FISHERY OCEANOGRAPHY--VII
ESTIMATION OF FLOW IN GULF OF ALASKA

Felix Favorite

Perhaps the most common immediate reaction to oceanographic studies by fishery groups is that the ocean is too large and that the extensive environmental studies required to direct fishery activities are too time consuming and expensive. After all, aren't you better off to cast your nets into the water and see if any fish are present than to use the time to make environmental observations and hypothesize the probability of catching fish. Of course, the answer to this question may be yes, especially if visual or electronic devices indicate the presence of fish. But in this manner one never answers the question why--why are the fish present; why are they here at this time; why are they so few or so abundant? How many fishermen spend the winter wondering why last summer's fishing was good or bad and if next year's will be worse or better? As soon as one begins to examine the causes of fluctuations in the sizes of catches, new problems demand attention. Information on reproduction and survival of the harvested stocks is required to estimate the numbers of fish in the sea. One must also know about the vagaries of the environment and the reaction of fish to its changes.

Much is said today about sea-surface temperatures as aids to fishing and the potential of satellites to monitor surface temperatures, but these data are in some respects very superficial. They are only indicative of a thin surface layer and are not necessarily indicative of the direction and intensity of ocean currents. It is these currents which disperse eggs and larvae of marine fishes into areas where conditions are favorable or unfavorable for survival, and transport passively drifting fishes from one area to another. Also, current boundaries appear to serve as guideposts to migrating fish, such as the Pacific salmon (genus Oncorhynchus).

Clues to Salmon Migrations

Frequently, unusual displacements of fish stocks occur. These are usually accompanied or foreshadowed by abnormal environmental conditions. Until satellite systems that monitor flow are devised, we must explore the methods presently available. We believed from the beginning of our studies that ocean currents and the inherent water properties of each current system provided some clue to migrations of salmon. Previous articles in this series showed that temperature and salinity distributions provide an indication of the southern limits of salmon distribution--but little information concerning their migration routes. These routes appear to be associated with the huge Subarctic gyres.

Geostrophic Flows

Usually, currents or water transport in these gyres are ascertained by the geostrophic method and are called geostrophic flows. Geostrophic velocities are proportional to the slope of the sea surface derived from observations, at two or more locations, of the vertical distribution of temperature and salinity above an arbitrarily selected reference level at which horizontal pressure gradients are believed to be negligible. The relation between the vertical distribution of mass (determined by distribution of temperature, salinity, and depth) and of flow is somewhat like the old query: which came first, the chicken or the egg? Does the flow result in the observed distribution of mass, or does the distribution of mass result in the flow? We will accept the fact that a slope indicates an imbalance of energy at the sea surface and consider how to ascertain this imbalance and its relation to flow.

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Above 4° C., water expands as the temperature rises. Thus, a column of warm water will stand higher above the common reference level than a column of cold water; a column of fresh water will stand higher than a column of salt water. As there is no way to ascertain a true reference level, an arbitrary depth is selected--usually where the least change of temperature and salinity with depth occurs. Although there are exceptions, a reference level of the order of 1,500 decibars is selected; this approximates a depth of 1,500 meters. By summing up effects of vertical structure of temperature and salinity on height of water column from this level at two or more locations, we are able to ascertain the topography of the sea surface relative to this level--and resulting geostrophic flow at sea surface relative to flow at this level. This is assumed to be zero and, in practically all cases, is insignificant compared to surface flow.

If you liken this topography to that of land, one might imagine intuitively that flow would be downslope. In the equilibrium state, the tendency for water particles to move downslope (pressure force) is assumed to be balanced by a centrifugal reaction (Coriolis force), and the resulting flow is normal, or at right angles to the slope. In the northern hemisphere, upslope is to the right of the flow as one looks downstream; the speed of, or transport of water in, the flow is related directly to steepness of slope. Thus, cyclonic (or counterclockwise) flow occurs around the topographic lows (the Gulf of Alaska gyre is an example); anticyclonic flow occurs around topographic highs. Using this technique, we have been able to ascertain geostrophic currents between fishing stations and the general circulation over large fishing areas. Of course, this method assumes unaccelerated, frictionless flow and is a gross simplification of actual flow conditions in the ocean. There is no need to pursue its limitations except to point out that distribution of temperature and salinity at depth are altered slowly, thus transient currents are not represented; furthermore, with even a number of ships, it is impossible to obtain synoptic observations over a large area.

