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FISHERIES RESEARCH BOARD OF CANADA

ANNUAL REPORT

of the

PACIFIC OCEANOGRAPHIC GROUP

NANAIMO, B.C.

for

1959

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J. P. TULLY, Oceanographer in Charge

(WITH INVESTIGATORS' SUMMARIES AS APPENDICES)

NANAIMO, B.C.

FEBRUARY 3, 1960

FISHERIES RESEARCH BOARD OF CANADA

Pacific Oceanographic Group
Annual Report - 1959

INTRODUCTION

This Group undertakes oceanographic observations and research in the eastern sub-Arctic Pacific Ocean, north of latitude 40° N and east of longitude 160° W. This is the area of immediate concern, because it is the ocean pasture of Canadian fish, and is the Canadian defence zone. United States agencies work to the south in the sub-Tropic Ocean, to the west in the Aleutian Islands and the Bering Sea. Japanese agencies work further to the west. Together these three nations provide regular and co-ordinated coverage of the whole North Pacific Ocean.

The objects of this Group are:

- (a) To describe oceanographic conditions quickly and accurately, while they still exist in Nature.
- (b) To provide records of the oceanographic conditions for climatological type studies.
- (c) To forecast oceanographic conditions.

The primary requirements are:

- (a) A comprehensive program of observations in Nature.
- (b) Rapid processing and distribution of the data for analyses and interpretation by all agencies.
- (c) Formulation of models of oceanographic mechanism by which the data can be rapidly interpreted.
- (d) Delivery of oceanographic information to Canadian users, in terms which they can understand and which are suited to their purposes.

The Group is part of the Biological Station at Nanaimo, which is the headquarters with offices, laboratories, administration, etc. However, the work of the Group serves the National requirement for Oceanography on the Pacific Coast. Hence it is closely co-ordinated with other Government Departments and Agencies through the Canadian Joint Committee on Oceanography.

The Royal Canadian Navy provides and operates two research ships C.N.A.V. "Whitethroat" and C.N.A.V. "Oshawa", for joint use by Pacific Naval Laboratory of Defence Research Board, the Institute of Oceanography of the University of British Columbia, and this Group. These vessels are programmed and allocated by a Ship's Committee of the three research groups.

The following Summary of Research deals only with the high lights of progress during the past year. The detail and scope of the work of this Group are given in the appended Summary Reports, written by the investigators.

SUMMARY OF RESEARCH

The area of interest is the sea region north of latitude 45° N and east of longitude 170° W. The level of sea effort, and the analysis and reporting of data has been maintained throughout the year. In addition a number of models of oceanographic state and mechanism, based on the data, have been described. This latter phase, interpretation of the data, is receiving increasing attention.

Oceanographic observations. As usual a winter survey (January 15 to February 16) was carried out with one ship, in the ocean area north of latitude 47° N and east of longitude 154° W. A summer survey (August 1-31) was carried out with two ships in the area north of latitude 38° N and east of longitude 157° W. These recorded the extremes of winter and summer conditions from the surface to more than 2000 metres depth. The monitoring

and research program of intensive observations through alternate six-week periods at Ocean Station "P" (Lat 50° N, Long 145° W) begun in 1956, have continued through the year. In addition serial observations, from surface to 1000 metres depth, were made at six positions en route from the coast to the Station, and return. During the past three years, 34,000 drift bottles have been released in lots of 500 to 1000 in various parts of the area to reveal the surface drift.

In the coastal approaches and inland seaways there have been three monitoring surveys (March-April, June, and November), each of one month's duration. Daily observations of seawater temperature and salinity at 14 positions on the British Columbia coast have been continued.

The data from each of the surveys have been processed by a digital computer and published (150 copies) in the Manuscript Report Series, within a few weeks of the conclusion of each sea operation. The data from Ocean Station "P" are published semi-annually, and the data from the coastal daily seawater observations are published annually. In addition, on-the-spot assessments of the data are circulated (60 copies) to interested agencies immediately following each cruise. Sometimes data are reported by radio and circulars, issued while the ships are still at sea. The daily seawater observations are summarized in weekly radio broadcasts, in monthly circulars, and provided for the monthly sea surface temperature charts issued by the Pacific Oceanic Fisheries Investigation at Honolulu.

Despite these efforts the density of observations in space and time is still extremely low. Over most of the area the behaviour of the ocean must be inferred from 2 to 3 observations a year. Meteorology, the corresponding science in the atmosphere, enjoys several simultaneous observations a day from a global network of stations. The disparity in data explains, to some degree, the disparity of progress between the sciences. However, despite the limitation of the data some knowledge has been gained about the

average structure, properties of the water, mechanism, and behaviour, and something about the variations that occur from year to year. In addition new techniques are envisioned and in development to amplify the data, and provide more knowing analyses.

Oceanic data collected during the past decade have been examined from several standpoints. Professor M. Uda of the Tokyo University of Fisheries, spent eight months examining all available survey data observed by Japanese, United States, and Canadian agencies, from 1952 through 1958, in the Bering and Ohkotsk Seas, and the Pacific Ocean northward of latitude 30° N. He has described and illustrated the principal features of structure, properties of the water, and mechanisms. This monograph, now being prepared for publication, will provide the first overall discussion of the area since the publication of "The Oceans" in 1942. It is considerably more complete, and will provide a much needed basic reference for all subsequent studies of particular features and localities in the sub-Arctic region.

Ocean circulation. The basic features of surface circulation have been known for many years. The west wind drift current flows across the ocean between latitudes 40° and 50° N. As it nears the American coast it divides; part turns south to form the California Current, and part turns north moving in a slow counter-clockwise gyral around the Gulf of Alaska. Recently the volume transport of the gyral has been determined to be about 16 million cubic metres per second, with surface velocities of 2 to 5 miles per day.

The circulation is not observed directly, but is inferred from the distribution of density. This relative geostrophic transport, calculated from the semi-annual survey data, assumes that the ocean flows are steady. The short term deviations are not recognized, although they are known to exist, and to be associated with the winds. The importance of such varia-

tions may be illustrated.

It appears that the point of division of the west wind drift shifts from time to time. When it shifts southward, the volume transport around the Alaska gyral increases, and warmer than usual water is swept northward past the Canadian coast. Such a situation developed through 1957, reached a maximum late in 1958. This diverted and delayed the homing migration of Sockeye salmon to the Fraser River. This feature was monitored by sea observations at approximately six week intervals through 1959, and by daily observations along the coast. The anomaly waned into the spring, waxed into early summer, and vanished in later summer. The surface temperatures decreased to the level observed in 1956, although the heat content of the deeper waters (100 to 200 metres) was similar to 1958. This phenomenon is attributed to variation in the wind pattern over the whole Pacific Ocean.

It has become increasingly apparent that it is necessary to know the volume transport of the currents in the area of interest, and the short term (monthly) variations in this transport. This could be evaluated from observations in Nature, only if there were monthly surveys over the whole ocean north of latitude 20° N. Such an undertaking is beyond the total resources of all the oceanographic agencies in the area.

Computations of these induced currents show that many features of observed oceanic circulation can be explained on the basis of winds. Apart from their direct effect in generating surface waves and mixing the surface layers, the winds exert a tangential stress on the sea surface causing shallow currents. However, the stress is not uniform over the ocean surface, hence there are accumulations and depletions of surface waters in various parts of the ocean. These induce pressure gradients which penetrate the depths of the ocean and cause flow in the deep water.

However, winds are variable in both space and time. Therefore it is necessary to know the time-dependent response of the ocean. So far,

knowledge of these processes is based on theoretical studies. Progress is slow because the low frequency response of the ocean is adequately described only by non-linear differential equations, and its oscillations cannot be broken down into simple modes. The labour involved in solving the equations far exceeds the capability of manual computations, hence it has not been done heretofore.

Recently the problem has been reconsidered. The theory relating barometric pressure to the wind stress over the ocean and thence to the water transport at all depths was reviewed. Then using the monthly average barometric pressures (which are published by the U.S. Weather Bureau) equations were produced defining the resultant transport. These were put into form for calculation on the Alvac III-E digital computer at the University of British Columbia.

These calculated total transports have two important features. First when they are compared to the relative geostrophic transport, calculated from the semi-annual survey data, the difference represents the short term deviations which are not recognized in the latter. Secondly, they are tantamount to a monthly synoptic assessment of transport which reveals the variations in a detail never before considered possible.

Each computation is accomplished in 12 minutes on the computer. The total computation of five years data (1955 through 1959) required about 10 hours machine time. It is conservatively estimated that manual calculation, using a desk calculator would require at least 5 man-years. This is a major advance in oceanographic research technique, because it allows utilization of data and theories which could not be economically calculated by manual methods.

Seawater structure. In the sub-Arctic Pacific, precipitation exceeds evaporation, and the fresh water accumulates to some extent, forming a low salinity upper zone, (0-100 m) separated by a halocline (100-200 m).

from the deep waters. The presence of a halocline distinguishes the sub-Arctic waters from sub-Tropic waters, which have no halocline. The sub-Arctic boundary curves from latitude 45° N off Japan to latitude 50° N in mid-ocean, to latitude 40° N off America. In the sub-Arctic, the upper zone and halocline contain about 1.8% fresh water (3.6 metres mixed with sea water to 200 metres depth). This is equivalent to about six years accumulation of precipitation and land drainage. These zones are dissipated into the sub-Tropics, largely in the California Current where the fresh water is removed by evaporation. The salt content of the upper zone and halocline throughout the sub-Arctic is maintained by entrainment of sea water from the lower zone at an average rate of about 20 metres per year. Hence there is a net inflow of deep water into the region. The sub-halocline water masses in the sub-Arctic are similar to, and continuous with the deep water in the sub-Tropics.

The limit of downward mixing due to wind is marked by the upper limit of the thermocline in summer (10-20 metres). The thermocline migrates downward and degenerates through the cooling season (autumn and winter) until the water becomes isothermal and isohaline to the halocline (80-120 m). The warming during the following spring and summer do not extend to this depth. Hence the extreme of winter conditions are preserved at the upper limit of the halocline, and may be observed during the following summer. This feature has been demonstrated by comparison of winter and summer data from the eastern sub-Arctic, and applied to indicate winter conditions in the central and western sub-Arctic, where only summer data are available.

The lower limit of the halocline is the limit of downward transfer of fresh water. Hence it marks the absolute limit of downward mixing from the surface by all causes (internal shear, diffusion, etc.) On this surface the only transfer is entrainment which is uni-directional upward.

Several features of the structure have become evident in the time series observations at Ocean Station "P" (Lat 50° N, Long 145° W). In summer the surface temperature structure above the thermocline (10-30 m) varies from a marked gradient to isothermal in periods of a day or less. The variation is not simply correlated to wind force, except under storm conditions. Further, there is evidence to show that there are patches where the surface temperature is one to three degrees warmer than the general surface temperature. It is probable that the usual isothermal layer is associated with the cooler water. In this background there are patches of warm water associated with an appreciable temperature gradient in the surface layer. Such situations would result from the variation of cloud cover and wind force from place to place in the sub-Arctic. As the surface waters drift past the Ocean Station it would appear that the structure varied with time.

The stability of the deep water in and below the halocline has been demonstrated. Since last January there has been a core of cold water (4.5°) a short distance west of Station "P", and a warm body (5° C) close by to the east. These water masses have moved less than 20 miles during the past three months. Recently the currents at these depths were traced with parachute drogues. They were observed to move in a clockwise circle with a net advance of less than one mile a day.

The data from consecutive lines of stations, observed every six weeks, between Station "P" and the coast were compared. During the six weeks it was found that the temperature had increased and decreased in alternate patches. During the next six weeks, the patches were similar but the sign of the variation was reversed.

Heat budgets. Neglecting any heat transfer from the Earth through the bottom of the ocean, which is very small, the ocean receives practically all its heat from solar radiation. About half this energy is visible or

ultra-violet light. The remaining half is the infra-red radiation, is absorbed in the surface few centimetres of the ocean, and is the source of heat.

The mean amount of solar radiation over periods of a month or more, can be estimated by the use of various empirical formulae involving a knowledge of latitude and cloud cover. However, for precise work it is necessary to make direct measurements with pyroheliometers. Such instruments have been installed at Vancouver (University of British Columbia) at Nanaimo, and on the Weathership (Ocean Station "P").

The ocean loses heat to the atmosphere mainly by long wave radiation and evaporation. Conduction is of lesser importance. Radiation losses can be measured by special pyroheliometers, sensitive in the infra-red. However, the conduction and evaporation losses can only be evaluated by empirical formulae, depending on the difference between sea and air temperatures, and the gradient of wind velocity above the sea.

It is possible, in principle, to compute "budgets" of heating and cooling for selected bodies of water, if sufficient observations can be made. Such calculations are still comparatively rare, but have been made at several coastal locations, and at Ocean Station "P". When the calculated heat budget coincides with the observed changes of heat content in the sea, it may be concluded that the principal ocean currents are along the latitudes, i.e. from west to east. If the heat content of the water is greater than calculated, it implies an intrusion of warm water from the south, conversely, the occurrence of "colder than expected" water indicates an intrusion from the north.

During the past year at Ocean Station "P" there is evidence of an intrusion of cold water from the cold centre in the Gulf of Alaska. This suggests a degree of re-circulation in the Alaska Gyral. Near the Canadian coast there is evidence of a northward intrusion of warm water. However,

this is much less than was observed in 1958, and has waned considerably through 1959.

Inland seaways. Tides present a serious complicating factor in the study of the coastal and inland seaway regions. Hourly observations at fixed positions and repeated observations of tidal sections during the ebb and flood phases have revealed the extent and nature of tidal variations of structure and currents. During the new and full moon the tidal currents and consequent mixing are greatest. The halocline becomes less distinct and the surface salinity increases. In summer the temperature gradient in the thermocline decreases and the surface waters are cooled by mixing with sub-thermocline water. In winter, when the surface waters are colder than the deep waters, the mixing results in a rise of surface temperature during these periods of maximum tidal mixing.

In straits, where the tidal flow is essentially reversing, the excursion of the tide varies with the lunar phase cycle. However, the net transport varies with the run-off. A model of estuarine structure and net transport has been developed and applied in a detailed study of Juan de Fuca Strait.

In the more open seaways, where rotary tidal currents prevail, there is a net circulation due to the Coriolis effect on the tidal movements. These are too complex for observation in Nature, or purely theoretical analyses. A hydraulic model has been built to define the purely tidal circulation in the Hecate region, between Queen Charlotte Islands and the Mainland. This model is 100 feet long by 40 feet wide, representing an area 250 miles long by 100 miles wide. Tides are generated by oscillating partitions in the two ocean approaches. These are controlled, and the tides monitored, by sophisticated electronic systems. The currents and paths of flow are recorded by sequence photographs of dye patches and floats. Run-off and natural stratification can be simulated by the use of fresh and sea water, and a flushing system designed into the model. The model is in

operation, and data are being collected and compared with previous observations in the prototype in Nature.

Primary productivity. As on land, all life in the sea is sustained by the photosynthetic production of plant material, using solar radiation and the abundant supplies of carbon dioxide found in all sea water. The amount and rate of production of plant substance must govern the overall food potential of any sea area.

Plant life is only possible in the upper few metres of turbid inshore waters, or in the upper fifty to one hundred metres of clear ocean waters, where there is sufficient solar radiation for photosynthesis to exceed respiration. A review of the role of light in marine primary productivity is being published in the Board's Journal.

The photo synthetically active region of the solar spectrum coincides roughly with the visual range. All wavelengths are about equally efficient on a quantum basis, although red light has more quanta for a given amount of radiation energy than the shorter wavelengths. Because of the thermodynamics of the process, the quantum efficiency of photosynthesis cannot exceed 25 percent, and even half this efficiency is difficult to realize in practice. In the sea, the overall conversion of solar energy does not exceed a few tenths of a percent. It now appears that the photosynthesis of sugar, fat, and protein formation are driven by the photochemical production of high energy phosphorus compounds and complex organic reductants. Evidently the process is the reverse of the better known respiration and fermentation found in living organisms.

The main problems are to measure the amount of phytoplankton in the water, both living cells and detrital matter, to measure the rate of photosynthesis, and to predict the growth factors (mainly nutrients and light) that decide the primary fertility of a given sea area.

The concentrations of all substances to be measured are exceedingly

low. The weight of organically combined plant carbon rarely exceeds half of one part per million in the sea water. The nutrients responsible for this plant growth (mainly nitrogen, phosphorus, and certain metallic growth promoters) occur in similar concentrations. Advanced micro-techniques are required. Each method must be practical in the hands of a sea-sick person, working in a cold laboratory, that may be swaying twenty degrees or more from the vertical. Despite these severe limitations, most of the assaying of sea water for plant nutrients has been perfected. In addition the amount of suspended plant cells, and their protein, carbohydrate, fat, and other food potential are determined regularly. Preliminary publication of these methods has been made in the Manuscript Report Series (300 copies) which is already out of print. Formal publication is being made in a Bulletin of the Fisheries Research Board, which may well become an accepted text book.

The study in the sub-Arctic Pacific reveals at least three main areas of different growth pattern. In the open ocean, the crop is comparatively low although the rate of growth is vigorous. Examination at Ocean Station "P" showed that the concentration was limited by zooplankton grazing. At inshore locations, grazing affects the crop in an erratic fashion. Much of the growth there depends on the winds that alternately allow plant cells to thrive in a stable upper layer, or disperse them by vigorous mixing with the deep, sub-euphotic waters. Finally, in the inland seaways, the plants completely strip the nutrients from the water in the stable upper zone. This is not re-charged until the thermocline is destroyed by autumn cooling, and deep fertilizer-rich water is mixed toward the surface by the strong winter winds. Light is rarely a limiting factor except in the periods of extreme cloud cover in late autumn and early spring. In these seasons the cessation or onset of plant growth is governed by the radiation pattern.

A review of the role of light in the sea, and the research and state

of knowledge on primary productivity throughout the world are being published in Bulletins of the Fisheries Research Board.

LIST OF SEA OPERATIONS - 1959

<u>Survey</u>	<u>Period of Operation</u>	<u>Ship</u>
North Pacific	January 19 to February 15	CNAV "Oshawa"
Ocean Weather Station "P"	January 20 to March 9	CGS "St. Catharines"
Coastal-Seaways	March 31 to April 22	CNAV "Oshawa"
Ocean Weather Station "P"	April 14 to June 1	CGS "St. Catharines"
Coastal-Seaways	June 8 to July 1	CNAV "Oshawa"
Ocean Weather Station "P"	July 7 to August 24	CGS "St. Catharines"
North Pacific	August 4 to September 1	CNAV "Oshawa"
North Pacific	August 3 to August 29	CNAV "Whitethroat"
Ocean Weather Station "P"	September 22 to November 2	CGS "St. Catharines"
Coastal-Seaways	November 11 to December 12	CNAV "Oshawa"
Ocean Weather Station "P"	December 8/59 to January 25/60	CGS "St. Catharines"

LIAISONS

Close working liaisons, as outlined in the attached investigators' summaries, were maintained with the following agencies.-

Department of Transport -

Marine Services
Meteorological Service

Department of National Defence

Royal Canadian Navy
Royal Canadian Air Force
Defence Research Board
Pacific Naval Laboratory
Directorate of Scientific Information Service

Department of Mines and Technical Surveys

Hydrographic Service
Tidal Branch
Polar Continental Shelf Project

University of British Columbia

Institute of Oceanography

Dalhousie University

Institute of Oceanography

United States Coast Guard

United States Fish and Wildlife Service

Ocean Research Group - Stanford

Seattle Laboratory

Honolulu Laboratory

Point Loma Laboratory

International North Pacific Fisheries Commission

International Pacific Salmon Fisheries Commission

Woods Hole Oceanographic Institution

Scripps Institution of Oceanography

University of Washington

Oceanographic Laboratories.

PUBLICATIONS

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Ocean". Prepared for "Pacific Fisherman".

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Proc. 8th Pac. Sci. Cong. Vol. III. Oceanography pp 705-724.
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the Northeast Pacific Ocean. Submitted to J. Fish. Res. Bd. Canada.
- Strickland, J.D.H. Measuring the production of marine phytoplankton.
Bulletin. Fish. Res. Bd. Canada (in press).
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ture, and dissolved oxygen content of the water at Ocean Weather
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Tully, J.P., A.J. Dodimead and S. Tabata. An anomalous increase of temperature in the ocean off the Pacific coast of Canada through 1957 and 1958. J. Fish. Res. Bd. Canada 17(1). 1959.

Tully, J.P. and F.G. Barber. An estuarine analogy of the Sub-Arctic Pacific Ocean. J. Fish. Res. Bd. Canada. 17(1).1959.

Manuscript Report Series (Oceanographic and Limnological)

McAllister, C.D., T.R. Parsons and J.D.H. Strickland. Data Record. Oceanic fertility and productivity measurements at Ocean Weather Station "P" July and August 1959. No. 55.

Pacific Oceanographic Group. Bathythermograms and meteorological data record. Swiftsure Bank and Umatilla Reef Lightships 1958. No. 37.

Physical and Chemical Data Record. North Pacific Surveys, January 20 to February 15, 1959. No. 43.

Data Record. Ocean weather station "P" (Latitude 50° N, Longitude 145° W) July 9, 1958 to January 24, 1959. No. 44.

Physical and Chemical Data Record. Coastal Seaways project, March 31 to April 22, 1959. No. 47.

Observations of seawater temperature and salinity. Volume XVIII, 1958. No. 48.

Oceanographic Data Record, P.N.L. Surveys, 1958. No. 49.

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Oceanographic Data Record, Coastal Seaways Project. June 8 to July 1, 1959. No. 52.

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Circulars

1959- 1 Coastal seaways cruise in C.N.A.V. "Whitethroat", November 12 to December 5, 1958. R.H. Herlinveaux.

1959- 2 Monthly review of daily seawater temperatures, December 1958. H.J. Hollister,

1959- 3 Oceanographic observations at Ocean Weather Station "P". C.G.S. "St. Catharines" Cruise P-58-4, October 28-December 15, 1958. C.D. McAllister.

1959- 4 Oceanographic conditions in the Canadian approaches, January 16 to 28, 1959. J.P. Tully.

1959- 5 Monthly review of daily seawater temperatures, January 1959. H.J. Hollister,

1959- 6 Northeast Pacific oceanographic cruise in C.N.A.V. "Oshawa" January 19 to February 16, 1959. A.J. Dodimead.

1959- 7 Monthly review of daily seawater temperature reports February 1959. H.J. Hollister.

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- 1959- 9 Oceanographic observations at Ocean Station "P". S. Tabata.
- 1959-10 Oceanographic conditions in the approaches to the Canadian Pacific coast. A.J. Dodimead, R.H. Herlinveaux.
- 1959-11 Oceanographic conditions along line from "Swiftsure" Lightship to Ocean Station "P". S. Tabata, D.G. Robertson.
- 1959-12 Monthly review of seawater temperature reports April 1959. H.J. Hollister.
- 1959-13 Coastal seaways cruise in C.N.A.V. "Oshawa" CS-59-1 March 31- April 22, 1959. R.H. Herlinveaux.
- 1959-14 Monthly review of daily seawater temperatures for May 1959. H.J. Hollister.
- 1959-15 Oceanographic observations from weathership C.G.S. "St. Catharines" April 14-June 1, 1959. C.D. McAllister, S. Tabata, D.G. Robertson, K.S. Booth.
- 1959-16 Monthly review of daily seawater temperatures June 1959. H.J. Hollister.
- 1959-17 Oceanographic conditions in the approaches to the Canadian Pacific Coast, June 1959. R.H. Herlinveaux.
- 1959-18 Coastal seaways cruise in C.N.A.V. "Oshawa", CS-59-2, June 8 - July 1, 1959. R.H. Herlinveaux.
- 1959-19 Monthly review of daily seawater temperature July 1959. H.J. Hollister.
- 1959-20 Primary productivity and fertility observations at Ocean Weather Station "P", C.G.S. "St. Catharines", P-59-3, July 7 - August 24, 1959. J.D.H. Strickland.
- 1959-21 Oceanographic investigations from Weathership C.G.S. "St. Catharines" cruise P-59-3, July 7 to August 24, 1959. C.D. McAllister.

- 1959-22 Monthly review of daily seawater temperature reports for August 1959. R.H. Herlinveaux.
- 1959-23 Northeast Pacific oceanographic survey, August 3 to September 1, 1959. N.P. Fofonoff and A.J. Dodimead.
- 1959-24 Oceanographic conditions at stations between "Swiftsure" Lightship and Ocean Weather Station "P". L.F. Giovando.
- 1959-25 Review of daily seawater temperature reports for September 1959. H.J. Hollister.
- 1959-26 Review of daily seawater temperature reports for October 1959. H.J. Hollister,
- 1959-27 Oceanographic observations from Weathership C.G.S. "St. Catharines" Cruise P-59-4, September 22 to November 2, 1959. S. Tabata.
- 1959-28 Daily seawater temperatures in November 1959 for B.C. coastal waters. H.J. Hollister.
- 1959-29 Coastal seaways cruise in C.N.A.V. "Oshawa" CS-59-3, November 16 to December 13, 1959. R.H. Herlinveaux.
- 1959-30 Daily seawater temperatures in December 1959 for B.C. coastal waters. H.J. Hollister.

