Canso Marine Environment Workshop Part 4 of 4 Parts Physical Oceanography and Environmental Effects

F. D. McCracken
Editor

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La page couverture porte le nom de l'établissement auteur où l'on peut se procurer les rapports sous couverture cartonnée.

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Fisheries and Marine Service
Technical Report 834

January 1979

CANSO MARINE ENVIRONMENT WORKSHOP
PART 4 OF 4 PARTS
Physical and Geological Oceanography

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CLIMATE AND ICE IN THE STRAIT OF CANSO REGION

by

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ABSTRACT

O'Neill, A. D. J. 1979. Climate and ice in the Strait of Canso region. Fish. Mar. Serv. Tech. Rep. 834.

From examination of climatological records for the Strait of Canso region, it is concluded that Causeway construction did not result in any significant change in climate there. The limited data available, however, indicate that substantial changes in sea-ice regime occurred along Nova Scotia's Atlantic coast subsequent to Causeway construction. It is suggested that breaching of the Causeway would have marginal effects on the climate in the region but might result in more severe sea-ice conditions along the east coast of Nova Scotia should the breach permit passage of significant quantities of ice through the Strait to the Atlantic.

Key words: Climate, weather conditions, sea ice, Canso Strait, causeway, precipitation, air temperature

INTRODUCTION

This paper summarizes the climatology of the Strait of Canso Region of Nova Scotia, including a brief review of sea-ice conditions. In particular, an attempt is made to examine the climate of the area both prior to and subsequent to construction of the Canso Causeway.

EXISTING DATABASE

CLIMATIC DATA

Lists of climatological stations in the vicinity of Canso Strait, details of the observing programs at these stations and their periods of operation are presented in Table 1. Fortuitously, observations of precipitation and temperature are available from Port Hastings, on the shores of the Strait, for a fairly extended period prior to construction of the Causeway. Subsequent to Causeway construction in the mid-1950's, climatic data are available from a number of stations in the area.

In addition to the site-specific observations noted above, synthesized, broader-scale information on various aspects of regional climate is available in the National Climatic Atlas (Anon. 1970a) and in a number of other publications available from the Atmospheric Environment Service. Among the latter, particular reference will be made to "Recent Climatic Fluctuations in Canada" (Thomas 1975), which contains an analysis of trends in regional climate in the Maritime Provinces and is highly relevant to this paper. An Appendix to the present paper presents a fairly complete list of reference material concerning the climate of the Strait of Canso region.

ICE DATA

The Atmospheric Environment Service Ice Branch is responsible for reconnaissance and forecasting of ice conditions in Canadian marine areas and for providing information on ice climatology. The AES Ice Branch was established in 1957, subsequent to construction of the Canso Causeway. Limited information on ice conditions prior to Causeway construction is available from a number of miscellaneous sources. For this presentation, I have utilized data from the Ice Atlas of the Northern Hemisphere (Anon. 1946) supplemented by additional information from an article by Forward (1954).

CLIMATE OF THE STRAIT OF CANSO REGION

Canso Strait is subject to both continental and maritime climatic influences due to its location on the eastern side of a continental land mass in middle latitudes. For the same reason, it is directly affected by the frequent passage of mid-latitude frontal depressions and during summer occasionally lies close to the track of tropical storms. These factors, combined with more local influences such as the seasonal freezing of the Gulf of St. Lawrence, produce a mid-latitude climate best characterized by its variability.

At Port Hastings on the shores of the Strait, mean daily maximum temperatures range from -1.8°C in February to 22.3°C in August with corresponding mean daily minima ranging from -9.9°C in February to 13.9°C in August. The

Table 1. Climatological stations in the Canso Strait area.

Station name	Period of operation	Observation program
Canso	Dec. 1963-Dec. 1971	Hourly observations plus rainfall rate
Eddy Point	Dec. 1971-	Hourly observations plus rainfall rate
Point Tupper	March 1970-	Precipitation and temperature
Port Hawkesbury	Feb. 1959-Dec. 1961	Wind velocity
Port Hastings	Jan. 1874-June 1913 June 1959-	Precipitation and temperature (incomplete) Precipitation and temperature
Port Hastings Canal	July 1974-	Wind velocity
Port Hood	July 1950-Nov. 1952 Feb. 1961-Nov. 1971	Precipitation and temperature Precipitation and temperature
Port Hood Island	July 1972-July 1975	Precipitation, temperature, wind velocity

continental influence is reflected in the extreme temperatures on record which are 37.2°C (extreme maximum) and -26.7°C (extreme minimum). The growing season at Port Hastings (defined as the number of days with mean daily temperature above 5.6°C) averages 191 days while freezing temperatures occur on an average of 158 days.

Precipitation falls on an average of 129 days per year of which 22 days between October and May are, normally, days with measurable snowfall. Average annual precipitation at Port Hastings totals 1205 mm of which 165 mm water equivalent is contributed by snow. Thunderstorms occur on about 10 days per year. Annual evaporative loss from open water in the area averages about 550 mm (Ferguson et al. 1970) while mean annual actual evapotranspiration is estimated at about 500 mm (den Hartog and Ferguson 1977).

CLIMATIC TRENDS

Thomas (1975) has recently published an historical review of the behavior, since 1940, of major climatic elements at a selection of observing stations across Canada. He utilized 10-yr running means of annual values (average or total as appropriate) to highlight longer-term trends in the data. Data from Fredericton, N.B., Sydney, N.S., and Gander, Nfld. were utilized to illustrate trends for the Atlantic Region.

The behavior of mean annual temperature and total annual precipitation in the Atlantic area since 1940 is illustrated in Fig. 1 and 2 from Thomas (1975). Major points to note are the downward trend of about 0.5°C in mean annual temperature since the mid 1950's and the slow, fairly uniform trend towards more precipitation over the past 35 yr - the precipitation index being about 7% higher at the end of the period than at the beginning. The trend in annual snowfall within the Atlantic region for the same period is shown in Fig. 3, also from Thomas. The trend line is based on data from Moncton, N.B., Charlottetown, P.E.I., and Halifax and Sydney, N.S. Clearly, annual snowfall has generally increased in the district during the period, though individual stations show deviations from this pattern. Simple decadal means of annual snowfall at the four stations were less than 229 cm early in the period but over the past 20 yr have been generally more than 241 cm.

It is of interest here to examine climatological records from the Strait of Canso area within the framework of the broader regional patterns discussed above. Port Hastings, on the north shore of the Strait, has been used since it is the only climatological station with sufficient depth of record to permit even a cursory examination of local climate before and after Causeway construction.

Figure 4 illustrates the behavior of mean annual temperature at Port Hastings for the two

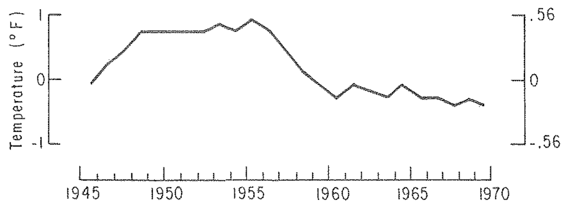


Fig. 1. Decadal moving mean temperatures in the Atlantic region 1940-75 (mean credited to mid-year of each 10-yr period).

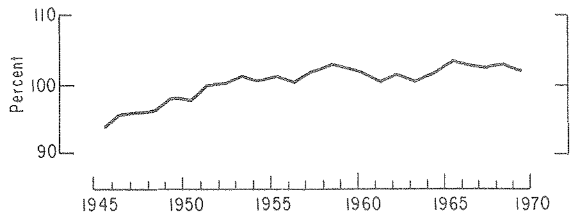


Fig. 2. The trend in annual precipitation over the Atlantic region 1940-75 (values credited to mid-year of each 10-yr period).

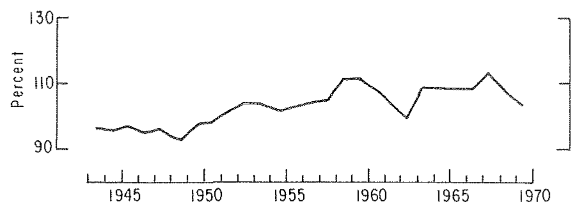


Fig. 3. The trend in annual snowfall over the Atlantic region 1940-75 (values credited to mid-year of 10-yr period).

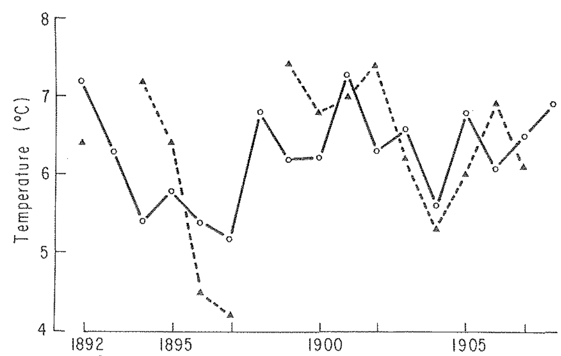


Fig. 4. Mean annual temperatures at Port Hastings during the periods 1892-1907 (triangles) and 1961-76 (circles).

periods 1892-1907 and 1960-1976. Total annual precipitation recorded during the periods 1890-1907 and 1961-1976 is shown in Fig. 5. The data represent unsmoothed annual means or totals.

Data in Fig. 4 indicate no major change in temperature regime between the 1892-1907 and 1960-1976 periods though greater variability in mean annual temperatures was observed during the earlier period. Mean temperatures over the two periods, from available data, were almost identical (approximately 6.3°C). Both greater variability in annual precipitation during the earlier period and increased annual precipitation during the later period are evident in Fig. 5. Mean annual precipitation averaged 1212.9 mm during 1890-1907 and 1369.2 mm during 1961-1976, consistent with the regional trend to greater precipitation reported by Thomas (1975).

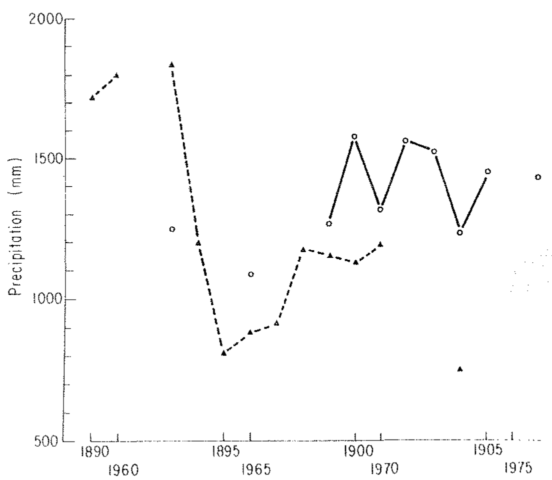


Fig. 5. Annual precipitation at Port Hastings during the periods 1890-1907 (triangles) and 1961-76 (circles).

ICE CONDITIONS

Historical data on distribution of ice along the coasts of Nova Scotia are far from adequate for a rigorous analysis of ice conditions prior to construction of the Canso Causeway. Some information is available in the U. S. Hydrographic Office publication "The Ice Atlas of the Northern Hemisphere" (Anon. 1946) and in an article by Forward (1954).

These sources indicate that prior to Causeway construction the northern entrance of Canso Strait usually became blocked by ice and closed to navigation about January 1, though the section south of Mulgrave remained open (Fig. 6). By mid-January, St. Georges Bay was usually filled with close pack ice and such a volume of ice was swept towards the entrance of Canso Strait that it often packed solid and froze into a compact mass locally known as a "bridge". This "bridge" prevented ice from drifting into the Strait during some years, and resulted in ice-free conditions in the eastern Strait making navigation in that stretch possible throughout most of the year. On other occasions, tidal currents were responsible for transporting significant quantities of ice through the Canso Strait - particularly when winds were blowing in the same direction as current flows.

Normal sea-ice distributions along the eastern seaboard in February and March prior to 1940 are illustrated in Fig. 7 and 8 (Anon. 1946). On average, significant quantities of ice were observed as far south as the Cape Sable area prior to Causeway construction.

More recently, the AES Ice Branch has produced a series of maps (Anon. 1970b) showing the maximum, median and minimum extent of sea ice on the east coast from data for the period 1963-1977. Ice conditions for February 26 and April 2 respectively for the 1963-1977 period are illustrated in Fig. 9 and 10. "Worst case" conditions in this period, since AES Ice Branch undertook observation and analysis of ice on the east coast, involved significant ice extending no farther south than Halifax.

The Director of AES Ice Branch (personal communication) suggests that the reduction in severity of ice conditions on the east coast of Nova Scotia may be, at least in part, a result of construction of the Canso Causeway and subsequent elimination of ice flow through the Strait. Certainly, available climatological information shows a cooling trend over Eastern Canada, in general, and the Maritimes in particular since construction. This trend, taken by itself, would suggest an increase in average extent and duration of sea-ice cover. Thus it is reasonable to postulate a non-meteorological cause for the observed reduction in severity of ice conditions along the Eastern and South Shores of Nova Scotia.

SUMMARY AND CONCLUSIONS

The two main points emerging from this review of the behavior of climate and ice conditions in the vicinity of Canso Strait are:

1) The climate of the Maritimes, like that of eastern Canada in general, has experienced a cooling trend which commenced in the mid-1950's, at about the same time as the Causeway was being constructed. This cooling trend has resulted in a decrease of about 0.5°C in decadal mean temperatures over the region since 1956.

2) Sea-ice conditions along the Eastern and South Shores of Nova Scotia appear to have moderated since Canso Causeway was constructed. Ice data (admittedly of

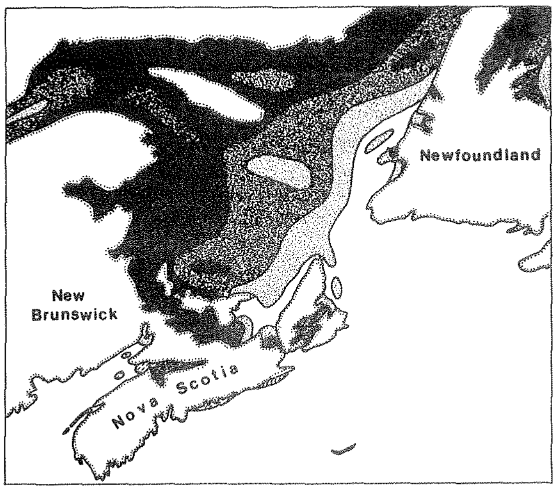


Fig. 6. Average sea ice conditions for January during the period 1901-37.

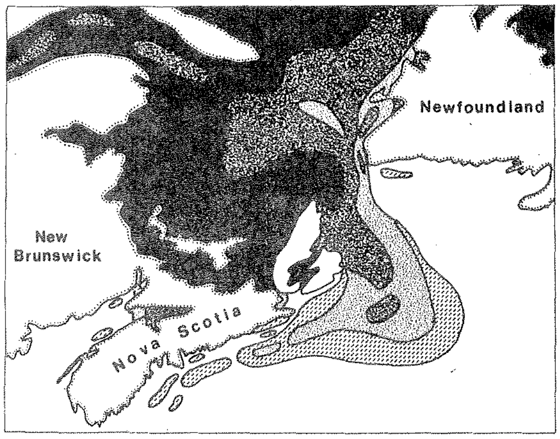


Fig. 7. Average sea ice conditions for February during the period 1901-37.

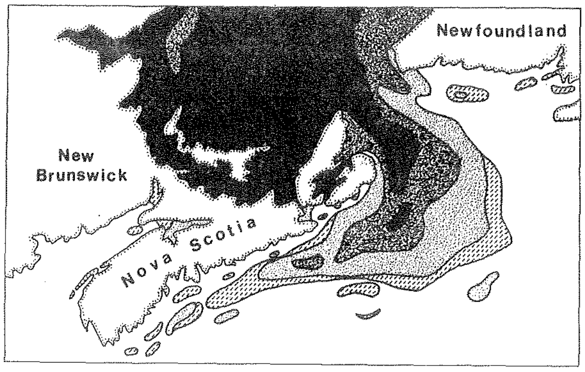


Fig. 8. Average sea ice conditions for March during the period 1901-37.

TYPES OF ICE

Unnavigable sea and land-fast ice, occasionally penetrable by powerful ice-breakers.

Generally unnavigable sea and land-fast ice. At times penetrable by heavily built vessels.

Sea and land-fast ice generally navigable by heavily built vessels.

Sea and land-fast ice generally navigable by unreinforced vessels.

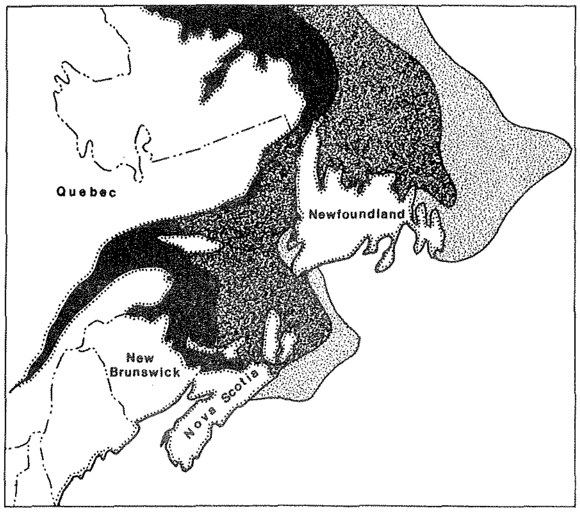


Fig. 9. Maximum, median and minimum extent of pack ice on Feb. 26, during the period 1963-77.

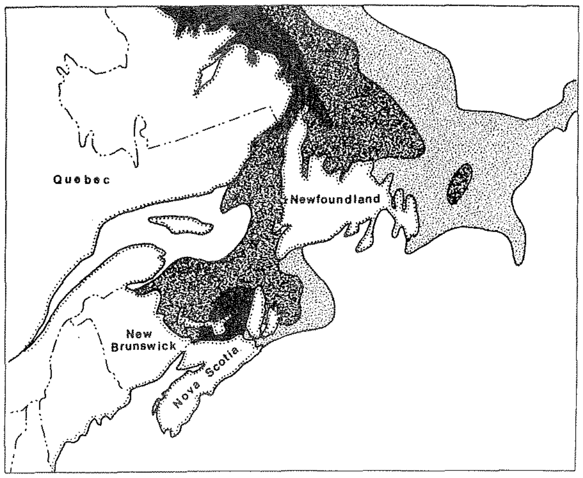
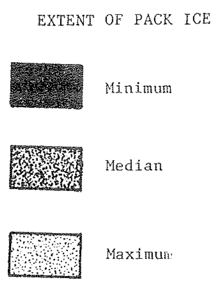


Fig. 10. Maximum, median and minimum extent of pack ice on Apr. 2, during the period 1963-77.



uncertain quality) for periods prior to Causeway construction indicate that large quantities of ice often extended as far south as Cape Sable, N. S. Subsequent to construction, ice has not been observed in significant quantities south of Halifax.

The above combination of factors lends qualified support to the thesis that construction of Canso Causeway may have resulted in a substantial change in distribution of sea ice along the coast of Nova Scotia by eliminating movement of ice through the Strait from the Gulf of St. Lawrence to the Atlantic. However, climatic data do not indicate any major change in climate in the Strait area resulting from Causeway construction. Very local, and temporally variable, changes (e.g. in temperature regime and heat and moisture fluxes) almost certainly resulted over and along the shores of the eastern half of the Strait when ice cover in that reach was largely eliminated by Causeway construction. Available data are inadequate to identify such small-scale climatic changes. In general, their overall influence on the climate of the Strait region is likely to have been marginal.

The preceding discussion suggests that breaching of the Canso Causeway would have rather marginal effects on the general climate of the area but might result in more severe sea-ice conditions in Chedabucto Bay and along the Eastern and South Shores of Nova Scotia should the breach permit passage of significant quantities of ice through the Strait to the Atlantic.

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DISCUSSION

Dadswell: What is the direction of the prevailing wind?

O'Neill: In Canso the prevailing winds are southwest to west.

Dadswell: Is there likely to be any difference in wind direction between the station at Canso and the northern end of the Strait of Canso that would affect larval transport?

O'Neill: No, I don't think there would be a marked difference.

Question: What was the drop in mean temperature between 1955 and 1967 due to?

O'Neill: We have no specific answer other than that the trend was a general one throughout eastern North America.

FLOW IN THE STRAIT OF CANSO AND ST. GEORGES BAY, NOVA SCOTIA

by

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ABSTRACT

Drinkwater, K. F. 1979. Flow in the Strait of Canso and St. Georges Bay, Nova Scotia. Fish. Mar. Serv. Tech. Rep. 834.

A difference in mean sea level between St. Georges Bay and Chedabucto Bay drove a residual southerly current through the Strait of Canso prior to completion of the Canso Causeway. Volume flux of this residual is estimated to have been 7 x 10^3 m^3/s based upon available tide gauge data and an empirical relationship between tidal heights and volume flow found by Fothergill (1954). The possible effects that this residual flow and the tidal flows through the Strait of Canso had on the currents, residence time and temperature salinity characteristics in St. Georges Bay are discussed.

Key words: Tidal currents, sea level, water currents, water temperature, salinity, Strait of Canso, causeway

INTRODUCTION

The Strait of Canso is the narrow body of water separating Cape Breton Island from the Nova Scotia mainland. A causeway across the Strait was begun in September 1952 and was completed in the fall of 1954. Prior to completion the Strait connected St. Georges Bay to the north with Chedabucto Bay to the south. Relative differences in sea level between these two bays produced a complex flow pattern within the Strait. These differences resulted in part from dissimilarities in tidal oscillations. St. Georges Bay is part of the Gulf of St. Lawrence and typically has a 1.4-m (4.5-ft) spring tidal range with marked diurnal inequalities. Chedabucto Bay is on the Atlantic coast and has a 2-m (6.5-ft) spring tidal range with only a small diurnal inequality. Other forces, such as wind and barometric pressure, also cause sea level differences between opposite ends of the Strait.

PREVIOUS INVESTIGATIONS

Fothergill (1954) undertook a study on the effects the Causeway had on circulation in the approaches and within the Strait itself. Tide gauges were installed at Auld Cove and Port Hastings (Fig. 1). The gauges were not levelled as it was felt the error involved (±0.06 m; 0.2 ft) would minimize the value of such a procedure. Current measurements were taken over a 24-h period at several stations (Fig. 1). Observations were taken at depths of 2.5, 6, 12, 18 and 24 m.

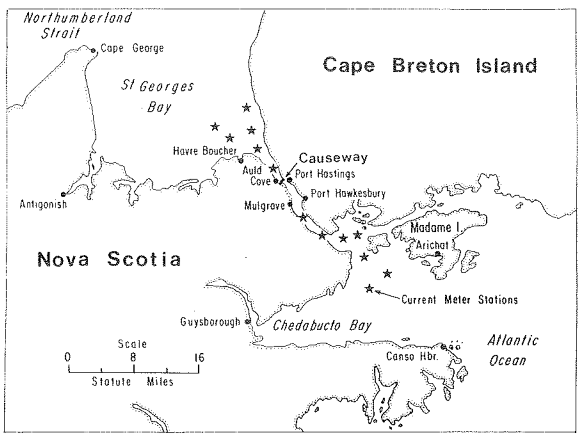

Fig. 1. Map of Canso region showing locations of Fothergill's (1954) current meter stations.