Our early studies in the Subarctic Pacific Region provided some indication of geostrophic currents during summer; subsequent winter cruises provided an indication of currents during that period also. But we never have been able to obtain a continuous year-round picture of ocean currents or of salmon distribution that did not lack continuity in time or space and, therefore, was somewhat fragmentary. This prevented any successful attempts at forecasting environmental or fishery conditions.

Estimating Flow Over Wide Area

There is another method that permits one to obtain an estimate of flow over wide areas. Although it is difficult to integrate into a continuous record of flow, it provides valuable information independent of actual measurements of water properties. The flow in major ocean current systems is dependent upon the stress of the wind on the sea surface. Knowledge of this stress permits us to compute flow generally referred to as wind-stress transport. Although the exact coupling between surface winds and surface ocean currents is complicated and not well known, there are empirical considerations that permit us to obtain an estimate of flow in the open ocean. This is done in the following manner: the mean sea level pressure over the area concerned for a selected period is obtained from the weather records. The accompanying mean winds are derived from the spacing of the isobars, under accepted meteorological concepts, for surface wind stress at grid points. Knowledge of the curl (vector cross product) of the wind stress and the rate of variation of the Coriolis parameter along a meridian permits computation of the north-south transport across a unit length of latitude that would occur when steady-state conditions are reached. Using continuity concepts from grid point to grid point, commencing at the west coast of North America and proceeding westward, one is able to construct a circulation pattern that has been shown to approximate actual flows based upon the time-consuming and costly shipboard observations.

Gulf of Alaska Gyre

As indicated in Article V, we are particularly concerned about the effect of the Gulf of Alaska gyre on the distribution of salmon. If we ignore boundary conditions imposed by the coast, and investigate seasonal effects on mean monthly wind-stress transports in the Gulf of Alaska for the decade 1950-59, several interesting features are evident (fig. 1). There is an appreciably greater flow into and out of the Gulf of Alaska during winter than in summer. Although cyclonic winds (associated

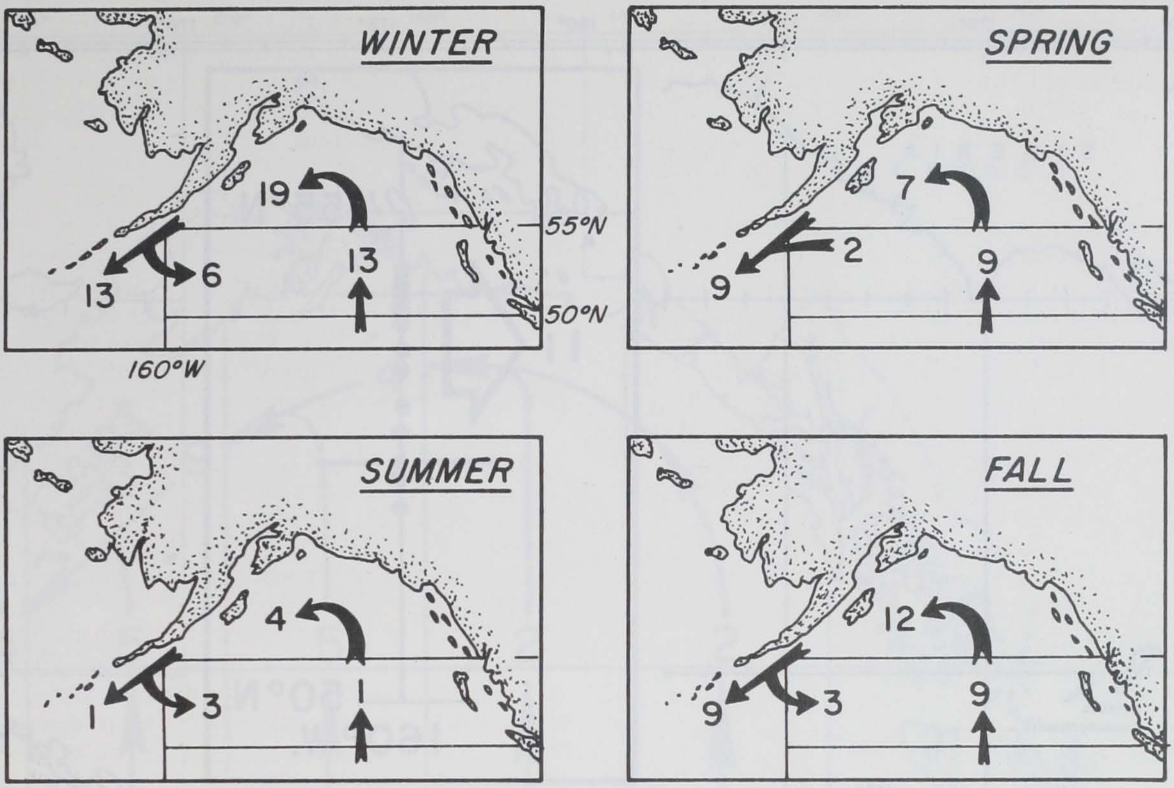


Fig. 1 - Mean seasonal flow (transport [X 10^6 m.^{3}/sec.]) into and out of the Gulf of Alaska, 1950-59.

