RADIOISOTOPE MEASUREMENTS OF THE VISCERA OF PACIFIC SALMON

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Abstract. Pacific salmon, Oncorhynchus spp., concentrate certain gamma-emitting radionuclides ($^{65}$Zn, $^{54}$Mn, $^{40}$K, and $^{137}$Cs) in their viscera. In some cases the pattern of concentration of radionuclides seems related to the position of the freshwater plume of the Columbia River, a well-known source of $^{65}$Zn in the northeast Pacific Ocean. Fishes whose migration paths were far south of the river had more $^{65}$Zn, but less $^{54}$Mn. In southeastern Alaskan waters there was a distinct difference in relative abundance of $^{65}$Zn and $^{54}$Mn in salmon. Manganese-54 was the dominant isotope in salmon of northern Alaskan waters and $^{65}$Zn was more prominent in the spectra of fishes from Canadian and contingent United States waters. The Columbia River plume undoubtedly accounted for this increase in $^{65}$Zn.

Concentrations of radionuclides differ with species and stocks of salmon. The chinook and coho salmon, which feed more on small fishes than the sockeye, accumulated the highest concentrations of $^{65}$Zn, $^{54}$Mn and $^{137}$Cs. On the other hand, the sockeye, feeding on a lower trophic level, had low radioactivity, with $^{54}$Mn the dominant radionuclide, some $^{65}$Zn and no $^{137}$Cs. The chum and pink salmon examined most nearly resembled the sockeye in radioactivity.

Ocean food habits and migratory pathways both appear relevant to the levels of artificially produced gamma-emitters in the viscera of salmon.

Introduction

The Columbia River is a major source of radioactivity in the northeast Pacific Ocean because of the radionuclides introduced by the nuclear reactors at Hanford, Washington. One of these, $^{65}$Zn, is found in most marine organisms in waters off Oregon. When it was learned that the viscera of salmon from this area also contained relatively large amounts of $^{65}$Zn, the likelihood that viscera could be used to monitor the northern-most extension of Columbia River effluent was considered.

Salmon runs occur in coastal streams from California to Alaska, and commercial fisheries exist along the entire range. Thus, viscera could be obtained from salmon taken from 640 Km south to about 4500 Km north of the mouth of the Columbia River. Analysis of these samples should provide a measure of the decrease in $^{65}$Zn activity with distance from the Columbia River. These data should in turn help further our understanding of the movement of Columbia River water at sea in response to winds and currents. Columbia River water forms a plume in the ocean which generally flows southward during the summer and northward during the winter with the prevailing surface ocean currents (Fig. 1). Hopefully, too, background information gained could eventually lead to a method of differentiating salmon of Asiatic stock from those originating in the streams of North America. Since the species are known to intermingle at times, a radioactive tag in the American fish would help resolve an international problem.

This, then, was the purpose of the study. While not all objectives were realized, the affinity of salmon for radionuclides and the sensitivity of our techniques clearly demonstrate that the influence of the Columbia River extends far north of its anticipated limit.

Zinc-65 (245-day half-life) was not the only radionuclide present. In some cases, $^{54}$Mn (310-day half-life) was present in even larger amounts. Cesium-137 (30-year half-life) was also observed on occasion. Both $^{54}$Mn and $^{137}$Cs appear to originate primarily from fallout, rather than
the Columbia River. Natural radioactive potassium-40 (1.3 x 10^9 year half-life) was also present in all samples, but was of no concern in this study.

Differences in the radionuclide content of various species were observed, and some of these differences seem to be related to diet. Some are clearly due to migration, or the lack of it. Therefore it seems likely that data of the type provided in this study could someday prove useful as an ecological tool, supplementing classical techniques already employed.

Methods and Materials

Salmon used in this study were caught in summer, 1964 and 1965, by commercial fishermen in eleven areas of the Pacific Ocean (Fig. 1). The entire salmon visceral mass was removed, placed in a glass or plastic container and preserved in formalin. The preserved samples were shipped to the Oregon State University laboratory for analysis. The samples were oven-dried (60°C) and ashed (650°C) for concentration. Ashed samples (in 15 cm³ plastic tubes) were then counted 100 or 400 minutes in the well of a five x five-inch NaI(Tl) crystal in conjunction with a Nuclear Data 130 AT 512 channel spectrometer. Photpeaks for the four principal isotopes were totaled and the radioactivity of each gamma-emitter was calculated in picocuries per gram of dry weight on an IBM 1620 computer.

Results

A total of 132 samples was analyzed from five species of Pacific salmon. All contained artificial radionuclides. Zinc-65, ⁵⁴Mn, ¹³⁷Cs and ⁴⁰K were the gamma-emitters identified.
Table 1. Artificial radionuclides (picocuries per gram dry wt.)* in viscera of Pacific salmon captured in the summer, 1964

<table>
<thead>
<tr>
<th>Collection Location</th>
<th>Chinook</th>
<th>Sockeye</th>
<th>Coho</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$^{65}\text{Zn}$</td>
<td>$^{54}\text{Mn}$</td>
<td>$^{65}\text{Zn}$</td>
</tr>
<tr>
<td>Bristol Bay, Alaska</td>
<td>(6)</td>
<td>1.77</td>
<td>1.71</td>
</tr>
<tr>
<td>Cook Inlet, Alaska</td>
<td>(3)</td>
<td>3.45</td>
<td>0.45</td>
</tr>
<tr>
<td>Petersburg, Alaska</td>
<td>(4)</td>
<td>3.45</td>
<td>0.18</td>
</tr>
<tr>
<td>Skeena River, Canada</td>
<td>(4)</td>
<td>3.45</td>
<td>0.18</td>
</tr>
<tr>
<td>Johnstone St., Canada</td>
<td>(4)</td>
<td>3.45</td>
<td>0.18</td>
</tr>
<tr>
<td>Barkley Sound, Canada</td>
<td>(8)</td>
<td>5.52</td>
<td>3.24</td>
</tr>
<tr>
<td>St. Juan de Fuca, Canada</td>
<td>(2)</td>
<td>44.88</td>
<td>0.08</td>
</tr>
<tr>
<td>Astoria, Oregon</td>
<td>(7)</td>
<td>49.15</td>
<td>0.04</td>
</tr>
<tr>
<td>Depoe Bay, Oregon</td>
<td>(4)</td>
<td>81.87</td>
<td>0.72</td>
</tr>
</tbody>
</table>

*Standard deviation range is ± 0.01 to ± 0.32.
Number of fish averaged.

Furthermore, distinct differences in radioisotope concentration by species and area of capture were evident.

