Reports

Chromium-51 as a Radioactive Tracer of Columbia River Water at Sea

Abstract. *The plume of the Columbia River was followed 350 kilometers to sea by measurement of its chromium-51 content. This radioactive tag, introduced into the river by nuclear reactors at Hanford, Washington, promises to provide a useful oceanographic tool for determining rates of transport and mixing, and for identifying plume waters in the presence of other sources of fresh water.*

The Columbia River is a major source of radioactivity, carrying some 25,000 curies per month from the Hanford, Washington, reactors to the sea (*1*). During the summer when vertical mixing is at a minimum, Columbia River water can be detected far from shore as a low salinity plume, floating on top of denser, saltier, sea water. Because of the large amount of water, levels of radioactivity in the river present no health hazard. In the plume, radioactivity is so low that it has become a challenge to those interested in its measurement.

Oceanographers have risen to the challenge because the radioactivity uniquely labels Columbia River water at sea, making it different from fresh water from nearby rivers or rainfall, a difference not detectable with the usual salinity measurements. Furthermore, radionuclides which move with the plume can provide information on the rates of water flow and vertical diffusion because of their known half-lives.

We succeeded in following the plume of the Columbia River from the mouth of the river, near Astoria, Oregon, to a point in the ocean southwest of Coos Bay, Oregon, some 350 km away, by measurements of its Cr^{51} content. This study, carried out on the U.S.C.G. *Modoc* (26 June to 1 July 1965), did not thoroughly test the sensitivity of our technique, since Cr^{51} was easily measurable in the spectrum of the sample from the collecting site most distant from the river's mouth (Fig. 1). Significantly, our data imply that mixing of radionuclides with ambient sea water can be a slow process. In the absence of losses by mixing, Cr^{51} remaining in plume waters is sufficient for use as a radioactive tag and timing device.

In previous efforts, Osterberg *et al.* (*2*) attempted to relate the Zn^{65} content of euphausiids (small shrimp-like animals) to the Columbia River plume. The euphausiids were taken with trawls from surface waters at a number of stations off Oregon over a period of 15 months. Plume location was defined by salinity measurements made simultaneously at each station. Although some correlations were apparent, it was realized that animals are essentially integrators and may not reflect the radioactivity of their immediate environment. These authors suggested that Cr^{51} might be a better indicator of Columbia River waters, since, unlike Zn^{65}, it remains in solution and is not appreciably concentrated by the biota. Gross *et al.* (*3*) were able to measure Cr^{51} directly in the water with an *in situ* γ-ray probe, but lack of sensitivity of the technique prevented detection beyond about 115 km from the mouth of the river. Chakravarti *et al.* (*4*) found Cr^{51} and other radionuclides in samples taken near the mouth of the Columbia River. The exact locations of their sampling sites were not given. Curl *et al.* (*5*) found Cr^{51} as far as 72 km from the mouth of the river on filters, through which surface sea water had been pumped. Since most of the chromium passes through the filters, their method had serious limitations. Our efforts to concentrate the Cr^{51} in the filtrate on ion-exchange or chelating resins were largely unsuccessful. These experiments led, however, to the development, by Cronin and Osterberg, of a large volume chemical apparatus with which coprecipitation of trace metals from sea water could be carried out aboard ship.

Surface water samples (600 liters each) were pumped through 10.5-inch (26.7 cm) membrane filters (0.45 μ pore size) with glass-fiber prefilters (Gelman Instrument Co.) into tanks coated with an inert liner (Sherwin-Williams Kem Cati-Coat enamel). Stable isotopes (as chlorides) of the several radioelements known to be in the Columbia River were added as carriers, along with $FeCl_3$. After 30 minutes of stirring, the *p*H was raised to 9.5 by adding NH_4OH, forming a ferric hydroxide precipitate (*6*). A flocculating agent (Separan ND 10, Dow Chemical) was added, and, after 5 minutes of stirring, the mixture was allowed to settle. In 2 to 3 hours the precipitate was concentrated in the conical bottom of the tank. After the bulk of the water was siphoned off, precipitate and residual water were drained into 50-liter plastic bottles. By successive decantings, after appropriate settling periods, sample volumes were reduced to less than 8 liters each.

In the laboratory, precipitates were dissolved in hydrochloric acid and reduced to 800 ml by heating in a water bath. The 800-ml samples were placed in plastic bottles and analyzed on top of a 5 by 3 inch (12.5 by 7.5 cm) NaI(TI) detector, coupled to a Nuclear Data 130 AT multichannel analyzer. Considerable speed of collection and processing is mandatory because of the short half-life (27.8 days) of Cr^{51}.

