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RADIOACTIVITY IN THE REEF FISHES OF BELLE ISLAND ENIWETOK ATOLL APRIL 1954 TO NOVEMBER 1955

by

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ABSTRACT

Studies of the radioactivity in reef fishes of Belle (Bogombogo) Island, Eniwetok Atoll, were made during a period of about one year following the atomic detonations in 1954. Thirty-four different collections were made and 693 specimens were analyzed to determine the trend or decline of radioactivity. The decline of radioactivity during the period under study was generally similar in all species. The relative amount of radioactivity per gram of tissue was greatest in the alimentary tract, with the liver, skin, bone and muscle having successively lesser amounts. This relationship prevailed throughout the period. The rate of decline was greatest during the first 100 days, with a loss of 90 per cent of the radioactivity during the period. Studies were made on the variation of total radioactivity in the tissues and species, on comparisons of the amount of radioactivity in the species and in their food, and on comparisons of the decline of radioactivity during the period with the decay of radioactivity in tissues collected soon after the shots.

CONTENTS

	Page
Introduction	
Materials and Methods	1
Results	6
Trends or Decline in the Levels of Radioactivity	6
Variation in the Samples	9
Comparison of the Decline of Radioactivity by Species	14
Comparison of the Decline of Radioactivity in Fish with that of their Food and with Other Factors	14
Comparison of Decline with Decay of Radioactivity	20
Conclusions	27
References	29
Appendix	31

FIGURES

Figure No. | Page

1. Map of the north reef and islands of Eniwetok Atoll (top) with an enlarged map of Belle Island (bottom) showing typical current patterns. The wind rose indicates prevailing winds. 3

2. Trends in the levels of radioactivity in tissues of fish from Belle Island. Preshot levels are plotted to the left of zero days. 7

3. Trends in the levels of radioactivity in tissues of surgeonfish (herbivorous) from Belle Island. 15

4. Trends in the levels of radioactivity in tissues of groupers (carnivorous) from Belle Island. 16

5. Trends in the levels of radioactivity of surgeonfish viscera compared with those of algae and sea water, all from Belle Island 1954, 1955. 17

6. Trends in the levels of radioactivity of liver tissue of omnivorous fish compared with those of algae and sea cucumber gut from Belle Island 1954, 1955. 19

7. Decline of radioactivity in goatfish viscera and bone tissues compared with decay. 21

8. Decline of radioactivity in goatfish liver and muscle tissues compared with decay. 22

9. Decline of radioactivity in mullet liver and muscle tissues compared with decay. 23

10. Decline of radioactivity in mullet viscera and bone tissues compared with decay. 24

11. Radioactive decay in various tissues of several species of fish from Belle Island 1954, 1955. 25

TABLES

Table No. Page

1. Dates of collection with number of specimens of the principal families of fish listed in order of approximate occurrence in the samples. 4

2. Coefficients of variation averaged for each family of fish as to tissue. Calculations are based on four or more fish with the number of coefficients used in parenthesis. 11

3. Comparison of average uc/kg and V in muscle tissue samples with and without goatfish and mullet and with and without combined samples. 12

Appendix

Radioactivity in fish from Belle (Bogombogo) Island, Eniwetok Atoll, listed by common name of family, date of collection, number of specimens, radioactivity in uc/kg and coefficient of variation (in per cent). 31

RADIOACTIVITY IN THE REEF FISHES OF BELLE ISLAND, ENIWETOK ATOLL, APRIL 1954 TO NOVEMBER 1955

Introduction

Previous studies of the radioactivity in the fishes in the Marshall Islands have been confined to single surveys made soon after an atomic detonation, occasionally followed by one to three resurveys a few months up to three years later (UWFL-7, UWFL-16, UWFL-19, UWFL-23, WT-616 (UWFL-33), and UWFL-43). Trends in the levels or decline of radioactivity in the fish populations could only be estimated by basing assumptions on physical decay.

The purpose of this investigation was to measure the trend or decline of radioactivity in the fish, to compare the decline in different species, in some of the organs or tissues, and in the environment and to compare the decline with the physical decay of radioactivity.

