data were obtained for the ratios of Mn-54 to Zn-65 because these radioisotopes were not present in measurable amounts in all samples (Table 3). It is apparent, however, from the available data that Mn-54 and Zn-65 were not concentrated in the same proportion by each species (Table 4). Filefish had a greater ratio than other species because they concentrated more Mn-54 and not a proportionately larger amount of Zn-65 (Table 3). Puffer, burrfish, and pinfish also concentrated more Mn-54 proportionately than Zn-65. Weakfish and possibly butterfish concentrated proportionately more Zn-65 than Mn-54.

If data on stable zinc concentrations were available, it would be interesting to determine from the ratios of the specific activity of Zn-65 and Mn-54 whether Zn-65 is also accumulated by some fish selectively over stable zinc. Filefish apparently accumulated Mn-54 selectively over stable manganese as indicated by the large Mn-54/Mn ratio (Table 3).

RADIOACTIVITY IN MOLLUSKS

Data on fallout radioactivity in four species of mollusks are presented as a basis for comparison with our samples of fish. Fewer samples of mollusks were used, but the conclusions we will derive from the data do not require large numbers of samples since the differences among the species were rather large. Mollusk samples were collected in 1963 and 1964 so we are not justified in making absolute comparisons of quantities of radioactivity with fish samples collected in 1965 and 1966.

Two obvious differences were found among the amounts of fallout radioactivity accumulated by the four species of mollusks (Table 5). Oysters contained greater concentrations of Zn-65 and scallops contained greater concentrations of

Mn-54 than the other species. The data indicate that oysters contained 6 times more Zn-65 than scallops and that scallops contained 40 times more Mn-54 than clams, mussels, and oysters. Concentrations of Zn-65 were greater in all the mollusks than in fish (Table 4) which may have been due to the earlier collection dates. Concentrations of Mn-54, however, in clams, oysters, and mussels were comparable to the amounts found in a number of species of fish so the much larger amounts found in scallops cannot be attributed entirely to time of collection.

Other workers have reported larger concentrations of Zn-65 in oysters than in other mollusks. On the East Coast, Zn-65 was found in oysters from Chesapeake Bay (Murthy et al. 1959) and the Thames River, Connecticut (Fitzgerald et al. 1962). On the West Coast, oysters collected near the mouth of the Columbia River, Washington, contained more Zn-65 than any other marine organism commonly used as food by man (Watson et al. 1960). Murthy et al. (1959) found from 3 to 4 times more Zn-65 in American oysters than in hard clams collected in Chesapeake Bay; our results (Table 5) indicate a similar relationship for samples from Beaufort estuaries.

CONCENTRATIONS OF IRON AND MANGANESE IN MOLLUSKS

Our data indicate that the concentrations of iron differed little among the four species of mollusks (Table 6). Scallops, on the other hand, had concentrations of manganese ten times greater than the other species. Concentrations of iron (Table 6) were generally an order of magnitude greater than in most of the fish samples (Table 4). Concentrations of manganese were also greater in the mollusks, excluding scallops, than in fish but not an order of magnitude larger as was noted for iron. Scallops had concentrations of manganese that were more than an order of magnitude greater than any species of fish.

Fe/Mn ratios

Iron/manganese ratios were more than 10-fold lower in scallops than in the other species of mollusks (Table 6). Ratios for scallops were lower than most species of fish except burrfish. The other species of mollusks had larger ratios than scallops and were similar to those for false albacore and Spanish mackerel (Table 4). Ratios in false albacore and Spanish mackerel were large because these fish contained small concentrations of manganese. Scallops, on the other hand, had smaller ratios because they contained larger amounts of manganese than other species of fish or mollusks (Table 6).

Specific activity of Mn-54

Among the four species of mollusks, scallops had a specific activity of Mn-54 ($\text{pCi}^{54}\text{Mn/mg Mn}$) that was similar to the other species (Table 6) even though they contained large amounts of Mn-54. Specific activities in scallops were low because scallops contained proportionately large concentrations of stable manganese as well as Mn-54. Specific activities of mollusks were similar to most of the species of fish and in fact appear to be lower than most fish, with the exception of filefish (Table 4). One sample of filefish had a specific activity of 31.5 and it was collected in September 1964, more than a year earlier than the next sample of filefish (Table 1). The specific activity of our scallop samples collected in 1963 and 1964 (Table 6) was lower than the specific activity of filefish collected in 1965 and 1966 (Table 4). The one large value for filefish may be related to time of collection.

ACCUMULATION OF Mn-54 and Zn-65 BY MOLLUSKS IN LABORATORY EXPERIMENTS

There are two possible explanations for the differential accumulation of radionuclides by mollusks (Fig. 2, Table 5). One is selective accumulation of soluble radionuclides and the other is selective accumulation from particulate material.

