The Anomalous Surface Salinity Minima Area Across the Northern Gulf of Alaska and Its Relation to Fisheries

W. J. INGRAHAM, Jr.

Introduction

The number of oceanographic activities in the Pacific Northwest has increased and there appears to be ample support of field activites in the northeastern Pacific Ocean for these groups. Although oceanographic studies by fisheries groups have not been a part of this increase, they have contributed a considerable amount of knowledge of environmental conditions and processes affecting living marine resources in this area. Recent studies by the NMFS Northwest and Alaska Fisheries Center (NWAFC) provide unprecedented insight into sea surface conditions in the Gulf of Alaska.

Background

The accumulation of knowledge of the marine environment in the Gulf of Alaska has been painfully slow and aperiodic. In the 237 years since the first arrival of "westerners" Bering and Chirikof in the Gulf of Alaska, there have been several significant periods of marine investigations in the Gulf of Alaska prior to current inshore studies supported by Bureau of Land Management funding of NOAA's Outer Continental Shelf Environmental Assessment Program (OCSEAP).

For 126 years the area was under the control of the Russian-America Company when numerous voyages of explorations and exploitation of natural resources (mainly marine mammals) occurred. For nearly 50 years, Russian officials controlled the port of New Archangel (now Sitka) and extensive traffic occurred not only from the Yukon River to southern California, but to various ports of the world (Chevigny, 1965). Much of the local oceanographic knowledge that stems from this period was compiled into the first Alaska Coast Pilot. Davidson (1869) reported that a 0.5-to 1.5- knot current was believed to flow northward, westward, and southwestward along the gulf coast.

Near the end of the 19th century and in the early part of this century, a series of cruises was conducted using the steamer *Albatross* of the U.S. Fish Commission. The location and general characteristics of the various offshore banks along the continental shelf were defined; sea surface and bottom temperatures were obtained. During this period it was generally accepted that water in the gulf originated from the Kuroshio or Japanese Current because of an analogous warming effect the Gulf Stream had on northern Europe. In fact, the Kuroshio was also believed to penetrate Norton Sound in the Bering Sea because of the warm summer temperatures encountered there also.

Extensive investigations in the northern gulf were conducted by the International Fisheries Commission (IFC) from 1927 to 1934. Winter data from only three lines of stations off Ocean Cape, Cape Cleare, and Cape Chiniak revealed a pronounced westward current at the edge of the continental shelf with surface flow as high as 55 cm/second; a marked eastward flow occurred immediately shoreward of this current, but flow over the shelf was generally weak and variable. Also at the shelf edge, the cold surface layer was determined to be underlain by a deeper, warmer stratum (McEwen et al., 1930; Thompson and Van Cleve, 1936), an indication of winter overturn recognized today as a major process in the surface layer.

The possible individual roles of and interactions between the atmospheric Aleutian low pressure system and the Eastern Pacific high pressure system on surface flow were recognized, and extensive drift bottle experiments were conducted across the gulf and seaward of Vancouver Island. The implied trajectories of the bottles indicated a broad sweep of cyclonic flow over the continental shelf with a strong onshore component around the entire gulf. However, the source of this flow was still considered to be the Japanese (Kuroshio) Current (Thompson and Van Cleve, 1936) until the transpacific, largely locally formed, Subarctic Water Mass was identified by Sverdrup et al. (1942).

W. J. Ingraham, Jr., is with the Northwest and Alaska Fisheries Center, NMFS, NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

During 1950-52, the Pacific Oceanographic Group of the Fisheries Research Board of Canada conducted four offshore oceanographic cruises from the southern end of Vancouver Island to the northern end of the Queen Charlotte Islands in an attempt to define the role of this area in relation to the oceanography of the northeast Pacific Ocean and to define subsystems within the Subarctic Water Mass. Doe (1955) showed the continuity and broad offshore extent of coastal and offshore water masses in the eastern and northern parts of the gulf and (on the basis of data from only a few stations) indicated that these water masses narrowed considerably along the western side of the gulf, suggesting the presence of a boundary current. Seaward of the offshore water mass a rather vague outline of a mid-gulf water mass was presented, defined by a few widely spaced stations obtained aboard the U.S. Coast Guard vessel *Ogalala* in 1936 subsequent to the IFC studies. Thus, only 20 years ago, the nature of the southwest flow out of the Gulf of Alaska and conditions in the mid-gulf area (other than at the surface) could be ascertained from the limited data at several oceanographic stations.

INPFC Studies

Our present concept of the physical environment of the Gulf of Alaska stems largely from the extensive oceanographic studies conducted under the supervision of the International North Pacific Fisheries Commission (INPFC) from 1953 and continuing in varying scope and intensity up to the present. These and other concurrent studies, such as the North Pacific Expedition (NORPAC) in 1955, provided the extensive data required to show the transpacific continuity of flow into the gulf and the origin of local water properties.

Summaries of oceanic environmental conditions from 1953 to 1959 (Dodimead et al., 1963) and from 1960 to 1971 (Favorite et al., 1976) and of conditions in the Gulf of Alaska (Ingraham et al.[1]) form the basis of much of our current knowledge of oceanic conditions. There is a greatly increasing body of information concerning physical conditions in the coastal regime at the head of the gulf as a result of OCSEAP and other studies (e.g., Royer, 1975; Royer and Muench, 1977; Muench et al., 1978; and others).

General Conditions

Changes in environmental conditions in the Gulf of Alaska are largely characterized by water temperature and salinity—the former largely reflects cycles of warming and cooling characteristic of high latitudes and results in relatively uniform conditions over large areas except in coastal regimes where snowmelt and tidal mixing results in lower values than in offshore areas; whereas, the latter largely reflects imbalances between evaporation and precipitation as well as seaward discharges of snowmelt and runoff from the coast and mountain ranges ringing the gulf that result in marked seaward gradients and contribute to a salinity maxima area in the central part of the gulf. The general nature of the permanent flow is cyclonic (counterclockwise) and, as coastal dilution in spring from the eastern side moves seaward, it is advected slowly northward around the gulf. During summer this offshore flow of dilute water in the eastern gulf is further altered by local northwesterly winds which cause an Ekman transport 90° to the right of the wind. These seaward intrusions were detected by Favorite (1961), Dodimead et al. (1963), and others, who reported offshore continuity of coastal plumes of dilute water in excess of several hundred kilometers along the northeast Pacific coast.

Sea Surface Studies

During a NWAFC oceanographic cruise aboard the NOAA research vessel *George B. Kelez* conducted in spring 1972 to ascertain environmental conditions in the vicinity of Portlock and Albatross Banks south and east of Kodiak Island in the western gulf, a band of surface salinity minima (<32.5 ‰) of unknown origin was discovered along a 500 km stretch generally paralleling the edge of the continental shelf (Favorite and Ingraham, 1977). It was assumed that this feature was probably continuous to the eastward around the head of the gulf and marked the boundary between coastal and oceanic water and could serve as a guidepost or path for migrating salmon.