Materials and Methods

Continuous, sequential studies of the amounts of radioactivity in the reef fishes of Belle (Bogombogo) Island, Eniwetok Atoll, were made from April 14, 1954, through November 1, 1955, during and after the weapons testing program at Eniwetok and Bikini Atolls. The Nectar shot of May 14, 1954, was the most important in these studies, since the detonation occurred but

2.7 miles east-northeast of Belle Island, and thus contributed the greatest amount of radioactivity to the Belle area. There was however, residual radioactivity present from previous atomic weapons detonated at Bikini Atoll and at Eniwetok.

Reef fishes were collected in the vicinity of Belle Island by using rotenone, hook and line, or spear in depths ranging from a few inches to about 12 feet. Almost all of the collections were made on the seaward side of the island in Area F (Fig. 1) in a habitat containing approximately equal amounts of coral and sand. The area is typical of the reef of the northern portion of the atoll except that it sustained a certain amount of physical damage because of its proximity to the shot.

Attempts were made to confine the specimens analyzed to those fish which were typical residents of the Belle area, but such efforts were not entirely successful. The fish collected during the first month after Nectar shot consisted mainly of goatfish and mullet, species which move along the north reef from island to island. Typical reef residents such as grouper, damselfish and surgeonfish appeared to be scarce during this period. In all, 34 different collections were made in 1954 and 1955 which included 693 specimens, these representing 57 species and 22 families of fishes. However, only 9 species from 9 families were consistently present in the collections (Table 1 and Appendix).

The collections and treatment of data were similar to those in earlier investigations by the Applied Fisheries Laboratory. For complete details see WT-616 (UWFL-33). The specimens were put on ice as soon as possible after collecting and placed in a freezer on being returned to the laboratory. Tissues were dissected, weighed, and dried at the Eniwetok laboratory. The tissues taken were skin, muscle, bone, liver and viscera (digestive tract and contents) from the larger fish, or like tissues were pooled from a number of small fish of the same species,or entire fish were used. At the University of Washington laboratory, the dried samples were ashed at temperatures up to 540° C, cooled, slurried, dried and counted in an internal gas-flow counting chamber. The total number of plates resulting from all 34 collections was 2,167 (averaging about 64 plates per collection).

All counts for radioactivity were corrected to the date of collection, the decay factors for all Eniwetok samples being based on a soil sample collected at Belle Island May 15, 1954. Corrections were also made for self-absorption, backscatter, geometry and coincidence. The radioactivity is expressed in microcuries per kilogram of wet tissue. Disintegrations per minute per gram can be converted to microcuries per kilogram using the relationship uc/kg = $(2.2)\ (10)^3$ d/m/g.

Results

Trends or Decline in the Levels of Radioactivity

General trends of the radioactivity in the fish collected at Belle Island are shown in Figure 2. Lines connecting the points for data on muscle and liver tissue reveal trends similar to those in other tissues. Differences are greatest in viscera in which the amount of radioactivity is much greater than in liver tissue the first 100 days; after this period the two tissues decline at about the same rate. Bone and skin fluctuate about a common intermediate range between muscle and liver, the muscle always having the least radioactivity on a per-gram-wet-weight basis.

During the first 100 days all tissues show a decrease in radioactivity of more than 90 per cent from early post-shot levels. By the 250th day the tissues had reached preshot levels, which, at Eniwetok, were higher than normal because of other detonations set off in previous tests.

The more or less consistent relationship of one tissue to another during the decline of radioactivity may indicate comparatively slight differences in selective uptake in the five tissues. An approximation of the relationship was obtained by dividing the total amount of radioactivity in all the samples of the same tissue by the number of samples to give the average amount present on a per-gram-wet-weight basis for the period of April 1954 to November 1955. The following results were produced:

	Skin	Muscle	Bone	Liver	Viscera
Average uc/kg	11	1.0	9.8	29	77
Percent of total of 5 tissues	8.3	0.8	7.7	22.9	60.3

The relationship varies depending on the time after shot and on the species of fish. For example, a halfbeak caught the day after shot had comparatively high concentrations of radioactivity in the skin (28% of total) and comparatively low amounts in the bone (1% of total). Presumably the radioactivity in the skin was due to both adsorption and absorption, whereas it had not yet reached the bone so soon after the shot. The average counts for viscera were higher in most fish for the first 100 days than subsequently. Differences in species in which there were 10 or more samples are to be seen in the low concentration of total radioactivity, for example, in the liver of wrasse, and the moderately high concentrations in bone and skin of goatfish (see Appendix).