To test whether or not accumulation was due to selective uptake of elements in the soluble form, a laboratory experiment was conducted in which clams, mussels, oysters, and scallops were placed in two fiberglass tanks, each containing approximately 150 liters of sea water, 5 μ Ci Mn-54, and 5 μ Ci Zn-65. Both radioisotopes were carrier free and were in the ionic form in 0.5M HCl. To remove different size fractions of the existing particulate material, the water in one tank was Millipore filtered (HA filter; pore size, 0.45 μ) and the water in the other tank was cotton filtered. Material passing an HA filter was considered "soluble" but may not have been ionic (Strickland and Parsons 1960).

After the water was filtered, the radioisotopes and eight individuals of each species were placed in each tank. Before the experiment was started, shells were scrubbed to remove particulate material and attached organisms. On the sampling days indicated (Fig. 3) all organisms were removed to determine accumulation of Mn-54 and Zn-65 and then returned to the tanks. Counts of Mn-54 were corrected for Compton scattering from Zn-65 activity. Accumulated radioactivity was calculated initially as net counts per unit weight of living animal (cmp/g) and then based on accumulation relative to net cpm/g for marsh mussels on day 2 (Fig. 3). Live weights of the organisms averaged: scallops, 83 g; oysters, 71 g; mussels, 41 g; and clams, 36 g. During the experiment the water temperature was about 15°C and the salinity was 30‰.

As mentioned previously, scallops and oysters concentrated Mn-54 and Zn-65 originating from fallout (Fig. 2). Under both laboratory conditions, however, scallops accumulated more Zn-65 than oysters (Fig. 3). In the tank containing Millipore-filtered water, there was no difference in the Mn-54 accumulated by scallops, oysters, and clams. In the cotton-filtered water, clams accumulated less Mn-54 than oysters or scallops, indicating that clams accumulated ionic or soluble Mn-54 more efficiently than particulate Mn-54. Neither clams nor oysters collected in nature contained as much Mn-54 as scallops (Table 5).

Apparently, the amount of radioactivity, particularly Zn-65, accumulated by these mollusks in the laboratory was a function of filtering rates. Filtering rates averaged 15 liters/hr for scallops with a maximum of 25 liters/hr (Chipman and Hopkins 1954), ranged from 6 to 15 liters/hr for oysters (Rice and Smith 1958), and ranged from 3 to 6 liters/hr for clams (Rice and Smith 1958), and averaged less than 5 liters/hr for marsh mussels (Kuenzler 1961). Scallops, the largest organisms, probably filtered more water than the other three species. Marsh mussels and clams probably filtered less water than scallops and oysters and accumulated smaller quantities of Zn-65 and Mn-54 (Fig. 3). However, any differences in rates of filtering that may have existed do not explain why oysters and clams accumulated Mn-54 in laboratory experiments but not in the environment or why scallops accumulated more Zn-65 in laboratory experiments than oysters but accumulated relatively little Zn-65 from the environment.

In the laboratory experiment scallop shells accumulated proportionately more Mn-54 and Zn-65 so that soft parts of scallops actually accumulated less Mn-54 than Zn-65. Also, in these laboratory experiments shells of oysters and scallops contained larger amounts of Mn-54 and Zn-65 in relation to soft parts than shells that accumulated these radionuclides from fallout in the environment. It is therefore evident that the mechanism of Zn-65 and Mn-54 uptake in our laboratory experiments was different than that for fallout radioactivity accumulated in nature.

In sea water, Zn-65 and Mn-54 exist in different physical-chemical states; Zn-65 is soluble whereas Mn-54 is hydrolyzed, being either colloidal or particulate. These differences are important to note because particulate material was removed from the sea water by filtering through cotton or a Millipore filter before radionuclides were added to the water. The relatively greater accumulation of Zn-65 and Mn-54 in the tank containing cotton-filtered water may have been due to uptake of radionuclides on particulate material that was removed from the

Millipore-filtered water (Fig. 3).

ECOLOGICAL IMPLICATIONS

A large range of concentrations of some radionuclides (Table 3) and iron and manganese (Table 4) were found among the species of fish. The largest range based on averages where available was for concentrations of Mn-54 which varied at least 100 fold if we assume that the concentrations in false albacore and Spanish mackerel were approximately $0.3 \text{ pCi } ^{54}\text{Mn}/100 \text{ g wet weight}$ (Table 3). Concentrations of Cs-137 ranged less than 10 fold among the species and K-40 ranged about a factor of two. Data for Zn-65 and Ru-106 were too few to warrant further discussion. Average concentrations of stable manganese ranged about 10 fold, as did the Fe/Mn ratios, even though the range of average concentrations of stable iron was less (Table 4). Ratios calculated from these measurements also had large ranges (Table 4).

There are many factors that might have affected the results we obtained on the content of radionuclides, iron, and manganese in fish. Among these are size, age, and sex of each species, temperature, salinity, seasonal variations, and yearly differences in the amount of fallout due to decreasing quantities during our study. Our data for any species are too few in number to determine whether these factors influenced the accumulation of radionuclides or stable elements. The data suggest, as we will discuss below, that the influence of these factors on species accumulation was small compared to the differences we found among the species.