A U.S.-Poland cooperative fishing-oceanographic survey aboard the Polish research vessel *Profesor Siedlecki* in July 1977 provided an opportunity to trace the band of salinity minima eastward. Data from a rather extensive grid of stations clearly indicated a marked separation at the eastern side of the gulf of surface water of salinity <32‰ near lat. 58° 30'N, long. 138°30'W (Fig. 1)—one branch extending northwestward along the coast over the shelf, and the other an offshore intrusion that protruded westward across the gulf as a band of offshore salinity minima. The latter was the first known indication of the existence of an offshore band of salinity minimum in this area.

At the head of the gulf, this offshore band was clearly separated from the extensive dilution caused by the runoff from the Copper River, one of the five largest gauged rivers in Alaska and the only one of the five that discharges into the Gulf of Alaska; with an average annual discharge of 8.3×10^6 cfs/year, it ranks third (Yukon, 62.3×10^6; Kuskokwim, 16.4×10^6; Kvichak, 6.4×10^6; Kuzitrin, 4.4×10^6)[2].

[1]Ingraham, W. J., Jr., A. Bakun, and F. Favorite. 1976. Physical oceanography of the Gulf of Alaska. NMFS Northwest and Alaska Fisheries Center, Seattle, Wash., Processed Rep., 132 p.

[2]Seifert, R., and D. Kane. 1977. Effects of seasonability and variability of streamflow on nearshore coastal areas. *In* Environmental assessment of the Alaskan Continental Shelf, annual reports of principal investigators for the year ending March 1977, Vol. 14. Transport, p. 96-250. U.S. Dep. Commer., Natl. Oceanic Atmos. Admin. and U.S. Dep. Inter., Bur. Land Manage., Boulder, Colo.

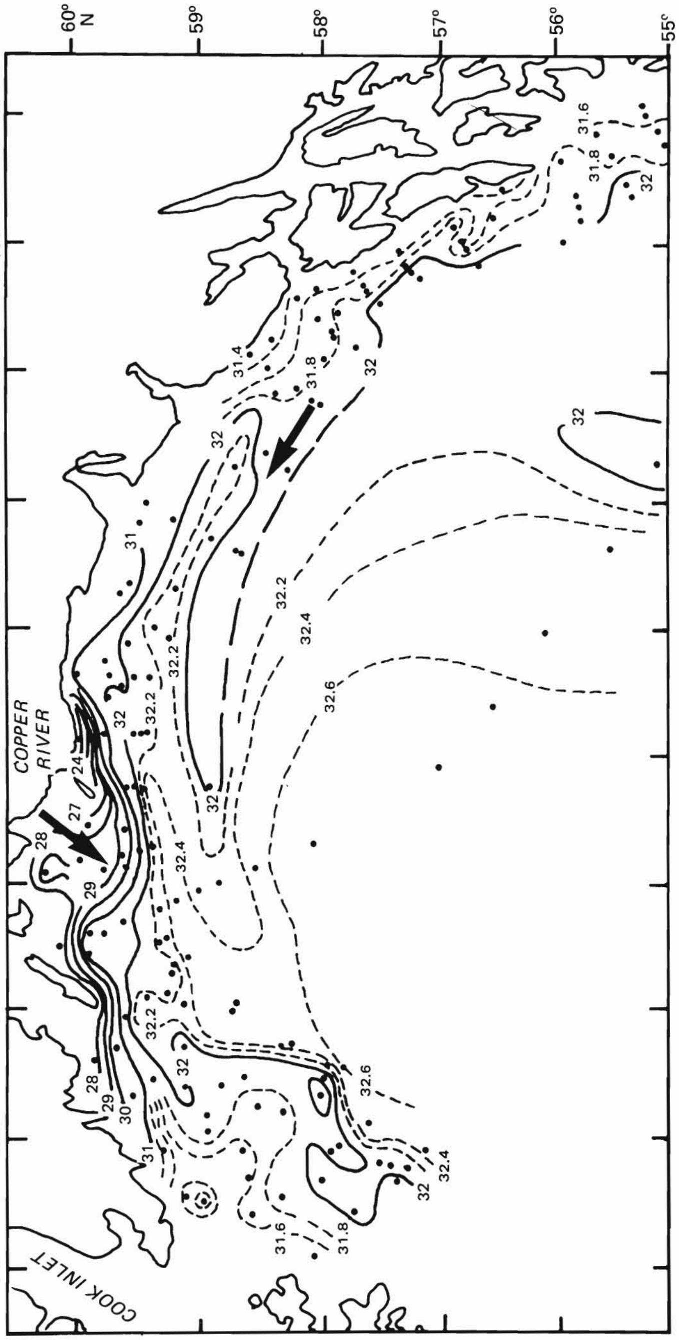

Figure 1.—Surface salinity (‰) taken from the Polish RV *Profesor Siedlecki*, 4-31 July 1977, and stations where salinity data were obtained. Arrows indicate the probable direction of movement of the major sources of dilution into the offshore area.

Although a mean daily discharge of approximately 10,000 cfs usually occurs from November to April, values of over 100,000 cfs may occur by June and continue into September. Thus, the *Profesor Siedlecki* data in July 1977, reflect only the initial stages of the annual discharge of Copper River water into the oceanic regime. This separation of dilute surface water in the eastern gulf is significant because it could determine whether fish eggs and larvae along the continental shelf and slope in this area would either be carried offshore or confined inshore; whereas, in the northern and western gulf planktonic forms over the shelf and slope would be confined entirely inshore.

The western gulf may be even more significant as a mixing zone of the minima caused by the Copper River plume and the offshore salinity minima area as they merge and flow southwestward out of the gulf. Thus, at any specific time or specific location either source may dominate. Unfortunately, the *Profesor Siedlecki* data are not adequate to detect the extension of the offshore salinity minima to the western side of the gulf, but fragmentary portions of one or both minima are evident in some data from OCSEAP cruises conducted off Kodiak Island during 1977. An area of salinity minima near the shelf edge was well defined in March with values < 32.0-32.2‰ (much lower than in May 1972), detectable in July, and strongly evident in September as a pronounced offshore minima area with values < 31.8‰.

During October the minima area was poorly defined as salinities increased slightly, but by November it became more pronounced as the salinities over some of the shallower banks at midshelf increased as a result of winter mixing and turnover. Thus, east of Kodiak Island the salinity minima occurs year-round and cannot be attributed to a single local, seasonal coastal source of runoff, for example, the Copper River—but a combination of local and trans-gulf sources.

The area of low salinity detected at lat. 55°-56°N, long. 139°W during the *Profesor Siedlicki* cruise (Fig. 1) suggests another source. The low salinity values in this area are believed to originate from seaward discharge in spring of coastal water out of Dixon Entrance (lat. 54°30′N) and/or Queen Charlotte Sound (lat. 51°-52°N). Favorite (1961) has shown that such plumes reach to at least long. 137°W.