Empirical relationships were found between observed velocities at each station and sea level differences as measured at Havre Boucher and Arichat. First a zero reference level was established between the latter two tide gauges. The tide tables in 1952 (Anon. 1952) contained predictions of times of slack water in the Strait of Canso. From these predictions the number of hours of north- and south-going flows for a 1-mo period were calculated. For the tidal height data at Havre Boucher and Arichat over this same period, Fothergill calculated the number of hours of north- and south-going flows. He found good agreement with predicted value if Arichat was read from low water datum and Havre Boucher was read from 0.3 m (1 ft) below its low water datum. This he chose as his reference level.

It was found that maximum observed velocities corresponded roughly with maximum sea level differences but the former were lagged by 2-3 h. Velocity versus sea level difference curves were constructed by neglecting this phase difference. A linear relationship was found at each station although the scatter was large. Velocities at any two stations for a given sea level difference were found to be related through their cross-sectional areas, i.e.

$$V_iA_i = V_jA_j = Q$$

where Q is the volume flux, V is the velocity, A the cross-sectional area and i and j denote different stations. Thus, volume flux was found to be conserved through the Strait.

A linear relationship between sea level difference and velocity is somewhat surprising, as hydraulic flows in open channels theoretically predict sea level difference to be proportional to velocity squared. The theoretical relationship has been observed in Seymour Narrows, B.C. (Lacroix and Tully 1954) where flow is driven in much the same way as it used to be in Canso Strait.

Deviation from theory in the Strait of Canso may be due to a wrong sea level reference plane or through errors in measured velocities or the deviation may indeed be real. As mentioned, the zero reference plane was determined through comparisons with predicted times of slack water. These predictions were based upon a harmonic analysis of visual observations of time of night and day surface slack water, taken over a period of four summer seasons in the central part of the Strait south of Mulgrave. These observations were first reported in tide tables of 1929 (Anon. 1929). Visual methods make precise determinations of time of slack water difficult and may have provided a source of error in the harmonic analysis. Even barring such errors, changes in wind and pressure patterns between the 1930's and 1950's could have produced a different pattern of slack water than that predicted. Errors of ±13 cm/s (0.25 knots) in the current measurements were caused by ship's motion due to boat drift from wind and fluctuating currents (Fothergill 1954). The current meters were at best accurate to within ±10% even without the difficulties of ship's motion. Better velocity measurements and the true reference plane might have produced results closer to theory, but this is only speculation.

NET RESIDUAL FLOW THROUGH THE STRAIT OF CANSO

An understanding of the physics of the flow is not provided from the empirical relationship between velocity and sea level difference; however, it can be used for crude predictions of volume flux through the Strait. Fothergill found the mean monthly sea level difference for September 1952 to be 0.11 m (0.35 ft), Havre Boucher greater than Arichat, giving a mean net velocity in the narrowest portion of the Strait of 35 cm/s (0.68 knots) to the south. Based on this net velocity the mean flux for the month was 8.5×10^3 m^3/s southwards. Fothergill felt the actual mean flux would be reduced by approximately 50% to 4.2×10^3 m^3/s due to wind and frictional effects.

Monthly mean sea level difference between Havre Boucher and Arichat can be expected to change from month to month and year to year through changes in the tides, winds and atmospheric pressure systems. What are the magnitudes of these variations? Between 1952 and 1955, 16 mean monthly sea level differences can be calculated (Anon. 1975) covering only the months May through October. Using Fothergill's reference plane, mean sea levels are found in all cases to be greater at Havre Boucher than at Arichat giving southward residual flow through the Strait of Canso. Height differences vary from 0.24 m (0.78 ft) during June 1953 to 0.11 m (0.35 ft) during September 1952 and June 1954. The mean over the 16 mo was 0.18 m with a standard deviation of ±0.04 m (0.59 ft - S.D. ±0.13 ft). During winter sea level difference would be greater than in summer due to north and northwest winds which pile up water at the north end of the Strait. The tide tables (Anon. 1952) remark on this effect with corresponding increases in the southerly transport through Canso Strait.

If Fothergill's velocity-sea level relationship is used, mean monthly flux for the 16 mo of data would have been 14.4×10^3 m^3/s. These and further results are summarized in Table 1. Note that Fothergill's estimate of residual flow corresponds to a month when sea level difference was a minimum.

Upon completion of the Causeway the northern section of the Strait (Auld Cove) became an extension of St. Georges Bay while the southern section (Port Hastings) became an extension of Chedabucto Bay. The head difference between the two bays is now confined to the Causeway site. Some information on magnitude of head difference at the completion date can be obtained from tide records at Auld Cove and Port Hastings.

Table 1. Residual transports through Canso Strait.

Conditions	Sea level difference (m)	Transports (10^3 m^3/s) No friction	Assuming 50% frictional losses
MSLD ± SD[a]	0.18±0.04	14.4±3.2	7.2±1.6
Max.	0.24	18.9	9.14
Min.	0.11	8.5	4.2
Fothergill	0.11	8.5	4.2

[a]MSLD - Mean sea level difference
SD - Standard deviation

Although Fothergill (1954, 1955) did not level these gauges, Farquharson (1957) states that by then they had been levelled in to Halifax. Relative to geodetic datum the mean sea level at the two sites was the same prior to construction of the Causeway. Monthly mean data are available from the Dept. of Environment (Anon. 1975) using a chart datum rather than the geodetic datum. Plots of mean monthly sea level difference between Auld Cove and Port Hastings (Fig. 2) show an increase in sea level difference over the period of Causeway construction. The sea level difference curve also shows a seasonal pattern of higher differences in winter than in summer. Twelve-month running means are plotted using chart datum as a reference. An increase in sea level difference of 0.12 m (0.38 ft) is observed from the 12-mo running means.

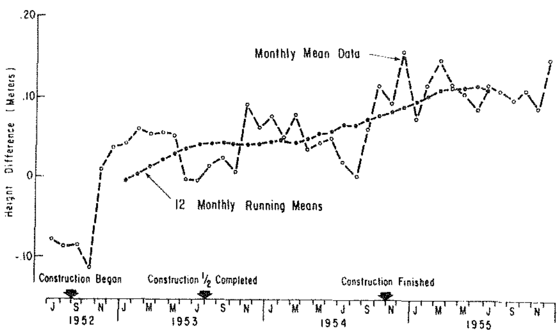

Fig. 2. Mean sea level difference between Auld Cove and Port Hastings, during the course of Canso Causeway construction (see Fig. 1 for place locations).

Over this same time period the relative sea level difference between Charlottetown and Halifax increased by 0.04 m (0.13 ft). Assuming, no doubt wrongly, that Auld Cove is similar to Charlottetown and Port Hastings mirrors Halifax then an increase in sea level difference between Auld Cove and Port Hastings of 0.08 m (0.25 ft) occurred due to the Causeway. This is similar to the 0.09-m (0.3-ft) change found by Fothergill and the 0.09-m (0.29 ft) change found by Farquharson (1957), using parts of the same data but analyzed in a slightly different manner. Assuming that during the 2 mo prior to beginning of construction mean sea level difference relative to geodetic datum was zero, both curves in Fig. 2 must be adjusted upwards by 0.08 m (0.27 ft). This would result in a mean sea level difference of 0.20 m (0.65 ft) at the Causeway upon its completion. This compares with a mean sea level difference between Havre Boucher and Arichat, using Fothergill's calculated reference level of 0.18 m (0.59 ft). Possible levelling errors of ±0.06 m provide further complications. From available data the best that can be said is that mean sea level difference at completion of the Causeway was between 0.09-0.20 m, with the north side higher than the south.

EFFECTS ON ST. GEORGES BAY

TEMPERATURE AND SALINITY

It is interesting to speculate upon the effects the flow through the Strait of Canso had on St. Georges Bay. Temperature and salinity data collected in 1974-75 (Petrie and Drinkwater 1977a, b) show similar profiles to the St. Georges Bay station occupied prior to the Causeway by MacGregor (1952). Only within the Strait have the temperature and salinity structures been altered significantly, changing from well mixed to stratified (Vilks et al. 1975).

FLUSHING TIME

A flushing time for the Bay can be calculated from residual flow through Canso Strait. Fothergill's (1954) observations showed uniform residual velocities with depth at the northern entrance where the maximum depth is 25 m. Table 2 presents the flushing times for this top 25 m of the Bay.

Tidal diffusion can also act to flush the Bay. Assuming the tidal volume is completely mixed within the Bay on a flood (highly unlikely) and that a percentage of the Bay's water is lost on an ebb, the decay of the Bay's original volume of water (V_0) is given by

$$V = V_0 e^{-at}$$

where V is volume of original water at time t and a depends on the amount of volume lost per time cycle. Within a 1-m tide range for

Table 2. Flushing times of the upper 25 m of St. Georges Bay from residual flow through Canso Causeway during summer months 1952-55. The volume of the upper 25 m of the bay is 2.20 x 10^3 m^3.

Sea level difference conditions	Flushing time (days) No friction	Flushing time (days) 50% frictional losses
MSLD ± SD[a]	19 ± 5	36 ± 6
Max.	30	60
Min.	13	27

[a]MSLD - Mean sea level difference
SD - Standard deviation

St. Georges Bay (Anon. 1952) and a loss of 1/3 of the tidal volume per cycle, 63% of the original water in the Bay (e-folding time) would be removed in 46 d. If the entire tidal volume were lost per tidal cycle, the e-folding time is reduced to 15 d. This tidal flushing would be the combination of exchange processes both in Canso Strait-Chedabucto Bay and in Northumberland Strait.

Residual flow and tidal flushing act simultaneously in nature and together they reduce residence time in the Bay to 24.5 d. A loss of 1/3 of the tidal volume has been assumed in this calculation. The combination of residual flow plus tidal diffusion through Canso Strait increases volume flux to Chedabucto Bay from St. Georges Bay to ≈6.7 x 10^8 m^3/d.

Table 3 compares pre- and post-Causeway flushing times. Post-Causeway conditions are taken from Petrie and Drinkwater (1978a) whose calculations are based on current meter data taken during the summers of 1974 and 1975. Their mean circulation consisted of a clockwise gyre within the Bay. Mean flushing time assumes one complete cycle of the Bay and does not account for the possibility of recirculation. The post-Causeway tidal flushing has been calculated like that of the pre-Causeway as described above. Tidal flushing times correspond since tidal volume in the Bay has not changed significantly. Petrie and Drinkwater (1978a) found the waters in the Bay could be exchanged in 2-3 d by low frequency (storm) events. This represents a lower bound. From the velocity spectra (Petrie and Drinkwater 1978a) total variance due to low frequency motions is ≈85% of tidal variance. This suggests mean flushing times due to the two processes possibly being similar. An upper bound of 40 d ± 10 d is chosen. Information on low frequency events is not available under pre-Causeway conditions, but a large difference

Table 3. Comparison of flushing times under pre- and post-Causeway conditions.

	Flushing time in days	
	Pre-Causeway	Post-Causeway
Mean	35	40
Tidal (e-folding time)	46	46
Mean + tidal	24.5	
Low frequency	no data	2.3 (lower bound) 40±10 (upper bound)

in the exchange they cause is not expected. This is because the major water exchange occurs at the northern end of the Bay since its cross-sectional area is an order of magnitude greater than that of Canso Strait. From Table 3 it appears no appreciable change in the residence time of waters in the Bay occurred with building of the Causeway.

CURRENTS

Changes in tidal and residual currents of St. Georges Bay probably occurred after the Causeway was completed. Largest changes would be expected to the north of the Causeway but still within the Strait where tidal currents were in the order of 200 cm/s (4 knots) with a summer residual current of approximately 50 cm/s southwards. With completion of the Causeway there would be small tidal and almost no residual currents.

Some current changes might also be expected in the interior and at the mouth of the Bay. Assuming uniform flow through the mouth (Cape George to Port Hood Island), a velocity of ≈0.8 cm/s is required to supply a residual flow through Canso Strait of 7.2×10^3 m^3/s. Slight increases over velocities at the mouth would occur in the interior of the Bay as the cross-sectional area decreases. Only within Canso Strait would residual current become greater than 5 cm/s.

Fothergill (1954) shows rapidly decreasing tidal velocities in St. Georges Bay as distance from the Strait increases. During northward currents, tidal streams in the interior of the Bay were shown to curve around towards the western shore. During southward flow the currents move uniformly toward the Strait. If true, then a tidally-averaged residual anti-clockwise gyre may have existed on the western side of St. Georges Bay. The existence of steady gyres in regions near narrow straits with strong tidal currents has been predicted by Sugimoto (1975) and observed by Yanagi (1976) and Tee (1976). The steady gyre is required to dissipate vorticity advected into the region. The advected vorticity is generated by strong tidal currents in the Strait and the requirement that current must be zero at the sides of the Strait (Tee 1976). Tee also found the amplitude of residual currents to be 1 to 10% of maximum tidal currents. Since maximum currents in Canso Strait are approximately 200 cm/s, Tee's results suggest the strength of the gyre in St. Georges Bay could have been in the order of 2 to 20 cm/s. Size of the gyre required by the dynamics is unknown and may range from bay size to very small. The present clockwise gyre within the Bay is of ≈5 to 6 cm/s strength (Petrie and Drinkwater 1977b, 1978a). They believe this gyre is generated by the need to dissipate vorticity advected into the Bay by steady eastward flow in Northumberland Strait and have modelled this process numerically (Petrie and Drinkwater 1978b). A steady flow in Northumberland Strait equivalent in magnitude to residual flow through Canso Strait is not large enough to generate a gyre in St. Georges Bay. Assuming the present gyre in St. Georges Bay is driven by a steady flow in Northumberland Strait and the same steady flow existed in pre-Causeway times, the residual flow in the Bay (prior to Causeway) would have been a combination of a clockwise gyre driven by steady flow, an anti-clockwise gyre driven by tidal flow and straight flow to supply residual currents in Canso Strait.

EFFECTS NORTH OF ST. GEORGES BAY

North of St. Georges Bay effects of the Causeway would be small. Farquharson (1959) mentions an increased flow along the northwest coast of Cape Breton Island after the Causeway was completed. He measured currents at two ship sites in the entrance to St. Georges Bay, each over one 24-h period. Residual currents at both sites set to the northeast and on this basis he stated:

> "...it would appear that the former outset through the Strait of Canso has been replaced by a fairly strong northeasterly outset along the shore of Cape Breton."

The actual magnitudes were not presented. The adjective, strong, pertaining to the flow was probably relative to other residual flows measured in Northumberland Strait which were typically <5 cm/s. An estimate of magnitude of increased currents along Cape Breton Island can be made assuming the residual flow through Canso Strait of 7.2×10^3 m^3/s now flows in a coastal band 20 km wide and 30 m deep. The increased velocity would be 1.2 cm/s. I feel that residual currents measured by Farquharson in St. Georges Bay did not reflect the former residual flow through Canso Strait but were due to other processes.

CONCLUSIONS

1) Fothergill's empirical relationship of velocity proportional to sea level difference is suspect but it does offer first approximations as to flow in Canso Strait prior to completion of the Causeway.

2) Using this relationship mean summer residual flux through the Strait was 7.2×10^3 m^3/s to the south. Together with tidal dispersion, $\approx 6.7 \times 10^8$ m^3/d of St. Georges Bay water reached Chedabucto Bay.

3) Mean sea level difference at the Causeway upon completion was between 0.09 and 0.20 m.

4) Temperature and salinity structure of St. Georges Bay did not appear to change with the Causeway except in the vicinity immediately north of the construction site.

5) The residence time of water in St. Georges Bay is ≈2-4 wk and did not change significantly with completion of the Causeway.

6) Residual currents in the Bay likely underwent a change with completion of the Causeway. The largest changes are expected near the Strait. Magnitude of the change would decrease with distance from the Strait.

7) Only small changes in flow are expected north of St. Georges Bay.

ACKNOWLEDGMENTS

I wish to acknowledge the helpful discussions and comments of R. Trites, B. Petrie, D. DeWolfe and W. H. Sutcliffe, Jr. I also thank G. Taylor for preparation of one of the diagrams.

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DISCUSSION

Question: Is there a tendency towards lesser currents now in St. Georges Bay than before closure of the Causeway?

Drinkwater: We don't really know what currents were like previously or if the gyre actually existed then.

Trites: The change in flushing times since closure is not significant. What is important is what the source of waters was in the two bays before and after closure.

Dadswell: It seems that all flushing used to go through the Strait.

Trites: No. There was some increase in tidal constraints at the entrance to St. Georges Bay.

Sandeman: It has been shown that enough water came through to affect temperature in Chedabucto Bay.

Doubleday: From the trend in sea level difference between the two bays, can you make any suggestions as to what would happen if the Causeway were breached?

Drinkwater: After the Causeway was constructed, the difference in sea level became concentrated at the Causeway. We can see seasonal differences in the pre-Causeway trend and expect those do still exist. If the Causeway were breached, the flow would be determined by the sea level difference on the two sides and hence exhibit seasonal as well as tidal and atmospherically forced fluctuations.

Sandeman: How much difference in head could be expected after several days of wind?

Drinkwater: Purely as a guess I would say .05 m. The real problem is that we don't know where the reference level is.

Stasko: Don't we have adequate data on the head now? We could check it today.

Drinkwater: No. Tide gauges would have to be established on either side of the lock and levelled in to a common reference.

Muir: After checking difference in level at the Causeway, can you calculate what would flow through if the Causeway were breached?

Drinkwater: This would be a standard open channel flow or weir problem which engineers are familiar with, so I think a flow could be easily calculated.

Stasko: How long a series of readings would be necessary to establish true levels?

Drinkwater: One year would be sufficient to establish seasonal changes. It would be less if the Causeway were breached only for the summer months when lobster larvae were present. Information on density of lobster larvae in St. Georges Bay would indicate whether breaching could affect lobster production.

Muir: Thinking in terms of net transport, would anything be transported north to St. Georges Bay? How about sediments from Chedabucto industry?

Drinkwater: Net transport would probably be to the south.

Ford: Consideration should be given to geometry of the stream. A flood tide would counteract the net movement and some fraction of what was brought in to St. Georges Bay would remain.

Comment: Apparently overall surface input as well as input in the more saline layers at the bottom depend upon how these layers move. There is a good chance that some pollution would be carried into St. Georges Bay.

Drinkwater: There is a great variation between sites as a result of winds and what happens at each site.

Doubleday: Anything at a depth of 30 m would move according to the "noise." There is a possibility of a net saline deep flow from Chedabucto towards St. Georges Bay.

Drinkwater: No, I don't think so.

Trites: There is a sill just north of the mouth of the Strait in St. Georges Bay and the possibility of highly saline water crossing this sill is very small.

Drinkwater: Apparently winds do not reverse the pattern of southerly flow.

Dadswell: There is a small flow through the Strait in winter, since the gates are cracked to allow enough flow to prevent freezing.

Clark: That is true. The gates are opened a couple of feet in winter but closed when there is considerable wave action.

FLOW PATTERNS IN CHEDABUCTO BAY, NOVA SCOTIA

by

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ABSTRACT

Lawrence, D. J. 1979. Flow patterns in Chedabucto Bay, Nova Scotia. Fish. Mar. Serv. Tech. Rep. 834.

Five current meter moorings were put in Chedabucto Bay for 18 d following the *ARROW* oil disaster in 1970. Notable flow features were abrupt changes in direction on at least three occasions and existence of an overall average counter clockwise gyre at all depths. The direction changes tended to occur simultaneously but were otherwise largely unconnected.

In the band from 0.07 to 1.7 c/d the RMS amplitude was highest (8 cm s^{-1}) but correlation coefficients were insignificant vertically across the 20-m interface and horizontally between stations. No significant correlation with the geostrophic wind was found. The gyre had an amplitude near the boundaries of ≃ 3 cm s^{-1}. Tidal currents from all 14 instruments were small but consistent (average 5.3 ± 0.8 cm s^{-1}), dominated by M_2, and nearly rectilinear. Orientation was consistently east-west. High frequency motion in the band 0.07 to 6 c/h was weak (RMS amplitude ≃ 4 cm s^{-1}) and no significant pattern was found. Temperature and salinity measurements confirmed the existence of seiche activity (≃ 2 c/h).

It was estimated that the only effect of the pre-Causeway inflow from the Strait of Canso would be to add perhaps 6 cm s^{-1} to the gyre in the southern portion of the Bay. This could reduce transit times from 12 to 4 d.

Key words: Current measurements, gyres, water temperature, salinity, seiches, water density, geostrophic wind, numerical models, Chedabucto Bay

INTRODUCTION

This report presents a further examination of oceanographic data from Chedabucto Bay. Five moorings were laid in two lines across the Bay during Project Oil activities following the *ARROW* oil spill (Fig. 1; Neu 1970). A total of 14 instruments out of 18 gave usable results. The instruments were the Hydrowerkstatten type, with a propeller speed sensor, and a magnetic compass sensing the orientation of the 2.5-m long, self-buoyant, torpedo-shaped instrument case. Data recording intervals of 5 and 10 min were used.

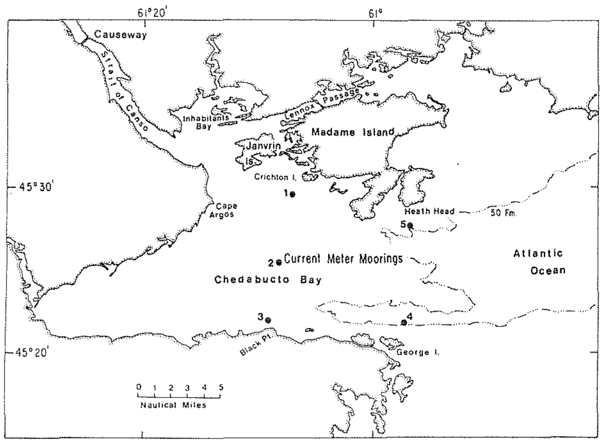

Fig. 1. Site location map.

The moorings were in place for a maximum of only 18 d (6-23 April 1970). This is a short time and needs to be remembered when judging results of any of the analyses. Following the work of Petrie and Drinkwater (1978) in analysis of much longer data series from St. Georges Bay in 1974, the circulation will be examined in separate frequency bands.

The comparison with St. Georges Bay is relevant for several reasons: the Bays are connected by the Strait of Canso, they are close enough geographically to be subjected to the same large weather systems, they have comparable surface areas, although Chedabucto Bay is somewhat deeper, and the tide ranges are similar although tide types do differ.