Chinook Salmon, Oncorhynchus tshawytscha (Walbaum 1792). Several features were noted in the concentration of radionuclides by chinook salmon (Table 1). Low, but nearly equal, levels of $^{65}\text{Zn}$ and $^{54}\text{Mn}$ (<2.0 pCi/g) were found in Bristol Bay samples. Bristol Bay lies north of the Aleutian Island chain. These islands provide a barrier to the intermixing of the Alaskan current with Bristol Bay or Bering Sea surface waters (Dodimead, Favorite, and Mirano 1963). Tag returns indicate that the Bristol Bay chinook spends its ocean life in the Bering Sea and central north Pacific (I.N.P.F.C. 1963), areas probably beyond the influence of Columbia River water so that low $^{65}\text{Zn}$ concentrations in fish would be expected because of the great distance (over 4500 km). Watson and Rickard (1963) also found low levels of radioactivity (<2.0 pCi/g) in pink and chum salmon taken farther north at Point Hope, Alaska.

The marked increase of $^{65}\text{Zn}$ concentrations in southeastern Alaska chinook may indicate that this is the northern-most limit of Columbia River influence. A herring (Clupea pallasi) from a Petersburg coho stomach had also concentrated over 14 pCi/g of $^{65}\text{Zn}$.

Farther south, chinook from the Strait of Juan de Fuca had higher $^{65}\text{Zn}$ levels (45 pCi/g, Table 1), definitely indicating association with Columbia River water which is chemically detectable in this area during the winter (Barnes 1964, Frederick 1967).

The highest concentrations of $^{65}\text{Zn}$ (82 pCi/g, Table 1) occurred in chinook caught 640 km south of the Columbia River at Eureka, California. These fish could have been in Columbia River plume water nearly all of their ocean lives. Plume water has been traced as far south as Cape Mendocino (Barnes and Gross 1966). Furthermore, chinook in the Eureka troll fishery are principally Sacramento River stocks which migrate northward as far as Vancouver Island, Canada (Moore, McLeod, and Reed 1960a). Similarly, Osterberg, Pattullo and Pearcy (1964) found more $^{65}\text{Zn}$ in euphausiids taken 183 km south of the Columbia River in summer than those collected 27 km off the river's mouth, both locations within influence of the plume. Radiozinc has also been measured in mussels (Mytilus californianus) collected off northern California (Osterberg 1965).

Two groups of chinook with different levels of radioactivity appear to be present in Astoria samples. These are probably two stocks with different migratory patterns (Fig. 2). Type A may have migrated out of the influence of the Columbia River whereas Type B, with the higher $^{65}\text{Zn}$ value, may have remained in plume waters. Recent tag studies tend to substantiate this theory.
Many Columbia River chinook confine their ocean life to the area between the mouth of the river and Vancouver Island, while others migrate great distances into northern waters along the Aleutian Chain (personal communication with Mr. Robert Loeffel, Oregon Fish Commission biologist, December 1965). To pursue this further, chinook viscera samples were collected in 1966 from several rivers of the Columbia Basin to determine if the two types were still present. The two types and other radionuclide concentrations were found which may be used to separate chinook by season and natal stream. The results are being prepared for future publication.

No noticeable correlation of radioactivity to size or sex was discernable in the eight samples (size 12-34 lb).

We can offer no plausible explanation for the higher $^{54}$Mn levels found in all species of salmon from northern waters than from southern waters.

Cesium-137 was found in small but measurable amounts in several chinook samples. Cesium is not considered biologically important, and little is known of its distribution in marine organisms (Vinogradov 1953). The preferential accumulation of $^{137}$Cs in some chinook is not readily explained. It may be an age or trophic level effect since the chinook has a relatively long life cycle and feeds more on small fishes than other salmon. Kolehmainen, Hässänen and Miettinen (1964) found an increase of $^{137}$Cs in the plankton to brown trout food chain of Lapland lakes, and Pendleton and Hansen (1964) also observed a 3.4 fold increase in concentration of $^{137}$Cs in higher trophic levels in a terrestrial environment.

Sockeye Salmon, Oncorhynchus nerka (Walbaum 1792). The similarity of spectra of sockeye samples from all collecting areas along the Pacific Coast was striking. All sockeye had low levels of both $^{54}$Mn and $^{65}$Zn (with $^{54}$Mn usually dominant) and there was no marked increase in $^{65}$Zn in samples taken close to the Columbia River (Table 1). Lower levels of $^{65}$Zn and $^{54}$Mn in sockeye may be due to an ocean life in the Gulf of Alaska or central North Pacific beyond the range of appreciable Columbia River influence. Bristol Bay sockeye which we analyzed had been tagged (physically tagged, not radioactively) in the Gulf of Alaska (see Fig. 1). Sockeye eat mostly amphipods, euphausiids, copepods and crustacean larva, (Allen 1956, Aron 1956), while chinook and coho consume more small fishes (Clemens and Wilby 1961).
Coho Salmon, Oncorhynchus kisutch (Walbaum 1792). The Cook Inlet coho had the highest concentration of $^{54}\text{Mn}$ of any salmon used in the study (Table 1, Fig. 3). Coho from this area generally migrate westward along the Aleutian Chain (I.N.P.F.C. 1961). Their feeding habits resemble those of the chinook, but coho are not as selective (Heg and Van Hyning 1951). Perhaps the coho had been feeding extensively on organisms rich in $^{54}\text{Mn}$. For example, crab megalops and young rockfishes collected at Eureka, California, had high levels of $^{54}\text{Mn}$, while other organisms from the same location showed no evidence of this radionuclide (Fig. 4, Table 2).

The definite reversal in relative abundance of $^{54}\text{Mn}$ and $^{65}\text{Zn}$ in southeastern Alaskan coho was similar to the chinook. In Cook Inlet coho, $^{54}\text{Mn}$ concentration was higher than that of $^{65}\text{Zn}$. At Petersburg, farther south, the two isotopes were nearly in equal concentrations with $^{65}\text{Zn}$ slightly higher. Four hundred miles farther south (Skeena River) $^{54}\text{Mn}$ was reduced to a trace and $^{65}\text{Zn}$ concentration more than doubled (see Table 1).

The southeastern Alaska coho has a generally random migration pattern of local movement (Moore et al. 1960b), possibly within the limits of the influence of Columbia River waters.

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**Fig. 3.** Gamma spectra of equal amounts of viscera from coho salmon taken from Alaska to California. Note the distinct reversal of the $^{65}\text{Zn}$-$^{54}\text{Mn}$ photopeaks (100 minute counts).
Fig. 4. The two gamma spectra illustrate the differences in radioisotope concentration by salmon food organisms. $^{65}$Zn and $^{54}$Mn in crab larvae and only $^{65}$Zn in euphausiids in the same area (100 minute counts).