The increased data coverage in 1977 thus provided knowledge of the seasonal complexities in the continuity of surface salinities which, although subject to mixing and stirring, reflect surface water movement. With this background, plans were made to take an opportunistic look at as much of the area as possible in summer 1978 during a NWAFC fishing cruise aboard the NOAA research vessel *Miller Freeman* in August-September. As a result of a meeting at the NWAFC on 13 July 1978, with scientists from the Korean Fisheries Research and Development Agency who were about to conduct operations in the northern gulf aboard the Korean research vessel *Oh Dae San,* a cooperative plan to obtain surface salinities was approved. Surface water samples obtained in the northern gulf during August from aboard the *Oh Dae San* would be discharged at Kodiak for analysis by NWAFC personnel when the *Miller Freeman* reached Kodiak in September. Subsequently a salinograph unit was installed aboard the *Miller Freeman* during an August 1978 port call in Seattle in order to obtain a continuous record of surface salinity along cruise tracks normal to the coast at the head of the gulf.

Because this study aboard the *Miller Freeman* had to be a part of a fishing cruise, observations were obtained during two different periods of vessel operations. From 25 to 30 August 1978, the salinograph was operated during hydroacoustic-fishing trawl transects over the shelf during the day and on offshore excursions during the night between Dixon Entrance and Sitka. Surface conditions in this area were quite dilute (Fig. 2) with surface water salinity over the shelf of 31.3-32.0‰ and offshore water from 31.6 to 32.2‰. Considerable complexity, with numerous lenses, offshore tongues, and small scale features was

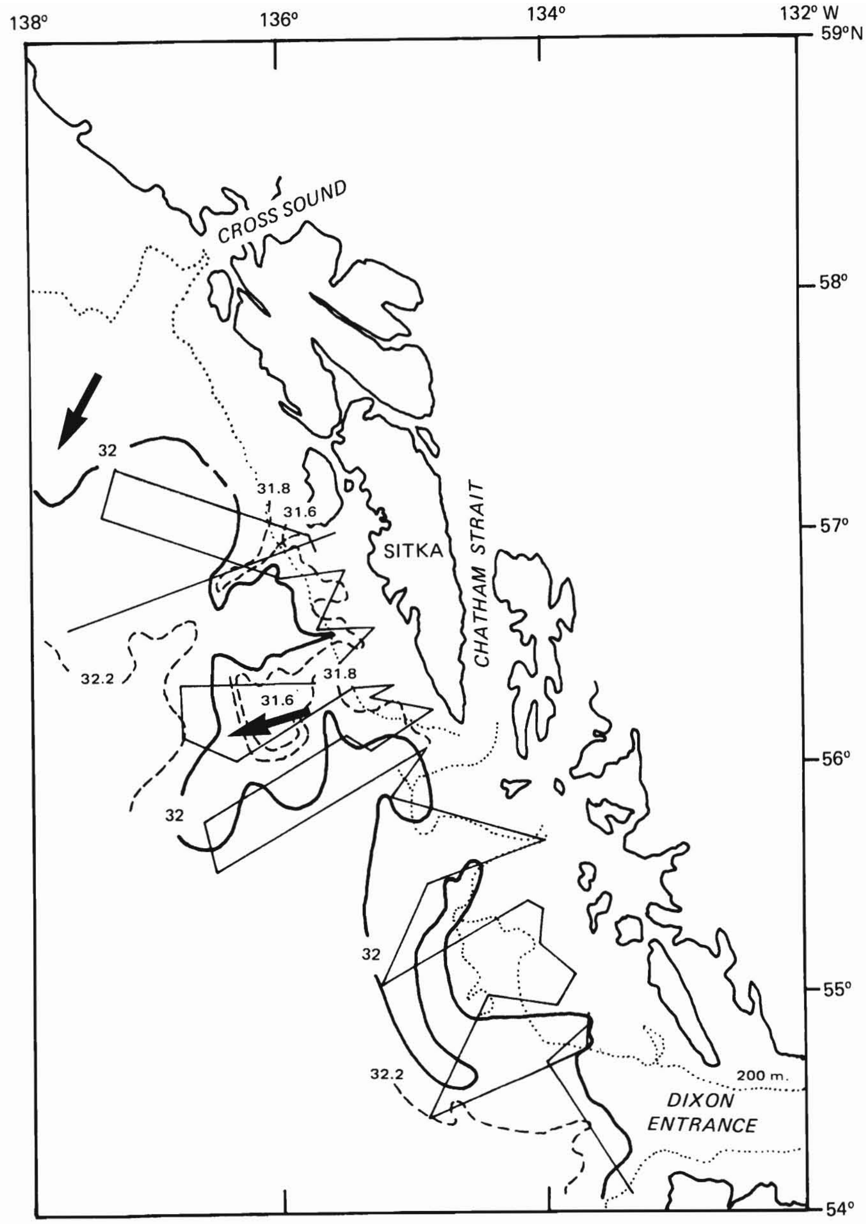

Figure 2.—Surface salinity (‰) taken from NOAA RV *Miller Freeman,* 25-30 August 1978, and cruise tracks along which continuous salinity measurements were made. Arrows indicate the probable direction of movement of the major sources of dilution into the offshore area.

