FISHERY OCEANOGRAPHY--IV

OCEAN SALINITY AND DISTRIBUTION OF PACIFIC SALMON

Felix Favorite

Pacific salmon (genus Oncorhynchus) have effective mechanisms for adapting to the osmotic pressures of fresh and salt water, but the significance of salinity on the distribution of salmon is open to question. Young fingerling salmon leaving fresh-water streams and entering the ocean appear able to control their movements so as to permit a gradual acclimatization to oceanic salinities. A fishery biologist studying salmon blood informed me that he routinely placed live adult salmon caught in salt water directly into fresh-water holding tanks without adverse affects. He could thus see no reason why salinity had any bearing on the distribution and migration of salmon in the ocean. Whether any distress was experienced by the salmon, or whether its fresh-water migration had already begun, are beside the point. Salinity, as defined scientifically, is basically determined from measurement of the amount of chloride ion. As such, it has no mysterious characteristics other than degree of concentration. I do not imply that salmon cannot detect small differences in concentration of other ions, but only that salt is salt. However, knowledge of the vertical and horizontal distribution of salinity permits us to ascertain general oceanographic conditions and processes.

Our early investigations (1955-56) were conducted during summer. The salmon were not caught south of the southern boundary of the temperature-minimum stratum described in part 3 of this series of articles. After the 1956 summer season, we were notified that the 'Charles H. Gilbert' of the BCF Honolulu Biological Laboratory had caught four pink salmon (O. gorbuscha) near lat. 41°30' N, long. 165° W in April 1956. The southern boundary of the offshore feeding grounds in the eastern part of the ocean was thereby extended several hundred miles. When sufficient oceanographic data were available, it was possible to show a striking change in the vertical salinity distribution at this latitude (42° N). To the north, salinity increased monotonically with depth, but to the south a salinity-minimum stratum existed at depth. This division was clearly indicated by a vertical 34 ‰ isohaline in the surface layer, which was separate and distinct from the underlying 34 ‰ isohaline (which sloped downward from north to south across this latitude--fig. 1).

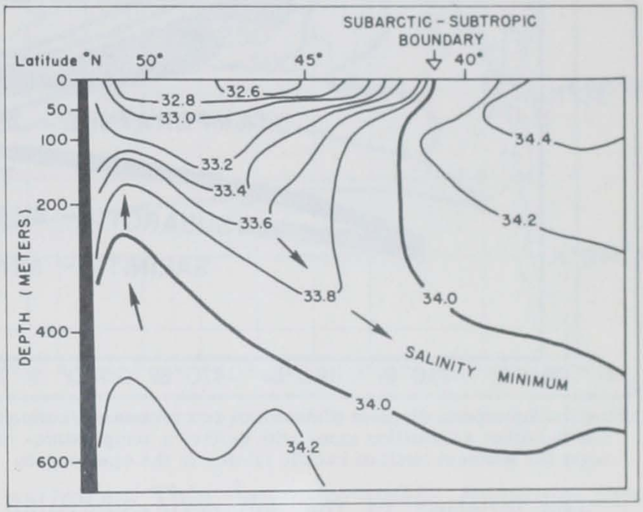

Fig. 1 - Vertical section of salinity in central North Pacific Ocean showing near vertical 34 ‰ isohaline near lat. 41° N, which marks the Subarctic-Subtropic Boundary and the southern limit of Pacific salmon. Arrows indicate probable vertical circulation.

At this point we had three environments: northern, characterized by a temperature-minimum at depth; transition, with monotonically increasing values of temperature and salinity with depth; and southern, characterized by a salinity minimum at depth (fig. 2). For convenience, the first two were subsequently defined as within the Subarctic Region, even though the transition environment should not be considered subarctic because of its occasional high temperatures. The boundary between the transition environment and that having the salinity-minimum stratum is now referred to as the Subarctic-Subtropic Boundary; it has withstood the test of time as the southern limit of the Pacific salmon in the central North Pacific Ocean.