DATA PROCESSING AND ANALYSIS

The geostrophic winds calculated by Neu (1970, his fig. 3, with an extension into April being found in his Project Oil file) were digitized, then converted to 'reduced' geostrophic winds at 6-hourly intervals (using: rate x 0.5 + 9 knots, direction + 180°-20°).

Currents were converted to north and east components, then each of the 14 records was subjected to the following analyses to enable separation of the variance into three bands:

1. overall mean and total variance computed;
2. 1st low pass filter applied, Cartwright type, 55 weights, nominal cutoff at 0.6 c/h and data were decimated to hourly;
3. tides removed using results of standard 15-d harmonic analyses for essentially two semidiurnal and two diurnal constituents, variance removed in this operation was attributed to the tidal band;
4. 2nd low pass filter applied, Cartwright type, 55 weights, nominal cutoff at 0.07 c/h, and data were decimated to 6-hourly. Variance remaining after this operation was attributed to the low frequency band.

The variance estimate for the high frequency band could then be made (total-tidal-low). For each record, variances were combined for north and east components, then converted to rms velocity. Statistics of these velocities are given in Table 1 to show relative importance of the various frequency bands.

CIRCULATION

MEAN CURRENTS

The mean amplitude, 2.9 cm s^{-1} (Table 1), is half that in St. Georges Bay but note that the standard deviation is large. Due to the short lengths of the records, stability of the estimate from any record is low. Nevertheless, it is useful to look for spatial patterns of flow. In Fig. 2-4, mean vectors are shown at three different levels. There is a tendency for anticlockwise flow at all three levels, with a strong topographic influence evident from directions at Station 3 near the southern coast. The amplitude of this anticlockwise circulation is of order 3 cm s^{-1} near the boundaries, and taking the perimeter of the Bay to be about 60 km gives an estimate of flushing time for water to move from the northern entrance to the southern exit of about 23 d, assuming no recirculation. In the pre-Causeway era, water injected from the Strait would only have to traverse half the route to escape, so flushing time for these waters would be shorter. As a crude estimate of the effect of Strait outflow on mean currents in Chedabucto Bay, consider an outflow of 7.2 x 10^3 m^3 s^{-1} (Drinkwater 1979), confined to a cross-section half the width of the Bay (6 km) and occupying the top 20 m. Resultant velocity would be 6 cm s^{-1}, which might cause a noticeable reduction in flushing time.

Another source of steady flow in the pre-Causeway era might be tidal. Due to asymmetry

Table 1. Analysis of variance, Chedabucto Bay 1970 current meters.

Frequency	Period (h)	rms amplitude, cm s^{-1} ($\equiv \sqrt{\text{variance}}$) Average of 14 records	Standard deviation	Extremes minimum	maximum
15-d mean		2.9	±3.0	0.9	11.5
low	>15	8.2	±2.6	4.0	12.5
tidal	12,24	3.6	±0.5	2.8	4.5
high	<15	4.0	±1.8	2.2	7.4

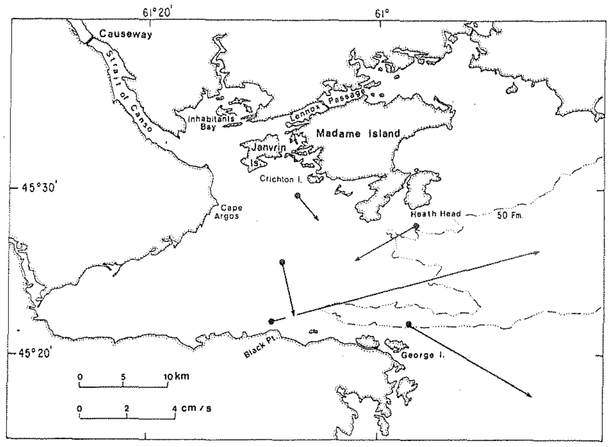

Fig. 2. 16-d mean currents at 3 m, Chedabucto Bay, April 1970. Scale such that distance covered by the current vector corresponds to $3\frac{1}{2}$-d average flow.

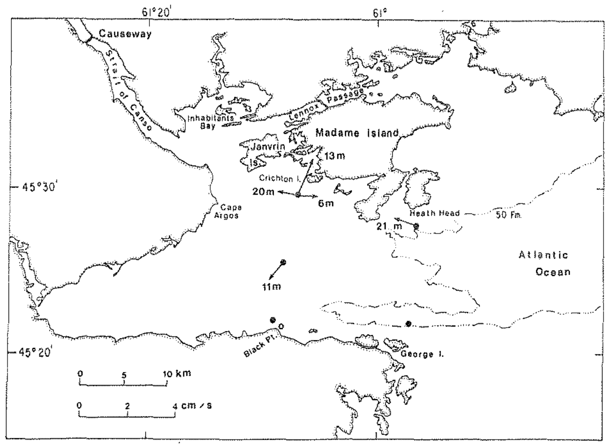

Fig. 3. 16-d mean currents at 6-20 m, Chedabucto Bay, April 1970. Scale such that distance covered by the current vector corresponds to $3\frac{1}{2}$-d average flow.

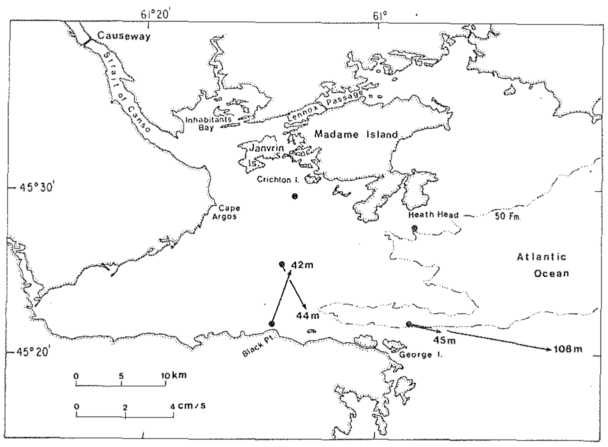

Fig. 4. 16-d mean currents at 42-108 m, Chedabucto Bay, April 1970. Scale such that distance covered by the current vector corresponds to $3\frac{1}{2}$-d average flow.

of ebb and flood flow patterns at the mouth of a strait, a tidally-averaged residual anticlockwise gyre can be formed, with amplitudes of 1-10% of the maximum tidal currents (Drinkwater 1979). Thus, strength of the gyre at either end of the Strait could have been of order 2-20 cm s^{-1}. Its size is unknown, and it might well have been confined to the immediate vicinity of the mouth of the Strait. Indeed, Fothergill (1954) makes reference to an anticlockwise circulation in Inhabitants Bay.

LOW FREQUENCY CURRENTS

This is easily the dominant band for Chedabucto Bay, in contrast to St. Georges Bay where the tidal band was slightly dominant. Mean energy level is comparable with that found for St. Georges Bay. Records from the outer stations (3-5) tend to have higher values, but there was no consistent behavior with depth.

To show the time sequence of low frequency events and relative importance of overall mean currents, the raw data have been displayed as progressive vector diagrams (Fig. 5-9). All are to the same scale except for Station 3 at 3 m depth. One factor common to all records is the absence of an immediately identifiable tidal signal. Three of the records are dominated by strong mean currents: Station 3 at 3 m, Station

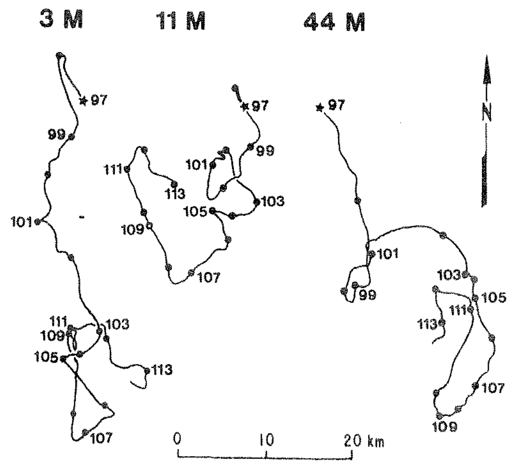

Fig. 6. Progressive vectors of observed currents at Station 2, Chedabucto Bay, April 1970.

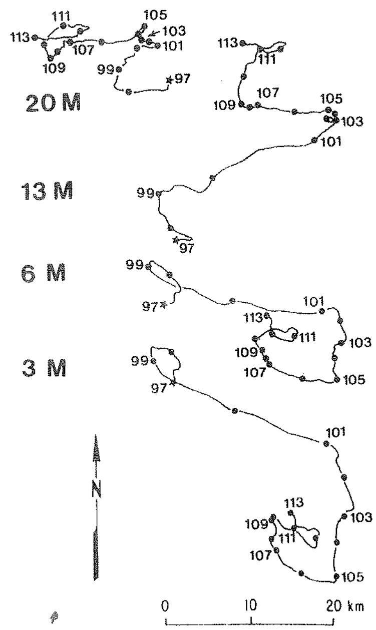

Fig. 5. Progressive vectors of observed currents at Station 1, Chedabucto Bay, April 1970.

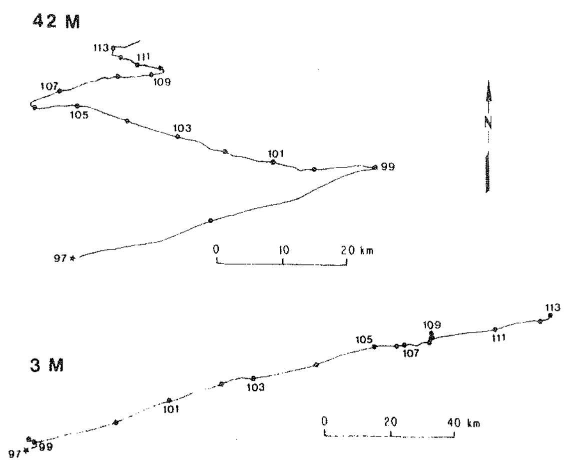

Fig. 7. Progressive vectors of observed currents at Station 3, Chedabucto Bay, April 1970.

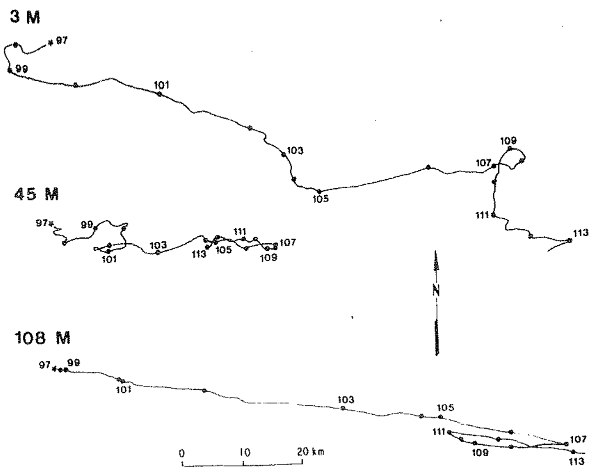

Fig. 8. Progressive vectors of observed currents at Station 4, Chedabucto Bay, April 1970.

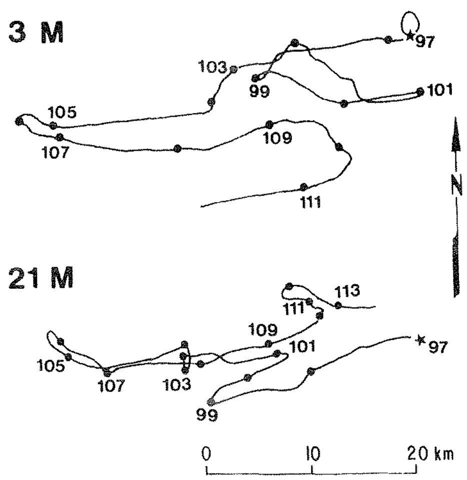

Fig. 9. Progressive vectors of observed currents at Station 5, Chedabucto Bay, April 1970.

4 at 3 m and at 108 m. The remainder of the records all show several abrupt direction changes. Records from a given station usually showed agreement in the times of these direction changes. Agreement between stations was poorer; in decreasing order, a direction change on day 101 was common to 4 of 5 stations, days 99, 109 and 112 were common to 3 of 5 stations. The sense of the direction change on a given day was not consistent horizontally or vertically. However, this can be due to effects of mean currents or bottom topography.

The progressive vector diagrams suggest, then, that low frequency currents are coherent vertically but not horizontally. Indeed, when the correlation coefficients were evaluated for like components of the low frequency current, vertical correlations were found to be generally high (0.7-0.9, significant at less than the 0.1% level) for records from 20 m and above, and considerably lower and sometimes negative for pairs in which one or both records came from below 20 m (Table 2). Correlations horizontally were generally low (<0.4) and often negative, similar to results for St. Georges Bay.

Low frequencies are considered to be due mainly to large-scale meteorological forcing over the continental shelf, and as such would be unaffected by any flow through the Strait of Canso. The intermittent nature of the forcing probably accounts for the low horizontal correlations, and means that flushing times vary over a wide range, and can become quite short during intense storms (see discussion under Events).

Correlation coefficients were evaluated between components of reduced geostrophic wind and low frequency currents (Table 2). They proved to be disappointingly erratic. No consistent patterns with depth, site, or component were found.

TIDAL CURRENTS

The tidal ellipse parameters were obtained from 15-d harmonic analyses for each of the constituents. Only the lunar semidiurnal constituent, M_2, was found to have a significant amplitude. At all sites, the ellipses were very flattened, amplitude ratios being always less than 1:4 and usually less than 1:10. Two notable features were constancy of the major axis amplitude over all records (mean velocity was 5.3 ± 0.8 cm s^{-1}) and constancy of the major axis direction (Stations 2 to 5 were within 90° ± 10°, while Station 1 was modified by topography to 120°). This suggests that all 14 instruments were operating well despite being in a relatively low current regime and undoubtedly being subjected to surface wave action.

The mean velocity corresponding to the tidal variance removed (3.6 cm s^{-1}, Table 1) was significantly less than that for St. Georges Bay. The M_2 tidal excursion corresponding to 5.3 cm s^{-1} is only 0.8 km, so tidal exchange should be small. For St. Georges Bay, Drinkwater (1979) finds a lower bound of 46 d for tidal mixing to remove 63% of the original bay water assuming a loss of one-third of the tidal volume per cycle. For Chedabucto Bay, the time would be expected to be considerably longer as volume is greater (x2) and tidal currents are less (x2). Thus, tidal exchange is considered to have a negligible effect on flushing the Bay. This conclusion would be expected to hold for the pre-Causeway era, too, as the tidal currents are expected to be virtually unchanged.

Table 2. Correlation coefficients, Chedabucto Bay, 6-23 April 1970.

Current data: low pass filtered tidal residuals, decimated to 6-hourly (48-64 data points) (r=0.32-0.37 is significant at 1%)

Stn.	Depth (m)	U components of current (90°) correlations: vertically	U correlations with wind: u	U correlations with wind: v	V components of current (0°) correlations: vertically	V correlations with wind: u	V correlations with wind: v
1	3		0.68	-0.25		-0.67	0.58
	3–6	0.97			0.85		
	6		0.66	-0.23		-0.54	0.30
	6–13	0.94			0.19		
	13		0.59	-0.29		0.41	-0.44
	13–20	0.79			0.68		
	20		0.57	-0.37		0.55	-0.63
	3–13	0.88			-0.18		
	6–20	0.71			-0.21		
	3–20	0.68			-0.45		
2	3		-0.11	-0.01		-0.19	0.47
	3–11	0.82			0.75		
	11		-0.08	-0.20		0.02	0.18
	11–44	0.05			0.57		
	44		-0.06	-0.30		0.50	-0.20
	3–44	0.08			0.30		
3	3		0.77	-0.53		0.57	-0.23
	3–42	-0.60			-0.22		
	42		-0.53	0.32		-0.36	-0.16
4	3		0.04	0.18		-0.48	0.76
	3–45	0.12			-0.38		
	45		-0.14	-0.20		-0.11	-0.13
	45–108	0.56			0.01		
	108		0.06	-0.36		0.07	-0.04
	3–108	0.40			-0.11		
5	3		0.15	0.43		-0.22	0.30
	3–21	0.92			0.14		
	21		-0.06	0.48		0.34	-0.13

HIGH FREQUENCY CURRENTS

There was a tendency for velocities to decrease with depth and to be less at inner stations (1, 2). A possible contributor to the estimates would be seiche activity, the fundamental resonance for Chedabucto Bay having a period of about 2½ h (Barber and Taylor 1977, based on tide gauge and numerical model data). Neu (1970) found such activity in currents in Lennox Passage and at the anchor station north of Station 1.

Another source of energy would be wind stress. In St. Margaret's Bay, the high frequency current variance was found to be related to wind stress, the relation being stronger when the wind had a longer fetch (Therriault et al. 1978).

In St. Georges Bay, the high frequency currents were found to be unimportant for flushing water out (Petrie and Drinkwater 1978) and this would be expected to be true also for Chedabucto Bay. The Canso Causeway would have no significant effect on these currents.

EVENTS

That currents were incoherent horizontally and seemingly uncorrelated with wind does not mean necessarily that meteorological forcing was unimportant. Likely it was due to the intermittent nature of the forcing. In this frequency band (1-15 d) the data are perhaps best scanned for events. To this end, reduced geostrophic wind and low frequency currents were plotted as time series of vectors (stick diagrams, Fig. 10-14). Axes for the data were chosen at each site to make most current vectors lie perpendicular to the time axes for clarity. The time axis for the wind plot was arbitrarily chosen eastward. Examination of all records showed that events in winds and currents might coincide during three time periods: days 98-101, 105-108, and 110-111. Of these, the middle period - days 105-108 - was the most common, with coincident events occurring in 11 of 14 records. Some idea of the spatial flow pattern resulting from steady wind forcing can be obtained from numerical modelling.

A numerical model (Baird et al. 1976) predicts currents in Chedabucto Bay for 20 knot winds from two directions. Values for the five current meter sites are given in Table 3. Although currents are vertically averaged in the model and so may not be very realistic, nevertheless the spatial complexity of response to a uniform wind field is demonstrated. Further comparison with the observed wind-current correlations of Table 2 was not possible due to the use of different axes.

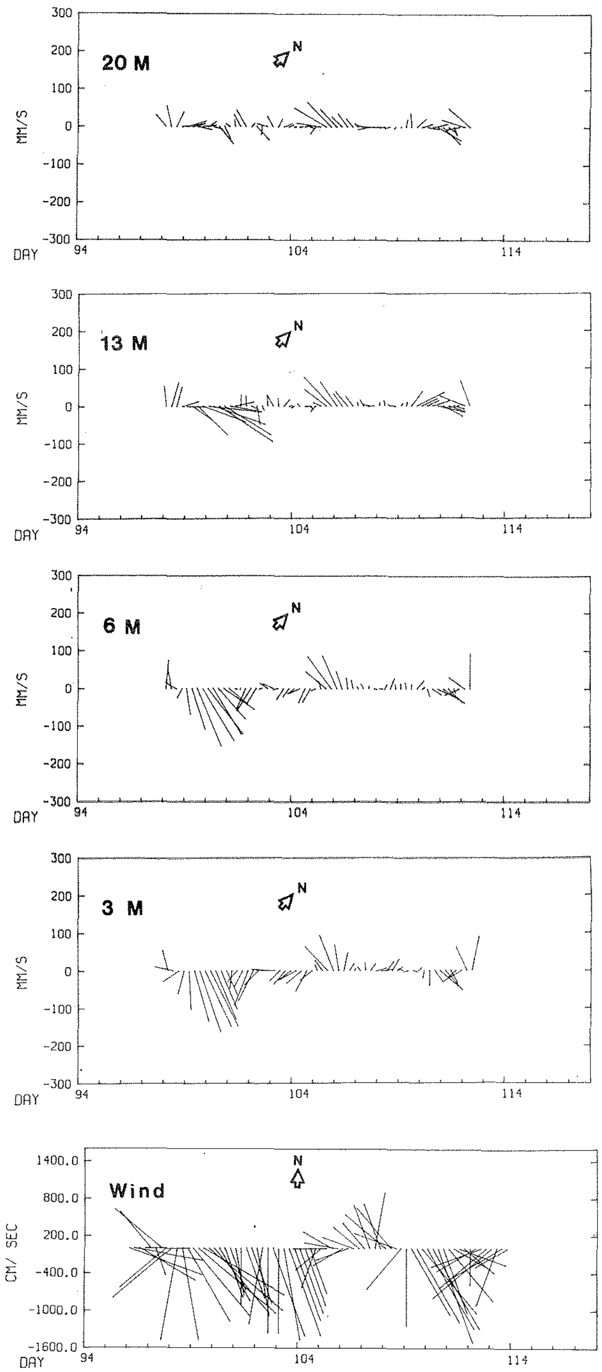

Fig. 10. Vector time series of low frequency observed currents at Station 1 and the reduced geostrophic wind, Chedabucto Bay, April 1970. The north arrow indicates axis orientation.

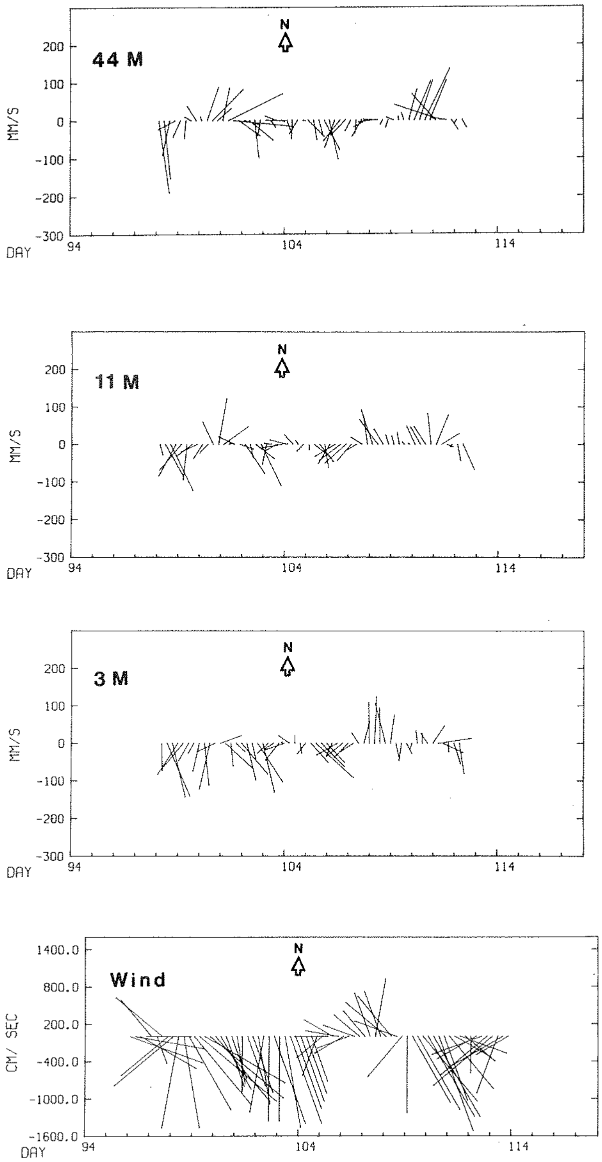

Fig. 11. Vector time series of low frequency observed currents at Station 2 and the reduced geostrophic wind, Chedabucto Bay, April 1970. The north arrow indicates axis orientation.