Results (Fig. 2) show that the plume of the Columbia River, as reflected by the Cr^{51} in surface waters, moves to the southwest off the Oregon coast in late June. This general summertime position is well known to oceanographers and can be (and was) verified by salinity measurements. There is no question of the relation

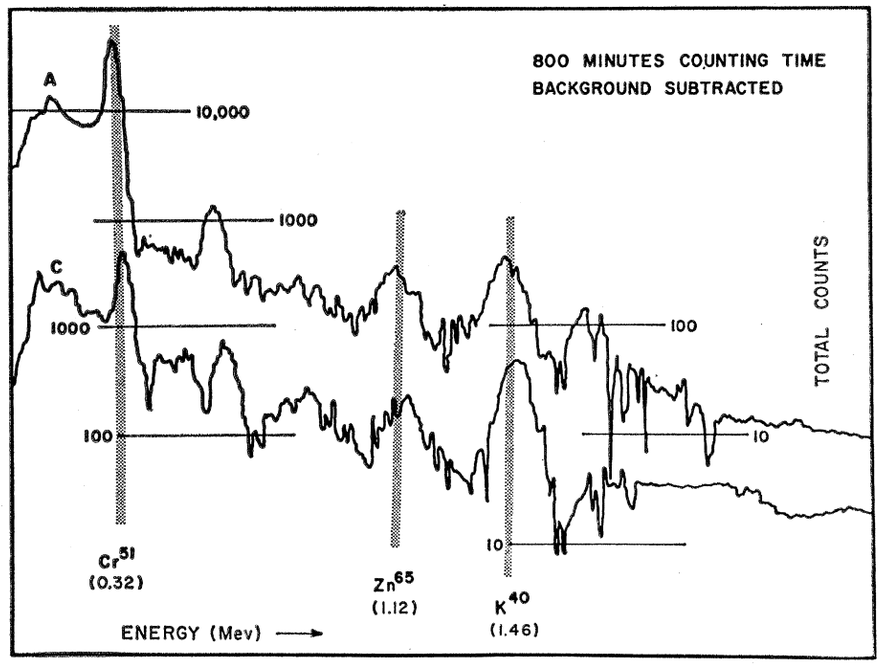
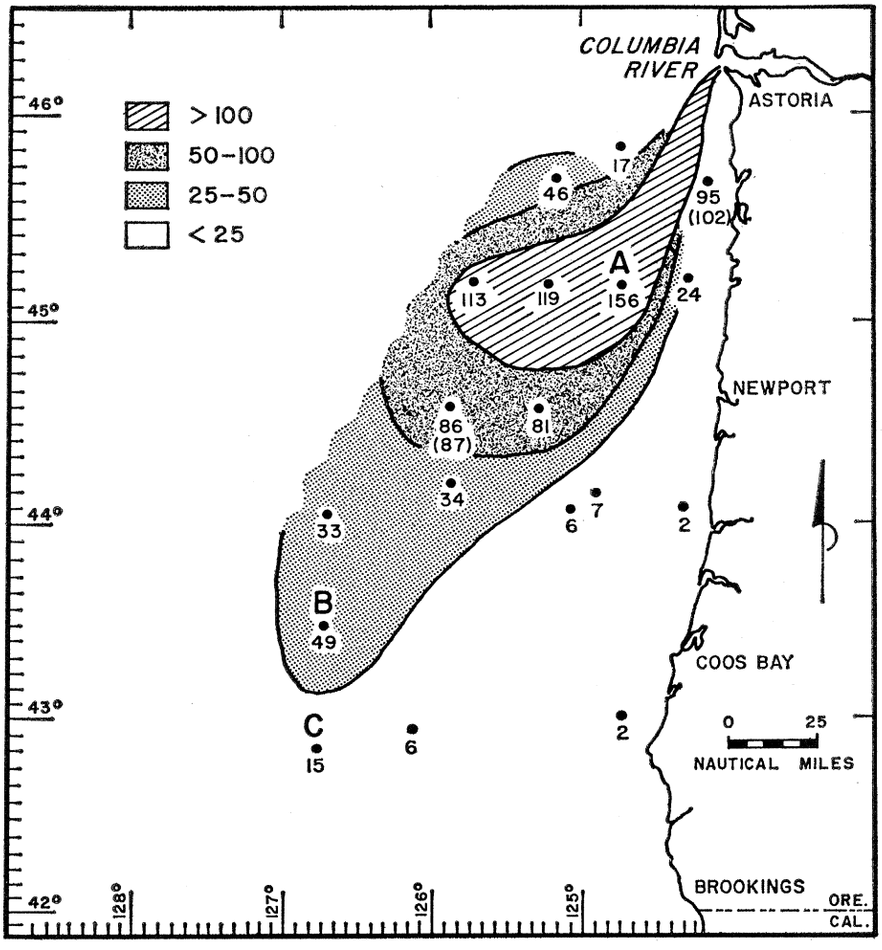


Fig. 1. Spectra of coprecipitates from sea water from the station with most Cr^{51} activity (*A*), and from the station at greatest distance from the mouth of the Columbia River (*C*). Collection sites of the two surface-water samples are points *A* and *C*, respectively, on the map in Fig. 2.



of Cr^{51} activity to the plume, since the Hanford reactors are the sole source of this radionuclide in the northeastern Pacific Ocean.