The fish can be grouped into several categories if the data in Table 3 and 4 are compared with the feeding types and habitat for different species. Four somewhat arbitrary groups are pelagic nektonic feeders, estuarine nektonic feeders, estuarine benthic feeders, and planktonic feeders (Table 7). Estuarine includes bays, sounds, and the nearshore coastal area for some species. The ben-

thic feeders we sampled were all relatively shallow water species; no deep water benthic species were sampled.

Pelagic benthic feeders contain two species, false albacore and Spanish mackerel (Table 7). The species in this group were characterized by larger concentrations of K-40 and Cs-137, larger Fe/Mn and Cs-137/Mn-54 ratios, smaller concentrations of Mn-54 and stable Mn, and smaller Mn-54/K-40 ratios than most of the other species (Tables 3 and 4). Estuarine benthic feeders, as characterized by puffer, burrfish, and filefish, were at the other extreme in relation to these data: they had smaller concentrations of K-40 and possibly Cs-137, smaller Fe/Mn and Cs-137/Mn-54 ratios, larger concentrations of Mn-54 and stable Mn, and larger Mn-54/K-40 ratios.

The other estuarine benthic feeders, pinfish, croaker, and spot, had intermediate values. The planktonic feeders, mullet and anchovy, had some of the same characteristics as the pelagic nektonic species except they had smaller Fe/Mn ratios, smaller concentrations of K-40 and smaller Cs-137/Mn-54 and Mn-54/K-40 ratios since they contained measurable amounts of Mn-54 and the pelagic nektonic feeders did not.

Large Cs-137 concentrations (Table 3) in pelagic nektonic fish are interesting because it is generally assumed that ocean fish would accumulate less Cs-137 than freshwater fish because the concentration of potassium is much larger in the ocean than in fresh water (Gustafson 1967). Data we have collected at Beaufort for a brackish water clam, *Rangia cuneata* Gray, show that accumulation decreases with increasing salinity (Wolfe 1967, Wolfe and Schelske 1969, Wolfe and Coburn 1970). Weakfish and single samples of spot, mullet, and croaker also have larger ratios of Cs-137/K-40 than other species. These additional species may migrate to offshore areas which leads us to conclude that the larger

accumulation of Cs-137 by some fish is related to offshore and pelagic habitats.

Larger amounts of Mn-54 were accumulated by estuarine benthic fish than by other species of fish (Table 3). Our data indicate that this is due partly to the fact that estuarine species concentrated larger amounts of stable Mn than pelagic and near shore species. The data also suggest that estuarine benthic species had larger specific activities of Mn-54 than other species--filefish definitely had larger specific activities (Table 4). Estuaries along the southeastern coast of the United States have been considered to be productive because they act as nutrient traps (Schelske and Odum 1962), this generalization has been documented for phosphorus and zinc by Pomeroy et al. (1969) and probably applies for manganese. It has been shown that increased runoff of freshwater and coprecipitation of stable manganese by ferric hydroxide in sea water resulted in increased accumulation of stable Mn by algae and sponges but that the increase was greater for Mn-54 than for stable Mn (Lowman, Stevenson, McClint Escalera, and Lugo Ufret 1967). Apparently, there may be a selective trapping mechanism for Mn-54 in estuaries in addition to that for stable manganese.

Accumulation of Mn-54 and Zn-65 by mollusks in our laboratory experiments (Fig. 3) was from water that had been Millipore filtered (0.45 μ pore size) and cotton filtered. Under both conditions, the amount of flocculent and particulate material in the water for radionuclide adsorption was limited so that Zn-65 and Mn-54 accumulation were due primarily to exchange processes. Apparently Zn-65 and Mn-54 accumulated in the environment were not ionic or available for exchange, because scallops and oysters accumulated Mn-54 and Zn-65 in different proportions in the laboratory than from fallout sources.

These results suggest a particulate source in the environment. One potential source of particulate material for these mollusks is phytoplankton. Rice (1963b) stated that various species of phytoplankton concentrate radionuclides differently and that the radioactivity passed through the food web from phyto-

plankton varies with cell size and cell number. The capacity of phytoplankton to concentrate radionuclides also depends upon the physical state of the radionuclide in sea water. Therefore, Mn-54 and Zn-65 may have been accumulated by different species of phytoplankton. Davis and Marshall (1963) have shown that scallops feed from a discrete vertical stratum called the epibenthic layer which has a characteristic phytoplankton assemblage. Food selectivity has also been shown in oysters (Loosanoff 1949).

If different species of food contained different radionuclides, selective feeding could be used to explain why the four species of mollusks accumulated different concentrations of radionuclides, particularly Mn-54 and Zn-65. Differential accumulation was found in filter feeders belonging to what is usually considered one trophic level and in organisms which we collected from the same habitat. It is our conclusion that these differences suggest different ecological niches among the four species.

