NOTES

THE SOURCE OF COBALT-60 AND MIGRATIONS OF ALBACORE OFF THE WEST COAST OF NORTH AMERICA

Cobalt is an integral part of the vitamin B_{12} complex and an important cofactor in enzyme systems (Lowman et al. 1971; Reichle et al. 1970). It is, therefore, an element whose cycle in oceanic ecosystems is of interest. The artificial radionuclide cobalt-60 (^{60}Co) has been observed in the livers of albacore, (*Thunnus alalunga* Bonnaterre) collected off the west coast of North America, Washington to Baja California (Pearcy and Osterberg 1968; Hodge et al. 1973).

The albacore is a commercially important migratory species of tuna which normally inhabits the epipelagic subtropical and transitional waters of the Pacific, Atlantic, and Indian oceans. In the North Pacific, albacore may undertake transpacific migrations between Japan and the west coast of America (Clemens 1961; Otsu and Uchida 1963; Clemens and Craig 1965).

While single-pass nuclear reactors were operated at Hanford, Wash., the Columbia River was an important source of artificial radionuclides in the Pacific Ocean off Oregon and Washington. Some radionuclides, formed by neutron activation of impurities in river water used to cool the reactors, were transported via the Columbia out into the ocean and were detectable in the plume water far at sea (Osterberg et al. 1965). Cobalt-60 was among the radionuclides carried by the Columbia River effluent (Gross and Nelson 1966). Fallout from nuclear detonations, however, was another source of ^{60}Co (Lowman and Ting 1973; Hodge et al. 1973). Which of these sources was more significant in contaminating tuna is not known. We shall attempt to use the temporal and geographical variations in ^{60}Co content of albacore livers to estimate the relative importance of the two sources and to provide information on migrations of albacore.

Methods

During the period June–October of 1963 through 1969, over 200 albacore livers were removed from fish (520–850 mm fork length, $\bar{x}$ = 640 mm) collected on surface jigs and preserved aboard ships either by freezing or with Formalin.[1] In the laboratory, livers were weighed, dried, ashed (500° to 570°C), ground, and packed into 15-cm^3 plastic counting tubes for radioanalysis. Samples were counted for 100 min using a 12.7-cm^2 NaI (Tl) crystal detector with a 512 channel pulse-height analyzer. See Pearcy and Osterberg (1968) for additional details on collection and analysis. Results are expressed in picocuries per gram wet weight to be compatible with other published results on cobalt in tuna livers.

Results and Discussion

Concentrations of ^{60}Co in the livers of albacore caught in three general regions along the west coast of North America are shown in Figure 1 for 1964. Of all the years, 1963–69, this year provided the most data for inter-regional and temporal comparisons. Two general trends are evident:

[1]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

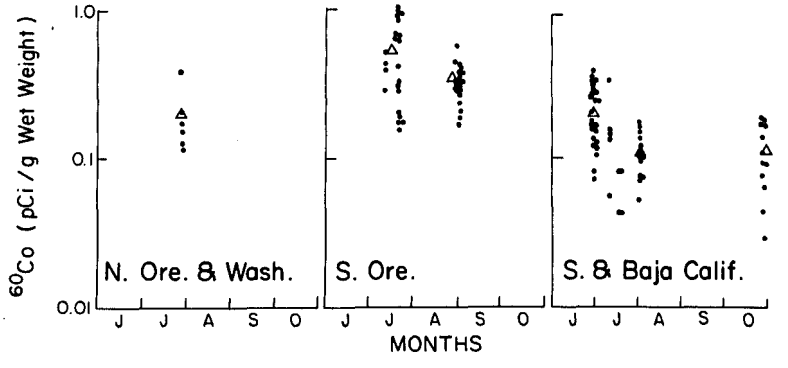

FIGURE 1.—Cobalt-60 concentrations (dots = actual observations, open triangles = $\bar{x}$ values) from livers of albacore captured off three west coast regions during June-October 1964.

first, relatively high ^{60}Co activities were seen off the southern Oregon coast and somewhat lower concentrations off northern Oregon and Washington as well as off southern and Baja California; second, ^{60}Co concentrations decreased with time during the summer–fall period. Data from other years corroborated these trends.

Annual variations of ^{60}Co in albacore off the Oregon coast (dots and solid line in Figure 2) indicate that ^{60}Co concentrations increased from 1963 to 1964 then declined steadily until 1967, but increased again in 1968.