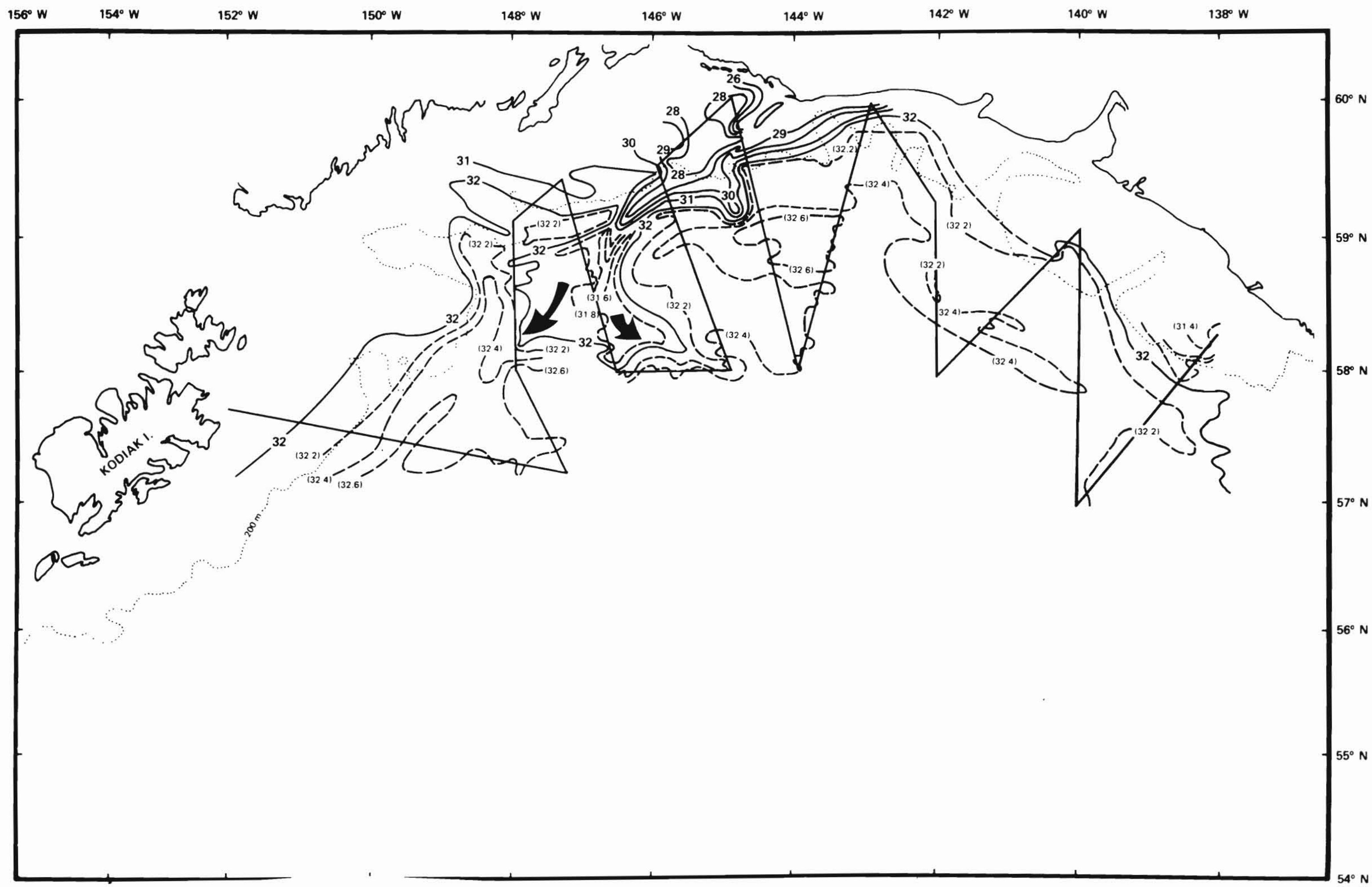

Figure 3.—Surface salinity (‰) taken from NOAA RV *Miller Freeman*, 1-6 September 1978, and cruise track along which continuous salinity measurements were made. Arrow indicates the probable direction of movement of the major sources of dilution into the offshore area.

evident. The predominant features along the southeast coast are the saline offshore water (>32.2‰) and tongues of dilute water (<32.2‰) which protruded as much as 135 km into the oceanic water from two major sources of dilution, Chatham Strait (near lat. 56°N) and Cross Sound (near lat. 58°N).

Much small detail is evident by the continuous sampling in the range of 0.1-0.2‰). Offshore minima were present where the seaward tongues were either cut off by mixing or turned with the flow beyond the shelf; but no continuous, alongshelf band of salinity minima was evident. Normal oceanic salinities >32.5‰were not encountered along any of the cruise tracks off southeastern Alaska.

Observations at the head of the gulf, the area of prime interest, were obtained by requesting a 3-day delay in the scheduled arrival of the *Miller Freeman* at Kodiak. Data were obtained from 1 to 6 September 1978 along 2,780 km (1,500 miles) of continuous zig-zag tracklines at a speed of 13 knots as the vessel was enroute (Fig. 3). Hourly water samples were taken and analyzed aboard ship with a precision laboratory salinometer (Autosal[3] 8400) and salinity and temperature values were digitized from the traces by hand to show linear trends and peaks on a 5-15 minute interval (about every 2-6 km). The analysis of these data, probably the most detailed and synoptic surface salinity record for the area, revealed several interesting features.

Along the northeast coast the trend of the isohalines was generally parallel to the shoreline apparently reflecting alongshore processes in the absence of major freshwater sources. The dominant feature is the seaward penetration of the low salinity (31.6‰) plume from the Copper River area extending 80 km south of the shelf break well into the oceanic regime of high salinity (>32.6‰) water.

[3]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

In July 1977 this plume was confined largely to the shelf area westward of the river mouth. The sharpest frontal zone (a change of 2-4‰) occurred at the head of the gulf; downstream to the southwestward both minima and maxima were evident along the shelf break. The seaward terminus of the plume reflects an anomalous eastward movement in the proximity of the Alaskan Stream, a narrow, high velocity (50 to 100 cm/second) boundary current which is known to flow in a southwesterly direction along the continental slope area. As evident in data from other years, intense mixing and stirring at the surface just east of Kodiak Island (lat. 58°N, long. 148°W) has largely eradicated most of the dilute plume south of lat. 58°N.

Unfortunately vessel-time limitations did not permit steaming far enough into the central portion of the gulf to adequately define the offshore features; however, fortunately, additional data from the University of Alaska research vessel *Acona* and from the NOAA research vessel *Oceanographer* obtained during the same time period, were made available to us (Fig. 4A). The former permitted clarifying distributional patterns at the head of the gulf; the latter provided evidence of a seaward extension of dilute water from the eastern side of the gulf at lat.56°-57°N to long. 143°W where it terminated at a salinity front oriented in a north-south direction.

Normal cyclonic circulation in the gulf would indicate that the dilute water of salinity<32.2‰ should have merged with the eastward component of the Copper River plume by fall. Whether the resulting water mass would eventually move northward to the head of the gulf before turning southwestward or turn westward near lat. 58°N, it is obvious that both sources will contribute to the offshore salinity minima east of Kodiak on a year-round basis.

Although surface temperature information is the most readily attainable data base to investigate ocean conditions and anomalies (e.g., the data are easily measured from an instrumentation standpoint, routinely collected by most vessels, and now supplemented by gradient information in cloud-free areas of infrared satellite photos), it is strikingly apparent (Fig. 4B) that neither of these sources of dilution nor the patterns of flow suggested by them are as clearly evident in the temperature distribution.

One feature readily apparent nearshore between lat. 56° and 57°N at the eastern side of the gulf is the colder (2-4°C) water associated with snowmelt and runoff; but, perhaps, more significant is the extensive seaward protrusion of the 14°C isotherm in this area that is similar to the 32.2‰ isohaline. Nevertheless, in the offshore area, there is only about a 1°C change across the entire gulf with the eastern gulf being generally warmer. Further, if one accepts the significance of 0.5°C temperature differences, the warm (>14°C), southward protruding tongue offshore in the northern gulf at long. 146°W, which occurs at the eastern side of the area of the offshore salinity minima, appears to support the idea of an eastward flow of Copper River dilution near lat. 58°N as suggested earlier. Finally, the possibility of the trans-gulf band of 14°C water near lat. 58°30'N being a harbinger of a trans-gulf salinity minima band is intriguing.

Discussion

The question of the existence and nature of the offshore salinity minima area across the head of the gulf and the mixing and merging area near lat. 58°N at the western side of the gulf is not completely resolved and will require more intensive observations along even more closely spaced tracklines and repeated surveys from month to month. Certainly the data presented indicate that the offshore salinity minima area eastward of Kodiak Island represents a convergence of surface water from two distinct sources but at times only one of these sources may be represented.