vith the low pressure system in the Gulf of Alaska each year during winter) should result in an intensification of flow, the differ- ences appear large because there is little evidence of this intensification in the distri- utions of temperature and salinity. How- ever, when one considers the monthly values of mean sea level for the same period at akutat (corrected for atmospheric pressure nd precipitation effects)--an increase in sea evel, indicating an increase in cyclonic flow, s found during winter.

There is no recirculation, or eastward low, during spring. This is interesting be- ause it is the season in which there is a pre- ominant westward movement out of the Gulf f Alaska of sockeye salmon (O. nerka) bound or spawning streams in the eastern Bering ea. Finally, northward flow across lat. 50° N. is at a minimum during summer, and most f the northward flow across lat. 55° N. is the esult of water recirculating in the gyre. In ddition to providing an indication of long- erm seasonal or annual conditions, this ethod can be used to ascertain recent con- itions--and provide enough insight to permit stimations or predictions of flow on a month- o-month basis.

Computations of geostrophic flow based upon shipboard observations of temperature and salinity, to 1,500-m. depth south of the Alaska Peninsula, indicated a westward transport of 11 x 10^6 m.^{3}/sec. in early March 1970. Data were required from numerous oceanographic stations parallel to the normal coastline because it was imperative to have observations at the high and low points of the topography of the sea surface to compute total flow. Computations of the mean wind-stress transport for February 1970 indicate an equivalent value for westward flow in this area (fig. 2). Furthermore, it is obvious that considerably more details of flow, particularly areas of possible divergence and convergence, are available from the wind-stress charts. Although this is, basically, a theoretical calculation, it is a method that permits insight into conditions in the ocean that cannot be obtained by a single ship or even by several. The technique requires no expenditure of research-vessel time, nor of a large staff to process data. At the end of each month, when the mean sea-level atmospheric pressure is available, the whole process is completed essentially by computer in minutes. It is through such techniques that we will be able to monitor and predict conditions in the