There are two possible sources of ^{60}Co for albacore in the northeastern Pacific. Until 1965, eight Hanford reactors were a relatively constant source of ^{60}Co entering the Columbia River (Gross and Nelson 1966). In 1965, however, a sequence of shutdowns of individual reactors began (Foster 1972). The other possible source of this isotope is fallout from atmospheric tests of nuclear weapons which also varied in time, but according to a different pattern (Lowman and Ting 1973; Hodge et al. 1973). Inputs of ^{60}Co into the environment by atmospheric tests that could directly effect the activity levels in the North Pacific include over 100 U.S. and U.S.S.R. tests in 1961–62 and Lop Nor, China, tests in 1964–65 (one test each year), 1966 (three tests), 1967 (two tests), and 1968 (one test) (U.S. Environmental Protection Agency 1960–72).

The relatively constant input from the Hanford plant fails to account for the low ^{60}Co values observed in albacore during 1963 nor the increased values in 1964 (Figure 2). Other evidence indicating that Hanford was not the major ^{60}Co source is based on our knowledge of the migration of albacore into the Pacific Northwest fishery and their subsequent movements. Albacore often first appear off the southern Oregon coast and move northward and inshore as the summer progresses (Powell et al. 1952; Keene 1974), sometimes along the axis of the warm Columbia River plume waters (Pearcy 1973). Levels of ^{60}Co did not increase with residence time of albacore in Oregon waters or proximity to the Columbia River in northern Oregon (Figure 1), as would be expected if Hanford was the main ^{60}Co source.

These trends are opposite of those noted in albacore livers for ^{65}Zn, a radionuclide that was known to be associated with the Columbia River effluent, but are similar to those of ^{54}Mn, a radionuclide associated with atmospheric fallout (Pearcy and Osterberg 1968). We conclude, therefore, that most of the ^{60}Co we find in albacore livers was

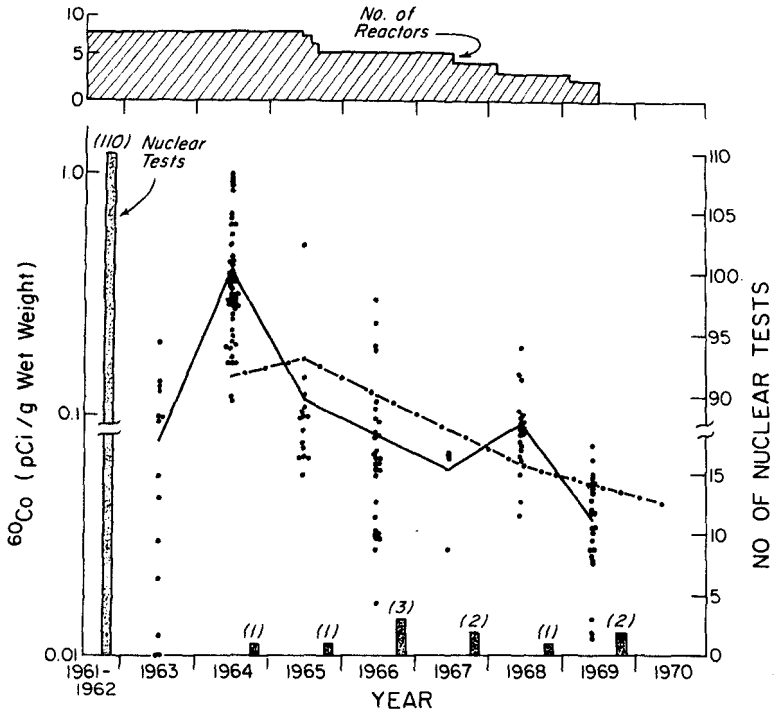

FIGURE 2.—Concentration of ^{60}Co in livers of albacore captured off Oregon and Washington. Solid line indicates mean values of our observations (dots); broken line is a plot of ^{60}Co levels off southern and Baja California as presented by Hodge et al. (1973). Also indicated is the number of Hanford reactors in operation and the number of nuclear atmospheric tests (bars = pre-1963 non-Chinese testing affecting the North Pacific and post-1963 testing at Lop Nor, China) which occurred during our study period.

derived from fallout, even off the coast of Oregon where the influence of the Columbia River plume should be the greatest.