Table 2. Artificial radionuclides (picocuries per gram dry wt.)* in organisms from salmon stomachs and in corresponding viscera

<table>
<thead>
<tr>
<th>Species</th>
<th>Location</th>
<th>Stomach Contents</th>
<th>Corresponding Salmon Viscera</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$^{65}$Zn</td>
<td>$^{54}$Mn</td>
</tr>
<tr>
<td>Pacific herring, <em>Clupea pallasii</em></td>
<td>Petersburg</td>
<td>4.06</td>
<td>0.85</td>
</tr>
<tr>
<td>Pacific herring, <em>Clupea pallasii</em></td>
<td>Petersburg</td>
<td>7.70</td>
<td>2.81</td>
</tr>
<tr>
<td>Pacific herring, <em>Clupea pallasii</em></td>
<td>Petersburg</td>
<td>14.57</td>
<td>3.80</td>
</tr>
<tr>
<td>Pacific herring, <em>Clupea pallasii</em></td>
<td>Depoe Bay</td>
<td>52.28</td>
<td>0.22</td>
</tr>
<tr>
<td>Northern anchovy, <em>Engraulis mordax</em></td>
<td>Depoe Bay</td>
<td>52.76</td>
<td>1.91</td>
</tr>
<tr>
<td><em>Euphausia</em> spp.</td>
<td>Eureka</td>
<td>43.04</td>
<td>0.57</td>
</tr>
<tr>
<td>Euphausia spp.</td>
<td>Eureka</td>
<td>127.50</td>
<td>0.65</td>
</tr>
<tr>
<td>Euphausia spp.</td>
<td>Eureka</td>
<td>27.75</td>
<td>2.20</td>
</tr>
<tr>
<td><em>Megalops, Cancer magister</em></td>
<td>Eureka</td>
<td>58.05</td>
<td>10.40</td>
</tr>
<tr>
<td><em>Megalops, Cancer magister</em></td>
<td>Eureka</td>
<td>124.11</td>
<td>8.18</td>
</tr>
<tr>
<td>Young Rockfishes (5) <em>Sebastodes</em> sp.</td>
<td>Eureka</td>
<td>122.50</td>
<td>5.71</td>
</tr>
<tr>
<td>Tapeworms (parasites)</td>
<td>Bristol Bay</td>
<td>7.98</td>
<td>5.20</td>
</tr>
</tbody>
</table>

*Standard deviation range is ±0.01 to ±0.92.

Estimates by multiplying wet weight by five.

Absolute delineation of the effects of Columbia River effluent is difficult because of the $^{65}$Zn background level throughout the world from nuclear testing (Osterberg et al. 1964).

The lower $^{65}$Zn level in coho from Johnstone Strait may appear anomalous in view of the relative proximity of the Columbia River, but this station is shielded from plume waters by Vancouver Island. Small coho tagged in the Gulf of Georgia moved in all directions but remained most of their lives in inside waters. Similar restricted migrations were evident in Hecate Strait where populations of many small streams were involved (Foerster 1955). These fishes probably had less contact with Columbia River water.
In the Strait of Juan de Fuca the definite increase in $^{65}$Zn (43 pCi/g) was undoubtedly a direct result of Columbia River discharge. The majority of these Canadian and Washington coho also have a short random migration (Moore et al. 1960b) and much of their ocean life has been spent in plume waters.

Coho samples taken in the Eureka area contained nearly as much $^{65}$Zn as samples taken closer to the mouth of the Columbia. Tag studies indicate that Eureka coho originate principally from Oregon coastal streams (ibid.) and would be associated with the Columbia River plume water most of their ocean lives.

Manganese-54 diminished in samples having high $^{65}$Zn concentrations. Lower $^{54}$Mn concentrations, as found in coho, were also noticeable in chinook from more southern waters (i.e., Vancouver Island to Eureka). Pearcy (1966) noted similar trends in the albacore, Thunnus alalunga, taken off Oregon. Albacore with high levels of $^{65}$Zn had less $^{54}$Mn than fish with lower amounts of $^{65}$Zn.

Cesium-137 appeared in three Canadian coho samples (<0.50 pCi/g). Coho, like chinook, feed at a higher trophic level but are generally smaller in size and mature earlier. Salmon that feed more on plankton (sockeye, pink, and chum) did not seem to concentrate $^{137}$Cs.

Pink Salmon, Oncorhynchus gorbuscha (Walbaum 1792), and Chum Salmon, O. keta (Walbaum 1792). Pink and chum salmon radioisotope concentrations are listed in Table 3. The higher concentrations of $^{65}$Zn in pink salmon may be due to a more extensive southern migration within the Columbia’s influence. Tagged Alaskan pink salmon have recently been caught in Oregon and Washington waters (personal communication with Mr. Jack Van Huyning, Oregon Fish Commission biologist, May 1966).

The chum had nearly equal low concentrations of both $^{54}$Mn and $^{65}$Zn (Table 3). These values are somewhat higher than those of sockeye. Although the two species have similar diets, chum feed more on small fishes than do the sockeye (Allen 1956). Pink and chum salmon normally migrate into far northern Pacific waters (Hartt 1960) beyond the influence of the Columbia River.

Comparison of Petersburg Samples. Differences in range and timing in the migration of the five species of Pacific salmon precluded simultaneous sampling of all species at all locations. However, all five species were collected at Petersburg, Alaska, within a few days. Variations in the concentrations and radionuclides found in the different species of salmon can best be seen in Fig. 5 and Tables 1 and 3. It is important to remember that, although all species were caught at Petersburg, the past history of the individual species may have been different. That is, much of the radioactivity contained in the fishes could have been accumulated elsewhere. Principal differences in the spectra (Fig. 5) are the higher $^{137}$Cs and lower $^{54}$Mn peaks in chinook than in the other species.

Western Pacific Salmon. The foregoing results were from salmon viscera taken along the Pacific Coast of North America in 1964. The following year, August 1965, salmon viscera were obtained from the Japanese Fisheries Agency. These samples were collected on the high seas with the R/V WAKASHIO MARU in the vicinity of the western Aleutian Islands (61° to 54° N and 169° to 175° E). The four species collected were chinook, coho, sockeye, and chum.

