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Some Oceanographic Features of the Waters of the Central British Columbia Coast

by A. J. Dodimead and R. H. Herlinveaux

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Biological Station, Nanaimo, B. C.
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I. INTRODUCTION

Intensive studies of young pink salmon (Oncorhynchus gorbuscha) in their coastal environment have been made in enclosed marine waters of the central British Columbia coast (Fig. 1). From 1962 to 1967, studies were carried out on pink salmon stocks of the Bella Coola River. This river enters the sea at the extreme head of Burke Channel (North Bentinck Arm) (Fig. 1). The primary purpose of these studies was to determine the mortality of the young salmon from the time they first enter salt water until they leave the coastal environment and details of mortality changes within a season and from year to year including external and/or internal factors affecting survival. The investigation was under the direction of Dr. R. Parker of the Biological Station, Nanaimo.

The general movements of these fish while in their coastal environment are fairly well documented (Parker, 1965). The fish first enter the estuary about mid-April. During the latter part of this month, they are most abundant in North Bentinck Arm. From here they move and/or are transported down Burke Channel, thence into Fitz Hugh Sound. Some of these fish have been found in the lower reaches of Dean Channel, in the northern part of Fisher Channel, and the adjacent passages which connect with the open waters of Queen Charlotte Sound and Hecate Strait (Fig. 1). By mid-June, most of the fish have passed out of the region into Queen Charlotte Sound and Hecate Strait.

Although the distribution of these fish seems to vary from year to year, some of their behaviour patterns are quite consistent. When they first enter North Bentinck Arm, they quickly form schools. Initially they are in close contact with the shores, being generally found along the southern shores of North Bentinck Arm. Later, they are commonly sighted in mid-channel, as well as along boundaries such as shores and tide lines. Throughout the period spent in the coastal waters, the juveniles appear to occupy only the immediate surface waters.

Based on this general pattern of distribution, a physical oceanographic program was initiated in 1963 and continued through 1967 for the purpose of providing data for the ecological studies of this stock. The purpose of this report is to provide a summary of the oceanographic program and results for the years 1963 through 1965. The program for 1966 and 1967 consisted primarily of the simultaneous measurements of currents, with continuous recording current meters, tidal heights and meteorological parameters made in cooperation with the Canadian Hydrographic Service. These data are presently being analyzed and will be reported at a later date.

The present report includes: (1) background information on the geography and climatology of the region; (2) a discussion of the physical oceanographic features considered significant to a study of the relationship of the environment to distribution, migration and behaviour of the fish; and (3) a pictorial presentation of the data, 1963-1965.

II. OCEANOGRAPHIC PROGRAM, PROCEDURES AND FACILITIES

The basic philosophy used in designing the oceanographic program was that oceanographic activities would generally be confined to an area centered about the main concentration of fish. Once the centre of concentration appeared to shift, the area of oceanographic activities would be shifted accordingly. It was not always possible to follow this plan because of difficulties of logistics. Therefore, some areas, in particular the central portion of Burke Channel, have either been missed or not studied as thoroughly as others.

A 76-foot barge, the "Velella", with living and laboratory facilities, was used as the base camp (Fig. 2). During the first two years, most of the oceanographic observations were made from aboard "Remora", a 26-foot aluminum gillnet research boat, adapted for oceanographic work (Fig. 3). This vessel lacked sleeping accommodations, making it necessary to return to the base camp after each day's operation. Because of this, the extent of the area of study for any one day was limited. During 1965, "Noctiluca", a 34-foot vessel with sleeping accommodation for two people, was used for most of the oceanographic work (Fig. 4). Since, with this vessel, it was not necessary to return to the base camp each evening, a relatively larger area could be studied in one day.

1. Program and procedures, 1963

The barge was anchored in Whiskey Bay, North Bentinck Arm (Fig. 1) from April 12 to May 12. The oceanographic program commenced April 18, with observations being confined to portions of the area extending from the head of North Bentinck Arm to and in Labouchere Channel.

The barge was shifted from Whiskey Bay to Nalau Passage, one of the connecting passages between Fitz Hugh and Queen Charlotte Sound (Fig. 1) on May 12 in order that the next phase of the biological program could be carried out. Operating from this anchorage, oceanographic activities were confined to the lower part of Burke Channel, Fitz Hugh Sound, Fisher Channel and Nalau Passage.

Although no detailed oceanographic observations were made in the central part of Burke Channel, a monitor of surface conditions was obtained during longitudinal transects of the Channel on May 12 and 27. Some oceanographic observations were also made by the Institute of Oceanography, University of British Columbia, May 16-19. Further, surface and 1-metre samples for salinity and temperature were obtained during fish scouting surveys.

Oceanographic observations consisted of temperature, salinity and currents, with most emphasis being placed on detailed studies of the surface waters.

Temperatures were obtained from bucket samples, from bathythermograms, and from reversing thermometers attached to water-sampling bottles. The maximum depth of sampling was 200 metres.

Salinity samples were analyzed each day by titration with silver nitrate to an accuracy of $\pm 0.1\%$.

Current observations were made at the surface, 1 and 2-metre depths, employing the Lagrangian method. Weighted drift sticks and small tri-plane drogues were used for these measurements. Positions were determined from sextant fixes.

2. Program and procedures, 1964

The overall program was similar to that carried out in 1963. From April 4 to May 4, the barge was again anchored in Whiskey Bay, North Bentinck Arm (Fig. 1). Oceanographic observations were made down to, and in Labouchere Channel. The majority of the observations were made in North Bentinck Arm.

From May 4 to May 17, the barge was anchored in Croyden Bay across from the mouth of Labouchere Channel (Fig. 1). From this location it was possible to carry out detailed observations of currents over a tidal cycle at the junction of Burke and Labouchere Channels and in Labouchere Channel.

The barge was shifted to Fougner Bay at the mouth of Burke Channel (Fig. 1) on May 17. Observations were made as far up as Kelkpa Point in the lower part of Burke Channel, in Fisher Channel and in Fitz Hugh Sound until May 25.

From May 25 to June 9, the barge was anchored in Nalau Passage (Fig. 1). Oceanographic observations were continued in Fisher Channel, Fitz Hugh Sound and Nalau Passage.

A change was made in some of the methods used in 1963. An "in situ" salinometer was used to a maximum depth of 27 metres to obtain temperature and salinity measurements at discrete depths. The accuracy of the instrument for salinity is about $\pm 0.1\%$, comparable to that obtained with the titration method used in 1963. Samples from greater depths than 27 m were again obtained with water sampling bottles, with reversing thermometers attached. The samples were analyzed aboard the barge using an inductive-type salinometer, with an accuracy of at least $\pm 0.01\%$.

Surface temperature and salinity values were obtained with the "in situ" salinometer by towing at speeds of 3 knots or less.

Current measurements were made at a depth of 1-metre using tri-plane drogues. Observations with a Savonius-type rotor current meter were also made at selected depths from the surface to 40 m depth at two anchor positions, one near the shore in the vicinity of Whiskey Bay (Fig. 64) and the other near the shore just south of Kwaspala Point (Fig. 75).

Zooplankton samples were obtained with a towed high-speed sampler, with flow meter attached. These data will be reported elsewhere.

3. Program and procedures, 1965

The oceanographic program was essentially a monitor of temperature and salinity conditions and zooplankton populations in the region. No current observations were attempted.

From April 19 to May 2, surface observations and cross sections were made from the head of North Bentinck Arm to and in Labouchere Channel. These surveys were the first to cover this area in one day.

From May 31 to June 7, sections were made in the lower reaches of Burke Channel, in Fisher Channel, in Fitz Hugh Sound and in Nalau Passage.

Salinity and temperature measurements were made with an "in situ" salinometer at discrete depths to a maximum depth of 50 m. Surface plankton hauls were also made, but again the data will be reported elsewhere.

III. GENERAL CHARACTERISTICS OF THE REGION

The "region" is considered to include Burke, Dean, Labouchere and Fisher Channels, Fitz Hugh Sound and Nalau Passage. A more thorough review of Burke Channel than of the adjacent areas is given, since this was the area of most intense work.

Pickard (1961) has reviewed the physical and oceanographic characteristics of many of the British Columbia mainland inlets. Most of the physical characteristics he has presented on Burke and Dean Channels are repeated here verbatim.

1. Physical characteristics

(a) Burke Channel

From its head Burke Channel extends seaward in a number of distinct reaches or "dog-legs" for about 50 nautical miles (Fig. 1). It has a mean width of about 1.4 miles. Approximately 15 miles from its head, it connects with Dean Channel through Labouchere Channel. Two relatively large inlets, South Bentinck Arm and Kwatna Inlet, join Burke Channel. The mouth of the Channel, which is defined by a line extending from Walker to Edmund Point, connects with Fitz Hugh Sound and Fisher Channel.

The mountain slopes are extremely steep, both above and below sea level. From the shoreline, the mountains rise quickly to heights between 3000 and 4000 feet. The 100-fathom contour line lies about 1200 feet from the shores. The mean mid-channel depth is about 220 fathoms (400 m) with a maximum depth of 320 fathoms (585 m). A striking bottom feature is a sill which peaks at about 5 miles (8 kilometres) from the mouth of the Channel. In mid-channel, the sill rises to within 16 fathoms (30 m) of the surface. Towards the northern shore, the sill depth is approximately 24 fathoms (44 m). The bathymetry of the sill area is shown in Fig. 5.

(b) Dean Channel

The physical characteristics of Dean Channel are similar to those of Burke Channel, with one notable exception, the absence of any pronounced sill at or near its mouth. The Channel is about 60 nautical miles (97 kilometres) long and has a mean width of 1.3 miles (2.1 kilometres). It connects with Burke Channel via Labouchere Channel, about 32 miles (52 kilometres) from its head. Cascade Inlet is the only major inlet tributary to Dean Channel. The mouth of Dean Channel connects with the northern extremity of Fisher Channel (Fig. 1).

The mean mid-channel depth of Dean Channel is 230 fathoms (420 m). It has the same maximum depth (320 fm) as Burke Channel. The sill depth is approximately 150 fathoms (275 m) as compared to 16 fathoms for Burke Channel.

(c) Fisher Channel and Fitz Hugh Sound

The boundaries of Fisher Channel have been defined arbitrarily as extending from the mouth of Dean Channel to the northern shore of the mouth of Burke Channel, a distance of about 22 miles (35 kilometres). The mean width is approximately 1.7 miles (2.7 kilometres), slightly wider than Burke and Dean Channels. Johnson Channel, Gunboat and Lama Passages form the beginnings of the routes from Fisher Channel to Queen Charlotte Sound (Fig. 1). The mean mid-channel depth of Fisher Channel is approximately 224 fathoms (410 m).

The portion of Fitz Hugh Sound which is considered in this report is that which extends from Burke Channel southward to Hakai Passage, a distance of about 12 miles (19 kilometres). Within this area, the width of the Sound is approximately 4 miles (6.5 kilometres). Nalau and Hakai Passages are the connecting passages to Queen Charlotte Sound (Fig. 1). The mean mid-channel depth is about 180 fathoms (330 m).

The surrounding terrain for these areas is very flat, compared to that surrounding Burke and Dean Channels.

2. Climatological features

(a) Precipitation

The precipitation in the region varies considerably from one area to another (Meteorological Branch, Annual). There is a rapid increase from a yearly average of 40 inches at Bella Coola, situated at the head of Burke Channel, to about 130 inches in the Labouchere area. From here to Fitz Hugh Sound and the open waters the average precipitation remains at about 130 inches per year. Precipitation data for Bella Coola, Ocean Falls and McInnes Island for 1962-65 reflect the areal, seasonal and annual variations (Fig. 6).

Precipitation is a maximum from October to March and a minimum in July and August. During April, May and June precipitation is relatively low (Fig. 6). It is apparent that there are marked annual variations. For example, during the first few months of 1964, the precipitation along the coast was about double that for the same period in 1963. Further, during 1965, there were some very low precipitation periods, particularly March, at Ocean Falls and McInnes Island.

(b) Air temperatures

The air temperature cycle in this region is in phase with that experienced along the whole British Columbia coast. The annual cycles at Bella Coola and McInnes Island show minimum temperatures in December and January and maximum temperatures in August (Fig. 7) (Meteorological Branch, Annual). The moderating influence of the sea is apparent at McInnes Island where the seasonal range is less than that at Bella Coola. Monthly mean values for February show the largest variations, and as would be expected, these are larger at Bella Coola than at McInnes Island (Fig. 7).

(c) Winds

Continuous wind data for the region are not available for this period. However, the winds in any British Columbia inlet blow either up-inlet or down-inlet, or for Burke and Dean Channels, westerly and easterly. Further, there is usually a marked diurnal variation, particularly during the spring and summer periods. This diurnal variability is apparent in Fig. 8, which shows a plot of wind data from records of the British Columbia Forestry Station, Bella Coola. The morning winds generally blow down-channel (easterly), and are usually light. The afternoon winds blow up-channel (westerly) and are more prevalent and stronger than the morning winds. As a result of the strong afternoon winds, oceanographic observations from small vessels must usually be curtailed during the late afternoon. In addition to the diurnal changes, there are usually marked cross-channel gradients associated with the topography and well-defined reaches of the channels.

In Fisher Channel and Fitz Hugh Sound, the winds are generally southerly or northerly, with easterly or westerly components. Again, afternoon winds are generally stronger than morning winds.

(d) Runoff

Since the salinity characteristics of the region are a consequence of the total fresh water discharge into it, information on this parameter is most important, but unfortunately, is very scanty. Discharge data are available for the Bella Coola River (measured at Hagensborg, 19 miles east of Bella Coola) from the Canadian Water Resources Branch (Annual) and for Clayton Creek, from records of the B.C. Hydro and Power Authority. Both rivers flow into the head of Burke Channel.

Irites (1955) has combined what data are available for river flow with precipitation data from the watersheds concerned and has estimated the total fresh water runoff into many of the inlets. For Burke Channel, the mean annual discharge was calculated to be $420 \text{ m}^3/\text{sec}$. Of this, the Bella Coola supplies $120 \text{ m}^3/\text{sec}$ (as measured at Hagensborg). In contrast, the mean annual discharge into Dean Channel was calculated to be $730 \text{ m}^3/\text{sec}$ of which $280 \text{ m}^3/\text{sec}$ occurs above Labouchere Channel.

The seasonal characteristics of the discharge are evident in the mean monthly values for the Bella Coola River (Fig. 9). Discharge is a minimum during March and a maximum during June-August. A secondary maximum may occur in October or November, which is associated with the precipitation maximum. In October, 1965 a large secondary maximum occurred (Fig. 9).

Monthly discharge values for the first four months (January through April) of the years 1962-1965, were similar and about average. In May 1962, 1963 and 1965, discharges were below average. The greatest anomaly for the years shown occurred in June, 1964 when the discharge was well above average.

Daily discharge curves for the periods March 15 to June 30 for the Bella Coola River and Clayton Creek show some similar and interesting features (Fig. 10). Marked changes occurred over a period of one to two days. Since the Bella Coola River discharge is 10-fold greater than that of Clayton Creek, the large variations in the latter are more significant. The peaks or surges were most pronounced in May and June, representing, in most cases, at least two-fold increases in run-off. Further, from one year to another, the time at which the peaks occurred differed by 10 to 15 days. For example, the sharp increase in the Bella Coola River discharge in 1964 started about May 25, in 1963 about May 15, while in 1965 there was a small peak at the end of April. Further, the discharge curve for 1964 has only one peak, which is about double the discharge for any day in 1962, 1963 and 1965. The curves for these years have two or three peaks and are displaced in time. Presumably these discharge features occurred in other rivers and streams in the region, and would markedly affect the surface salinity characteristics of the waters in the region, particularly those areas closest to the source of the fresh water.

3. Tides

The principal characteristics of the tides of the British Columbia coast are that they are semi-diurnal and markedly declinational (having a marked inequality between the heights of successive low waters). Predicted tide curves for Bella Bella, situated 23 miles north of the mouth of Burke Channel, have been used for the region (Fig. 1). The maximum range is approximately 17 feet, while the minimum range is about 4 feet. Between the head and mouth of an inlet there is usually little difference in tide. At the head of Burke Channel, the time of high or low water is later by not more than 10 minutes than at Bella Bella near its mouth. The range is only 1.0 to 1.5 feet greater than near the mouth for mean and large tides, respectively (Canadian Hydrographic Office, 1960, p. 212). Examples of tidal characteristics appear in most of the figures in this report.

4. Oceanographic characteristics

Pickard (1961) has described some of the oceanographic features of this region, in particular, for Burke and Dean Channels. He has shown them to be typical estuarine systems, as a result of the large fresh water runoff into the heads of the channels. The net circulation and water structure of such a system are well established (Tully, 1958). There is a net seaward motion in the surface layer which is a consequence of the discharge of fresh water into the head of the channel. Being light, it over-runs the sea water, and as it moves seaward, gains in volume by entrainment of saline water from below into the out-flowing surface layer. There is a net subsurface inflow. The principal features of the salinity structure are: (1) an upper zone of brackish water, (2) a marked halocline, and (3) a lower zone of saline water. The features of the net circulation and salinity structure are summarized in Fig. 11. However, because of tides, variable winds and runoff, the circulation, salinity structure and salinity distribution vary considerably at any one time. These parameters,

along with temperature, will be discussed further. Burke and Labouchere Channels are discussed first, followed by discussions of Fitz Hugh Sound, Nalau Passage and Fisher Channel.

(a) Burke and Labouchere Channels

Burke Channel can be divided into three distinct oceanographic regimes, which have been designated "upper", "middle" and "lower" regimes. The division is based primarily on the features and magnitude of the longitudinal surface gradients of salinity and temperature (Fig. 12 and 13). The "upper regime" is considered to extend from the head of Burke Channel (North Bentinck Arm) to the vicinity of Kwaspala Point. Within this regime there were marked longitudinal salinity gradients (salinity increasing seaward). Temperature gradients, although not as marked as salinity, were also common. Usually temperature increases to a maximum and then decreases seaward (Pickard, 1961). It will be shown later that there were also marked cross-channel gradients, particularly of salinity. Since Labouchere Channel has somewhat similar features as this regime, it will also be considered as part of the upper regime of Burke Channel.

The middle regime is considered to extend from Kwaspala Point to the vicinity of Restoration Bay (Fig. 1). Within this area, horizontal salinity and temperature gradients were relatively small, except in late June, at the peak of the fresh water runoff (Fig. 12 and 13). By this time the small fish have completely left this area. The few data obtained in this regime were from observations made in close proximity to either the upper or lower regime.

The lower regime extends from Restoration Bay to the mouth of Burke Channel. Within this area, surface gradients were again fairly pronounced. Salinity increased to a maximum in the vicinity of the sill and then decreased, whereas, temperature decreased to minimum and then increased (Fig. 12 and 13). The area is also characterized by tide rips, boils and eddies. As will be shown later, all these features are associated with the sill located in the centre of this regime (Fig. 5).

(i) Upper regime

Surface distributions, vertical profiles and sections of salinity and temperature, and current observations for the upper regime are presented in Fig. 14 to 74. Salinity and temperature data are first discussed and are presented in chronological order in Fig. 14 to 60. However, the current observations have been arranged firstly by area and then in chronological order for each sub-area of the upper regime (Fig. 61-74). In the following discussions only some of the figures are cited, as examples pertinent to points made in the discussions.

(a) Salinity and temperature

The salinity profiles and sections show the characteristic features of structure of an estuarine system; namely, an upper zone, a halocline, and a lower zone. In North Bentinck Arm, the upper zone was generally absent and instead, the halocline extended to the surface. The latter feature had usually developed by mid-April (Fig. 14, sta. 1 and Fig. 27), coinciding with a small increase in the Bella Coola River discharge. Further down the regime, the upper zone tended to be isohaline to a depth of 5 to 10 m (Fig. 38, sta. 1-3; Fig. 56, sta. 16-18).

A common feature of this regime was the presence of a double halocline. Near the head of North Bentinck Arm, the double-halocline structure was observed in April (Fig. 14, 18 and 27). The deeper (15-20 m) and comparatively small halocline is considered to indicate the extent of winter convective overturn. The shallower (0-10 m) halocline is considered to be a result of the recent spring runoff. However, as the season progressed, the winter-formed halocline vanished. Thereafter, in this area, further haloclines may be formed at relatively shallow depths by successive dilutions from intermittent high discharges from the Bella Coola River.

In Labouchere Channel, and its vicinity, the double-halocline structure was also a common feature (Fig. 23; sta. 27). It is usually formed by late April or early May. Here its formation is a result of the introduction of two different surface water masses. The deeper halocline appears to be associated with Burke Channel water. The shallower halocline appears to be a result of the introduction of relatively fresh water from Dean Channel which overrides the deeper Burke-Labouchere Channel water. The mechanism is confirmed in the results of the current observations. The double-halocline structure can easily be destroyed or united into a single halocline through tidal or wind mixing, or complete removal of the upper layer through wind transport.

The bottom of the halocline can be approximated by the isohaline surface of 31‰, occurring at depths generally less than 15 m. Throughout the entire region, this surface was generally indicative of the bottom of the halocline, except in the vicinity of the sill, where the basic three-zone structure could be destroyed through turbulent mixing over the sill.

Variations in the depth of the upper zone and halocline occurred across the channel. In most cases, the upper zone was deepest on the northern shore (right hand side looking down-channel), associated with the accumulation of fresh water due to the Coriolis effect acting to the right or northern shore. Associated with the fresh water accumulation was a downward slope of the isohalines (Fig. 20, sta. 22-24; Fig. 44, sta. 1-3). This general picture did not occur in areas where adjoining channels and bays complicated the circulation. Further, this pattern could be altered by winds transporting surface waters to the opposite shore. Such changes would be expected to occur during persistent up-channel winds, when surface waters are transported to the southern shore, resulting in a downward slope of the isopleths toward that shore. In Labouchere Channel, fresh water accumulated on the western shore and the near-surface isohalines deepened from the eastern to western shore (Fig. 38).

Consistent with the features of an estuarine system, the surface salinities were lowest at the head of North Bentinck Arm near the fresh water source, and increased seaward (Fig. 52). Relatively low-salinity surface water was also present in Labouchere Channel.

Some of the small cells of low salinity water adjacent to the shores may be attributed to the fresh water discharge from the local mountain streams. Examples of such cells are those that occurred in and near Green Bay (Fig. 21 and 25). However, these waters were generally clearer than waters of similar

salinity, in which the fresh water was derived from the silty Bella Coola River. An example of two river systems having markedly different optical properties is the Necleetsconnay and the Bella Coola Rivers. This difference is apparent in the aerial photograph shown in Fig. 58. The lighter tone is the silt-loaded water from the Bella Coola River.

Generally, the larger bays were filled with relatively fresh water during some phase of the tide. There was usually a sharp discontinuity separating these large cells from the surrounding high-salinity water. This feature was most pronounced in Windy Bay (Fig. 48) and results from the complicated tidal circulation brought about by the configuration of the shoreline.

The most marked surface gradients were found in North Bentinck Arm, particularly from its head to Flagpole Point (Fig. 48 and 50). The longitudinal and cross-channel gradients were also a result of complicated tidal flow in areas associated with junctions and dog-legs in the channel. As a result of these gradients, changes in salinity as great as 15‰ occurred over a tidal period as a result of a slight shift of these boundaries, through surface movements. Marked variations could also be expected under varying wind conditions. In particular, strong persistent down-channel winds would flush the relatively fresh surface layer down-channel. High-salinity water would remain until the winds decreased or reversed direction. Diurnal variations in surface transport could also be expected, associated with the diurnal variations in wind direction.

Tongue-like features also occurred, formed by the relative movements (current shear) of high- and low-salinity water. They were most pronounced at the junctions of channels (Fig. 20 and 44). This was a characteristic feature at the junction of North and South Bentinck Arms on the ebb tide. Here a tongue or bands of low-salinity water extended to just southeast of Menzies Point (Fig. 20). On the flood tide the low-salinity tongue is displaced toward the northern shore of Burke Channel and the high-salinity water extends from Menzies Point to Flagpole Point. This feature is apparent in the aerial photographs shown in Fig. 59 and 60.

The waters adjacent to the shoreline on either side of Flagpole Point had relatively permanent characteristics; namely, high-salinity water on the western side and low-salinity water on the eastern side, with an abrupt demarcation (Fig. 42, 48, 50). This results in permanent ecological differences in this area. Animals associated with high-salinity water were found on the western side, but were absent in Windy Bay.

From South Bentinck Arm to Labouchere Channel, salinity gradients were relatively weak (Fig. 50 and 52). Variability, therefore, over a tidal period was also relatively small.

In Labouchere Channel, in April, surface salinities were generally higher or similar to those found at the Burke-Labouchere junction (Fig. 46). However, by May, salinities were considerably lower in Labouchere Channel than near the junction of the two channels (Fig. 23 and 52). Thus, early in the season, the salinity gradient may be either positive (decreasing) or negative (increasing) from Dean to Burke Channel. However, in May, the salinity gradient is usually

negative. The low-salinity surface water in Labouchere Channel is considered to have originated from Dean Channel.

The corresponding temperature structures, sections and distributions for the upper regime are included in Fig. 14 to 57. At the head of North Bentinck Arm, the temperature structure, in mid-April, was generally characterized by a cold surface layer overriding a warm layer (Fig. 15, sta. 1). Near the end of April, a thermocline had started to develop as a result of the onset of spring warming. The development of the thermocline occurred at a depth coincident with that of the shallowest halocline (Fig. 27). Below this depth, the effect of winter cooling was evident, from the temperature maximum at 20 - 50 m depth (Fig. 27 and 33). A mechanism for the formation of this positive structure in these intermediate waters has been given by Tabata and Pickard (1957). However, for this report, discussions will be limited primarily to the near-surface waters (above the halocline).

In the horizontal distributions, the isotherms show the same general configuration as the isohalines. In April and early May, in North Bentinck Arm, the cold water was associated with the low-salinity water and usually occurred on the northern shore (cf Fig. 52 and 53). However, probably in late May, as local heating increases, high-temperature water would be associated with low-salinity water, as the stability of the low-salinity surface layer would confine the heat input into a relatively shallow layer. Thus, early in the year in North Bentinck Arm, it is expected that low temperatures indicate river outflow, while later in the year, high temperatures indicate low-salinity water warmed locally by insolation.

Temperature gradients occurred in conjunction with salinity gradients. Generally the gradients were of the order of 2 C or less during April and early May (Fig. 12 and 15) but may have been as much as 5 C later in the season (Fig. 13). Marked local temperature gradients may occur as a result of the translation of the thermocline gradient to a horizontal surface gradient by the process of upwelling through wind transport. A similar translation would occur in the vertical salinity gradients. Such gradients may give some indication of past processes.

In the cross-sections, the slopes of the isotherms are similar to those of the isohalines (Fig. 20 and 56).