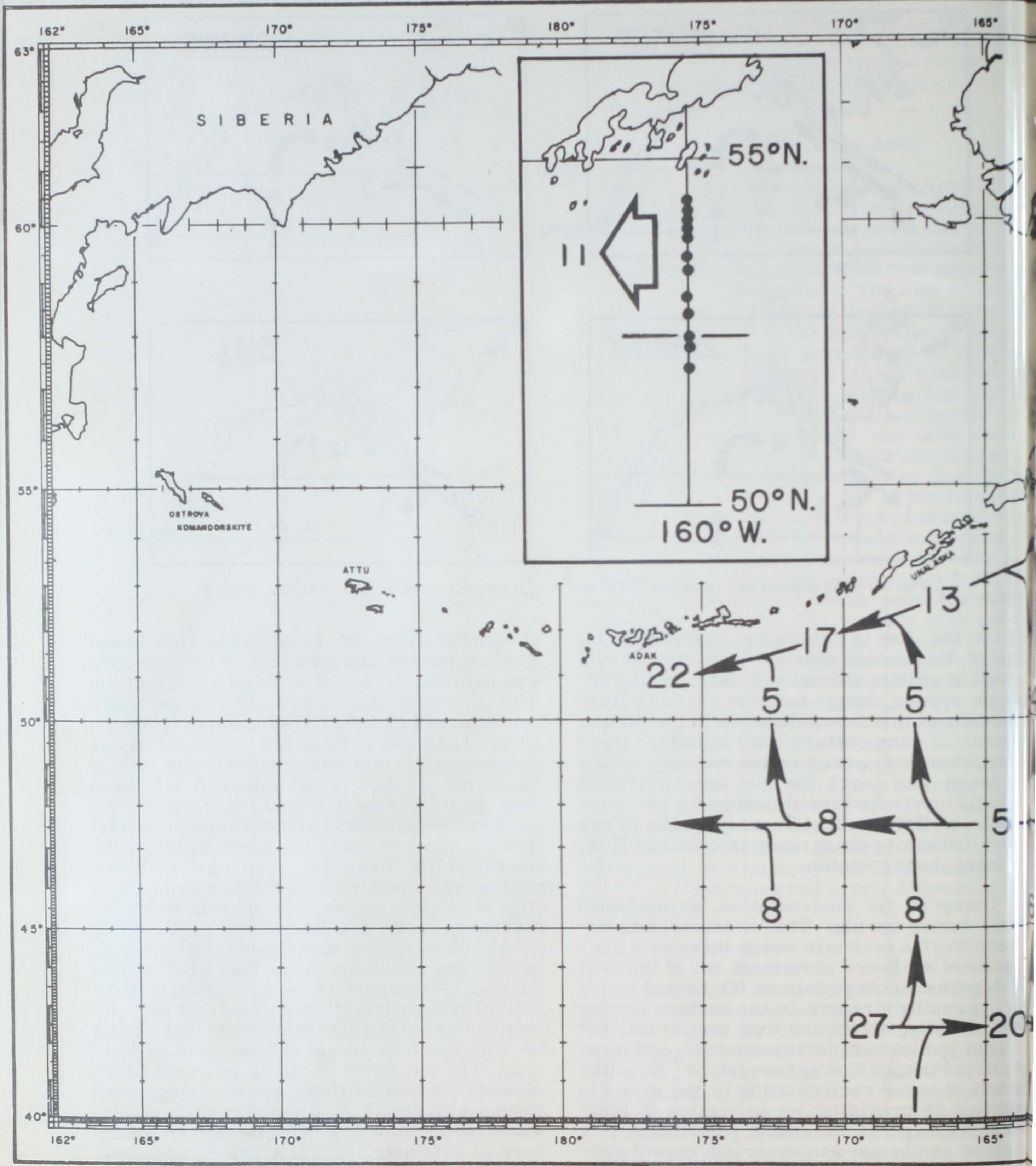
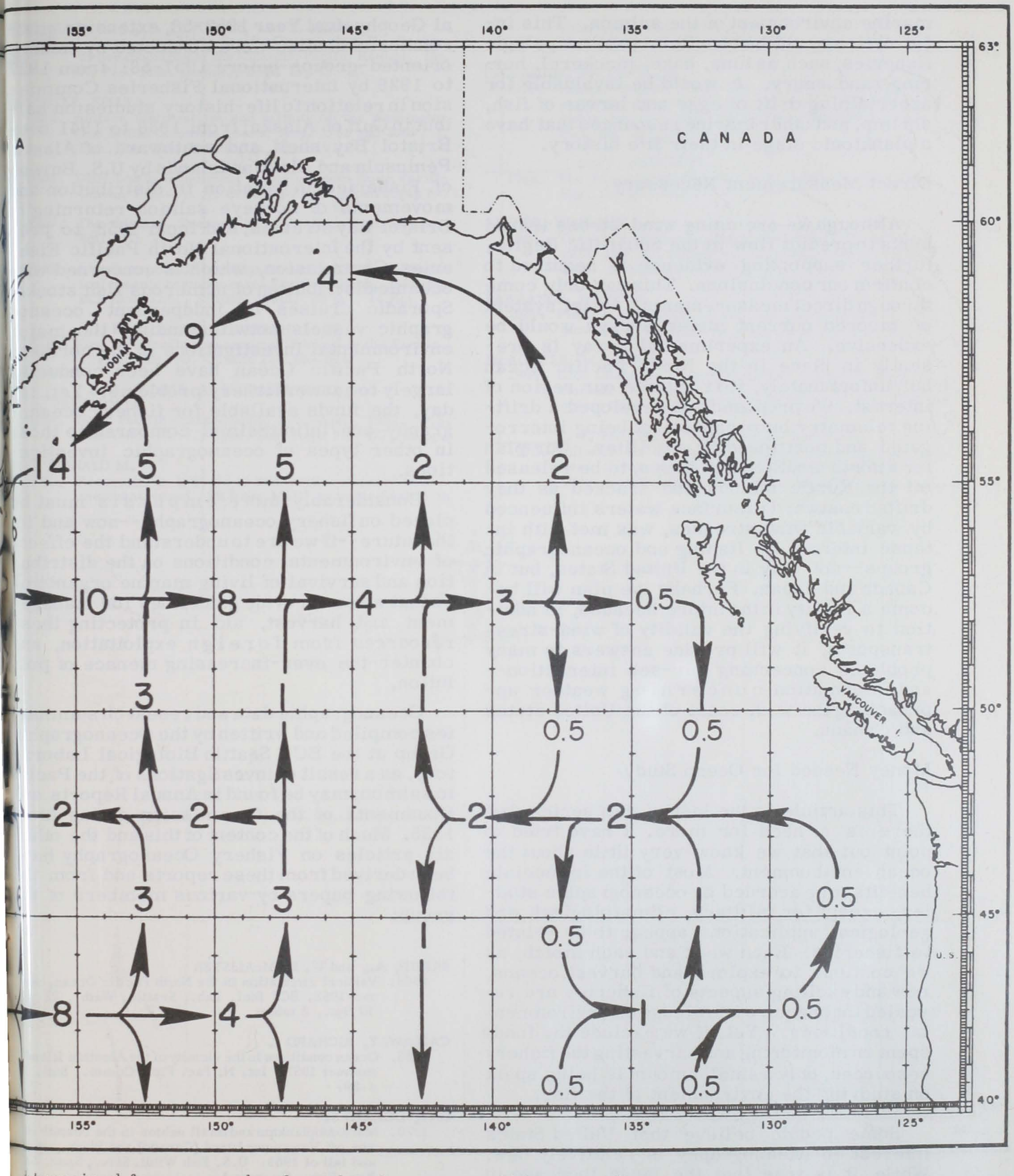