STAFF LIST

J.P. Tully, M.B.E., Ph.D.	Principal Scientist	Oceanographer in Charge
J.D.H. Strickland, Ph.D.	Senior Scientist	I/C Productivity
N.P. Fofonoff, Ph.D.	Senior Scientist	I/C Marine Physics
A.J. Dodimead, M.A.	Associate Scientist	I/C North Pacific Fisheries Oceanography
F.G. Barber, B.A.	Associate Scientist	Military Oceanography
S. Tabata, M.A.	Associate Scientist	Weathering (Physics)
C.D. McAllister, M.A.	Associate Scientist	Weathering (Productivity)
T.R. Parsons, Ph.D.	Associate Scientist	Productivity
L.F. Giovando, Ph.D. (from August 3, 1959)	Associate Scientist	North Pacific
N.E.J. Boston, B.Sc.E. (from May 3, 1959)	Assistant Scientist	Hecate Model
R.K. Lane, B.A. (from May 3, 1959)	Assistant Scientist	Coastal
H.J. Hollister,	Technician 4	Chief Technician I/C Daily Seawater Obs. I/C Data processing and records
R.H. Herlinveaux	Technician 4	I/C Coastal-Seaways
L.D.B. Terhune	Technician 4	Model Laboratory
R.L. Johnston, B.A.	Technician 2	Sea Technician
K.V. Stephens	Technician 2	Laboratory Technician
J.A. Stickland	Technician 2	Supply and Maintenance
D.G. Robertson (on leave of absence October 29, 1959 to April 29, 1960)	Technician 2	Sea Technician
K.B. Abbott-Smith (from January 5, 1959)	Technician 1	Sea Technician
W.W. Anderson (to January 6, 1959)	Technician 1	Sea Technician
K.H. Austin (to March 31, 1959)	Technician 1	Laboratory Technician
N. Bdinka, B.A. (from January 4, 1960)	Technician 1	Sea Technician
R. Cagna	Technician 1	Machinist
J.D. Carswell	Technician 1	Electronics Technician
O.D. Kennedy	Technician 1	Sea Technician
J.H. Meikle (from March 16, 1959)	Technician 1	Sea Technician
M.C. Cairns (Miss)	Assistant Technican 2	Computer Technician
M.M.N. Smith (Miss)	Stenographer 2	Secretary

Seasonals and Term employees

M. Uda, Ph.D. (to May 15, 1959)	Senior Scientist	North Pacific
C. Froese (Miss), Ph.D. (May 15 to July 15, 1959)	Assistant Scientist	Computer
W.R. Harling (from October 1, 1959)	Technician 1	Sea Technician
K.S. Booth	Seasonal (Student Assistant)	Sea Technician
F.M. Boyce	Seasonal (Student Assistant)	Sea Technician
N.K, Chippindale	Seasonal (Student Assistant)	Sea Technician
J.A. Gow	Seasonal (Student Assistant)	Sea Technician
J.D. Lewis	Seasonal (Student Assistant)	Sea Technician
G.S. Pond	Seasonal (Student Assistant)	Sea Technician
T. Tabata	Seasonal (Student Assistant)	Sea Technician

Complement

Full Time	25
Professional	11
Technical	13
Clerical	1
Seasonals	7

INVESTIGATORS' SUMMARIES OF RESEARCH

1. North Pacific Surveys A.J. Dodimead
2. Depth of Seasonal Influence in the sub-Arctic Pacific Ocean. A.J. Dodimead
3. Monograph on the sub-Arctic Pacific Ocean by Dr. Mithitaka Uda. L.F. Giovando
4. Observations at Ocean Station "P"
(Lat 50° N, Long 145° W) S. Tabata and C.D. McAllister
5. Temporal Changes of Water Properties at Ocean Station "P" (Lat 50° N, Long 145° W) S. Tabata
6. Range of Variation of Water properties at Ocean Station "P" (Lat 50° N, Long 145° W) S. Tabata
7. The Coastal-Seaways Program R.H. Herlinveaux
8. Coastal Investigation R.K. Lane
9. Daily Seawater Observations H.J. Hollister
10. Hecate Model N.E.J. Boston
11. Filter for Hecate Model Tide Gauge N.P. Fofonoff
12. Wind Induced Transport in the North Pacific Ocean N.P. Fofonoff
13. Time Dependent Response of a Bounded Ocean N.P. Fofonoff
14. The Primary Productivity and Fertility of Sea Water J.D.H. Strickland, T.R. Parsons, and C.D. McAllister.
15. Determination of Primary Productivity in situ from Shipboard Measurements of Photosynthesis C.D. McAllister
16. Primary Productivity Studies at Ocean Station "P"
(Lat 50° N, Long 145° W) C.D. McAllister
17. Sound Speed in the Eastern sub-Arctic Pacific Ocean F.G. Barber
18. Forecasting Sound Speed Structure F.G. Barber
19. Sound Speed in Arctic Waters (Paclabar) F.G. Barber
20. Airborne Radiation Thermometer J.P. Tully, M. Pirart, and R.K. Lane
21. Technical Services.

Two oceanographic surveys co-ordinated with the research program of the International North Pacific Fisheries Commission were accomplished this year. The first, a winter survey, was carried out between January 20th and February 15th, aboard C.N.A.V. "Oshawa" north of latitude 47° N and east of longitude 157° W (Figs. 1 and 2). The second, a summer survey was carried out during the period August 4th to September 1st. Two ships, C.N.A.V. "Oshawa" and C.N.A.V. "Whitethroat", were used and they covered the area north of latitude 38° N and east of longitude 160° W to the North American coast (Figs. 3 and 4).

The data have been published. Observations of temperature, salinity, dissolved oxygen were made at all stations. During the summer cruise observations were made at some stations to a depth of 4000 metres. Zooplankton samples were obtained from a depth of 150 metres to the surface.

January - February 1959

The observed temperature distribution at 10 metres depth (a more realistic level than the surface) is shown in Figure 3. Temperatures in the Alaska Gyral and mid-ocean region were practically the same as in March - April 1958. However, around the coast the water was about one degree ($^{\circ}$) colder than in the previous winter, but still warmer than the average. There is evidence of a northward intrusion about 300 miles off the Washington-Vancouver Island coast.

It is notable that these data do not represent the winter minimum, which occurred in late March, as shown by the data from Ocean Station "P" (Lat 50° N, Long 145° W) (see Summary Report by Tabata).

The distribution of temperature at 100 metres depth (not shown) was similar, except near the coast where it was generally warmer than at 10 metres. This temperature inversion was especially marked in the northern part of the Gulf. The warm water intrusion off the Washington-Vancouver Island coast was also apparent at this depth.

The salinity distribution at 10 metres depth (Fig. 4) was very similar to that observed during the previous winter. The high salinity centre ($< 32.8\%$) south of Kodiak Island, which was absent during the previous summer, was again present. As usual, there was a band of low salinity water close along shore, all around the coast.

At 100 metres depth (not shown) high salinity ($< 33.4\%$) was present off Vancouver Island and southeast of Kodiak Island. The cells of low salinity water, observed during the previous summer, had dissipated at the time of this survey.

The distribution of dissolved oxygen at 10 metres depth (not shown) was similar in conformation to the temperature. Regions of high dissolved oxygen were associated with regions of low temperature.

August 1959

The temperature distribution at 10 metres depth (Fig. 1) was similar to that observed during August 1956. Between Ocean Station "P" and the coast, the water was considerably cooler (3° C) than was found during August 1958 and somewhat cooler than during August 1957. Similar conditions existed at the surface at Ocean Station "P" during this period. Immediately off the coast of Vancouver Island temperatures were relatively cold, being similar to those observed during the previous summer.

The salinity distribution (Fig. 2) unlike the temperature distribution at 10 metres depth, was more similar to that observed during the summers 1957 and 1958 than that observed during the summer 1956. However, the 32.6‰ isohaline did not extend as far offshore as observed during the two previous periods.

The salinity and temperature distributions suggest "upwelling" off the coast of Vancouver Island and the California coast.

The warm water intrusion

The distribution of temperature on the surface $\sigma_t = 26.60$ (density 1.02660) has been used in earlier reports to show the intrusion of warm water below the level of seasonal influence since 1956. The distribution of temperature on this surface for August 1959 is shown in Figure 5. This temperature distribution was very similar to that observed during August 1956, particularly off the British Columbia coast. In the Gulf of Alaska there were marked boundaries where previous studies have generally shown a gradual change of properties.

This preliminary analyses of the data suggests that the oceanographic conditions in this region were generally similar to those observed during August 1956. Whether this trend to cooler conditions continues will be seen in the data of the proposed winter survey for 1960.

Deep water characteristics

The deep water in this region is remarkably uniform in its properties at a given depth. Both temperature and salinity exhibit little horizontal and vertical variation below depths of 3500 metres. Oxygen values, however, increase steadily with depth and show a greater range of variation than either temperature or salinity.

The temperature decreases slightly with depth to about 3500 metres, where the range is only 1.48 to 1.59° C. At any one station temperature differences between 3500 and 4000 metres are almost impossible to detect with the present equipment. It is known from other data that below 4000 metres the temperature increases slightly. The minimum temperature lies between 3500 and 4000 metres with a range of 1.48° C to 1.52° C over most of the northeast Pacific Ocean. Slightly higher temperatures, 1.54° C to 1.59° C, were found in the region immediately west of the United States coast and near Ocean Station "P".

The temperature differences at depths of 2500 to 3000 metres are large enough to establish broad features of the deep water characteristics. Temperature distribution on the surface $\sigma_t = 27.70$ (density = 1.02770)

which lies in this depth interval is shown in Figure 6. The temperatures on this surface were slightly higher around the periphery of the Gulf of Alaska, and to the south of latitude 40° N. The most interesting feature is the presence of a large area of relatively warm water stretching west from the Queen Charlotte Islands to longitude 150° W in a band about 300 miles wide. This feature may have been produced by a westward flow of warm water in this latitude, or by an eastward flow of relatively cold water to the south (centred about latitude 45° N). The latter interpretation is supported by the fact that the temperatures reported by the Oceanographic Department, University of Washington, in this region were somewhat higher in 1958 than in 1959. However, this interpretation is based on temperatures in situ and will have to be verified by computation of potential temperature. It is proposed to continue the deep observations on future cruises.

A.J. Dodimead

2. DEPTH OF SEASONAL INFLUENCE IN THE SUB-ARCTIC PACIFIC OCEAN.

Previous reports have shown that the salinity structure, with minor variations, is a permanent feature of the eastern sub-Arctic and that this structure could be accurately delineated by plotting salinity as a function of the logarithm of the depth. Such a plot leads to a definition of three distinct zones; an upper zone of relatively homogeneous low salinity water, a transition zone characterized by a marked halocline, and a lower zone in which the salinity increases gradually with depth. These are separated by two marked discontinuities at the upper and lower limit of the halocline. They have been designated "D" and "L" respectively.

A study of the upper zone now has been completed on all available data for the whole of the sub-Arctic region of the North Pacific Ocean for the periods 1956 through 1959.

As a result of this study it can now be shown that an upper zone and hence a limit "D" can be defined and can be interpreted logarithmically throughout the sub-Arctic region. The lower limit "L", however, is not an invariable feature of this region. In areas of mixing such as the vicinity of the Aleutian Islands and in some areas of the Bering Sea the marked halocline deepens and the lower limit "L" becomes indefinite. These features are shown in Figure 7.

It has also been shown that in the western sub-Arctic, when the lower limit of the halocline can be defined, the salinity at "L" approximates 33.8 ‰, very near the values that have been reported previously for the eastern sub-Arctic.

It is now apparent from an examination of data at Ocean Station "P" (Fig. 8) that the upper zone is established during the period of cooling, and although it undergoes changes, it can be defined throughout the period of heating, April - September, and is again re-established during the winter period when surface cooling and mixing by either wind action or convection, or both, produces isohaline and isothermal structures to "D". These processes do not extend below "D".

Changes that occur in the salinity structure during the period of heating

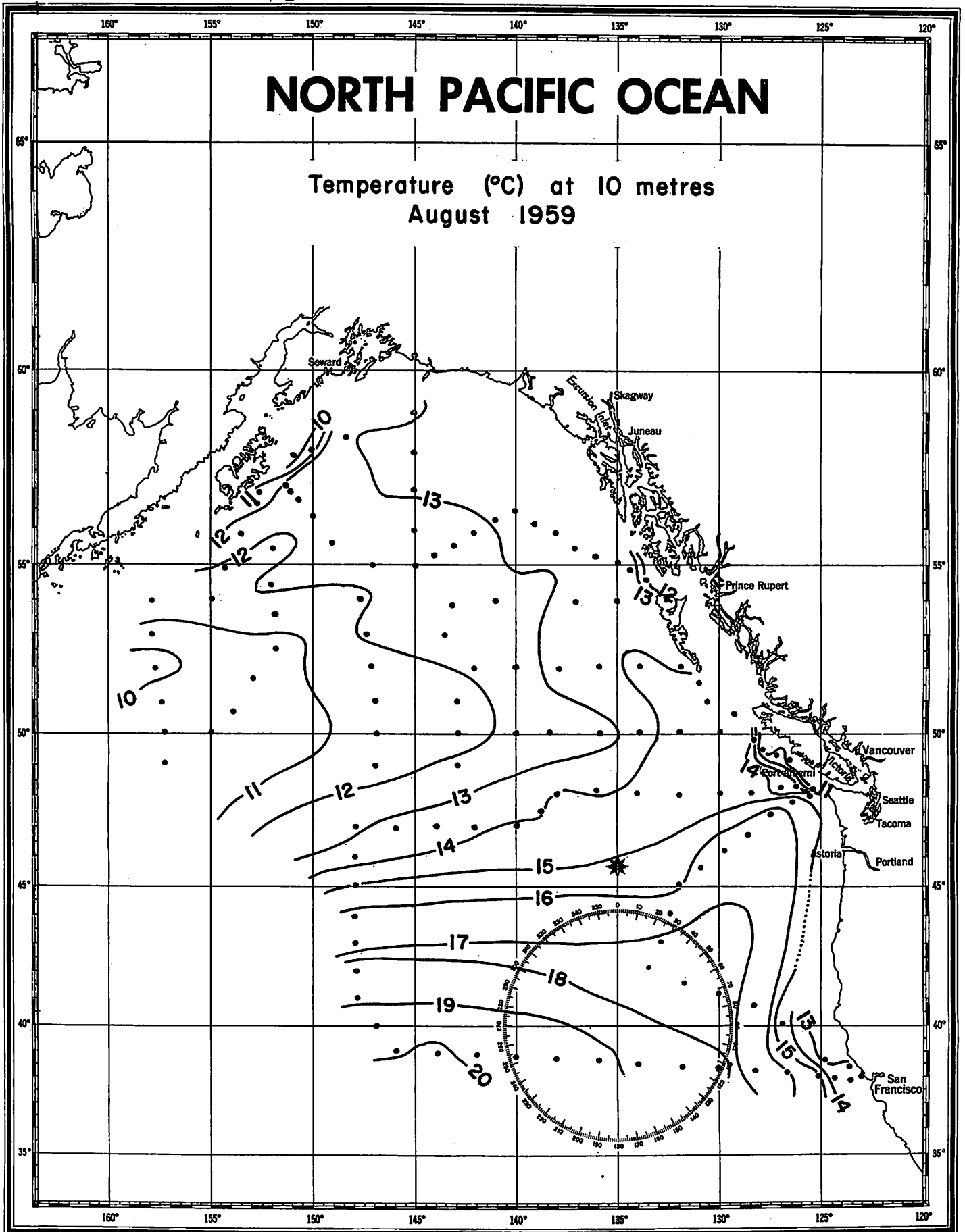


Figure 1

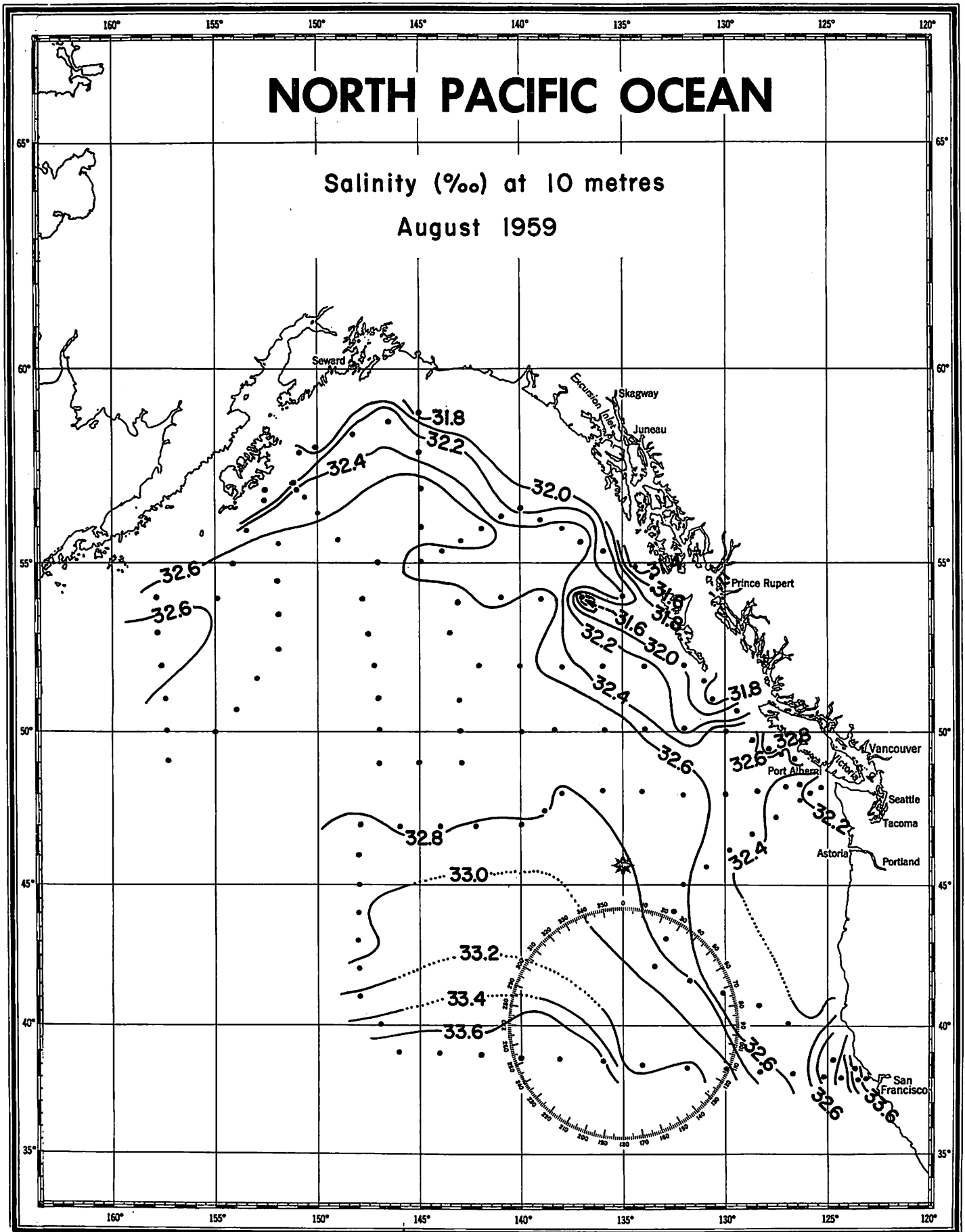


Figure 2

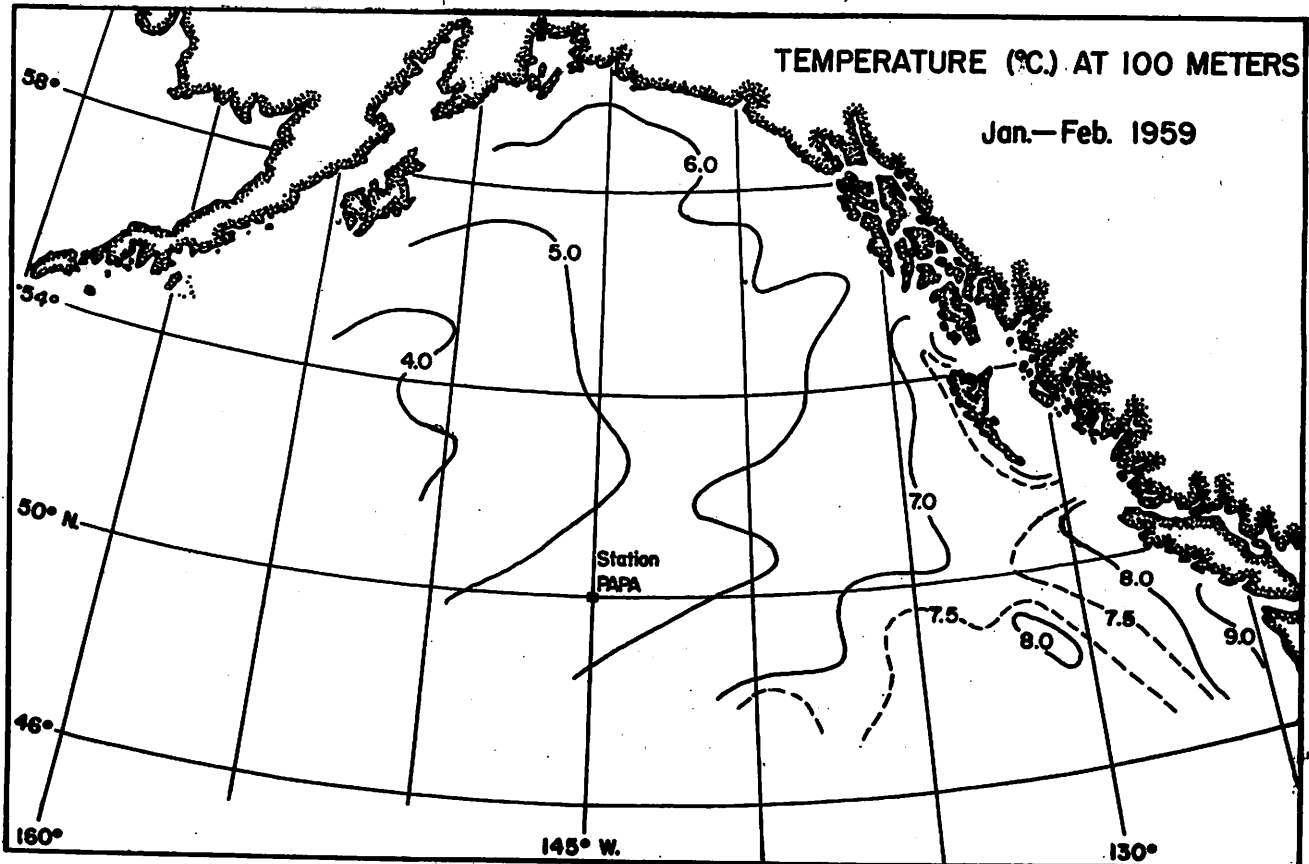
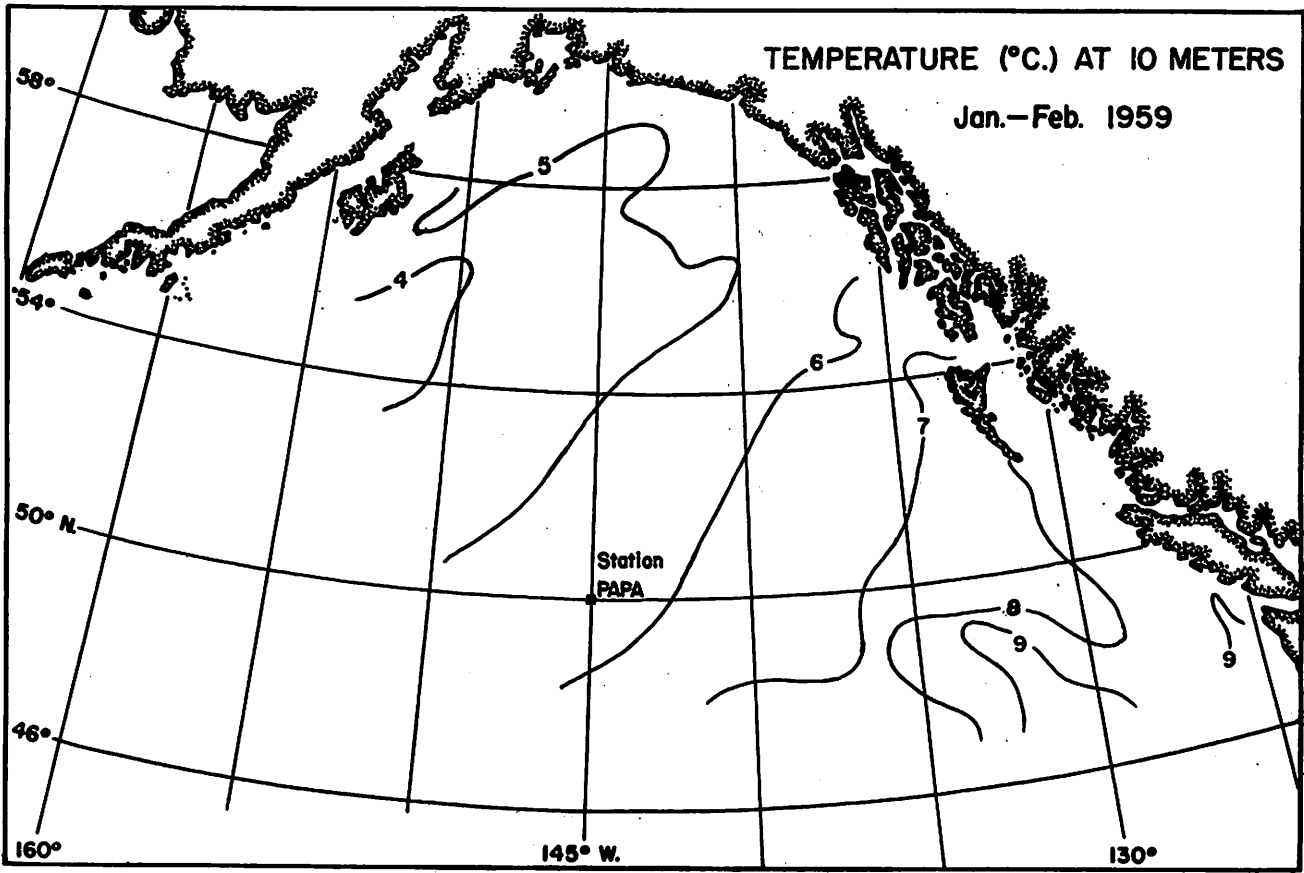