(b) Currents

A number of attempts were made to define the surface and/or near-surface currents over a tidal cycle, using free-floating drogues or weighted drift sticks. It was not always possible to follow the floats through a complete tidal cycle because of adverse wind conditions. Nevertheless, from the accumulated data, it is possible to define some of the principal features of the surface currents and at the same time to logically extrapolate these data to define the surface movement under variable conditions of runoff, winds and tides in this area. Measurements were made in North Bentinck Arm, at the junction of North and South Bentinck Arms, and in Labouchere Channel. The results are shown in Fig. 61 to 74. Time-series observations were made at two anchor stations in North Bentinck Arm, off Whiskey and Bachelor Bays (Fig. 64). The results are presented in Fig. 66-68.

North Bentinck Arm

Initially, observations were made in North Bentinck Arm on April 22, 1963, commencing at the beginning of an ebb tide. Winds were of sufficient strength, starting at 8 and increasing to 20 miles per hour, to reverse the surface flow against the out-flowing ebb tide (Fig. 61). The flow was strongest (0.8 knots) on the southern side, decreasing to 0.3 knots on the northern side. In this area, a cross-channel gradient of wind occurs because of the configuration of the shoreline. Up-channel winds are strongest on the northern shore. One would also expect the wind-driven currents to be strongest on the northern shore. However, the out-flowing ebb tide is also strongest on this shore, and was nearly strong enough to compensate for the wind-driven flow. The resultant up-channel flow was on-shore. The high-salinity water at Station 1 is indicative of the retention of low-salinity water up-channel from this station and of a low-runoff period (Fig. 61). In all probability, if these measurements could have been continued, the net up-channel movement would have continued, but at a much reduced rate. Further, the outflow, although not measured, would probably have increased at deeper levels to compensate for the surface in-flow.

Observations made near the beginning of the flood tide and under conditions of little wind showed an outflow of 0.5 to 0.9 knots (Fig. 62). The strongest flow occurred in mid-channel. The surface salinity (21‰) suggests that this was a period of low-runoff. Measurements were repeated two days later on the flood tide (Fig. 63). The surface flow was initially down-channel, under conditions of no wind. The flow reversed to the flood direction as a result of the influence of up-channel winds and the flood tide. Waters from mid-channel moved into Whiskey Bay and then up-channel on the southern shore. Near high-water slack the up-channel surface flow was strongest on the northern shore because of the stronger winds on this shore. The flow at 1-metre depth seemed to be tidal dominated.

The results of these measurements suggest a residual down-channel surface flow at a rate of less than one knot. This flow persists until at least the mid-flood period under conditions of low-runoff. If relatively strong up-channel winds prevail, the flow is reversed. Under most tidal conditions and up-channel winds, surface water from mid-channel moves into Whiskey Bay and onto the southern shore. Overall, there appears to be a net movement to seaward on all shores over a tidal day.

In the large bays, such as Windy Bay, gyres are usually found (Fig. 64). Here, the net circulation was clockwise on the flood tide. For a time, the waters are retained in the Bay, and may move out into mid-channel, where on an ebb tide, they would be moved rapidly down-channel, providing there is no opposing wind. Thus, there is a mechanism for the partial retention of water in the larger bays, through the formation of gyres. It would be expected that this feature could occur in most bays.

The current observations made at selected depth at one position over a tidal cycle provide information on the variations of flow at depth and on the net circulation. The first series of observations were taken off Whiskey Bay (Fig. 64) and are summarized along with the salinity observations in Fig. 66 and 67. The longitudinal and transverse flows off Whiskey Bay are shown in

Fig. 66. It is evident that, at any one time, there is outflow at some depths and inflow at others. The variations in flow with depth do not seem to be related to the features of the salinity structure, although, in some cases, the shear zones occur in or at the boundaries of the halocline (Fig. 66). It appears that, when the transverse flow is large and directed to the near-shore, the longitudinal flow is also large.

In Fig. 67 are shown the in- and out-channel components at selected depths for a 25-hour series. The currents at the surface and 1-metre depth changed directions several times, but the predominant direction was down-channel. The greatest down-channel surface velocity occurred after the mid-ebb tide, nearly 2 knots. At the surface, an up-channel flow on the first flood tide occurred after mid-flood. On the following flood tide, the flow was predominantly up-channel at all levels, excepting at 25 m depth.

The calculated net or residual velocity at the surface over a tidal cycle was 0.08 knots, down-channel, under calm conditions. Although the observations at other depths were not continuous over a tidal day, the net flow, down to 25 m depth, also appears to be down-channel (Fig. 67).

The marked freshening that occurred at 2-metres depth was probably associated with a cloud of water having characteristics different than the surrounding waters at this depth.

Another time series was attempted in which observations at the surface and 2-metres depth were made simultaneously on opposite sides of the channel off Whiskey Bay and off Bachelor Bay (Fig. 64). The results are summarized in Fig. 68. The net residual surface current over a 12-hour period was 0.2 knots up-channel on the Bachelor Bay side of the channel. However, these measurements were made during periods of relatively strong up-channel winds.

Junction of North and South Bentinck Arms

The surface salinity distributions showed tongue-like features from the centre of North Bentinck Arm to the southern shore, just east of Menzies Point (Fig. 20). The results of the current observations offer a mechanism for the formation of this tongue, and are summarized in Fig. 69 to 72. On May 1, 1963, measurements were started at high-water slack and were continued until low-water slack (Fig. 69). The floats released near the northern shore were soon lost, but the movement was relatively swift and down-channel. The floats released in mid-channel moved to the southern shore, near Menzies Point. Floats released near the southern shore initially moved across the mouth of South Bentinck Arm and then continued up the centre of the Arm (Fig. 69). The latter movement was a result of up-channel winds that occurred at this time. Measurements were repeated near the southern shore on the following day under calm conditions (Fig. 70). The surface movement was directly across the mouth of South Bentinck Arm and was in the form of a jet stream with a marked piling up on the shore in the vicinity of Menzies Point. The current at 1-metre depth was similar in direction, but its velocity was about one-half that observed at the surface.

Measurements were made the following year under different conditions of wind and tide (Fig. 71 and 72). Near the end of the ebb tide, the flow at 1-metre depth was up-channel and was strongest on the southern shore (Fig. 71). On the flood tide the results showed an up- and cross-channel movement to the southern shore. On the ebb tide, the movement was to the southern shore, but a reversal of flow at 1-metre depth occurred at the time the in-blowing (westerly) winds increased in strength (Fig. 72).

It is reasonable to assume that the strength of the jet flow toward Menzies Point is directly related to the freshwater runoff. The greater the runoff, the greater the flow across South Bentinck Arm to Menzies Point. Further, the strength of the jets would vary depending on whether spring or neap tides were occurring. In the presence of up-channel winds, the ebb flow may reverse to the flood direction.

Labouchere Channel

Pickard (1961) suggested that some low-salinity surface water from Burke Channel is lost by way of Labouchere Channel. It now appears from the results of current observations in this area that there is a net surface movement under conditions of no wind. On the flood tide, the waters move out of Labouchere Channel, then move in a counter-clockwise gyre at the junction (Fig. 73 and 74) or move out of Labouchere Channel and then down Burke Channel (Fig. 73 and 74). Speeds at the surface and 1-metre depth were generally less than 1 knot.

Very near the shore, small up-channel movements (towards Dean Channel) were observed. These were small compared to the down-channel movements in the other parts of Labouchere Channel. Therefore, under conditions of no wind, the surface layer (to at least 1-metre depth) from Burke Channel does not move into Dean Channel. Only under unusual wind conditions would such transport occur.

(ii) Middle regime

(a) Salinity and temperature

The observations made in this regime are few. Nevertheless, they show the typical features of salinity and temperature that are encountered, Fig. 75, 82, 83 (sta. 1) and 85 (sta. 1-4). In mid-May, the upper zone is fairly well established to a depth of about 5 metres (Fig. 75). In the upper part of the regime, the cross-channel gradients and slopes of the isopleths were relatively slight (Fig. 75). However, in the lower part of the regime, the slopes of the isopleths were relatively steep (Fig. 85, sta. 1-4), suggesting a strong down-channel flow along the northern side during the ebb tide. As noted previously the longitudinal gradients were comparatively small (Fig. 12 and 13).

(b) Currents

Current measurements using drogues were made at the surface and 1-metre depth in the upper part of the regime (Fig. 73). From mid-channel to the northern shore, the movement was down-channel on the flood tide. During these observations a tide line, running longitudinally, was observed

between the centre of the channel and the southern shore. Presumably on the southern side of the tide line, the flow was up-channel. In mid-channel, velocities were slightly greater at 1-metre depth than at the surface.

Continuous current observations in this regime were made at selected depths below the junction of Labouchere and Burke Channels, relatively close to the southern shore (Fig. 75). It was planned to make the observations over a tidal cycle (25 hours). However, the observations were discontinued because of strong down-channel winds which started to blow in the early morning. The results, along with salinity, are summarized in Fig. 76 and 77. The shear zones appear to occur in or at the boundaries of the halocline (Fig. 76), as noted in North Bentinck Arm (Fig. 66). The relatively strong down-channel flow from the surface to 2-m depth during the early morning, on the small flood tide was, in part, due to the down-channel winds experienced at this time. The flow at other depths was generally up-channel, even on the ebb tide, although the ebb tidal fall was relatively small (Fig. 76 and 77). The net down-channel surface flow during the initial tidal cycle (12 hours) was 0.3 knots. Using this result and that obtained in North Bentinck Arm gives an average down-channel surface flow of about 0.2 knots. It is concluded that from mid-April to mid-May a surface water mass from the head of North Bentinck Arm would reach the mouth of Burke Channel in about 10 days, during calm conditions.

(iii) Lower regime

The interesting physical features of the lower regime are the sill and the marked dog-leg in the channel (Fig. 78), and their effects on the salinity distributions and structures and the currents.

(a) Salinity and temperature

The salinity and temperature distributions for the lower regime are shown in Fig. 79 to 87. In the vicinity of Restoration Bay, surface salinities were relatively low and surface temperatures were relatively high. The halocline and thermocline gradients were also large (Fig. 85, sta. 5-7). However, in the vicinity of the sill, a marked doming of the isopleths, accompanied by a partial breakdown or shallowing of the vertical salinity and temperature gradients occurred (Fig. 83 and 86). Horizontal gradients were also present in the vicinity of the sill (Fig. 81 and 82).

At the mouth of the channel, the vertical gradients were generally small in May (Fig. 85, sta. 14-16). However, by the beginning of June, these were more pronounced (Fig. 87, sta. 1-3).

The tongue-like features above the sill are indicative of the relative movements of the surface waters (Fig. 81 and 82). Down-channel from the sill, the marked downward slope of the isopleths towards the northern shore indicates that the flow on the ebb tide was strongest along this shore (Fig. 84, sta. 1-3).

(b) Currents

The flow in the vicinity of the sill is very complicated, especially during the flood tide. Marked turbulence occurs, particularly during periods of maximum tidal movements (spring tides). Fronts of relatively steep waves, about 4-5 feet in height, have been observed. Such conditions

occur when the tidal flow is opposed to the residual or estuarine flow. It is impossible to make oceanographic observations from a small vessel under these conditions. However, it is reasonable to assume that vigorous vertical mixing occurs and the basic estuarine structure is destroyed. During small tidal movements (neap tides), these waves were not observed and vertical mixing is not so marked. Instead the isopleths dome, resulting in higher salinities and temperatures at all levels than at the corresponding levels in the adjacent waters, as shown in Fig. 83 and 86.

The current observations at 1-metre depth are shown in Fig. 88 to 94. Current measurements made down-channel of the sill on the flood tide showed that the flow to the vicinity of the sill was a relatively simple up-channel flow (Fig. 90). Near the sill the flow became complicated, particularly on the up-channel side of the sill (Fig. 88 to 93). The flow generally occurred along distinct tide lines that formed and dissipated intermittently. Floats entering the tide rip would move quickly along the tide lines, usually in a clockwise gyre. Further, there were cross-channel movements of the order of 0.5 knots (Fig. 93). Towards the end of the flood tide, the movement was down-channel.

Current measurements made on the ebb tide indicate a marked movement down-channel (Fig. 94). Wind was a dominant factor in moving the surface water at the speeds shown in this figure. Still, even at the beginning of the ebb, when the winds were light, a marked ebb flow was observed.

The direction of flow was noted at the time observations were being made on two sections across Burke Channel (Fig. 84). At Station 2 and 3, the flow was down-channel, while near the southern shore, the set was up-channel. A noteworthy feature was the ebb jet stream past "Have". Here, there was an onshore transport which resulted in back eddies being formed in the small bays. (Fish appeared to be transported on shore and into the bays where they remained in the back eddies and tide lines.) Similar features were noted on the opposite shore.

(b) Fitz Hugh Sound

(a) Salinity and temperature

Salinity and temperature sections were taken across Fitz Hugh Sound during various phases of the tide (Fig. 95 and 97). Surface salinities were relatively high and temperatures were relatively low in late May. By early June, surface salinities were low and temperatures were high. The halocline and thermocline extended from the surface to a depth between 15 and 20 metres. The bottom of the halocline generally coincided with the 31‰ isohaline surface, as was noted in Burke Channel.

On the ebb tide and at low-water slack, the isohalines and isotherms in the upper 20 m tended to slope downward from the eastern shore to the western shore, inferring a cross-channel velocity gradient (Fig. 95, sta. 55-57; Fig. 96, sta. 7/6-9/6).

The configuration of the isohalines and isotherms below the halocline suggests that during the mid-flood period, the movement here was northward along the eastern side of Fitz Hugh Sound and southward along the western side (Fig. 95).

During other phases of the tide, the slopes of the isopleths were less pronounced, suggesting small gradients of flow across the Sound (Fig. 95 and 97).

(b) Currents

Current measurements were made at the mouth of Burke Channel (Fig. 98) and on the western side of Fitz Hugh Sound near Nalau Passage (Fig. 99) on various phases of the tide. Drogues at 1-metre depth were released at the start of the ebb tide at three positions across the mouth of Burke Channel (Fig. 98). The drogue released in the centre of the Channel moved in a south-west direction across Fitz Hugh Sound during the ebb and then moved southward during the flood tide. The initial direction of the float released near the northern shore was first influenced by the southerly ebb movement down Fisher Channel. However, once it reached the centre of the mouth of Burke Channel, its movement was similar to the float released in the centre. The float released near the southern shore moved southwestward on the ebb tide, but reversed direction on the change of the tide and moved back to the centre of the mouth of Burke Channel. Presumably, on the following ebb tide it would move across Fitz Hugh Sound, similar to the other floats. The flow in the central part of the mouth of Burke Channel appears to be in the form of successive jets across Fitz Hugh Sound, associated with the ebb tide.

Measurements of drift made off Hunter Island indicate a southward movement on the ebb tide (Fig. 99). At the mouth of Nalau Passage, the general movement was predominantly into Nalau Passage on all tides, except under westerly wind conditions, where the flow was in the same direction as the wind (Fig. 99).

It must be kept in mind that, because of the size of the vessels used, all observations were taken during relatively calm periods. Therefore, it may be concluded, that for periods of calm to light winds, surface waters move out of Burke Channel and across Fitz Hugh Sound as a jet stream on the ebb tide. Near the mouth of Nalau Passage, the flow is, in general, into the Passage.

(c) Nalau Passage

During the first two years of the biological program, pink salmon migrated primarily through Nalau Passage. It was believed that this passage was the main migration route to the open waters. Therefore, oceanographic observations were carried out in this area at selected stations (Fig. 100), primarily to see if there was a marked change in properties which might coincide with the time of migration through the area. It is evident in Fig. 101, that marked surface changes can occur within a period of one to three days. The occurrence of low-salinity water in Nalau Passage is nearly coincident with the occurrence of low-salinity water at the mouth of Burke Channel and in Fitz Hugh Sound.

The isohalines and isotherms, in general, sloped downward from Station 2 to 4, inferring that low-salinity, warm water moves into Nalau Passage from Fitz Hugh Sound, and moves along the northern shore of Nalau Passage (Fig. 103). Some observations of drifting material in Nalau Passage suggests that the surface movement is in the form of a counter-clockwise gyre.

The longitudinal distributions indicate that there may be an accumulation of low-salinity water in Nalau Passage or an accumulation outside the Passage (Fig. 104). These features may be associated with the wind conditions. Westerly winds displace low-salinity waters out of Nalau Passage into Fitz Hugh Sound. Southeast winds result in a retention of low-salinity water in and at the eastern mouth of Nalau Passage.

(d) Fisher Channel

Figures 105 to 107 show the cross-sectional distributions of salinity and temperature observed during 1963 and 1964 in Fisher Channel. These sections show that the slopes of the isohalines and isotherms tended to slope downward from west to east, looking northward. This suggests that there was a predominantly northward flow, although the few surface drift measurements taken close to Walker Point gave no indication of such a flow.

The vertical profiles indicate that surface salinities were lower in mid Fisher Channel than in mid Burke Channel (Fig. 105, sta. 2 and 4). This feature, along with the features noted in the cross-sectional distributions, suggest a net flow northward on the eastern side and a net flow southward on the western side. The net northward flow on the eastern side would be difficult to detect in the vicinity of the mouth of Burke Channel because of the back eddies formed along the edge of the main jet flow out of Burke Channel. Under such conditions, waters moving around Walker Point may be retained in the area. Dissipation northward would occur under conditions of southeast winds.

IV. SUMMARY

Burke Channel is a very dynamic estuarine system, which can be divided into 3 regimes, each having distinct oceanographic properties. In each of the regimes the surface properties and currents are dependent upon fresh water runoff, tides, meteorological events, and the topographic and bottom features. The configuration of the shoreline affects the water movement and results in marked cross-channel and longitudinal gradients, particularly of salinity. Gyres, jets, and back eddies also are common features of the circulation.

The main source of fresh water in Burke Channel is the Bella Coola River, which flows into the head of North Bentinck Arm as a definable silt-loaded water mass. The general movement of the fresh water on entering the Arm is toward the northern shore. Associated with the accumulation of fresh water on the northern shore, there is a downward slope of the salinity and temperature isopleths from the southern to northern shore. Under conditions of in-blowing winds, when the flow is decreased or reversed, the surface waters are displaced towards the southern shore, and there is a downward slope of the isopleths toward the southern shore.

There are many striking features in the surface circulation. A major gyre is formed in Windy Bay in North Bentinck Arm. On the ebb tide, a strong jet stream occurs at the junction of North and South Bentinck Arms and is directed towards Menzies Point.

The waters moving out of North and South Bentinck Arms tend to accumulate along the northern shore, moving towards Mesachie Nose at the junction of Burke and Labouchere Channel. Here a large back eddy or counter-clockwise gyre is generated.

In Labouchere Channel, observations taken during calm to light winds indicate there is a predominant southerly flow of low-salinity water from Labouchere into Burke Channel at the surface and 1-metre depth. On the ebb tide, this water continues down-channel. On the flood tide, the water may circulate in a counterclockwise gyre up-channel of the junction and mixes with the waters from North and South Bentinck Arms, or may move directly down channel.

Tidal velocities are generally less than one knot. The average daily excursion of surface water during mid-April to mid-May is approximately 5 miles, during relatively calm periods.

Although few observations were taken in the area between the mouth of Labouchere Channel and Restoration Bay (middle regime), it appears that topographic features again play a major role in the distribution of surface properties and currents. Again gyres and back eddies are characteristic features. However, the gradients are not as marked as in North Bentinck Arm. Current velocities are similar to those observed in the upper regime.

Near the mouth of Burke Channel, tidal movements and a very shallow sill play a major role in the distribution of oceanographic properties. Here there are several degrees of tidal mixing and movement at the sill, associated with the daily tides and the spring and neap tides. The environment is subject to major changes in this area. During spring tides, the features of the estuarine structure are destroyed by turbulent tidal mixing in the sill area. During neap tides, the estuarine structure is continuous over the "sill", from Burke Channel into Fitz Hugh Sound.

The flow has many interesting features. On the flood tide, the flow is up-channel between the mouth of Burke Channel and the sill. Up-channel of the sill, the flow is in the form of a large gyre, and there is very little excursion. In this area large accumulations of surface materials are evident throughout the year on the flood tide. The ebb flow is swift, but again gyres form in the bays.

At the mouth of Burke Channel, the ebb flow during calm to light winds is in the form of a jet. The waters move across Fitz Hugh Sound and then move southward on the following flood tide. This is compensated by a northward flow along the eastern side of Fitz Hugh Sound.

Near the mouth of Nalau Passage, the movement of water is predominantly into Nalau Passage during periods of calm to light winds. In Nalau Passage, there is an accumulation of fresh water on the northern shore and evidence of a counter-clockwise circulation. Marked variations in surface salinities occur over a period of 1-3 days.

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- Fig. 77 Current velocities and salinities at selected depths below Kwaspala Point in Burke Channel, May 15-16, 1964.
- Fig. 78 Bathymetry of the "sill" area near the mouth of Burke Channel.
- Fig. 79 Vertical distribution of salinity at the mouth of Burke Channel, May 16, 1963.
- Fig. 80 Vertical distributions of salinity and temperature and surface drift at the mouth of Burke Channel, May 16 and 19, 1963.
- Fig. 81 Surface salinity and salinity profiles in Burke Channel, June 2, 1963.
- Fig. 82 Surface temperature and temperature profiles in Burke Channel, June 2, 1963.
- Fig. 83 Vertical distributions of salinity and temperature in the area of the sill in Burke Channel, May 19 and 23, 1964.
- Fig. 84 Vertical distributions of salinity and temperature in Burke Channel, May 20, 1964.
- Fig. 85 Vertical distributions of salinity and temperature in Burke Channel, May 26-27, 1964.
- Fig. 86 Vertical distributions of salinity and temperature in the area of the sill in Burke Channel, May 26, 1964 (station positions shown in Fig. 85).
- Fig. 87 Vertical distributions of salinity and temperature at the mouth of Burke Channel, and vertical distributions of salinity and temperature across Fitz Hugh Sound, June 1, 1964.
- Fig. 88 One-metre drift near the mouth of Burke Channel, May 29, 1964.
- Fig. 89 One-metre drift near the mouth of Burke Channel, May 29, 1964.
- Fig. 90 One-metre drift near the mouth of Burke Channel, May 29, 1964.
- Fig. 91 One-metre drift near the mouth of Burke Channel, May 30, 1964.
- Fig. 92 One-metre drift near the mouth of Burke Channel, May 30, 1964.
- Fig. 93 One-metre drift near the mouth of Burke Channel, May 30, 1964.

- Fig. 94 One-metre drift near the mouth of Burke Channel, May 31, 1964.
- Fig. 95 Vertical distributions of temperature and salinity in Fitz Hugh Sound, May 21-22, 1963.
- Fig. 96 Vertical distributions of temperature and salinity in Fitz Hugh Sound, June 6, 1964.
- Fig. 97 Vertical distributions of salinity and temperature in Fitz Hugh Sound, June 3, 5, 6, 1965 (station positions shown in Fig. 96).
- Fig. 98 One-metre drift in Fitz Hugh Sound, May 20, 1963.
- Fig. 99 One-metre drift in Fitz Hugh Sound and at the mouth of Nalau Passage, June 5, 7, 9, 1964.
- Fig. 100 Station positions in Nalau Passage and Fitz Hugh Sound.
- Fig. 101 Vertical distributions of salinity and temperature in Nalau Passage, May 15, 18, 24, 28, 1963 (station positions shown in Fig. 100).
- Fig. 102 Vertical distributions of salinity and temperature in Nalau Passage, June 2, 4, 9, 1964 (station positions shown in Fig. 100).
- Fig. 103 Vertical distributions of salinity and temperature in Nalau Passage, June 3, 5, 6, 7, 1965 (station positions shown in Fig. 100).
- Fig. 104 Vertical distributions of salinity and temperature in Nalau Passage and in Fitz Hugh Sound, June 2, 4, 9, 1964 (station positions shown in Fig. 100).
- Fig. 105 Vertical distributions and profiles of salinity and temperature in Fisher and Burke Channels, May 29, 1963.
- Fig. 106 Vertical distributions of salinity and temperature in Fisher Channel, May 22, 1964.
- Fig. 107 Vertical distributions of salinity and temperature in Fisher Channel, May 24, 1964.

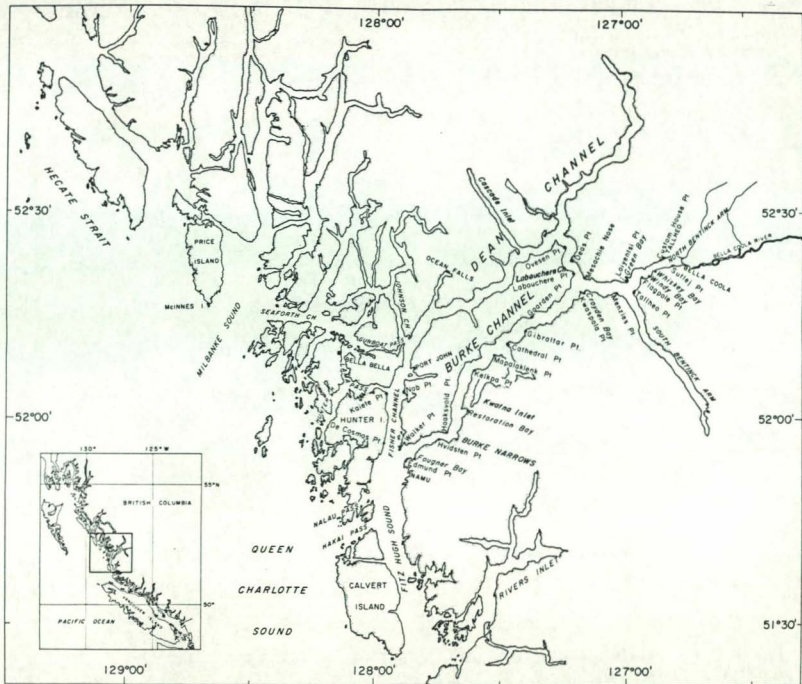


Fig. 1 Burke Channel, Dean Channel, Fisher Channel, Fitz Hugh Sound, Nalau Passage and vicinity in the central British Columbia Coast.



Fig. 2 Fisheries Research Board barge "Veleva" used as a base camp during 1964-67.

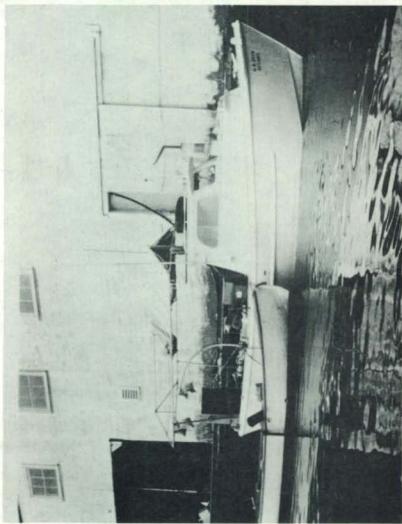
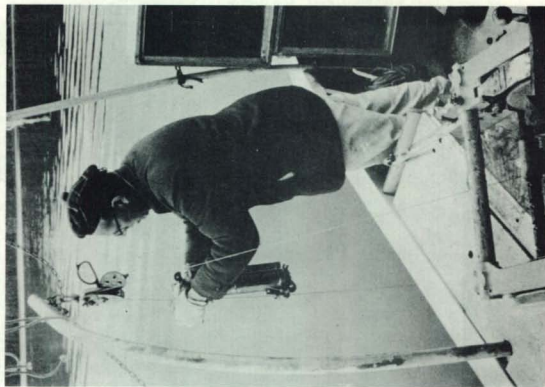


Fig. 3 Research vessel "Remora" and oceanographic facilities.