In order to use Cr^{51} data to determine absolute transport rates, chromium must be conserved (that is, not lost to animals or sediments) in the plume waters. While some losses do occur, Cr^{51} is probably the most conservative of the more abundant radionuclides in the Columbia River, since in the form present it is not appreciably concentrated by most oceanic animals. An allowance must also be made for "dilution" of the plume as the distance from the river's mouth increases, although, in this case, fresh water is being diluted with sea water. This is done by correcting the Cr^{51} activity of each 600-liter sample for the amount of sea water present in it, based on salinity measurements. When the correction is made, we find that the maximum rate of plume movement, based on loss of Cr^{51} by radioactive decay, is 11.4 km per day (*7*). This is a minimum speed, since Cr^{51} losses other than to radioactive decay would decrease the apparent rate of flow. Likewise, addition of fresh water from any other source, though not likely in summer, would decrease the apparent rate.

The value thus determined agrees well with those based on physical measurements but is faster than the apparent southward movement derived from measurements of Zn^{65} in euphausiids (*2*). This difference was expected since Zn^{65} is biologically active and subject to losses other than radioactive decay; that is, Zn^{65} does not remain in solution in the plume to the same extent that Cr^{51} does.

Techniques for following the Columbia River plume at sea based on measurements of Cr^{51} have their greatest potential during the winter months. Then, Columbia River flow is at a minimum, and the salinity pattern is confused. A seasonal change in prevailing winds drives the reduced plume

Fig. 2 (left). Chromium-51 (counts per minute per 100 liters of surface sea water), corrected to date of collection, 26 June to 1 July 1965. Parentheses indicate duplicate samples. The number of counts per minute per 100 liters can be converted to picocuries per liter by multiplying by 0.861. The greatest velocity of water movement was between points *A* and *B*.

northward and shoreward off Washington where it quickly loses its identity in the flood of fresh water from swollen coastal streams and winter rains. How far north the plume extends or how deep it mixes under these conditions have been problems beyond solution by the classical tools of oceanography (*8*). Radiochemical techniques should help resolve these uncertainties (*9*).

CHARLES OSTERBERG
NORMAN CUTSHALL
JOHN CRONIN

Department of Oceanography, Oregon State University, Corvallis

References and Notes

1. This is the number usually reported by Hanford Laboratories, but some reduction should have occurred during the first 6 months of 1965, when phasing out of three of the eight reactors began.
2. C. Osterberg, J. Pattullo, W. Pearcy, *Limnol. Oceanog.* **2**, 249 (1964).
3. M. G. Gross, C. A. Barnes, G. K. Riel, *Science* **149**, 1088 (1965).
4. D. Chakravarti, G. B. Lewis, R. F. Palumbo, A. H. Seymour, *Nature* **203**, 571 (1964).
5. H. Curl, N. Cutshall, C. Osterberg, *Nature* **205**, 275 (1965).
6. The coprecipitation techniques used are well known to chemists. We checked our methods both in the laboratory and at sea to give maximum recovery of Cr^{51}, but yields for the other radioelements were not determined.
7. The estimate of speed depends on a constant rate of delivery of Cr^{51} to the ocean. Probably changes in reactor output occur, but hopefully they are minimized by mixing in the river and in the three lakes through which the Cr^{51} must pass on its 530-km trip to the sea.
8. K. Park, in our laboratory, has a paper in press, *Limnol.* and *Oceanog.*, in which specific alkalinity is used to identify Columbia River water at sea.
9. Supported by AEC contract AT(45-1)1750 and PHS training grant 1T1-WP-59-01. We thank the U.S. Coast Guard for making the *Modoc* available to us and L. Frederick and W. Vermeere for assistance with the sampling program.