Now that presence of this surface feature has been clearly established, it is easy to find evidence of it in previous data, which in most cases were too fragmentary to justify assuming the extensive continuity that apparently exists. (It should be pointed out that such data were obtained largely to define large-scale features of oceanic circulations in the eastern Pacific Ocean.) For example, data for 19 July to 11 August 1958[4] (Fig. 5) reflect surface salinity minima in several lines of data normal to the coast at the head of the gulf that is not evident on the map of surface salinity presented in Dodimead et at. (1963:133) because of isoline intervals and map scale. Further, this feature can also now be detected in data for 22 May to 10 June 1961[5] off Kodiak Island and other more fragmentary data sources. Although the overall patterns of surface salinity are markedly different, the presence of the band of offshore salinity minima is readily apparent.

A schematic of the effect of the annual cycle of dilution is presented with likely locations by season of the extent of dilute water (Fig. 6). During spring the initial movement offshore occurs at sites of extensive runoff. In summer, spring dilution has extended farther offshore in the eastern gulf with some contributions from the south. By fall, runoff sources are diminishing with the advent of freezing, and dilution that entered the area from the southeast is traversing the gulf, while spring and summer dilution from the eastern gulf has reached the eastern Kodiak mixing area. Here, overturn and mixing produce high salinities on the shallow shelf areas—thus the offshelf minimum is most pronounced.

Finally, in winter there are no major sources other than a general area

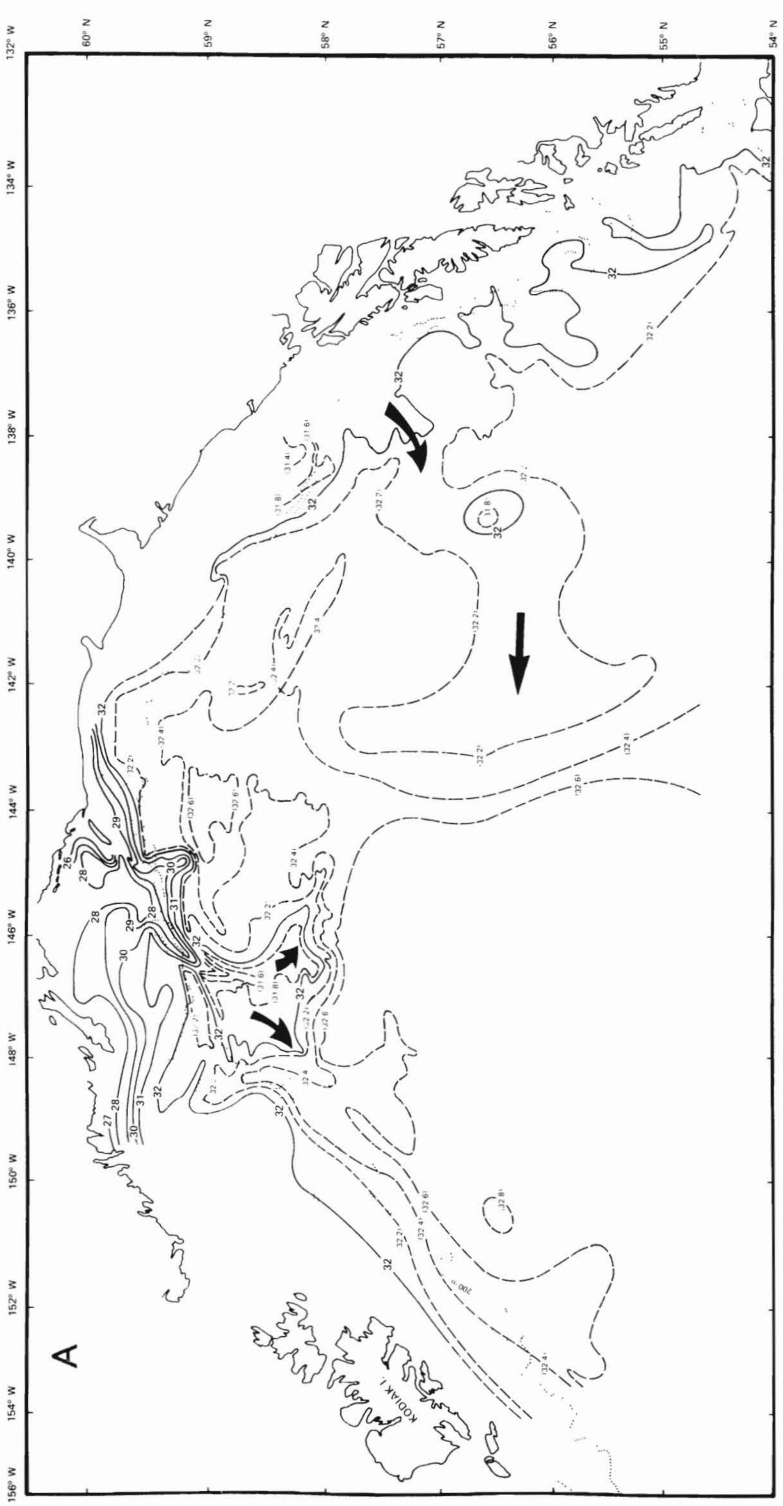

Figure 4A.—Surface salinity (‰) taken from NOAA RV *Miller Freeman*, 25 August-6 September 1978, and stations where data from the University of Alaska RV *Acona*, Korean RV *Oh Dae San*, and NOAA RV *Oceanographer* were obtained. Arrows indicate the probable direction of movement of the major sources of dilution into the offshore area.

[4]Pacific Oceanographic Group. 1958. Physical and chemical data record North Pacific surveys continental shelf and Gulf of Alaska July 22 to August 16, 1958. Fish. Res. Board Can., Manuscr Rep. Ser., Oceanogr Limnol 29, 107 p. + append

[5]Dodimead, A. J., F M Boyce, N K Chippendale, and H J Hollister 1961. Oceanographic data record North Pacific surveys May 16 to July 1, 1961 Fish Res. Board Can., Manuscr Rep. Ser., Oceanogr Limnol 101, 337 p.

contribution from precipitation at sea which is not considered. Mixing is increased both vertically and horizontally but spring and summer dilution from the eastern side of the gulf is still sufficient to maintain a remnant of the trans-gulf salinity minima area. This suggests year-round convergence in the offshore band of salinity minima and divergence in the band of salinity maxima that occurs shoreward of the minima at the head of the gulf.

Relations to Fisheries

For over half a century fishery biologists have been trying to ascertain how Pacific salmon, *Oncorhynchus* spp., find their way in the ocean. Although the extensive INPFC studies have fairly well documented the oceanic distribution of various species, little is known about seaward migrations of smolts or shoreward migrations of adults. The available evidence indicates that the seaward migration path of nearly a billion juvenile sockeye salmon, *O. nerka*, in the Vancouver Island-Queen Charlotte Sound area is northward along the coast and around the Gulf of Alaska to the Kodiak Island area, where they diffuse into the oceanic regime.