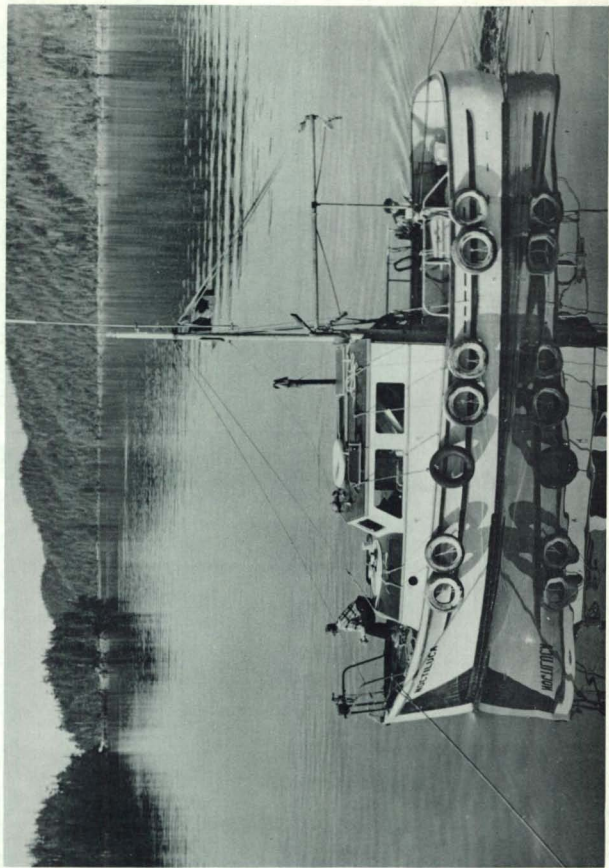


Fig. 4 Research vessel "Noctiluca".

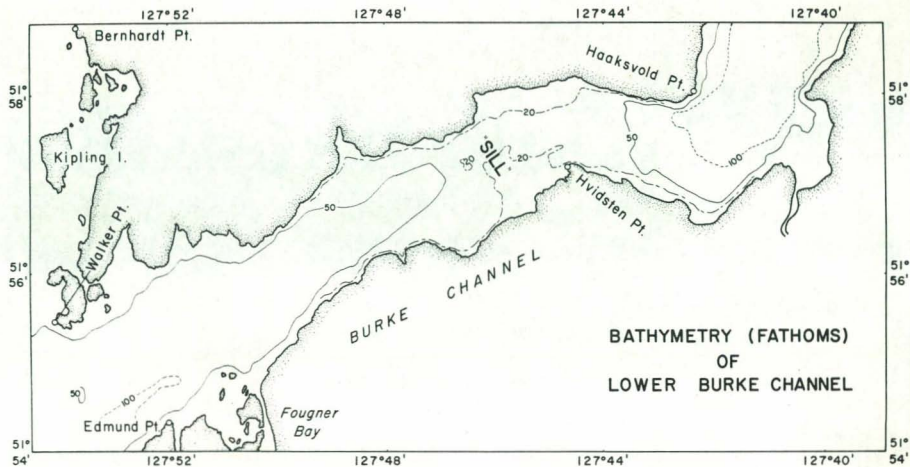


Fig. 5 Bathymetry of the "sill" area near the mouth of Burke Channel.

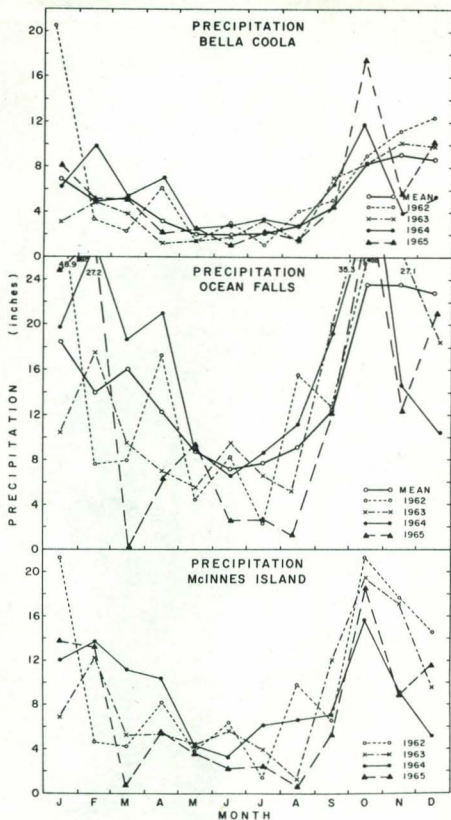


Fig. 6 Monthly mean precipitation at Bella Coola, Ocean Falls and McInnes Island, 1962-65.

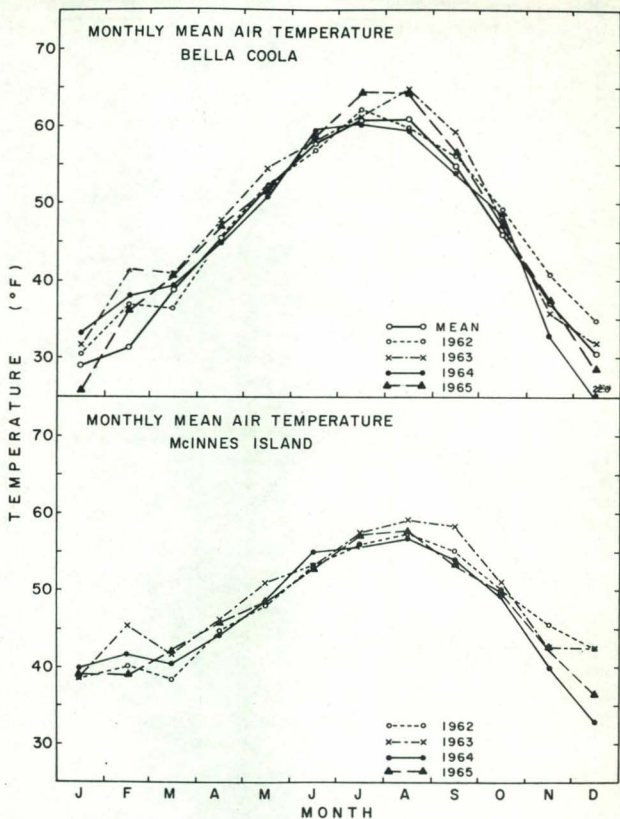


Fig. 7 Monthly mean air temperatures at Bella Coola and McInnes Island 1962-65.

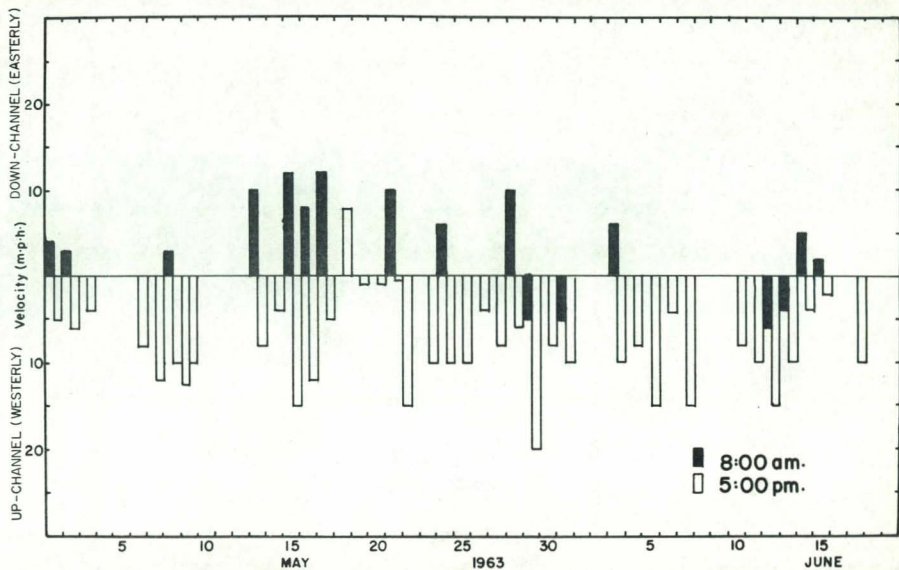


Fig. 8 Diurnal winds at Bella Coola (from records of the British Columbia Forestry Station, Bella Coola).

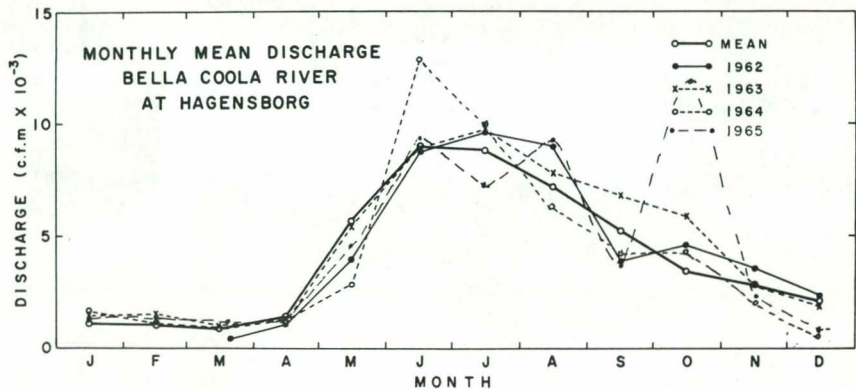


Fig. 9 Monthly mean discharge of the Bella Coola River, 1962-1965.

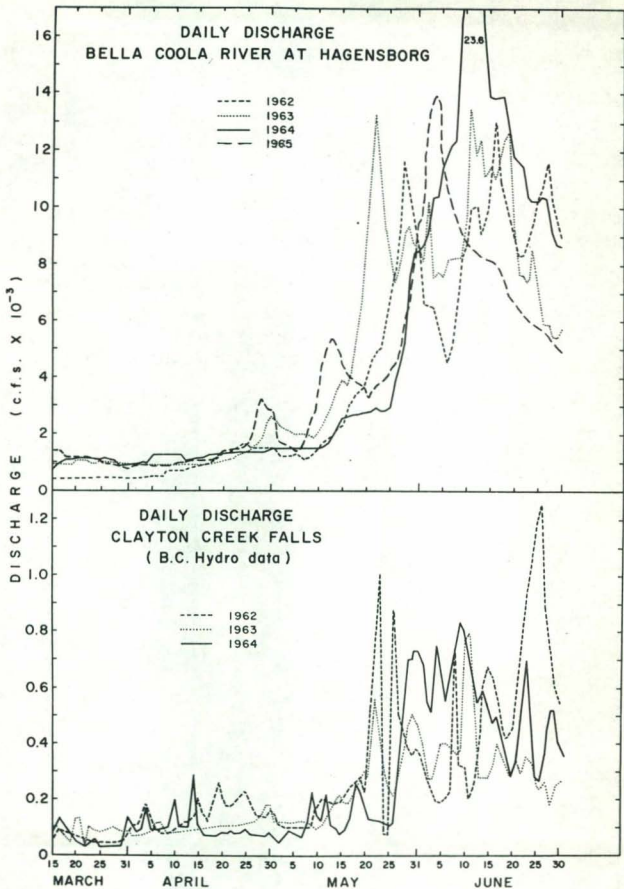


Fig. 10 Daily discharge curves, March 15 to June 30 for the Bella Coola River (1962-1965) and Clayton Creek Falls (1962-1964).

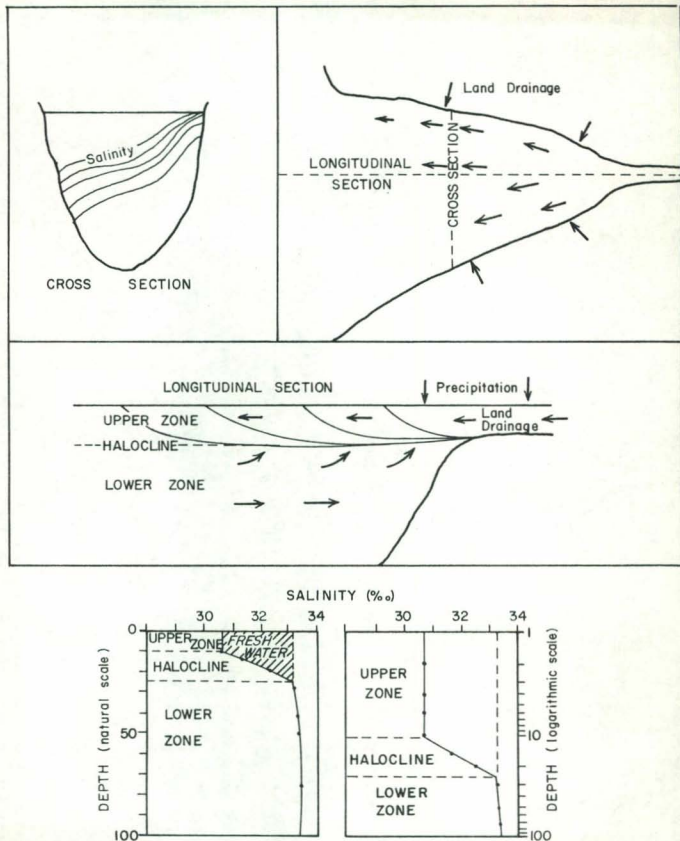


Fig. 11 Net circulation and salinity structure in an estuarine system (from Tully, 1958).

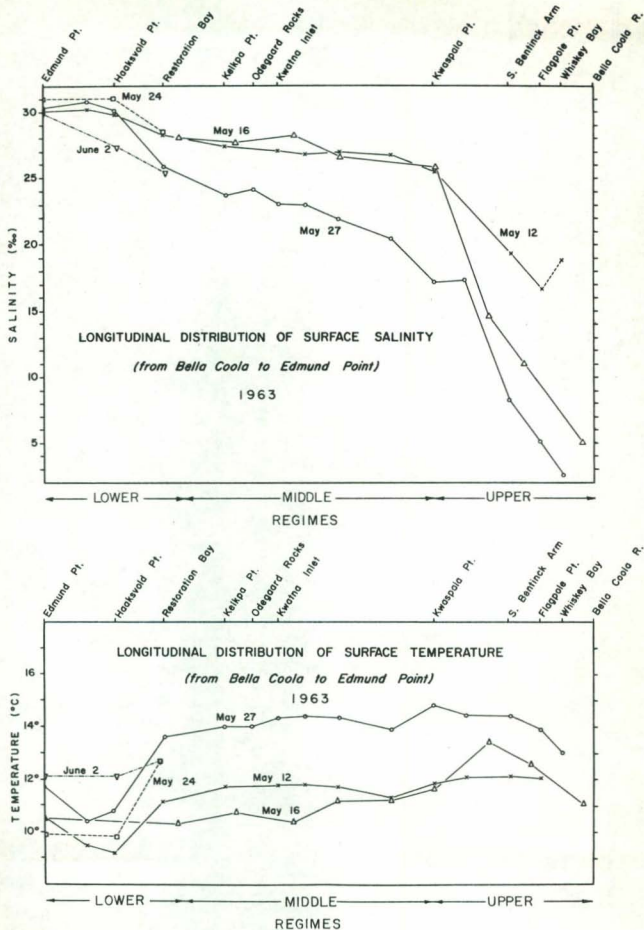


Fig. 12 Longitudinal distributions of surface salinity and temperature, and oceanographic regimes in Burke Channel, May, 1963.

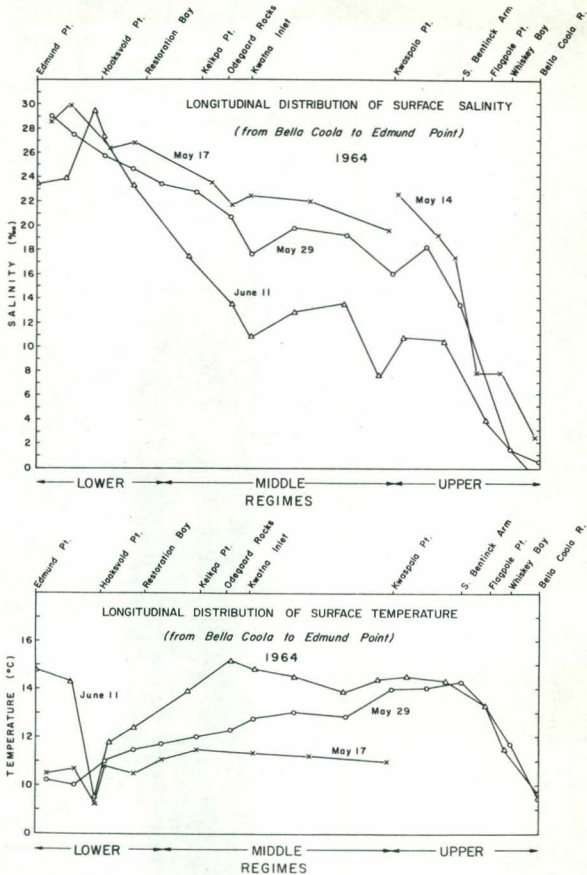


Fig. 13 Longitudinal distributions of surface salinity and temperature, and oceanographic regimes in Burke Channel, May-June, 1964.

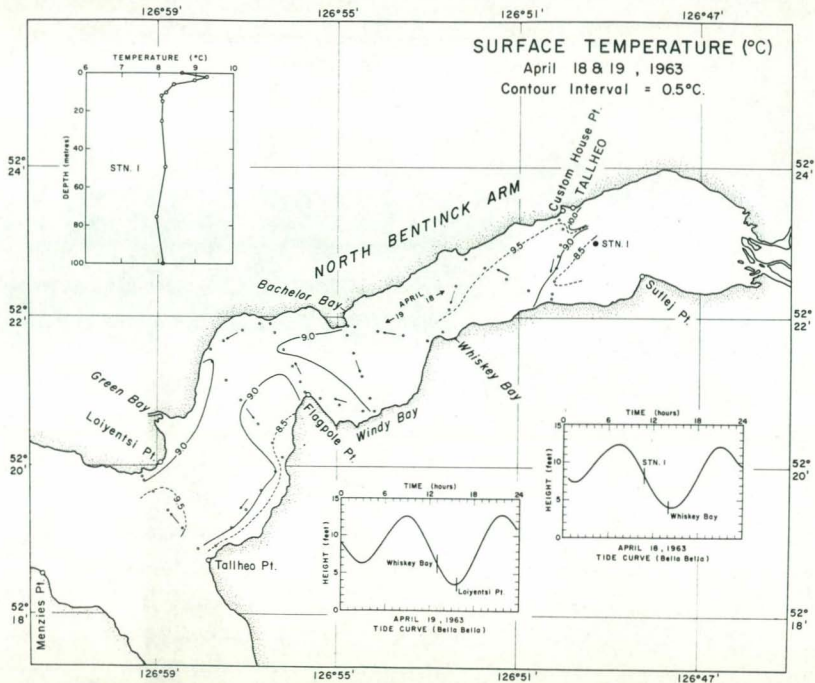


Fig. 15 Surface temperature in North Bentinck Arm, April 18-19, 1963.

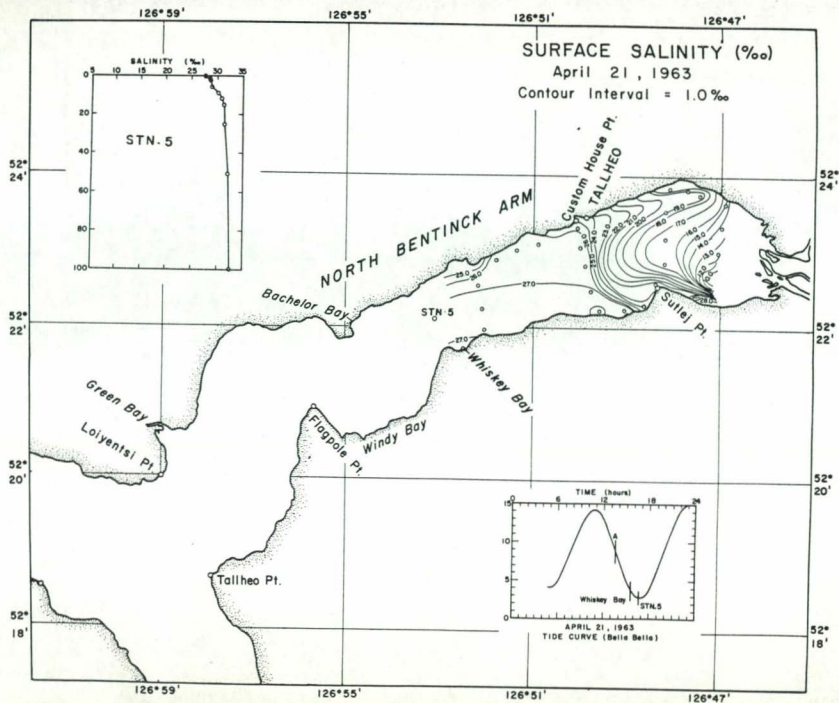


Fig. 16 Surface salinity in North Bentinck Arm, April 21, 1963.

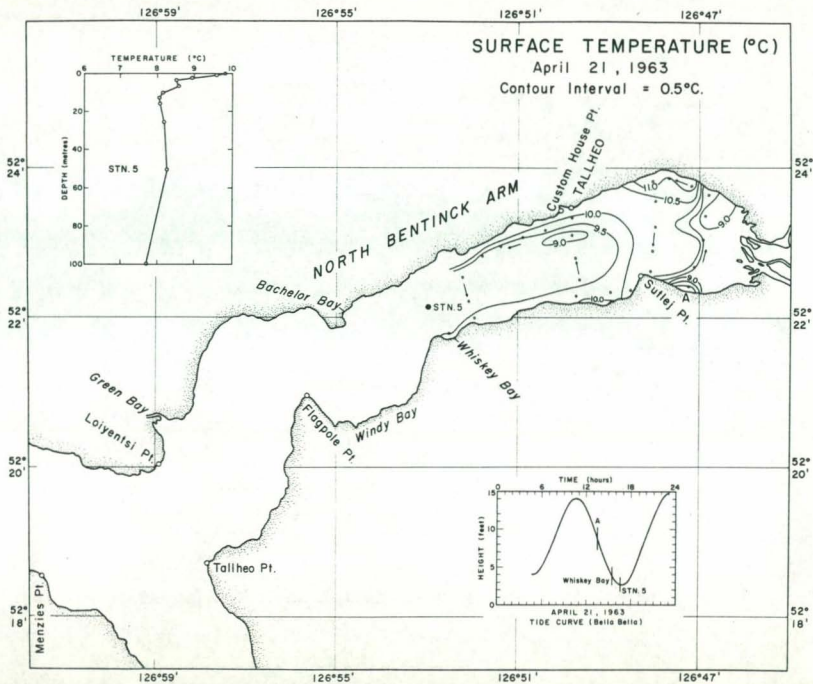


Fig. 17 Surface temperature in North Bentinck Arm, April 21, 1963.

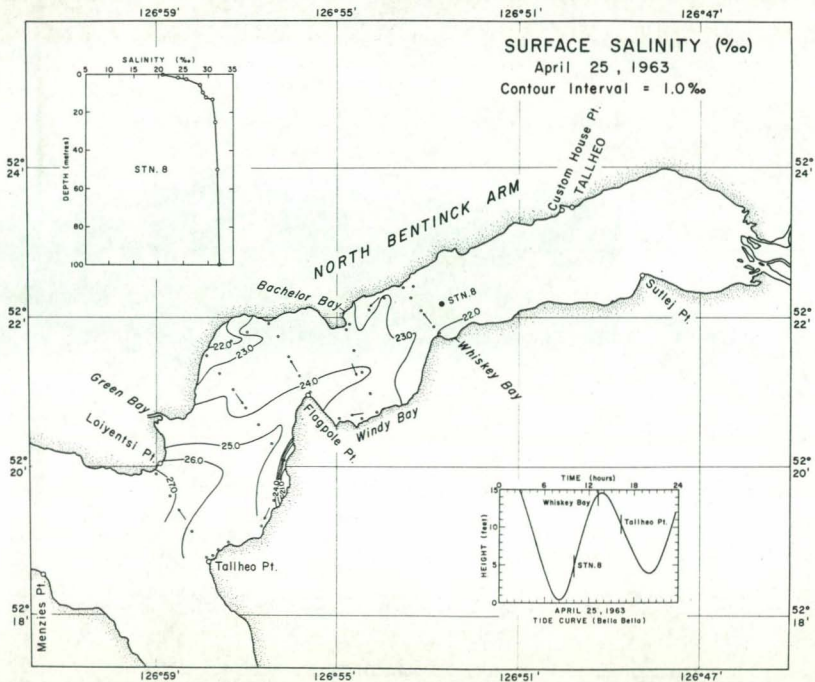


Fig. 18 Surface salinity in North Bentinck Arm, April 25, 1963.

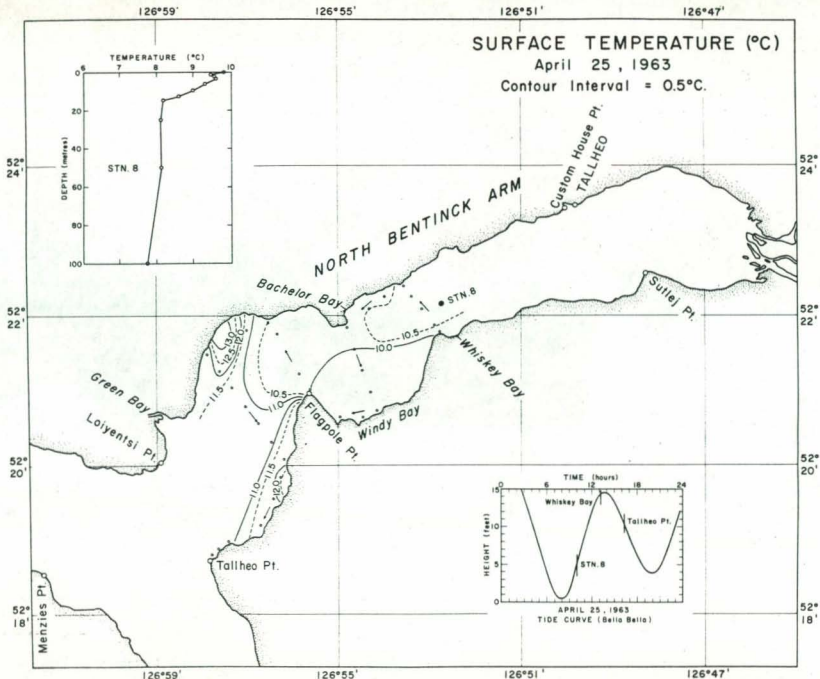


Fig. 19 Surface temperature in North Bentinck Arm, April 25, 1963.