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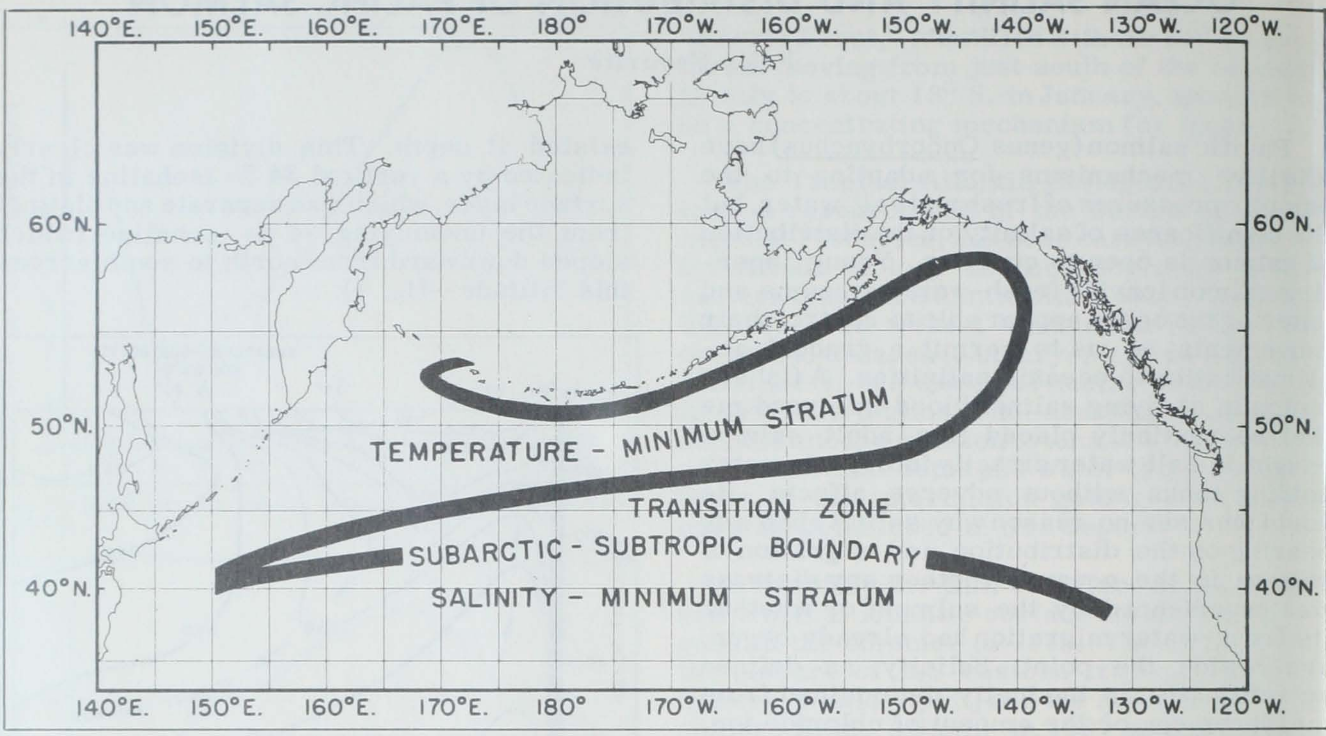

Fig. 2 - Schematic diagram of extent of two salmon environments--one characterized by a subsurface temperature-minimum stratum and the other a transition zone, with neither a temperature- nor salinity-minimum stratum. The Subarctic-Subtropic Boundary denotes the southern limit of Pacific salmon in the open ocean.

The location of the Subarctic-Subtropic boundary also was found later to be an area of distinct changes in type and amount of planktonic forms. But no investigation has been made of the tongue-like intrusion of typically subarctic water, which extends as a salinity-minimum stratum south of lat. 40° N under the surface lens of the saline subtropic surface water. A number of years ago, before we were able to conduct winter salmon fishing, I speculated that some salmon might winter in this deep stratum far removed from the winter storms prevalent at the surface. Although we caught enough salmon at the surface at higher latitudes during winter to challenge this hypothesis, we have never caught them in sufficient quantities to establish a winter distribution pattern. Indeed, it would be interesting to investigate the biomass in this stratum during winter.

The distribution of salinity at depth also provides some clue as to cause of the temperature-minimum stratum. A plot of depth at which the 34 ‰ isohaline occurs (fig. 3) indicates that it rises closest to the surface in a plateau-like structure around the temperature-minimum stratum. If we accept the premise of a northward flow of deep or bottom water from the Antarctic region into the North Pacific Ocean, the physical barrier imposed by the boundary of the Gulf of Alaska and Aleutian Islands could deflect this water upward and cause a certain type of water structure. The subsequent formation of a sharp halocline at the interface of the deep saline water, transported upward, and the bottom of the surface layer of dilute water limit the downward movement of cold but dilute surface water during winter turnover to 100-200 m. depth, and the temperature-minimum stratum occurs.