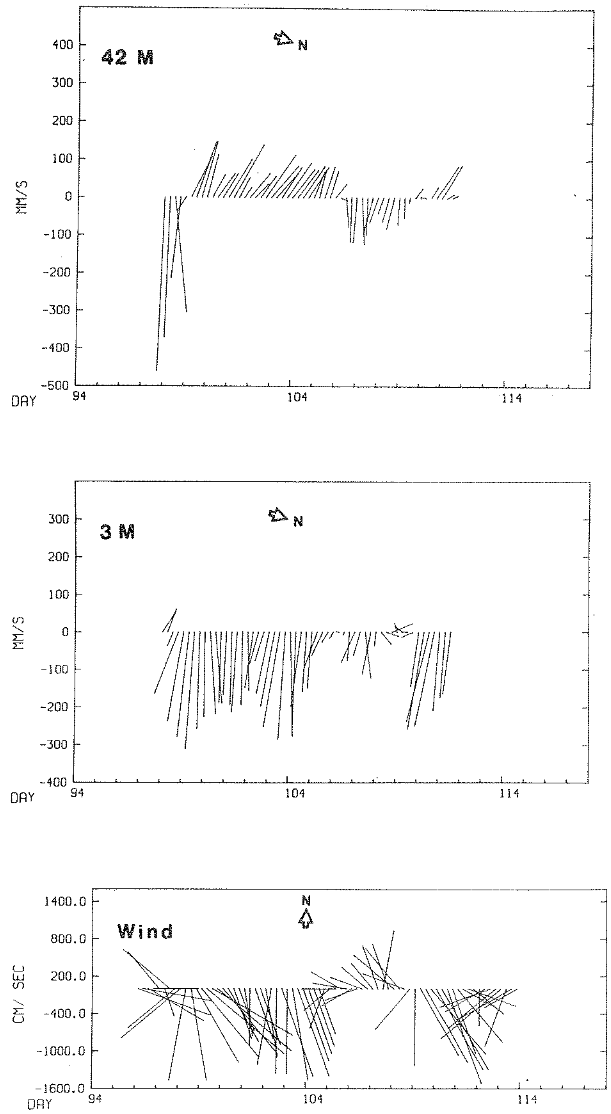

Fig. 12. Vector time series of low frequency observed currents at Station 3 and the reduced geostrophic wind, Chedabucto Bay, April 1970. The north arrow indicates axis orientation.

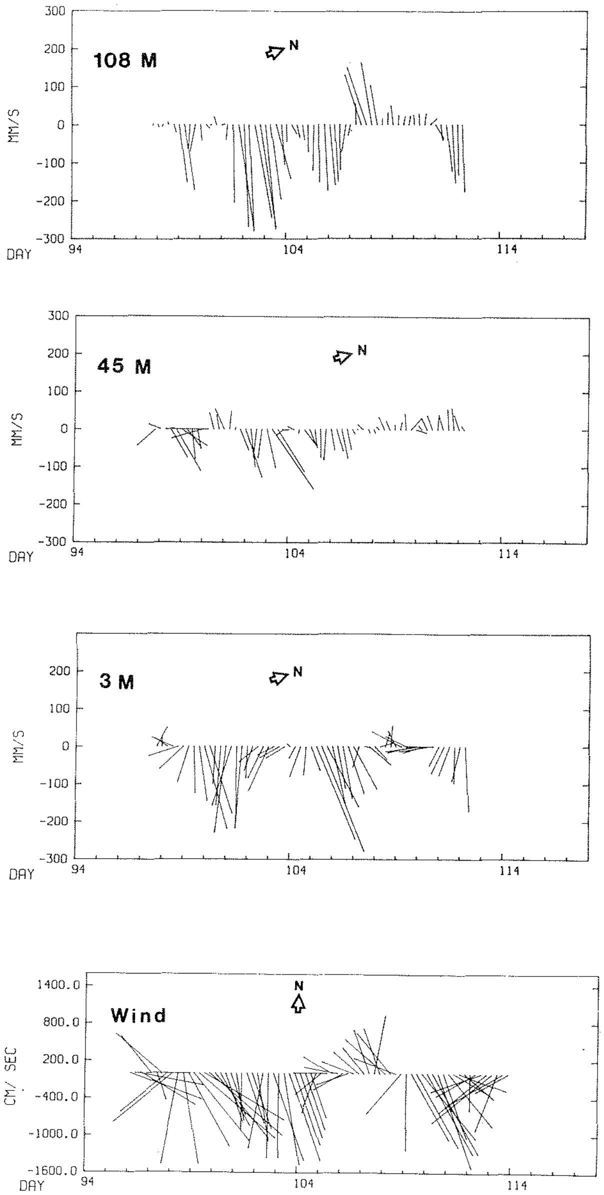

Fig. 13. Vector time series of low frequency observed currents at Station 4 and the reduced geostrophic wind, Chedabucto Bay, April 1970. The north arrow indicates axis orientation.

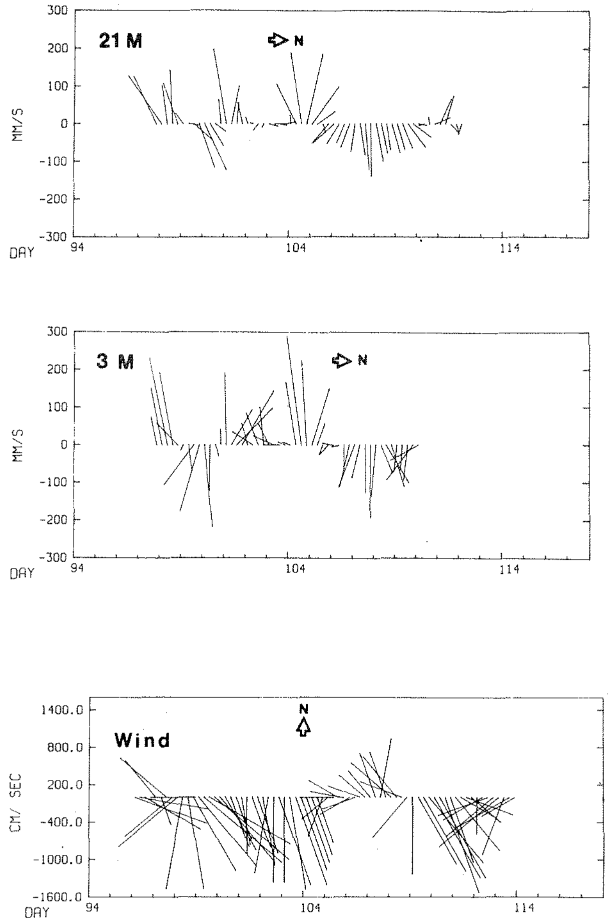

Fig. 14. Vector time series of low frequency observed currents at Station 5 and the reduced geostrophic wind, Chedabucto Bay, April 1970. The north arrow indicates axis orientation.

Table 3. Chedabucto Bay wind-driven currents as predicted by MEDS numerical model.

	Predicted current, vertically averaged, from grid points surrounding the current meter sites			
	wind toward NW at 20 knots		wind toward SE at 20 knots	
Current meter station	Current speed (cm s^{-1})	Current direction	Current speed (cm s^{-1})	Current direction
1	20	NW, W	20	E, S
2	7	SE	10	NW
3	10	NE	7	SW
4	7-40	NW	7	E, SE
5	10	SW, NW	10	NE, SE

NUMERICAL MODELS

Two models were developed during the project done by the Department of Public Works for Transport Canada (Baird et al. 1976; Barber and Taylor 1977). The larger of these models (due to the Marine Environmental Data Service) covered all of Chedabucto Bay and the Strait of Canso, was two-dimensional, time-dependent, and was driven by wind and tide heights. The resolution was only 0.75 km, just the width of the Strait. Wind impulse forcing was used to excite resonances and spectral analysis to determine their frequencies. The model showed that in Chedabucto Bay, the vertically averaged velocities produced by wind forcing could equal the tidal velocities (see under Events).

The second model (due to NRC) covered the Strait from the Causeway to the beginning of Chedabucto Bay at Cape Argos. The resolution was better, about 0.27 km, but wind forcing was not included. The model showed strong tidal flows around the extremities of Janvrin Island and in the channel leading to Inhabitants Harbour.

DENSITY

Temperature and salinity were measured at anchor stations at the ends of the current meter section lines (Neu, unpublished data, his Project Oil file). The data (Table 4) show that generally a three-layer structure was present with interfaces at about 4 and 9 m. Temperatures were in the range 0-2°C, salinities 30-31 o/oo, and densities 24-25 σ_t. The density structure was dominated by salinity. When density structure was present, the density difference between upper and lower layers was in the range 0.2-1.0 in σ_t. Often there was as much change in structure between successive hourly profiles as between sites or between daily occupations of the same site. Wind mixing and seiche activity were clearly important. Analysis of the currents showed appreciable high frequency energy (Table 1). Low frequency currents were well correlated in the top 20 m, and poorly correlated across or below 20 m. However, the TS measurements did not extend below 20 m so the possibility of another interface could not be investigated.

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Table 4. Temperature-salinity anchor stations, Chedabucto Bay, April 1970. Data due to Neu, unpublished, Project Oil file. Sampling interval = 1 h.

Day	Site	Nearest current meter station	Duration (h)	Tide range (m)	Density structure layers	Density structure interface depths (m)	Deepest measurement (m)	Structure behavior with time	Comments
11	Crichton I.	1	12	1.1	1	-	11	smooth	well mixed
	Black Pt.	3	12	1.1	3	2,9	18	irregular	
15	Crichton I.	1	13	0.6	3	2,6	10	irregular	
	Black Pt.	3	13	0.6	3	5,9	13	irregular	
16	Heath Hd.	5	20	0.6	2	5	11	irregular	
	George I.	4	20	0.6	2 to	8	18	irregular	
					4	2,8,13		irregular	
17	George I.	4	12	0.8	2	5	12	smooth	$\Delta\sigma_t$ small
21	Crichton I.	1	12	1.5	3	3,9	13	irregular	
	Black Pt.	3	12	1.5	2	6	24	smooth	
22	Heath Hd.	5	12	1.5	1	-	13	smooth	well mixed
	George I.	4	12	1.5	3	5,13	16	iregular	

DISCUSSION

Cook: Do we have any information on water current patterns towards Louisburg?

Lawrence: No, just rough estimates based on averages.

Stasko: Is there an eddy on the south shore of Cape Breton Island?

Lawrence: We have little data as there has been no detailed oceanographic study.

Ford: Satellite photography has been used for tracking movement of oil in the water column in February and March following the *ARROW* oil spill. A band of oil 10 mi wide was visible between Chedabucto Bay and Halifax.

Stasko: The question about the presence of an eddy off Cape Breton Island is crucial to Robinson's report on lobster populations.

Drinkwater: Kumbhare has made a pertinent contribution for the period 1968-70 in his "Strait of Canso Water Quality Model" report tabled at this workshop. Table 4 indicates that mean currents for 15-30 d at a depth of 10-13 m was 1 cm/s at the mouth of the Strait toward Chedabucto Bay. Flow can be unidirectional for several days. This likely occurs when tidal flow is overcome by the effect of storms on the shelf. This same effect can be observed in Halifax Harbour. Department of Public Works' data show that this phenomenon can occur during any season.

Cook: What information is available from the Isle Madame area?

Lawrence: There is some information collected in connection with closing of the area at the time of the oil spill. Chedabucto Bay, for example, has a resonance time of 2 h. Apparently, there can be a net current towards the Causeway under certain circumstances that would be significant in terms of pollution transport.

Muir: Was this damped out prior to construction of the Causeway?

Lawrence: The resonance of Chedabucto Bay would be virtually unchanged. Velocities due to resonance in the Strait would be altered due to the increased length and lack of barrier for reflection in the pre-Causeway era. Flow patterns within the Strait (in response to storms, etc. in excess of several days) might be expected to be different in the pre-Causeway era. This phenomenon is not well understood at present.

Ford: Could closing of Lennox Passage in the spring of 1970 have had any effect?

Lawrence: Closing of Lennox Passage would have had local effects on circulation, but the Passage is small and effects would be localized.
The survey carried out by the Department of Public Works for the Department of Transport was primarily for engineering purposes and does not include Chedabucto Bay. The report contains tide gauge measurements and numerical model studies and confirms the occurrence of oscillations.

OBSERVATIONS ON PARTICLE DISTRIBUTION IN THE STRAIT OF CANSO AND VICINITY

by

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ABSTRACT

Kranck, Kate, and R. W. Sheldon. 1979. Observations on particle distribution in the Strait of Canso and vicinity. Fish. Mar. Serv. Tech. Rep. 834.

Observations on suspended particulate matter show normal open coastal distributions of plankton and sediment in Chedabucto Bay. In the Strait of Canso east of the Causeway the particulate matter consisted mostly of particles of industrial pollutants which appeared to have affected the plankton distribution. On the west side of the Causeway normal plankton distributions occurred. Bottom sediments in the Strait of Canso are bimodal; a silt mode represents the fine sediment now being deposited and a coarse sand mode is relict from the pre-Causeway strong current conditions.

Key words: Suspended matter, sediment structure, plankton, industrial wastes, benthic sediment, Canso Strait, causeway

SUSPENDED PARTICULATE MATTER

METHODS

The distribution of particles in suspension in the Strait of Canso and Chedabucto Bay was surveyed during the periods March 9-13 and April 27-May 8, 1970. This was shortly after the wreck of the oil tanker *ARROW* on February 4, 1970. A year later, on July 15, near surface samples from both sides of the Canso Causeway were collected.

The size distribution of the suspended particulate matter was measured with a model T Coulter Counter immediately following collection of the sample. A logarithmic particle size range from 1 μ to 100 μ was considered in terms of particle concentration (Sheldon and Parsons 1967a, b). This included most of the nano- and phytoplankton and non-living particles of similar size. We were, therefore, concerned primarily with particles of a size such that they formed the initial stages of the marine food web. One-liter samples were also drawn onto membrane filters and dried for qualitative microscopic examination.

RESULTS

In March the size frequency characteristics of the suspended matter in the open waters of Chedabucto Bay were what we would have expected in a temperate rocky coastal environment in early spring (Fig. 1). There was a general low background concentration of particles of all sizes which included organisms, inorganic material and organic detritus. In the surface waters a development of phytoplankton (mainly diatoms) caused a distinct peak in the 30- to 100-μ size range. At a depth of about 50 m there was a particle minimum layer with a low total concentration and no well defined peak. Below 50 m, particle concentrations were greater with a broad peak in the size range 1-20 μ. This was mainly flocculated inorganic sedimentary material.

Size-frequency distribution profiles of the type described above were found everywhere except for two stations in the Strait of Canso and one in the western part of Lennox Passage (Fig. 1). In the Strait of Canso the size spectra were dominated by greasy looking grey coloured particles. These were probably industrial and domestic pollutants. Similar abundances of very small particles have been measured in samples of pulp and paper effluent and these are not found naturally under open marine conditions (Kranck 1974, and pers. obs.). The changes in the size spectra in the western part of Lennox Passage were caused by oil particles which had dispersed downwards into the water beneath a surface oil slick.

On average, total particle concentrations in the Bay were about 1 ppm (by volume) at the surface, decreasing to about 0.3 ppm at 50 m,

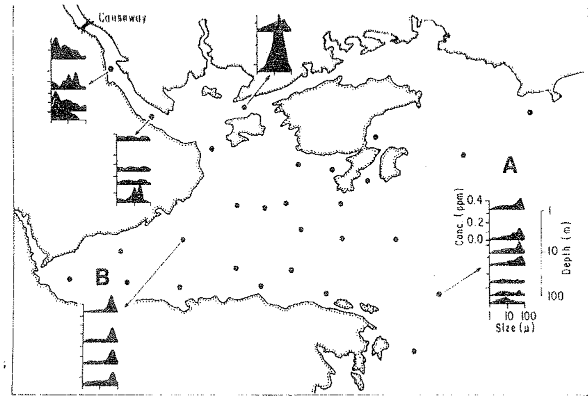

Fig. 1. Sample stations and particle size distributions March 9-13, 1970. Distribution profiles were either of form A in deep water or B in shallow water at all stations except those indicated.

then increasing to about 0.5 ppm near the bottom. In the western part of Lennox Passage the concentration of particulate material was 5.0 ppm at a depth of 10 m.

In April and May the size-frequency distribution profiles were generally similar to those of March, but some noticeable changes had occurred. The distribution of particle spectra was less uniform (Fig. 2). In the surface waters the 30- to 100-μ peak did not always occur, and when it did it was rather broader than it was in March. There was less evidence of stratification. The 50-m particle minimum

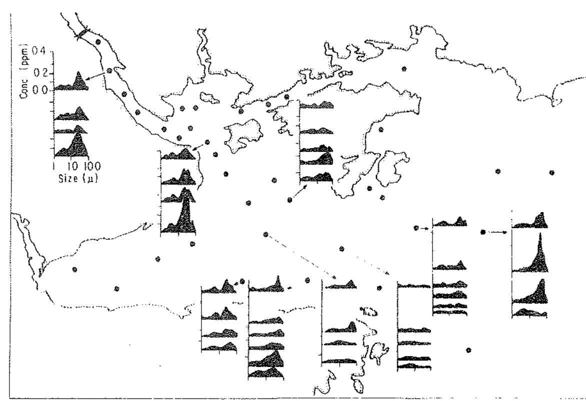

Fig. 2. Sample stations and selected size distributions April 27-May 8, 1970. Note that in contrast to Fig. 1 most profiles were not similar. Those illustrated were selected to show the variation encountered.

could not always be found and at some stations well out into the Bay typically "surface" spectra were found in samples taken near to the bottom. In those samples diatoms were common. Clearly, in the interval between surveys the bloom had declined and some vertical mixing of particulate material had occurred. Water from the Strait of Canso could still be recognized by its particle spectra, but less easily than in March. It tended to spread into the Bay to a greater extent than it did earlier.

In June 1971 particle spectra of industrial effluent were again present in the Chedabucto Bay side of the Strait of Canso (Fig. 3). West of the Canso Causeway the particle concentrations were low and the spectra had the even featureless shape often found in midsummer in coastal waters.

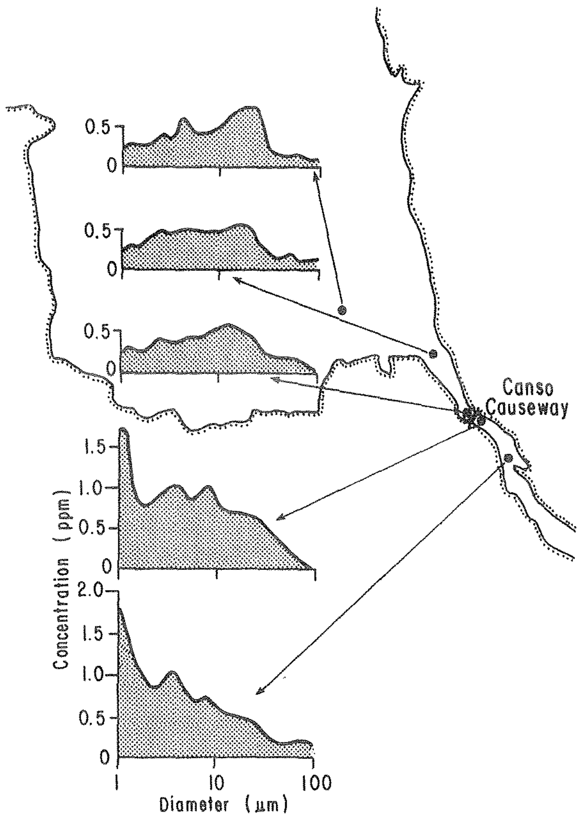

Fig. 3. Particle size distribution at near surface July 15, 1977.

DISCUSSION OF OBSERVATIONS OF SUSPENDED MATTER

We were able to recognize, sometimes very easily, discrete water masses by their characteristic particle spectra. The situation was clearest and easiest to understand in March when the water was stratified, with phytoplankton near the surface and inorganic sedimentary material near the bottom. Later in the spring, some vertical mixing occurred and the phytoplankton was dispersed downwards. The sinking of diatoms, following the spring flowering, may not be unusual in April on the coast of Nova Scotia, as Platt and Subba Rao (1970) also observed this in 1969.

We could not detect any short-term direct effects of the oil on the natural particles in the Bay. The concentration of small particles was low and relatively constant, and this seems to be a normal occurrence. The diatom bloom also seemed to develop and die away normally although the average concentration of cells seemed very low. We would have expected an average concentration of around 5-10 ppm instead of the average of about 1 ppm that we actually found. Platt and Subba Rao (1970) give values of particulate carbon for St. Margaret's Bay (about 150 miles S.W. of Chedabucto Bay) which indicate volume concentrations up to about 4 ppm during the 1969 bloom. However, as we have no earlier data for Chedabucto Bay, we do not know if these low values are normal or abnormal.

Oil particles were recognized in most of the filtered samples but, except in those samples taken under and around oil slicks, oil particles were never abundant. In most of the samples no effect of the oil particles on the form of the particle spectra could be detected. From this, and from the microscopic examinations, we concluded that the oil particles must have accounted for less than 10% of the total particulate material.

The particle distributions in the Strait of Canso during March were remarkably different from the rest of the survey area. There was no sign of diatoms either in the particle spectra or in the microscopic preparations. The innermost of the two stations was dominated by effluent particles. Most samples from the outer station contained similar volume concentrations of particles in every size class forming nearly flat spectra. Such spectra have been found in waters from which particles were settling out of suspension during flocculation (Kranck unpubl.). The absence of a diatom bloom in these waters seems to indicate that diatom growth was inhibited there.

The presence of effluent particles in June 1971 showed that the March 1970 pattern was not an isolated occurrence. The absence of what seems to be normal plankton populations could indicate that the plankton is either replaced or inhibited by particulate material of industrial origin. This could have a pronounced effect on primary production in the Strait of Canso. The effect on Chedabucto Bay as a whole is impossible to predict.

BOTTOM SEDIMENT: OBSERVATIONS AND DISCUSSION

Studies of sediment distribution in Northumberland Strait showed a close correlation between grain size and current speed (Fig. 4). No detailed current measurements are available from the Strait of Canso-Chedabucto Bay area but current speeds are generally low (Lawrence et al. 1973). The mud at present being deposited in Chedabucto Bay (La Have Clay of Maclean et al. 1977) is probably dynamically and structurally identical to the mud in Northumberland Strait (Pugwash Mud of Kranck 1971).