Our data indicate that Mn-54 is accumulated selectively over stable Mn by filefish and possibly by other fish that are estuarine benthic feeders (Table 4). Bay scallops, also accumulate Mn-54 selectively--a relationship that is not apparent from the data in Table 6. But data on the tissue distribution of Mn-54 show a large range in specific activity of Mn-54 ($\text{pCi}^{54}\text{Mn/mg Mn}$) with the kidney having the highest specific activity and the other tissues which comprise the bulk of the organism having hundred fold lower specific activities (Schelske 1966). These data point to a selective mechanism for Mn-54 accumulation by bottom feeders in estuaries.

In addition to selective feeding, there are several other hypotheses for differential accumulation. First, selective assimilation, particularly of Mn-54 and possibly Cs-137, may occur from fallout particles. Radioactivity associated with fallout particles was only slightly soluble in water (Mamuro et al. 1965) so some fallout radioactivity may be ingested in the form in which it entered

the environment. Second, different chemical composition may account for the differences observed if the radionuclides are present in equal proportions (equal specific activities) in all animals. Third, differences in metabolism of the elements and differences in life cycles may, however, be as important as chemical composition. In a given time, animals that have greater rates of turnover of an element will have greater specific activities and animals with relatively long life cycles will accumulate smaller amounts of a particular element, especially if the half-life of the radioisotope is short compared to the rate of turnover.

We have postulated some mechanisms for selective accumulation of radionuclides by estuarine organisms but have not defined these mechanisms. An additional conclusion that can be derived from our study relates to specific activity and its use in predicting the fate and concentration of radionuclides in the environment. Our data demonstrate that for management of radioactive wastes in addition to consideration of specific activity (National Academy of Sciences 1962) one must know the chemical and physical form of the radionuclide that is released. Some forms of radionuclides may not behave as tracers in the environment due either to the form released or to the form of the stable element in the environment. Predictions of concentrations in components of the environment, consequently, could be either larger or smaller than the concentrations that would occur in the environment.

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TABLE 1. Date of collection, site of collection and average size of fish collected near Beaufort, North Carolina.

Date	Station	Sample No.	Species	Average of total length in cm
Sept. 1965	Ottis Fish House	1201	False albacore	68
Aug. 1965	#5 Sea Buoy to Cape Lookout	1150	False albacore	83
Aug. 1965	#5 Sea Buoy to Cape Lookout	1149	Spanish mackerel	45.4
Aug. 1965	" " "	1175	Spanish mackerel	45.4
Aug. 1965	" " "	1176	Spanish mackerel	
Sept. 1965	Ottis Fish House	1206	Spanish mackerel	49
Sept. 1965	Ottis Fish House	1207	Spanish mackerel	
Nov. 1965	Davis Fish House	1591	Spanish mackerel	47
Apr. 1965	#1 Beaufort Inlet	682	Weakfish	17
July 1965	#3 Mouth Core Creek	1105	Weakfish	18.4
May 1966	#1 Beaufort Inlet	1675	Butterfish	10.5
Nov. 1965	#1 Beaufort Inlet	1331	Butterfish	16.3
May 1965	#1 Beaufort Inlet	766	Banded drum	15.2
Apr. 1965	#1 Beaufort Inlet	684	Spot	13
June 1965	#1 Beaufort Inlet	869	Spot	14.4
July 1965	#1 Beaufort Inlet	1109	Spot	16.4
Apr. 1966	Davis Fish House	1593	Spot	26
May 1966	#3 Mouth Core Creek	1636	Spot	14.4
Apr. 1965	#1 Beaufort Inlet	686	Croaker	13
May 1965	#1 Beaufort Inlet	767	Croaker	14.1
Nov. 1965	#1 Beaufort Inlet	1328	Croaker	18.3
Sept. 1964	#1 Beaufort Inlet	711	Puffer	15

Apr. 1965	#1 Beaufort Inlet	691	Puffer	20
Apr. 1965	#1 Beaufort Inlet	692	Puffer	--
May 1965	#2 Straits	746	Striped burrfish	20.5
July 1966	Pivers Is. Beach	1761	Striped burrfish	12.5
May 1965	#2 Straits	745	Striped anchovy	10.8
July 1965	#1 Beaufort Inlet	1104	Striped anchovy	10.9
May 1965	#2 Straits	743	Pinfish	11.3
May 1965	#2 Straits	744	Pinfish	11.4
July 1965	#4 T. B. Smith Fish House	1145	Pinfish	16.7
July 1965	#4 T. B. Smith Fish House	1146	Pinfish	16.7
May 1966	#3 Mouth Core Creek	1635	Pinfish	12.5
Sept. 1966	#2 Straits	1808	Pinfish	11.1
Jan. 1966	Davis Fish House	1439	File fish	18.9
Jan. 1966	Davis Fish House	1440	File fish	19.1
Dec. 1965	Davis Fish House	1361	File fish	18.2
/Dec. 1965	Davis Fish House	1360/62	File fish	17.7
Sept. 1964	#1 Beaufort Inlet	713	File fish	18.0
Nov. 1965	Davis Fish House	1338	Mullet	38

Note: Fish from fish houses were caught in the ocean by commercial fishermen except for pinfish from T. B. Smith. These were caught in trap off his dock.