<table>
<thead>
<tr>
<th>Location</th>
<th>Pink</th>
<th>Chum</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$^{65}$Zn</td>
<td>$^{54}$Mn</td>
</tr>
<tr>
<td>Cook Inlet, Alaska</td>
<td>3.73</td>
<td>3.52</td>
</tr>
<tr>
<td>Petersburg, Alaska</td>
<td>5.17</td>
<td>1.49</td>
</tr>
</tbody>
</table>

*Standard deviation range is ±0.02 to ±0.07.
*Number of fish averaged.
Fig. 5. Gamma spectra of viscera of all five species taken in the same area illustrate the differences by species, especially accumulation of $^{137}$Cs in chinook (100 minute counts).

Table 4. Artificial radionuclides (picocuries per gram dry wt.) in western pacific salmon viscera obtained from Japan (1965)

<table>
<thead>
<tr>
<th>Species</th>
<th>$^{65}$Zn</th>
<th>$^{54}$Mn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chinook</td>
<td>(2) 0.55</td>
<td>1.63</td>
</tr>
<tr>
<td>Sockeye</td>
<td>(10) 0.31</td>
<td>0.90</td>
</tr>
<tr>
<td>Coho</td>
<td>(2) 0.37</td>
<td>2.08</td>
</tr>
<tr>
<td>Chum</td>
<td>(16) 0.38</td>
<td>1.08</td>
</tr>
</tbody>
</table>

$^a$Standard deviation range is ±0.07 to ±0.14.

$^b$Number of fish averaged.

The results are listed in Table 4 and the spectra in Fig. 6. The low $^{65}$Zn concentrations indicate that the fish have not been associated with Columbia River water. The spectra of sockeye and chum are similar to those of Alaska samples collected the previous year; both have low levels of $^{65}$Zn and $^{54}$Mn with $^{54}$Mn dominant. Unfortunately, only two chinook and two coho were available. More samples of these species would be needed to establish the extent of the Columbia River influence in this area.
Other Related Results. Herring, anchovies (*Engraulis mordax*), euphausiids, crab larvae, and rockfishes (*Sebastodes* sp) taken from salmon stomachs had measurable amounts of gamma-emitters (Table 2). Herring and anchovies contained approximately the same concentrations of $^{65}$Zn and $^{54}$Mn as their salmon predators; euphausiids contained only $^{65}$Zn; crab larvae from the same area concentrated both $^{65}$Zn and $^{54}$Mn (Fig. 4); and small rockfishes contained the most $^{65}$Zn. The higher values in the prey than the predator, particularly of $^{65}$Zn, are probably due to more thorough drying prior to weighing of the smaller organisms than large salmon viscera.

Liver, stomach, pyloric caeca, gonads, and gills of the salmon were sometimes examined individually. Liver and ovaries had the most $^{54}$Mn and the pyloric caeca and testes tended to concentrate more $^{65}$Zn. Gills of two coho examined had the highest concentration of $^{54}$Mn.

Mussels, *Mytilus* sp., and clams, *Siliqua* sp. and *Clinocardium* sp., taken in Alaska contained less than 1.0 pCi/g of dry wt. of $^{65}$Zn. This value appears to be due to world-wide fallout and may be considered indicative of background levels in organisms in water free from contamination by the Columbia River.

Conclusion

Although our data are sparse when we consider the dimensions of our sampling area and the size of the salmon populations, our study suggests that radioactive elements introduced by the Columbia River can be of ecological value. Combination of our techniques with studies of tagged fishes may help establish migratory patterns. Where we were able to compare our radiotracer results with those obtained with physical tags there was general agreement. Perhaps of more immediate interest is the possibility that salmon from the North American fishery can be distinguished from Asiatic stocks by differences in their $^{65}$Zn content.
Acknowledgments

This research was supported by AEC contract AT(45-1)1750 and USD grant 1TI-WP-111-01. We wish to thank the following people who collected the samples and made this study possible: Harold Hendrickson, Kaarlo Kama and son Michel of Astoria; Norman Jensen, Corvallis; Carl Lehman, Petersburg; W. C. Johnson and H. T. Bilton, Nanaimo; Steve Matthews, Seattle; Fred Robison and sons, Depoe Bay; Tadashi Maeba, Tokyo, Japan.

Literature Cited


THE EFFECT OF TEMPERATURE, SEDIMENT, AND FEEDING ON THE BEHAVIOR OF FOUR RADIONUCLIDES IN A MARINE BENTHIC AMPHIPOD

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Abstract. Laboratory studies were conducted to determine the effects of temperature, feeding, and presence of sediments on the behavior of 65Zn in a new species of gammarid amphipod (Anonyx sp.). This benthic amphipod was captured in 80 meters of water off the Oregon coast. In the feeding experiments, 144Ce, 45Sc, and 51Cr were used in addition to 65Zn. Accumulation and elimination rates of 65Zn were temperature dependent, although the effect appeared to be minimal within this organism's seasonal temperature range. Individual differences in 65Zn accumulation rates for amphipods of similar size had a mean standard deviation range of 14–19%. Elimination rates of 65Zn were increased in the presence of sediment and were significantly greater in feeding than in non-feeding amphipods. Anonyx which fed on adult Artemia labeled simultaneously with 65Zn, 144Ce, 45Sc, and 51Cr retained 55% of the 65Zn and less than 10% of the 144Ce and 45Sc. Transfer of 51Cr was not measurable. Zinc-65 loss during molting depended upon whether the zinc had been accumulated from food or from water. When uptake was from water, approximately 20% of the 65Zn body burden was lost with the cast exoskeleton, whereas only 2.0% was lost when 65Zn was accumulated from food. The potential role of Anonyx in the cycling of radioactivity in the marine environment is discussed.

Introduction

The distribution of radioactive wastes in the sea partly depends upon the biota. Motile forms may accumulate radioactivity in a specific locality and disperse it by means of horizontal or vertical migrations. Less-motile or stationary forms, however, may tend to concentrate and retain radioactivity within a given locality. This last process may be significant in situations where radioactivity is being introduced into the sea via river systems. Large benthic populations living near the river mouth would be exposed to radiocantamination before the physical processes of dilution and dispersion could become fully operative. Radioactivity associated with organic detritus would probably be consumed and cycled back into the food web at a rate faster than bacterial decomposition. Certain benthic populations may also be able to remove radioactivity from the inorganic fraction of the sediment, thus reducing the biological safety factor often attributed to sedimentary processes involving radioactive wastes (Waldichuk 1961). Local populations of commercially important demersal fishes feeding on these benthic organisms might require radiological monitoring.