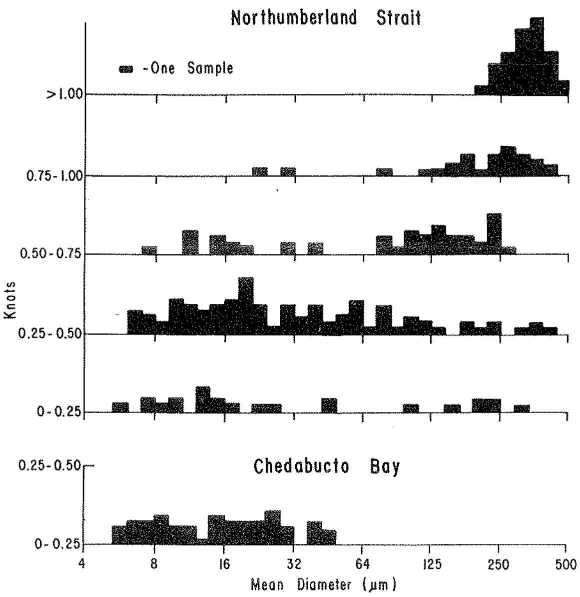

Fig. 4. Medium grain size of bottom sediment with less than 3% gravel in Northumberland Strait and Chedabucto Bay (inc. Strait of Canso). Northumberland Strait data from Kranck (1972). Chedabucto Bay samples from study of Maclean et al. 1977 and Fader, pers. comm.).

In the Strait of Canso mud deposition has occurred since the building of the Causeway and forms a discontinuous veneer on top of older coarse pre-Causeway sediment (Maclean et al. 1977). Grain size spectra of bottom sediment are bimodal and illustrate pre- and post-Causeway dynamic conditions (Fig. 5).

Modification or removal of the Causeway would lead to deposition of sediment with grain size in equilibrium with the new current regime. Some erosion and resuspension of the present mud

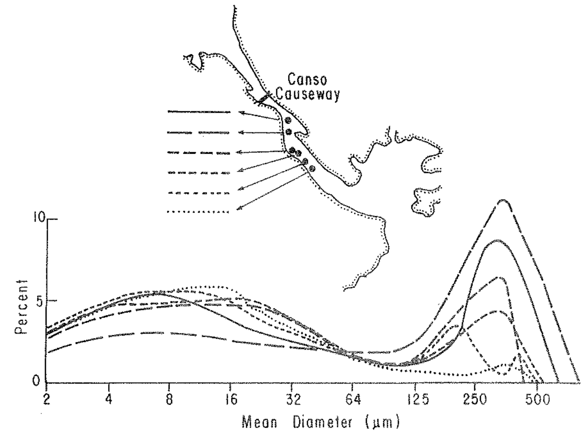

Fig. 5. Grain size spectra of bottom sediment in Chedabucto Bay. Samples collected by G. Fader (pers. comm.) and analyzed with a Coulter counter assuming a density of 2.65 for 100% of the inorganic sample volume.

would be expected. It is noteworthy, however, that Fader et al. (1977) and Amos (1978) have shown that coarse sediments in the high current environment of Bay of Fundy and Minas Basin are underlain by fine muddy material. This was not eroded away when the present tidal regime was established. Mud is more difficult to erode than coarser particles (Hjulstrom 1935) and the muddy bottom in the Strait of Canso could persist until coarser sediment was deposited on top of it.

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SUSPENDED AND SEDIMENTED PARTICULATE MATTER IN ST. GEORGES BAY

by

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ABSTRACT

Hargrave, B. T. 1979. Suspended and sedimented particulate matter in St. Georges Bay. Fish. Mar. Serv. Tech. Rep. 834.

Temperature and plant pigment measurements in surface water along transects normal to shore in St. Georges Bay during 1976-77 indicated the temporary formation of a nearshore chlorophyll rich coldwater zone. Sedimentation of dry matter, plant pigments, organic carbon and nitrogen were highest inshore. Depth-dependent differences in absolute amounts and organic composition of deposited material imply extensive resuspension and horizontal movement of previously settled particulate matter.

Key words: Pigments, chlorophyll, sedimentation, suspended matter, organic carbon, St. Georges Bay

INTRODUCTION

Measurements of chlorophyll *a*, particulate carbon and nitrogen in suspended and sedimented particulate matter in St. Georges Bay along an onshore-offshore transect were made during 1976 to provide a basis for considering the overall biological production cycle in the Bay. These observations were continued during 1977 to include measures of phytoplankton primary production and nutrient concentrations. The seasonal and spatial distribution of particulate matter derived from biological production is assumed to reflect availability of food for pelagic and demersal larval fish. The general aim of the study is to describe and predict how physical and biological variables interact to determine the nature and concentration of particulate organic matter in the water column and at the sediment surface.

SUMMARY OF WORK COMPLETED

The existence of nearshore enrichment of pigments from phytoplankton and benthic macro-algae in St. Georges Bay was examined by collecting suspended material along two transects normal to shore off Crystal Cliffs and Ballantynes Cove (Prouse and Hargrave 1977). Maximum chlorophyll *a* concentrations occurred during August along both transects with a sharp decline during September. Nearshore gradients of increased chlorophyll concentration occurred along both transects during June. The enrichment intensified during early August and then spread to offshore areas.

Sediment traps suspended at various depths at two locations (14 m and 33 m bottom depth) along the transect off Ballantynes Cove demonstrated differential supply of freshly produced organic matter to sediments in shallow and deep water. Maximum chlorophyll *a*, carbon and nitrogen content in settled material occurred between 20 and 25 m during June at the offshore station. Equivalent high concentrations appeared in material deposited immediately above the bottom inshore during July. There were also marked differences in organic content of material deposited at different depths throughout the summer at the deep central bay station, while organic matter in material settled at different depths in shallow water tended to be similar. Absolute sedimentation rates of dry matter, carbon, nitrogen, chlorophyll *a* and phaeophytin were 2-3 times higher inshore than offshore although depth-dependent differences occurred at both locations. Mean daily rates of carbon deposition are similar in magnitude and variation with depth to data collected in other coastal marine bays (Table 1).

Carbon:nitrogen ratios in material deposited in sedimentation traps provided evidence of periodic resuspension of bottom

Table 1. Particulate carbon deposition derived from annual or seasonal studies in different marine environments (modified from Hargrave et al. 1976; Prouse and Hargrave 1977).

Location	Bottom depth (m)	Trap depth (m)	mg C m^2 day
St. Georges Bay June-Sept. 1976			
Stn. 13	14	8	180.9
		11	228.9
		13	269.9
Stn. 7	33	20	60.9
		25	60.6
		30	125.7
Bedford Basin Annual 1973-74		20	150.7
		60	207.3
St. Margaret's Bay 1971		13	323
		65	367
Lock Ewe (U.K.)	25	18	82.2
Kiel Bight (Baltic)	25	24	109.6

deposits even during periods of stratification. Ratios were generally between 5 and 8 for material settled at different depths inshore - indicative of a fresh biological origin. Values of 10-12 were common in material settled in deeper water. Resuspension of previously deposited material and subsequent sedimentation are the most probable causes for enhanced deposition. These events appear to occur most frequently at shallow depths, where surges from surface waves may reach bottom to resuspend freshly settled particulate matter. Increased deposition also occurs at 30 m offshore, however. Sediments in these regions are thus either resuspended in a similar fashion or transported horizontally by advective and turbulent near-bottom flow. In either case, these differences in sedimentation indicate non-homogeneous conditions of deposition at different depths that imply movement of sedimented particulate matter in both inshore and offshore areas.

SYNOPSIS OF WORK DURING 1977

Sampling that began during May and was completed in November was concentrated along the 8-station transect off Ballantynes Cove. Weekly measurements of temperature, dissolved nutrients, salinity, phytoplankton primary production, plant pigments, carbon and nitrogen in suspended and sedimented material were made at a nearshore and offshore station at various depths. The results show the formation of regions of high plant pigment concentration nearshore during early summer and late fall with more homogeneous concentrations along the transect during August. Weekly measurements of *in situ* phytoplankton production integrated through the water column at each station between May and October, however, were not significantly different. Thus, because of depth differences between the two stations, phytoplankton production per unit volume at the more shallow nearshore location was approximately 40% higher than that occurring offshore. These differences and their relation to the vertical distribution of dissolved nutrients and sedimentation will be discussed in detail elsewhere.

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Prouse, N. J., and B. T. Hargrave. 1977. Chlorophyll, carbon, nitrogen in suspended and sedimented particulate matter in St. Georges Bay, Nova Scotia. Fish. Mar. Serv. Tech. Rep. 721, 69 p.

DISCUSSION

Scarratt: Referring to the sediments you were speaking about in St. Georges Bay - is there a possibility of non-natural events contaminating the results?

Hargrave: Yes, trawlers.

Scarratt: My experience has shown that downstream of scallop draggers the bottom 10-15 ft may be like pea soup.

Hargrave: The activity of draggers could be considered an important geo-chemical event. The effect on scallops could be significant, although fauna may be accustomed to being covered with a film of sediment.

Scarratt: Perhaps not at the time when they normally feed.

Stasko: Fine sediment may have an effect on young lobster but the critical level is not known.

Hargrave: Turbidity increases as summer progresses due to storms and particulate matter production in St. Georges Bay.

Scarratt: Clearer water exists below the thermocline, however.

Hargrave: Not always. Attenuance meter measurements we have made show that near bottom layers of high turbidity may occur regularly, even during periods of stratification.

COMMENTS ON RESIDUAL CURRENT PATTERNS IN THE INSHORE AREA SOUTH OF CAPE BRETON ISLAND

by

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ABSTRACT

Trites, R. W. 1979. Comments on residual current patterns in the inshore area south of Cape Breton Island. Fish. Mar. Serv. Tech. Rep. 834.

Based on returns of drift bottles and sea bed drifters, it appears that the inshore surface water is primarily supplied from Cabot Strait. However, some evidence suggests that flow along the south coast of Cape Breton Island may at times be directed to the northeast, particularly during spring and summer months, before the effects of the spring freshet from the St. Lawrence drainage basin have reached the Scotian Shelf.

Key words: Drifters, freshwater outflow, water currents, surface water, Cabot Strait, Scotian Shelf, Cape Breton

INTRODUCTION

At the Canso Strait Workshop held in November 1977, interest was expressed in having available data on currents for the region along the southern coast of Cape Breton Island examined to see whether sufficient information was available to shed light on residual current patterns. While the broad pattern of circulation (Fig. 1) indicates that water flows out of the Gulf of St. Lawrence and subsequently a major portion is transported southwestward along the Scotian Shelf, on a smaller scale the current pattern might be significantly different. A northeastward flowing current inshore along the Cape Breton coastline appeared to be a possibility. Accordingly it was agreed to look at the drift bottle and seabed drifter database held by the Biological Station in St. Andrews to see if it would shed light on this circulation question.

AVAILABLE DATA

The inventory of the St. Andrews drifter database has been reported by White and Akagi (1974). They summarized releases and recoveries by defined release areas (Fig. 2). A magnetic tape was prepared for all recoveries made in the 1960-73 period. A copy is on file at the Marine Environmental Data Service (MEDS), Ottawa, and has been utilized in preparing this report.

Besides the St. Andrews' database covering the period 1960-73, releases were made by the Biological Board of Canada in 1922 and 1924, and by the Defence Research Establishment Atlantic in 1957. These will be discussed as well.

RESULTS

For the St. Andrews' database, the area of particular interest is referred to as "Eastern Scotian Shelf" by White and Akagi (1974). A total of 662 bottles were released over the period 1962-67. Only 20 were subsequently returned (3%); 2265 seabed drifters were released between 1962 and 1969 and 183 recovered (8%). Percentage returns were much lower for this particular area than for the whole region (19% and 25% for drift bottles and seabed drifters respectively).

Although the release pattern was not examined in detail, apparently most releases were made over the offshore banks, and hence would be of limited value in developing a current pattern for the inshore region. It was thought useful, however, to look at the pattern of recoveries made along the inshore region and see where they had been released. In this way one might gain some idea about the source of surface water, and if sufficient data existed determine whether there were significant differences in source waters and in their times of arrival along different parts of the coastline.

The release point and straight-line trajectory were plotted for all recoveries made within the rectangle bounded by 45°N and 46°N latitude lines and by 59°W and 62°W longitude lines (Fig. 3). One plot was prepared for each year for drift bottle recoveries and similarly for seabed drifters for the 1961-73 period. As examples the year 1966 was chosen for drift bottles and 1963 for seabed drifters (Fig. 4, 5).

Excepting 1961, all drift bottle recoveries were from releases made in Cabot Strait or the Gulf of St. Lawrence. Bottles were recovered all along the coastline, and no clear pattern of recovery was apparent.

The pattern for seabed drifters as indicated in Fig. 5 appears to be significantly different from the drift bottles in their "source" distributions. While Cabot Strait and the Gulf of St. Lawrence were principal source areas, a significant number came from Eastern Scotian Shelf releases. In terms of local patterns of recovery, relatively few were found in Chedabucto Bay.

About 550 bottles were released on June 8, 1922, along a line running across the Scotian Shelf from Cape Canso. Approximately 16% were returned. The recovery pattern is shown in Fig. 6. For those released within 35 miles from Cape Canso, most recoveries came from the Nova Scotia coastline. Spreading was both northeastward and southwestward from the release line, with proportionately more of the inshore releases moving northeastward, and those released in the 15- to 35-mi zone stranding southwestward of the Section Line.

Between July 8-15, 1924, releases were made along three sections: one off Cape Canso, one to the southwest, and one to the northeast (Fig. 7). The recovery pattern suggests that the flow was eastward. Releases were made a second time on the Cape Canso line on August 1, 1924 (Fig. 8). This time the recovery pattern was totally different from that of the earlier release. The "classical" picture of the Scotian Current was revealed.

Between May 29 and June 24, 1957, 1427 drift bottles were released at a network of stations over the Scotian Shelf (Fig. 9); 131 were subsequently returned. The inferred drift, based on these releases, is shown in Fig. 10. There were no returns from along the Cape Breton Island coastline (except for one from Scatarie Island, released nearby). There is no evidence that a Scotian Current was even present during this period. The flow appeared to be eastward over nearly all the Shelf.

DISCUSSION

Although available data suggest that the Gulf of St. Lawrence and Cabot Strait areas are the main source water regions for inshore waters along the southern Cape Breton Island shoreline, some evidence suggests that the inshore flow between Cape Canso and Louisburg is north-easterly at times. If the Scotian Current is considered to be primarily driven by freshwater outflow from the Gulf, then it should be at a minimum during late spring and early summer, since the spring freshet from the St. Lawrence system would not normally reach the Shelf before August or September. Thus, the easterly drift of bottles occurred at a time when freshwater outflow from the Gulf of St. Lawrence onto the Scotian Shelf was probably relatively weak. Some evidence for a clockwise gyre south of Cape Breton Island is given by Ingram (1972). He studied the surface currents around Cape Breton Island by tracking ice fields during the winters of 1964 and 1965 as shown in Fig. 11.

CONCLUSION

Examination of available drift bottle and seabed drifter data suggests that the inshore surface water is primarily supplied from the Cabot Strait area. Based on seabed drifter returns, significant upwelling appears to occur along much of the coastline, but is minimal in Chedabucto Bay.

There is some evidence suggesting that flow along the coast may at times be directed to the northeast, particularly during spring and summer months, before the effects of spring freshets from the St. Lawrence drainage basin have reached the Scotian Shelf.

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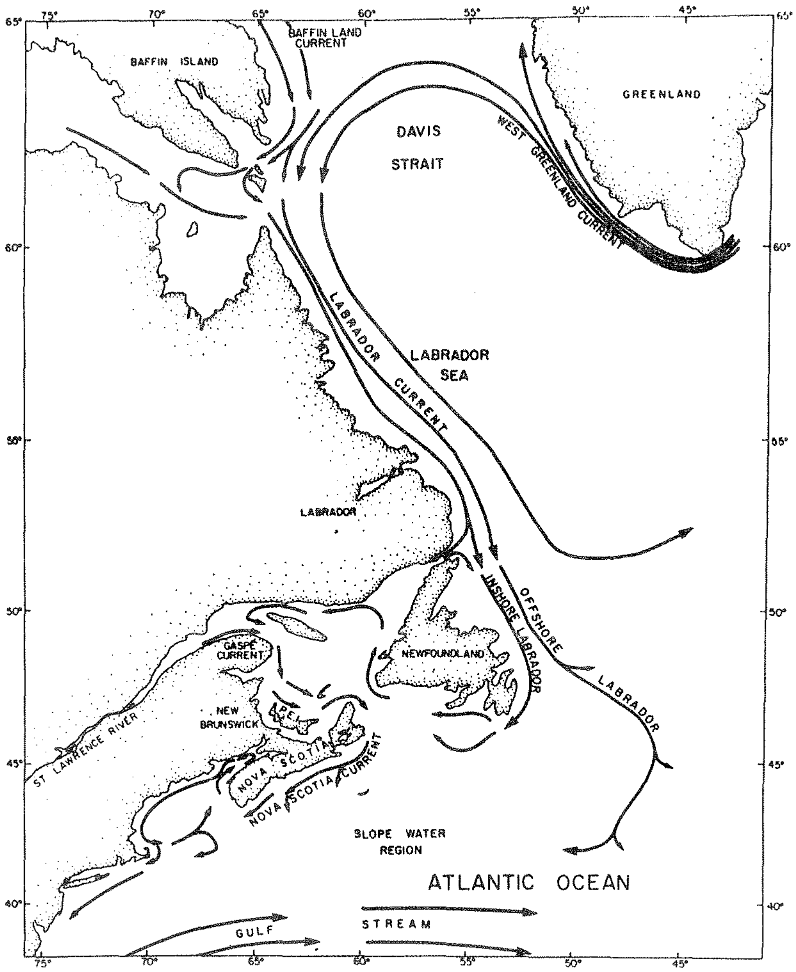

Fig. 1. Northwestern Atlantic coast showing general circulation patterns (from Sutcliffe et al. 1976).

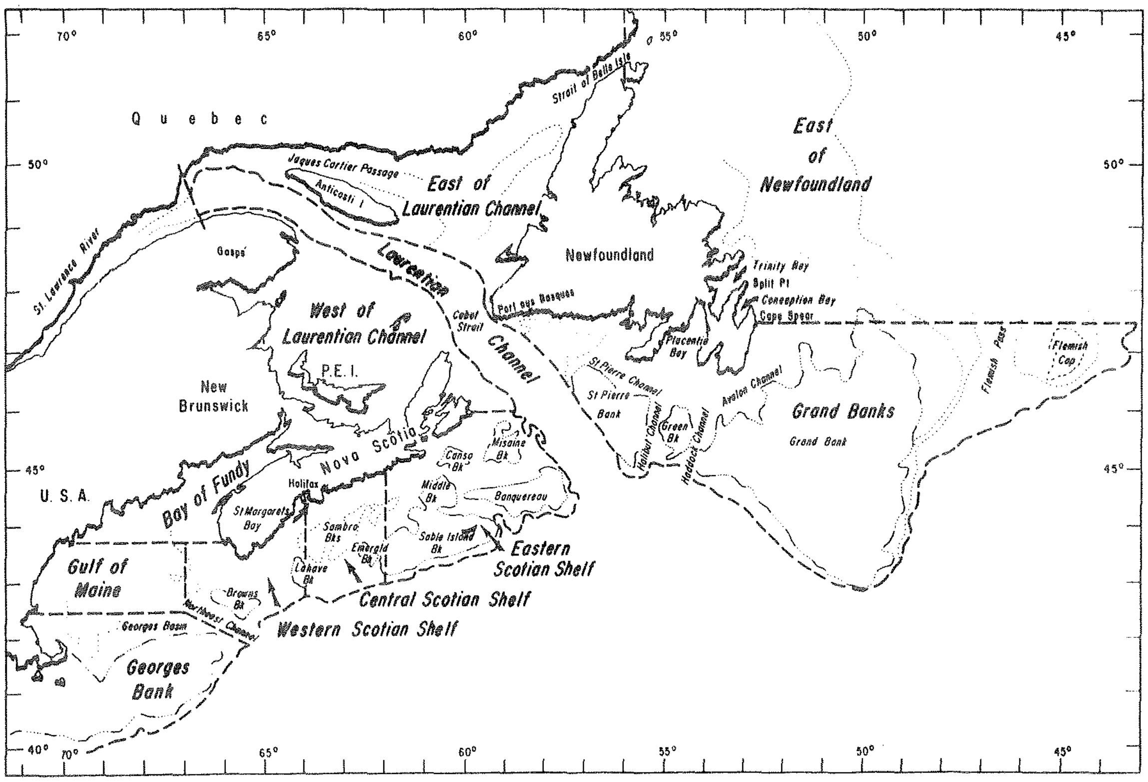

Fig. 2. Drift bottle and seabed drifter release areas as defined by White and Akagi (1974).

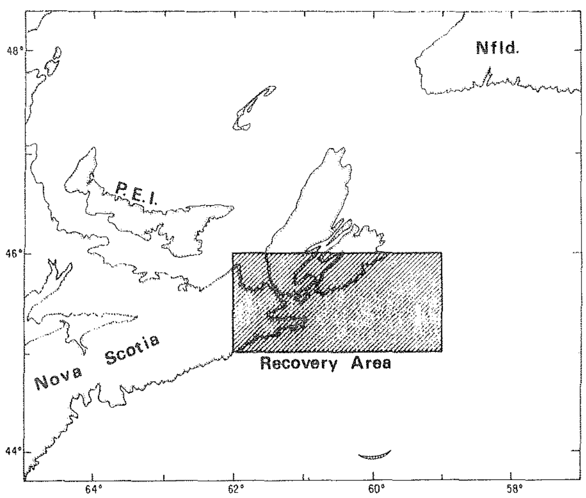

Fig. 3. The area of recovery for which all release points and straight-line trajectories were plotted.

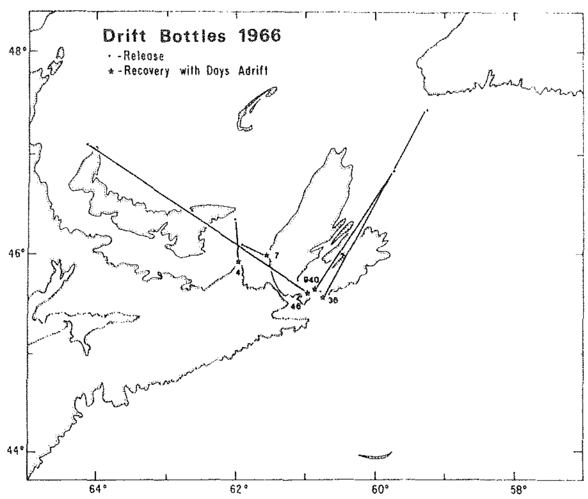

Fig. 4. A selected example of drift bottle recoveries from releases made in 1966 to show recovery pattern.