Correcting the percent of total activity per tissue from the above table for the tissue weight by using the percentages 8, 63, 18, 2, and 9 as relative values of the total weight of skin, muscle, bone, liver and viscera respectively, one uc of radioactivity would be distributed as follows:

Skin	Muscle	Bone	Liver	Viscera
.079	.061	.163	.054	.643

Variation in the Samples

The trend or decline in radioactivity fluctuates rather widely, due, in part, to inadequate sampling and in part to actual fluctuations in the amount of radioactivity in the Belle Island area. The downwind, downcurrent position of the island relative to the target area would undoubtedly subject the Belle region to varying amounts of effluent from the target area.

The amount of contamination would, in turn, be subject to such variables as tides, winds and currents. Biological variables, such as migration of the fish, mortality, influx and outflow of breeding populations and their young also could contribute to the variation.

In order to determine the extent of the variation, calculations of the coefficient of variation (V) were made (1) by families, using four or more specimens for the calculations (Table 2) and (2) by date, using muscle tissue from all families combined (Table 3).

The data in Table 2 indicate that there are differences in the coefficient of variation between families, i.e., distinctly high in goatfish and mullet, and between tissues, averaging highest in viscera. The average coefficient of variation for all families and all tissues combined was 56 per cent. By omitting the goatfish and mullet in the calculations the average is lowered to 37 per cent. The latter value is similar to that found for algae (37%) (Palumbo, 1957) and for invertebrates (Bonham, 1957).

The fact that goatfish and mullet prefer the open sandy bottom areas of the reef, moving in schools from island to island may account for the higher coefficient of variation in these fishes.

The average coefficient of variation is much greater when samples of mixed families or species are used. Table 3, in which the data for muscle tissue are summarized, indicates that the coefficient varies from 16 to 209 per cent. The coefficient of variation of muscle in all the collections averages 97 per cent, but when goatfish and mullet are excluded the average is 53 per cent.

Comparison of the Decline of Radioactivity by Species

A comparison of the decline of radioactivity in two species with different feeding habits is made in Figures 3 and 4. Surgeonfish, with herbivorous habits, and grouper, with carnivorous habits, were selected as representing the conditions that probably prevailed in the fish in the vicinity of Belle Island. For comparisons of other species, reference may be made to Figures 7 through 10, which depict the decline in goatfish and mullet tissues. As has been pointed out, goatfish and mullet, because of their movement along the reef from island to island, are not strictly comparable to Belle Island "resident" fish, and the decline trends apparently reflect these differences.

Surgeonfish and groupers were obtained fairly regularly throughout the period of investigation. The former feed principally on filamentous algae (Dawson, et al., 1955), whereas the groupers feed principally on fishes. The radioactivity in the surgeonfish, Figure 3, declines at a greater rate than that of the groupers, Figure 4, for all tissues for the first 50 to 100 days after the shot. For example, muscle tissue of surgeonfish contained approximately four times as much radioactivity as that of the grouper immediately after the shot, but by 125 days the two species contained similar amounts.

Comparison of the Decline of Radioactivity in Fish with that of their Food and with Other Factors

In Figure 5 the radioactivity in surgeonfish viscera is compared with that in algae and found to be quite similar, as would be expected in a species which is principally herbivorous. The decline in the radioactivity of sea water is included on a different scale to indicate the dependence or similarity in the trends. Algae are dependent on sea water for their radioactivity, which they concentrate up to several thousand times (Palumbo, 1957). The surgeonfish take in considerable amounts of radioactive material by feeding on the algae. The data from Belle Island (an area in which the supply of radioactive material is only slowly decreasing) indicate that, for every microcurie of radioactive material ingested into the alimentary tract, about 0.55 microcuries are distributed to the skin, muscle, bone and liver combined.

In Figure 6, the decline of radioactivity in the liver tissue of omnivorous fishes is compared with that of the sea cucumber gut contents (Bonham, 1957) and algae. The similarities appear to be marked during the early period of decline, with liver tissues of omnivorous fishes and sea cucumber gut averaging greater amounts of radioactivity than algae at 531 days.