Since radioactivity originating from fallout is higher in the open ocean than in coastal waters where upwelling occurs (Pillai et al. 1964; Folsom and Young 1965; Gross et al. 1965), the spatial-temporal trends evident in Figure 1 may be explained by the residence time of albacore in coastal waters. Highest levels of ^{60}Co are expected in oceanic waters off southern Oregon in June and July; lower levels are expected later in the season after albacore have migrated northward and shoreward and have resided in coastal waters, provided that the biological half-life of ^{60}Co in tuna livers is short enough. The decrease in ^{60}Co levels in albacore (Figure 1) is much more rapid than would be expected from natural radioactive decay of 5.26 yr. Biological turnover must be rapid in order to produce a short effective half-life.

Hodge et al. (1973) related the levels of ^{60}Co in albacore to fallout deposition and found that maximum uptake of ^{60}Co by albacore lagged nuclear atmospheric detonations by 1–2 yr. Annual changes of ^{60}Co concentrations observed off Oregon (Figure 2) show a similar delayed response, but the peak activity levels in albacore occurred a year earlier than the peaks seen by Hodge et al. (1973) off southern California (dashed line, Figure 2). The main atmospheric input by nuclear detonations occurred in 1961–62. Our main peak of ^{60}Co in albacore occurred in 1964, and that reported by Hodge et al. occurred in 1965, indicating a delay of about 2 and 3 yr respectively after testing before the uptake is observed in albacore. This not only suggests that the source of ^{60}Co in albacore is from atmospheric fallout, but that the availability of the radionuclide was different between the albacore caught off California and those caught off Oregon, perhaps because of differences in distributions and migratory patterns than those described by Clemens (1961).

Laurs and Lynn (1977) presented data that confirm this suggestion. Based on recapture of tagged albacore and length-frequency distributions, they concluded that the albacore population found off Oregon is different from that found off southern and Baja California. They further suggest that albacore which migrate into Oregon waters may come from a portion of the offshore population which is located north of the 35th parallel, while those that move into the California waters are located south of the 35th parallel.

The bomb detonations at Lop Nor (lat. 40°N) gave the heaviest fallout input into the North Pacific at about this latitude. Due to the circulation in the North Pacific (Sverdrup et al. 1942), it appears quite possible that albacore which were associated with waters north of lat. 35°N may have experienced high levels of ^{60}Co up to a year before the tuna associated with waters to the south. Circulation in the North Pacific and the latitudinal differences in the location of the two portions of the albacore population appear to be a plausible explanation for the difference of 1 yr in activity peaks between albacore caught off Oregon by us and those off southern and Baja California by Hodge et al. (1973).

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Literature Cited

CLEMENS, H. B.
1961. The migration, age, and growth of Pacific albacore (*Thunnus germo*), 1951–1958. Calif. Dep. Fish Game, Fish Bull. 115, 128 p.

CLEMENS, H. B., AND W. L. CRAIG.
1965. An analysis of California's albacore fishery. Calif. Dep. Fish Game, Fish Bull. 128, 301 p.

FOLSOM, T. R., AND D. R. YOUNG.
1965. Silver-110m and cobalt-60 in oceanic and coastal organisms. Nature (Lond.) 206:803-806.

FOSTER, R. F.
1972. The history of Hanford and its contribution of radionuclides to the Columbia River. *In* A. T. Pruter and D. L. Alverson (editors), The Columbia River estuary and adjacent ocean waters, p. 3–18. Univ. Wash. Press, Seattle.

GROSS, M. G., C. A. BARNES, AND G. K. RIEL.
1965. Radioactivity of the Columbia River effluent. Science (Wash., D.C.) 149:1088-1090.

GROSS, M. G., AND J. L. NELSON.
1966. Sediment movement on the continental shelf near Washington and Oregon. Science (Wash., D.C.) 154:879-885.

HODGE, V. F., T. R. FOLSOM, AND D. R. YOUNG.
1973. Retention of fall-out constituents in upper layers of the Pacific Ocean as estimated from studies of a tuna population. *In* Radioactive contamination of the marine environment, p. 263-276. Int. At. Energy Agency, Vienna.

KEENE, D. F.
1974. Tactics of Pacific Northwest albacore fisherman - 1968, 1969, 1970. Ph.D. Thesis, Oregon State Univ., Corvallis, 102 p.