I am aware that it would be advantageous to characterize stream runoff by specific chemical constituents or ratios of chemical constituents. The chemistry of sea water, however, is infinitely complex. Several years ago, when we established a chemical oceanography section in our Oceanography Program, we made little progress even though we adopted relatively new techniques, such as atomic absorption spectrophotometry. Dr. T. Joyner (a member of our group at that time) measured particulate aluminum in the plume of the Columbia River by this method. He showed that this technique was almost as effective as that of using salinity to define the extent of the plume; however, particle setting rates which affect the horizontal distribution were not considered.

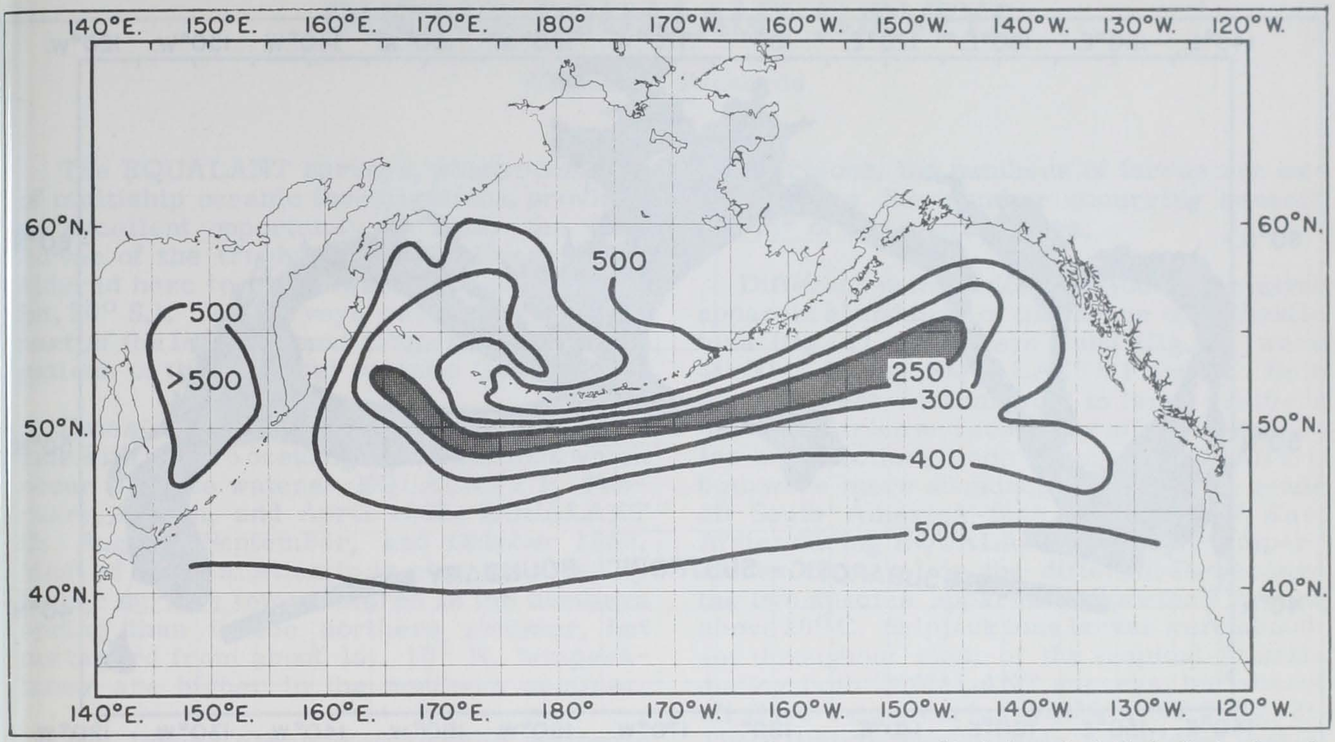

Fig. 3 - Schematic diagram of the depth of 34 ‰ isohaline, showing area of minimum depth (shaded) south of Alaska Peninsula and Aleutian Islands.

That other properties are also advected with the dilute runoff is not extensively documented because most of the elements amenable to analysis at sea are nonconservative--in other words, they are modified by other processes. These properties are primarily nutrients such as phosphate, silicate, or nitrate, which may be consumed by living plants--or replenished by decaying plants and animals as the plume moves seaward. Improvements in chemical analytical techniques for accurate determination of trace elements and other chemical constituents of sea water are sorely needed; such improvements will greatly aid in determining where in the ocean a homing salmon first chemically detects its natal stream, if indeed it ever loses contact.