Gammarid amphipods are an important member of shallow water benthic communities along the Oregon coast and constitute over 50% of the fauna in this region (Carey 1965). An important group in this amphipod community is the family Lysianassidae which actively seek out and consume detrital accumulations and dead or dying organisms (Enequist 1949). A characteristic genus of

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this family is Anonyx which occurs along northern coast lines at relatively shallow depths (Sars 1895). Some members of this genus are efficient skeletal cleaners and will even attack and eat live animals whose movements are restricted. Hart (1942) reported that Anonyx mugax consumed herring and cod held in live boxes and Scarratt (1965) listed Anonyx sp. as damaging 50 lb of lobster which were being held in the same manner overnight.

In this study, a new species of Anonyx\(^4\) (Fig. 1) was trapped in sandy sediment at depths of 80–120 m off the central Oregon coast. This organism apparently burrows into the sediment during the day and emerges to feed at night as we have been unable to trap it during daylight. Anonyx sp. proved to be excellent for experiments, because they could be maintained in the laboratory for several months, were of suitable size (average 21–23 mm in length and over 200 mg in wet weight), and could be obtained in large numbers.

The purposes of this study were: (1) to examine \(^{65}\)Zn metabolism in the laboratory as influenced by temperature, food, and sediment \(^{14}\)Sc, \(^{144}\)Ce, and hexavalent \(^{51}\)Cr were also used in the feeding experiments), and (2) to call attention to the potential role of these organisms in the cycling of radionuclides in northern coastal waters.

Materials and Methods

Field Collection Procedures. Test animals were captured in traps made of 1-gal cans with lids modified so that amphipods could enter but not escape (Cross 1968). These traps were baited with freshly killed herring, anchored to the bottom and left for several hours. The captured amphipods were placed in glass jars in a refrigerated case and transported either to the Battelle Northwest Laboratories or to the Department of Oceanography at Oregon State University where experiments were conducted.

\(^4\)This species is currently being described by Dr. J. Laurens Barnhard of the U.S. National Museum using specimens from our collections.

![ANONYX sp.](image)

Fig. 1. Typical specimen of Anonyx sp. from Oregon coastal waters.
Results and Discussion

Effect of Temperature on the Accumulation of $^{65}$Zn from Seawater. The effect of temperature on the accumulation of $^{65}$Zn from seawater was studied in amphipods at temperatures of 3, 7, and 12 C ± 0.5 C in filtered (pore size 0.45 μ) seawater containing 25 μCi/liter of $^{65}$Zn (specific activity 1.8 μCi/μg). Periodically six amphipods were removed, blotted on an absorbent napkin, weighed, and radioactivity. Two 5-ml samples of the seawater also were taken with each group of amphipods. Zinc-65 measurements were made with an auto gamma spectrometer in a 3 x 3 inch well crystal. The original data were reduced by computer processes to microcuries $^{65}$Zn/g wet weight of each amphipod. Mean values and standard deviations were calculated for each sample of six amphipods and appropriate corrections for geometry and physical decay were included in the computer program.

The accumulation of $^{65}$Zn by Anonyx sp. was temperature dependent (Fig. 2) although uptake curves were similar for 7 and 12 C, two temperatures that approximate the seasonal range for this organism. It is evident from the shape of the curves that equilibrium was not attained during the experiment.

Although the mean weights of the amphipods did not vary significantly within any temperature group ($P > 0.05$), the grand mean of the amphipod weights in the 7 C experiment was significantly less ($P < 0.01$) than the 3 and 12 C group. Many amphipods died due to mechanical failure of the refrigeration system, leaving only enough organisms for the experiment at 7 C. A second collection, made approximately 1 month later to obtain amphipods for the 3 and 12 C experiments, contained significantly larger organisms.

The range of the standard deviations, expressed as percent, for each sampling interval and its mean value represents differences in the ability of individual amphipods to concentrate $^{65}$Zn (Table 1). These mean values are very similar to a standard deviation value of 19.5% for concentrations of $^{65}$Zn in eight peamouth chubs (Mylocheilus caurinus) of nearly equal lengths and weights taken in a single seine haul from the Columbia River estuary (Renfro 1966).

![Graph](image)

*Fig. 2.* Accumulation of $^{65}$Zn by Anonyx sp. as a function of temperature. Each point represents the mean and standard error for six amphipods.
Table 1. Individual variation in the accumulation of $^{65}$Zn from seawater by similar-sized amphipods, based on the percentage standard deviation of six individuals from each sampling interval.

<table>
<thead>
<tr>
<th>Temperature (C)</th>
<th>Standard Deviation Mean (percent)</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>14.1</td>
<td>7.7–25.2</td>
</tr>
<tr>
<td>7</td>
<td>18.7</td>
<td>12.3–32.5</td>
</tr>
<tr>
<td>12</td>
<td>14.4</td>
<td>9.3–24.7</td>
</tr>
</tbody>
</table>

These sources of variation must be considered when comparing the 7 and 12 C curves. Although no inverse correlation between the amount of $^{65}$Zn/g and body weight was apparent, adsorption processes are probably involved in accumulation of $^{65}$Zn from seawater (Fowler 1965, Kormondy 1965, Watson, Davis, and Hanson 1963). Since the amphipods used in the 7 C experiment were smaller than those used in the other two experiments, they had a higher surface area to volume ratio and might be expected to accumulate more $^{65}$Zn per unit weight than the larger organisms. Although the uptake curves at 7 and 12 C are very similar, the ability of the smaller organisms to accumulate more $^{65}$Zn per unit weight and the higher individual variation within the 7 C group may have caused the two curves to appear more similar than would have occurred had the amphipods been of equal size.

The accumulation of $^{65}$Zn from seawater also has been shown to be temperature dependent in euphausiids (Fowler 1966) and in attached marine algae (Gutzkecht 1961). Saltman and Borroughs (1960) have demonstrated a temperature dependency in accumulation of $^{65}$Zn for fish liver slices in vitro. Kormondy (1965), however, reported uptake of $^{65}$Zn in the freshwater dragonfly, Plat-phemis lydia, to be independent of temperature.

Most marine animals, when accumulating $^{65}$Zn from seawater, do not reach equilibrium within a few days as reported for the freshwater Odonata (Kormondy 1965). Anonyx sp. did not reach equilibrium after a period of 99–168 hr. This agrees with similar experiments reported for euphausiids (Fowler 1966), echinoderms and shrimp (Hiyama and Shimizu 1964), blue crab (Rice 1963), post-larval flounder (Hoss 1964), hard clams (Price 1965), and oysters (Chipman, Rice, and Price 1958).