Fig. 2 - Flow (wind-stress transport [X 10^6 m.^{3}/sec.]) in the eastern North Pacific Ocean from oceanographic data obtained at indicated stations.



etermined from records of sea level pressure, February 1970. Insert shows flow computed marine environment of the salmon. This information would be beneficial to other pelagic fisheries, such as tuna, hake, mackerel, herring, and saury. It would be invaluable for ascertaining drift of eggs and larvae of fish, shrimp, and other marine resources that have a planktonic stage in their life history.

Direct Measurement Necessary

Although we are using wind-stress transports to predict flow in the Subarctic Region, further supporting evidence is required to confirm our conclusions. This can only come through direct measurements. A vast system of moored current meter arrays would be expensive. An experimental array is presently in place in the North Pacific Ocean but, unfortunately, it is outside our region of interest. We proposed and developed a drifting telemetry buoy capable of being interrogated and positioned by satellites. Our plan for a north-south line of buoys, to be released off the Kurile Islands and tracked as they drifted eastward in surface waters influenced by variable wind stresses, was met with intense interest by fishing and oceanographic groups--not only in the United States, but in Canada and Japan. Perhaps the plan will become a reality in the future because, in addition to verifying the validity of wind-stress transports, it will provide answers to many problems concerning air-sea interaction--and information concerning weather approaching the west coast of the United States and Canada.

Money Needed for Ocean Study

This article is the last of this series, but there is a need for more. I have tried to point out that we know very little about the ocean environment. Most of the immediate benefits to be accrued by oceanographic studies, except for military, climatological, and geological applications, appear to be related to fisheries. Each week and each month, as we continue to explore and harvest oceans, new and exciting aspects of fisheries are revealed that require knowledge of environmental conditions. Yet, if we exclude the funds spent on monitoring and harvesting the fishery resources, only a small amount is being spent on studying the environment of the fish.

Some people believe that United States interest in oceanography is relatively new. While it is true that the large increase in oceanographic funds followed the International Geophysical Year 1957-58, extensive environmental studies were conducted by fishery oriented groups before 1957-58: from 1927 to 1929 by International Fisheries Commission in relation to life-history studies on halibut in Gulf of Alaska; from 1938 to 1941 over Bristol Bay shelf and southward of Alaska Peninsula and Aleutian Islands by U.S. Bureau of Fisheries in relation to distribution and movements of sockeye salmon returning to Bristol Bay streams; and from 1953 to present by the International North Pacific Fisheries Commission, which is concerned with oceanic distribution of numerous fish stocks. Sporadic cruises by independent oceanographic vessels notwithstanding, the major environmental investigations in the northern North Pacific Ocean have been conducted largely to answer fishery problems. Yet, today, the funds available for fishery oceanography are infinitesimal compared to those in other types of oceanographic investigations.

Considerably more emphasis must be placed on fishery oceanography--now and in the future--if we are to understand the effects of environmental conditions on the distribution and survival of living marine organisms so that we can provide guidelines for management and harvest, aid in protecting these resources from foreign exploitation, and counter the ever-increasing menace of pollution.

Oceanographic data and research summaries compiled and written by the Oceanographic Group at the BCF Seattle Biological Laboratory, as a result of investigations of the Pacific salmon, may be found in Annual Reports and Documents of the Commission dating from 1955. Much of the content of this and the other six articles on Fishery Oceanography have been derived from these reports and from the following papers by various members of the group:

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