LAURS, R. M., AND R. J. LYNN.
1977. Seasonal migration of North Pacific albacore, *Thunnus alalunga*, into North American coastal waters: Distribution, relative abundance, and association with Transition Zone waters. Fish. Bull., U.S. 75:795-822.
LOWMAN, F. G., T. R. RICE, AND F. A. RICHARDS.
1971. Accumulation and redistribution of radionuclides by marine organisms. *In* Radioactivity in the marine environment, p. 161-199. Nat. Resour. Counc., Natl. Acad. Sci., Wash., D.C.
LOWMAN, F. G., AND R. Y. TING.
1973. The state of cobalt in seawater and its uptake by marine organisms and sediment. *In* Radioactive contamination of the marine environment, p. 369-384. Int. At. Energy Agency, Vienna.
OSTERBERG, C., N. CUTSHALL, AND J. CRONIN.
1965. Chromium-51 as a radioactive tracer of Columbia River water at sea. Science (Wash., D.C.) 150:1585-1587.
OTSU, T., AND R. N. UCHIDA.
1963. Model of migration of albacore in the North Pacific Ocean. U.S. Fish Wildl. Serv., Fish. Bull. 63:33-44.
PEARCY, W. G.
1973. Albacore oceanography off Oregon—1970. Fish. Bull., U.S. 71:489-504.
PEARCY, W. G., AND C. L. OSTERBERG.
1968. Zinc-65 and maganese-54 in albacore *Thunnus alalunga* from the west coast of North America. Limnol. Oceanogr. 13:490-498.
PILLAI, K. C., R. C. SMITH, AND T. R. FOLSOM.
1964. Plutonium in the marine environment. Nature (Lond.) 203:568-571.
POWELL, D. E., D. L. ALVERSON, AND R. LIVINGSTONE, Jr.
1952. North Pacific albacore tuna exploration—1950. U.S. Fish. Wildl. Serv., Fish. Leafl. 402, 56 p.
REICHLE, D. E., P. B. DUNAWAY, AND D. J. NELSON.
1970. Turnover and concentration of radionuclides in food chains. Nuc. Saf. 11:43-55.
SVERDRUP, H. U., M. W. JOHNSON, AND R. H. FLEMING.
1942. The oceans, their physics, chemistry, and general biology. Prentice-Hall, Inc., N.Y., 1087 p.
U.S. ENVIRONMENTAL PROTECTION AGENCY (previously Public Health Service).
1960-72. Radiation data and reports, 1960 through 1972. (Mon. Rep.) U.S. Gov. Print. Off., Wash., D.C. 13 vol.

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LENGTH-WIDTH-WEIGHT RELATIONSHIPS FOR MATURE MALE SNOW CRAB, *CHIONOCOETES BAIRDI*

Snow crabs have been exploited commercially in Alaska since 1961 (Alaska Department of Fish and Game 1975). *Chionocoetes bairdi* is the predominant species with *C. opilio* composing up to 25% of the catch from the Bering Sea. Landings were small and intermittent in the early 1960's but increased to about 3.2 million lb in 1968. Landings expanded dramatically thereafter and exceeded 60 million lb in 1974, with an ex-vessel value of more than $12 million.

Carapace width measurements have been collected from the commercial snow crab catch by biologists since the inception of the fishery; individual weights, however, are not routinely collected because the task is rather time-consuming. The relationships between carapace width, length, and body weight are of interest to biologists and processors. The relationship between carapace length and width is of interest because the carapace shape is one of the diagnostic characteristics to distinguish between *C. bairdi* and *C. opilio* and hybrids of the two species (Karinen and Hoopes 1971). The relationships between carapace width and weight and carapace length and weight have many uses. They are, for example, indicators of condition, used to calculate biomass, and used to estimate recovery of edible meat from crabs of various sizes.

Materials and Methods

Carapace length and width and body weight measurements were taken from 240 mature male *C. bairdi* from commercial catches made south of the Alaska Peninsula in the vicinity of the Shumagin Islands in May 1975. Length and width measurements were taken to the nearest millimeter with vernier calipers and weights were recorded to the nearest gram. Length was measured from the posterior medial edge of the carapace to the anterior medial point of the right orbit. The rostrum was not included in the length measurement because it often erodes when crabs are carried in the live tank of fishing vessels. Width was measured at the widest part of the carapace and included the lateral branchial spine. Width ranged from 128 to 185 mm, weights from 635 to 2,230 g, and lengths from 92 to 143 mm.

The basic linear regression formula $W = a + bL$ was used to express the relationship between width (W) and length (L). Weight (Wt) was related to width and length by the power functions, $\log_{10} Wt = \log_{10} a + b \log_{10} W$ and $\log_{10} Wt = \log_{10} a + b \log_{10} L$. The constants a and b were determined empirically.