Effects of Temperature and Presence of Sediment on Elimination Rates of $^{65}$Zn. Three groups of amphipods (24 animals per group) were placed in filtered seawater containing 25 $\mu$Ci $^{65}$Zn/liter at 3, 7, and 12 C for 10, 8, and 6 days. Unequal periods of accumulation were used so that the three groups would accumulate similar levels of $^{65}$Zn. Each amphipod was then weighed, measured for radioactivity, and placed in individual containers with $^{65}$Zn-free seawater of the same temperature. Twelve animals from each temperature group were placed in containers with ocean sediment and 12 in containers without sediment. Each amphipod was removed from its container at regular intervals for 29 days, placed in a test tube with 2 ml of chilled seawater, radionalyzed in a single channel analyzer, and returned to the container. The seawater was changed frequently to prevent cycling of $^{65}$Zn between the amphipods and seawater. Mortality in the 3 C group reduced the number of available amphipods from 24 to 11.

The logarithm of the fraction of $^{65}$Zn retained was plotted versus time for each amphipod. The slope ($b$) of a least squares fit to the straight-line portion of the curve was used to calculate the effective half-life from the equation: $T_e = (\ln 2)/b$. The biological half-life ($T_b$) was then obtained from the expression: $T_b = T_p \sqrt{(T_p - T_e)}$, where $T_p$ = physical half-life.

Temperature appears to influence the biological half-life ($T_b$) of $^{65}$Zn, especially between 3 and 7 C (Fig. 3). Also $T_b$ values obtained in the presence of sediment are less at each temperature than $T_b$ values obtained in the absence of sediment.
Fig. 3. Effect of temperature and sediment on the biological half-life of $^{65}$Zn. Each point represents mean and standard error for the number of individuals indicated in the parentheses.

Table 2. Analysis of variance of the effect of the temperature and sediment on the biological half-life of $^{65}$Zn in Anonyx sp.

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>Sum Squares</th>
<th>Mean Squares</th>
<th>F-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>A$^a$ adjusted for B</td>
<td>2</td>
<td>0.28150</td>
<td>0.14075</td>
<td>13.64$^b$</td>
</tr>
<tr>
<td>B$^c$ adjusted for A</td>
<td>1</td>
<td>0.03605</td>
<td>0.03605</td>
<td>3.49$^d$</td>
</tr>
<tr>
<td>AB$^e$ adjusted for A and B</td>
<td>2</td>
<td>0.00471</td>
<td>0.00236</td>
<td>0.23$^d$</td>
</tr>
<tr>
<td>Error</td>
<td>48</td>
<td>0.49544</td>
<td>0.01032</td>
<td></td>
</tr>
</tbody>
</table>

$^a$Effect of temperature.

$^b$Highly significant (at 99% level).

$^c$Effect of sediment.

$^d$Not significant (at 99% level).

$^e$Interaction effect of temperature and sediment.

A weighted squares of means analysis of variance (Steel and Torrie 1960) was employed to test if these differences were statistically significant. This particular test was used because mortalities resulted in unequal numbers of individuals in each treatment group. The results of this test showed that temperature significantly affects the biological half-life of $^{65}$Zn in Anonyx sp.; but neither the effect of sediment nor the interaction of temperature and sediment could be considered ($P > 0.05$) to alter the elimination rate of $^{65}$Zn significantly (Table 2).

A positive correlation between temperature and elimination rates of $^{65}$Zn has been shown for the isopod, Isothoe (Odum and Golley 1963), the estuarine fish, Fundulus (Shulman, Brisbin, and Knox 1961), the snail, Littorina (Mishima and Odum 1963) and the euphausiid, Euphausia pacifica (Fowler 1966). Odum and Golley (1963) and Mishima and Odum (1963) suggested that the elimina-
tion rate of $^{65}$Zn can be used as a "tag" for the turnover of organic matter in both terrestrial and aquatic organisms. This hypothesis, however, has been questioned by both Fowler (1966) and Kormondy (1965) for organisms which accumulated $^{63}$Zn from water. Fowler demonstrated that formalin-preserved euphausiids lost $^{65}$Zn at rates similar to live euphausiids and Kormondy found that loss rates of $^{65}$Zn in the dragonfly, Platthemis lydia, were independent of temperature. This latter finding does not agree with results obtained in the present study.

Although the elimination rates of $^{65}$Zn were higher in the presence of sediment at all three temperatures tested (Fig. 3), the differences were not statistically significant ($P > 0.05$). Some cycling of $^{65}$Zn between the amphipod and the seawater may have occurred, although the seawater in the individual containers was changed at least once a week. In the containers with sediment, some of the $^{65}$Zn eliminated by the amphipods may have become sorbed onto the sediment eliminating the possibility of it being accumulated again by the amphipods. This sorption of $^{65}$Zn to sediment might result in lower $T_b$ values for the amphipods than if the sediment had not been present. The observed differences in elimination rates of $^{65}$Zn in Anonyx sp. might also be explained by the release of stable zinc to the seawater due to the presence of sediment. An increase in the concentration of stable zinc in the seawater would probably increase the exchange of zinc, both stable and radioactive, between the amphipod and the water. The net result would be an increase in the elimination rate of $^{65}$Zn from Anonyx sp.

The absence of a significant interaction between temperature and the presence or absence of sediment on the elimination rates of $^{65}$Zn suggests that these two environmental factors are acting independently. Duke et al. (1969) measured the effects of four environmental factors (temperature, salinity, pH, and total zinc) on the accumulation of $^{65}$Zn in some estuarine invertebrates and reported that interaction of these factors at the levels tested was not statistically significant.

The Transfer Efficiency of $^{65}$Zn, $^{46}$Sc, $^{51}$Cr, and $^{144}$Ce to Anonyx Through Food. Adult brine shrimp (Artomia salina) were placed in plastic containers with 400 ml of membrane filtered seawater. Four microcuries of each of $^{65}$Zn, $^{51}$Cr, $^{46}$Sc, and $^{144}$Ce were added to the water. Since $^{51}$Cr was purchased in the trivalent state, it was oxidized to the hexavalent state before being used because radiochromium in the Columbia River complex is predominantly Cr(VI) (Cutshall, Johnson, and Osterberg, 1966). The brine shrimp accumulated radioactivity for 5 days and then were held for 2 days in a similar container with non-radioactive seawater. This last procedure allowed the brine shrimp to lose much of the loosely bound radioactivity and thus reduced losses to the water when the brine shrimp were fed to the amphipods.

Fifteen amphipods were held individually in 400 ml polyethylene beakers suspended in 12 C water and received a single feeding of one brine shrimp having known concentrations of all four radionuclides. Feeding was scheduled in the late afternoon, allowing the amphipod to feed during the night. If the brine shrimp was eaten, the radioactivity in the amphipod was measured the next morning and on subsequent days. During this time the amphipods were not fed. The seawater in the individual containers was changed weekly to prevent cycling of radioactivity between it and the amphipods.