Since downstream migrations occur as snowmelt and runoff commence or peak, it is reasonable to assume that salmon, particularly the sockeye, could have some affinity to river plumes and remain within their influence as long as possible. This would suggest that seaward migrants from the above area move offshore and into the central gulf south of southeastern Alaska, thereby avoiding not only the necessity of intermingling with stocks in the northern areas, but also the encounter of seaward discharges and associated water characteristics of innumerable other coastal streams.

Perhaps most significant is the fact that such a migration path would serve to isolate these salmon from the juvenile sockeye salmon from the Copper River until the latter had entered the oceanic regime.

Keys to shoreward migrations are

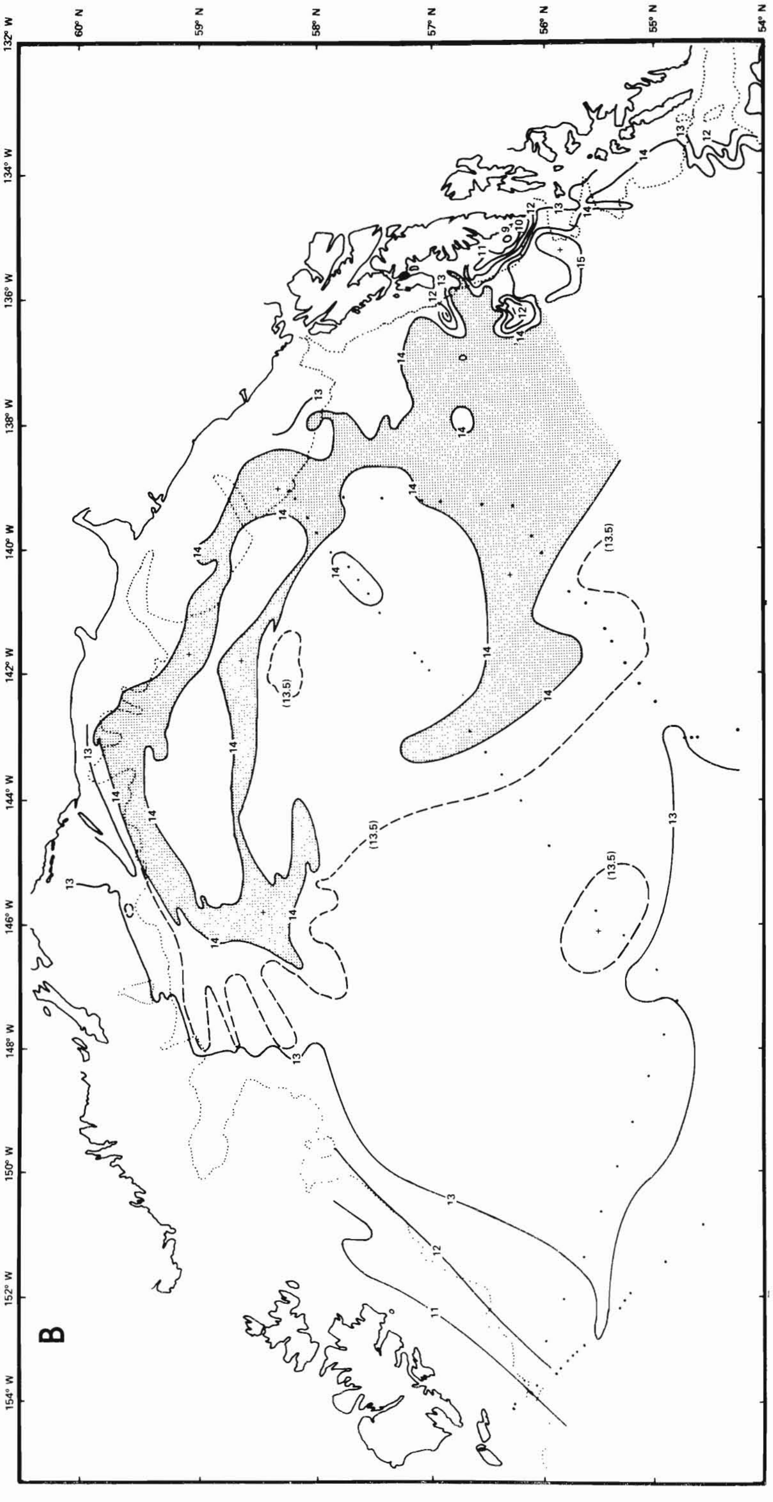

Figure 4B.—Surface temperature (°C) taken from NOAA RV *Miller Freeman*, 25 August-6 September 1978, and stations where data from the University of Alaska RV *Acona*, Korean RV *Oh Dae San*, and NOAA RV *Oceanographer* were obtained.

complex because widespread ocean migratons involve environmental considerations from a wider area than considered here; however, the data presented here indicate for the first time that salmon returning to the Copper River can find strong clues to the river discharge over 200 km seaward of the river mouth. As a result of this, studies on the oceanic distribution and migration of salmon in this area should no longer be undertaken without extensive knowledge as to immediate location of seaward extensions of coastal or river plumes.

Obviously it is difficult to relate surface phenomenon to behavior of groundfish, although it can be shown that surface manifestations of subsurface flows are common, i.e., upwelling wherein offshore transport of surface water by winds requires replenishment of mass from subsurface water along the coast. This causes an inshore flow at some point along the sea floor that is subsequently readily apparent at the surface in lower sea surface temperatures. However, those species of bottomfish having pelagic eggs and larvae can be greatly affected by surface conditions.

Pacific halibut, *Hippoglossus stenolepis,* for example, have two known major spawning grounds: 1)South of Queen Charlotte Island, and 2)off Yakutat. Eggs deposited off the shelf at depth, 200 m or greater, in winter rise to the surface layer in spring. Larvae, whose survival is dependent on settling out of the water column in coastal areas, are at the mercy of surface currents during spring and summer.