TABLE 2. Systematic classification of fish collected near Beaufort, North Carolina.

Class Chondrichthyes

Order Squaliformes

Family Squalidae (dogfish sharks)

Spiny dogfish, *Squalus ancanthias* Linnaeus

Family Rajidae (skates)

Clearnose skate, *Raja eglanteria* Bosc

Class Osteichthyes

Order Clupeiformes

Family Engraulidae (anchovies)

Striped anchovy, *Anchoa hepsetus* (Linnaeus)

Family Clupeidae (herrings)

Atlantic thread herring, *Opisthonema oglinum* (Le Sueur)

Order Perciformes

Family Sciaenidae (drums)

Atlantic croaker, *Micropogon undulatus* (Linnaeus)

Spot, *Leiostomus xanthurus* Lacépède

Banded drum, *Larimus fasciatus* Holbrook

Weakfish, *Cynoscion regalis* (Bloch and Schneider)

Southern kingfish, *Menticirrhus americanus* (Linnaeus)

Family Sparidae (porgies)

Pinfish, *Lagodon rhomboides* (Linnaeus)

Family Trichiuridae (cutlassfishes)

Atlantic cutlassfish, *Trichiurus lepturus* Linnaeus

Family Scombridae (mackerels and tunas)

False albacore, *Euthynnus alletteratus* (Rafinesque)

Spanish mackerel, *Scomberomorus maculatus* (Mitchill)

Family Stromateidae (butterfishes)

Butterfish, *Poronotus triacanthus* (Peck)

Family Mugilidae (mulletts)

Striped mullet, *Mugil cephalus* Linnaeus

Order Tetraodontiformes

Family Balistidae (filefishes and triggerfishes)

Planehead filefish, *Monacanthus hispidus* (Linnaeus)

Family Tetraodontidae (puffers)

Northern puffer, *Sphaeroides maculatus* (Bloch and Schneider)

Family Diodontidae (porcupinefishes)

Striped burrfish, *Chilomycterus schoepfi* (Walbaum)

Table 3. Fallout radioactivity in fishes collected near Beaufort, North Carolina

Species	Sample Number	pCi/100 g wet weight				
		^{40}K	^{65}Zn	^{54}Mn	^{137}Cs	^{106}Ru
False Albacore	1150	346 $\pm$ 8.1	-0-	**	8.29 $\pm$ 0.44	-0-
Little Tuna (Muscle only)	1201	301 $\pm$ 5.6	1.14 $\pm$ 0.40	**	2.46 $\pm$ 0.26	**
Spanish mackerel	1149	398 $\pm$ 8.5	-0-	-0-	28.7 $\pm$ 0.58	-0-
body less viscera	1175	462 $\pm$ 21	**	-0-	38.6 $\pm$ 1.54	-0-
viscera	1176	357 $\pm$ 101	-0-	-0-	-0-	168 $\pm$ 41
body less viscera	1206	350 $\pm$ 16	**	**	10.6 $\pm$ 1.02	-0-
viscera	1207	336 $\pm$ 33	-0-	-0-	-0-	**
	1591	296 $\pm$ 8.6	-0-	**	3.37 $\pm$ 0.48	-0-
	Avg.	367			20.3	
Weakfish	682	250 $\pm$ 7.0	**	0.72 $\pm$ 0.27	8.47 $\pm$ 0.42	**
	1105	247 $\pm$ 6.9	3.66 $\pm$ 0.63	1.23 $\pm$ 0.28	6.25 $\pm$ 0.41	**
Butterfish	763					
	764					
	1106					
	1107					
	1331	330 $\pm$ 4.6	2.66 $\pm$ 0.43	2.09 $\pm$ 0.19	3.39 $\pm$ 0.19	3.91 $\pm$ 1.07
Banded drum	766	282 $\pm$ 8.6	-0-	2.44 $\pm$ 0.36	2.09 $\pm$ 0.47	4.87 $\pm$ 2.3
Spot	684	216 $\pm$ 6.1	2.85 $\pm$ 0.55	2.69 $\pm$ 0.26	5.90 $\pm$ 0.36	4.96 $\pm$ 1.6
	869	313 $\pm$ 12.9	-0-	3.87 $\pm$ 0.60	3.89 $\pm$ 0.80	15.0 $\pm$ 3.9
	1109	304 $\pm$ 7.9	-0-	3.85 $\pm$ 0.33	4.28 $\pm$ 0.42	4.76 $\pm$ 2.0
	1593	261 $\pm$ 13.0	**	2.23 $\pm$ 0.64	1.83 $\pm$ 0.83*	**
	1636	293 $\pm$ 7.5	**	2.07 $\pm$ 0.34	3.57 $\pm$ 0.40	**
	1330	255 $\pm$ 4.5	0.96 $\pm$ 0.46	1.46 $\pm$ 0.20	2.91 $\pm$ 0.21	3.59 $\pm$ 1.2
	Avg.	274		2.70	3.73	7.08
Croaker	686	251 $\pm$ 7.2	2.34 $\pm$ 0.64	2.74 $\pm$ 0.30	9.47 $\pm$ 0.45	**
	767	247 $\pm$ 9.9	-0-	2.56 $\pm$ 0.46	3.17 $\pm$ 0.61	8.16 $\pm$ 3.0
	1328	224 $\pm$ 4.3	**	1.43 $\pm$ 0.20	2.28 $\pm$ 0.20	2.84 $\pm$ 1.2
	685					
	Avg.	240		2.24	4.97	
Puffer						
body less viscera	691	240 $\pm$ 6.5	2.78 $\pm$ 0.58	8.79 $\pm$ 0.32	3.24 $\pm$ 0.35	8.11 $\pm$ 1.7
viscera	692	254 $\pm$ 10.2	**	5.78 $\pm$ 0.50	2.19 $\pm$ 0.62	**
	711	247		7.29	2.72	--
	Avg.	247		7.29	2.72	
Burrfish	746	154 $\pm$ 6.6	2.48 $\pm$ 0.68	7.77 $\pm$ 0.36	1.78 $\pm$ 0.41	4.06 $\pm$ 2.0
	1761	180 $\pm$ 15.0	3.93 $\pm$ 1.8	6.79 $\pm$ 0.83	**	10.8 $\pm$ 5.2
hovy	745	215 $\pm$ 9.1	2.95 $\pm$ 0.93	2.18 $\pm$ 0.42	3.23 $\pm$ 0.57	**
	1104	304 $\pm$ 7.3	3.59 $\pm$ 0.62	3.10 $\pm$ 0.29	2.65 $\pm$ 0.37	**