Figure 3

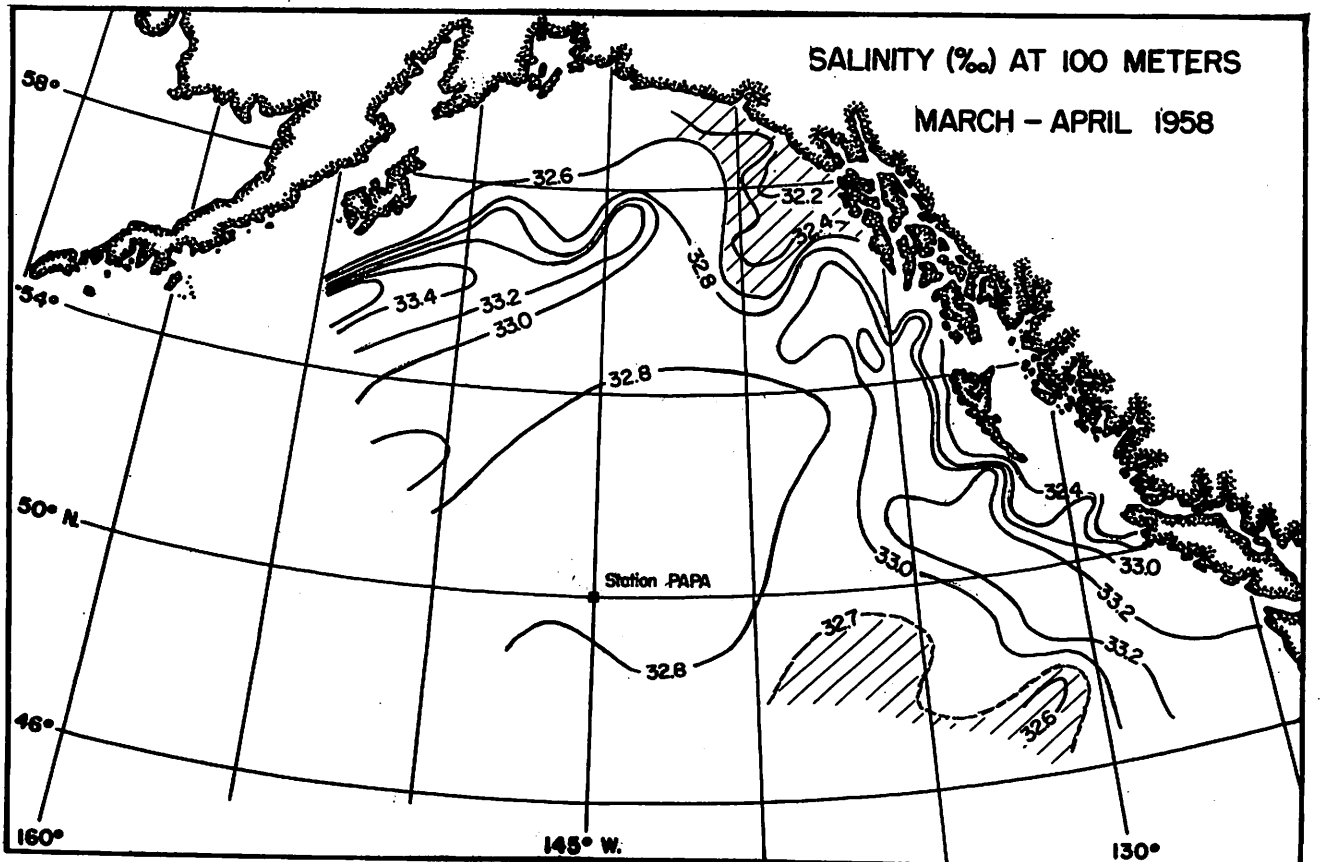
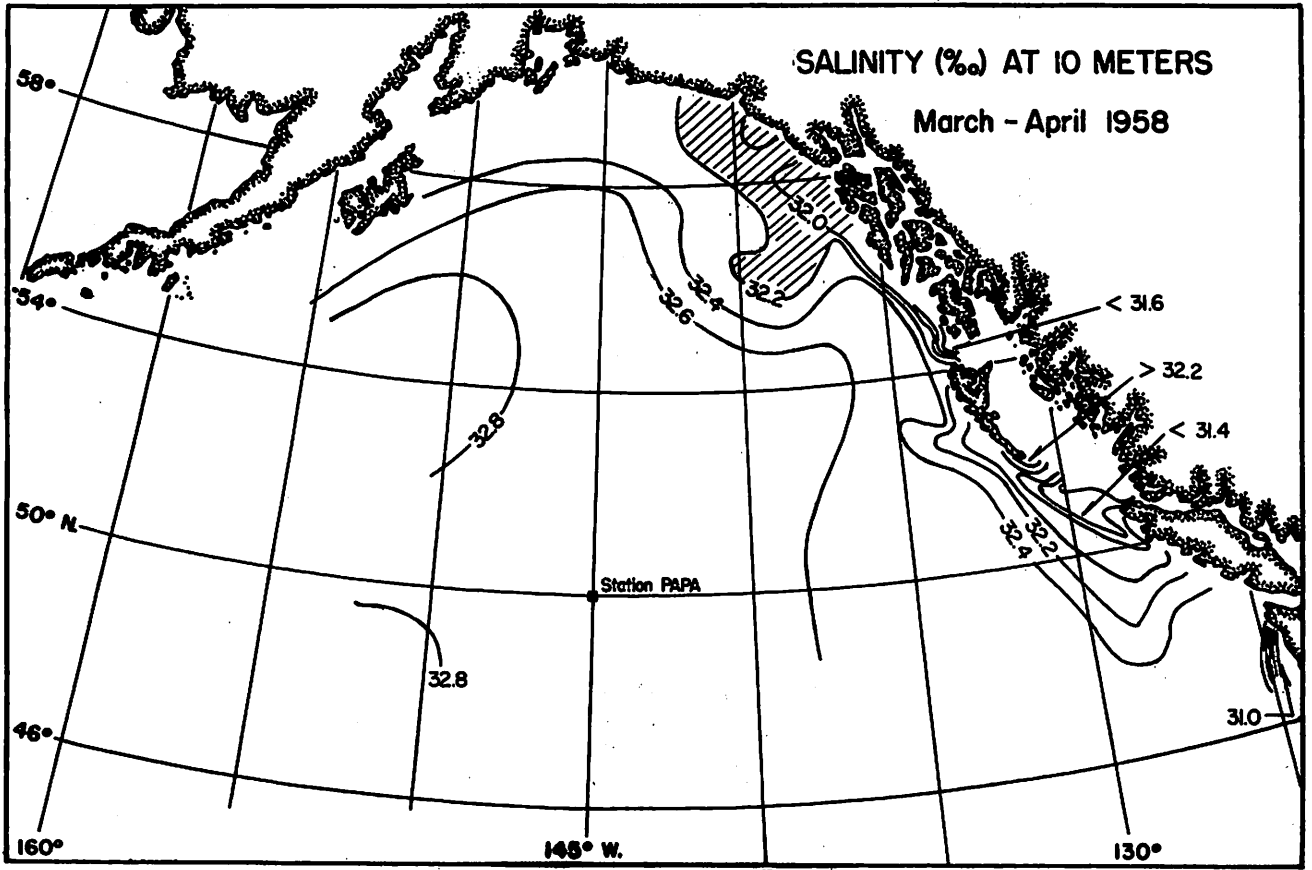


Figure 4

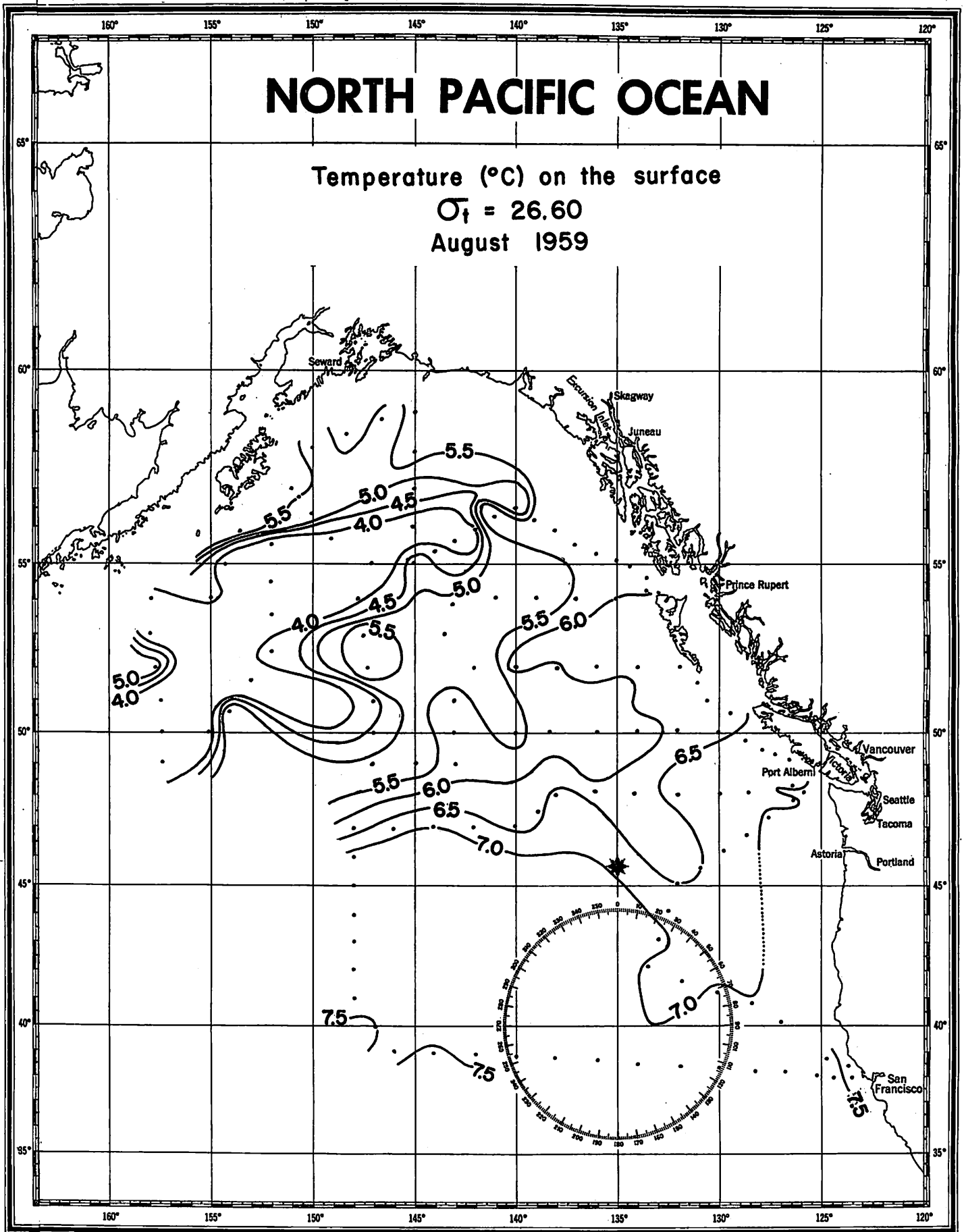


Figure 5

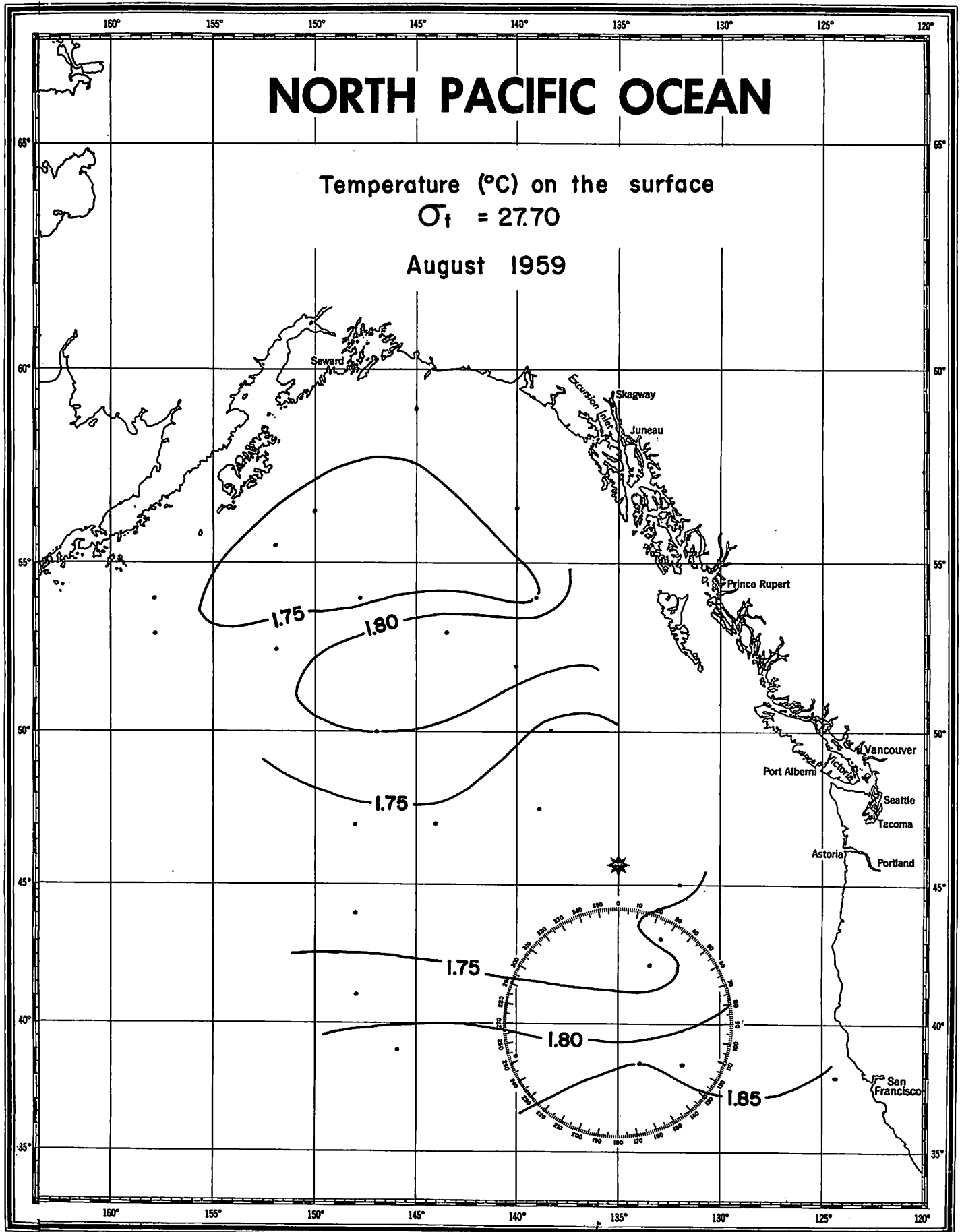


Figure 6.

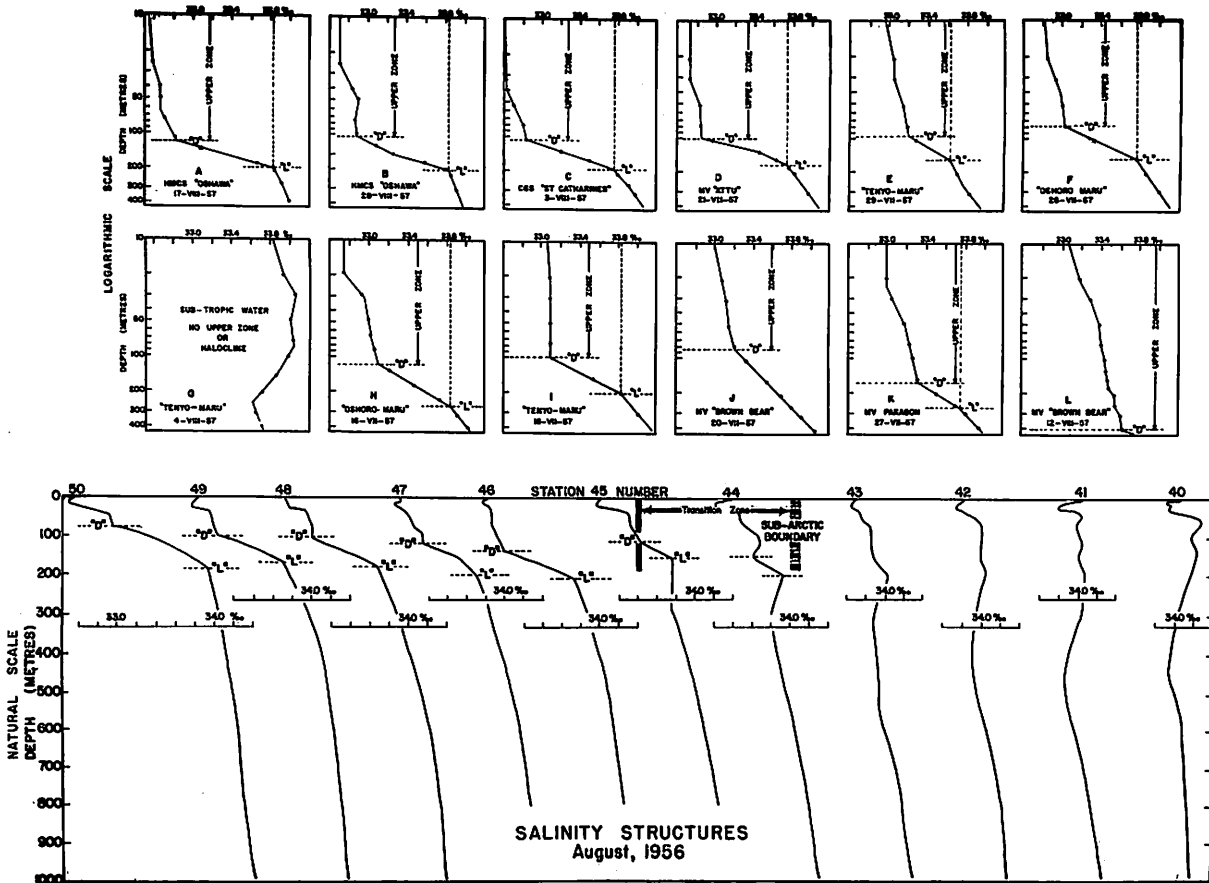
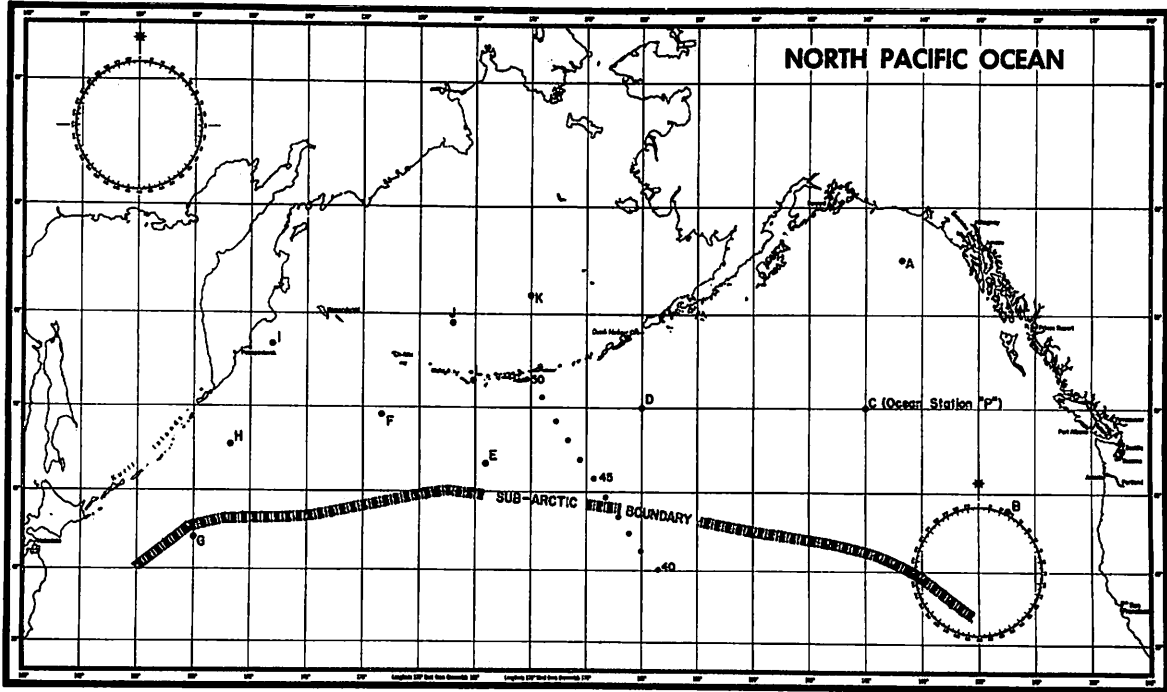


Figure 7.

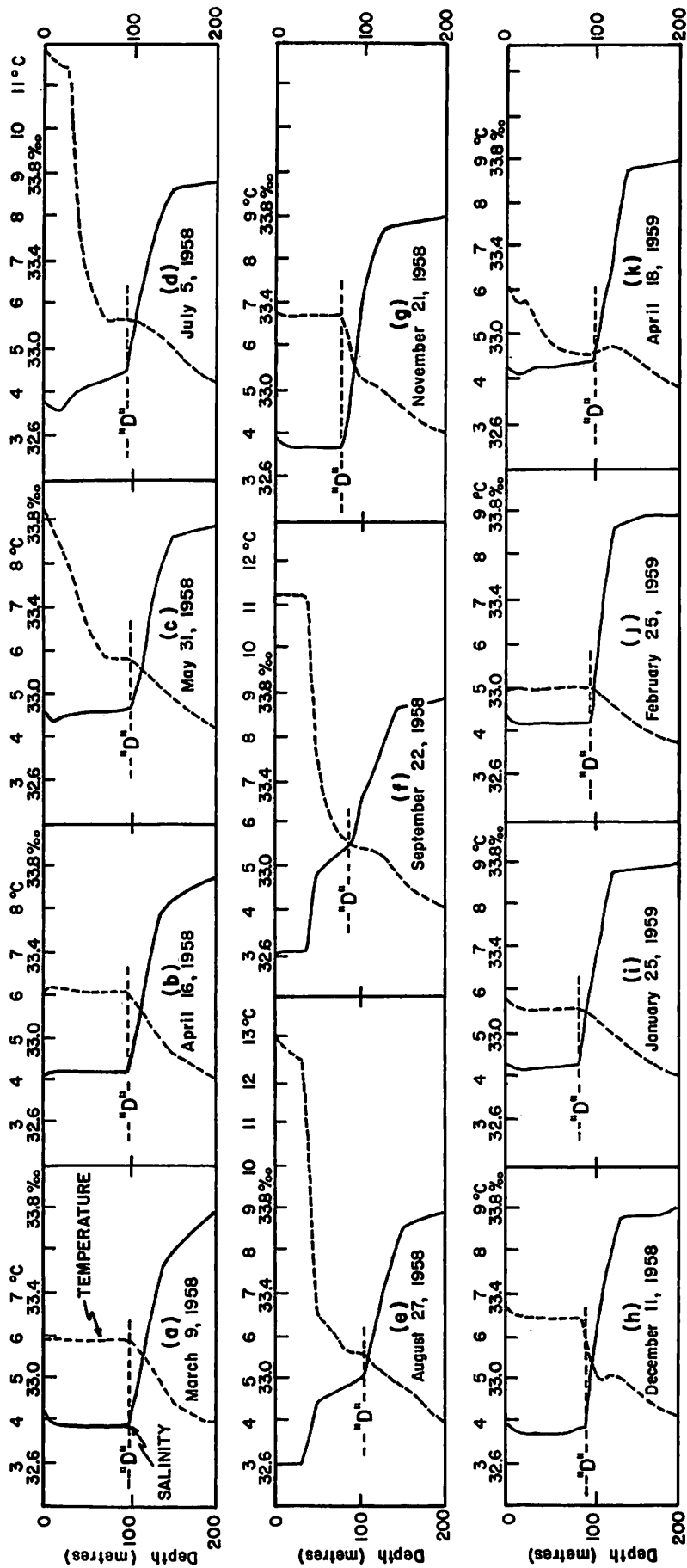


Figure 8.