Heretofore, it has been assumed that the general surface winds and cyclonic flow in the gulf have provided mechanisms wherein surface transport along the coast has been shoreward, thereby contributing to, if not responsible for, the successful survival of halibut larvae. Obviously evidence presented here indicate some mechanisms that are not conducive to the

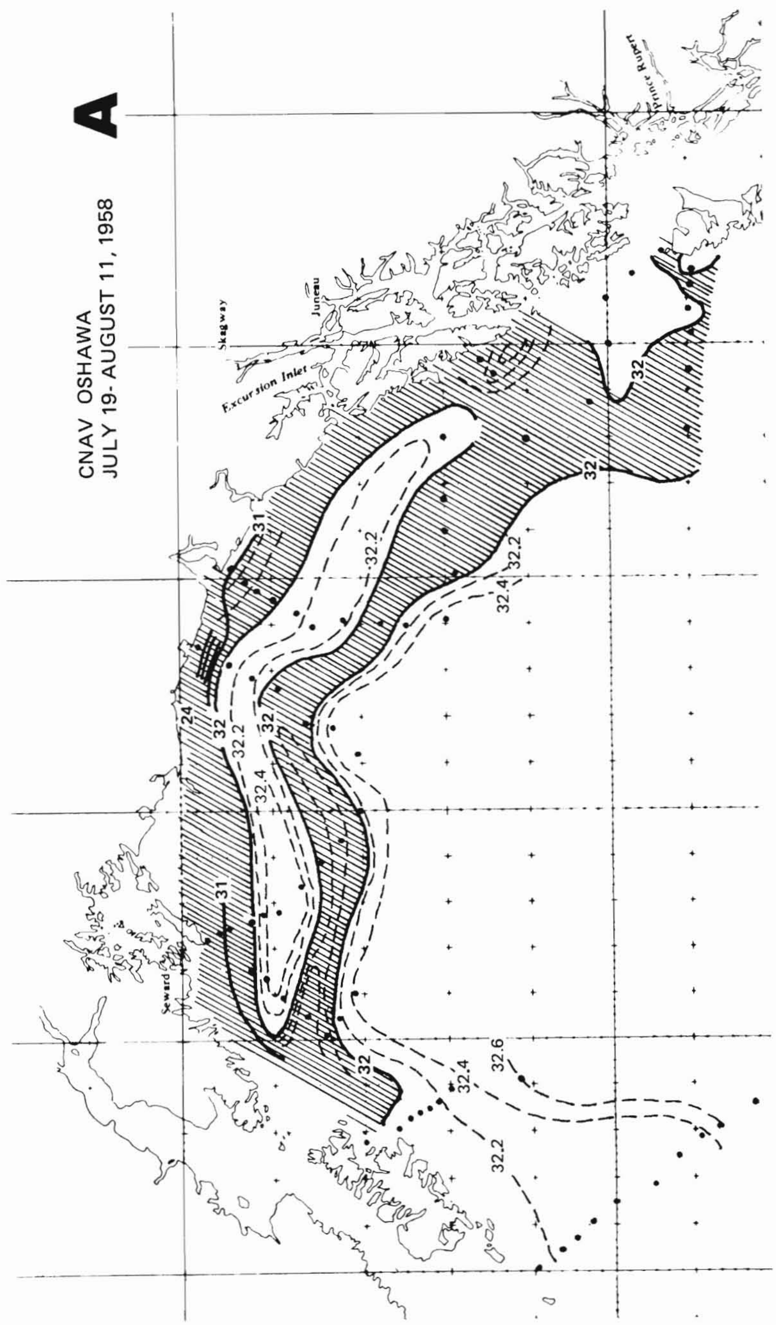

Figure 5A.—Surface salinity (‰) taken from Canadian RV *Oshawa*, 19 July-11 August 1958, and stations where salinity data were obtained.

survival of the larvae and must be considered in any study of this species, or other groundfish species with similar early life stages. One can easily extend these remarks to concur as to the ultimate fate of larvae of decapods such as king crab, *Paralithodes camtschatica,* and snow crab, *Chionoecetes* spp., and pandalid shrimp which are also abundant along this stretch of coastline.

Finally, it should be obvious that any hydrodynamic-numerical or other circulation or water transport models developed by OCSEAP and other groups to forecast or to ascertain the ultimate fate of pollutants from potential oil drilling sites in this area, must include aspects of all the conditions and processes associated with the year-round occurrence and variability of this phenomenon.

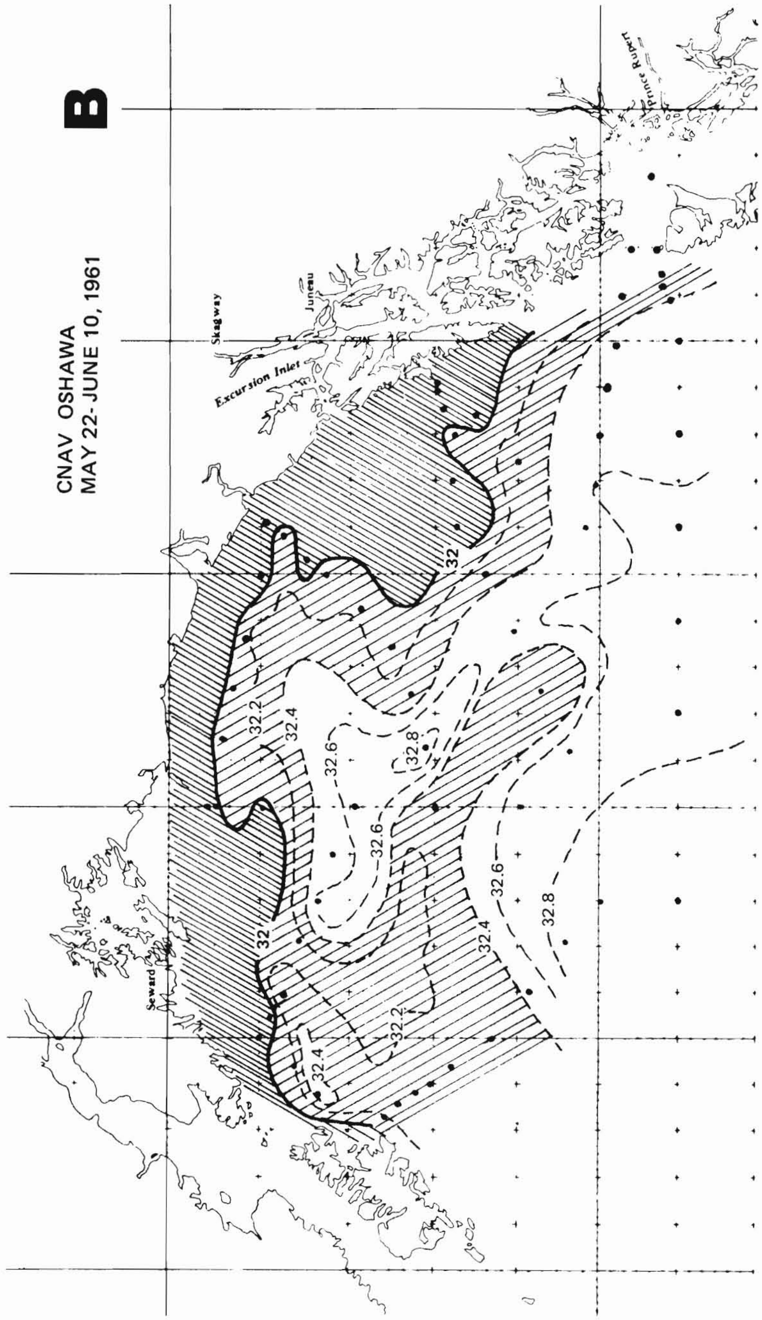

Figure 5B.—Surface (‰) taken from Canadian RV *Oshawa*, 22 May-10 June 1961, and stations where salinity data were obtained.