Species	Sample Number	pCi/100 g wet weight				
		^{40}K	^{65}Zn	^{54}Mn	^{137}Cs	^{106}Ru
Anfish	743	-----	-----	-----	-----	-----
	744	363 $\pm$ 8.2	2.43 $\pm$ 0.66	11.6 $\pm$ 0.39	4.61 $\pm$ 0.42	8.89 $\pm$ 1.9
	1145	272 $\pm$ 8.7	**	5.10 $\pm$ 0.39	2.53 $\pm$ 0.49	**
	1146	-----	-----	-----	-----	-----
	1635	271 $\pm$ 5.3	1.21 $\pm$ 0.48	4.06 $\pm$ 0.24	2.73 $\pm$ 0.25	5.06 $\pm$ 1.3
	1808	329 $\pm$ 8.1	1.76 $\pm$ 0.67	3.27 $\pm$ 0.32	3.07 $\pm$ 0.42	**
	Avg.	309	1.80	6.01	3.24	
Filefish	713	282 $\pm$ 12.5	**	80.0 $\pm$ 1.57	2.73 $\pm$ 0.79	32.3 $\pm$ 5.9
	1360/62	203 $\pm$ 4.4	3.13 $\pm$ 0.48	27.7 $\pm$ 0.38	2.44 $\pm$ 0.22	8.2 $\pm$ 1.2
	1361	219 $\pm$ 5.1	3.25 $\pm$ 0.59	26.8 $\pm$ 0.43	2.39 $\pm$ 0.26	6.1 $\pm$ 1.5
	1439	215 $\pm$ 5.9	2.91 $\pm$ 0.65	34.2 $\pm$ 0.52	2.30 $\pm$ 0.32	8.3 $\pm$ 1.8
	1440	196 $\pm$ 4.4	2.74 $\pm$ 0.46	23.6 $\pm$ 0.36	1.62 $\pm$ 0.22	5.1 $\pm$ 1.2
	1760	-----	-----	-----	-----	-----
	Avg.	223	2.41	38.5	2.30	12.0
Mullet	1338	213 $\pm$ 4.7	1.39 $\pm$ 0.53	1.60 $\pm$ 0.23	7.84 $\pm$ 0.28	4.0 $\pm$ 1.4
Cutlass fish	681					
Sea mullet	1592					
Southern kingfish	1108					
	1809					
Skate	690					
	714					
Squalus	687 body less viscera					
	688 liver only					
	689 viscera less liver					

-0- denotes oversubtraction, negative counts

** below limit of detection

Table 4. Concentration of iron and manganese and ratios of measurements of stable elements and fallout radioactivity in fishes collected near Beaufort, North Carolina. Data on radioactivity are from Table 3.