All measurements of radioactivity were made in the well of a 5 × 5 inch NaI(Tl) crystal coupled to a 512-channel pulse height analyzer. Because of the complex spectra obtained from measuring four radionuclides simultaneously, the data were reduced by computer techniques. In this process, over-lying photopeaks and interfering Compton effects were stripped from the spectra before quantitative determinations were made for each radionuclide.

The data were analyzed in the same manner as described above for the determination of biological half-lives. The intercept of the straight-line portion of the curve with the abscissa then represents the percentage of radioactivity originally present in the brine shrimp which was retained by the amphipod as a long-lived component. This percentage is the transfer efficiency.

A comparison of gamma spectra of an individual brine shrimp with an amphipod the day after feeding shows discrimination in favor of $^{65}$Zn (Fig. 4). Very little of the $^{144}$Ce, $^{51}$Cr, and $^{46}$Sc in the brine shrimp was retained by the amphipod, whereas a significant $^{65}$Zn peak is present in the amphipod spectra.
Fig. 4. Comparison of gamma spectra between an adult brine shrimp (Artemia) labeled with four radionuclides and an amphipod (Anonyx) 12 hours after consuming that particular brine shrimp.

Table 3. Mean transfer efficiency values for $^{65}$Zn, $^{46}$Sc, and $^{144}$Ce resulting from feeding on labeled adult Artemia

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>$n^a$</th>
<th>Mean (%)</th>
<th>S.E.M. $^b$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{65}$Zn</td>
<td>7</td>
<td>55.7</td>
<td>2.6</td>
</tr>
<tr>
<td>$^{46}$Sc</td>
<td>14</td>
<td>9.4</td>
<td>1.7</td>
</tr>
<tr>
<td>$^{144}$Ce</td>
<td>14</td>
<td>6.2</td>
<td>1.8</td>
</tr>
</tbody>
</table>

$^a$Number of individuals.
$^b$Standard error of the mean.

Since Anonyx sp. demonstrated little ability to retain significant amounts of $^{46}$Sc, $^{144}$Ce, and $^{51}$Cr(VI) through feeding, transfer efficiencies could not be determined by graphical analysis as with $^{65}$Zn. Instead, estimates of transfer efficiency were made by taking the ratio of the amount of each radionuclide remaining in the amphipod on the day after feeding to the amount originally present in the brine shrimp (Table 3). Hexavalent $^{51}$Cr was not measurable by either technique. Because of the greater amount of $^{65}$Zn in the amphipod, many counts in the area of the $^{144}$Ce and $^{51}$Cr photopeaks resulted from Compton interactions from $^{65}$Zn. This increased the counting errors making accurate determinations of low amounts of $^{144}$Ce and $^{51}$Cr much more difficult.

The mean transfer efficiencies (Table 3) cannot be generally applied to Anonyx sp. because the nature of the food and the amount eaten may affect the percentage of radioactivity retained.
The present values, obtained on the basis of a single feeding, are also based on the assumption that 100% of the radioactivity accumulated by the brine shrimp was ingested by the amphipod since no partially eaten brine shrimp were ever noted. Some radioactivity might be lost with small bits of gills, pleopods, etc., which may have broken off the brine shrimp when it was clapped and consumed by the amphipod.

Another factor affecting the transfer efficiency from one trophic level to another is tissue localization of the radionuclide. The brine shrimp accumulated the four radionuclides directly from seawater. Thus more of the radioactivity might adsorb onto the less digestible tissue than if accumulation had been from feeding. For example, Baptist and Hoss (1965) fed grass shrimp (\textit{Palaemonetes pugio}), which had accumulated $^{144}$Ce from seawater, to the estuarine fish, \textit{Fundulus}. They reported no transfer of $^{144}$Ce and attributed this to the presence of the radionuclide on the undigestible carapace.

In comparison with the present study, Nakatani and Liu (1964) fed gelatin capsules containing 200 $\mu$Ci of $^{65}$Zn to 100 yearling rainbow trout (\textit{Salmo gairdneri}) and reported that only 13% (about 26 $\mu$Ci) was present 8 days after feeding. Chipman, Rice, and Price (1958) found only 27% of the original doses present in croaker (\textit{Micropogon undulatus}) after 12 hr, regardless of whether they had been fed $^{65}$Zn in gelatin capsules or had it pipetted directly into their stomachs. The reef fish, \textit{Chaetodon miliaris}, is reported to have assimilated only 10% of the $^{65}$Zn while feeding on labeled \textit{Artemia} (Townsley 1960). These variable transfer percentages of $^{65}$Zn probably illustrate species differences, differences in feeding rates, amount fed, and mode of $^{65}$Zn accumulation of the consumed organism.

The low transfer values of $^{144}$Ce obtained in this study are not surprising when compared with values reported for other marine organisms (Baptist and Hoss 1965, Baptist 1966, and Chipman 1958). Apparently the particulate nature of $^{144}$Ce (Greendale and Ballou 1954) and a low biological demand by marine organisms for this element result in poor transfer across the gut wall. Osterberg, Pearcy and Curl (1964) reported that the levels of $^{144}$Ce in predaceous animals were much lower than in filter feeders captured off the Oregon coast after the Russian atmospheric tests of 1961–62.

Because of their chemical similarity, scandium behaves in much the same manner in nature as cerium (Palumbo 1963). Scandium-46 is a neutron-induced radionuclide present in the Columbia River system from the Hanford Atomic Products Operation. Nelson, Perkins and Nielsen (1961) have identified $^{46}$Sc in Columbia River water and on suspended sediments. Haertel and Osterberg (1965) observed the occurrence of $^{46}$Sc in the estuarine copepod, \textit{Eurytemora hirundoides}, and on detritus (mainly wood fiber) in the Columbia River estuary. Very little laboratory data exist on the behavior of this radionuclide in marine organisms. Gutknecht (1961a) has shown that the accumulation of $^{46}$Sc by marine macroalgae is due to adsorptive processes. In the present study the small amount of $^{46}$Sc retained by the amphipods during feeding was quickly eliminated. Thus it behaved much like $^{144}$Ce.

**Effect of Food Consumption on the Biological Half-Life of $^{65}$Zn in Anonyx sp.** Fifteen amphipods, held individually in 400 ml polyethylene beakers suspended in 12 C water, were fed 10 brine shrimp labeled with $^{65}$Zn once a week for 4 weeks. After this period each amphipod received a single feeding of five non-radioactive brine shrimp in an attempt to clear the gut of any residual radioactive food. Then 8 of the amphipods each were fed 10 non-radioactive brine shrimp per week for 3 weeks, while the remaining 7 amphipods were not fed during the same time period. Amphipods were measured for $^{65}$Zn twice a week during this 3-week period in the same manner as described in the previous experiment.