Acknowledgments

I thank Felix Favorite, NWAFC Resource Ecology Studies Coordinator, for instigating this study; Kim Yeon-Hwan, Korean Fisheries Research and Development Agency, for surface water samples from the *Oh Dae San*; Henry J. Niebauer from the Institute of Marine Sciences, University of Alaska, and Ronald K. Reed from the National Oceanic and Atmospheric Administration, Pacific Marine Environmental Laboratory, for data from the *Acona* and *Oceanographer,* respectively; Robert L. Charnell, Pacific Marine Environmental Laboratory for access to OCSEAP cruise data; and Roger E. Pearson of NWAFC for editorial comments.

Literature Cited

Chevigny, H. 1965. Russian America. The Viking Press, N.Y., 274 p.

Davidson, G. 1869. Report of assistant George Davidson relative to the resources and coast features of Alaska Territory. U.S. Coast Survey Report 1867. App. 118, U.S. Gov. Print Off., Wash., D.C., p. 205.

Dodimead, A. J., F. Favorite, and T. Hirano. 1963. Salmon of the North Pacific Ocean. Part II. Review of oceanography of the Subarctic

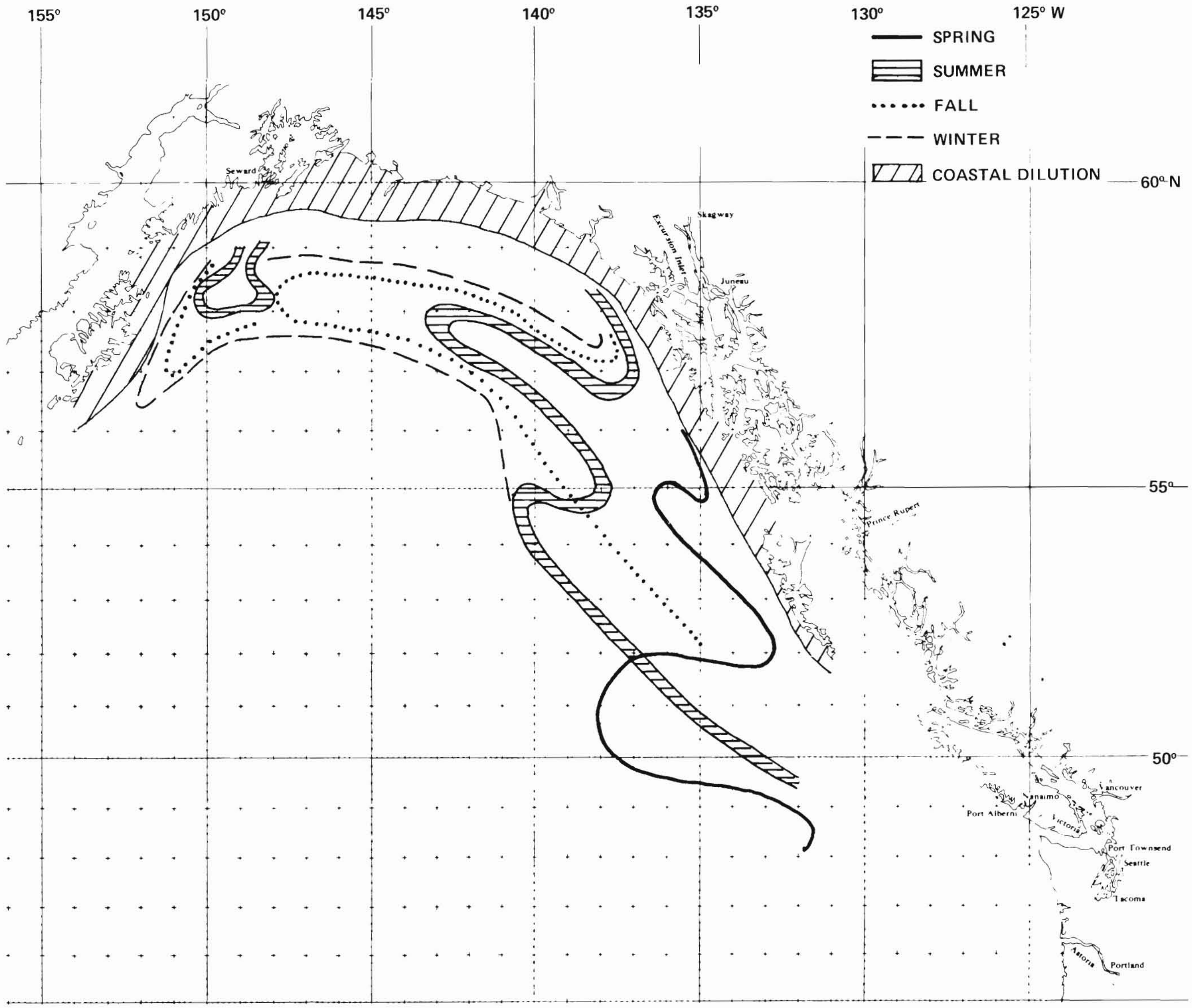

Figure 6.—Schematic diagram of the seaward extent of the major effects of coastal dilution by season.

Pacific Region. Int. North Pac. Fish. Comm., Bull. 13, 195 p.
Doe, L. A. E. 1955. Offshore waters of the Canadian Pacific coast. J. Fish. Res. Board Can. 12:1-34.
Favorite, F. 1961. Surface temperature and salinity off the Washington and British Columbia coasts, August, 1958 and 1959. J. Fish. Res. Board Can. 18:311-319.
________, A. J. Dodimead, and K. Nasu. 1976. Oceanography of the Subarctic Pacific Region, 1960-71. Int. North Pac. Fish. Comm., Bull. 33, 187 p.
________, and W. J. Ingraham, Jr. 1977. On flow in northwestern Gulf of Alaska, May 1972. [In Engl.] J. Oceanogr. Soc. Jpn. 33:67-81.
McEwen, G. F., T. G. Thompson, and R. Van Cleve. 1930. Hydrographic sections and calculated currents in the Gulf of Alaska, 1927 and 1928. Rep. Int. Fish. Comm. 4, 36 p.
Muench, R. D., H. O. Mofjeld, and R. L. Charnell. 1978. Oceanographic conditions in lower Cook Inlet: spring and summer 1973. J. Geophys. Res. 83:5090-5098.
Royer, T. C. 1975. Seasonal variations of waters in the northern Gulf of Alaska. Deep-Sea Res. 22:403-416.
________, and R. D. Muench. 1977. On the ocean temperature distribution in the Gulf of Alaska, 1974-1975. J. Phys. Oceanogr. 7:92-99.
Fleming. 1942. The oceans: their physics, chemistry, and general biology. Prentice-Hall, Inc., N.Y., 1087 p.
Thompson, W. F., and R. Van Cleve. 1936. Life history of the Pacific halibut. (2) Distribution and early life history. Rep. Int. Fish. Comm. 9, 184 p.