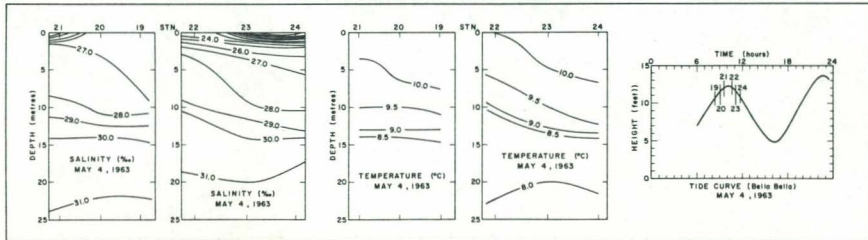
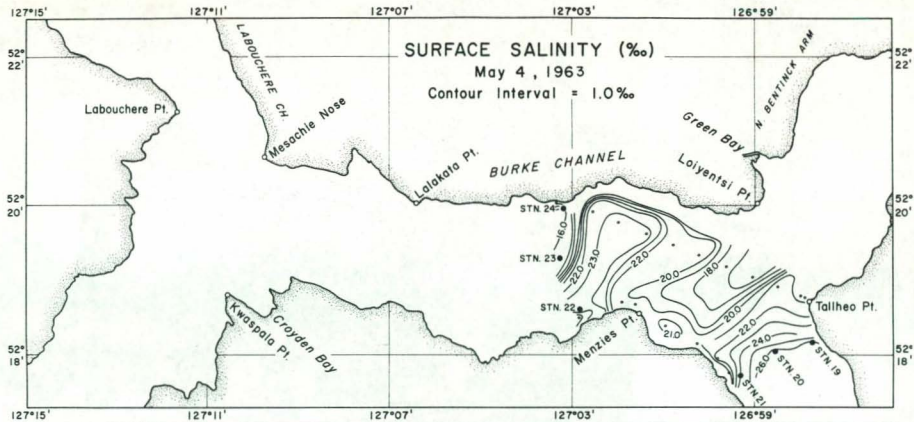


Fig. 20 Surface salinity and vertical distributions of salinity and temperature at junction of North and South Bentsinck Arms, May 4, 1963.

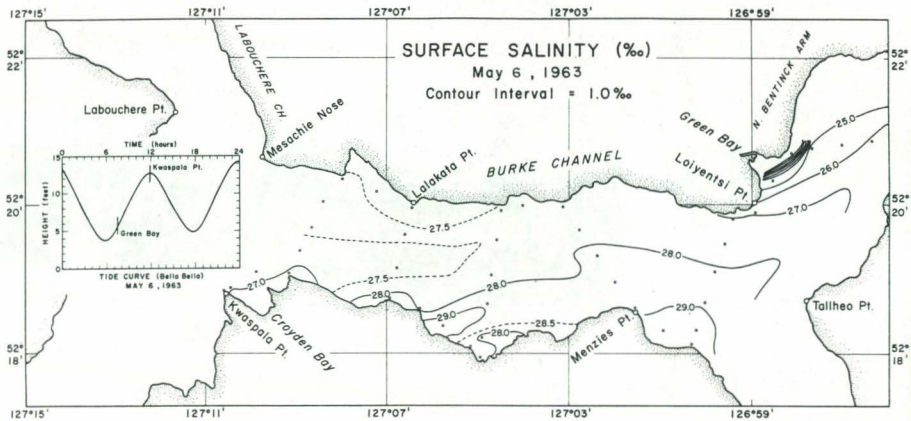


Fig. 21 Surface salinity in Burke Channel, May 6, 1963.

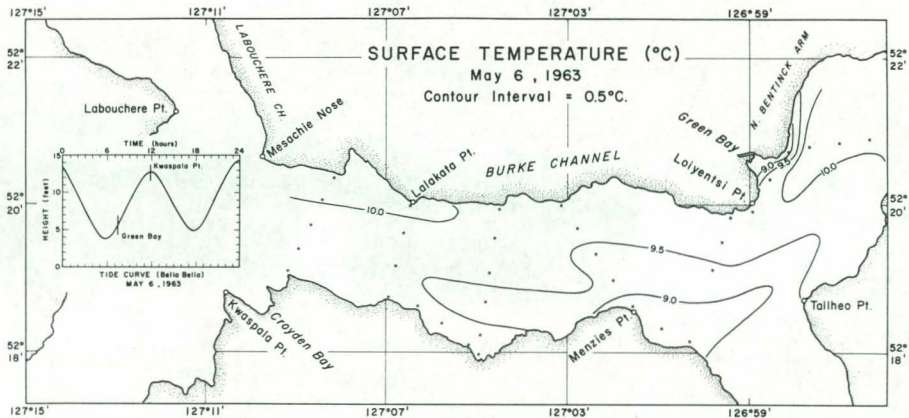


Fig. 22 Surface temperature in Burke Channel, May 6, 1963.

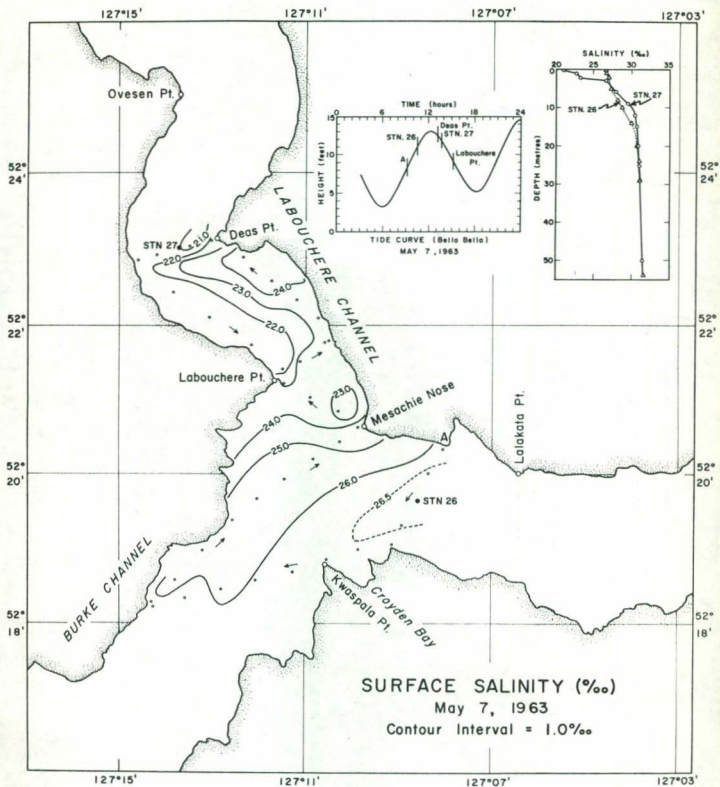


Fig. 23 Surface salinity in Labouchere and Burke Channels, May 7, 1963.

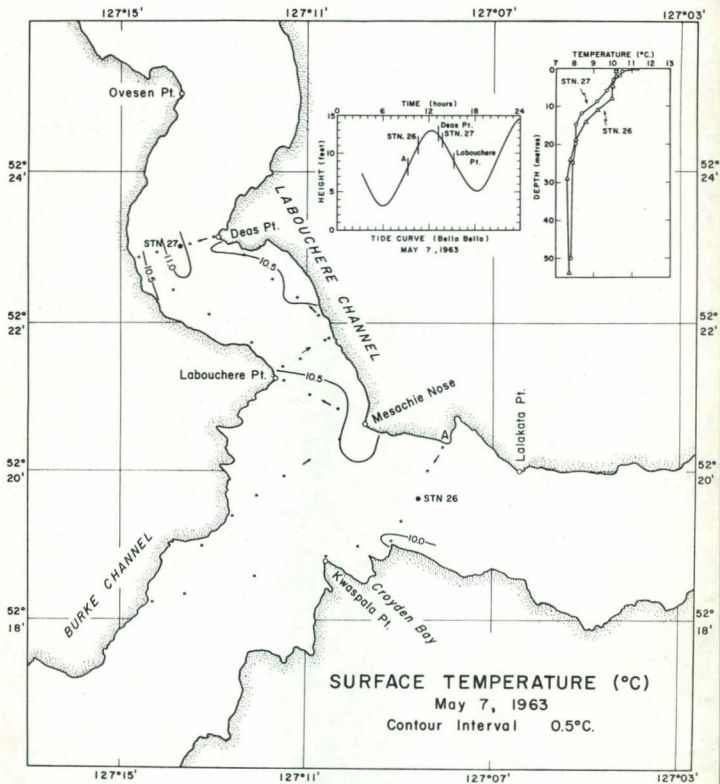


Fig. 24 Surface temperature in Labouchere and Burke Channels, May 7, 1963.

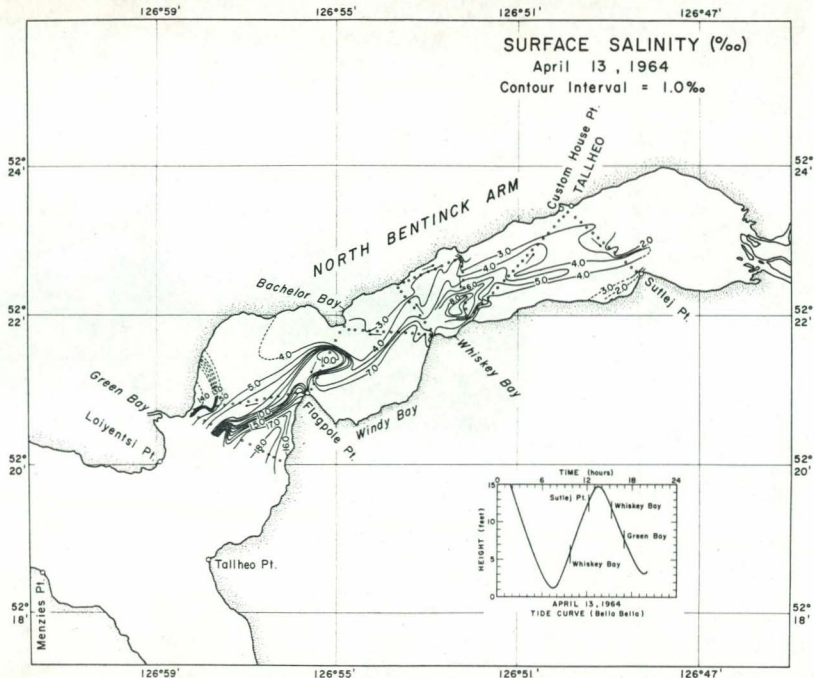


Fig. 25 Surface salinity in North Bentinck Arm, April 13, 1964.

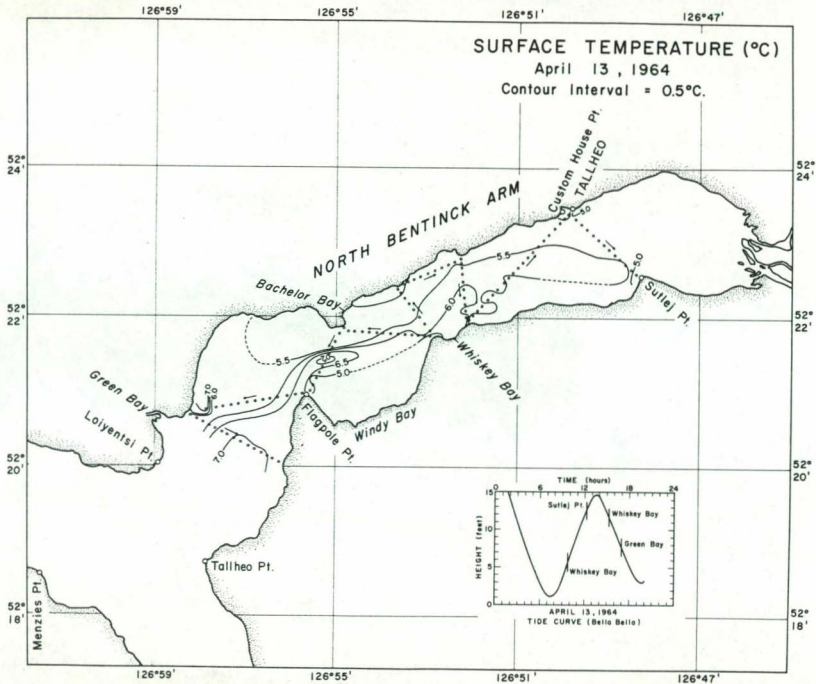


Fig. 26 Surface temperature in North Bentinck Arm, April 13, 1964.

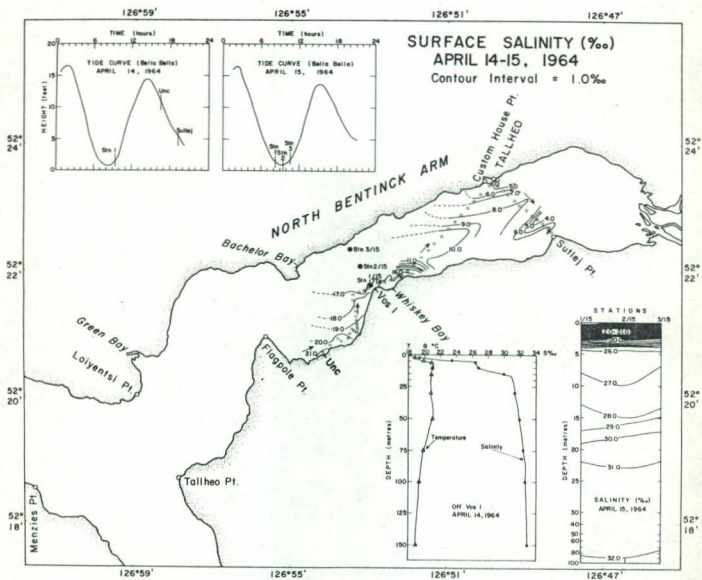


Fig. 27 Surface and vertical salinity distributions in North Bentinck Arm, April 14-15, 1964.

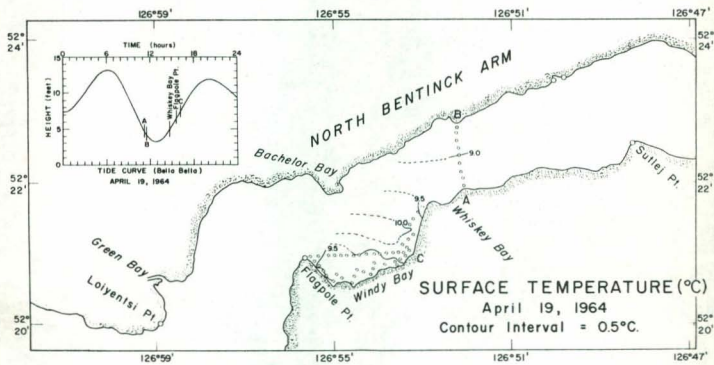
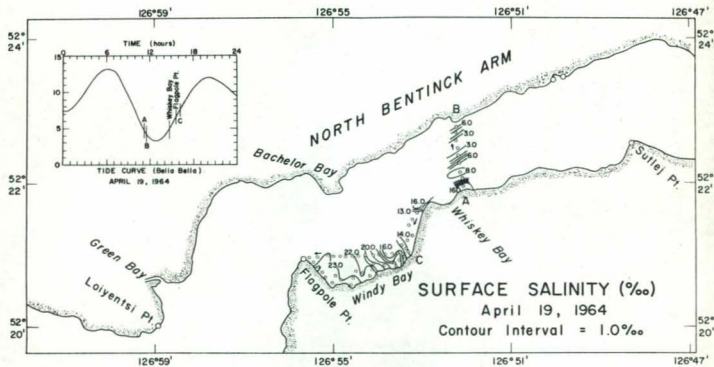


Fig. 29 Surface salinity and temperature in North Bentinck Arm, April 19, 1964.

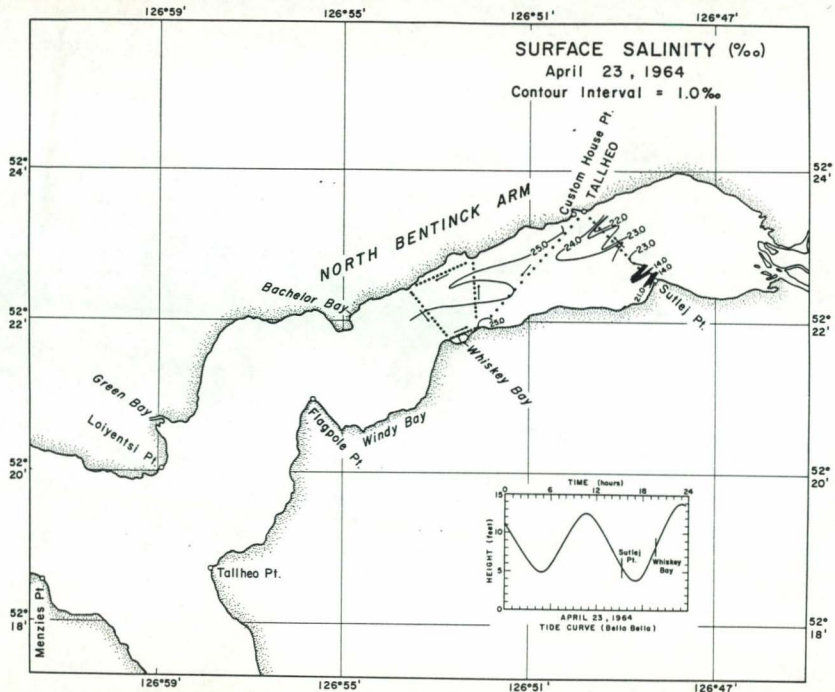


Fig. 30 Surface salinity in North Bentinck Arm, April 23, 1964.

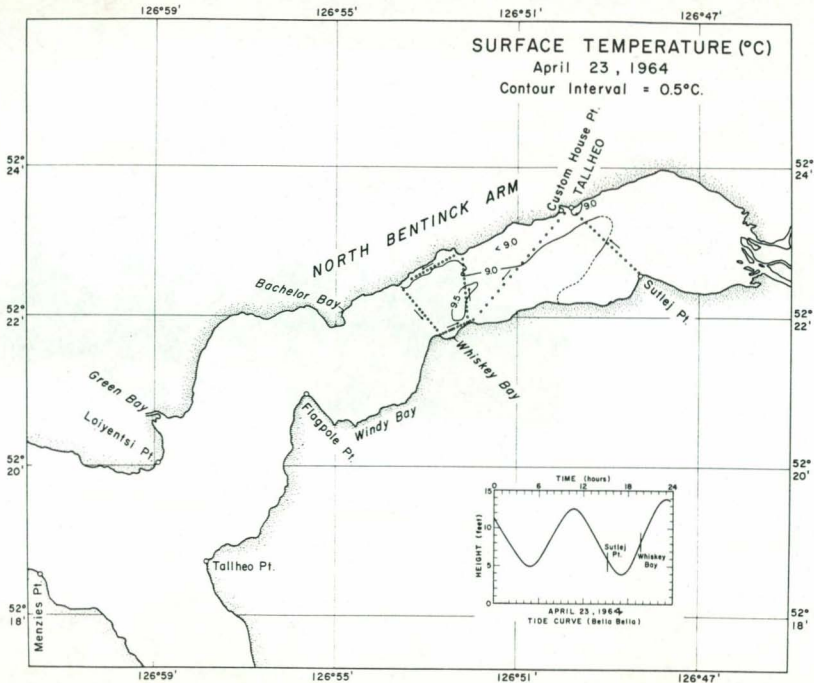


Fig. 31 Surface temperature in North Bentinck Arm, April 23, 1964.

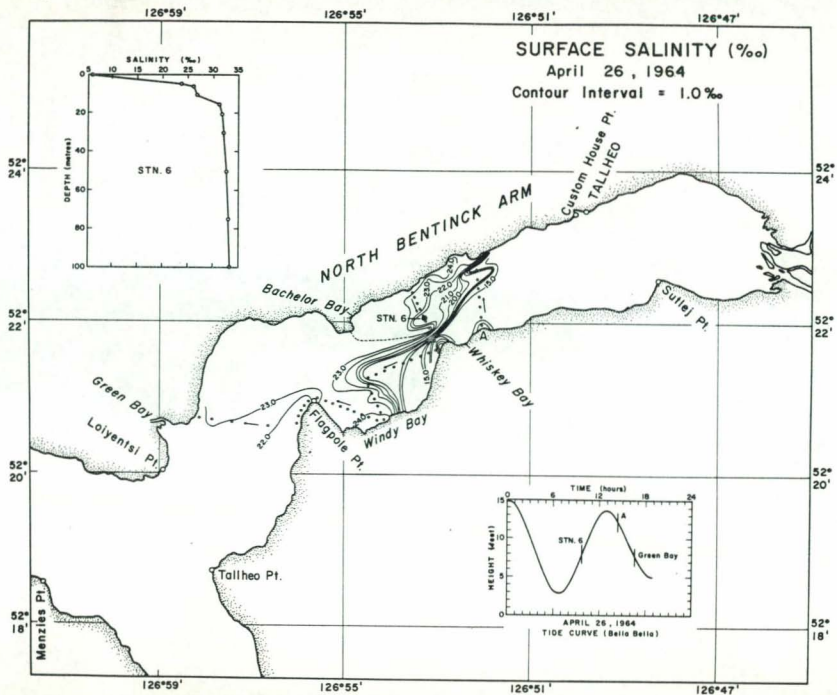


Fig. 32 Surface salinity in North Bentinck Arm, April 26, 1964.

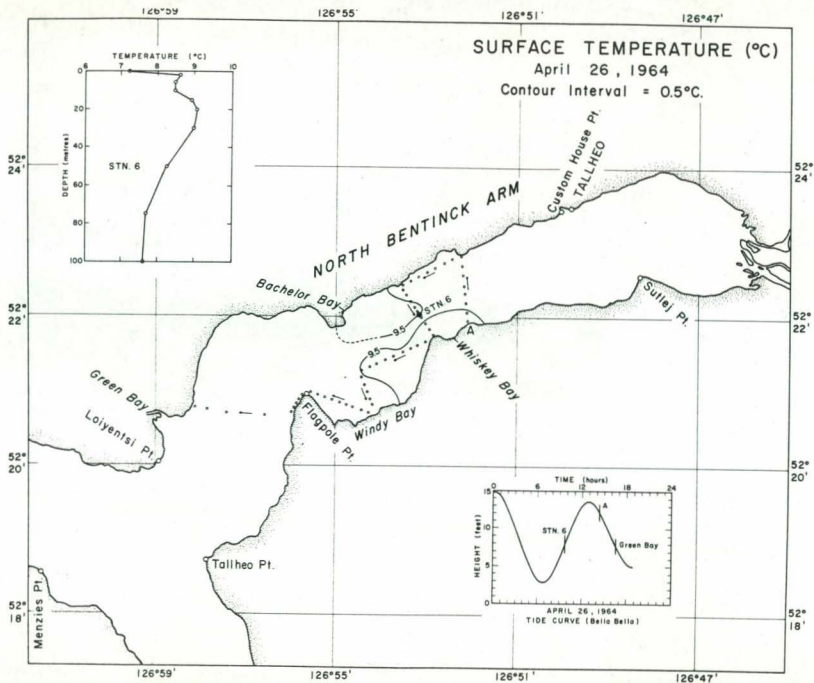


Fig. 33 Surface temperature in North Bentinck Arm, April 26, 1964.

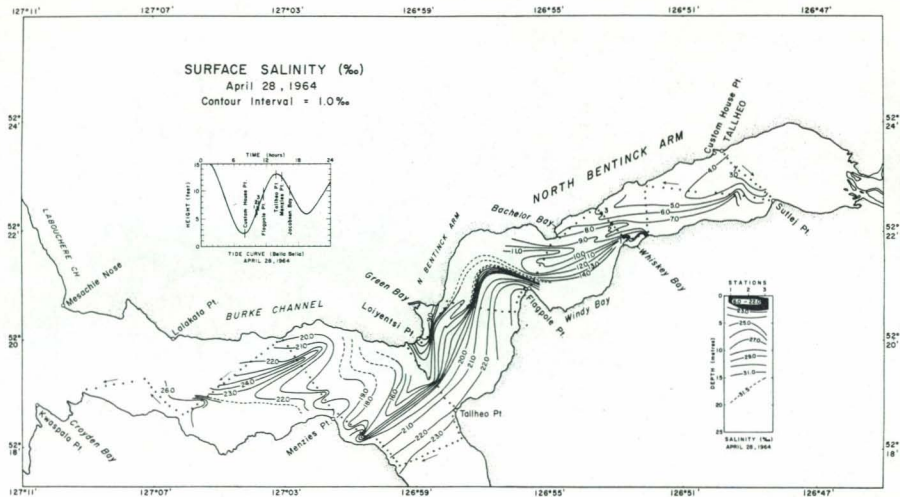


Fig. 34 Surface and vertical salinity distributions in North Bentinck Arm and Burke Channel, April 28, 1964.

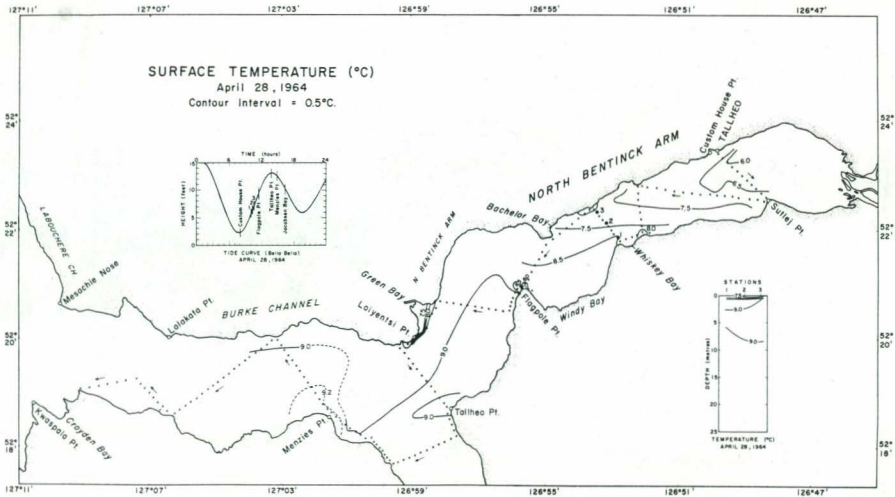


Fig. 35 Surface and vertical temperature distributions in North Bentinck Arm and Burke Channel, April 28, 1964.