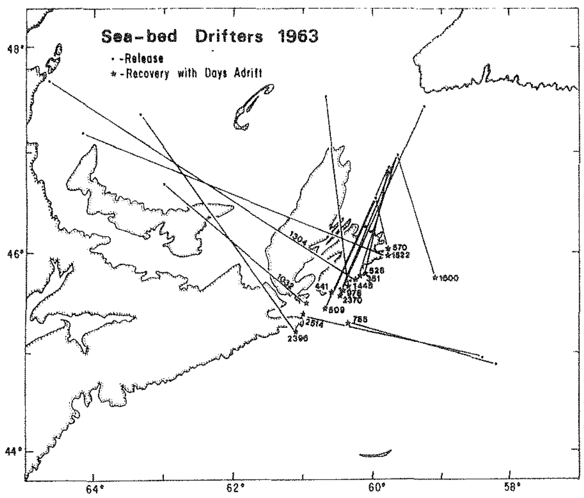

Fig. 5. A selected example of seabed drifter recoveries from releases made in 1963 to show recovery pattern.

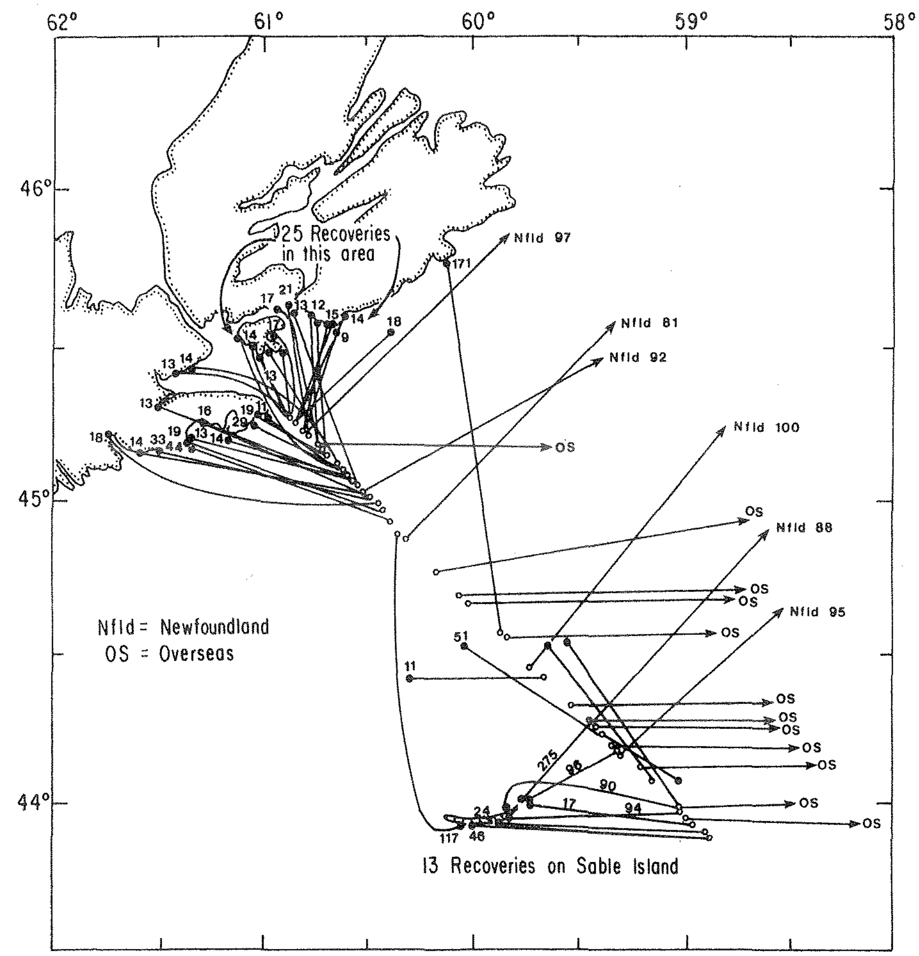

Fig. 6. Recovery pattern for drift bottle releases made along a line running across the Scotian Shelf from Cape Canso, June 8, 1922.

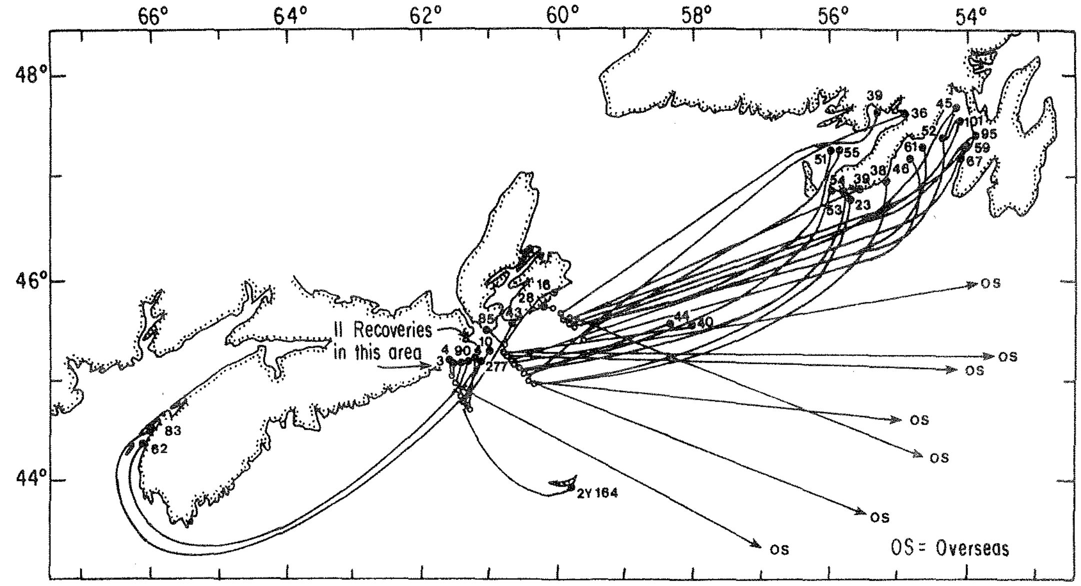

Fig. 7. Recovery pattern for drift bottle releases made along three section lines, July 8-15, 1924.

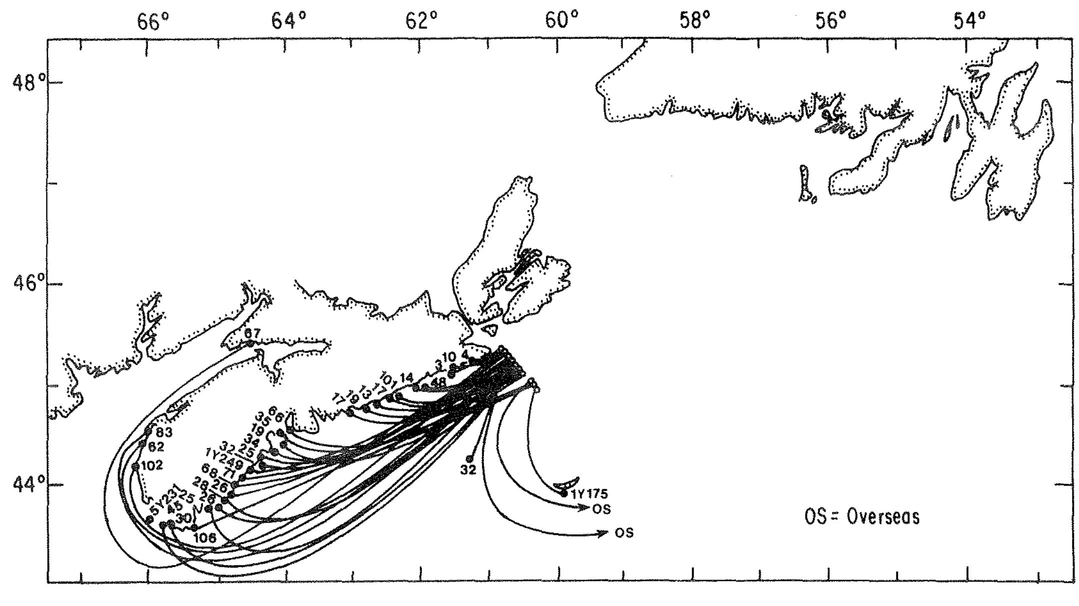

Fig. 8. Recovery pattern for drift bottle releases made along a section line off Cape Canso, August 1, 1924.

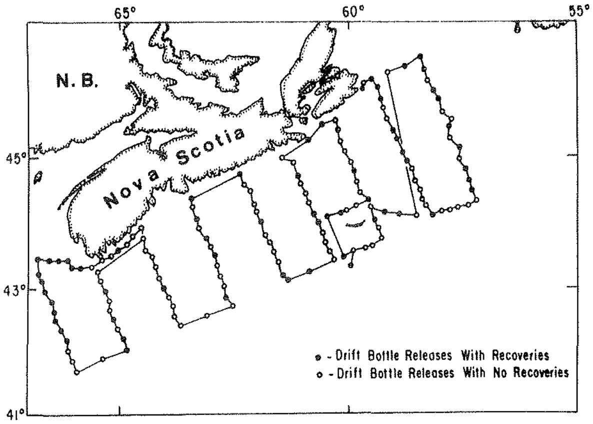

Fig. 9. Release pattern for drift bottle releases made during the period May 29-June 24, 1957.

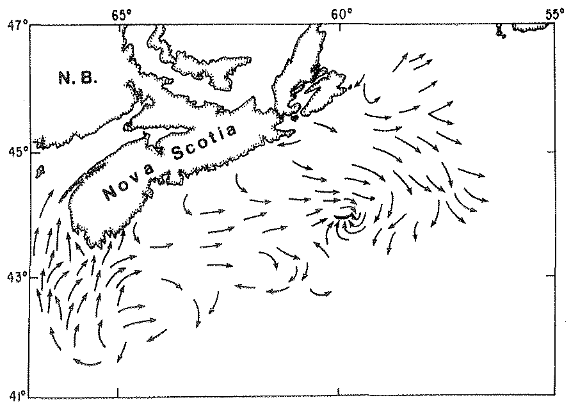

Fig. 10. Surface circulation pattern inferred from release-recovery pattern for May 29-June 24, 1957 releases.

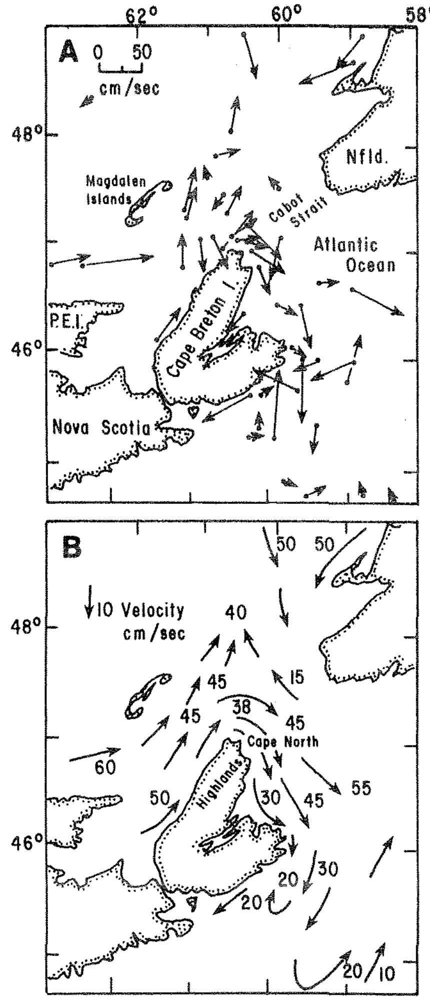

Fig. 11. A, Individual surface current vectors calculated from wind and ice data. B, Composite derived surface circulation around Cape Breton Island (from Ingram 1972).

NUTRIENT ENTRAINMENT IN CHEDABUCTO BAY AND ITS POSSIBLE EFFECTS ON PRODUCTION

by

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ABSTRACT

Drinkwater, K. F. 1979. Nutrient entrainment in Chedabucto Bay and its possible effects on production. Fish. Mar. Serv. Tech. Rep. 834.

Historical data are shown to be consistent with the hypothesis that prior to building of the Canso Causeway a net residual southward flow of water into Chedabucto Bay produced entrainment of deeper water. Through nutrient entrainment this process is estimated to have accounted for 10-20% of primary production in the Bay during the months of May to October. The residual flow and entrainment ceased with completion of the Causeway and hence its construction may have caused a drop in production of the Bay.

Key words: Nutrient entrainment, primary production, Canso Strait, Causeway, residual flow

INTRODUCTION

Prior to building of the Canso Causeway, the Strait of Canso connected waters of St. Georges Bay to the north with those of Chedabucto Bay to the south. An earlier study by Fothergill (1954) related velocities in the Strait to sea level difference between the bays. Using one month's sea level data he calculated a mean net southward transport of 4 x 10^3 m^3/s. Using all available data (16 mo taken over 4 summers) the mean transport was re-estimated to be southward at 7 x 10^3 m^3/s (Drinkwater 1979). Although these numbers are not certain, it is interesting to speculate on the effects that such a residual transport might have had on the Chedabucto Bay system.

DISCUSSION

Flow through the Strait of Canso into Chedabucto Bay could be likened to a river entering a fjord. In fjord-like estuaries a secondary circulation pattern is established where bottom or mid-depth waters are entrained into the outflowing surface layer. Conservation of volume requires a compensating inflow below the surface layer to replace the entrained waters. Data from MacGregor (1952) and Fothergill (1954) support the hypothesis that a similar entrainment process occurred in Chedabucto Bay before the Causeway. MacGregor, from extensive hydrographic data, found a consistent downward sloping of isotherms and isohalines from south to north in the central and southern regions of the Strait. He inferred a net residual surface transport to the south and a reverse flow at the bottom. Fothergill took current meter measurements over a 24-h period at several stations from an anchored ship and found that net flow overrode the deeper layers as it moved southward into Chedabucto Bay. More important, at a station at the south end of the Strait off Eddy Point, southward transport of water was found to be 1.6 times the transport in the center of the Strait. This also suggests entrainment had occurred. He postulated a northward inflow between 25 m, his deepest measurement, and the bottom (≈ 38 m) to compensate for the increased outflow in the surface layer.

Analysis of water densities allows an estimate of entrainment. Assuming that water from the Strait (ρ_s) overrides and mixes with bottom water (ρ_b) from Chedabucto Bay to form the upper layer of Chedabucto Bay (ρ_u), then from the conservation of mass

$$\rho_s(1-x) + \rho_b x = \rho_u$$

where x is the fraction of entrained water. Using MacGregor's (1952) data, $\rho_s \approx 1.02175$ g/cm^3, $\rho_b \approx 1.02300$ g/cm^3, and ρ_u 1.02225 g/cm^3. These values are based upon mean density distributions from observations during 13 cruises between May and November 1952. The value of ρ_s is the average density over the upper 30 m at MacGregor's station 5, slightly north of the present Causeway. The values of ρ_u and ρ_b are the average densities for the upper 15 m and for a layer 15-30 m deep at MacGregor's station 1, towards the center of Chedabucto Bay. Using the above densities and x = 0.4, the volume of southward flowing water at the center of Chedabucto Bay would be 1.7 times the inflow from Canso Strait. This agrees well with Fothergill's observed transport off Eddy Point of 1.6 times the central Strait. Taking the value of 1.7 and a flow through Canso Strait into Chedabucto Bay of 7 x 10^3 m^3/s (Drinkwater 1979), the entrainment rate would have been 5 x 10^3 m^3/s.

Entrainment replenishes the surface layer with nutrients which can then be utilized by phytoplankton. Knowledge of nutrient concentrations in the entrained waters is required to determine nutrient input to the surface layers. Unfortunately, no nutrient data are available for Chedabucto Bay, either pre- or post-Causeway. Nutrient data have been collected in St. Margaret's Bay, located on the Nova Scotia coast 250 km southwest of Chedabucto Bay. There the mean nitrate concentration at 25 m at Platt and Irwin's (1968) station A was 1.8 mg-atm/m^3, from May to October 1967. The 25-m depth was at or below the pycnocline during most of this time. Assuming a similar concentration in the entrained waters of Chedabucto Bay, the calculated entrainment rate would supply 9 gm-atm/s of nitrate to the surface layer. If entrainment was uniform over the 500 km^2 area of the bay, this equals 1.5 mg-atm/m^2/day of nitrate. Further, assuming 1 mg of nitrate produces 1 mg of chlorophyll *a* (Platt and Rao 1970) and a particulate carbon to chlorophyll *a* ratio of 50 (McAllister et al. 1961; Glen Harrison, pers. comm.), then 1.5 mg/m^2/day of chlorophyll *a* and 75 mg/m^2/day of particulate carbon are produced over the whole bay through entrainment. In these calculations nitrogen is considered the growth limiting factor, an assumption supported by several studies in coastal marine environments (e.g. Ryther and Dunstan 1971).

What we wish to know is the importance of this input relative to other production processes in the bay. Again, no data are available for Chedabucto Bay. However, Platt and Irwin (1968) calculated monthly production figures for St. Margaret's Bay from May through October based on weekly or semi-weekly samples. Average production of living carbon over the 6 mo was 531 mgC/m^2/day with 84% of production occurring in the upper 15 m. Assuming a similar production rate now in Chedabucto Bay, then the calculated production input of 75 mg/m^2/day of particulate living carbon due to entrainment represents 17% of production in the upper 15 m and approximately 14% of overall production. During the rest of the year nutrients are not expected to be important in limiting production, since the water column is mixed.

The above calculation of the effects of entrainment on production depends upon rate of residual flow through Canso Strait into Chedabucto Bay, rate of entrainment, depth from which the entrainment occurs, nutrient concentrations at this depth, nitrogen to production ratios and total production in the Bay at present. As all of these variables are unknown, any calculation is a crude approximation. However, given likely values, the primary production in Chedabucto Bay might be expected to have decreased from pre- to post-Causeway conditions by 10-20% over the months May to October. Entrainment would have had little effect on spring or fall blooms, but would have maintained higher production levels through the summer. Different nutrient levels before and after the Causeway could also have affected species succession.

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DISCUSSION

Muir: Are you saying that before the Causeway there was an enrichment in Chedabucto Bay because of entrainment and that this enrichment has been eliminated?

Drinkwater: That's right.

Scarratt: Is there any suggestion now that productivity in that area is nutrient limited?

Drinkwater: I don't know of any.

Robinson: Studies in the Strait of Georgia indicate that the system is driven by outflow of water from the Fraser River.

Drinkwater: There you have a much larger system.

Robinson: Does any inferential data exist which suggest that general production along the southeast coast of Nova Scotia may or may not have increased or decreased over some period of time?

Drinkwater: I don't know of any.

Messieh: Do you think that this entrainment of water that occurred previously had anything to do with stratification of the water especially in winter?

Drinkwater: I only looked at May to October because I don't think that this process would be important in winter when the major mechanism for getting nutrients to the surface is through mixing caused by storms.

Scarratt: The entrainment might have something to do with water temperatures which could be significant in the overwintering of herring.

Drinkwater: I looked at water temperatures and I couldn't see any significant difference between the water temperatures measured by MacGregor in 1952 and those measured by Vilks in 1973 and MacGregor in 1957 and 1959.

Messieh: Even in the deep water?

Drinkwater: I looked mostly at the surface waters but I would say that there wasn't any significant difference in deep waters either (30-50 m).

Messieh: This is the Bay where most of the herring overwinter.

Drinkwater: I wouldn't think that this process would change the water temperature that much.

INFLUENCE OF POLLUTION IN THE CANSO AREA, A SUMMARY

by

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ABSTRACT

Wilson, R. C. H. 1979. Influence of pollution in the Canso Strait area, a summary. Fish. Mar. Serv. Tech. Rep. 834.

Information on industrial effluent quality and the associated zones of influence in the Canso area is presented. The total effluent loadings from the major industries located on the Strait of Canso are about: BOD_5 - 105,000 kg/d; SS - 32,700 kg/d; oil and grease - 8300 kg/d.

The composition of bottom sediments and the benthic community both reflect the adverse effect of the addition of pulp and paper mill effluent.

Key words: Industrial wastes, sediment composition, benthos, biological oxygen demand, Canso Strait

INTRODUCTION

The Environmental Protection Service maintains an up-to-date inventory of effluent quality and toxicity for industries in the Canso Strait area. In the period 1972-73 EPS also collected data on the environmental effects of industrial discharges and developed a water quality model for dissolved oxygen. This report summarizes some of the information obtained.

INDUSTRIAL AND MUNICIPAL DEVELOPMENT

The Canso area is the site of three major industries, a thermal electric generating station and several smaller manufacturing operations. In addition, there are six communities located around the inner part of Chedabucto Bay.

Industries	Communities
Nova Scotia Forest Industries	Port Hastings
Atomic Energy of Canada Ltd.	Port Hawkesbury
Gulf Oil Ltd.	Point Tupper
Canso Sea Foods Ltd.	
Nova Scotia Power Corp.	Sand Point
Mulgrave Machine Works Ltd.	Melford
Concrete Services Ltd.	Mulgrave
Metro Ready Mix Ltd.	
Scotia Sun Ltd.	
Strait Printing & Publishing Ltd.	
Atlantic Concrete Ltd.	
Breton Industries & Marine Ltd.	
Toorie Kitchens Ltd.	

Only the first four industries listed produce significant effluents, in comparison with which contribution from municipal wastes is relatively small. The effluents from NSFI, AECL and Gulf are summarized below; more details can be found in Day (1979).

Nova Scotia Forest Industries Ltd. produces bleached sulfite market pulp and mixed sulfite-groundwood newsprint. The effluent discharge is about 95×10^6 L/day, with a pH in the range of 2.5-3.0. The loadings of BOD_5 and suspended solids are about 64,000 kg/day and 12,000 kg/day respectively. The effluent has an LC50 of 0.5-3.2% to rainbow trout (Table 1).

In a study done for the Committee for Pollution Abatement Research, the Nova Scotia Research Foundation examined the toxicity of effluent from NSFI to three species of algae (*Chondrus crispus*, *Ascophyllum nodosum* and *Fucus vesiculosus*). In the laboratory, rates of net photosynthesis were practically unaffected by effluent concentrations of 0.5% and 2.0%. The health of plants collected from within 3 km of NSFI, as measured by gross photosynthetic and respiratory activity, was impaired at certain times of the year when compared to control plants collected at a distance of 8 km.

Atomic Energy of Canada Ltd. makes heavy water from a process which involves hydrogen sulfide stripping. The plant has regulatory limits for hydrogen sulfide, oil and temperature in the process effluent, and a limit of 1.0 ppm residual chlorine for a separately treated sanitary sewage stream.

Table 1. Acute lethal toxicities of industrial effluents from Point Tupper, N. S.