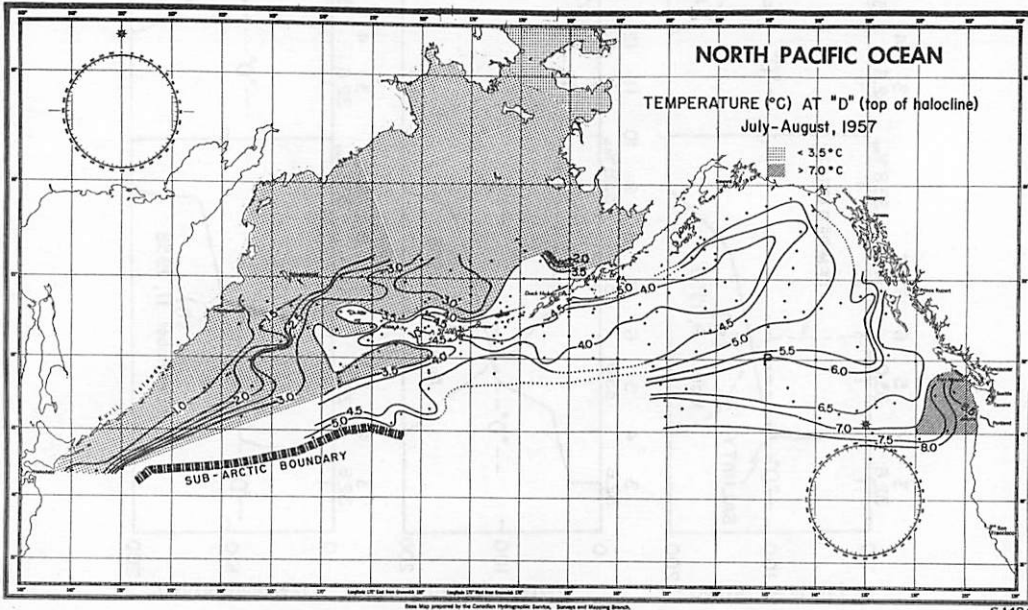
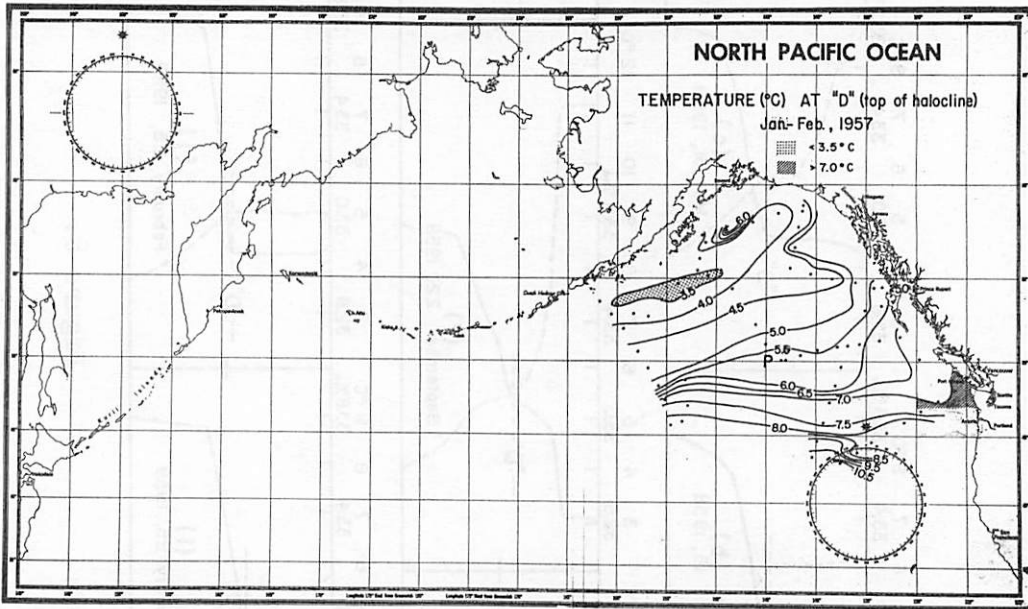
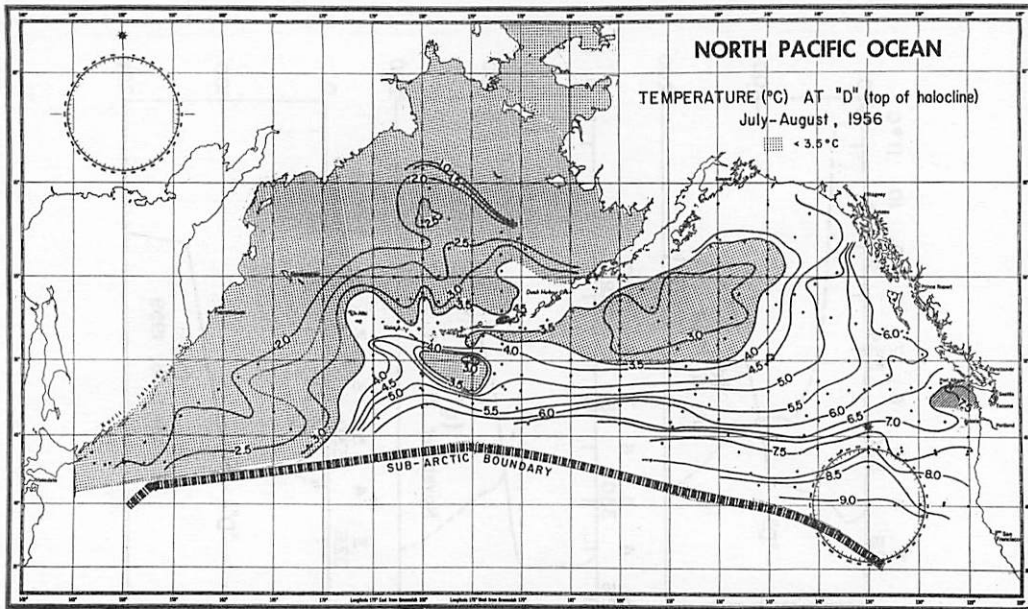


Figure 9.

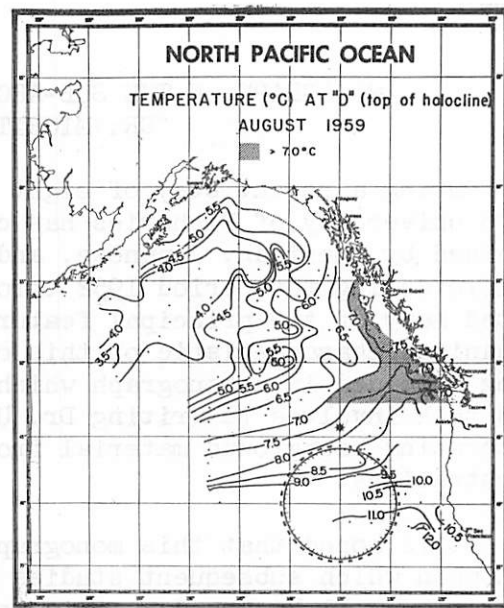
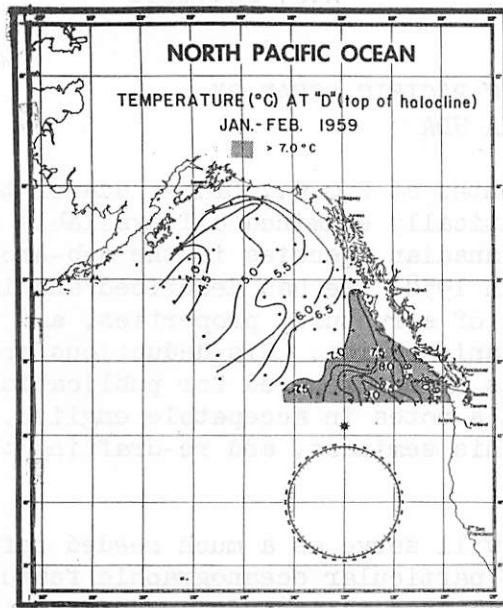
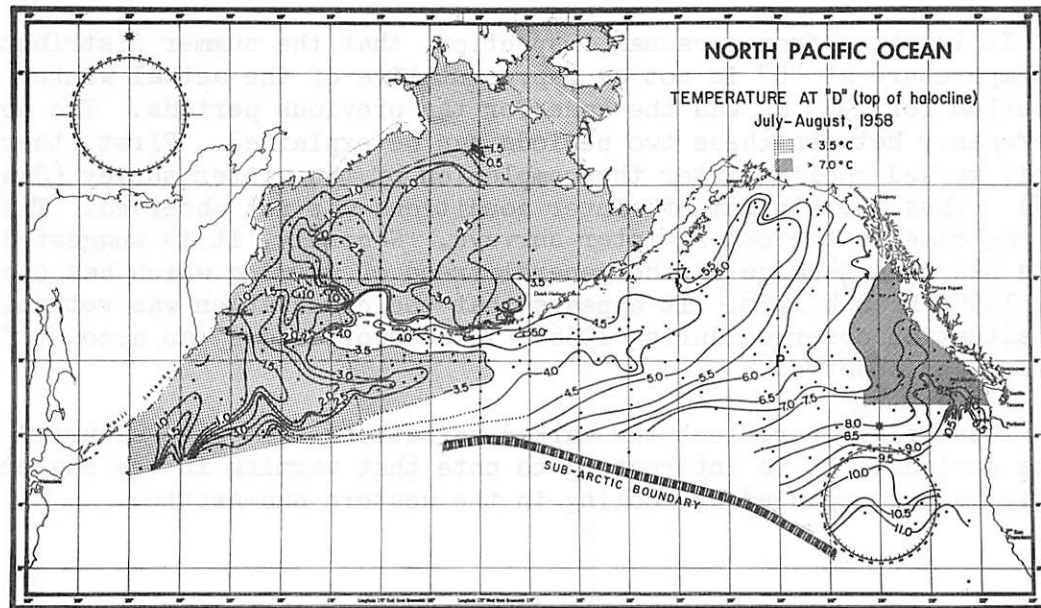
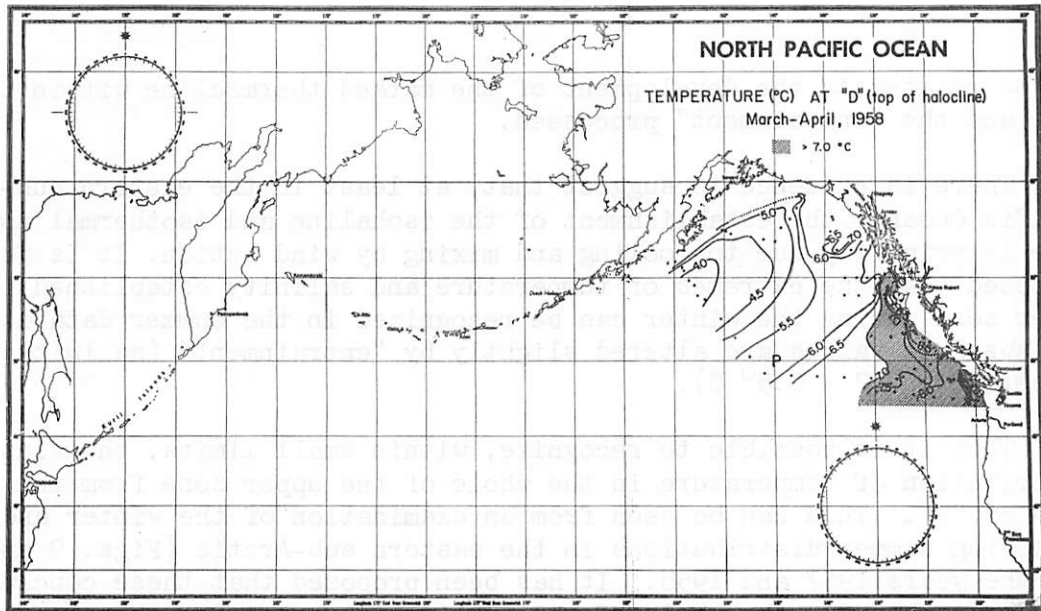


Figure 10.

can be related to the development of the marked thermocline within the upper zone and the "entrainment" processes.

There is evidence to suggest that, at least in the eastern sub-Arctic Pacific Ocean, the establishment of the isohaline and isothermal upper zone is primarily due to cooling and mixing by wind action. It is further proposed that the extremes of temperature and salinity established in the upper zone during the winter can be recognized in the summer data at "D". The absolute values are altered slightly by "entrainment" (salinity 0.2‰; temperature 0.2 - 0.5° C).

Thus it is possible to recognize, within small limits, the winter distribution of temperature in the whole of the upper zone from the summer data at "D". This can be seen from an examination of the winter and the following summer distributions in the eastern sub-Arctic (Figs. 9 and 10) for the years 1957 and 1958. It has been proposed that these conclusions are applicable for the whole of the sub-Arctic region for these periods.

It is noted from a casual inspection, that the summer distributions of temperature at "D" is not as representative of the actual winter distribution for 1959 as was the case for the previous periods. The apparent discrepancy between these two periods can be explained. First, there was fairly marked cooling after the completion of the winter survey (January 1959). Thus the minimum of winter conditions was not observed. This was not the case in the other winter surveys. Secondly, it is suggested that there has been a change in the general trend of warming which has occurred from 1955 through 1958. It appears that the circulation was returning to the situation observed during 1956. These two factors can account for the differences observed.

These figures reflect the marked variations that have occurred during these periods. It is interesting to note that warming in the eastern sub-Arctic was accompanied by cooling in the western sub-Arctic.

A.J. Dodimead

3. MONOGRAPH ON THE SUB-ARCTIC PACIFIC OCEAN BY
DR. MICHITAKA UDA

During a recent stay of eight months at P.O.G., Dr. M. Uda of the Tokyo University of Fisheries has critically examined all available data obtained by American, Japanese, and Canadian agencies in the sub-Arctic Pacific during the period 1952 through 1958. He has described and illustrated many of the principal features of structure, properties, and mechanisms characteristic of this oceanic region. His deductions are now being embodied in a monograph which is being prepared for publication. This task involves re-writing Dr. Uda's notes in acceptable English, incorporating background material from his seminars, and re-drafting the illustrations.

It is hoped that this monograph will serve as a much needed reference work upon which subsequent studies of particular oceanographic features in the region will be based. It is not planned to include any discussion of the interrelationships between fish populations and the oceanographic

characteristics of the region, because this study is not complete and it is felt that it should be the subject of a separate report. However, it is hoped that the present monograph will also be of use in providing interested workers in fisheries with the necessary background to expedite any researches in the region. It is expected that the monograph will be completed in early 1960.

L.F. Giovando

4. OBSERVATIONS AT OCEAN STATION "P" (LAT 50° N, LONG 145° W)

The following program of observations was carried out:

1. Both ships, the "St. Catharines" and "Stonetown" (9 patrols)

- (a) Bathythermograph (BT cast to depths of 270 m every 3 hours en route to and from Station "P").
- (b) BT cast to depths of 270 m twice daily at 0200 and 1700 G.M.T. hours
- (c) Daily sampling of surface water at 0200 G.M.T. for salinity analysis. Observations started in January 1959.
- (d) Fishing with hook and line. (The fishing gear was supplied by the Biological Station). Interesting specimens of fish and its measurement, stomach contents, etc. are sent to the Biological Station. This is a voluntary effort. After a few trials in 1958, started in 1959 as routine effort. P.O.G. acts as liaison between the ship and the Biological Station.

2. One ship, "St. Catharines" (5 patrols).

- (a) Weekly deep cast to depth of 2000 m. Analyses made for temperature, salinity, dissolved oxygen, and silicate.
- (b) Weekly shallow-cast to depth of 300 m. Analyses made for temperature, salinity, dissolved oxygen, silicate and nitrite.
- (c) Detailed observations of shallow isothermal layer with frequent BT casts.
- (d) Plankton observations. Observational program supplied by Biological Station. All samples and data turned over to the Biological Station.
 - i 150 m vertical haul every third day.
 - ii 1250 m vertical haul twice during the patrol.
 - iii 20 minute surface horizontal tow for 3 consecutive evenings at the beginning, middle, and end of patrol.
- (e) Submarine light penetration measurements. After one preliminary measurement during 1958, a routine observational program of light penetration was initiated in 1959. Several sets of observations were made.
- (f) Surface current measurements. Parachute drogues were used and hourly positions determined. Two sets of observations were made. Measurements started during 1959.

- (g) Hydrographic stations between Swiftsure Lightship and Station "P". A very significant expansion of the program was made in April 1959 when the group received permission from the Department of Transport to occupy 6 hydrographic stations en route to and from Station "P" (Fig. 11).
- (h) Productivity measurements. An extensive series of observations related to productivity measurements were made during the summer patrol (Cruise P-59-3) by the team of McAllister, Parsons and Strickland. The details of these are reported elsewhere under appropriate title. Since then, routine measurements of plant pigments and carbon 14 uptake by phytoplankton have been made on subsequent patrols.
- (i) Observations of solar radiation and total radiation. This is a joint effort with the Meteorological Services of the Department of Transport. Observations started January 1959.

Some results of observations during 1959

As shown in Figure 12, the monthly mean surface sea temperatures were generally greater than the 10-year means. Only during July to September were they less than the means.

A temperature inversion, occurring at depth of 100-150 m appeared to have been caused by the intrusion of warm water at these levels.

The temperature between depths of 150-200 m, well below the depth of influence of seasonal processes (see Dodimead) decreased from summer 1958 through winter then increased during 1959.

According to one set of surface current measurements made with parachute drogue for a period of 50 hours, a clockwise rotary current of possible diurnal period was observed. But in two days, the net drift was two miles, northwestward.

Early in 1959, crab larvae and small octopi ($3/4$ " long) were obtained from plankton samples. Subsequently large amounts of floating debris, composed of kelp, logs, etc. were observed. It is implied from these observations that the surface coastal water off the Aleutian Islands and Alaska is fed back into the sub-Arctic Current. Another explanation for the abundance of these floating debris may be the accumulation of debris from horizontal divergence of the water, allowing some water from the B.C. coast to reach the Station.

From the several sets of measurements of submarine light penetration during April to October, it was found that the vertical extinction coefficient of the water was between 0.02 to 0.04 for a band of light centered around wavelength of 4300 Angstrom.

A comparison of changes of temperature at various periods between April and October (Fig. 13) revealed that appreciable changes occurred not only in magnitude but also in the changes of sign. For example, in the vicinity of Stations 5 and 6 (Fig. 11) the changes alternate between increase and decrease of temperature.

S. Tabata
C.D. McAllister.

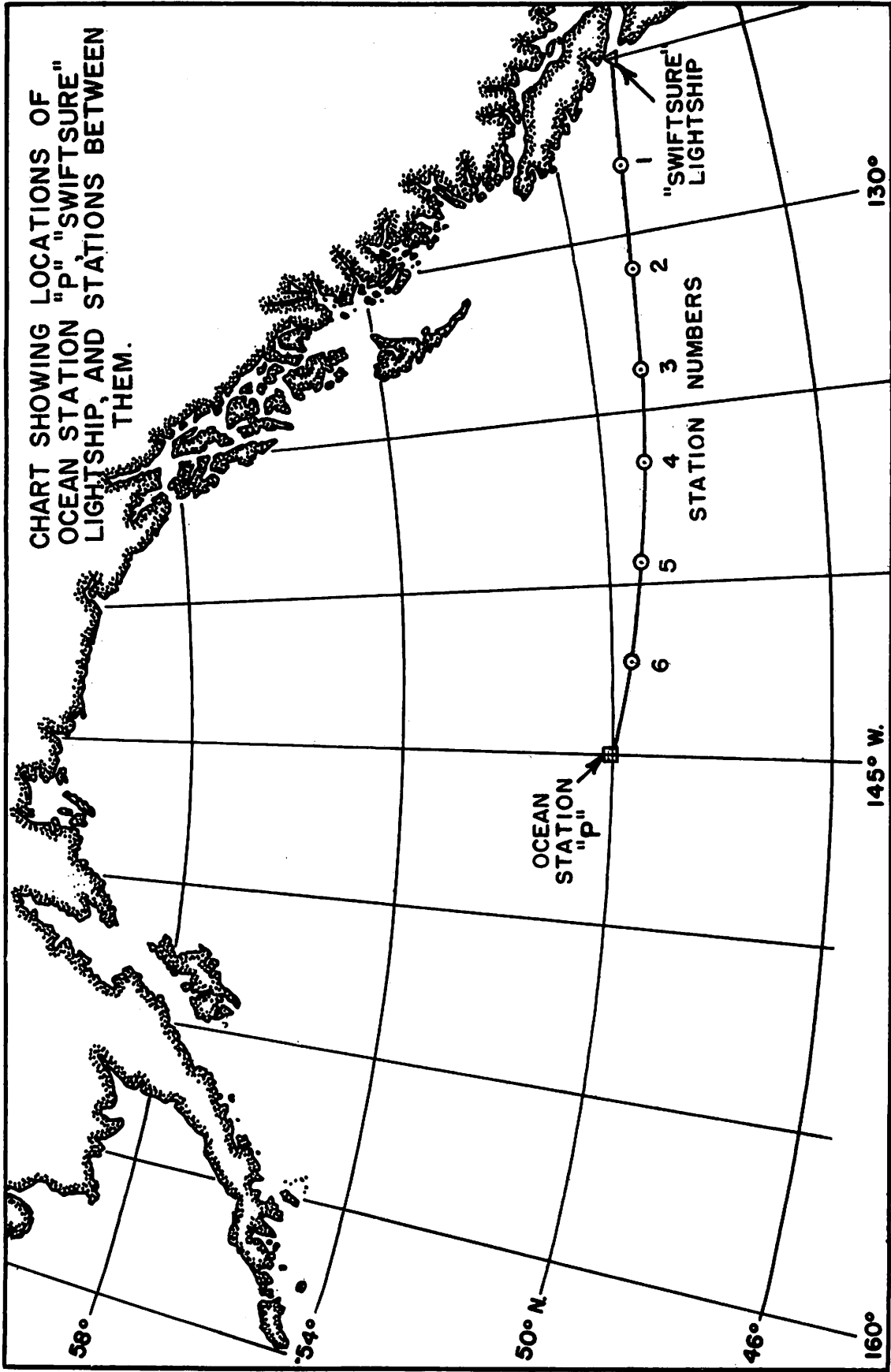


Figure 11.