23 September 1965

Avifauna: Turnover on Islands

Abstract. *The percentage of endemic species of birds on islands increases with island area at a double logarithmic rate. This relation is apparently due to extinction, which is more rapid the smaller the island. The turnover resulting from extinction and replacement appears to be far more rapid than hitherto suspected.*

Extinction is perhaps the most elusive of all evolutionary phenomena. What little we know about it has been contributed by paleontologists and biogeographers. In the case of "many . . . extinctions . . . there are no visible causes for the sudden disappearance of a form, except that the total size of the population was so small and genetic composition probably so uniform that the most minute change of environmental conditions became fatal. There is little doubt that . . . well isolated islands are evolutionary traps, which in due time kill one species after another that settles on them" (*1*). If size of the population is the crucial factor, it should follow that the rate of extinction should be the more rapid the smaller the island. A further expected consequence is that the smaller the island the lower the percentage of endemic species should be, because most of the populations become extinct before they reach species level, or soon thereafter. MacArthur and Wilson (*2*), on the basis of slightly different considerations, arrived at a similar conclusion.

It is only rarely recognized how much smaller than one might expect is the percentage of endemics among birds as the result of extinction, even on relatively large and old islands. New Caledonia, an island going back to the Mesozoic, has only one old avian endemic, the kagu *Rhynochetos jubatus* (*3*). Fleming (*4*) has similarly shown in a very original analysis that about three-quarters of the land birds of New Zealand are recent immigrants.

The relationship between island size and percentage of endemics appears to be far more regular, at least among birds, than previously recognized. In Figs. 1 and 2 the logarithm of island area is plotted against the logarithm of the percentage of endemic species of land birds. The relative goodness of fit can be seen from the graphs. These graphs must be considered as mere approximations, for the exact number of the resident, breeding, land-bird fauna is not certain for some of these islands, and in many cases an arbitrary decision must be made whether to call an endemic isolate a species or a subspecies.

The curve for each type of island has a different zero point, but the slope is the same for the four kinds of islands shown. Solitary, well-isolated islands (Fig. 1, curve A) show only small deviations from expectancy. Manus and Socotra (Fig. 1, curve B, points 9 and 10) have a higher than expected endemicity; both are far enough from the nearest mainland or archipelago so that they are somewhat intermediate between islands shown in curves A and B. In the case of islands in scattered archipelagos

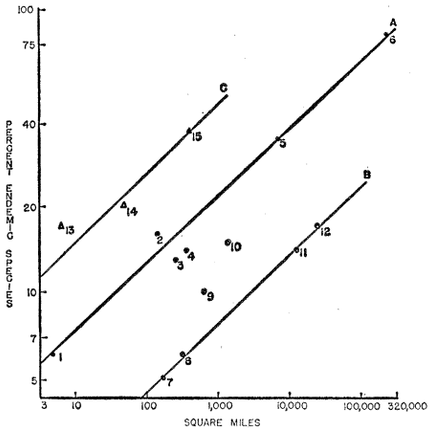


Fig. 1. Double logarithmic plottings of area against percentage of endemic species of birds on three kinds of islands. (*A*) Solitary, well-isolated islands: Lord Howe, 1; Ponape, 2; Rennell, 3; Chatham, 4; New Caledonia, 5; Madagascar, 6. (*B*) Single islands near mainlands or large archipelagos: St. Matthias, 7; Pemba, 8; Manus, 9; Socotra, 10; Timor, 11; Tasmania, 12. (C) Islands in the Gulf of Guinea: Annobon, 13; Principe, 14; San Tomé, 15.

(Fig. 2) most major deviations—for example, Kauai, Viti Levu, and Jamaica (points 8, 11, and 12)—can be explained in terms of relative isolation. The relation shown in Figs. 1 and 2 does not hold true for islands that are members of tight archipelagos (Solomon Islands, Bismarck Archipelago, Moluccas) or, of course, for islands in the temperate zone which had a complete faunal turnover during the Pleistocene.

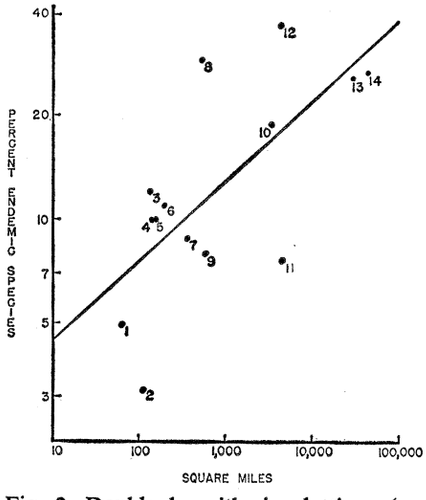


Fig. 2. Double logarithmic plottings (see Fig. 1) for islands in scattered archipelagos: Vanikoro, 1; Moheli, 2; Mayotte, 3; Anjouan, 4; Kandavu, 5; Santa Cruz, 6; Grand Comoro, 7; Kauai, 8; Oahu, 9; Puerto Rico, 10; Viti Levu, 11; Jamaica, 12; Hispaniola, 13; Cuba, 14.