Company	Dates of samples	No. samples tested	96-h LC50, range
Atomic Energy of Canada, Heavy Water Plant	Sept. 1972-July 1977	8	Not acutely lethal at 100% effluent.
Gulf Oil Refinery	Sept. 1972-July 1977	9	Not acutely lethal at 100% effluent.
Nova Scotia Forest Industries	Oct. 1971-Sept. 1973	18	LT50 of 65% effluent ranged from 0.25 to 28 h.
	Jan. 1974-July 1977	5	0.5-3.2%

The hydrogen sulfide limit on the process effluent stream is 1 ppm, but this limit was exceeded 56 times between January and October of 1977, usually because of process fluctuations which upset the hydrogen sulfide stripper. When this occurs, the hydrogen sulfide level is usually 1-2 ppm with rare excursions to 10 ppm. One extreme value of 494 ppm was recorded at a time when the plant was being prepared for shutdown. Undiluted effluent is not acutely lethal to rainbow trout in laboratory bioassays, presumably owing to the rapid disappearance of hydrogen sulfide (Table 1).

Canso Seafoods Ltd. is one of Nova Scotia's largest fish processing operations. The volume and characteristics of the effluent vary seasonally with the type of fish being processed. Separate wastewater streams are generated from fish unloading, groundfish processing and fish meal production, with the total maximum discharge being about 20.5×10^6 L/day. Effluent loadings are about 41,000 kg BOD_5/day, 20,500 kg SS/day and 8200 kg oil and grease/day. Undiluted effluent cannot be aerated sufficiently for fish to survive in it.

The Gulf Oil refinery produces a range of refined oils and gasolines. There are two effluent streams, one for process water and stormwater runoff and the other for once through cooling water. The normal discharges of process and cooling water are about 3.2×10^6 L/day and 0.6×10^6 L/day respectively, but the amount of stormwater runoff depends on rainfall. In a typical month, the effluent loadings are about 93 kg oil and grease/day, 210 kg SS/day, 0.1 kg phenol/day, less than 0.2 kg sulfide/day and 22 kg NH_3-N/day. The pH is about 7. The refinery effluent is not acutely lethal to rainbow trout (Table 1).

DISSOLVED OXYGEN MODEL

In 1973 a dissolved oxygen model for the inner part of Chedabucto Bay was developed (Khumbare 1974). It is a one-dimensional, steady-state model in which the area from the Causeway to Cape Argus-Janvrin Island is divided into 78 segments of equal length. A complete description can be found in Khumbare's (1974) manuscript report.

The model was developed as a tool to assist the management of waste discharges at a time when it appeared that the Strait of Canso might be subject to rapid and heavy industrialization.

It was developed around constants and coefficients derived from theoretical calculations (reaeration) or from field observations (dispersion, advection, decay) with the data supporting the water movement components being provided by the Coastal Oceanography Division of OAS. The model was then scaled to fit dissolved oxygen data provided by OAS and verified against data collected by EPS. A significant correlation between observed and predicted values was obtained.

The lowest DO observed near the NSFI plant during the model calibration study was 6.40 mg/L. The lowest concentration predicted by the model from worst theoretical conditions applied to observed values is 5.48 mg/L. In the segment 1 km down the Strait from the NSFI mill, average dissolved oxygen deficit was only 0.16 mg/L. Scaling and verification studies showed that similar depressions of DO occurred near the Causeway, presumably because of an increase in concentration of pollutants at the head of the bay caused by unfavourable wind and current conditions. This situation could not be predicted by the model because of underlying assumptions which were made to reflect average direction of mass flow.

RECEIVING WATER INVESTIGATIONS

Investigations related to environmental effects of industrial effluents were conducted in 1969, 1972 and 1973. The 1969 survey was conducted for Gulf Oil Ltd. as a pre-operational survey by T. W. Beak Ltd., who also undertook a second survey for Gulf in 1971. Results of the latter survey are not known.

Beak Ltd. sampled benthos at eight locations from the Causeway to a point about 4.8 km below the refinery outfall. Benthos in the samples was identified to the family level and tabulated. All eight samples were dominated by a relatively large number of Polychaeta (181±57) compared to all other organisms (33±33) per square foot of bottom.

This observation was not confirmed by the EPS surveys in 1972 and 1973 (Machell et al. 1974), by which time the refinery had been operating for 2 1/2 yr and the new newsprint mill at NSFI for 2 yr. Sediment along 67-m transects off the loading wharf at NSFI and in Cass Cove showed greatly elevated carbon and nitrogen levels. At these two locations, the bottom was covered with a layer of either fiber or fine particulate matter and the benthic community lacked a bivalve population as well as their common predators. These two locations clearly showed the effect of pulp and paper wastes.

Sediment off the Gulf refinery outfall had carbon and nitrogen levels which were close to background, similar to those found on the opposite side of the Strait off Melford and in Inhabitants Bay. Fewer taxa were found at this location in 1973 than in 1972, the most notable changes being the disappearance of Anthozoa and bivalve molluscs.

In contrast with the survey conducted by Beak Ltd. in 1969, in which Polychaeta predominated, the 1972 and 1973 EPS surveys found only one Annelida at the three sites mentioned above. This taxon was found at all five sites farther down the Strait, however.

Sediment heavy metal concentrations were measured in 1973. Between the Causeway and Bear Head, copper concentrations ranged from 4.1 to 13.4 mg/kg (dry wt), zinc from 14.8 to 80.9 mg/kg, lead from 7.7 to 16.1 mg/kg and iron from 1.0 to 1.7%. The mercury level in triplicate samples of sediments at four locations ranged from 0.011 to 0.148 mg/kg (dry wt).

Further details of these surveys have been reported (Machell et al. 1974).

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DISCUSSION

Robinson: You didn't see any rock crab while carrying out your survey in the Strait down to a point of 5 km below the refinery outfall?
Wilson: A rock crab was observed on the last transect.
Cook: Do they have a bark burner yet at the NSFI plant?
Wilson: I have no idea, but the amount of suspended solids has been reduced.
Question: Since the two turbines (Heavy Water Plant and N.S. Power Corp.) are water cooled, there will be some release of heated water into the Strait? Has this replaced to a significant degree the heat load formerly derived from St. Georges Bay?
Wilson: Yes, there is a small area of 30° water, but I don't know to what extent this affects the overall heat load.
Robinson: How far does the influence of this effluent extend?
Wilson: As far as Ship Point.
Question: How far out is wood fibre found?
Wilson: In 1973 an area of 2500 m centred on the NSFI plant was blanketed and wood fibre is recognizable as far as Eddy Point.
Lakshminarayana: What was the cause of the closure of the clam flats from 1955-57?
Wilson: Fecal contamination.
Lakshminarayana: Why were they reopened?
Wilson: The tests were not valid, but they served as a yardstick to measure industrial treatment.
Cook: What is the effect of kraft mill effluent on lobster larvae?
Wilson: Lobster larvae are twelve times tougher than salmon.
Robinson: The lobster fishery has failed from the Halifax County line to Scatarie Island, how far is the effect of the effluent felt? At Canso?
Wilson: No.
Scarratt: Flocculation and settlement change the bottom; a change in structure alone may determine what animals can live there. Is Ship Point the furthest point where the effects can be detected?
Wilson: No. The line bends off at Ship Point and continues on.
Kranck: Does it relate to bottom grain size?
Wilson: No.
Dadswell: Were the 6- to 8-inch plaice that you mentioned caught or observed?
Wilson: Caught.
Dadswell: That is of interest because molluscs are a major food of plaice.
Wilson: Where the wastes are several feet thick there are no gastropods but scallops and horse mussels are found further out at a depth of 80 ft - about 1500 scallops were taken off Canso ship area.

A SUMMARY OF INDUSTRIES LOCATED IN COMMUNITIES BORDERING THE STRAIT OF CANSO

by

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ABSTRACT

Day, J. K. 1979. A summary of industries located in communities bordering the Strait of Canso. Fish. Mar. Serv. Tech. Rep. 834.

This paper presents details on those industries and municipal treatment plants located in communities bordering the Canso Strait.

For the minor industries with no effluent discharge, only information concerning products is listed. For the major industries, details of processes involved, effluent treatment and waste loadings are provided. Types of treatment, disinfection practices, population served and effluent flows are provided for municipal sewage treatment plants.

Key words: Industrial wastes, industries, sewage treatment, waste treatment, wastes, heavy water, Canso Strait, oil wastes, biological oxygen demand

MINOR INDUSTRIES IN COMMUNITIES NEAR CANSO STRAIT

1. Mulgrave Machine Works Ltd.
   Mulgrave, Guysborough Co., N.S.

   Products - machine shop (manufacturing and repair of machine parts for offshore oil drilling operations); pressure tanks; custom industrial design; general metal fabrication.

2. Concrete Services Ltd.
   Steep Creek, Guysborough Co., N.S.

   Products - ready mix concrete.

3. Metro Ready Mix Ltd.
   Port Hawkesbury, Inverness Co., N.S.

   Products - ready mix concrete.

4. Scotia Sun Ltd.
   Port Hawkesbury, Inverness Co., N.S.

   Products - newspaper publishing.

5. Strait Printing & Publishing Co. Ltd.
   Port Hawkesbury, Inverness Co., N.S.

   Products - commercial offset printing, yearbook publications.

6. Toorie Kitchens Ltd.
   Port Hawkesbury, Inverness Co., N.S.

   Products - bakery, mincemeat.

7. Atlantic Concrete Ltd.
   Point Tupper, Richmond Co., N.S.

   Products - ready mix concrete, precast concrete.

8. Breton Industrial & Marine Ltd.
   Port Hawkesbury, Inverness Co., N.S.

   Products - ship conversion and repair; barges, marine railway drydock; steel plating; machining; conveyor frames; structural steel; trusses.

MAJOR INDUSTRIES NEAR CANSO STRAIT

1. Atomic Energy of Canada Ltd.
   Port Hawkesbury Heavy Water Plant

   - produce heavy water (D_2O).

The Port Hawkesbury Heavy Water Plant (PHHWP) produces heavy water (D_2O) via the Girdler-Sulphide process. This process uses a hydrogen sulphide (H_2S) carrier gas to extract heavy hydrogen atoms (deuterium) from natural water. Extraction of deuterium from the feed water is accomplished in trayed, counter current extraction towers where the water feed cascades down the towers and is contacted by a circulating H_2S carrier gas stream moving upwards. The top of the tower is operated at a lower temperature (30°C) than the lower section of the tower (140.5°C) to take advantage of the physical properties of the H_2S-H_2O system. In the hot section of the tower, deuterium atoms are stripped from the liquid phase into the vapour (H_2S gas) phase. In the cold section of the tower, the reverse relationship occurs and deuterium atoms are absorbed from the gas into the liquid phase. The net result is that deuterium in the feed water is stripped into the H_2S gas phase in the hot tower section and then reabsorbed and driven back down the cold tower section by incoming feed water, causing the deuterium to be concentrated between the hot and cold tower sections. At this point, product is drawn off at approximately 400 ppm compared to the influent 140 ppm in the feed. Subsequent stages work via the same principle at higher influent and effluent deuterium concentrations.

The design D_2O extraction performance of the Port Hawkesbury plant is 45.77 kg/h, but due to deviations in some process parameters, the actual extraction achieved is sometimes lower. The plant has operated at an extraction level 64% of its design capacity, producing 128,601 kg of heavy water in the 4,392 h of operation as of October, 1977.

Under the requirements of the PHHWP Operating License, the Senior Engineer for Safety and the Environment provides a monthly Technical summary to the Environmental Protection Service. The report documents safety performance, plant performance, effluent data and production statistics. With respect to effluent entering the Strait, the main areas of concern are H_2S, oil and temperature where regulatory limits must be complied with.

These are:

H_2S	not >1.0 ppm in effuent ditch
visible oil in effluent	<u>never</u>
temperature in effluent ditch	not to exceed 165°F (73.89°C)
residual chlorine in sewage effluent	0.5 ppm (minimum) 1.0 ppm (maximum)

The plant's objective is never to exceed these limits, but the H_2S limit has been exceeded 56 times to date in 1977. When limits are exceeded, an explanation is expected and routinely supplied in the Monthly Technical Summary. The upper limit is usually less than 2 ppm in the event of stripper malfunction, with extreme upper values near 10 ppm. One level of 494 ppm was reported during preparations for a plant maintenance shutdown.

2. Canso Sea Foods Ltd.
Canso, N.S.

- subsidiary of H.B. Nickerson & Sons Ltd.
- products - fish (frozen catfish, frozen filleted cod, flounder, sole, haddock, hake, cusk, halibut, ocean perch, pollock, turbot, sea fish); fish and herring meal and oil.

Plant operation

Canso Sea Foods Ltd. is one of Nova Scotia's largest fish processing operations with facilities for production of fresh and frozen packaged fillets, and fish meal. The plant processes both pelagic and groundfish at an annual combined rate of approximately 23 million kg with an annual product yield of approximately 8 million kg. During peak production, the Company operates two 8-h shifts, 6 d per wk, employing about 350 people.

Groundfish arrive at the plant by boat or truck, are weighed, scaled and manually processed before being frozen and stored for marketing. All spoiled fish are sent via an offal flume to the fish meal plant. Wastewater generated from unloading, weighing and scaling operations flows via floor drains into Canso Harbour, while waste from filleting and trimming goes to the offal flume.

Pelagic fish, mainly herring, are pumped to storage tanks upon arrival at the plant to await mechanical filleting and packaging. All wastewaters are transported to the offal flumes.

In the fish meal plant, cooked offal from the flumes is pressed to remove liquid; the press water is conveyed to an oil centrifuge and press cake goes to a dryer.

Dewatering screen wastewater from the dewatering of offal flume solids is the major source of liquid effluent from the plant. This includes water from air scrubbers, dewatering screen sump overflow, evaporator condenser water and oil centrifuge flush water.

The total maximum waste volume has been calculated to be approximately 17,000 m^3 per day.

Waste water characteristics

Biochemical Oxygen Demand (BOD_5)	200-400 mg/L
Suspended Solids (SS)	100-300 mg/L
Oil & Grease	100-300 mg/L

Due to excessive waste loads and charges laid under the Fisheries Act, the Canso Sea Foods plant is now bound to a compliance schedule to meet the "Fish Processing Operations Liquid Effluent Guidelines"; negotiations concerning same are still under way.

Fish Processing Operations Liquid Effluent Guidelines

- all contaminated process water should be treated for solids removal to produce an effluent similar in quality to that produced by 25 mesh screening of contaminated water (25 mesh screen has openings of 0.71 mm).
- no discharge of stickwater, pressliquor or bloodwater (except where <u>no</u> recovery is possible).
- sewer and drainage systems should be designed to allow sampling at outfall.
- flow metering of contaminated H_2O should be provided.
- all effluents are to be discharged at a point below the surface of the water under low tide conditions.

3. Nova Scotia Forest Industries Ltd.
Port Hawkesbury, Nova Scotia.

products - bleached sulphite pulp newsprint

Plant operation

The mill is a sulphite pulp and paper mill producing approximately 380 tonnes of market pulp and 380 tonnes of newsprint per day. Market pulp is produced via the following unit processes: conventional wet debarking, a two-stage cook in a solution of sodium sulphite, five-stage bleaching in chlorine (Cl_2), chlorine dioxide (ClO_2) and sodium hydroxide (NaOH), drying and baling as market pulp. The cooking chemicals are recovered in a Stora Chemical Recovery process and recycled into the cook.

Newsprint is produced from mixed sulphite and groundwood pulp. Seventy-five percent of the pulp is mechanically ground to produce groundwood; 25% is digested in sulphite cooking liquor to yield high sulphite pulp. The two ingredients are combined in a conventional newsprint machine to produce newsprint.

Wastewater results from most of the unit processes, notably the pulping, bleaching and paper machine operations. Under the Pulp and Paper Regulations, NSFI is required to monitor SS, BOD_5 and toxicity in the effluent. The industry sends monthly reports to EPS Atlantic Region, showing weekly averages for these parameters, plus pH. Average values are listed below:

Parameter	Discharge
Suspended solids (SS)	9.0 tonnes/day
Biochemical Oxygen Demand (BOD)	43.8 tonnes/day
Toxicity	LC_{50} 0.5-3.2%
pH	2.5-3.0

Due to the exceptionally low pH values of the discharge, the Nova Scotia Department of Environment and EPS have asked the company to consider neutralization practices using $CaCO_3$. Toxicity values are high and the company in 1973 ran a pilot scale high rate activated sludge unit to assess its toxicity removing efficiency. The project was unsuccessful and, since the company has no land available for a low rate biological treatment system, no viable alternatives for reducing toxicity are available at the present time. However, the industry has been asked to do a mill inventory to discover the in-plant sources of toxicity in an effort to reduce toxic effect by process modifications.

4. Point Tupper Gulf Oil Refinery
   Port Hawkesbury, Nova Scotia

   Products - liquid sulphur, jet fuel, stove oil, diesels, furnace oil, propane, gasoline, gas oil, bunker.

   Employs - 135 Gulf employees and ca. 100 contract employees.

Plant operation (represented in Fig. 1)

The Gulf Oil refinery uses basic distillation procedures to separate the crude elements. A 14 x 10^6 liter-per-day topping unit separates raw light oil fractions from heavier residual materials which are then sent to finished product storage.

The bulk desulphurization section, with a capacity of 6 x 10^6 liters-per-day, removes sulphur compounds from the raw light oil taken overhead at the topping unit. The reaction takes place over a catalyst which speeds the reaction rate. Trace metals and nitrogen contaminants are also removed. Fractionating equipment then separates naphtha for further processing, and the jet, stove and diesel products are sent to storage.

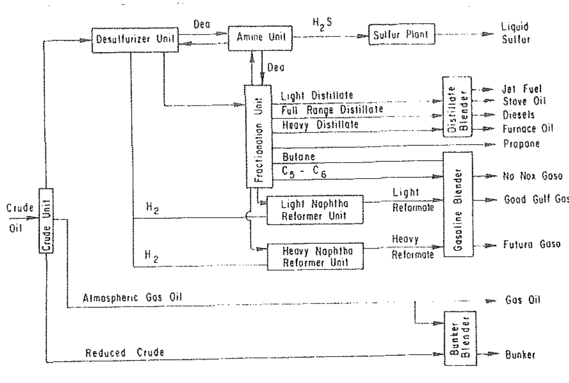

Fig. 1. Gulf Oil Canada's Point Tupper refinery block process flow diagram.

In the catalytic reforming unit, using platinum as a catalyst, naphtha is processed into high octane reformate, the essential component of today's gasoline. Gulf Oil has two of these units, a .8 x 10^6 liter-per-day light unit and a 1.1 x 10^6 liter-per-day heavy naphtha unit.

In the propane recovery unit, all refinery light gases are stripped of hydrogen sulphide (H_2S) and fractionated to yield liquified petroleum gas - more commonly called propane.

In the sulphur plant, the H_2S is treated over a bauxite catalyst to produce elemental molten sulphur, at a capacity of 30.5 tonnes product/day. Two boilers produce a total of 163,000 kg-per-hour of steam for the refinery's use. The refinery is completely air-cooled and requires a minimal amount of water makeup from nearby Landrie Lake.

The refinery submits reports each month to the EPS Atlantic Regional Office detailing effluent flows, test results and effluent toxicity data. The refinery is now operating at a Reference Crude Rate of 12 x 10^6 liters/day (76.2 MB/D - thousand barrels per day).

Waste flows originate from the crude oil fractionation process, sour water from stream strippers and overhead accumulators or fractionators, spent caustic from sulphur removal and general refinery wastes from other unit processes. Liquid effluent process flows vary depending upon production operating rate but usually range from 3000-6000 cubic meters/day. Storm water discharge depends upon weather conditions, but usually ranges between 900-2200 cubic meters/day. Once-through cooling water discharge is fairly consistent at 636 cubic meters/day.

The parameters of major concern are monitored daily and reported monthly.

Following is a typical effluent analysis for the refinery (when operating at 89% of the reference crude rate):

Liquid Effluent:

Process Flow:	3000-6000	cubic meters/day
Storm Water Discharge:	900-2200	" " "
Once-through cooling water:	636	" " "

Parameter	Discharge
Oils	18 ppm
SS	30 ppm
Phenols	.05 ppm
Sulphide	.032 ppm
Ammonia nitrogen (NH_3-N)	4.4 ppm
pH	7.0

Discharge values vary monthly, but the refinery is currently in compliance with regulations as verified by monthly company reports and periodic sampling by the regulatory agencies (EPS and NSDOE).

5. Nova Scotia Power Corporation
   Point Tupper, N.S.

   Products - electricity

   Employs - ca. 100

Plant operation

The 230 MWe capacity plant is fired with Bunker C oil and has a 70% capacity factor. There are three boilers: 1A, 1B and 2 which operate under 2,000 lb pressure with 1000°F reheat. The two small boilers 1A and 1B produce 80 MWe of electricity at full load and with excess steam supplied for process purposes at the heavy water plant. There is no requirement here then for cooling water, as exhausted steam (at 200 lb pressure) from the back pressure turbine goes to the AECL D_2O plant.

The 150 MWe capacity expansion unit consists of a boiler, radial turbine, generator arrangement with a once-through cooling water condenser. The cooling water is withdrawn from the Strait of Canso and discharged, untreated.

The sluice water used to transport fly and bottom ash is impounded with an overflow discharge.

No guidelines exist which generally cover Power Plant effluents. Rather site specific recommendations are made under the auspices of the Fisheries Act. A Task Force is now examining promulgation of guidelines for Thermal Power Generating Plants.

MUNICIPAL SEWAGE TREATMENT PLANTS

1. Canso:

Responsible authority	-Province of Nova Scotia
Design flow	-380 cubic meters/day
Disinfection of effluent	-yes
Primary treatment	-bar screen grit removal comminution
Biological treatment	-extended aeration

2. Mulgrave:

Responsible authority	-municipality
Design flow	-220 cubic meters/day
Average flow	-140 " " "
Population served	-900
Disinfection of effluent	-yes
Primary treatment	-bar screen grit removal primary clarifier
Biological treatment	-extended aeration

3. Port Hawkesbury:

Responsibile authority	-municipality
Design flow	-3,600 cubic meters/day
Average flow	-1,200 " " "
Population served	-4,200
Disinfection of effluent	-yes
Primary treatment	-bar screen grit removal primary clarifier
Biological treatment	-trickling filter
Sludge processing	-aerobic digester

CHANGES IN THE WATER QUALITY OF THE NORTHUMBERLAND STRAIT, N.B.

by

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ABSTRACT

Lakshminarayana, J. S. S., and H. Bourque. 1979. Changes in the water quality of the Northumberland Strait, N.B. Fish. Mar. Serv. Tech. Rep. 834.