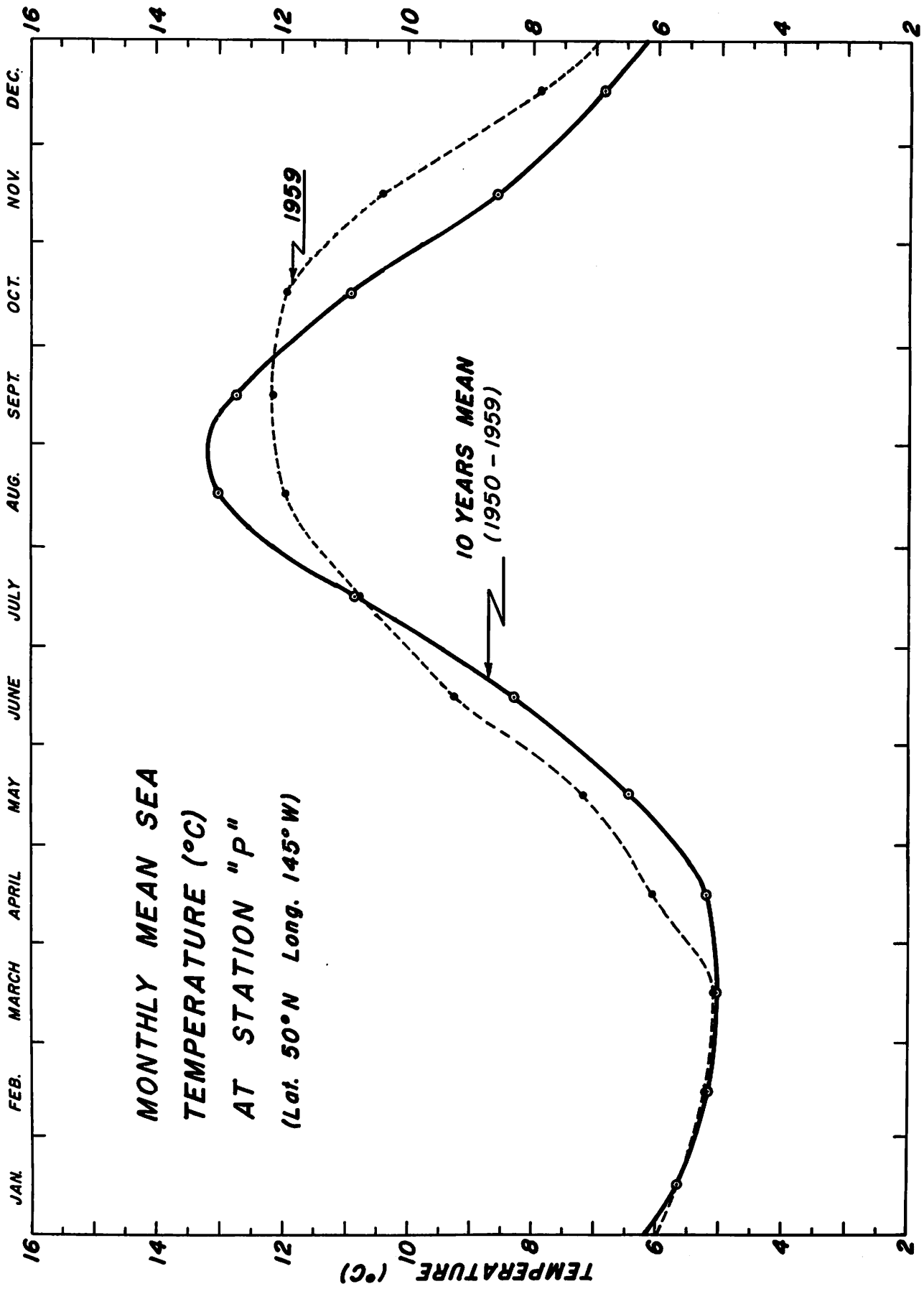
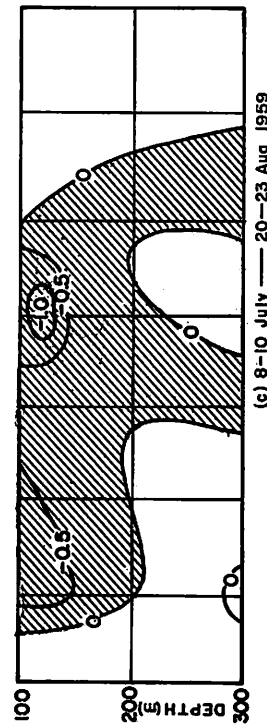
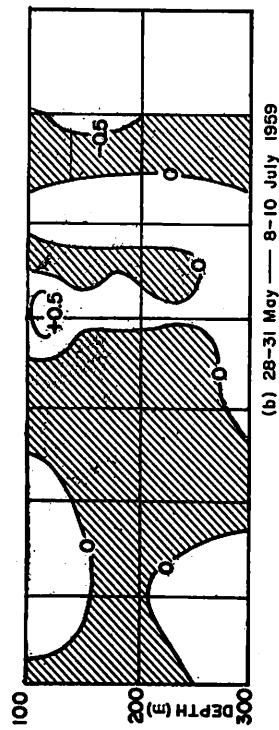
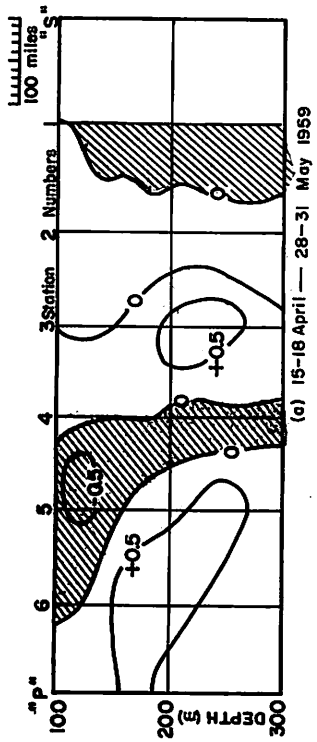
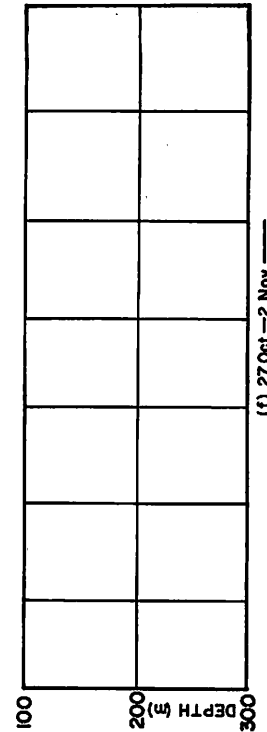
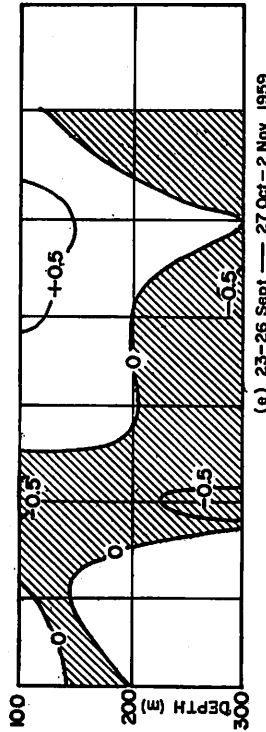
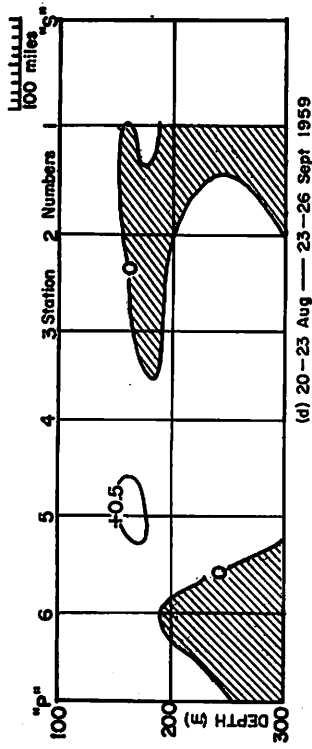


Figure 12.



TEMPERATURE CHANGES ($^{\circ}\text{C}$) BETWEEN
STATION "P" AND "SWIFTSURE" LIGHTSHIP

Temperature Decrease



TEMPERATURE CHANGES ($^{\circ}\text{C}$) BETWEEN
STATION "P" AND "SWIFTSURE" LIGHTSHIP

Temperature Decrease

Figure 13

5. TEMPORAL CHANGES OF WATER PROPERTIES AT
OCEAN STATION "P" (LAT 50° N, LONG 145° W)

Oceanographic data (salinity, temperature, and dissolved oxygen content) collected at Station "P" from August 1956 to July 1958 were examined for periodic trends and other temporal variations. There was no well-defined annual cycle of salinity variation in the upper zone (0-100 m).

During the two year period, the salinity in this zone was at a minimum in spring, 1957, and at a maximum in summer 1958. Some evidence of periodicity was present at depth of 100 m. The maximum occurred in autumn and the minimum in winter. Significant variations occurred in the halocline (100-200 m) and in the lower zone (below 200 m).

In contrast, the variations of temperature in the upper zone showed marked annual variations to a depth of 100 m. The annual cycle of surface sea temperature was in phase with that of air temperature, having a maximum in late summer and a minimum in late winter. While minima at various levels in the zone occurred in late spring, the maxima occurred progressively later with depth. A temperature inversion was evident at depths between 100 and 150 m during summer, 1956, to summer, 1957. There was a definite trend of increasing temperature generally being greater during the second half of the period studied, than during the first half.

Marked cyclic annual variations of dissolved oxygen content occurred in the upper zone, particularly in the layer near the surface, reaching a maximum in winter, and dropping to a minimum in summer or autumn. They were in phase with the solubility of oxygen in the water. The surface water was supersaturated throughout the year, the condition being more pronounced in summer, 1957, and spring, 1958. Below the depth of 100 m there was little evidence of cyclic annual variations of dissolved oxygen content. However, in both the halocline and lower zone, appreciable long term variations are present. A definite trend of increasing concentration was evident during the spring of 1957, through the spring of 1958.

Precipitation minus evaporation accounts for a good part of salinity changes in the upper zone, especially from summer through winter of 1956, as shown in Table I. The main factor influencing temperature in this is heat exchange at the air-sea boundary as shown in Table II. Dissolved oxygen content in this zone is governed primarily by the solubility of oxygen in water. The occurrence of the maximum in the structure of dissolved oxygen content in summer, is attributed to the decrease of dissolved oxygen content in the layer above the thermocline, due to warming of water.

Northward transport of water caused the general increase of salinity, temperature, and dissolved oxygen content during summer, 1957, through summer, 1958. Transport of water from the centre of the Alaska Gyral located northwest of the Station; and from the west, also appears to have influenced the water at the Station during autumn and winter. Vertical mixing during these seasons affects the structure of water in the upper zone by redistributing the properties. This mixing apparently causes water at depth of 100 m to be less saline in winter than at other times of the year. The progressive warming of water with depth in the upper zone during autumn and winter is attributed to this effect.

Table I

Observed seasonal changes of salinity in upper zone (0-100 m), precipitation minus evaporation (P-E), and possible effect of P-E in changing the salinity in upper zone.

Seasons	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter	Spring	Summer
Cruise No.	56-1	56-2	57-1	57-2	57-3	57-4	57-5	58-1	58-2
	Increase (+) or Decrease (-) of Salinity								
Upper zone (0-100 m)	-	-	-	+	+	-	+	+	
Halocline (100-200 m)	+	-	-	+	-	+	+	+	
Lower zone (200 m)	+	-	-	+	-	-	Negligible		

Observed change of salinity (‰/month) in
Upper Zone

-.014 -.019 -.007 +.023 +.032 +.033 +.054 +.020

Precipitation minus evaporation (cm/month)

+3.71 +4.75 +1.03 +3.94 +4.34 +5.01 -.081 -1.31

Salinity change (‰/month) in upper zone that can be
accounted for by effect of P-E

-.014 -.016 -.003 -.013 -.013 -.016 +.003 -.011

Table II

Observed seasonal change of heat content in upper zone (0-100 m) and halocline (100-200 m) and changes brought about by heat exchange at air-sea boundary.

Seasons:	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter	Spring	Summer
Cruise No.	56-1	56-2	57-1	57-2	57-3	57-4	57-5	58-1	58-2
	Increase (+) or Decrease (-) of heat content								
Upper zone (0-100 m)	-	-	+	+	+	-	-	+	
Halocline (100-200 m)	-	0	+	-	+	+	+	+	
Lower zone (200 m)	-	+	negligible	negl.	negl.	+	negl.	-	

Observed change of heat content (g-cal/cm²/day)
(mainly in upper zone)

Depth interval -197 -79 +126 +194 +138 -473 -130 +198
 0-120 0-130 0-150 0-150 0-100 0-100 0-110 0-130

Change of heat content (g-cal/cm²/day) from heat exchange at
air-sea boundary

-74 -80 +87 +170 +69 -309 -111 +109

Percent of change accounted for by heat exchange at air-sea
boundary

32 101 69 88 50 65 85 55

6. RANGE OF VARIATION OF WATER PROPERTIES AT
OCEAN STATION "P" (Lat 50° N, Long 145° W)

Salinity, temperature, and dissolved oxygen content data from 9 surveys between August 1956 and July 1958 have been examined for water characteristics and deviations about their mean values.

Tables III, IV, and V show the standard deviations of salinity, temperature, and dissolved oxygen content. Large deviations are generally encountered in the halocline. It is believed that these deviations are caused by internal waves.

In the depths below 200 m the deviations of salinity and temperature approach those arising from observational errors. But the deviations of dissolved oxygen content appear greater than that can be accounted for by observational errors. The large deviations are presumably due to water movements in the region.

In the upper zone (0-100 m) the salinity remained in the narrow range (0.4‰) between 32.6 and 33.0‰. The range increased to a maximum of 1.0‰ at depth of 125 m in the halocline (100-200 m). The temperature range decreased from a maximum of 9 C° in the upper 50 m depth to less than 3 C° at depth of 125 m. Below the halocline (200-1500 m) the scatter, and hence the ranges of both the salinity and temperature decreased with depth. At depth of 150 m the scatter was still appreciable, the salinity range was 0.6‰ and temperature range was 1.5 C°. However, at depth of 1000 m the ranges were only 0.05‰ and 0.2 C°.

The frequency distributions of both the salinity and temperature at the various depths was generally asymmetric. In some, the distributions were unimodal, notably those of salinity and temperature at depths greater than 400 m. In others, especially in the upper zone, they were bi-modal. At present it is difficult to ascertain whether the distributions are of NORMAL or POISSON type.

The two modes in the frequency distribution of salinity in the upper 50 m depth were due to the alternation of two different water masses in the region. In the frequency distributions of the temperature in the upper 50 m depth, there is one large peak in the winter temperatures and a smaller one in the summer temperatures. The large peak was associated with the large volume of water and hence larger heat capacity when the mixed layer was deepest in winter. The minimum frequency at temperatures between 9 and 10° C was due to the short period in spring and autumn when these temperatures occur. These periods corresponded to time of the maximum seasonal rate of change of temperature.

S. Tabata

	25 Aug - 26 Sep 1956	10 Nov - 7 Dec 1956	27 Jan - 2 Mar 1957	20 Apr - 29 May 1957	13 Jul - 21 Aug 1957	28 Sep - 29 Oct 1957	14 Dec 1957 - 22 Jan 1958	9 Mar - 16 Apr 1958	31 May - 8 Jul 1958
Cruise No.	56-1	56-2	57-1	57-2	57-3	57-4	57-5	58-1	58-2
Depth (m)									
0	.05	.03	.05	.07	.06	.05	.05	.05	.08
10	.04	.02	.02	.03	.05	.04	.04	.04	.05
30	.03	.03	.02	.02	.03	.03	.04	.04	.05
50	.01	.03	.02	.02	.03	.08	.03	.04	.04
75	.01	.01	.01	.03	.03	.03	.03	.04	.03
100	.02	.26	.08	.08	.07	.03	.13	.09	.04
125	.13	.18	.16	.16	.12	.09	.08	.26	.14
150	.12	-	.12	.07	.07	.08	.05	.07	.07
175	.04	-	.06	.05	.05	.07	.05	.02	.02
200	.01	-	.02	.04	.06	.09	.02	.02	.01
250	.01	-	.02	.02	.03	.05	.01	.02	.02
300	.02	-	.01	.02	.02	.04	.01	.02	.02
400	.00	-	.00	.01	.01	.02	.01	.01	.01
500	.01	-	.04	.01	.02	.01	.02	.01	.01
700	.00	-	.03	.01	.01	.01	.01	.01	.01
1000	.01	-	.02	.02	.01	.01	.01	.01	.01
1200	-	-	.03	.02	.02	.01	-	.00	.01
1500	-	-	-	-	.01	-	-	-	-

Table III. Standard deviations of salinity (‰) of water at Station "P" during period, August 1956 to July 1958.

Cruise No.	25 Aug - 26 Sep 1956		10 Nov - 7 Dec 1956		27 Jan - 2 Mar 1957		20 Apr - 29 May 1957		13 Jul - 21 Aug 1957		28 Sep - 29 Oct 1957		14 Dec 1957 - 22 Jan 1958		9 Mar - 16 Apr 1958		31 May - 8 Jul 1958	
	56-1	56-2	57-1	57-2	57-3	57-4	57-5	58-1	58-2									
Depth (m)																		
0	.82	.46	.11	.64	.86	.55	.66	.17	1.10									
10	.45	.46	.09	.61	.83	.51	.66	.17	.79									
30	1.65	.47	.09	.59	.71	.49	.65	.15	1.08									
50	.44	.47	.10	.60	.72	1.31	.64	.16	.20									
75	.14	.35	.09	.42	.27	.43	.56	.14	.24									
100	.15	.11	.28	.31	.10	.28	.66	.20	.07									
125	.11	.14	.19	.41	.22	.32	.38	.29	.15									
150	.06	-	.09	.05	.07	.37	.24	.26	.12									
175	.03	-	.03	.07	.06	.05	.14	.16	.12									
200	.07	-	.06	.03	.04	.05	.11	.11	.12									
250	.04	-	.03	.02	.04	.05	.05	.13	.05									
300	.01	-	.03	.08	.05	.05	.03	.08	.07									
400	.02	-	.02	.06	.07	.05	.04	.07	.08									
500	.06	-	.03	.01	.04	.04	.03	.05	.02									
700	.02	-	.02	.04	.03	.03	.02	.04	.03									
1000	.03	-	.03	.02	.02	.02	.02	.01	.03									
1200	-	-	.03	-	.03	.02	-	.02	.03									
1500	-	-	-	-	.03	-	-	-	-									

Table IV. Standard deviations of temperature (°C) of water at Station "P" during period, August 1956 to July 1958.

Cruise No.	25 Aug - 26 Sep 1956	10 Nov - 7 Dec 1956	27 Jan - 2 Mar 1957	20 Apr - 29 May 1957	13 Jul - 21 Aug 1957	28 Sep - 29 Oct 1957	14 Dec 1957 - 22 Jan 1958	9 Mar - 16 Apr 1958	31 May 0 8 Jul 1958
Depth (m)									
0	.014	.012	.010	.011	.016	.010	.012	.032	.038
10	.023	.013	.009	.011	.010	.007	.012	.032	.015
30	.028	.014	.012	.010	.012	.012	.011	.032	.018
50	.017	.014	.016	.020	.014	.024	.011	.033	.009
75	.011	.010	.010	.011	.009	.017	.021	.034	.019
100	.013	.008	.033	.019	.021	.007	.015	.038	.014
125	.044	.028	.033	.042	.036	.014	.024	.050	.039
150	.038	-	.052	.033	.032	.022	.025	.029	.018
175	.022	-	.022	.035	.035	.022	.022	.015	.012
200	.014	-	.020	.030	.041	.026	.023	.024	.014
250	.014	-	.020	.010	.029	.025	.029	.020	.019
300	.009	-	.026	.010	.026	.016	.034	.017	.014
400	.005	-	.010	.020	.016	.016	.020	.002	.008
500	.010	-	.004	.012	.003	.003	.030	.005	.007
700	.010	-	.006	.004	.005	.005	.019	.007	.006
1000	.012	-	.005	.007	.006	.003	.014	.005	.000
1200	.010	-	.012	.005	.008	.009	-	.023	.002
1500	-	-	-	-	-	-	-	-	-

Table V. Standard deviations of dissolved oxygen content (mg at/l) at Station "P" during period, August 1956 to July 1958.

7.

THE COASTAL-SEAWAYS PROGRAM

Three Coastal-Seaways cruises were carried out in 1959 with the purpose of monitoring oceanographic conditions from the open ocean into the seaways, and to allow description of some of the variation in properties related to tides. The surveys were carried out during the periods March 31 - April 22, June 8 - July 2, and November 16 - December 13, 1959. An example of a cruise plan is shown in Figure 14.

At each station the usual serial observations of temperature, salinity and dissolved oxygen were made as well as a BT lowering. Nitrates were determined at three stations in the Hecate Straits, in each survey. Plankton samples were taken when possible.

During the cruises anchor stations were occupied for 24 hours off McInnes Island (Pos. 74, Milbanke Sound) in April and June, off Amphitrite Point (Pos. 34) in June, and in Saanich Inlet (Pos. 1-7) in June and November. At these stations observations of temperature, salinity and dissolved oxygen were made as well as direct current measurements. The vertical distribution of each was determined at regular intervals. Some turbidity measurements were also made.

The Data

Salinities. Studies of the data indicate that relatively low salinity water exists adjacent to the coast during most of the year (Fig. 15). The water appears to be continuous along the entire coast from the Columbia River, in through Queen Charlotte Sound, through Hecate Strait, out through Dixon Entrance, and along the Alaskan Coast.

The source of this low salinity water is mainly land drainage. Seasonal variation in the fresh water runoff appears to be reflected in variation in the low salinity coastal water. In order for this system along the coast to have continuity it must be continually replenished by land drainage. A preliminary summary of all available data from past surveys, shows that on the average the continuity is most marked in winter and summer, and less so in early spring and fall.

Temperature. It is considered that the survey during the period March - April was made at a time when surface temperatures were near their annual minimum. These varied between 9.5° to 7.0° C, from the southern to the northern part of the region. Temperatures increased by 0.5° C in 60 miles offshore, then decreased.

The June surveys (Fig. 16) showed that the water temperatures had increased by 4.0° to 5.5° C from the April survey. Stations repeated eight days apart showed an increase of about 0.12° C per day. During June, temperatures increased by about 1.0° C for 60 miles offshore, then decreased again, as in March.

By November temperatures had dropped from their June levels and there was a 2.0° C range between offshore and inshore areas.

A summary of all available data is nearing completion. From this it is evident that the isotherm distribution takes on the shape of a "tongue" which extends northward along the coast, intensifying and

expanding from April to September, then decaying to March. The "tongue" is divided off Queen Charlotte Sound, part extends along the coast like a long finger, and part extends into Queen Charlotte Sound and Hecate Strait.

Time series. Studies of the data obtained at anchor stations indicate that considerable tidal variation of the properties occurred at some depths, and very little at others. The range of these is shown in Table VI.

Observations taken at a position at high water slack, and again on low water slack, showed marked differences. This was noticed especially in tidal passages. For example, in Discovery Passage (Positions 127, 128) the salinity and dissolved oxygen concentration changed by much as 1.00 ‰ and 1.00 ml/l during one tide in November. In another tidal passage very little variation occurred.

In any seaway where there is a longitudinal gradient of properties, and there is reversing tidal movement, there will be a cyclic variation in water properties at any one position in the system. Such things as diurnal heating and winds distort the fundamental cycle of variation related to tidal movement.

Current measurements. Current data observed 1.5 miles off Amphitrite Point (Position 34) showed the current direction rotated clockwise. The currents tended to be onshore at high tide and offshore at low tide, northwest during the flood and southeast during the ebb. Velocities to the northwest were of the order of 0.4 to 0.5 knots. Those to the southeast were 0.4 to 0.5 knots. Surface currents tended to be biased toward the southeast, and those 10 metre depth toward the north. Bottom currents were of the order of 0.2 to 0.4 of a knot flowing almost steadily to the northwest.

In Milbanke Sound (Position 74) the surface and 10 metre currents showed a definite outflow from Milbanke Sound. At 50 and 100 metres depth the currents tended to rotate. At 240 metres depth the movement tended to be toward the southern shore. Maximum velocities varied between 0.5 and 0.6 knots at the surface and 10 metres. At 50 and 100 metres depth the maximum velocities varied between 0.4 and 0.5 knots. At the bottom the maximum velocities varied between 0.3 to 0.4 knots.

R.H. Herlinveaux

Table VI

Maximum and minimum values of temperature and salinity
observed at time series anchor stations in June 1959.