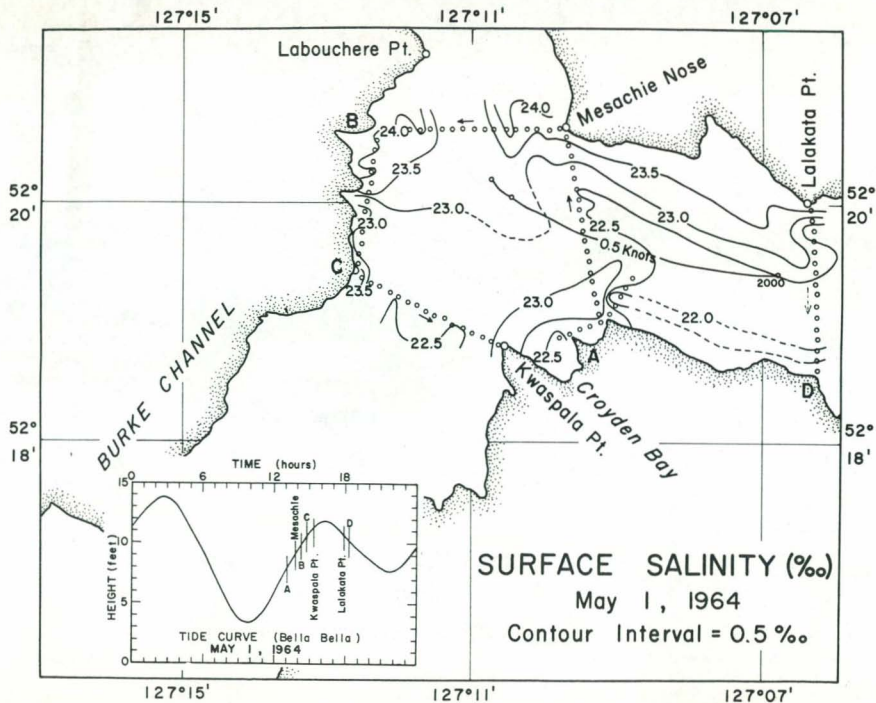


Fig. 36 Surface salinity at junction of Labouchere and Burke Channels, May 1, 1964.

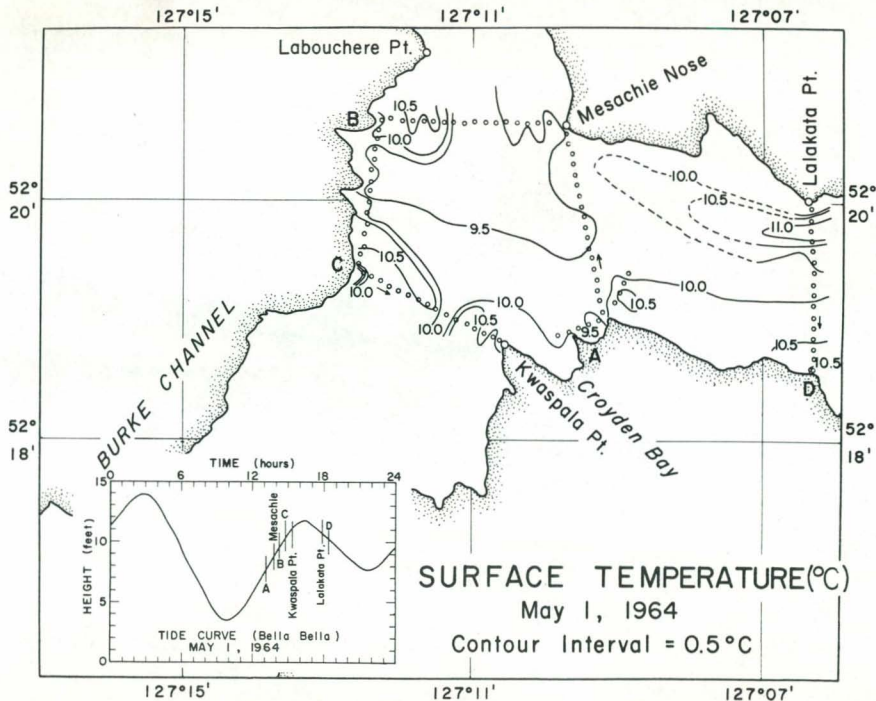


Fig. 37 Surface temperature at junction of Labouchere and Burke Channels, May 1, 1964.

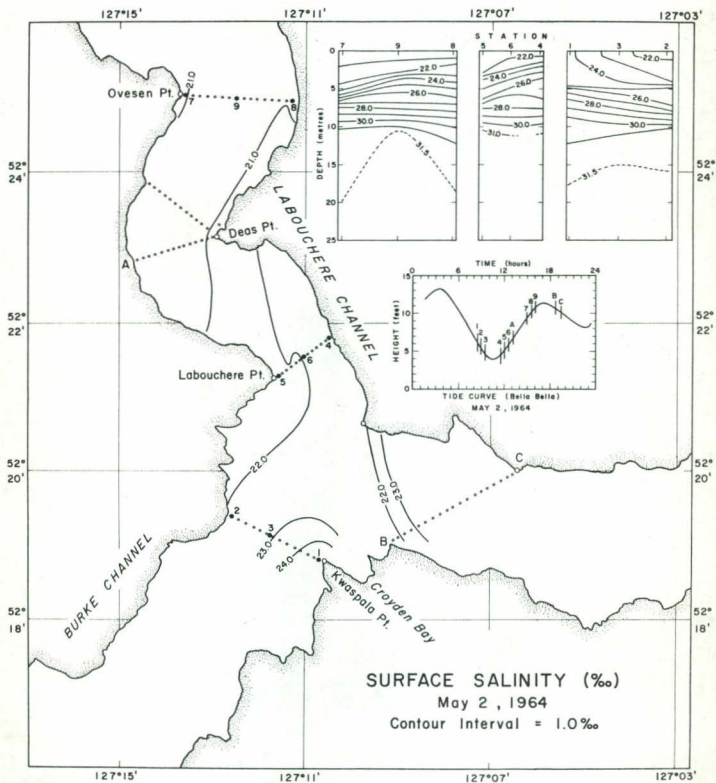


Fig. 38 Surface and vertical salinity distributions in Labouchere and Burke Channels, May 2, 1964.

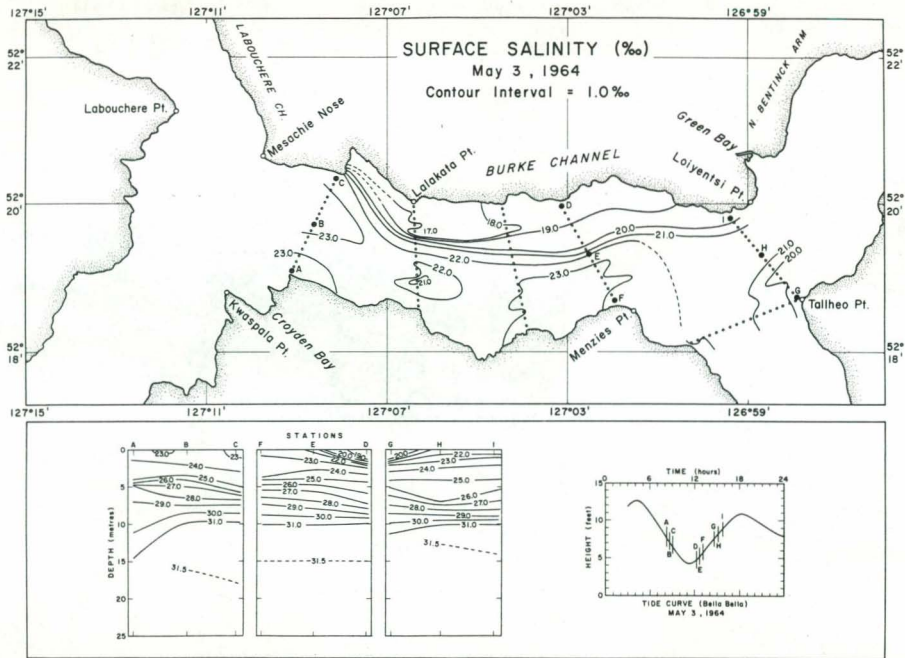


Fig. 40 Surface and vertical salinity distributions in Burke Channel, May 3, 1964.

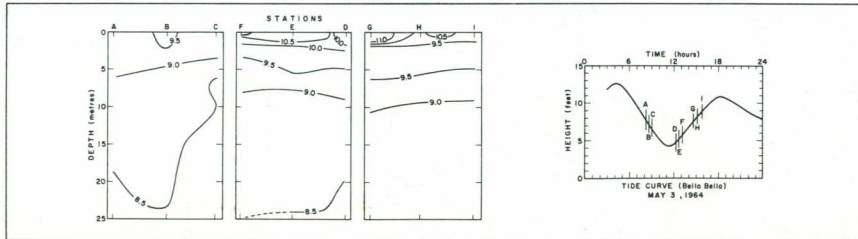
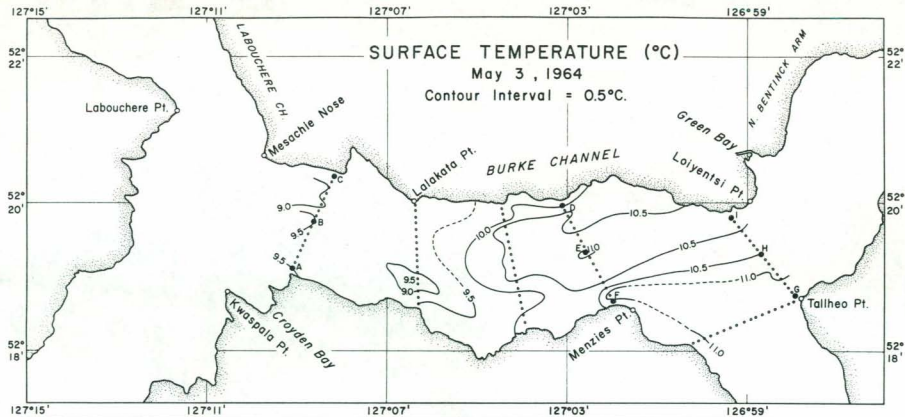


Fig. 41 Surface and vertical temperature distributions in Burke Channel, May 3, 1964.

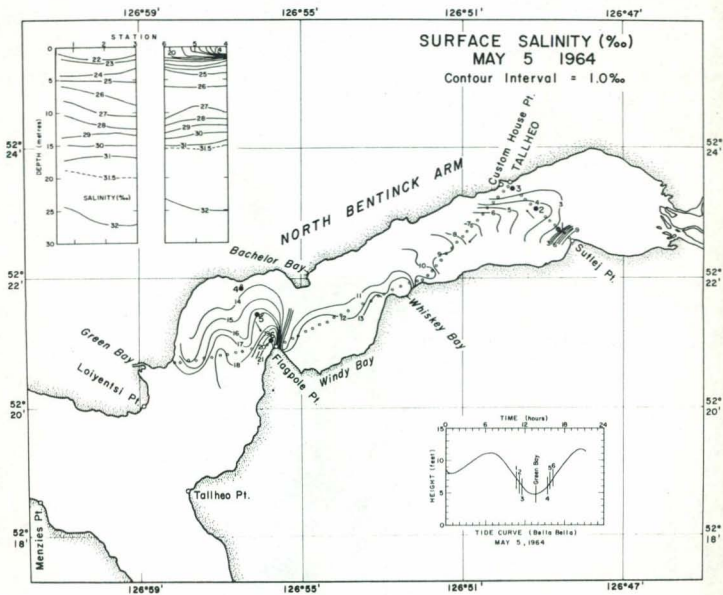


Fig. 42 Surface and vertical salinity distributions in North Bentinck Arm, May 5, 1964.

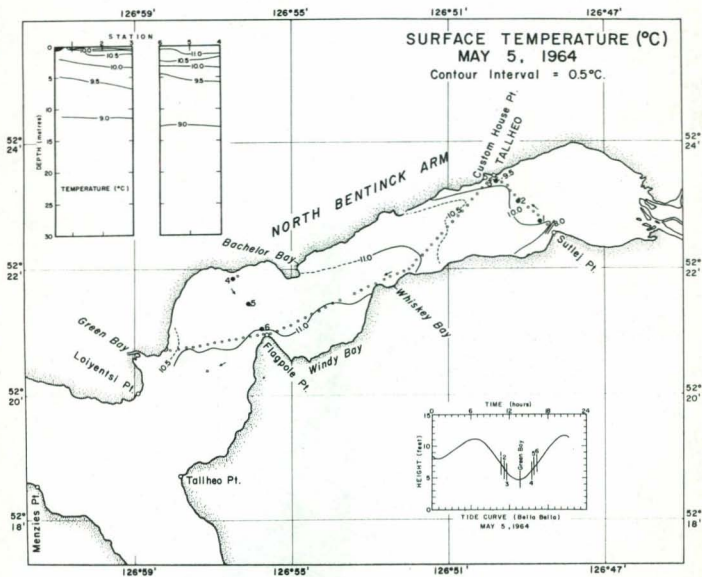


Fig. 43 Surface and vertical temperature distributions in North Bentinck Arm, May 5, 1964.

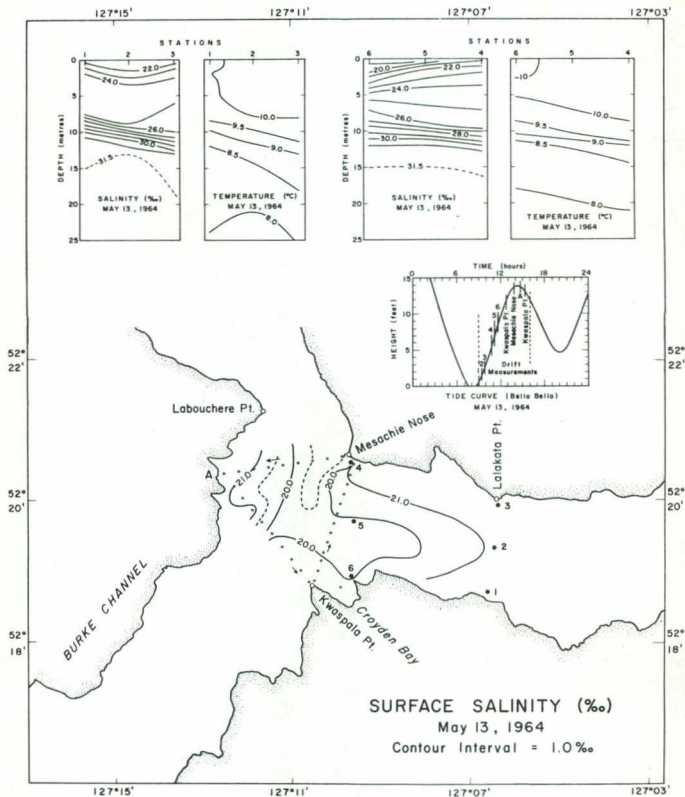


Fig. 44 Surface and vertical salinity distributions in Burke Channel, May 13, 1964.

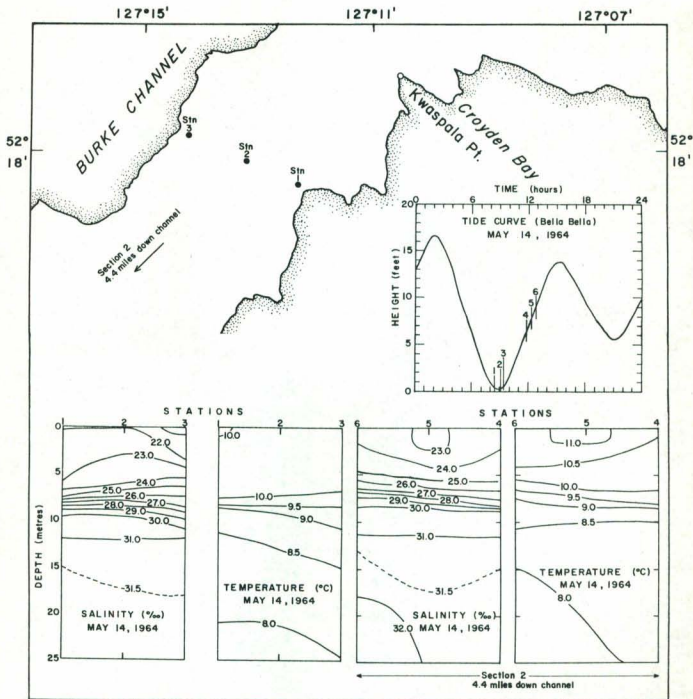


Fig. 45 Vertical distributions of salinity and temperature in Burke Channel, May 14, 1964.

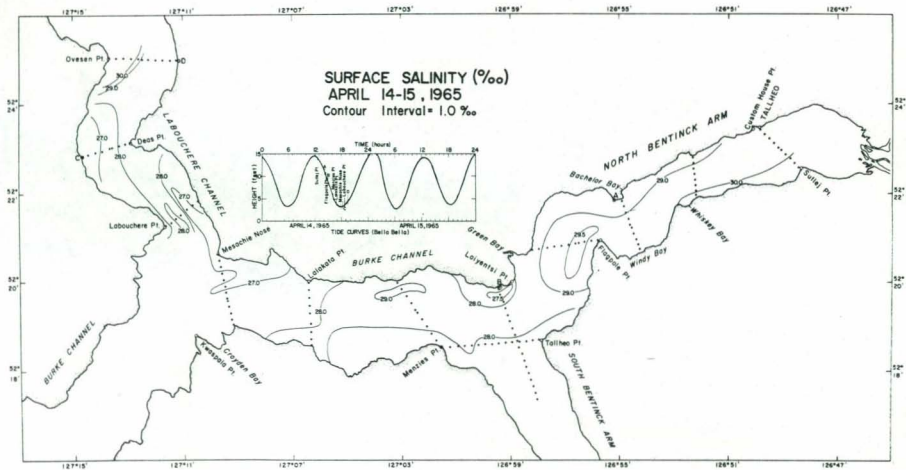


Fig. 46 Surface salinity in North Bentinck Arm, Burke and Labouchere Channels, April 14-15, 1965.

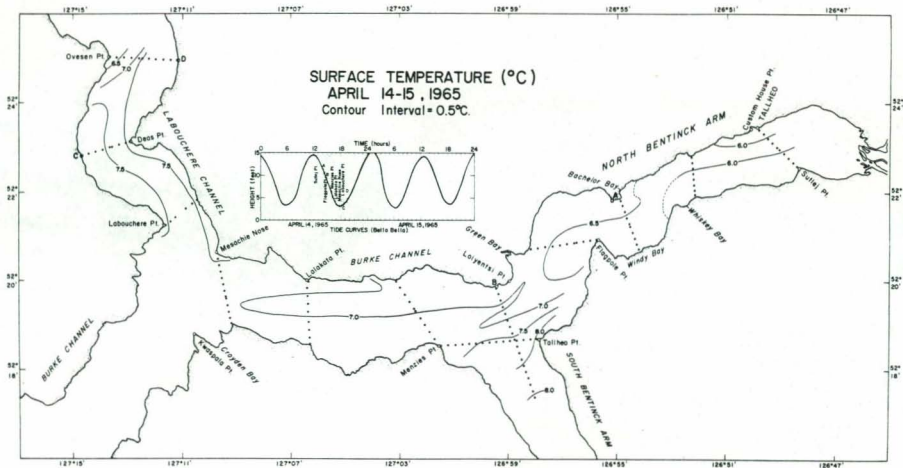


Fig. 47 Surface temperature in North Bentinck Arm, Burke and Labouchere Channels, April 14-15, 1965.

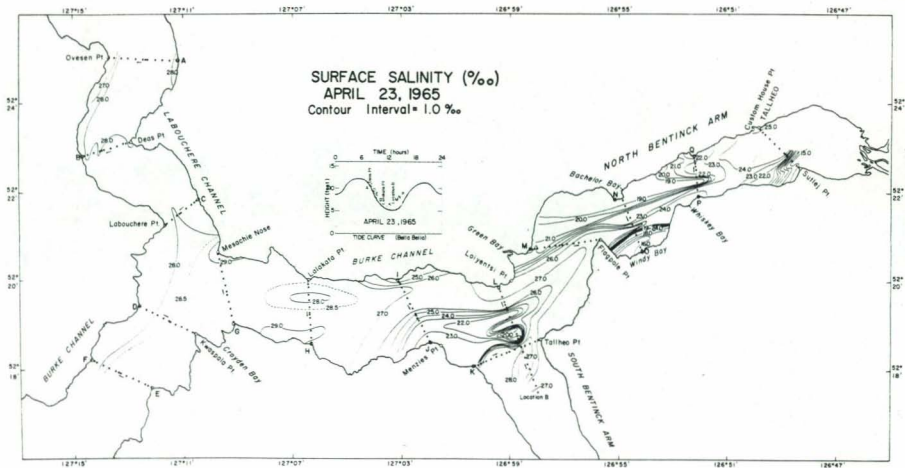


Fig. 48 Surface salinity in North Bentinck Arm, Burke and Labouchere Channels, April 23, 1965.

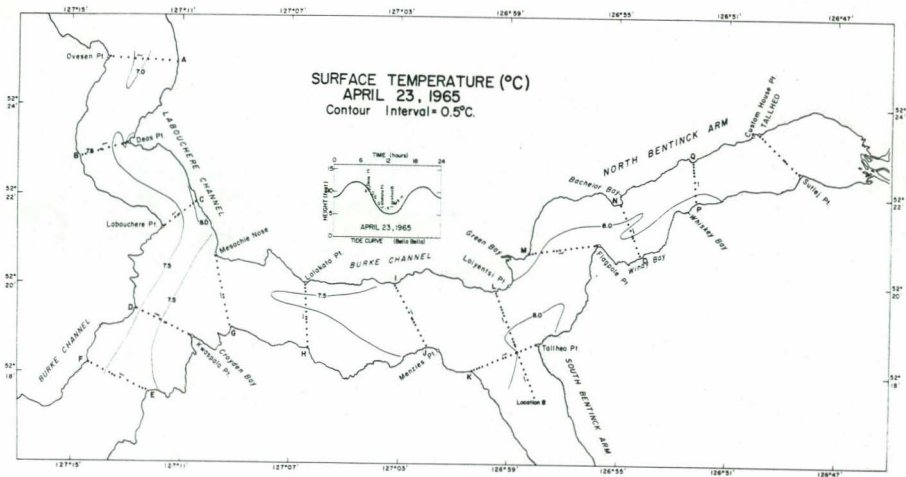


Fig. 49 Surface temperature in North Bentinck Arm, Burke and Labouchere Channels, April 23, 1965.

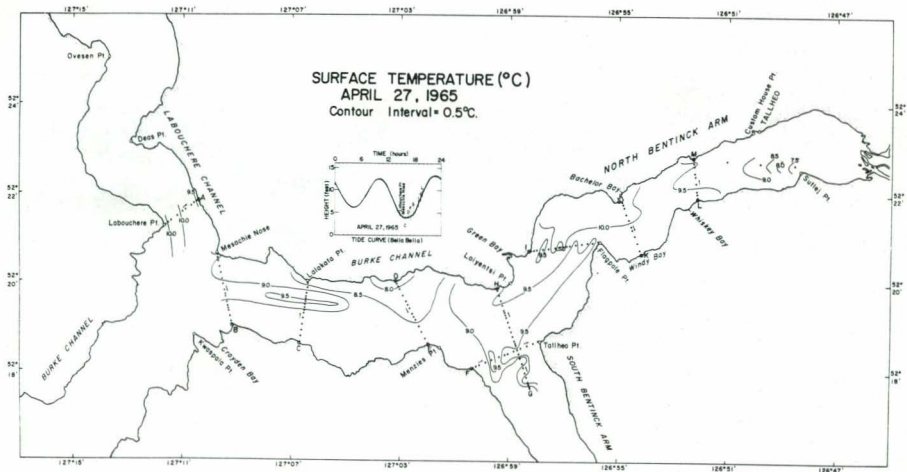


Fig. 51 Surface temperature in North Bentinck Arm, Burke and Labouchere Channels, April 27, 1965.

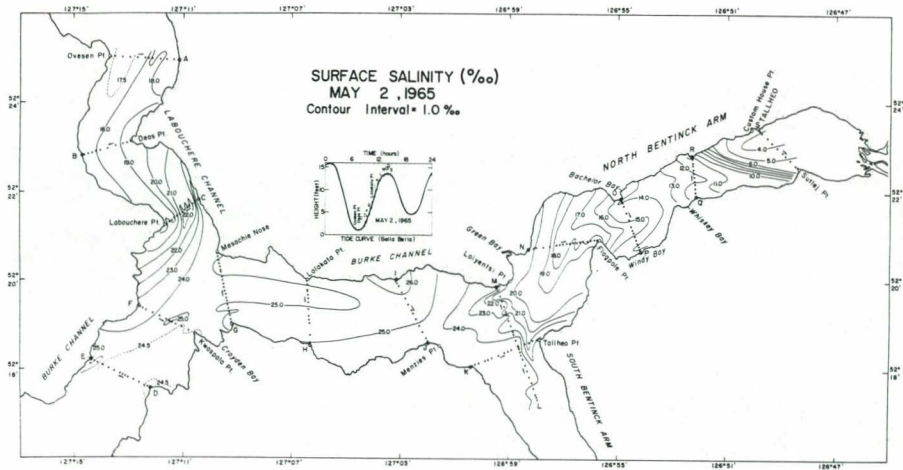


Fig. 52 Surface salinity in North Barents Arm, Burke and Labouchere Channels, May 2, 1965.

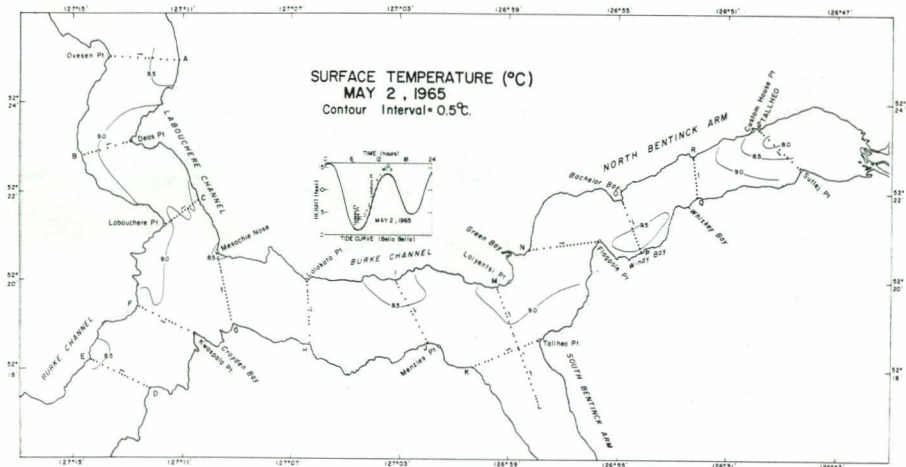


Fig. 53 Surface temperature in North Benthinck Arm, Burke and Labouchere Channels, May 2, 1965.

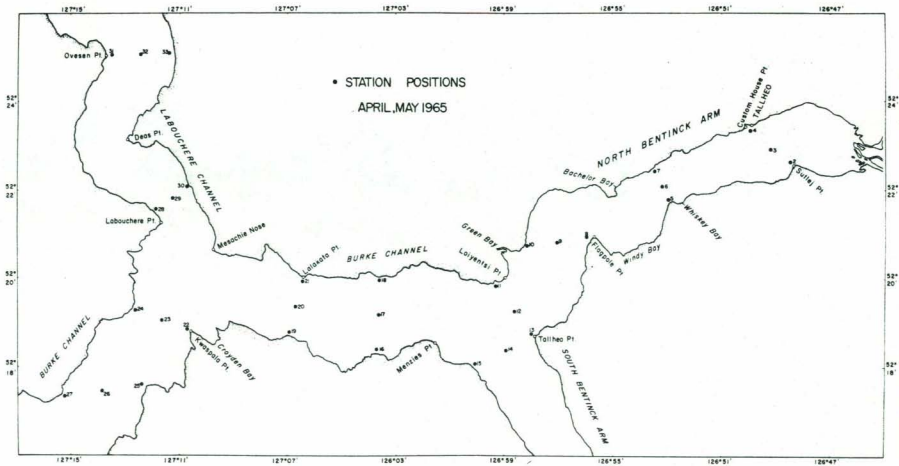


Fig. 54 Station positions in North Bentinck Arm, Burke and Labouchere Channels during April, May, 1965.