Sea cucumber gut content is made up mostly of coral detritus, since this invertebrate obtains its food from this material. Coral fragments are also found abundantly in the alimentary tract of the mullet, a detritus feeder, along with plant and animal material. However, comparisons of the decline in these two organisms in Figures 6 and 10 show marked differences in the trends of radioactivity. It will also be noted that the decline of radioactivity in mullet tissues is considerably different from that of other fish tissues. Goatfish viscera (Fig. 7), on the other hand, declines similarly to that of sea cucumber gut, the liver of an omnivore, and to some degree, algae. Goatfish feed largely on brachyuran crabs, which, in turn, feed on algae, dead fish, etc., so that the diet of goatfish is, to a certain degree, comparable to that of omnivorous fishes.

Comparison of Decline with Decay of Radioactivity

Figures 7 through 10 show certain marked differences between decline and decay of radioactivity in the same tissues for both goatfish and mullet. In goatfish the differences are evident in the first 100 days after shot, while in mullet the differences are greatest for the first 150 to 200 days. Variations due to sampling and other causes, which have been discussed in a previous section, might explain some of the differences. Also they might be due to the differential affinity of various species for shorter-lived isotopes. In goatfish the radiation varies to around 50 to 170 uc/kg for liver, about 20 to 50 uc/kg for bone and 3 to 7 uc/kg for muscle.

Similarities in the decay curves are shown in Figures 7, 8, 9, 10, and 11. For example, liver decay in goatfish (Fig.8) is similar to that of mullet liver after 100 days; muscle decay in goatfish is similar to surgeonfish liver and surgeonfish bone after 200 days; while bone decay of goatfish is similar to bone decay of mullet and surgeonfish after 100 to 250 days. Dissimilarities in the decay curves appear to be greatest during the first 100 to 200 days after the shot, the curves tending to approach each other in pattern with passage of time. During the early period after the shot there is, of course, a greater variety of radioactive isotopes present than later, and there is some indication that selective uptake might be more marked or selective exclusion less marked during this period. As the shorter-lived isotopes decay and decrease in importance, leaving fewer radioactive materials available, the decline and decay of radioactivity in the different tissues and species show greater similarities.

The data presented do not permit exact distinctions between tissues or between different species on the basis of differences in the uptake of radioactive materials. It appears from the decay curves and the decline trends that the fish tissues differ mainly in orders of magnitude rather than in quality after the first 100 days, although there is the possibility of different isotopes with similar half lives being present.

Radiochemical analysis done within two months on fish collected two to three months after shot contained Mn^{54}, Fe^{55},Co^{57}, Co^{58}, Co^{60}, and Zn^{65}, with Fe^{55} and Zn^{65} as the dominant isotopes. Fish collected within one month after the 1954 shots and analyzed January 1957 contained 95 percent Fe^{55}; Mn^{54}, Co^{57}, and Co^{60} (Lowman, Palumbo and South, 1957) contributed the remainder of the radioactivity. There may be fission products in the fish the first few weeks or months after the shot, but after four or five months fission products contribute very little, if any, to the total radioactivity in the fish.

Conclusions

Biological decline of radioactivity in the fishes of Belle Island, Eniwetok Atoll, is generally similar in all species. Differences which are evident may be attributed to differences in feeding habits and, these differences, which appear greatest during the first 100 to 200 days after shot, may be attributed to differences in the uptake and retention of the short-lived isotopes. The decline of the radioactivity in omnivorous fishes is more rapid than that in carnivorous fishes so that 200 days after shot the amount of radioactivity in the two types of fish appears to be quite similar. It might be postulated that omnivorous fishes ingest food which contains comparatively greater amounts of the shorter-lived isotopes than the food of carnivorous fishes.

The decay of radioactivity in the tissues of fish from Belle Island also differs during the first 100 days after the shot, reflecting, to some degree, the unstable ecological conditions prevailing in that region at the time.

The relationship of the amounts of radioactivity retained in each of the five tissues examined prevails more or less consistently and substantiates findings of previous investigations. The greatest per-gram concentration of radioactive materials occurs in the alimentary tract with the liver, skin, bone and muscle having successively lesser amounts. The greatest variation from this pattern appears during the first few weeks after shot.

The rate of decline of the radioactivity in almost all of the fish was greatest during the first 100 days, during which time more than 90 percent of the post-shot radioactivity was lost.

The variation in amounts of radioactivity in tissues from the same collection of fish, as measured by the coefficient of variation (V), may be due to several causes, prominent of which are the differences between different species of fish. The variations definitely indicate that large samples of many species are necessary to obtain reliable information on the amount of radioactive materials present in fish populations.

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APPENDIX