Species	Sample Number	mg/100 g wet weight		Ratios					
		Fe	Mn	Fe/Mn	⁵⁴ Mn/Mn	¹³⁷ Cs/ ⁵⁴ Mn	¹³⁷ Cs/ ⁴⁰ K	⁵⁴ Mn/ ⁴⁰ K	⁵⁴ Mn/6
False Albacore	1150	4.200	0.142	29.6	---	----	0.0239	----	----
Little Tuna (muscle only)	1201	3.512	0.0725	48.4	---	----	0.0081	----	----
Spanish mackerel	1149	3.49	0.0885	39.4	---	----	0.0721	----	----
body less viscera	1175	0.504	0.0255	19.8	---	----	0.0835	----	----
viscera	1176	4.014	0.0710	56.5	---	----	----	----	----
body less viscera	1206	0.522	0.0866	6.03	---	----	0.0302	----	----
viscera	1207	0.511	0.0106	48.2	---	----	----	----	----
	1591	1.192	0.0860	13.9	---	----	0.0113	----	----
	Avg.	1.71	0.0613	30.6			0.0492		
Weakfish	682	1.462	0.236	6.19	3.05	11.8	0.0338	0.0028	----
	1105	1.546	0.233	6.63	5.28	5.08	0.0253	0.0049	0.336
Butterfish	763	1.983	0.251	7.90					
	764	2.336	0.293	7.97					
	1106	2.617	0.232	11.3					
	1107	2.732	0.324	8.43					
	1331	2.129	0.321	6.63	6.51	1.62	0.0102	0.0063	0.786
	Avg.	2.360	0.284	8.45					
Banded drum	766	2.184	0.412	5.30	5.92	0.856	0.0074	0.0086	----
Spot	684	4.113	0.578	7.11	4.65	2.19	0.0273	0.0124	0.944
	869	4.554	0.572	7.96	6.77	1.01	0.0124	0.0123	----
	1109	7.534	0.686	10.98	5.61	1.11	0.0140	0.0126	----
	1593	3.393	0.554	6.12	4.02	0.821	0.0070	0.0085	----
	1636	9.864	0.558	17.67	3.71	1.72	0.0121	0.0070	----
	1330	6.40 *	0.478*	13.39*	3.05*	1.99	0.0114	0.0057	1.52
	Avg.	5.976	0.571	9.97	4.53	1.47	0.0140	0.0097	
Croaker	686	4.165	0.880	4.69	3.08	3.46	0.0377	0.0109	1.17
	767	5.502	0.738	7.45	3.47	1.24	0.0128	0.0103	----
	1328	3.170	0.528	6.00	2.71	1.59	0.0101	0.0063	----
	685	13.31	0.827	16.1					
	Avg.	6.540	0.743	8.56	3.09	2.10	0.0202	0.0091	

Species	Sample Number	mg/100 g wet weight		Ratios					
		Fe	Mn	Fe/Mn	⁵⁴ Mn/Mn	¹³⁷ Cs/ ⁵⁴ Mn	¹³⁷ Cs/ ⁴⁰ K	⁵⁴ Mn/ ⁴⁰ K	⁵⁴ Mn/ ⁶⁵ Zn
Puffer									
body less viscera	691	1.33	1.46	0.911	6.02	0.368	0.0135	0.0366	3.16
viscera	692	9.68	0.842	11.5	6.86	0.378	0.0086	0.0227	----
	711	3.80	1.47	2.59	4.97	0.373	0.0110	0.0295	----
	Avg.	4.94	1.26	5.00	5.95	0.373	0.0110	0.0296	
Burrfish									
	746	6.18	3.33	1.86	2.33	0.229	0.0115	0.0504	3.13
	1761	3.57	1.48	2.41	4.59	----	----	0.0377	1.73
Anchovy									
	745	1.56	0.365	4.27	5.97	1.48	0.0150	0.0101	0.739
	1104	1.56	0.439	3.55	7.06	0.85	0.0087	0.0101	0.864
Pinfish									
	743	6.45	0.811	7.95					
	744	9.29	0.971	9.57	11.94	0.397	0.0126	0.0319	4.77
	1145	2.29	0.526	4.35	9.70	0.496	0.0093	0.0187	
	1146	2.57	0.369	6.96					
	1635	8.76	0.962	9.11	4.22	0.672	0.0100	0.0149	3.36
	1808	11.21	1.196	9.37	2.73	0.938	0.0093	0.0099	1.86
	Avg.	6.76	0.806	7.89	7.15	0.626	0.0103	0.0188	3.33
Filefish									
	713	6.45	2.54	2.54	31.5	0.0341	0.0096	0.284	----
	1360/62	11.44	1.75	6.52	15.8	0.0880	0.0120	0.136	8.84
	1361	9.82*	1.69*	5.80*	15.8*	0.0891	0.0109	0.122	8.25
	1439	9.82*	1.69*	5.80*	20.2*	0.0672	0.0106	0.159	11.7
	1440	9.82*	1.69*	5.80*	13.9*	0.0686	0.0082	0.120	8.61
	1760	11.58	0.784	14.8					
	Avg.	9.82	1.691	6.88	19.4	0.0694	0.0102	0.164	9.35
Mullet									
	1338	6.42	0.782	8.21	2.05	4.90	0.0368	0.0075	1.15
Cutlass fish									
	681	3.13	0.274	11.4					
Sea mullet									
	1592	1.85	0.220	8.41					
Southern kingfish									
	1108	3.45	0.425	8.12					
	1809	3.81	0.452	8.43					