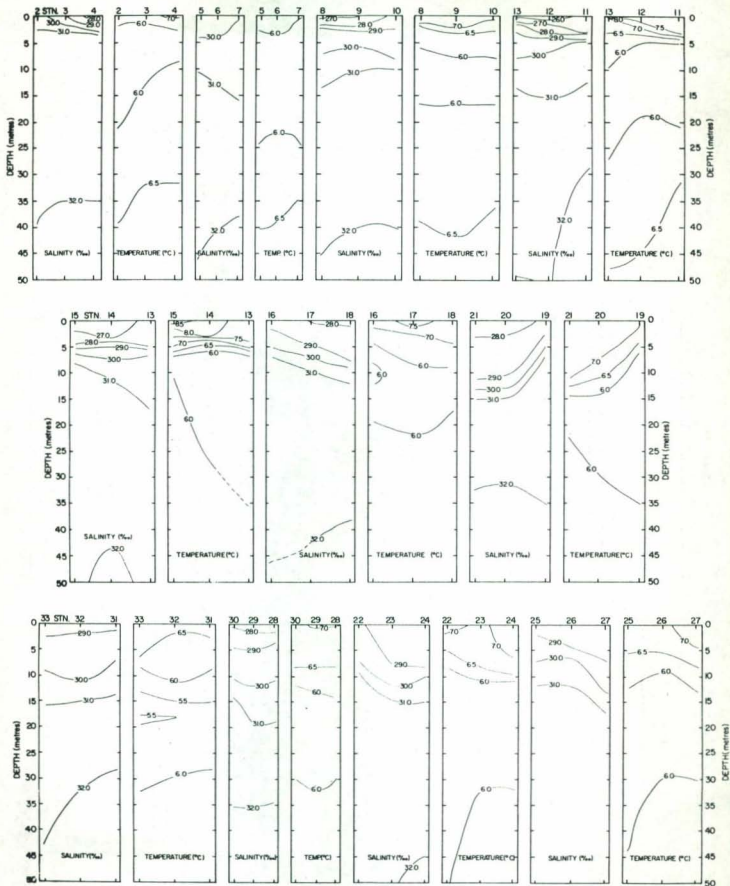


Fig. 55 Vertical distributions of salinity and temperature in North Bentinck Arm, Burke and Labouchere Channels, April 15, 1965 (station positions shown in Fig. 54).

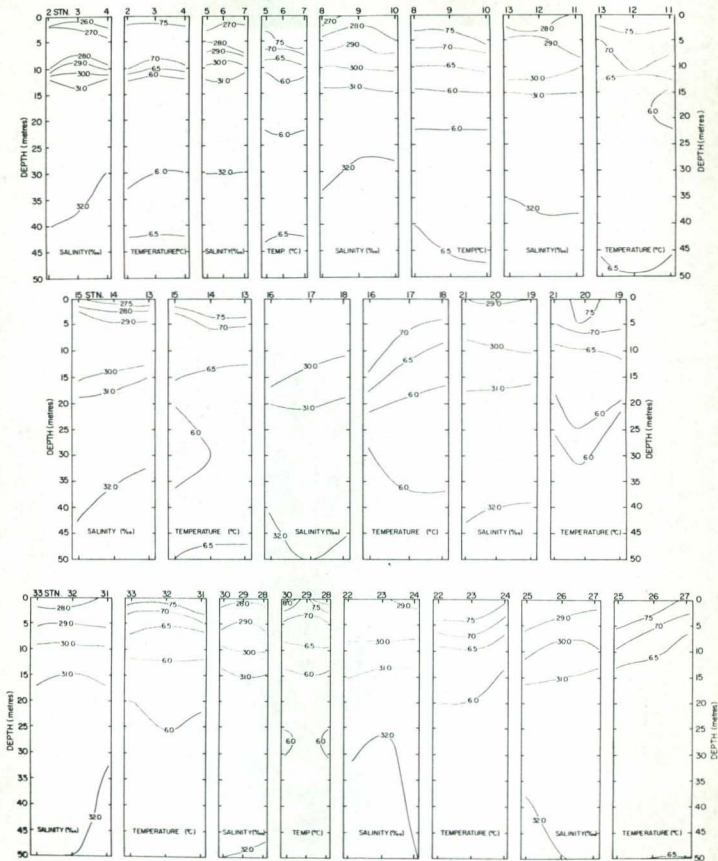


Fig. 56 Vertical distributions of salinity and temperature in North Bentinck Arm, Burke and Labouchere Channels, April 22, 1965 (station positions shown in Fig. 54).

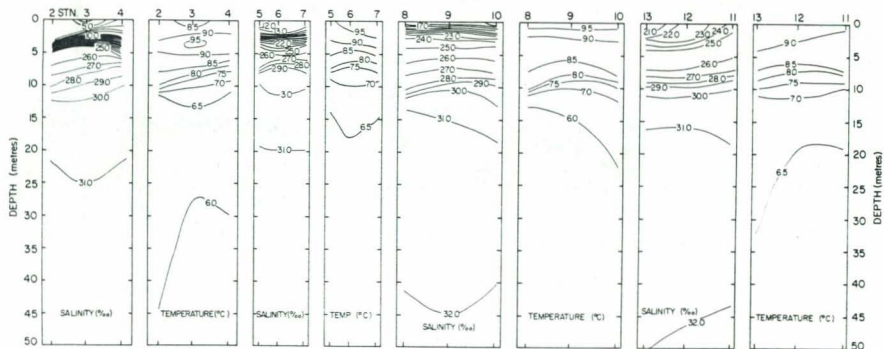


Fig. 57 Vertical distributions of salinity and temperature in North Bentinck Arm, Burke and Labouchere Channels, May 2, 1965 (station positions shown in Fig. 54).



Fig. 58 Aerial photograph of the head of North Bentinck Arm, showing the silt-loaded Bella Coola River and relatively clear Necleetsconnay River water.

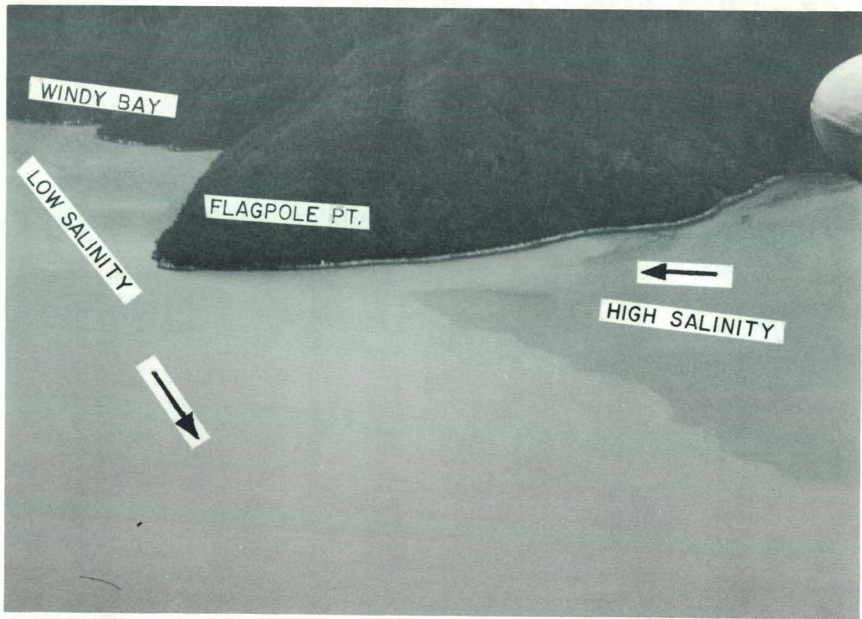


Fig. 59 Aerial photograph of North Bentinck Arm in the vicinity of Flagpole Point, showing the relative movements of high- and low-salinity water.

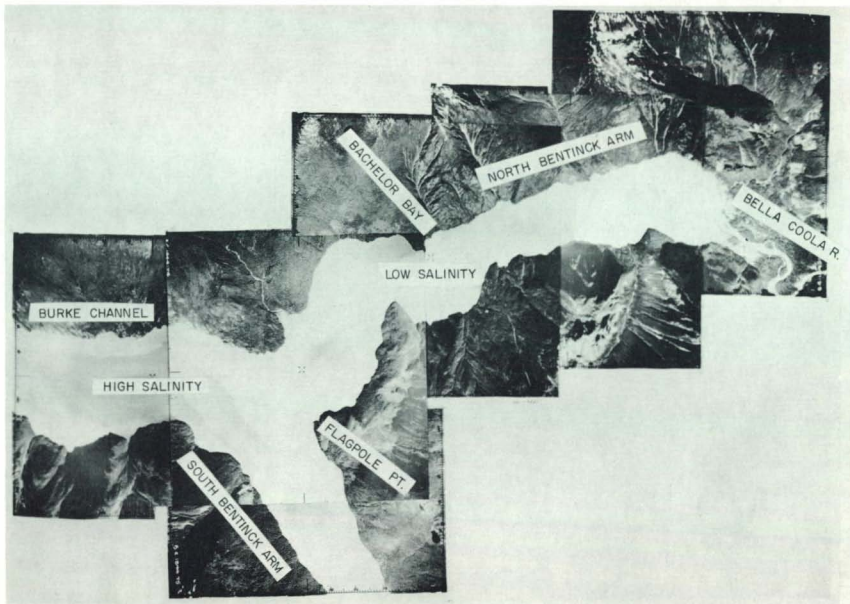


Fig. 60 Aerial photograph of North and South Bentinck Arms, showing the high- and low-salinity water at their junctions on the flood tide.

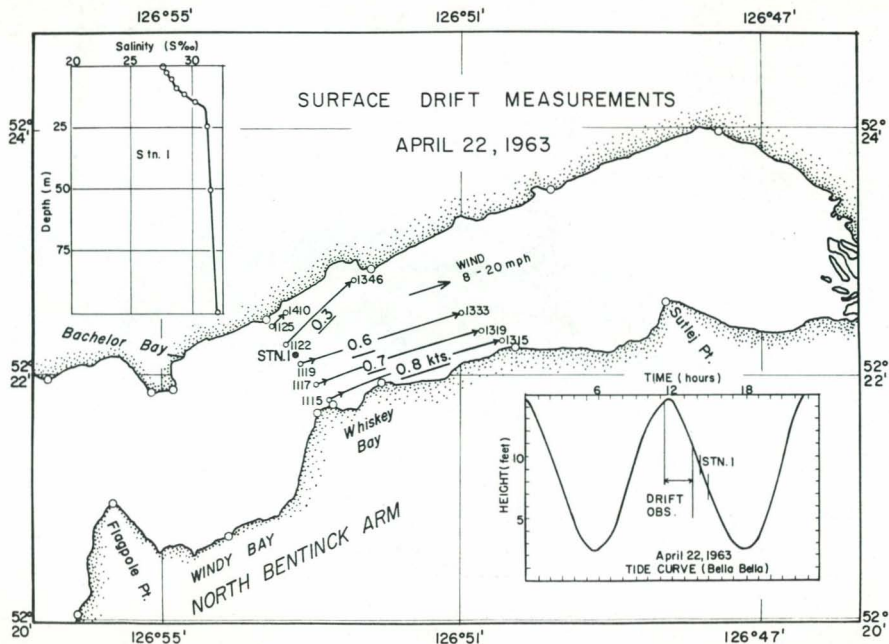


Fig. 61 Surface drift in North Benthick Arm, April 22, 1963.

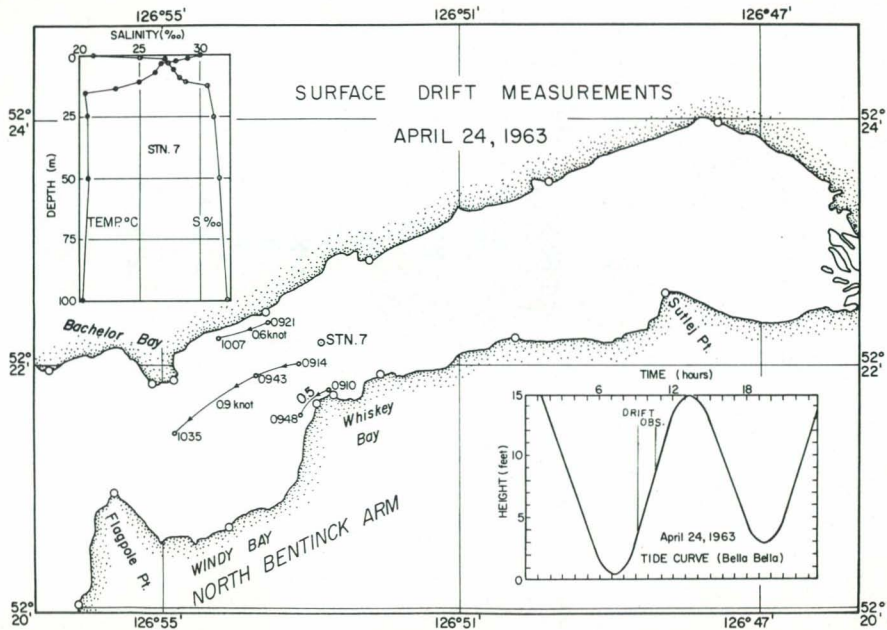


Fig. 62 Surface drift in North Bentinck Arm, April 24, 1963.

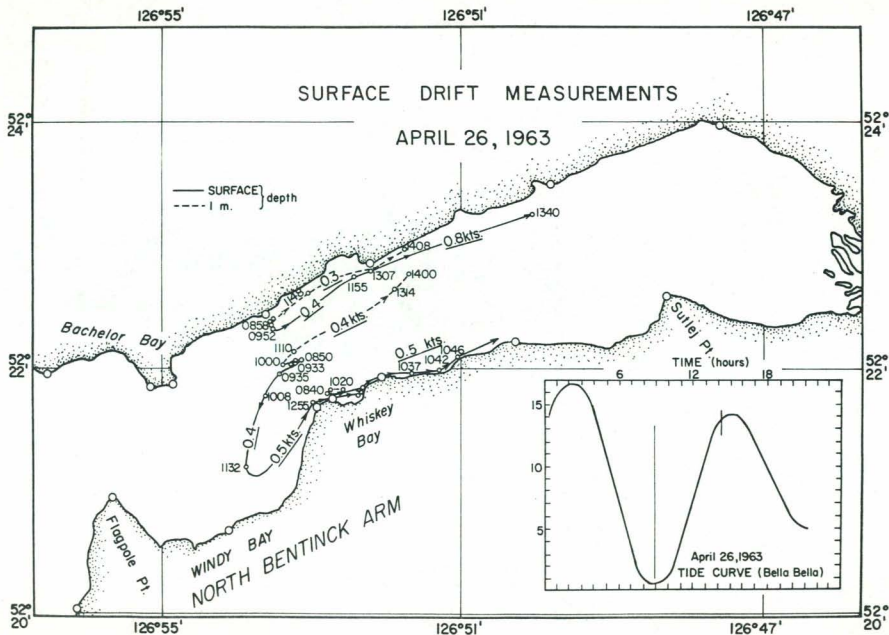


Fig. 63 Surface and 1-metre drift in North Bentinck Arm, April 26, 1963.

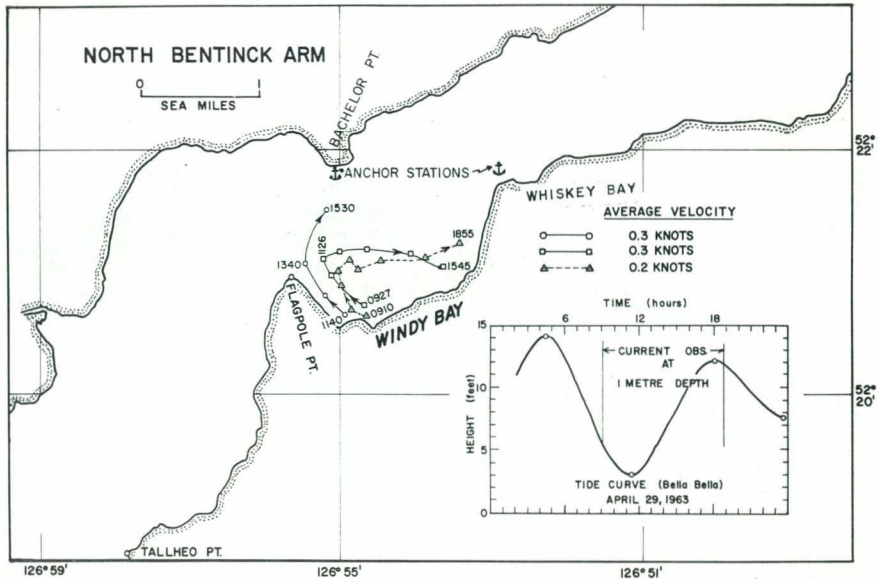


Fig. 64 One-metre drift in Windy Bay, North Bentinck Arm, April 29, 1963.

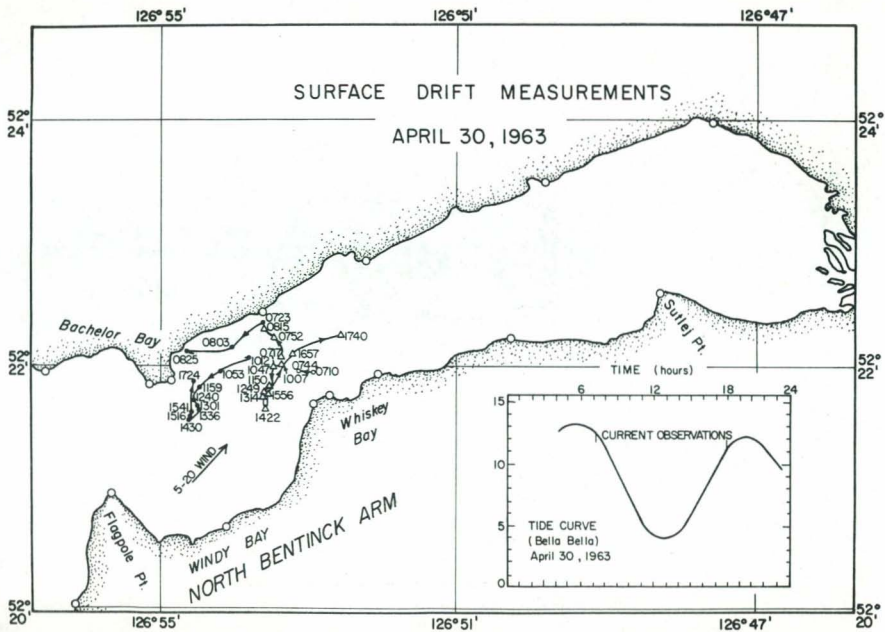


Fig. 65 Surface drift in North Bentinck Arm, April 30, 1963.

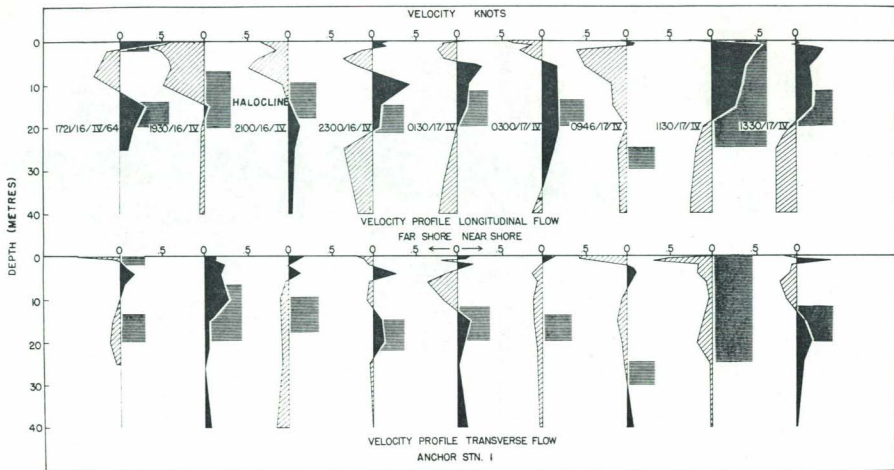


Fig. 66 Longitudinal and transverse flows off Whiskey Bay in North Bentinck Arm, April 16-17, 1964 (position shown in Fig. 64).

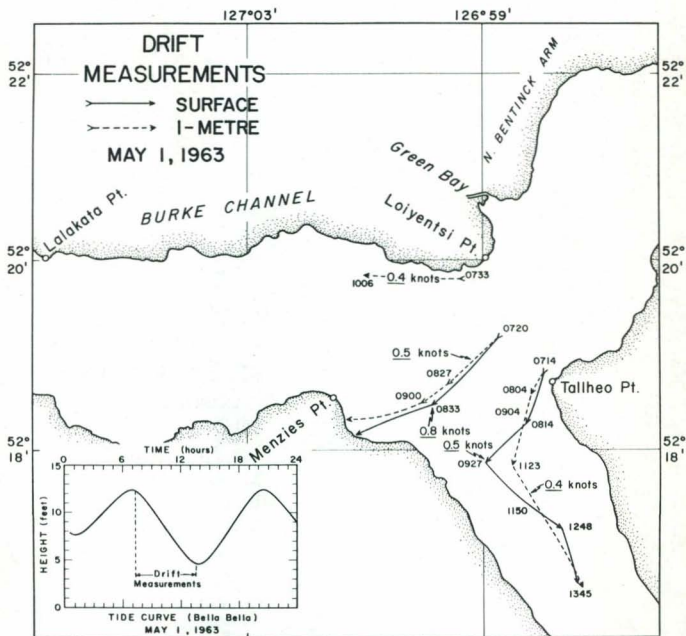


Fig. 69 Surface and 1-metre drift at junction of North and South Bentinck Arms, May 1, 1963.

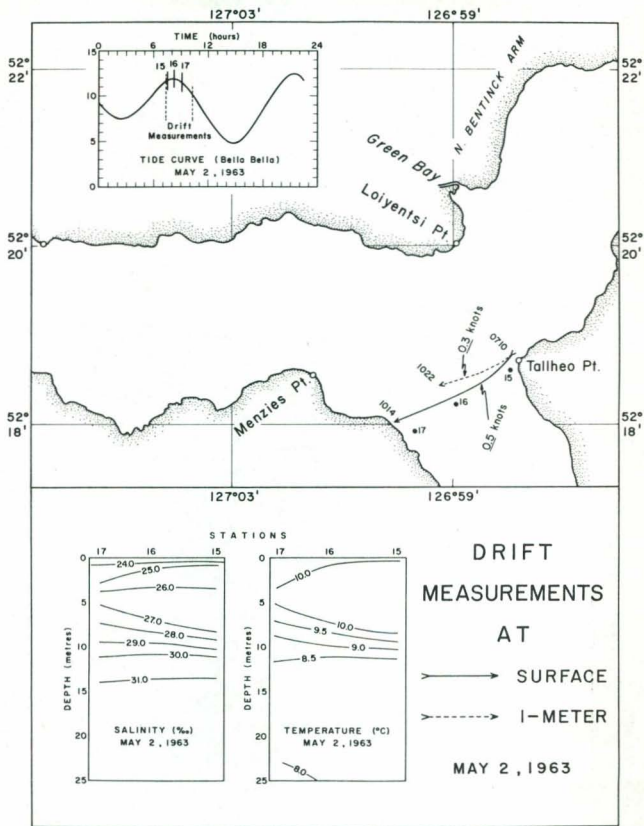


Fig. 70 Surface and 1-metre drift, and vertical distributions of salinity and temperature at the junction of North and South Bentinck Arms, May 2, 1963.

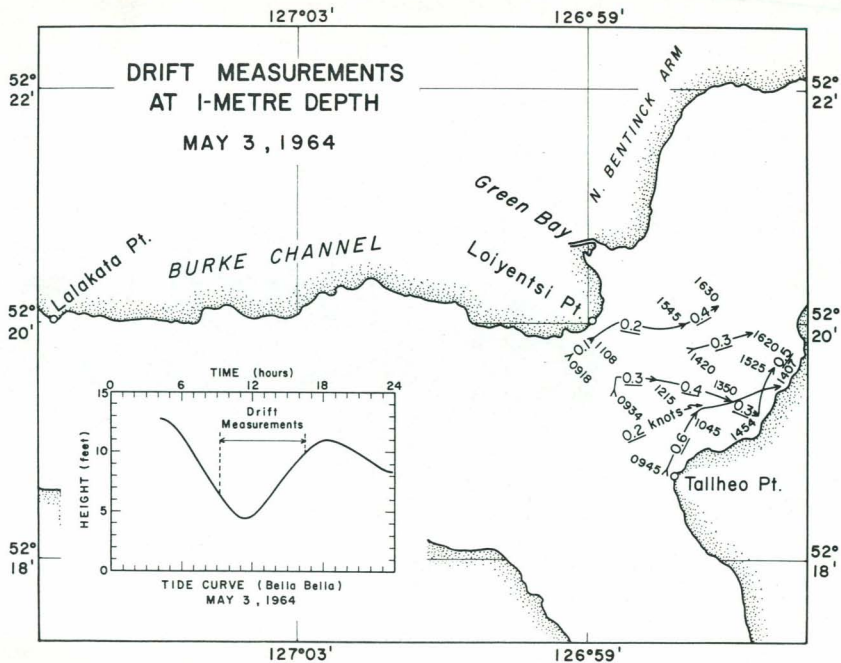
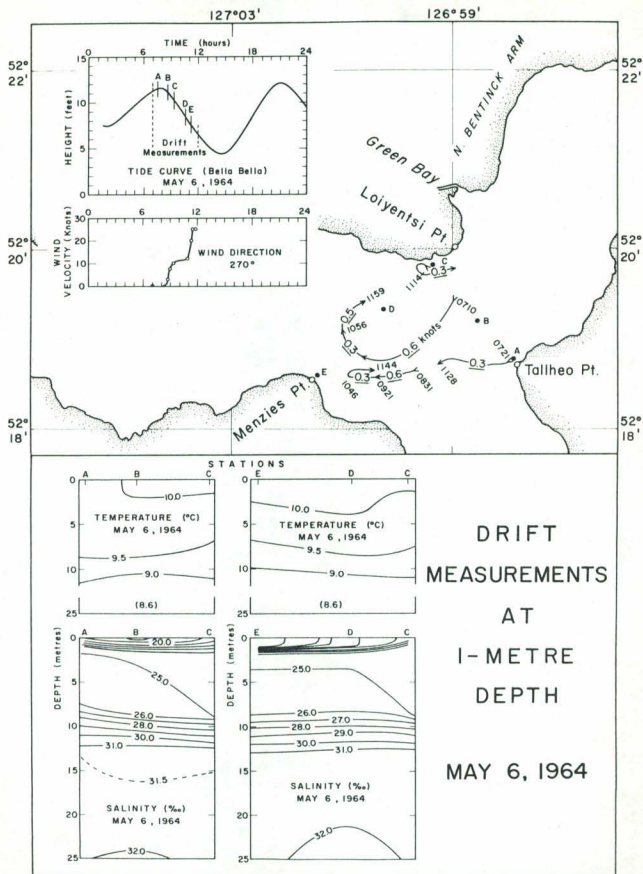


Fig. 71 One-metre drift at junction of North and South Bentinck Arms, May 3, 1964.