Food consumption greatly influenced the elimination rate of $^{65}$Zn (Table 4). The average biological half-life of $^{65}$Zn was 34.7 days for fed amphipods and 104.2 days for unfed ones. Thus feeding increased the elimination rate of $^{65}$Zn in \textit{Anonyx} by approximately a factor of three.

The effect of food consumption on elimination rates of $^{65}$Zn agrees with the findings of Odum and Golley (1963). They reported that the biological half-life of $^{65}$Zn in marine isopods which ate large amounts of non-radioactive food was less than in individuals which ate little or no food. Bryan (1966) obtained similar results when comparing elimination rates of fed and unfed crabs.
Table 4. Mean biological half-lives of $^{65}$Zn ($T_b$), effective half-lives ($T_e$), and elimination rates ($k$) for: (A) amphipods receiving multiple feedings of labeled brine shrimp and starved during measurement of elimination rates, and (B) amphipods receiving multiple feedings of labeled brine shrimp and fed non-labeled brine shrimp during elimination measurements.

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th></th>
<th>B</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (days)</td>
<td>S.E.M. $^c$</td>
<td>Mean (days)</td>
<td>S.E.M. $^c$</td>
</tr>
<tr>
<td>$T_b$</td>
<td>104.2</td>
<td>12.3</td>
<td>34.7</td>
<td>8.2</td>
</tr>
<tr>
<td>$T_e$</td>
<td>73.1</td>
<td></td>
<td>30.4</td>
<td></td>
</tr>
<tr>
<td>$k$</td>
<td>-0.0067</td>
<td></td>
<td>-0.0200</td>
<td></td>
</tr>
</tbody>
</table>

$^a$Number of individuals = 4.  
$^b$Number of individuals = 5.  
$^c$Standard error of the mean.

Shulman, Ershbin, and Knox (1961), however, were not able to demonstrate any effect on the biological half-life of $^{65}$Zn in small estuarine fish by varying food intake. The mean $T_b$ value of 34.7 days for the feeding amphipods in our studies is similar to biological half-lives for $^{65}$Zn reported by Mishima and Odum (1963) for the gastropod Littorina irrata at 15°C. These snails also fed on non-labeled food during the observations.

Loss of $^{65}$Zn Through Molting. Although molting was infrequent, several molts occurred during the experiments in which elimination rates of $^{65}$Zn were measured. Since molting took place in seawater free of radioactivity, very little contamination of $^{65}$Zn could have occurred from the surrounding medium, although a small amount of $^{65}$Zn could have been lost to the seawater before the exoskeleton was discovered and measured for radioactivity. Daily checks were made during the experiments to assure quick recovery of exoskeletons. As soon as a molt was discovered, the amphipod and the cast exoskeleton were radioanalyzed separately to determine the fraction of radioactivity lost at each molt.

The percentage of $^{65}$Zn remaining with the cast exoskeleton depended upon the mode of uptake. When accumulation was initially from water the fraction of $^{65}$Zn lost at molt was 19.7% ± 4.6% (eight observations). If accumulation was through feeding, however, the fraction of $^{65}$Zn lost at molt was 2.0% ± 1.6% (four observations). These differences appear reasonable since accumulation from water should result in a greater amount of $^{65}$Zn sorbed to the exoskeleton. This molting loss value of 19.7% is very similar to that given for the euphausiid, Euphausia pacifica. Fowler (1966) reported that, under similar conditions, E. pacifica lost approximately 18% of the total body burden of $^{65}$Zn in the first molt. The values reported in this paper and those obtained by Fowler are substantially less than the 94% molting loss of $^{65}$Zn listed by Kromondy (1965) for the dragonfly larvae, Platymysis lydia.

The Potential Role of Anonyx in the Cycling of Radionuclides. Amphipod populations, as represented by the genus Anonyx, may be important in the cycling of radioactivity introduced into the sea via river systems. During the period 1961–63 approximately 900 curies per day of neutron-induced radioactivity flowed into the Columbia River estuary and adjacent Pacific Ocean (Environmental Studies and Evaluation Staff 1962, 1963, 1964). While much of the radioactivity remaining in the dissolved state would be confined to the plume which is located in the top 40 meters (Barnes and Gross 1966), some of it would be carried down to the benthic environment as a result of sedimentary processes (Jennings 1966, Osterberg, Kulm and Byrne 1963, Gross, McManus, and Creager 1963).

The pelagic biota also would contribute to the descent of radioactivity from the surface waters to the benthic environment as Polikarpov (1966) stated: “Continuous transport of radio-


active substances to the bottom deposits occurs as a result of the death of organisms and detritus formation. The total amount of radionuclides thus transported to the bottom of a water in the course of a single season may be hundreds of times greater than their content in the whole mass of live organisms in the water at any given moment. Therefore, the living matter of a water behaves like a pump in pumping radioactive substances from the water into bottom deposits.” This biological transport of radioactivity to the benthic environment should be especially important directly off the mouth of the Columbia River during summer since the nutrient rich water of the plume has much higher standing crops of both phytoplankton (Anderson 1964) and zooplankton (Cross 1964) than ambient waters.

The main source of radioactivity for Anonyx is probably the food web since most of the radioactivity in the dissolved state would remain in the plume and nearby surface waters. Radioactivity associated with dead organisms and fecal pellets would sink through the water column and be available to Anonyx and other benthic organisms. For example, the rapid descent of $^{144}$Ce to depths of 2800 meters has been attributed to the association of this radionuclide with fecal pellets voided by filter-feeding zooplankton (Osterberg, Carey and Curl 1963).

The exact position of Anonyx sp. in the food web is not known. In the laboratory it consumed dead fish, beef liver, and both live nauplii and adults of Artemia. These diverse feeding habits may also be employed by this organism in nature as some gammarids undergo seasonal or nocturnal swarming in the water column (Fage 1933). The excellent swimming ability and large eyes of Anonyx sp. may allow it to undertake these migrations and feed on zooplankton although no indication of this was seen in the present study.

Since Anonyx sp. is of good size and at times abundant, it seems reasonable to assume that it is preyed upon by demersal fishes inhabiting Oregon coastal waters. Thus it appears that benthic amphipods, as represented by the genus Anonyx, are important in the cycling of organic matter along the Oregon coast and their role in the cycling of radionuclides may be underestimated.

Acknowledgments

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