Table 5. Fallout radioactivity in mollusks collected near Beaufort, North Carolina

Species	Sample Number	Sampling Date	pCi/100 g wet weight				
			⁴⁰ K	⁶⁵ Zn	⁵⁴ Mn	¹³⁷ Cs	¹⁰⁶ Ru
Clams	249	1/24/64	127	9.65	5.47	3.79	57.6
	299	5/26/65	218	-0-	5.81	**	**
Mussels	278	1/31/64	63.9	5.50	6.79	3.01	37.8
	122	10/1/63	57.4	5.54	1.75	**	33.9
Oysters	248	1/23/64	86.2	35.4	1.16	5.93	1.28
	761	5/26/65	116	6.26	4.79	2.22	20.0
Scallops	121	10/1/63	100	6.05	214	55.6	241
	490	10/20/64	302	16.5	745	-0-	221

** below limit of detection

-0- denotes oversubtraction, negative counts

Table 5. Fallout radioactivity in mollusks collected near Beaufort, North Carolina.

Species	Sample Number	pCi/100 g wet weight				
		^{40}K	^{65}Zn	^{54}Mn	^{137}Cs	^{106}Ru
Clams	249	119	9.1	5.0	7.3	52
Mussels	278	64	5.5	6.8	5.5	38
Oysters	248	114	35.0	5.4	6.8	25
Scallops	121	110	6.0	214.0	73.0	241

Table 6. Concentration of iron and manganese and ratios of measurements of stable elements and fallout radioactivity in fishes collected near Beaufort, North Carolina. Data on radioactivity are from Table 5.

Species	Sample Number	mg/100 g wet weight		Ratios					
				Fe/Mn	$^{54}\text{Mn}/\text{Mn}$	$^{137}\text{Cs}/^{54}\text{Mn}$	$\frac{^{137}\text{Cs}}{^{40}\text{K}}$	$\frac{^{54}\text{Mn}}{^{40}\text{K}}$	$\frac{^{54}\text{Mn}}{^{65}\text{Zn}}$
		Fe	Mn						
Clams	249	62.4	1.78	35.1	3.51	----	----		1.19
Mussels	278	72.7	2.32	31.3	2.90	----	----		1.02
Oysters	248	57.8	1.44	40.1	2.33	3.06			0.0879
Scallops	121	69.8	5.47	12.8	36.5	0.277			21.6

TABLE 7. Habitat and food sources of fish collected near Beaufort, North Carolina. Species are separated into three types of feeders: nektonic, benthic, and planktonic-detrital.

Species	Habitat	Primary Food
<i>Nektonic Feeders</i>		
False albacore	Pelagic	Fish, Squid
Spanish mackerel	Pelagic (continental shelf)	Fish, Squid
Weakfish	Inshore, Estuaries	Fish (menhaden), Shrimp, Crabs
Butterfish ²	Inshore, Estuaries	Small Fish, Squid, Annelid Worms
Banded drum ²	Estuaries in summer	Fish, Shrimp
<i>Benthic Feeders</i>		
Pinfish	Inshore, estuaries, vegetated areas ¹	Omnivorous, Small Crustaceans
Croaker	Estuaries, coastal (winter) ¹	Mollusks, Polychaete Worms
Spot	Estuaries to fresh water ¹	Small Amphipods and Mollusks
Puffer	Estuaries, beach (winter)	Oysters, Scallops and Crustaceans
Burrfish	Estuaries, beach (winter)	Mollusks, Crustaceans
Filefish	Estuaries (weed beds), Inshore	Bryozoans, Crustaceans, and Mollusks
<i>Planktonic-Detrital Feeders</i>		
Mullet	Estuaries (summer), Offshore (winter) ¹	Plankton, Detritus, Benthic Diatoms
Anchovy	Schools on sandy shores	Copepods, some bottom Invertebrates

¹Spawns offshore and larvae develop in estuary.

²Nektonic feeders seasonally.

FIGURE LEGENDS

Figure 1. Spectra of gamma radioactivity in Spanish mackerel and filefish.

Figure 2. Spectra of gamma radioactivity in four species of lamellibranch molluscs.

Figure 3. Uptake of Mn^{54} and Zn^{65} from sea water by four species of lamellibranch molluscs. Upper curves show uptake in Millipore-filtered water.

COUNTS OF GAMMA RADIOACTIVITY

ENERGY (Mev)

RELATIVE UPTAKE OF Mn⁵⁴

RELATIVE UPTAKE OF Zn⁶⁵