DRIFT
MEASUREMENTS
AT
1-METRE
DEPTH
MAY 6, 1964

Fig. 72 One-metre drift, and vertical distributions of salinity and temperature at the junction of North and South Bentinck Arms, May 6, 1964.

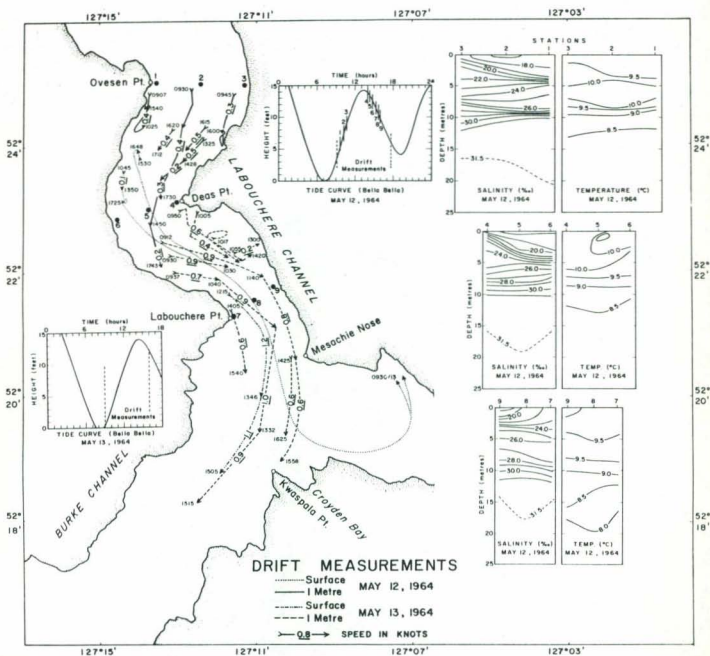


Fig. 74 Surface and 1-metre drift, and vertical distributions of salinity and temperature in Labouchere and Burke Channels, May 12-13, 1964.

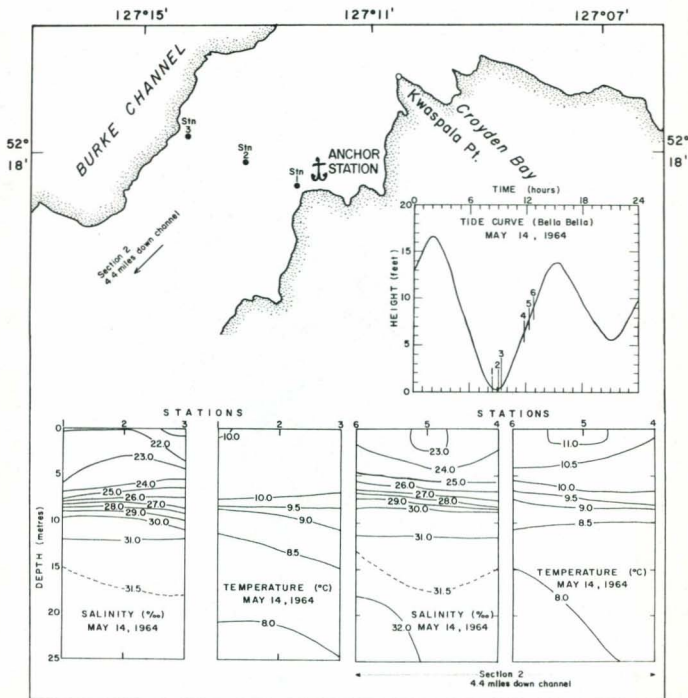


Fig. 75 Vertical distributions of salinity and temperature in Burke Channel, May 14, 1964.

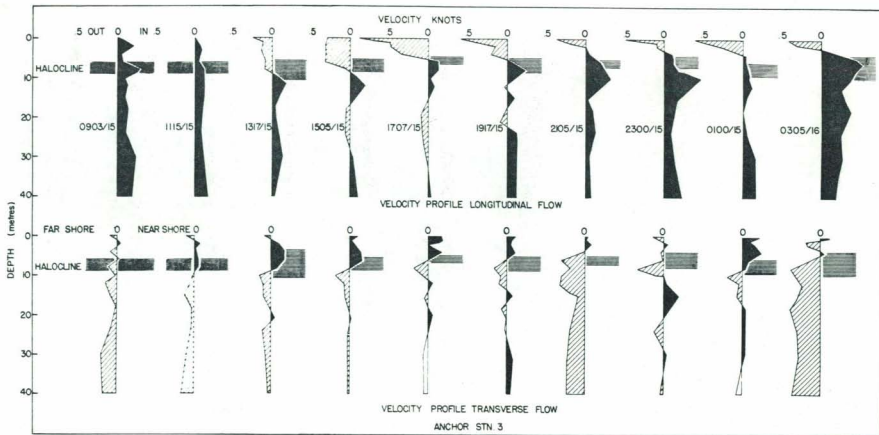


Fig. 76 Longitudinal and transverse flows below Kwaspala Point in Burke Channel, May 15-16, 1964 (position shown in Fig. 75).

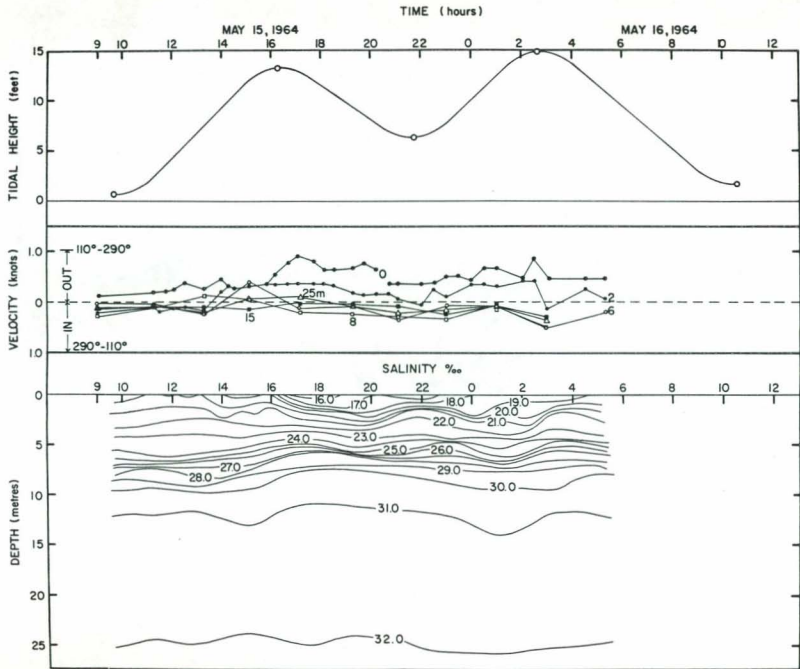


Fig. 77 Current velocities and salinities at selected depths below Kwaspala Point in Burke Channel, May 15-16, 1964.

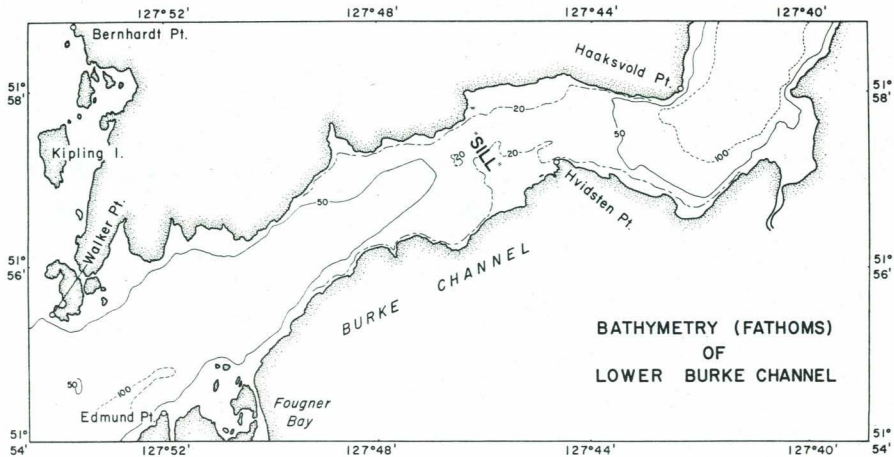


Fig. 78 Bathymetry of the "sill" area near the mouth of Burke Channel.

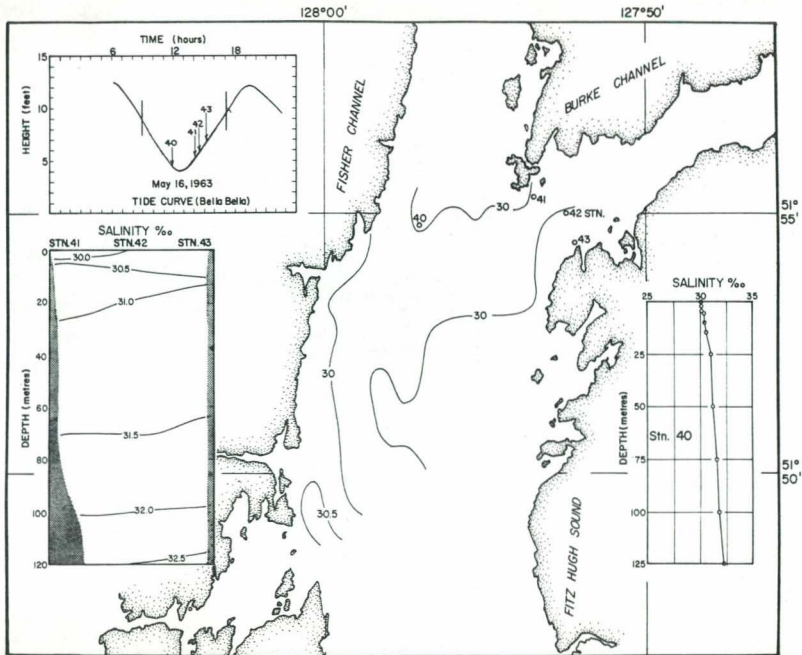


Fig. 79 Vertical distribution of salinity at the mouth of Burke Channel, May 16, 1963.

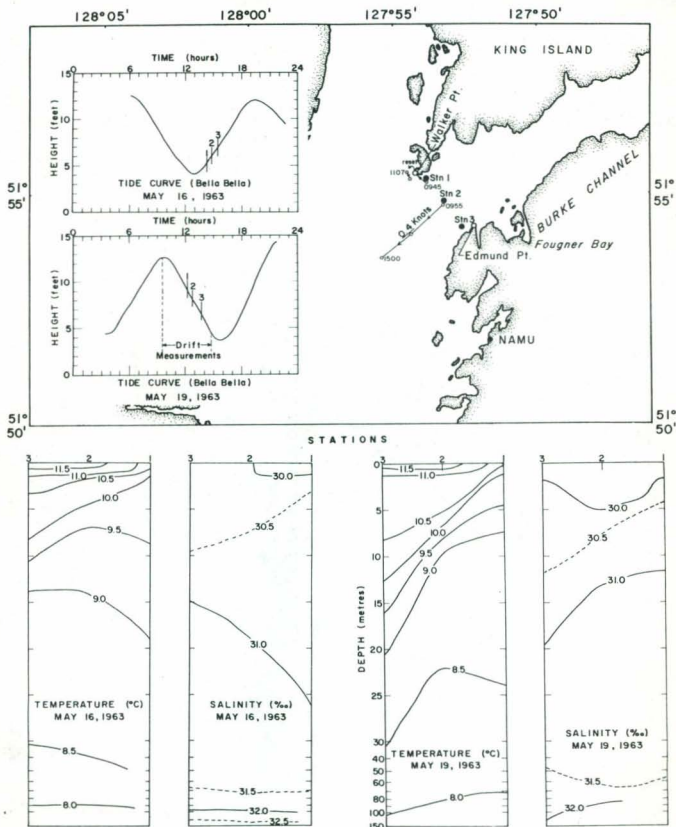


Fig. 80 Vertical distributions of salinity and temperature and surface drift at the mouth of Burke Channel, May 16 and 19, 1963.

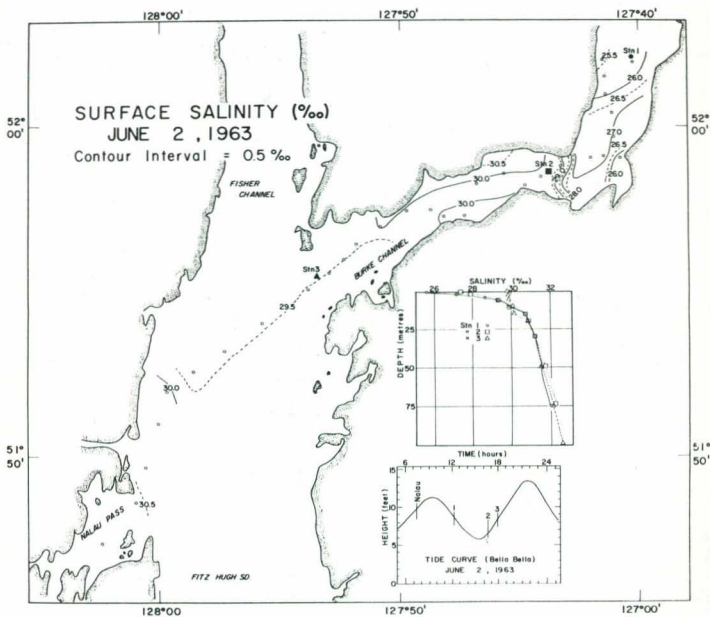


Fig. 81 Surface salinity and salinity profiles in Burke Channel, June 2, 1963.

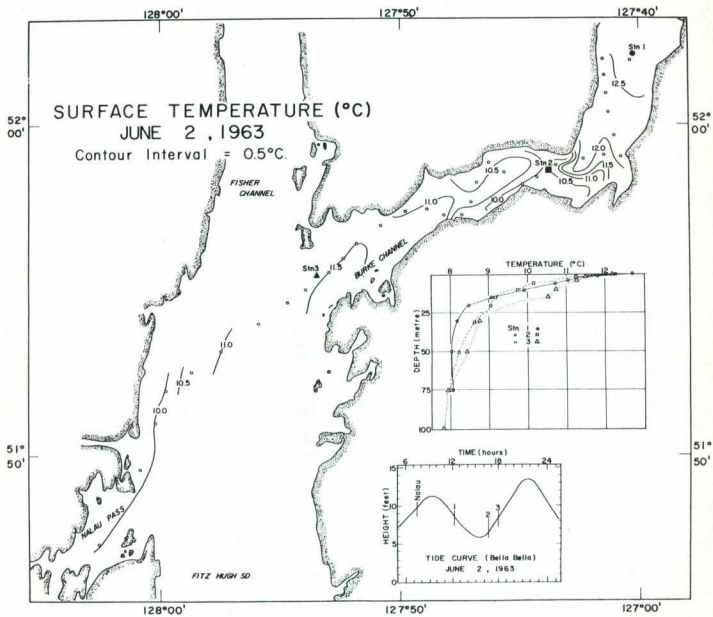


Fig. 82 Surface temperature and temperature profiles in Burke Channel, June 2, 1963.

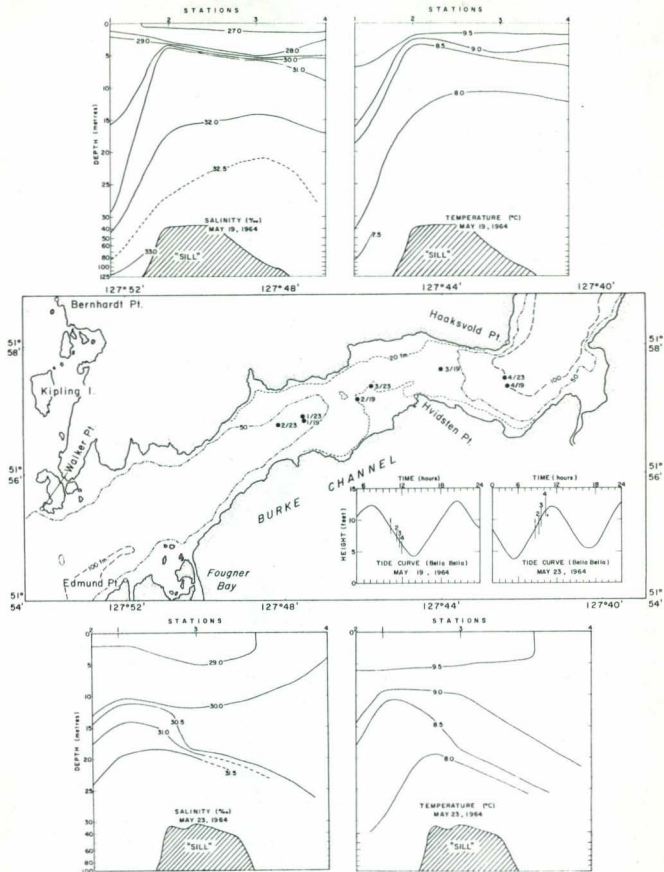


Fig. 83 Vertical distributions of salinity and temperature in the area of the sill in Burke Channel, May 19 and 23, 1964.

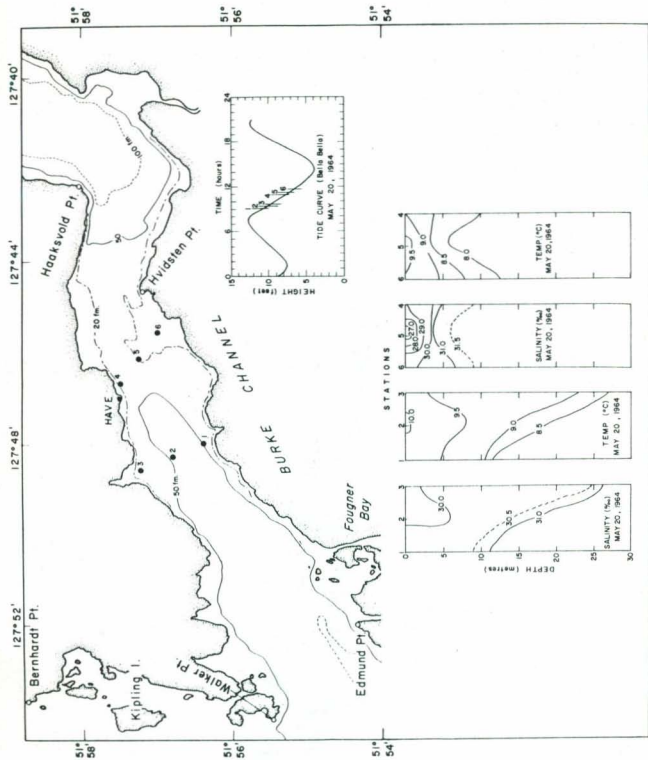


Fig. 84 Vertical distributions of salinity and temperature in Burke Channel, May 20, 1964.

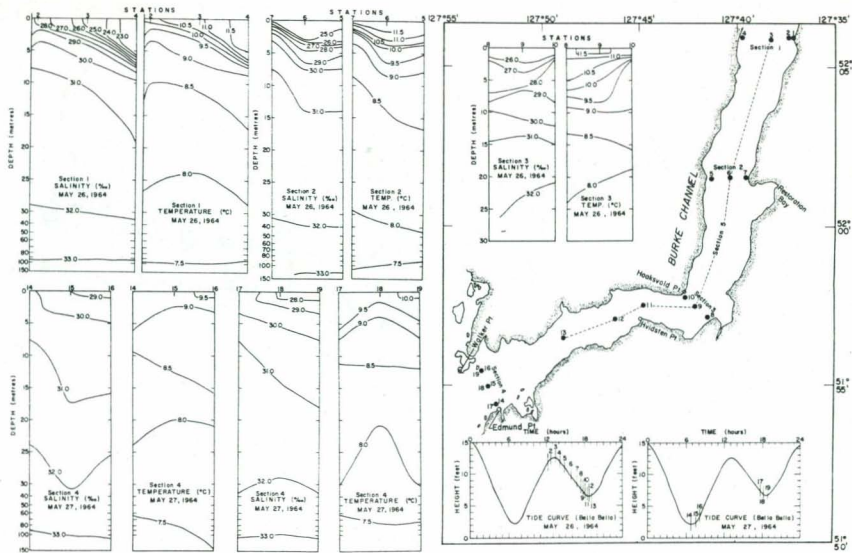


Fig. 85 Vertical distributions of salinity and temperature in Burke Channel, May 26-27, 1964.

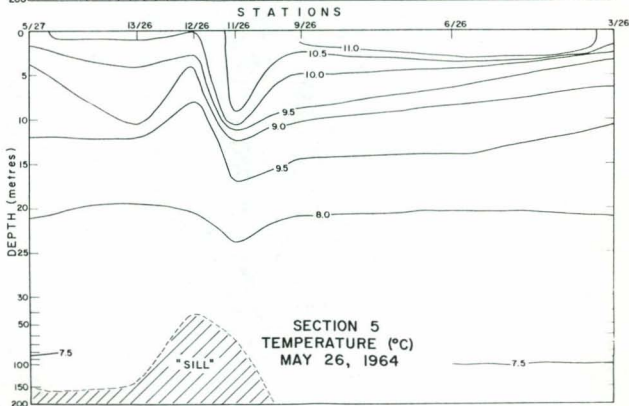
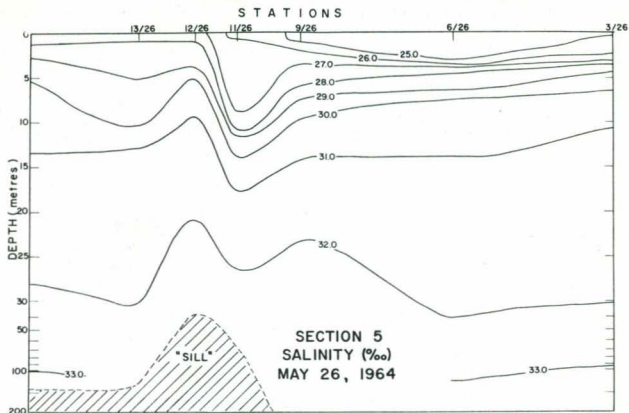


Fig. 86 Vertical distributions of salinity and temperature in the area of the sill in Burke Channel, May 26, 1964 (station positions shown in Fig. 85).

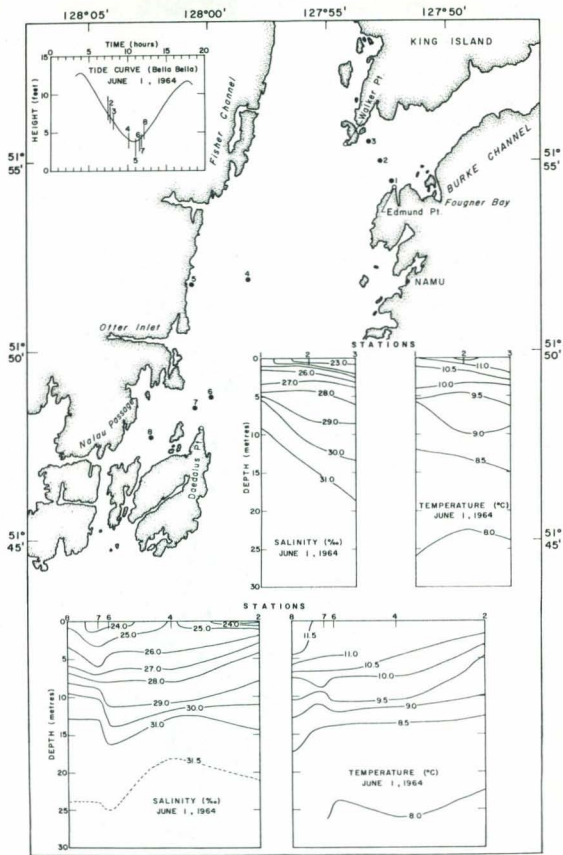


Fig. 87 Vertical distributions of salinity and temperature at the mouth of Burke Channel, and vertical distributions of salinity and temperature across Fitz Hugh Sound, June 1, 1964.

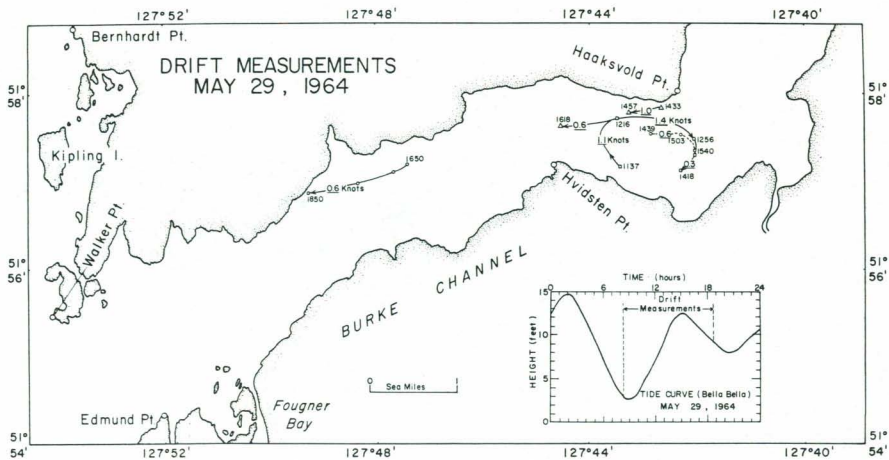


Fig. 88 One-metre drift near the mouth of Burke Channel, May 29, 1964.

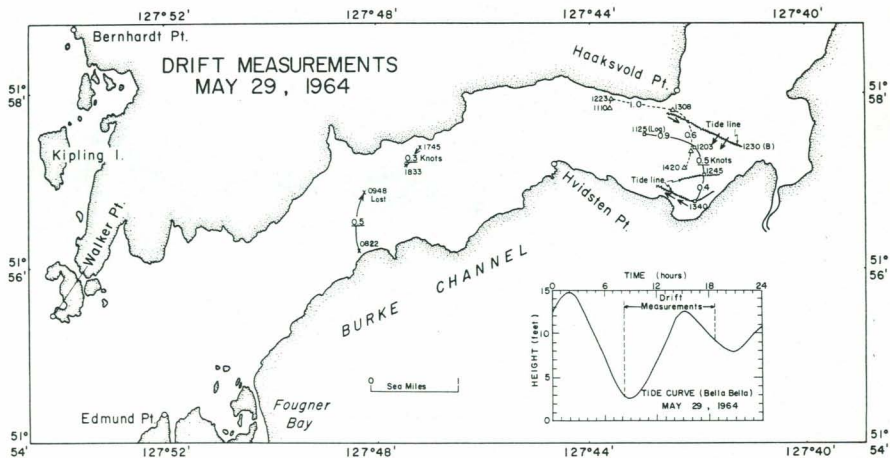


Fig. 89 One-metre drift near the mouth of Burke Channel, May 29, 1964.