Depth (m)	Milbanke Sound Position 74		Amphitrite Pt. Position 34		Saanich Position 1-7	
	Max.	Min.	Max.	Min.	Max.	Min.
Temperature						
0	14.8	12.7	14.2	12.2	13.1	12.5
10	12.1	10.8	12.3	11.4	9.9	9.6
20	* 10.8	10.3	11.3	10.6	10.1	9.0
50	* 8.4	7.9	9.3	8.9	9.3	9.0
100	7.4	7.2	8.3	8.0	8.9	8.7
Salinity						
0	29.8	29.4	30.5	29.5	29.0	28.7
10	31.0	30.0	31.1	30.7	29.3	29.2
20	* 31.3	30.7	31.5	31.3	29.7	29.5
50	* 32.0	31.7	32.2	31.8	30.2	30.0
100	33.1	32.9	33.0	32.5	31.0	30.2

* Interpolated

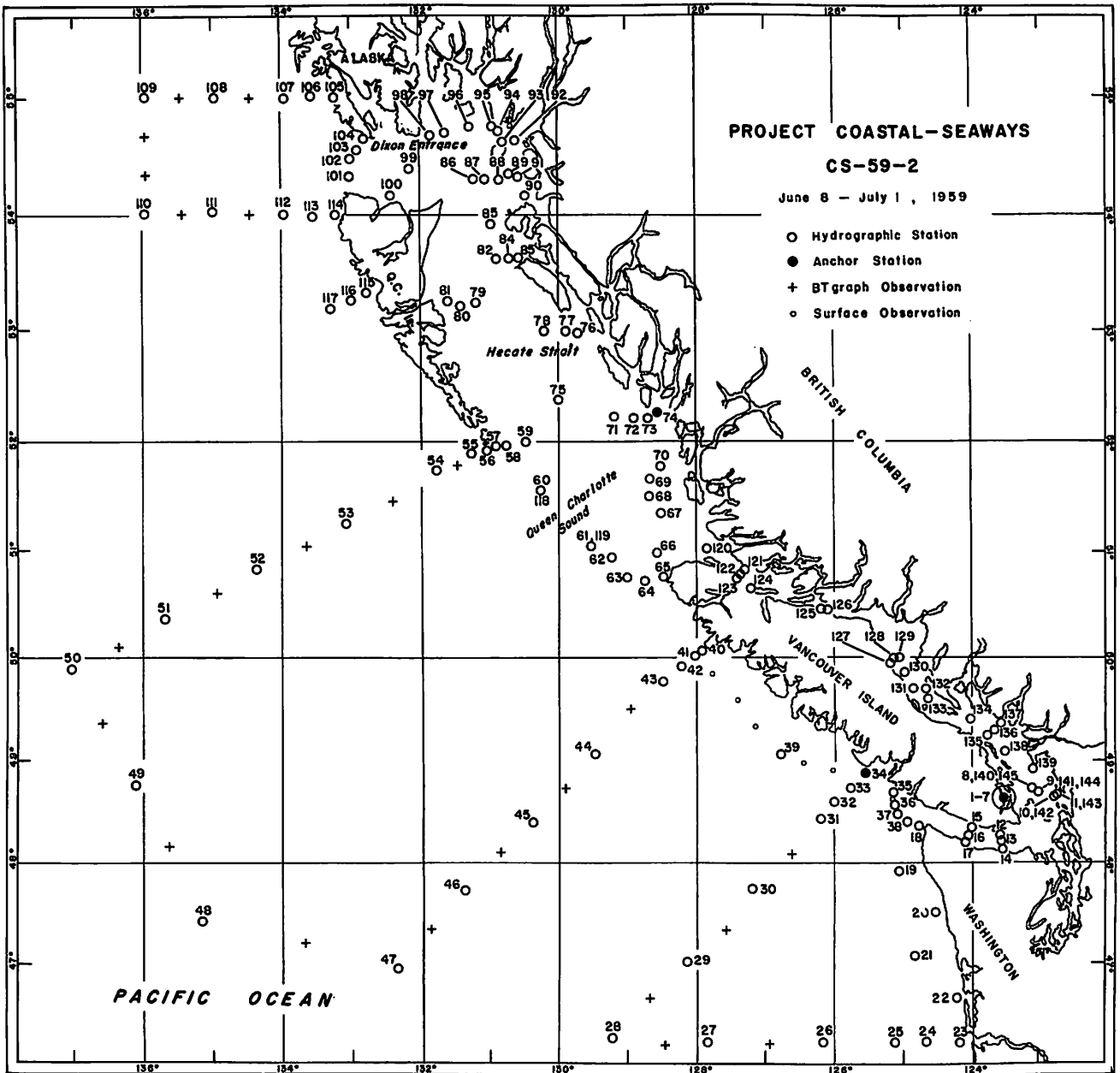


Figure 14.

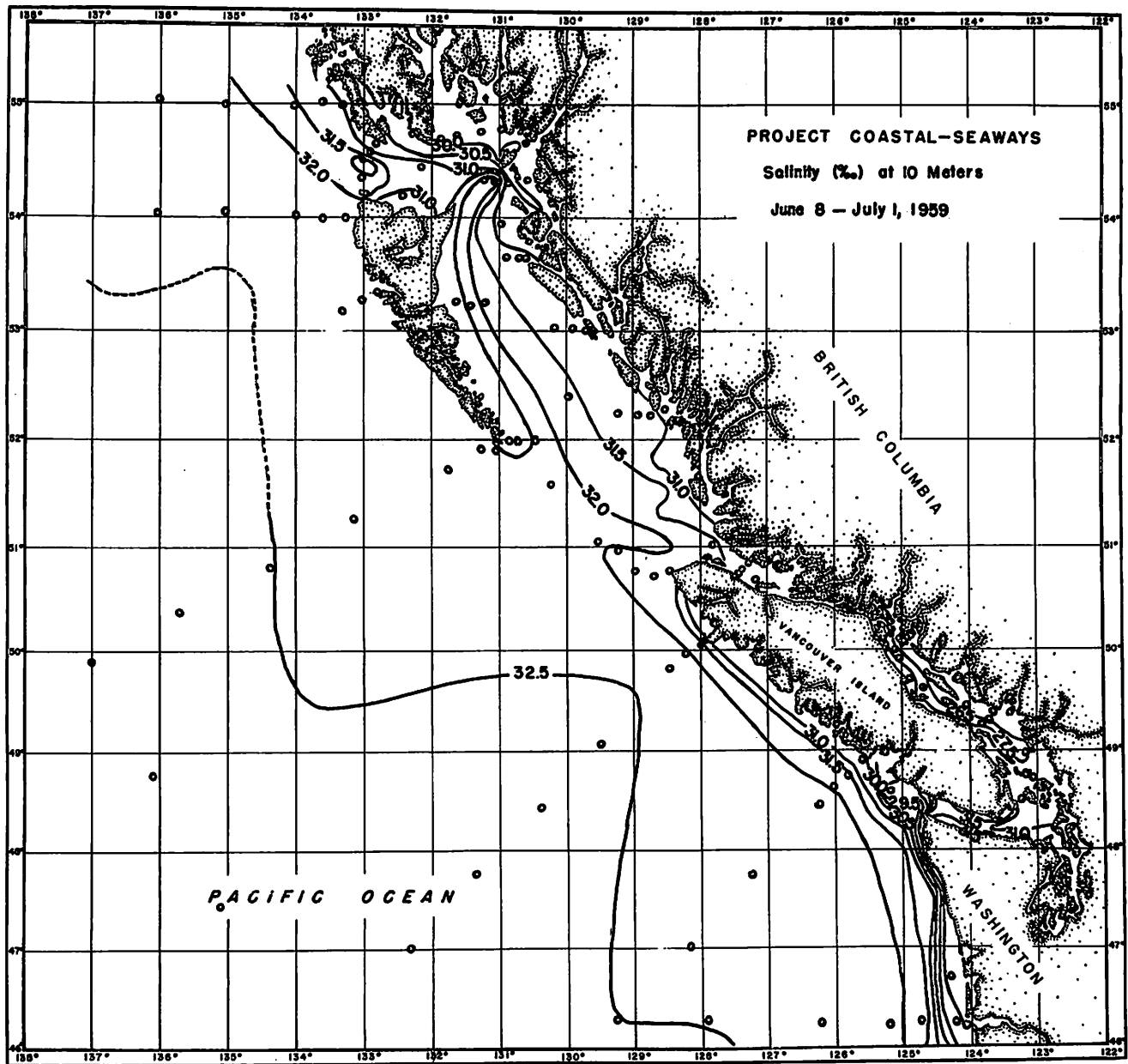


Figure 15.

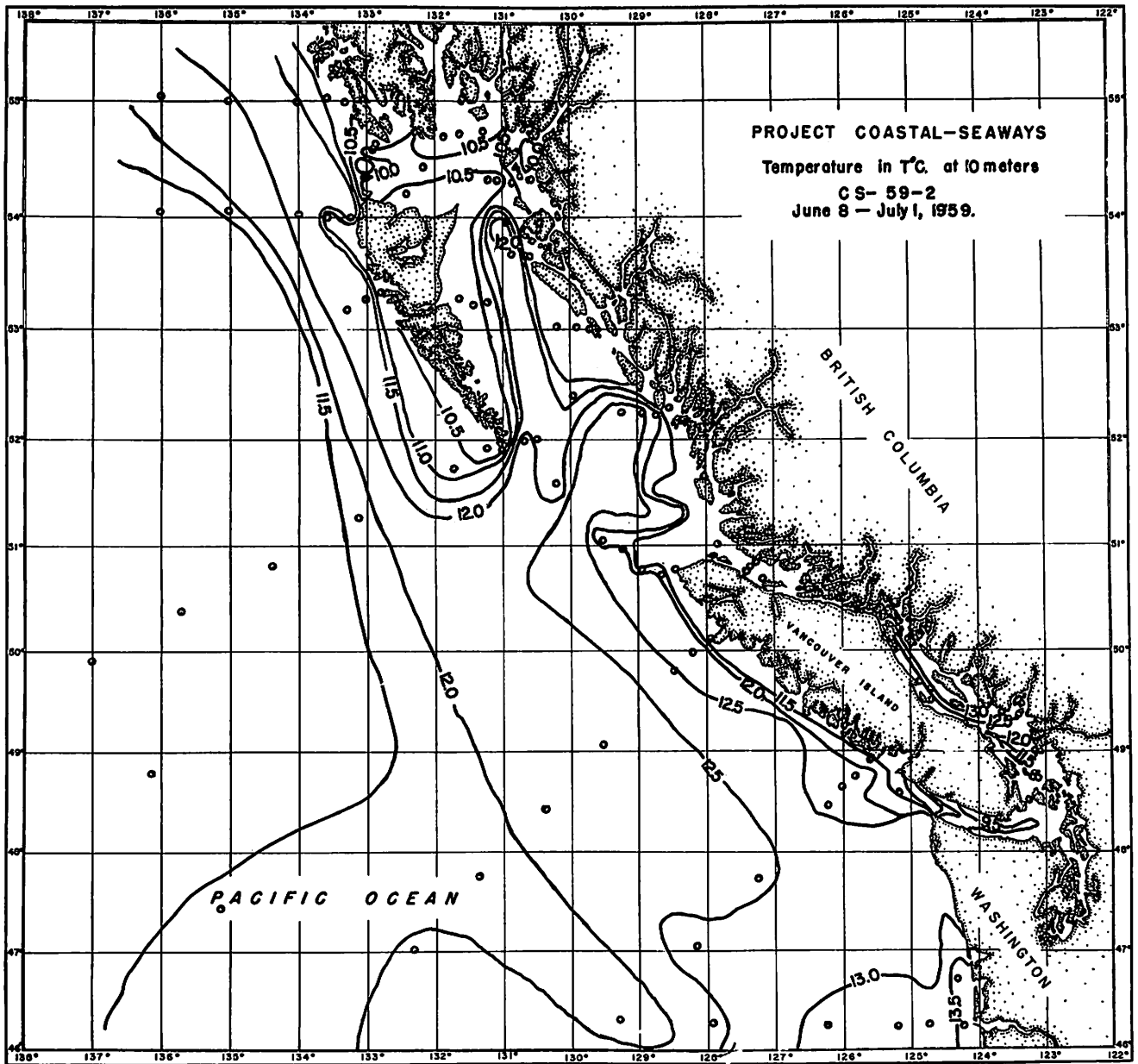


Figure 16.

8.

COASTAL INVESTIGATION

A preliminary investigation was made of all available data gathered by P.O.G. in the waters over the continental shelf along the west coast of Canada. This material was reviewed with an intent to establish the groundwork for a more comprehensive investigation of these waters. In addition to this review and to a study of several papers involving this area, much of the available meteorological data were used. The latter were acquired for the purpose of clarifying the relationships between the meteorological elements and the oceanographic properties being observed.

The vertical temperature and salinity profiles were studied in the light of the effect of basic physical mechanisms on their seasonal variations. Two major difficulties encountered were the supposed representativeness of the data, and the time scales involved. It was found that isolated sets of data were necessarily taken to be representative for large periods of time. Land meteorological data, modified or not, had to be used for the sea area being studied. Some of the basic mechanisms could not be adequately considered as the data dictated too great a time scale.

Several features were apparent, as expected. For example, seasonal changes in atmospheric temperature, precipitation and fresh water runoff, with provision for shallow-water mixing, were found to contribute satisfactorily to salinity and temperature changes in the upper layers of the sea. Special attention was paid to the wind mechanism and its effects. It was found that there is evidence of an upwelling situation on the shelf under proper wind conditions and yet stronger evidence of the reverse situation (i.e. convergence) under others. The time scale involved was not detectable, but the existence of the summer high pressure area and the winter low pressure area over the northeast Pacific provide an almost seasonal representativeness of the wind directions in the area of study.

It is felt that for even a preliminary report on the oceanographic features of this region, a planned study of the meteorological elements, tidal action, transport processes, and the interaction of coastal and oceanic waters must be made using the necessary time scales. These processes should be considered for a detailed explanation of the temperature and salinity distribution and continuity.

R.K. Lane.

9.

DAILY SEAWATER OBSERVATIONS, 1959

Observations

Surface (3-foot) seawater temperature observations and collection of salinity samples have been continued at twelve lighthouse locations on the B.C. coast (Fig. 17). Daily observations have also been made at the Swiftsure Bank and Umatilla Reef lightships by personnel of the U.S. Coast Guard service. Twice-daily bathythermograph casts and relevant meteorological observations were also made at these two latter locations. Personnel of the Department of Fisheries have made daily water temperature observations of the Fraser River at New Westminster, B.C.

An inspection trip to most of the observing lightstations was made during the period September 8 to 23. Rough weather prevented completion of the trip to stations on the west coast of Vancouver Island. Water sampling equipment and procedures were examined and discussed. A remarkable spirit of cooperation and interest was prevalent amongst this group of observers.

Circulation of data

A weekly report of daily seawater temperatures from the four lightstations of Amphitrite Point, Entrance Island, Triple Island and McInnes Island, is received each Monday at Nanaimo through the facilities of the Marine Radio Branch of the Department of Transport. These reports are tabulated and a summary of conditions and trends is prepared and sent to the Farm and Fisheries Department of the Canadian Broadcasting Corporation at Station C.B.U. in Vancouver, B.C. This is presented every Wednesday morning at 0640 on the Fishermen's Broadcast program. This service to the C.B.C. has been provided continuously since April 1955.

Mid-month (11 to 20 incl.) reports of daily seawater temperature records have been received since February 1959 over the Department of Transport Marine Radio facilities from the lightstations at Langara Island, Cape St. James and Kains Island. These reports, along with records from Amphitrite Point, have been sent to the Albacore Investigations Section of the Bureau of Commercial Fisheries, U.S. Fish and Wildlife Service, in Honolulu, Hawaii. These data were used by U.S. oceanographers to assist in the compilation of their monthly surface temperature charts of surface seawater temperatures for the mid-month period (11 to 20 incl.) in the Northeast Pacific Ocean. The preparation of these charts by the Honolulu Laboratory was discontinued in December 1959. Instead, a full month chart will now be prepared, starting January 1960, by the Point Loma Biological Laboratory of the Bureau, at San Diego, California. Arrangements have been made to send them a more extensive report of daily seawater temperatures, from the four stations for the monthly period 1 to 27 inclusive.

The immediate availability of these data from eight daily seawater observation stations made it possible to prepare a monthly analysis and summary of surface temperature conditions in B.C. coastal waters. These reports were presented as multilithed circulars, one for each month, and were usually printed and distributed (70 copies) 10 days after the end of the month reported.

During the past year, computations have been made, using the ALWAC III-E digital computer, that show the standard deviations of the monthly mean temperatures and salinities from the 10-year average values for the period 1949-58. The significance of monthly anomalies can now be assessed, and the following report has been made with these allowable limits of deviation in mind.

Temperature

Generally, B.C. coastal seawater temperatures in 1959 were warmer than the 10-year average values of 1949-58. This was a continuation of the same trend noticed in 1957 and 1958, but the anomaly was much less (about 2° F) in 1959 than in 1958. In quite a number of instances (Table VII) the positive anomalous value (1959 warmer-than-average) could be considered to be within the range of the normal deviation of monthly mean temperatures,

and thus would indicate average conditions. In comparison with 1958 levels of seawater temperatures, 1959 monthly means were usually colder, with the notable exception of the period June to December at Langara Island, when temperatures were about 2° F warmer than in 1958.

In the northern B.C. coastal regions, monthly mean seawater temperatures at Langara Island were about 2° F warmer than average (10-year) during the months of March, July, September and December, and average for the remainder of the months. Further inshore, Tiple Island temperatures were significantly warmer-than-average during April, May and July. McInnes Island monthly mean temperatures were also quite warm in July, but otherwise only slightly warmer than average. Air temperatures in northern B.C. coastal regions were generally average, or warmer than average during the period March to July.

Cape St. James temperatures were about 2° F warmer than average during the first five months of the year - January to May. Following a period of average summer water temperatures, there was a significant cooling off in September. This was succeeded by an equally significant warming up in October. This cool September could be related to the fact that during this month air temperatures were 2° below normal. Water temperatures at Cape St. James during the summer months of May to September were about 3° F colder than in 1958, but warmed up rapidly in October to give a warmer anomaly.

Along the west coast of Vancouver Island, monthly mean water temperatures at Kains Island were warmer than average during the first seven months, especially in March. This same trend was recorded at Amphitrite Point with March, April and June anomalies being most significant. Temperatures were average, or cooler than average, during the remainder of the year, especially during August at Kains Island, and during November at Amphitrite. Air temperatures on the west coast had been 2° below normal during both months. Temperatures at Swiftsure Bank and Umatilla Reef Lightships also followed this same general trend of warmer in the first half and cooler in the second half of the year, as compared to their shorter term average periods of 4 and 3 years.

The warmer-than-average trend was more noticeable in the three stations of Pine Island, Cape Mudge and Race Rocks, than in any of the others. These Stations are typified by having small annual ranges of temperature due to the fast flowing well-mixed character of the waters surrounding them. Thus they sample a much larger body of water and are not so subject to the local vagaries of short-term meteorological and oceanic fluctuations. At Pine Island there was a significant warmer-than-average trend for the five-month period of March to July. At Cape Mudge a similar anomalous condition was noted for the same period and again in September. Further south, Race Rocks' monthly mean temperatures were significantly warmer than average during the six-month period March to August.

In the Strait of Georgia, temperatures were generally average, or slightly warmer, at Entrance Island and Departure Bay. The months of March and April were significantly warmer at Entrance Island. During the latter half of the summer the average-condition trend was interrupted at Departure Bay during August and September by a real (1° F) colder-than-average anomaly, which was paired at Entrance during September. Conditions then returned to more normal temperatures for the remainder of the year. The temperature anomaly pattern at Entrance Island was closely duplicated in

the Fraser River water temperature values where March and April monthly means were significantly warmer than average, and September was colder than average. These Strait of Georgia surface water temperature anomalies are closely allied with meteorological anomalies of similar nature. March and April air temperatures were normal or slightly above normal on the B.C. coast, and in September they were 2° to 4° below normal. East Point temperatures appear to show opposite anomalous trends than at the other two Strait of Georgia stations. The early summer months of May and June were colder than the 6-year average, whilst the following two months of July and August were warmer than the average.

The salinity records are not as complete as the temperature because in most instances the case of water samples for the last quarter of the year have just been received, but the salinities have not been determined. The general trend in the first eight months of 1959 is to normal and/or lower-than-average monthly means, with the exception of Langara Island records. Here, February salinities were significantly lower than average, but June and July were higher than average.

Triple Island salinities were average until May and June when there was a significant lowering of values. Further south, McInnes Island salinities were definitely lower than average during May and June. Both stations were probably affected by increased mainland run-off in these months due to greater-than-normal precipitation, especially in June when there was a 50-100% surplus along the northern B.C. coast. Cape St. James' salinity was normal during the first part of the year. Delivery of water sample cases from this location has been delayed considerably due to inconvenient three-month interval between light-tender trips. Pine Island salinities were average.

There is some correlation between the salinity anomalies at the two west coast stations of Kains Island and Amphitrite Point. January, March and June salinities at Kains Island were significantly lower than average. This same trend was reflected to a lesser degree in the Amphitrite Point values, but then a significant, higher-than-average anomaly was recorded at this location in July and August. This was followed in September by a return to the lower-than-average anomaly. Swiftsure Bank and Umatilla Lightships both tend to have lower-than-average salinities, especially in the summer months.

In the Strait of Georgia, Cape Mudge salinities were average until August when a higher-than-average anomaly was observed. This condition was also recorded in Depature Bay salinity data, where otherwise the monthly means were average. Entrance Island salinity records showed a lower-than-average anomaly in January, followed by average values for the remainder of year's first half. East Point salinity anomalies are all quite high, and it is probable that if 10-year comparison values were available there would be significant lower-than-average salinity values.

Race Rocks monthly mean salinities were significantly lower than average during the months of April, May and July.

H.J. Hollister

Table VII

B.C. Coastal Monthly Mean Seawater Temperatures and Salinities, 1959

Differences from 1949-58 10-year Means

(+ higher, - lower, than mean)

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Langara I.	T ^o F	-0.8	-0.3	+1.7	+0.8	+0.3	+0.2	+1.7	+0.1	+1.9	-0.1	+2.2
	S‰	-0.25	-0.29	-0.37	+0.08	+0.22	+0.18	+0.17				
Triple I.	T ^o F	+0.3	+1.3	+0.7	+1.3	+0.3	+3.2	-0.5	-0.9	+0.6	-0.5	-0.5
	S‰	-0.15	-0.06	-0.08	-0.13	-0.71	-0.19	-0.48	-0.32	+0.04		
McInnes I. (1955-58, 4 yrs)	T ^o F	+0.9	+0.6	+1.5	+0.8	+0.1	+2.0	-1.3	-0.5	+0.4	+0.4	+0.5
	S‰	+0.17	-0.22	-0.34	-0.35	-0.65	-0.87	+0.00	+0.33	-0.65	+0.72	
Cape St. James	T ^o F	+1.4	+1.8	+1.6	+2.3	+1.3	+0.7	+0.2	+0.8	-1.3	+1.5	+0.1
	S‰	+0.04	+0.05	-0.01	-0.02	-0.07	-0.04	-0.01	-0.07	+0.20	+0.07	+0.08
Pine I.	T ^o F	+0.7	+1.1	+1.2	+1.3	+0.9	+1.4	+0.7	+0.2	+0.3	-0.1	-0.4
	S‰	-0.11	-0.04	-0.15	-0.09	-0.14	-0.12	-0.04	-0.05	+0.13	+0.26	+0.38
Kains I.	T ^o F	+0.6	+1.0	+1.2	+0.6	+0.7	+0.9	+0.5	-1.7	-0.1	+0.4	-1.1
	S‰	-1.26	+0.22	-1.15	-0.07	-0.46	-0.57	-0.29				-
Amphitrite Pt.	T ^o F	+1.4	+1.2	+1.3	+1.4	+1.1	+1.6	+0.0	-0.2	+0.7	+0.0	-1.3
	S‰	-0.29	+0.04	-0.35	-0.41	-0.38	-0.52	+0.47	+0.65	-0.59	+0.39	+1.16
Swiftsure I/s (1955-58, 4 yrs)	T ^o F	+0.2	+0.1	+1.0	+0.6	+0.4	+1.7	+0.1	-1.1	-0.8	-1.1	-2.5
	S‰	+0.34	-0.37	+0.29	-0.26	-0.79	-0.42	-0.24	-0.11	-0.49		+0.6
Umatilla I/s (1956-58, 3 yrs)	T ^o F	+1.0	+0.4	+0.1	-0.8	-0.3	+1.4	-0.4	-1.5	-0.1		
	S‰	-0.33	-0.22	-0.06	-0.36	-0.17	-0.92	-0.24	+0.09	-0.20		
Cape Mudge	T ^o F	+1.2	+0.7	+0.7	+0.8	+1.2	+2.3	+2.0	+0.5	+1.9	+1.1	-0.4
	S‰	-0.51	-0.06	-0.28	-0.19	+0.17	-0.69	-0.31	+0.70	-0.05	+0.15	+0.64

Table VII (cont'd)

B.C. Coastal Monthly Mean Seawater Temperatures and Salinities, 1959

Differences from 1949-58 10-year Means

(+ higher, - lower, than mean)

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Entrance I.	T ^o F	+1.2	+0.2	+1.5	+0.9	+0.5	+0.7	-0.2	-0.3	-1.0	+0.5	+0.8	+0.3
	S ‰	-0.83	-0.62	+0.29	-0.25	-0.76	-0.38	+0.65	+1.49	-1.54	-2.10	-0.33	-0.19
Departure Bay	T ^o F	+1.6	+0.2	+0.8	+1.3	-0.1	+0.8	-0.2	-1.2	-1.3	+0.6	+0.6	+0.6
	S ‰	-0.87	+0.32	-0.19	-0.01	-0.50	-0.97	+0.26	+1.89	-2.07	-1.63	+0.74	+0.86
East Point (1954-58, 6 yrs)	T ^o F	-0.2	+0.2	-0.3	-0.8	-1.2	-1.1	+2.3	+1.6	±0.0			
	S ‰	-2.05	-2.42	-2.46	-2.68	-0.98	-5.15	-3.34	-0.23	+0.74			
Race Rocks	T ^o F	+1.0	+0.9	+1.3	+1.8	+1.1	+1.1	+1.7	+0.9	+0.1	+0.3	-0.5	-0.1
	S ‰	-0.15	-0.24	-0.09	-0.25	-0.16	+0.02	-0.50					
Fraser River		+2.4	+1.5	+2.5	+2.0	+0.7	+1.3	+0.5	-1.7	-2.7	-0.6	-1.3	+1.0

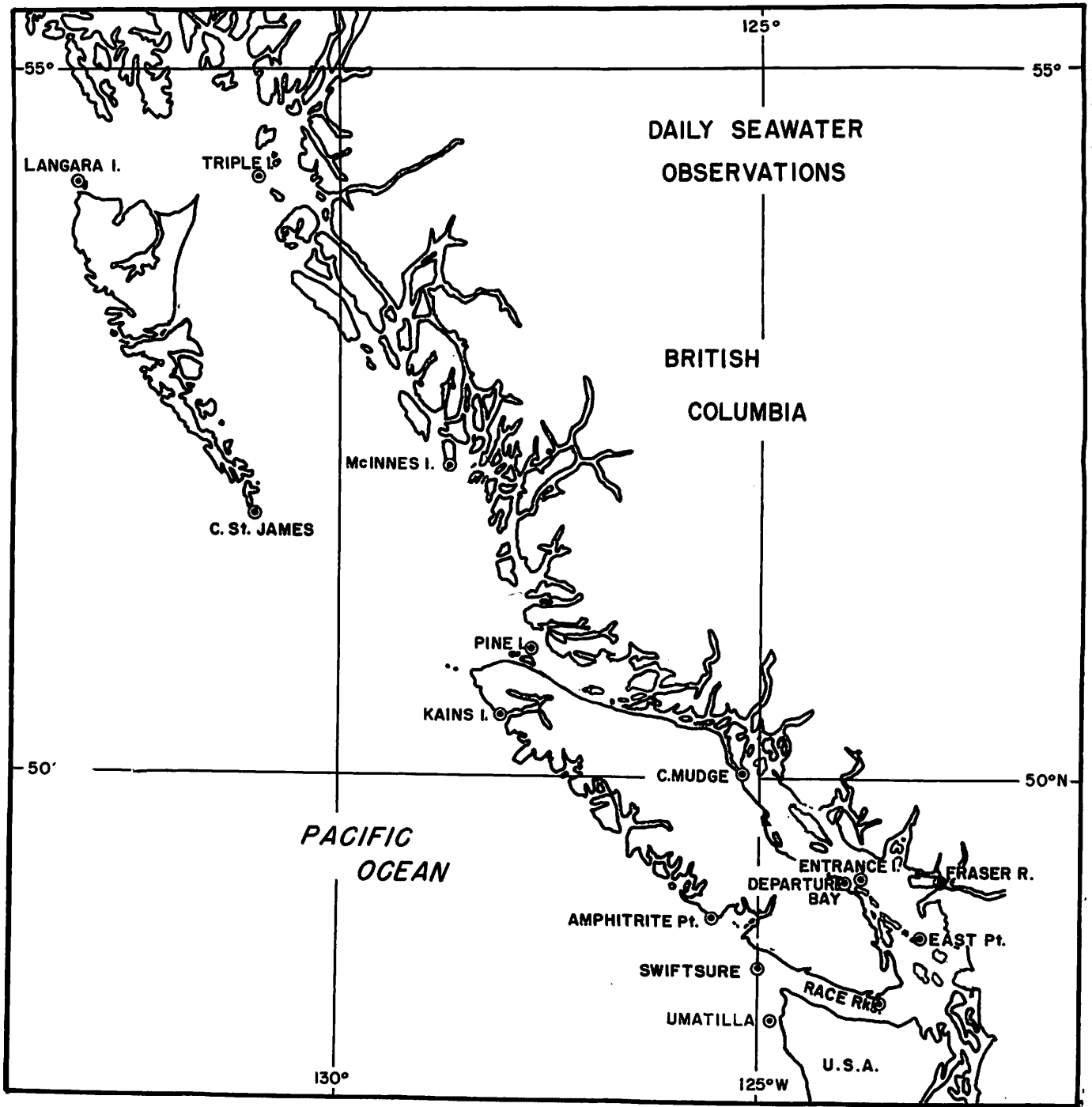


Figure 17.