Surface temperature was not discussed in the previous article because the so-called latitudinal "march" of isotherms, northward in spring and southward in summer as a result of the increasing and decreasing latitude of the sun, is well documented. From ships and satellites, we now obtain data at 5-day intervals on distributions of surface temperature, but no data on distributions of surface salinity. This is unfortunate because the salinities would be more useful than the temperatures in determining flow. Such observations are not made aboard "Ships of Opportunity" (merchant vessels), and remote sensing of salinity is not possible. Equilibration of heat at the sea-air interface and other processes tend to mask advective temperature anomalies, but salinity anomalies in some areas can be traced for great distances.

Surface salinity across the North Pacific Ocean above lat. 45° N is about 33 ‰. At no other place in the world's oceans (except in coastal regions or the Arctic) is there water of such low salinity. At these latitudes in the North Atlantic Ocean, salinity is over 2 ‰ higher (34 ‰ is about the mean value for the surface salinity of the oceans). The Subarctic Pacific Region is characterized by a net precipitation over evaporation. The extensive spring runoff from snowsheds at these latitudes lowers salinity of coastal waters during spring and summer. If we consider the 32.6 ‰ isohaline as indicative of coastal water, we find that it extends over a wide area of the Region (fig. 4).

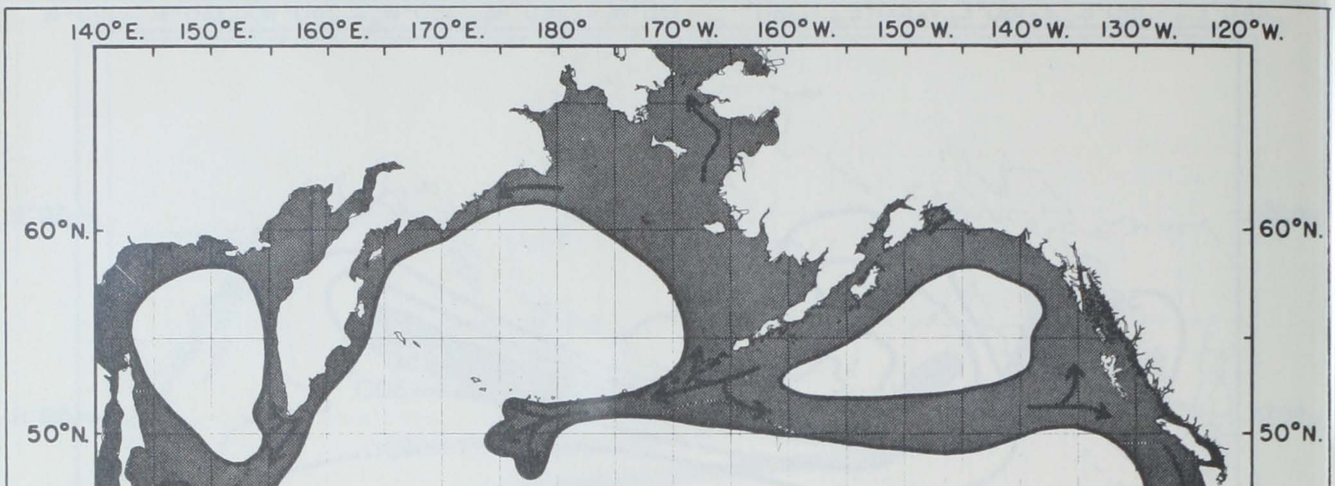

Fig. 4 - Schematic diagram of the seaward extent of the 32.6 ‰ isohaline at the sea surface. Arrows indicate flow suggested by salinity distribution.

The broad continental shelf in the Bering Sea is covered with dilute water from various river runoffs. The absence of any source of deep, saline water (because of the shallow depths) prevents surface salinities in this area from attaining the higher values found in oceanic areas. South of the Bering Sea, it is obvious that dilute water occurs largely inshore of water overlying the temperature-minimum stratum, except where definite intrusions are made into oceanic areas. One location is offshore of the Columbia River, and another is south of the Alaska Peninsula, where a southward intrusion clearly denotes a closed circulation in the Gulf of Alaska. Intrusions at the westward extremity of the Aleutian Islands and on the western North Pacific from the Kuril Island area quickly lose their identity by mixing with more saline oceanic waters; their extents are no longer indicated by surface salinity because of the broad area of rather uniform oceanic salinities. Other characteristics of these two plumes permit us to follow them farther seaward.

In the next article, I shall describe other methods that are used to trace these intrusions of water from the North American and Asian coasts farther into oceanic areas. We shall see how the intrusions appear to influence the ocean distribution of North American and Asian stocks of sockeye salmon (O. nerka).