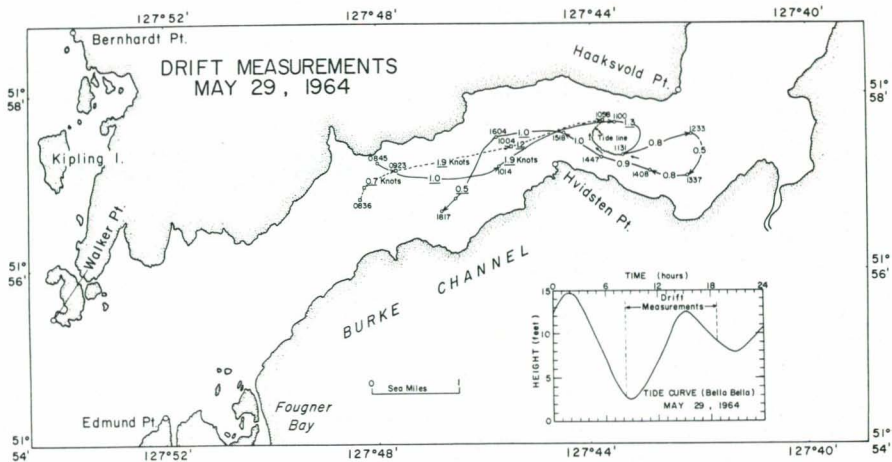


Fig. 90 One-metre drift near the mouth of Burke Channel, May 29, 1964.

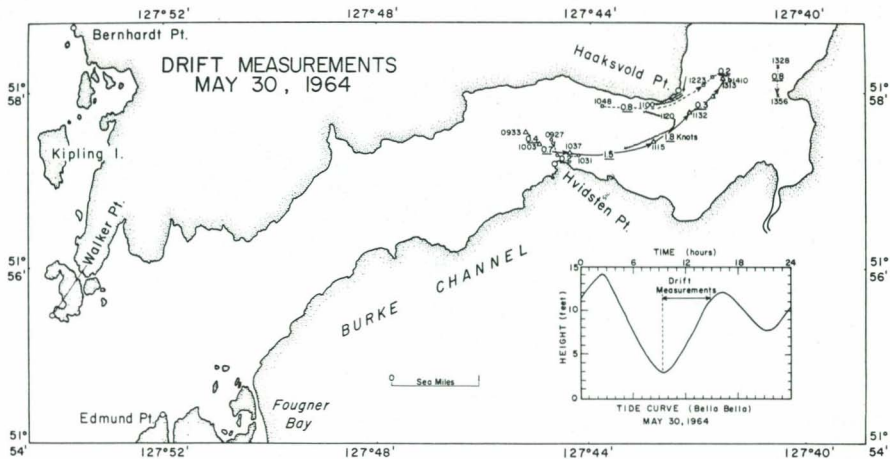


Fig. 92 One-metre drift near the mouth of Burke Channel, May 30, 1964.

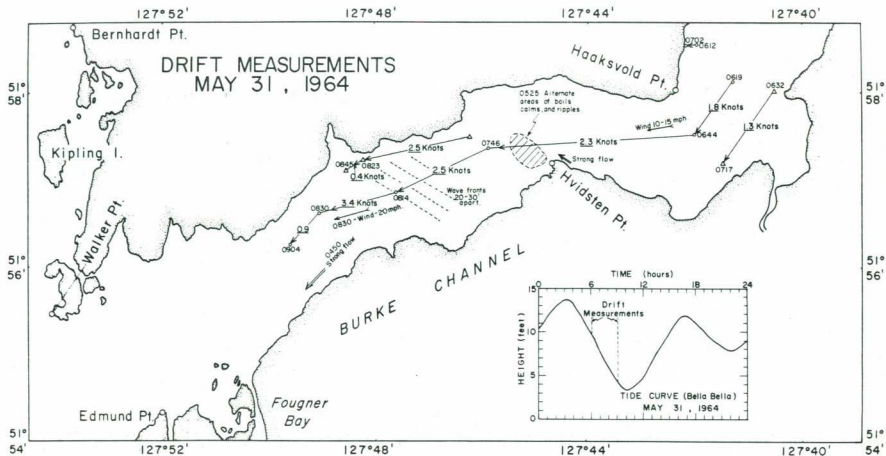


Fig. 94 One-metre drift near the mouth of Burke Channel, May 31, 1964.

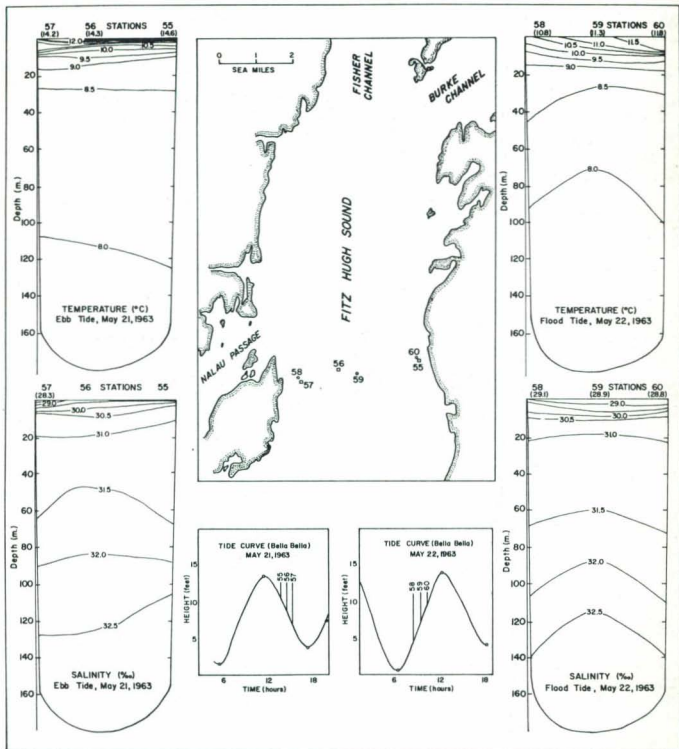


Fig. 95 Vertical distributions of temperature and salinity in Fitz Hugh Sound, May 21-22, 1963.

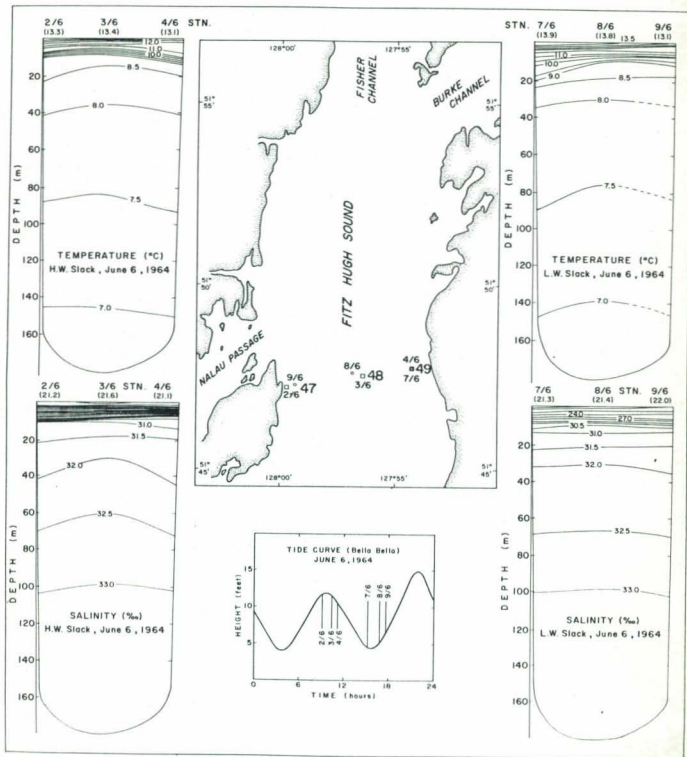


Fig. 96 Vertical distributions of temperature and salinity in Fitz Hugh Sound, June 6, 1964.

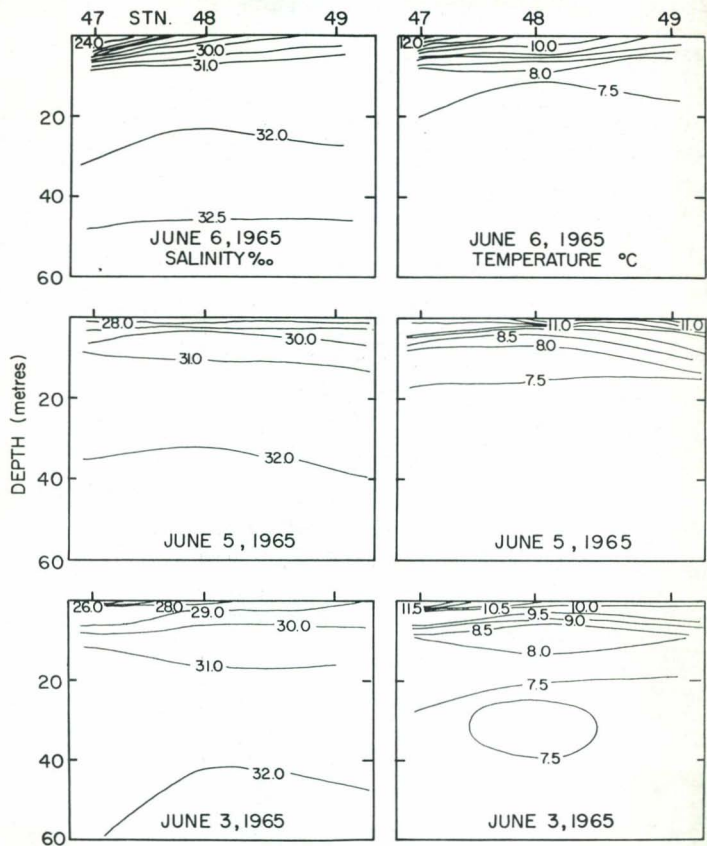


Fig. 97 Vertical distributions of salinity and temperature in Fitz Hugh Sound, June 3, 5, 6, 1965 (station positions shown in Fig. 96).

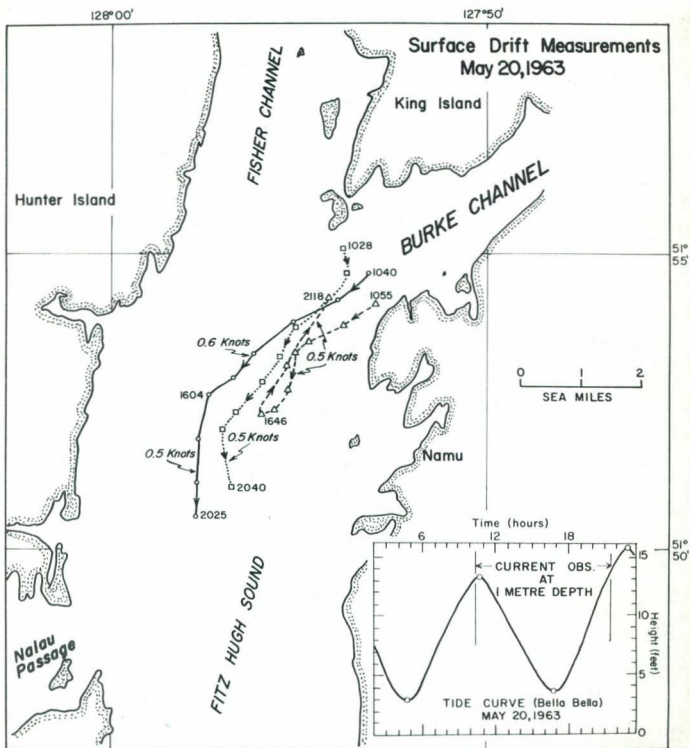


Fig. 98 One-metre drift in Fitz Hugh Sound, May 20, 1963.

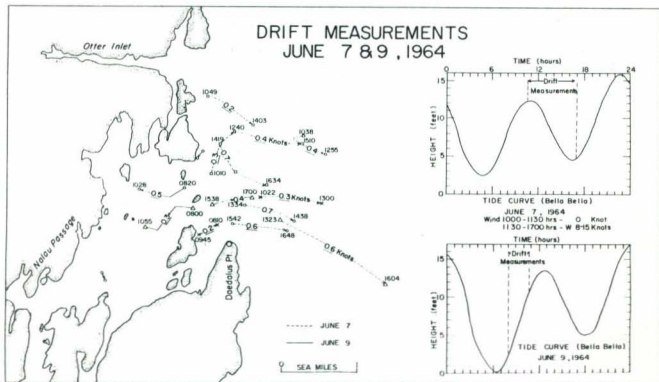
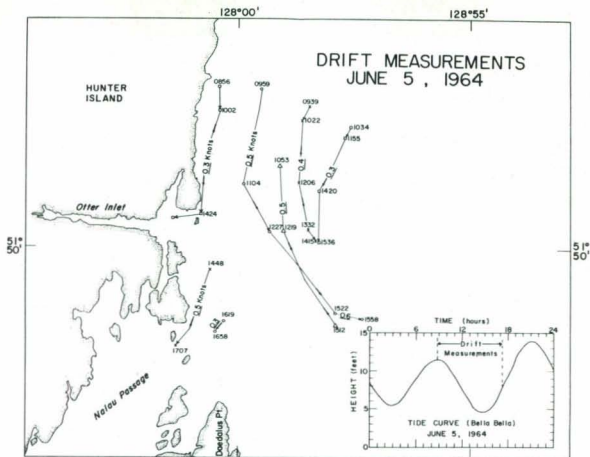


Fig. 99 One-metre drift in Fitz Hugh Sound and at the mouth of Nalau Passage, June 5, 7, 9, 1964.

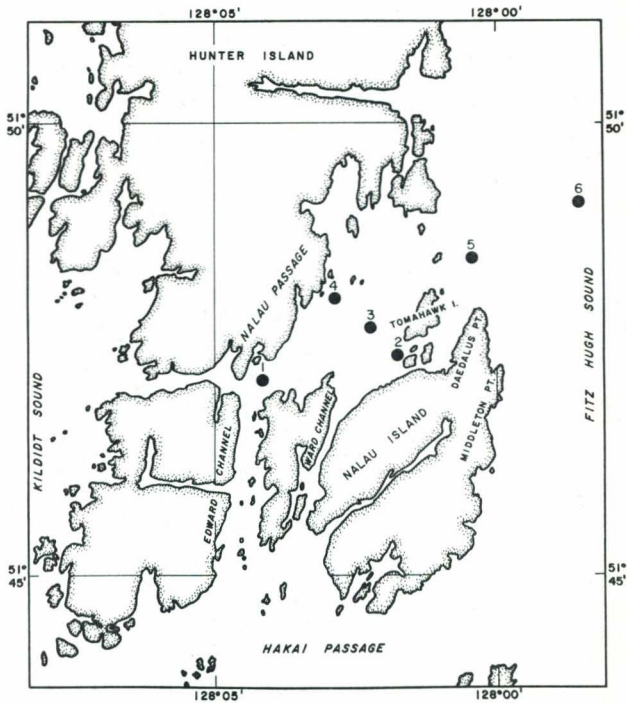


Fig. 100 Station positions in Nalau Passage and Fitz Hugh Sound.

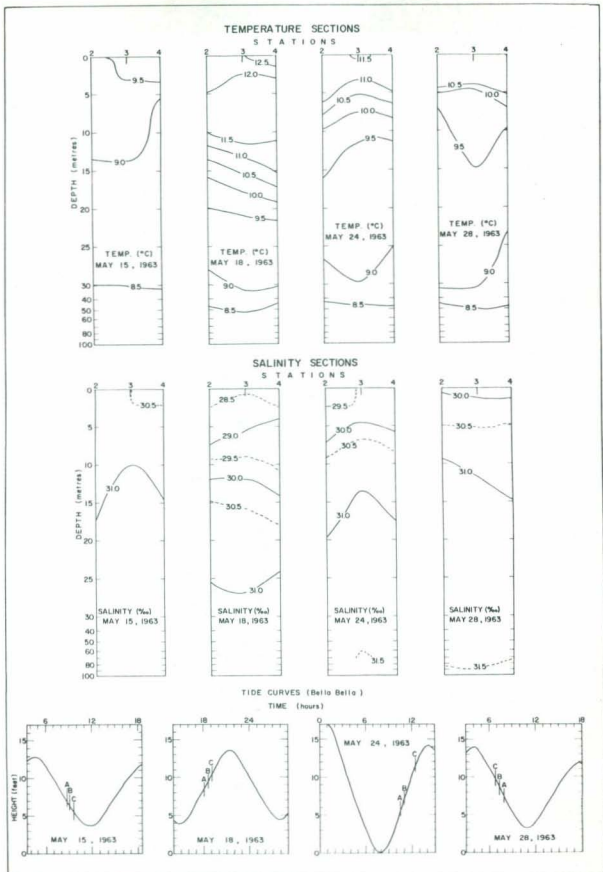


Fig. 101 Vertical distributions of salinity and temperature in Nalau Passage, May 15, 18, 24, 28, 1963 (station positions shown in Fig. 100).

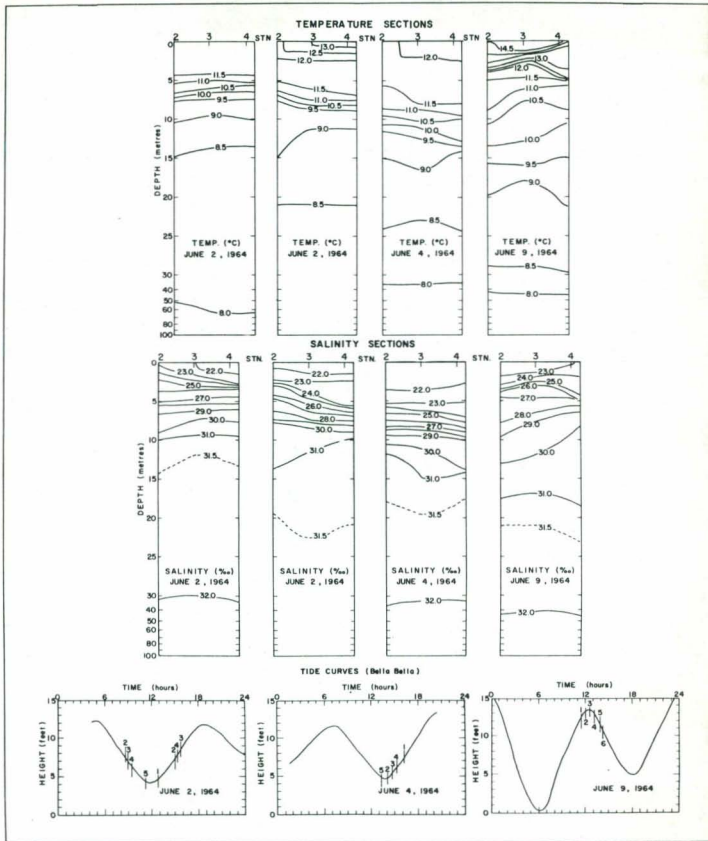


Fig. 102 Vertical distributions of salinity and temperature in Nalau Passage, June 2, 4, 9, 1964 (station positions shown in Fig. 100).

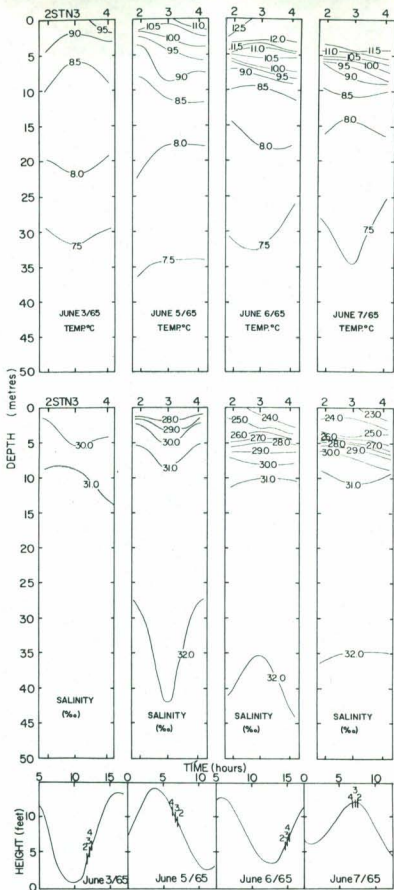


Fig. 103 Vertical distributions of salinity and temperature in Nalau Passage, June 3, 5, 6, 7, 1965 (station positions shown in Fig. 100).

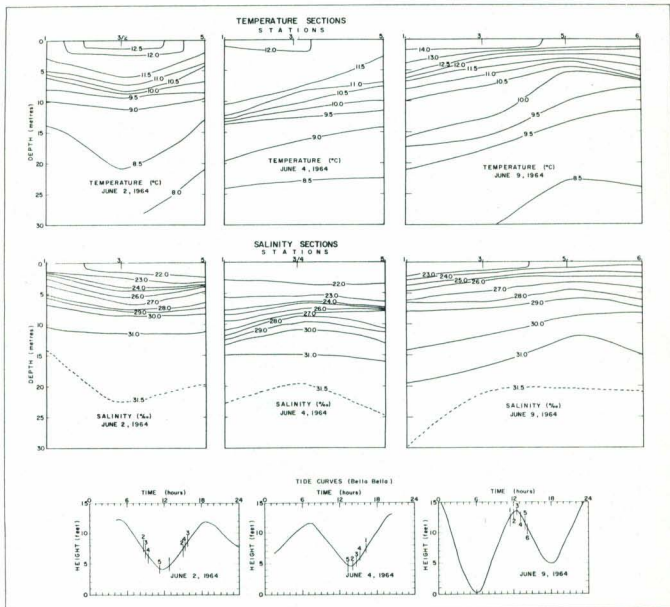


Fig. 104 Vertical distributions of salinity and temperature in Nalau Passage and in Fitz Hugh Sound, June 2, 4, 9, 1964 (station positions shown in Fig. 100).

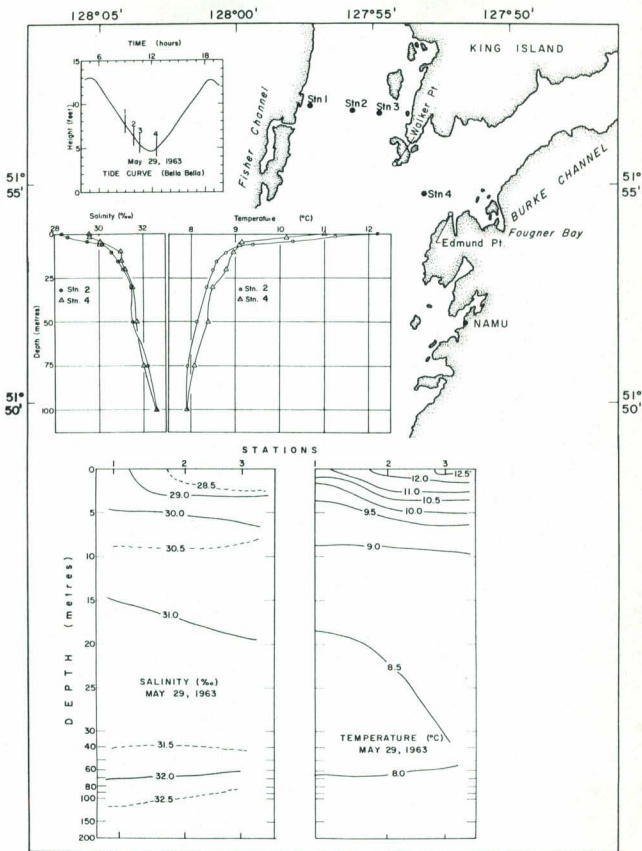


Fig. 105 Vertical distributions and profiles of salinity and temperature in Fisher and Burke Channels, May 29, 1963.

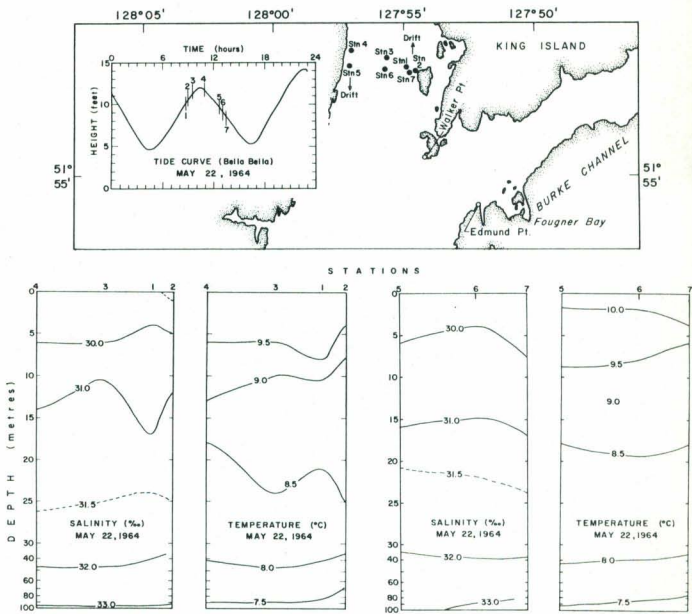


Fig. 106 Vertical distributions of salinity and temperature in Fisher Channel, May 22, 1964.

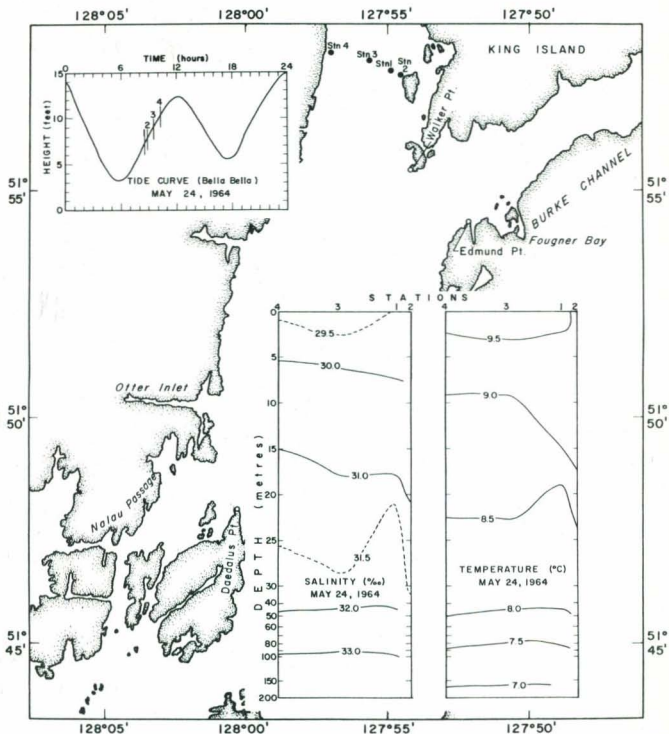


Fig. 107 Vertical distributions of salinity and temperature in Fisher Channel, May 24, 1964.