10.

HECATE MODEL

May - June, 1959

This period was primarily used to determine what weather conditions were favourable for reliable results to be expected of the model.

Finding the effect of wind proved difficult because there was no adequate device for accurate measurement of its velocity. Attempts were made to find some correlation between size of surface ripples and (a) wind direction, (b) wind velocity.

However, results were so scattered that no correlation was found with direction while a velocity greater than one mile per hour ruffled tide curves considerably. This was very unfortunate because there are invariably gusts exceeding one mile per hour several times a day.

Solar heating provided two problems. First, unequal heating of shallows and depths caused convection currents, and second, the apparatus functioned poorly on hot days. This meant that consistent results could not be obtained in the daylight hours, so it was necessary to work at night. The model was usually put into operation one hour after sunset and shut down before sunrise. This period of day was judged to be the most stable. Weather reports were always consulted before attempting night work. The change of hours produced astonishing results, not only in the functioning of the model, but also in the number of tests carried out.

July - September, 1959

During these months, extensive testing was done to determine the relationship between the two tide machines and the two reference points. Initial trials were based on the assumption that the tide produced by one machine operating alone would combine linearly with the tide produced by the other machine operating alone. This assumption proved false. Extremely artificial tides were produced by single machine operation. A different approach was indicated by a simple mathematical analysis of the situation.

Rise and fall at any point in the model is governed by the combined motion of the two tide machines. The time interval for high water to pass from one point to a second point is governed similarly. By considering the two reference points, Prince Rupert and Wadhams, a relation involving a set of four simultaneous equations in four unknowns was found. The equations were linear with constant coefficients. The coefficients were in the form of first partial derivatives, involving changes in reference amplitude and phase with respect to incremental changes in tide machine amplitude and phase. (The term "phase" is used loosely here. The reference phase refers to the time interval required for high water to pass from Wadhams to Prince Rupert. The tide machine phase refers to the position of the tide generators, maximum inward displacement corresponding to high water.) This gives a total of sixteen coefficients which were determined experimentally. These are as follows. The notation used is described immediately below them.

$$\left[\begin{array}{cccc}
 \frac{\partial a_{PR}}{\partial a_{DE}} & \frac{\partial a_{PR}}{\partial a_{QC}} & \frac{\partial a_{PR}}{\partial \phi_{DE}} & \frac{\partial a_{PR}}{\partial \phi_{QC}} \\
 \frac{\partial a_W}{\partial a_{PE}} & \frac{\partial a_W}{\partial a_{QE}} & \frac{\partial a_W}{\partial \phi_{DE}} & \frac{\partial a_W}{\partial \phi_{QE}} \\
 \frac{\partial \phi_{PR}}{\partial a_{DE}} & \frac{\partial \phi_{PR}}{\partial a_{QC}} & \frac{\partial \phi_{PR}}{\partial \phi_{DE}} & \frac{\partial \phi_{PR}}{\partial \phi_{QC}} \\
 \frac{\partial \phi_W}{\partial a_{PE}} & \frac{\partial \phi_W}{\partial a_{QE}} & \frac{\partial \phi_W}{\partial \phi_{DE}} & \frac{\partial \phi_W}{\partial \phi_{QE}}
 \end{array} \right]$$

- a_{PR} - amplitude at Prince Rupert in feet.
- a_W - amplitude at Wadhams in feet.
- ϕ_{PR} - phase lag at Prince Rupert in seconds.
- ϕ_W - phase lag at Wadhams in seconds.
- a_{DE} - amplitude of Dixon Entrance tide machine in inches.
- a_{QC} - amplitude of Queen Charlotte tide machine in inches.
- ϕ_{DE} - number of degrees Dixon Entrance tide machine leading Queen Charlotte tide machine.
- ϕ_{QC} - number of degrees Queen Charlotte tide machine leading Dixon Entrance tide machine.

"Phase lag" refers to the time interval between maximum inward displacement of the Queen Charlotte machine and high water at the point in question. "Number of degrees" refers to a setting on the computer.

It was mentioned that the equations were linear. This is not entirely true. For example, the plot of amplitude of tide at Prince Rupert (a_{PR}) versus phase of the Queen Charlotte tide machine (ϕ_{QC}) is a curve which can be approximated by two straight lines. See Figure 18.

Since it was not anticipated that a large difference in phase would be needed to produce a natural tide, the more sloping curve was chosen. This choice of discriminant was born out in practice. The slope of the line gives $\partial a_{PR} / \partial \phi_{QC}$

The curve shown in Figure 18 indicates the manner in which the coefficients were determined. Each coefficient required a plot of its two variables. The slope of the curve gives the numerical value of the coefficients if the units indicated above are retained.

Once the coefficients were found, the set of equations enabled computation of the necessary tide machine relations to produce a desired tide at the reference points.

It must be emphasized that this is not an exact solution of the calibration problem nor does it give unique results. This is because:

- (a) all the curves were not exactly straight lines. The best straight lines computed by the method of least squares was used in all cases.
- (b) some of the curves are definitely non-linear at the extremis.

In consequence the mean ranges of tides are followed quite well (negligible error) but very low (less than 10 feet at Prince Rupert) or very high tides (more than 20 feet) shown considerable discrepancy.

All tests were carried out on a single tidal component. The lunar semi-diurnal was chosen because it accounts for 47.3% of the tide in this region. The question of frequency response therefore arose. Further tests showed that within the semi-diurnal group, there is no frequency dependence. The same is true of the diurnal group. However, there is a small difference when moving from one group to the other.

October - November, 1959

In order to test the accuracy of the coefficients, a tide starting at October 1, 1959 was set on the computer. Prince Rupert tidal constants were used in establishing the initial conditions. The resulting tides were recorded and compared with the Prince Rupert Tide Tables. The agreement was best in the latter half of the period, and only in cases of extreme tides did the discrepancies exceed two feet (8% of the range) in Nature. This was permissible since the main features of the tidal sequence were reproduced.

Floats were introduced at points corresponding to the positions where tidal current data had been collected in Nature. A sequence of photographs, one every high tide, were made starting from the last week in November and running till January, 1960. The resulting water movements compared well with those observed in Nature.

Summary

The weather conditions under which the model can operate are now established.

A semi-empirical method to compute movements of the tide generating machines to produce a desired tide has been developed.

A first trial at reproducing a natural tide has been made and found successful within the limits of the semi-empirical method.

N.E.J. Boston.

QUEEN CHARLOTTE LEADING DIXON ENTRANCE

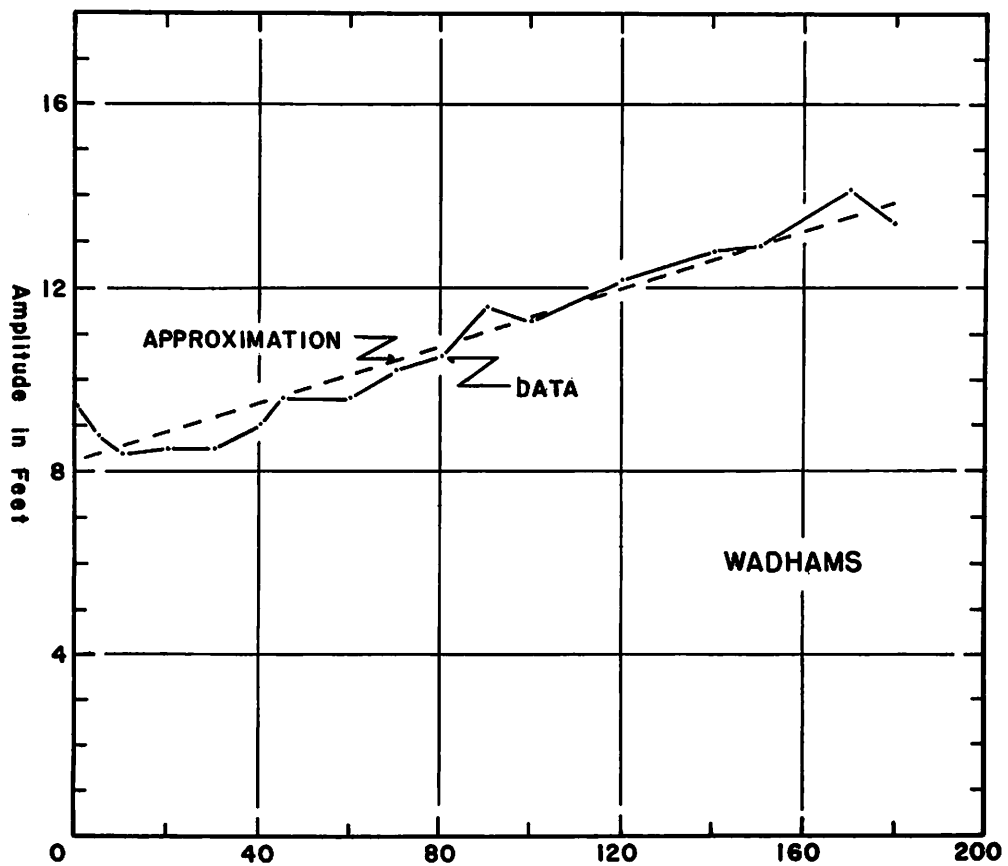
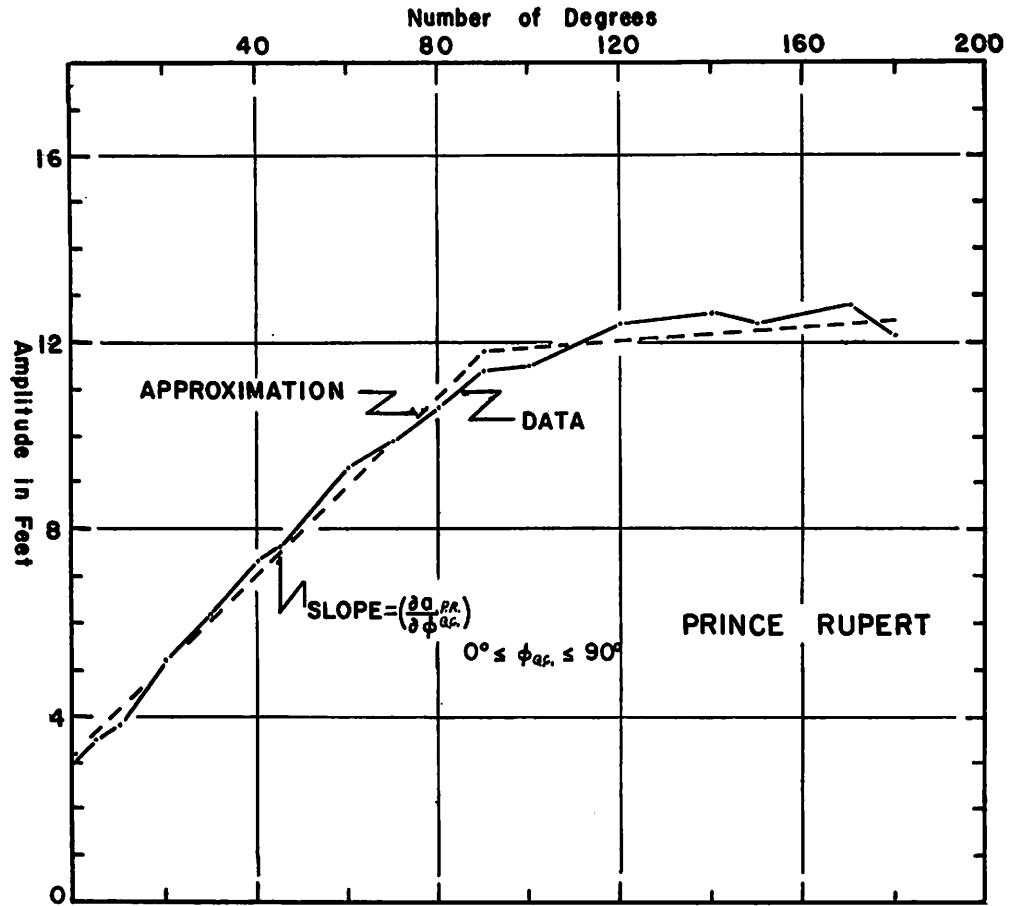


Figure 18.

11. FILTER FOR HECATE MODEL TIDE GAUGE

A problem encountered this summer was the design of a suitable filter for the tide gauges used on the Hecate Model. The filters consisted of a cylindrical well with a small opening in the bottom housing the sensing probe. The problem was to select the opening so that the minimum amount of ripples would penetrate into the well without affecting the response to the longer period tidal oscillation. The response of the well to changes of water level is non-linear, so that the response depends on amplitude as well as frequency. Moreover, there is coupling between frequency components. The problem of choosing the optimum size of the opening was solved by simulating the filtering well on the Heath Analogue computer. We were able to study effect of frequency, amplitude, and the cross-coupling between frequency components on the response of the well. The computer was set up so that any opening up to half an inch in diameter could be studied. The final design (9/32 inches) was chosen on the basis of the analysis made on the analogue computer.

N.P. Fofonoff

MARINE PHYSICS

12. WIND INDUCED TRANSPORT IN THE NORTH PACIFIC OCEAN

The main features of the circulation in the North Pacific Ocean have been established for a long time. Surface currents were known with reasonable accuracy even in the days of sailing vessels. The problem facing oceanographers is how to explain the persistent circulation and to account for observed changes in the strength and distribution of currents in the Pacific Ocean.

Twelve years ago, H.U. Sverdrup, at the Scripps Institution of Oceanography, developed a simple theory of the influence of wind drag on the ocean surface in producing currents. The theory explained many features of the circulation, and has been further developed and refined over the past decade, but, because of the great volume of computations required to calculate water movement from winds, has never been applied extensively to study ocean circulation.

Early in the summer of 1959, we decided to use an electronic digital computer to overcome the computation barrier that had prevented full utilization of the theory. With the aid of Dr. C. Froese of the Department of Mathematics at the University of British Columbia, who joined our staff during the summer months, we developed a computer program for the calculation of ocean circulation using Sverdrup's Theory in a modified form. The program was completed, and tested on the ALWAC III-E computer, operated by the University of British Columbia Computing Centre.

We started with charts of mean monthly sea-level atmospheric pressure published by the Extended Forecast Section of the U.S. Weather Bureau. These charts were chosen because atmospheric pressures were calculated and recorded at fixed points forming a diamond-shaped grid covering all of the Pacific Ocean north of 10° N, with the exception of the southeast

corner where observations extended from 20° N. Having a regular grid greatly simplifies the computation.

From differences in atmospheric pressure from one grid point to another, we can calculate mean wind speed and estimate the direction and amount of drag exerted on the ocean surface by the wind. The surface drag causes the water near the ocean surface to move, and because the drag is not uniform, the water movement will cause accumulation of surface waters in some regions and depletion in others. This, in turn, will produce differences of pressure in the ocean and will cause compensating currents to flow at all depths. The compensating flow is affected by the Earth's rotation and tends to flow southward in a region of accumulation and northward in a region of depletion. At the same time there is sinking or rising motion to compensate the accumulation or depletion in the surface flow.

From the atmospheric pressure values at grid points, the computer evaluates the amount of surface flow, the rate of accumulation or depletion in the surface layer, and the total amount of circulation in the ocean. The computed values are punched on paper tape by the computer. The tape is then fed into a special typewriter (Flexowriter) which prints the values directly onto charts of the North Pacific as shown in the Figure (Fig. 19). Computation of all of these quantities is accomplished in about 12 minutes for each monthly chart of atmospheric pressure. During November of this year, sixty charts, for the five-year period 1955-59, were processed at the U.B.C. Computing Centre in 12 hours of computing time, at a cost of about \$600. Manual processing of the same data would have taken several years and cost at least \$30,000.

The computations do not give the entire answer to oceanic circulation. The ocean cannot respond quickly to the rapidly changing atmospheric system. Consequently, the ocean circulation must be determined in terms of averages of the surface winds. How long an average has to be taken, and how much of the variation of the ocean circulation we can attribute to winds, has to be decided by a careful comparison of the results of oceanographic surveys with the computed results from purely meteorological data. This phase of the research is considerably more difficult and will require the development of new computer programs to analyze oceanographic data.

The fact that the ocean responds to an average of at least several months of winds make forecasting feasible. It means that the ocean has sufficient lag in its response to the atmosphere, that meteorological data can be collected and processed in time to follow and predict trends in ocean circulation.

One of the major advantages of using meteorological data is that the coverage is much more extensive and continuous. Oceanographic data is difficult and expensive to obtain. Regular surveys have been carried out only in some regions of the Pacific Ocean. Analysis of meteorological data will help to fill in the gaps between surveys.

Benefits to fisheries are difficult to evaluate at present. These will depend on the extent to which particular species of fish are affected by their movement. It is known, for example, that the homing migration of Sockeye salmon to the Fraser River was delayed and diverted northward by the intrusion of unusually warm water past the Canadian Coast in 1958. The intrusion was monitored by oceanographic surveys at regular intervals.



Values indicating the amount of circulation produced by surface winds are typed directly onto charts of the North Pacific Ocean by the flexewriter from paper tape punched by the digital computer.

Figure 19.

This feature will be closely studied to see whether or not it was produced by changes in the wind system over the ocean. Another example, is the correlation found between tuna catch and surface water salinities in the region of the Hawaiian Tuna Fishery. The salinity changes reflect changes in the oceanic circulation pattern and thus, could possibly be linked to atmospheric changes. If this is found to be the case, prediction of oceanographic conditions and hence, of the fishery, would be possible.

Much more study is required to evaluate the method of computing ocean circulation that has been set up. It has at least opened up to oceanographers a large resource of information describing the driving forces in the ocean that was not previously available in usable form.

N.P. Fofonoff

13. TIME-DEPENDENT RESPONSE OF A BOUNDED OCEAN

The study of the oscillation modes of an idealized bounded ocean were investigated with the assistance of Mr. R. Revzen (summer research assistant). The investigation was an attempt to calculate the oscillation frequencies of a rectangular, homogeneous ocean containing no dissipative mechanisms. A similar program, neglecting rotation, was solved more than a century ago. G.I. Taylor gave the solution for uniform rotation about 30 years ago. However, his solution is applicable only to small bodies of water. For large bodies of water such as an ocean, a variable Coriolis parameter must be used. We found that the analysis could be carried out by Taylor's method. However, instead of a single infinite determinant from which oscillation frequencies may be obtained, we derived a linear equation involving four such determinants. We have not been able to obtain a solution, or even to show that a solution exists. We were able to show that the symmetric and anti-symmetric modes obtained under the assumption of uniform rotation do not occur with a variable Coriolis parameter. These modes are coupled together, and the coupling is proportional to the rate of change of the Coriolis parameter with latitude.

We have obtained evidence in the course of this investigation which indicates that the equations used for the study of the time-dependent modes may not be complete. As these equations are in wide use at present, their adequacy must be established. Further work on this problem is planned.

N.P. Fofonoff

14. THE PRIMARY PRODUCTIVITY AND FERTILITY OF SEA WATER.

Chemical nutrients

Work on methods development for micro-nutrients has been completed, at least as far as it is proposed to go for some years to come. Methods for soluble organic nitrogen, manganese and copper have been completed and tested this year. These methods, together with the procedures already published in MS Report Series 18 and 19, have been incorporated as a

Bulletin entitled "A manual of seawater analysis" by J.D.H. Strickland and T.R. Parsons, and the manuscript sent to the Board's Editor.

The determinations involved are for salinity by titration (two levels of precision); dissolved oxygen; CO_3^{2-} , HCO_3^{1-} , free CO_2^{2-} and pH; reactive silicate; reactive phosphate; total phosphorus; NO_3 ; NO_2^{1-} ; NH_3 ; soluble organic nitrogen; biologically reactive iron; Mn and Cu, in addition to analyses for particulate matter and photosynthetic rates mentioned later.

Standing crop of particulate matter

Great strides have been made in this work and the preliminary methods development stage is almost completed. The discovery that pre-coating a Millipore filter with magnesium carbonate enables all particulate matter to be removed from it without contamination (Nature - in press) has made it possible to devise analytical methods for the total particulate matter in coastal or oceanic water that are rapid and suitable for ship-board use. The following analyses for particulate matter have been perfected and incorporated in the Manual of Analysis - Pigments, organic carbon, phosphorus, nitrogen, lipid, carbohydrate, chitin and protein.

The outstanding problems, still being actively studied, are techniques for separating the particulate matter into its constituent phytoplankton, small zooplankton, and detritus, and methods for distinguishing living plant metabolites from the rest of the particulate organics. More work on the xanthophyll pigments in phytoplankton is underway, and the full analysis of pure cultures of a few "typical" phytoplankters is being undertaken.

Preliminary work on the aerial measurement of particulate matter by means of the light-scattering properties of the water has indicated that the method may have promise but a photographic technique is too crude. A photocell assembly for this work is being designed and it is hoped to recommence field work this spring.

Photosynthetic productivity

Development work in this field has continued on a part-time basis. It has been restricted mainly to obtaining preliminary experience of methods and evaluating their precision and significance. A start has been made on the problem of predicting in situ productivity from the photosynthesis in samples illuminated in a constant light incubator. Equipment has been constructed for suspending B.O.D. bottles in the euphotic zone, either from an anchored buoy, or from a free-floating buoy that can be tracked by radar.

It has been decided to abandon an acid wash in the standard radio-carbon technique, as losses have been recorded that appear to be excessive. The agreement between results obtained by the oxygen and radiocarbon method was very poor during a vigorous growth period in Departure Bay in early summer. The C-14 method gave results substantially lower than the net photosynthesis as indicated by oxygen results. The rate of photosynthesis in the open ocean was too low for direct comparisons to be made, but one result using net concentrated samples, indicated that agreement might be better than at the coastal location.

A small monograph is being written (C.D. McAllister) which reviews all proposed techniques for comparing in situ and "incubator" productivity

and the underlying theories. Future research will be largely centred around this problem, but better facilities for incubation and submarine light measurement will be necessary. To this end a "research" incubator of great flexibility of operation has been designed and is to be constructed by outside contract. This will enable experiments in plant physiology to be carried out with much greater facility than heretofore

Field work

A synthesis of the above programs, with most of the newly developed techniques, was brought about in a 6-week field trip on the Weathership, at Ocean Station "P" (50° N, 145° W) (see elsewhere). The purpose of this work was to study the fertility and primary productivity of a typical oceanic area in the northern Pacific Ocean, by the near-simultaneous measurement of as many factors as possible. A program of such complexity has not been attempted at sea before, and the continual monitoring of one oceanic location for such a long period is also new. A paper on the findings has been submitted to J. du Conseil pour l'Exploration de la Mer, the outstanding discoveries being as follows: The ocean at Station "P" contained a comparatively large amount of microscopic particulate organic matter but 80 to 90% of it was detrital. The detritus was probably all of animal origin, except for a portion that appeared to consist of cellulose fibre of terrestrial origin, and occurred to at least 1000 metres. The standing crop of plant material was fairly constant during the six weeks, but a culturing experiment showed that growth was not inhibited by nutrient concentrations or by light. The ocean was capable of sustaining a plant crop comparable to that found in coastal waters (some 50-times greater than observed in the open ocean). This tight control of an "explosive" growth situation seems to be almost entirely by grazing. There was evidence of one or more "biotic sub-masses" in the surface waters at the Station, differing but little in temperature, salinity, phosphorus, or oxygen, but having markedly different silicate and nitrate concentrations.

No further work at the above level of effort is contemplated in the open ocean for some time. Plant pigments, however, will continue to be monitored at the Weathership during 1960. The next major field program will be in Departure Bay with an in situ culturing experiment being made in a 20 foot diameter plastic "bag" which is now under construction.

Weekly surveys, through three months, of density changes at different depths, at a point where the proposed "productivity bag" will be situated in Departure Bay was carried out, as well as a time-series of observations, at intervals of two hours, through 36 hours.

J.D.H. Strickland
T.R. Parsons
C.D. McAllister

15. DETERMINATION OF PRIMARY PRODUCTIVITY IN SITU FROM SHIPBOARD MEASUREMENTS OF PHOTOSYNTHESIS

The technique of suspending samples in the sea for measurement of the rate of photosynthesis of organic material under natural illumination and temperature conditions requires that the survey ship remain in restricted areas for long periods of time. This is an expensive and time consuming procedure. However, several methods for calculating in situ production from measurements of photosynthesis carried out aboard ship have been published.

A detailed assessment of these methods has been initiated and new methods are being devised.

All the methods except one, require (directly or indirectly) -

- (a) measurement of solar radiation
- (b) measurement of the extinction coefficient of photosynthetic light in the water mass concerned.
- (c) that the vertical distribution of plant cells, and
- (d) the variation of photosynthesis with light intensity be taken into account.

For regions where solar radiation, water transparency and vertical distributions are known to be relatively constant throughout the area, methods have been proposed in which the above factors are not directly measured. Instead their effects are summarized in empirical factors, determined at suitable intervals of time, from comparisons of simultaneous shipboard and in situ measurements. Then, in subsequent experiments samples from one or more depths are measured aboard ship, to characterize the level of population, and the product of the resulting photosynthetic rate, and the empirical factor is taken as the in situ rate of production.

Reasonable results have been claimed for such methods in regions as diverse as the Equatorial Indian Ocean, Subarctic regions of the North Atlantic and large Russian reservoirs. However, in regions where light, water transparency, and vertical distributions are variable, or are not known to be constant, use of such methods may result in considerable error.

At the other extreme, methods are in use in which light is either measured directly or taken from published tables, water transparency is determined, measurements are made on samples from many depths, and the variation of photosynthesis with light intensity is measured and used as such, or is taken from published curves. In these methods samples are incubated aboard ship, all at the same known light intensity (usually near I_{max} , the optimum intensity for photosynthesis). Incident light and the extinction coefficient are used to determine intensities of photosynthetic light at the depths from which samples were taken. Then, the graph of photosynthesis versus light intensity is used to convert the photosynthetic rates of the samples at the shipboard light intensity, to those at in situ light intensities.

Computations in this type of method may be simplified by computing daily relative photosynthesis beforehand, using anticipated curves of the daily variation of light intensity, extinction coefficient, and the P vs I (productivity vs light intensity) curve, providing the light intensity of the incubation is also known. Relative photosynthesis is computed for

hourly intervals at each depth. The relative photosynthesis at each depth may then be integrated with time and, if populations are homogeneous vertically, they may be integrated with depth to give a daily value.

Eight permutations and combinations of a few of the possible methods have been applied to data obtained during the July-August 1959 patrol of Weathership C.G.S. "St. Catharines" (at Ocean Station "P"). The effects of different methods of taking population into account, different methods of assessing light intensity, and two methods of incubation were studied.

Most of the estimates are lower than figures accepted as most reliable and the scatter is great (approximately $\pm 50-100\%$). The disparities resulted from two major sources; the different methods of assessing the population, and methods of taking the variation of daily light intensity into account.

It was found that use of one published graph of daily relative photosynthesis versus total daily radiation could result in errors as great as 30%. This error results from entering the graph with daily amounts of radiation. A summer and a winter day may have the same total radiation. However, due to the difference in duration of daylight, light intensities during the two days may be quite different, resulting in different rates of relative photosynthesis. Similarly, graphs of daily relative photosynthesis entered with mean light intensity may also introduce error. Although requiring more labour, it was found to be more accurate to prepare graphs of relative photosynthesis versus "instantaneous" light intensity, and from these to integrate daily values for each separate experiment, using the observed light.

Most photosynthesis versus light intensity curves in use are either taken from published results obtained using laboratory cultures, or from determinations on aliquots of a sample from a single depth. Recent publications indicate that, in stratified water, plant cells from different depths have differing responses to changes in light intensity. Thus, all results in stratified water based on P vs I curves (directly or empirically) determined in the usual manner are subject to error, which may exceed 30%.

Only one method is free from all the possible errors mentioned above. In this method samples from successive depths are incubated in daylight with neutral density filters to simulate the in situ light intensities at the sample depths. Incubation is carried out from either sunrise to noon, or from noon to sunset.

C.D. McAllister.

16. PRODUCTIVITY STUDIES AT OCEAN STATION "P"

In April, 1959, with the cooperation of the Department of Transport personnel, the oceanographic laboratory in C.G.S. "St. Catharines" was reconstructed and expanded to facilitate the carrying out of detailed productivity observations by an increased complement of oceanographers.

Accommodation for three oceanographers was provided during the July-August patrol of C.G.S. "St. Catharines" and an intensive study of productivity and associated factors was carried out.

In addition to the regular physical observations, weekly studies were made of nutrients (inorganic, dissolved organic, and particulate phosphorus, nitrite, nitrate, silicate, oxygen, iron and manganese); standing crop of phytoplankton (total carbon, carbohydrates, lipids, protein, chlorophylls a, b, and c and carotenoids); rates of photosynthesis (as measured in samples suspended in the sea, and illuminated aboard ship in a specially designed incubator, and measurement of variation of photosynthesis with light intensity). Also the patchiness of standing crop and silicate during short N-S and E-W traverses, a study of growth and nutrient utilization in a culture experiment of two weeks duration, and experiments concerned with technique of measuring photosynthesis, were carried out.

Results of this study are presented elsewhere in this report.

An interim method, whereby untrained personnel can undertake observations which enable the rate of basic production of organic matter to be calculated, has been devised. A program of weekly observations by this method has been initiated in order to monitor production throughout the year. In addition, weekly measurements of the phytoplankton standing crop are being carried out.

C.D. McAllister.

17. SOUND SPEED IN THE EASTERN SUB-ARCTIC PACIFIC OCEAN

Since 1957 values of the speed of sound have been calculated and included with the serial observations in data records. Much of this material (all oceanic cruise data observed in 1958 and 1959) has been compiled and presented in pictorial form (Pacific Naval Laboratory Technical Memorandum). An interim report describing the observed sound speed structure has been prepared and is to be reported (also in a P.N.L. Tech. Memo.).

The speed of sound in sea water is a function of the temperature, salinity and pressure. The effect of pressure is the dominant one but, as it varies linearly with depth (nearly) it is of little significance insofar as variations of sound speed in time and space are concerned. These are due to variations of salinity and temperature.

It has been shown that the significant feature of the waters of the sub-Arctic region is the existence of a marked salinity stratification. Here a relatively low salinity surface layer to 100 metres depth (the upper zone) is separated from deeper water of oceanic salinity (the lower zone) by a transition zone (the halocline) in which the salinity increases markedly with depth. Based on this structural feature, a zonation has been defined to which the observed temperature structure has been associated.

Further, it has been shown that the depth distribution of salinity is essentially constant throughout the region. Thus the distribution of sound speed directly reflects the temperature distribution, and as with the temperature, may be described in terms of the zones defined by the salinity distribution.

In the upper zone the sound speed structure is markedly seasonal. In late winter an iso-speed condition exists throughout the zone. By late summer, it develops a structure which includes a strong speed-cline (the

summer thermocline). In the depth above the speed-cline (layer depth) the gradients are generally slight. Throughout the year the distributions are such that a surface sound channel to some depth usually exists.

A consideration of the growth and decay of the oceanic thermocline structure as observed at Ocean Station "P" leads to two conclusions. The first is that a mixed layer to some depth always exists. Hence, with regard to surface propagation, the sub-Arctic oceanic structure may never be limiting. The second concerns the intensity of the negative gradient in the seasonal thermocline. This may be as much as 8 C°/25 metres of depth, in late summer. Here, in a specific application, the oceanic environment may be extremely limiting.

In the halocline the gradients are frequently positive. This leads to a channel with an axis located at the top of the halocline. During the period of anomalous increase of temperature (late 1957 through 1958) the intensity of the halocline channel was much reduced. Oceanic data obtained during 1959 show that the channel has become prominent again, although not to the same level which prevailed prior to 1957.

In the lower zone (200 to 1000 metres depth) the sound speed structure is dependent on the intensity of the negative temperature gradient which exists there. It has been shown that this varies markedly over the region. In the northern and central part it is not sufficiently strong to cause the formation of a negative speed gradient in the presence of the inherently positive pressure gradient. However, elsewhere a negative gradient is formed. Thus in the latter areas, a minimum in the vertical distribution of sound speed occurs in the lower zone.

In the lower zone the temperature gradients are dependent on the nature of the circulation pattern. In general terms this appears to be consistent from year to year. In the upper zone the temperature structure is a seasonal function. Therefore, it is possible to say that the only major structural change with time to be expected, is that which has been described for the upper zone. Furthermore, and considering the region as a whole, it is possible to say that the principal features of the sound speed structure at a given position are, to a large extent, defined by the season, and by the location of the position within the area.

It is noted that the foregoing description can, in some specific instances, be shown to be a simplification of that actually observed. In the upper zone, in the depth above the thermocline, considerable microstructure may be observed in late spring and summer. In the lower zone, marked boundaries between water masses are frequently observed. However, an essential feature of the study is that there is a continuity of sound speed structure, which is dependent on the continuity of the temperature gradients and is independent of the difference in levels of temperature which occur.

Significant year to year differences in the timing and extent of certain type structures have been observed which are not yet completely understood. Such understanding will necessarily await further knowledge of the processes, and the manner in which they determine upper zone structure.

Deviations of sound structure appear to be most marked in peripheral areas close to the continental shelf. Here the influence of coastal processes is apparent but not well understood. Such oceanic features as the surface and halocline channels are not well defined, and frequently not observed.

18. FORECASTING SOUND SPEED STRUCTURE

Support in oceanography extended to the various Department of National Defence agencies (through the Pacific Naval Laboratory) included the provision of forecasts and assessments of oceanic sound speed structures, and assistance with oceanographic observations.

Forecasts of sound speed structure at given oceanic positions and to all depths are made frequently. For most purposes the important features are those relative to the near surface layers (to 300 metres depth) and comprise layer depth, thermocline intensity, and intensity of the halocline channel.

At the present time the forecasts are based on recent observations and on the fact that the general characteristics of near surface structures are, as shown by the data, recurrent from year to year. Thus, in a general sense, the problem of forecasting is a relatively simple matter.

F.G. Barber.

19. SOUND SPEED IN ARCTIC WATERS (PACLABAR)

Sound speed structure was assessed from serial observations made from the ice cover, by members of the Pacific Naval Laboratory in early 1959, at a position in the Canadian Arctic island archipelago. Of particular interest here was the existence of a salinity structure similar to that observed in the sub-Arctic Pacific. It appears that the sound speed structure may be described, as in the sub-Arctic Pacific, in terms of the salinity structure. The existence of a halocline provides a clue to the possible structures which could occur in the region. Here, as in the sub-Arctic Pacific, a stable positive temperature gradient of considerable intensity could exist within halocline depths.

The existence of the halocline has a further significance, in that the effect of local surface processes are restricted to a depth shallower than the halocline. In deep-ocean areas this influence appears to be necessary to the formation of ice cover. Thus the existence of a halocline is indicated in all such areas where ice cover occurs.

F.G. Barber.

20. AIRBORNE RADIATION THERMOMETER

A prototype model of an Airborne Radiation Thermometer (ART) has been built at the Woods Hole Oceanographic Institution. With this equipment, carried in a research aircraft (PBY) they were able to observe sea surface temperatures with an accuracy better than 0.5° C, and to resolve temperature gradients of 0.02° C in 50 to 100 metres distance.

Recent studies in the sub-Arctic Pacific Ocean has shown a need for rapid and frequent synoptic surface temperature surveys, the location of the size, shape and limits, of cool and warm water masses, and the variations of surface

temperatures in distances less than 1000 metres, for oceanographic, military, and fisheries purposes. It was concluded that the effort to accomplish these objectives would be worthwhile, and the program would be practical if the instrumentation was reliable, and the existing resources of the Maritime Air Command of the Royal Canadian Air Force could be utilized.

Lacking first hand knowledge of the equipment and procedures, a series of feasibility tests were planned and carried out. The ART-MkI (less recorder) was borrowed from the Woods Hole Oceanographic Institution. The electronics engineer of the Biological Station assembled, tested, and standardized it in the laboratory. The Maritime Air Command provided three flights in Neptune aircraft. The instrument was installed and operated by the engineer, with the assistance of R.C.A.F. personnel. The data were monitored and analyzed by an oceanographer.

These tests confirmed the accuracy and precision claimed in the literature, and allowed assessment of the requirements for a unit suited to these conditions of operation.

The ART-Mark I is a prototype model. It can, and has been made to perform satisfactorily under ideal conditions in the PBV attached to the Woods Hole Oceanographic Institution. However, it is somewhat fragile and will require considerable modification to be reliable in operational aircraft. These modifications include stabilization of power supply, precise control of the reference black body temperature, rugged packaging, and more reliable recording than was available in these tests.

J.P. Tully
M. Pirart
R.K. Lane

21.

TECHNICAL SERVICES

Programming for the AIWAC III-E Computer

The major effort during the past year has been the construction of a program to compute transport in the ocean from the distribution of sea-level atmospheric pressure. This is described under a separate heading. In addition, a major revision of the program for routine processing of oceanographic station data was carried out. These included a new interpolation formula which eliminated most of the short-comings of the three-point formula used earlier. The new formula consists of a linear interpolation with respect to the logarithm of depth, and uses two observed depths rather than three. The input format has been changed so that all data is now available on the tape. Previously, only station number, depths, temperatures, and salinities were punched. The revised program interpolates oxygen and computes sound velocity and potential temperature at standard depths, in addition to the quantities computed by the earlier program.

Sub-routines for computing specific heat and specific volume has been written. The specific volume routine uses Eckart's new formula for the equation of state of sea water, and will be used for comparisons with the old formula. The specific heat routine will be used in studies of heat budgets, for the computation of heat content of a column of sea water. It

includes terms giving the effect of pressure on the specific heat.

N.P. Fofonoff.

Data processing

A total of 834 hydrographic stations were prepared in 1959 for computation by the AIWAC computer at the Computing Centre of the University of B.C. The input tapes were prepared by Miss Mary Cairns on the Flexowriter at the Group. The resulting computations of oceanographic data at observed and interpolated depths were received on output tapes, which were transferred by the Flexowriter process directly to multilith masters, for offset duplication in data records.

Computations and preparation of multilith masters were done for 18 hydrographic stations observed by the Polar Continental Shelf Project of the Department of Mines and Technical Surveys.

A total of 3,767 bathythermograph slides were received and processed by the Group in 1959 (Table). This is an increase of 400 over last year. The largest number of these, 2355, were reproduced in appropriate data records. Those photoprinted, were placed in the Group's geographical index files for BT records.

Table VIII

Catalogue of Bathythermograph Slides Received and Processed at the Pacific Oceanographic Group during 1959

Source	Type of Survey	No. of Slides	Processed as:
P.O.G.	North Pacific Surveys	301	Multilithed Data Record
	Coastal-Seaways Surveys	676	" " "
	Station "P"	624	" " "
	Swiftsure Bank L/S	631	" " "
	Umatilla Reef L/S	<u>123</u>	" " "
	sub total	<u>2,355</u>	
P.N.L.	B.C. coastal waters	129	Photoprint
R.C.N.	B.C. coastal waters	300	"
	Cruises to southern waters (Hawaii, South Pacific, etc.)	<u>672</u>	"
	sub total	<u>972</u>	
F.R.B. (Biological Station, Nanaimo, B.C.)	North Pacific exploratory fishing surveys	233	Multilithed Data Record (proposed)
	B.C. coastal fishing in- vestigations	78	Photoprint
	sub total	<u>311</u>	
	1959 Grand Total	<u><u>3,767</u></u>	

H.J. Hollister.

Data records

The data records are published by the Group in the Manuscript Report Series (Oceanographic and Limnological) of the Fisheries Research Board. They list tabulations of temperature, salinity, density as σ_t , sound velocity, dissolved oxygen, occasionally dissolved nutrients (Station "P") at observed depths; and temperature, salinity, density as σ_t , density in situ as $\sigma_{s, t, p}$, pressure, specific volume anomaly, anomaly of dynamic height at interpolated depths. A new hydrographic station computations program, was introduced with the production of MS Report No. 54, Oceanographic Data Record, North Pacific Survey, August 4 to September 1, 1959. The change was in the interpolated depths portion where the following listed tabulations are now recorded: temperature, salinity, density as σ_t , sound velocity, dissolved oxygen, anomaly of dynamic height, and potential temperature. Bathythermogram reproductions are also included in each data record.

The data records are printed through the facilities of the Queen's Printer, Esquimalt Unit, Esquimalt, B.C., who has offered splendid cooperation and produces a very good job. An average of 150 copies of each data record is printed, of which 90 are immediately distributed to a world-wide list of scientific institutions and research workers. The remainder are held in storage at the Group for future requests. Two copies of all data records are sent to IGY World Data Center "A".

During 1959 eleven data records were published, as listed in the Manuscript Report publication section. In addition to these, three atlases containing illustration plates of horizontal and vertical distributions of physical oceanographic properties (temperature, salinity and sound velocity) were published. These are listed in the publications records as MS Report No. 50 (F.R.B.) and P.N.L. Technical Memoranda Nos. 59-10 and 59-12.

H.J. Hollister.

Bathythermograph calibration unit

During 1959 sixty-two bathythermographs were calibrated. Approximately 60% of the instruments were for the Pacific Oceanographic Group, 25% for the Royal Canadian Navy, the remainder for the Biological Station and other Government departments. Techniques of calibration and grid printing procedure have been improved, resulting in more accurate and higher contrast grids.

Closer liaison was established between the Royal Canadian Navy Bathythermograph Repair Shop, and the Calibration Unit, by arranging a tour of both establishments for those concerned. The main problems discussed were techniques of bathythermograph repair, also recognition and causes of bathythermograph failures. Information and illustrations on the problems are being compiled with a view to publication, and for use as general reference.

As accurately controlled water pressure, up to 450 lbs. per square inch, can be developed in the tank, the unit was found suitable for testing a variety of other underwater gear. These included various types of underwater lights, net floats, etc. used by the Biological Station.

J.A. Stickland.

Chemical laboratories

The new chemical laboratories were partially completed in August. Three main investigations have taken up allocated bench space, viz., Pollution Studies (M. Waldichuck), Fish Physiology (R. Brett), and the Oceanographic Group responsible for marine chemistry, fertility and productivity. K. Stephens is Technician-in-Charge of the laboratory with J.D.H. Strickland in general administrative control. A considerable amount of alteration and extra installation, arising out of incompletions and deficiencies in the original contract, remains to be undertaken but this work should commence before the first of April. The laboratory is restricted to research work of a chemical nature. Algal and fish physiology experiments are conducted elsewhere and the chemicals and apparatus for field work are stored in other locations. The "old chemical laboratory" has been converted into a store room and preparations laboratory for sea-going operations. In addition, shore-base salinity determinations, and a program of algal culturing work is being carried out in this room.

A third conductimetric salinometer was purchased from the University of Washington.

The salinities of eight thousand samples have been determined by the conductivity bridges, five hundred by silver nitrate titration.

J.D.H. Strickland
K.V. Stephens.

Hecate model

The considerable operation of the Hecate Model has necessitated more or less continuous maintenance and many minor adjustments to the equipment. On the whole, operation has been satisfactory and continuous. However, the following modifications have been found necessary.

1. Synchronization of tide computer and clock. The motors driving the clock and tide computer have been found to be inaccurate to give the required synchronization of clock and computer. Very exact, synchronous motors have been ordered and will be installed before spring operation.

2. Photography. The camera and associated equipment are now performing satisfactorily although the opacity of the water has made few poor quality pictures. Further resolution has not been as good as might be hoped for, partly because of the grain of Super-Anscochrome film and partly because of the resolution of the wide angle lens at maximum aperture. The use of new high speed Ektachrome film will improve resolution. It has finer grain and its higher speed will allow use of a smaller lens aperture.

A good 35 mm projector has been obtained. An automatic advance, film strip adapter has been designed and will be fabricated in our shop.

A projector board with sliding and tilting movements in all directions for rectification of projected pictures has been designed and will be fabricated here.

Contrast of pictures has been improved by darker colouring of the

model land areas.

Trials have shown that 6 inch floats of 8 colours and 3 shapes can be readily distinguished. This should provide a sufficient number of readily distinguishable markers of water masses. By adding weights and thin buoyant stems these markers can be made to indicate water movement at definite depths.

Three colours of dyes have been tried and found suitable in that they do not stain the model. They are all slowly bleached by chlorine.

A moveable low level observation platform has been built, and a small tower with adjustable height will be added.

3. Filtration of water. The considerable opacity of the water in the model and the obscuring of the bottom by sediment is caused by silt and vegetable dyes in the Nanaimo water supply and by dust blown into the model.

A recirculating diatomaceous earth filter has been ordered and will be installed before spring operation. This should remove the silt and dust.

A chlorinator, already at hand will be installed to bleach out the natural vegetable dyes. It will also slowly bleach out the dyes used in operation, thus eliminating the need for frequent water changes.

L.D.B. Terhune.

Machine shops and design services

1. During the year the ocean model laboratory complete with machine and hand tools, and the machinist, R. Cagna, was turned over to the management of the Biological Station. The Group now requisitions shop services the same as any other sub-group in the Station.

2. Oxygen stripping column. Methods of stripping dissolved oxygen from water for Experimental Biology have been investigated and a stripping column to de-oxygenate one gallon per minute to a level of not more than 0.3 p.p.m. of oxygen decided upon and ordered.

3. Ground water standpipe, Mark VII. A new Mark VII groundwater standpipe for measurement of seepage into lakes at depths to 80 feet has been designed and calibrated in collaboration with Mr. Wickett. Its purpose is to investigate conditions of survival of lake-spawning sockeye salmon.

Permeability measurements are carried out in the shore end of 200 ft. length of 2" pipe connected to a Mark VI standpipe driven into the lake bottom. These measurements are similar to those done in the Mark VI standpipe with corrections for pipe friction.

The pressure head causing flow into the lake is measured by comparing the level in a tube connected to the standpipe to that in a tube connected to the lake at the position of the standpipe. Since the lake level, and gravel pressure level tubes, are identical narrow tubes enclosed in one plastic pipe the effects of waves and seiches are averaged out, and temperature effects made identical.

From the pressure difference of lake and standpipe, a pressure gradient is calculated, and this combined with the permeability to obtain velocity of flow out of the gravel.

L.D.B. Terhune.

Electronics laboratory

The electronics instrumentation for the Hecate Model was completed and installation finalized in May.

Four reports on the model instrumentation are in various stages of preparation, for publication in 1960. These are:-

A Tide Gauge for the Precise Measurement of Water Level Changes in Model Studies.

A Measurement System for the Hecate Model.

The Tide Simulator for the Hecate Model.

The Automatic Control System for the Hecate Model.

M. Pirart.

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