This is a short account of water quality studies on the New Brunswick coastal waters of Northumberland Strait since 1972. Water quality there varies depending on the seasonal freshwater discharge from coastal rivers, water bodies, natural drainage, primary and untreated sewage effluents and local industries. Temperature, transparency, salinity, pH, conductivity, dissolved oxygen, nitrate and nitrite nitrogens, orthophosphates, total carbon, copper, cadmium, iron, nickel, manganese, lead, zinc, phytoplankton and biomass were measured at six sampling stations in the Saint-Édouard-de-Kent and Cap Pelé regions of Northumberland Strait during 1976 and 1977. A brief report of the results is presented. Phytoplankton biomass was found to be higher in the lobster-abundant region of Richibucto.

Key words: Water quality, biochemical analysis, chemical composition, sea water, Northumberland Strait, temperature, salinity, biomass, marine environment, phytoplankton

INTRODUCTION

Lobsters are a traditional inshore fishery in northern and southern areas of Northumberland Strait. The decline in lobster landings has been causing anxiety to local fishermen and other related organizations. For wise management of the fishery and other biological resources of this area one needs to understand the complex interactions of the ecological systems with their environment. Frequently the decline in lobster landings has been attributed to (i) legal destruction of too many female lobsters, (ii) overexploitation of lobsters with carapace length below 3 3/16 in., (iii) destruction of breeding grounds by pollution, irish moss raking, etc., and (iv) the natural existence cycles in its annual production. A detailed investigation on lobster populations in relation to the key factors in natural processes of Northumberland Strait is imperative, in order to understand the present levels of population and to suggest methods of improving numbers there.

At the Université de Moncton, Moncton, N.B., most marine and coastal zone research is conducted by the Groupe Universitaire de Recherche en Biologie Aquatique (GURBA). This group (now six faculty members) was organized as a unit in 1975 and conducts interdisciplinary research. Some members of the group are engaged in a study on the lobster fishery and water quality of Northumberland Strait. This paper reports the changes in water quality, phytoplankton and lobster larvae populations in the Northumberland Strait during recent years.

BACKGROUND INFORMATION

Water quality measurements were made since 1972 on Northumberland Strait waters to study changes in the chemical milieu in which organisms live. Bartlett (1971) stated that bacteria, especially members of the *Escherichia coli* group, have increased significantly over the last decade in marginal polluted waters near the populated areas of the Atlantic region. He also showed that physical parameters and nutrient content vary widely, with phosphates, sulphates and silica increasing from 1966 to 1976.

Our studies on the shoreline waters of Shediac, N.B., indicated the post-winter and pre-summer bacterial contamination of these waters (Lakshminarayana and Jean-Pierre 1975). Twelve hourly variations in the temperature, salinity, turbidity, pH, free carbon dioxide, dissolved oxygen and coliforms in the coastal waters (Fig. 1) off Grande Digue (Station A) and Shediac (Station B) during 1972 showed correlations with tidal changes (Fig. 2). The waters were well oxygenated, varied between mesohaline and polyhaline conditions with reduced circulation between bay and river waters during pre-summer conditions (Fig. 2, 3). The coliform populations (Fig. 4) were more than the

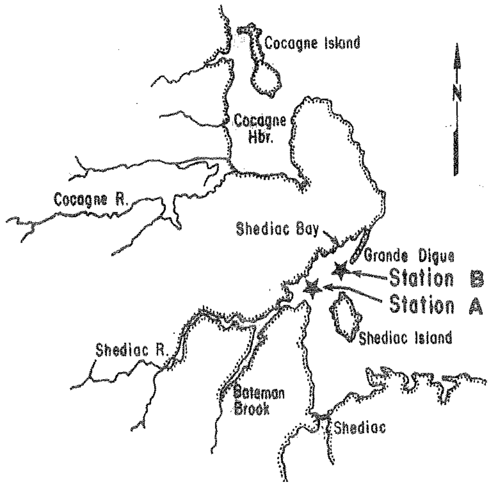

Fig. 1. Sampling site location off Grande Digue (Station A) and Shediac (Station B).

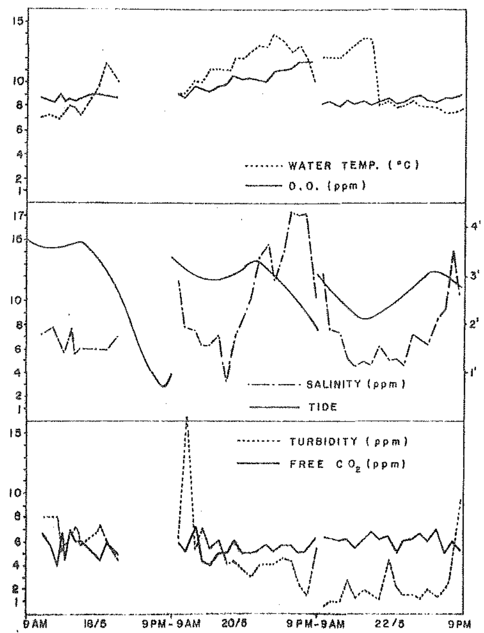

Fig. 2. Hourly variation in water temperature, dissolved oxygen, salinity, turbidity, free carbon dioxide and tidal level at Station A off Grande Digue in Northumberland Strait.

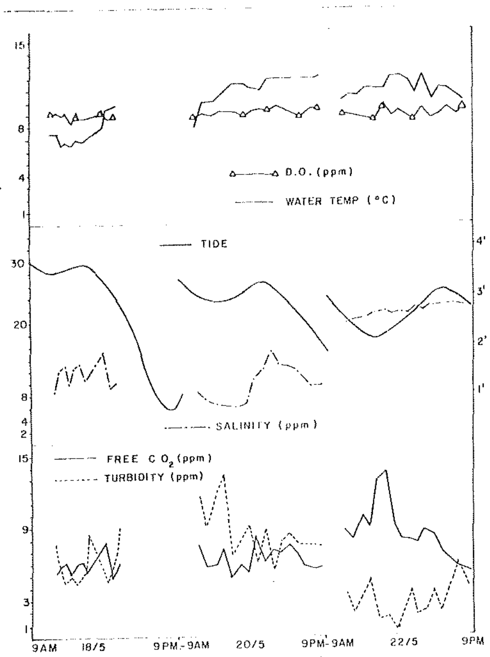

Fig. 3. Hourly variation in water temperature, dissolved oxygen, salinity, turbidity, free carbon dioxide and tidal level at Station B off Shediac in Northumberland Strait.

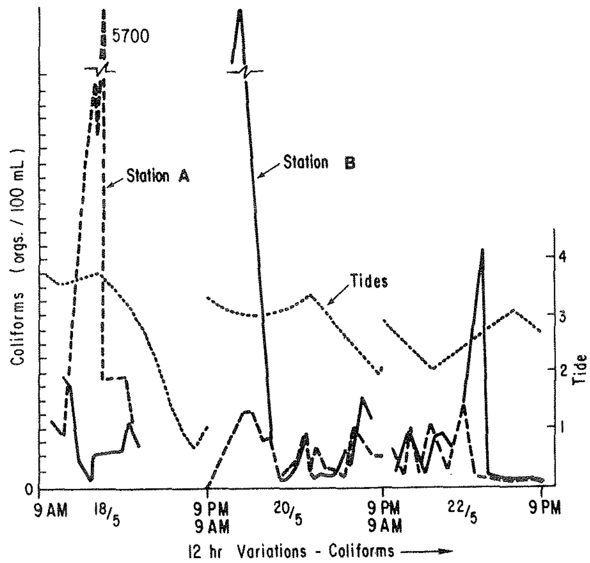

Fig. 4. Hourly variations in coliform in Northumberland Strait waters off Grande Digue (Station A) and Shediac (Station B).

normal permissible limit for recreational waters. Salinity changes in the bay waters of this region are rapid. For example, on July 10, 1973, and August 7, 1973, Buctouche Bay waters showed salinity decreases due to rain and surrounding drainage from 16.0 to 11.0 o/oo and 17.0 to 4.7 o/oo in the surface waters and 21.5 to 11.7 o/oo and 17.0 to 6.1 o/oo in the bottom waters.

A multidisciplinary, environmental impact study on lobster populations of Northumberland Strait was completed in 1976 by the Biological Station, St. Andrews. To provide for continuation of some of these studies measurements of water quality and phytoplankton changes of these waters were started by GURBA in the summer of 1975. The regions of Saint-Édouard-de-Kent and Cap Pelé were chosen as study areas representing high and low densities of lobster populations. The following summarizes the work carried out during 1976 and 1977.

MATERIALS AND METHODS

During 1976 six sampling stations (Fig. 5) were established in the study area in the coastal waters of Saint-Édouard-de-Kent and Cap Pelé (46°40"N, 64°40"W; and 46°17"N, 64°17"W). Water samples were taken both from the surface and bottom regions using a motor boat and a Kemmerer sampler. Analyses made were according to known standard methods. The detailed procedures for collections, analyses and calculations were followed according to the descriptions given by the authors of the respective methods. However, analyses of the samples were carried out on unfiltered samples.

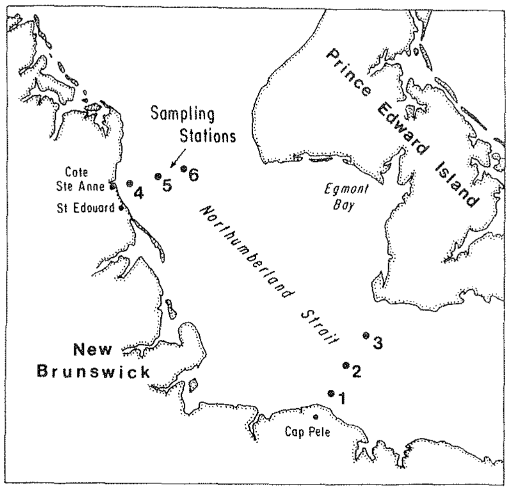

Fig. 5. Sampling site locations near Saint-Édouard-de-Kent and Cap Pelé in Northumberland Strait.

Hydrogen ion activity was measured with a Beckman pH meter. Temperature was determined with a mercury hand thermometer and a temperature probe. A Beckman induction salinity meter and D.O. analyzer (Y.S.I. - Model 54) were used to measure the salinity, conductivity and dissolved oxygen concentrations. Water samples of 1976 were analyzed for salinity using the titration method described in Strickland and Parsons (1968). D.O. oxygen was also determined per the Winkler method (Strickland and Parsons 1968). Transparency and depth of water were measured using a Secchi disc. Total phosphate (Persulfate digestion), orthophosphate (stannous chloride method), nitrate nitrogen (brucine method in 1976 and cadmium reduction method in 1977), and nitrite nitrogen (diazotization method) were estimated according to the standard methods (American Public Health Association 1971). The heavy metals Fe, Mn, Cu, Ni, Zn, Pb and Cd were determined with an atomic absorption spectrophotometer (Jarrel Ash - 810) using the direct absorption method (cf. E.P.A. Methods, U.S.A. 1972).

The water samples were collected in clean 250 mL acid resistant, amber colored, rigid polyethylene narrow mouth bottles and acidified with 2 mL nitric acid (A.C.S. grade). They were allowed to rest for 30 d before analysis. Phytoplankton was examined with a research microscope and an Utermohlts inverted microscope. Total carbon was estimated with an organic carbon analyzer (Beckman - 915A). The samples were acidified with concentrated sulfuric acid (A.C.S. grade) to pH less than 2. Chlorophyll *a* and phaeophytin were determined by fluorescence of acetone extracts using a Turner Fluorometer, Model III with Wratten 47B and 25 filters for excitations and emission respectively (Yentsch and Menzel 1963; Holm-Hansen et al. 1965; Lorenzen 1966). Pure chlorophyll *a* from Sigma Chemicals was used to standardize the fluorometer.

RESULTS

Between May and October 1976 and 1977, 185 water samples were collected representing the two areas of study. Maximum, minimum and average values for temperature, transparency, salinity, pH, conductivity, dissolved oxygen, nitrate and nitrite nitrogens, phosphates, chlorophyll *a* and phaeophytin are given in Tables 1 and 2.

The results indicated that the temperatures (Fig. 6) of surface and bottom waters followed the general pattern of air temperatures. Surface water temperatures of the Cap Pelé region reached a maximum of 22°C while the minimum recorded was 4.5°C. Surface waters of Saint-Édouard-de-Kent showed similar increases to a maximum of 17°C to the end of July and thereafter was less than 17°C. The bottom temperatures were above surface temperatures in June at Stations IV and V in both 1976 and 1977.

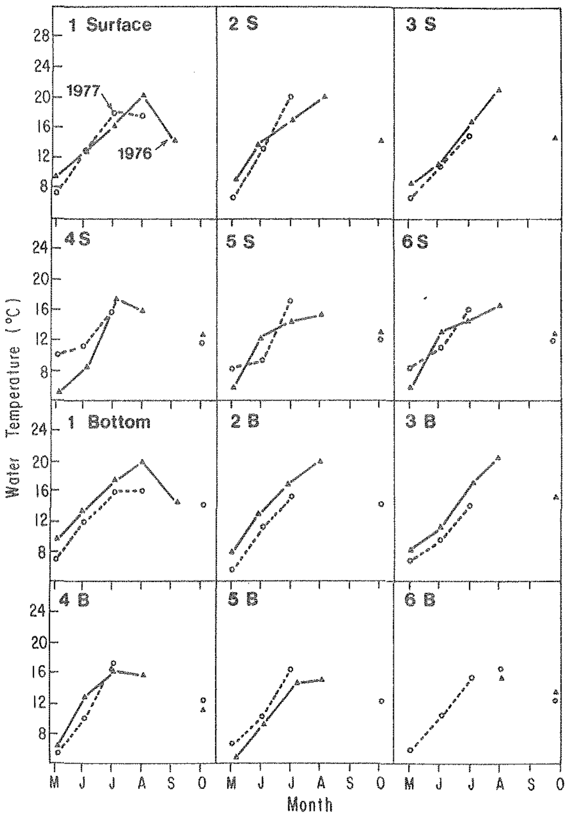

Fig. 6. Variations in Northumberland Strait water temperature (°C) during 1976 and 1977.

In July 1977 at Station IV higher bottom than surface temperatures were found. The surface and bottom temperatures were found to be the same at Station I during 1976 (cf. Fig. 6). In general, water temperatures of the Cap Pelé region were higher than those at Saint-Édouard-de-Kent. Air temperatures were higher (6-28°C) in 1976 than those (10-23°C) of 1977.

Salinity increased in June reaching a maximum of 29.0 o/oo. Salinities generally decreased during the end of May and the beginning of July. The lowest salinity recorded was 18 o/oo. Salinities of Cap Pelé waters were higher (22.0-29.5 o/oo) than those of Saint-Édouard-de-Kent (18.0-27.4 o/oo) (Fig. 7).

Transparency of Cap Pelé waters varied between 3.4 and 23.0 m and between 4.0 and 22.0 m, at Saint-Édouard-de-Kent. The pH of waters was normally around 8.0 but at Cap Pelé it varied between 7.3 and 8.4

The dissolved oxygen content was near saturation concentrations during most of the period studied. It varied between 2.7 and 10.4 ppm. The concentration of dissolved oxygen gradually declined in both surface and bottom waters from July to August as the season advanced (Fig. 8).

Table 1. Changes in the water quality of coastal waters of Northumberland Strait, 1976.

Sampling station		Air temp. (°C)	Water temp. (°C) S	Water temp. (°C) B	pH S	pH B	Salinity o/oo S	Salinity o/oo B	Trans-parency (m)	D.O. (ppm) S	D.O. (ppm) B
1	Max	16.5	20.6	20.2	8.1	8.2	26.8	26.1	7.3	7.62	10.6
	Min	9.0	9.5	9.0	7.6	8.0	24.0	22.1	4.9	4.8	3.71
	X̄	14.5	14.96	14.1	7.85	8.04	25.16	24.72	5.64	6.04	6.83
2	Max	16.5	20.6	20.2	8.1	8.2	25.3	26.2	7.3	8.42	8.1
	Min	9.0	8.2	13.2	7.8	7.9	23.5	23.0	4.9	4.0	4.3
	X̄	15.34	14.7	14.42	7.96	8.02	24.64	24.92	5.64	6.4	6.19
3	Max	25.0	21.0	20.5	8.2	8.02	25.9	27.4	8.4	7.8	8.0
	Min	11.0	8.5	8.2	7.9	7.9	23.0	18.0	4.9	4.4	4.68
	X̄	15.82	14.52	14.6	8.02	8.02	24.56	24.5	6.2	5.97	6.31
4	Max	20.4	16.9	16.1	8.0	8.0	28.0	27.0	6.8	8.16	8.72
	Min	8.5	5.5	5.2	7.6	7.7	23.5	21.2	4.3	4.26	5.21
	X̄	15.98	11.78	12.12	7.9	7.94	25.18	24.38	5.36	6.23	6.85
5	Max	22.0	15.6	15.4	8.0	8.0	26.1	26.0	9.9	6.73	6.64
	Min	9.0	5.0	4.7	7.7	7.8	21.3	22.3	4.4	4.12	4.39
	X̄	16.74	12.22	11.74	7.93	7.95	24.0	24.1	6.58	5.91	5.57
6	Max	19.2	16.3	15.4	8.0	8.0	25.8	26.0	12.1	8.98	8.04
	Min	8.2	5.7	5.1	7.5	7.7	23.0	24.2	4.8	3.8	4.1
	X̄	16.0	12.64	11.88	7.9	7.92	24.2	25.1	7.1	6.44	6.27

X̄ = mean; S = surface; B = bottom; Max = maximum; Min = minimum; T = trace

Table 2. Changes in the water quality of coastal waters of Northumberland Strait, 1977.

Sampling station		Air temp. (°C)	Water temp. (°C) S	Water temp. (°C) B	pH S	pH B	Salinity o/oo S	Salinity o/oo B	Trans-parency (m)	D.O. (ppm) S	D.O. (ppm) B
1	Max	23	17	17	8.4	8.4	29	28.5	20	10	10
	Min	13	6	5.5	7.8	7.8	22	22	10	3.3	3.9
	X̄	17	12.5	17.4	8.0	8.1	25.8	25.7	4.9	5	5.7
2	Max	20	22	17	8.5	8.5	29.5	29	22	10	7.0
	Min	10	5.5	4	7.8	7.8	22	22	15	3.2	5.3
	X̄	15.6	11.4	10.6	8.1	8.1	25.7	26.0	5.6	7.7	6.1
3	Max	20	16	14	8.1	8.2	28.5	29	23	9.4	10.4
	Min	10	4.5	2.5	8.0	7.8	23	25.5	16	8.0	4.8
	X̄	14	10.8	9.4	8.1	8.0	26.3	27.3	5.9	8.9	6.9
4	Max	21	16	13	8.0	8.0	29	28	18	10.2	7.3
	Min	11	10	5	7.9	7.8	22	22	13	3.7	4.4
	X̄	16.3	12.4	10.9	8.0	7.9	26.2	26.4	4.9	7.6	5.9
5	Max	19	17	16	8.2	8.1	29	29	6.7	10.0	4.3
	Min	11	8	6.5	8.0	8.0	19.0	18.0	5.5	2.7	3.6
	X̄	15.0	11.8	11.3	8.1	8.0	25.6	25.4	5.8	6.1	3.9
6	Max	18.0	16.0	15.0	8.2	8.2	26.0	27.0	22.0	8.4	8.4
	Min	10.0	8.0	5.5	8.0	8.0	20.0	20.0	16.0	4.1	2.1
	X̄	15.0	11.7	10.1	8.1	8.1	24.3	24.1	5.4	6.3	5.7

X̄ = mean; Max = maximum; Min = minimum; PPB = parts per billion; S = surface; B = bottom

Table 1. (cont'd)

Depth (m) B	Conductivity (MmHO) S	B	Ortho-P (PPB) S	B	Total - P (PPB) S	B	NO -N (PPB) S	B	Chl.-*a* µg/L S	B	Phaeophytin µg/L S	B
12.8	345	350	10(80)	10	580	510	50	70	2.21	3.24	8.6	1.69
10.4	203	196	T	T	280	T	T	10	0.302	0.22	0.1	0.07
11.46	279.6	278.2	6.66	2.6	378.7	356.25	21.0	31.2	1.03	1.34	2.21	1.18
15.2	345	350	13	30	900	480	60	50	1.62	2.06	2.1	1.35
10.4	203	196	T	T	220	200	10	6	0.44	0.59	0.29	.29
12.06	279.6	279.2	3.8	11.6	463.8	318	30.8	21.2	1.22	1.12	0.97	.87
23.2	350.0	350	26.0	20.0	330	640	56(110)	50	3.54	2.2	2.7	1.64
19.8	202	202	T	T	120	130	T	20	0.52	0.59	0.36	0.24
21.94	278.4	270.4	10.2	5.0	235.6	298	26.5	34.6	1.47	1.54	1.3	1.02
15.0	330	330	5.0	60	365	440	35	65.0	2.43	2.4	1.67	1.46
7.0	195	192.0	T	T	200	200	5.0	5.0	0.81	0.7	0.74	0.94
10.2	272.4	272.4	1.0	13.33	259.2	317.5	22.0	28.3	1.35	1.33	1.16	1.14
17.1	320	335	50	10	565	315	20	30.0	4.73	3.02	1.62	1.3
10.0	212	202	T	T	T	150	5	5.0	0.66	0.81	0.60	1.01
12.42	269.8	275	16.0	2.5	430	253.3	12	19.17	2.0	1.64	1.13	1.11
27.4	330	330	20.0	60	530	440	30	30.0	2.29	1.7	0.94	1.14
14.0	207	200	T	T	160	180	15	5.0	0.74	0.29	0.31	0.48
19.19	271.6	276.4	4.0	13	294.0	297.5	21.66	18.75	1.31	0.85	0.51	0.79

Table 2. (cont'd)

Depth (m)	Conductivity (MmHO) S	B	PO (PPB) S	B	NO -N (PPB) S	B	Chl.-*a* µg/L S	B	Phaeophytin µg/L S	B
13	340	340	46	55	.29	0.2	1.0	1.0	0.06	0.07
8	290	280	11	11	0.1	0.1	0.02	0.04	0.0008	0.004
11.0	302	306	19	27	0.12	.12	0.4	0.6	0.03	0.03
18	340	340	73	37	1.8	0.4	1.4	1.0	0.15	0.11
10	260	260	10	15	0.1	0.1	0.03	0.4	0.002	0.01
13.3	301	300	34.8	24	0.38	0.18	0.5	0.5	0.03	0.05
25	380	380	55	44	4	4.0	0.6	0.6	0.07	0.06
14	260	260	12	10	0.1	0.1	0.06	0.03	0.005	0.0002
20.1	295	303	35.3	24.6	1.1	1.4	0.3	0.2	0.03	0.02
10	370	370	36	44	1.3	0.11	3.1	0.5	0.08	0.06
7	240	240	T	5	0.1	0.1	0.2	0.03	0.01	0.005
8.7	309	307	21.8	23	0.48	.09	1.2	0.2	0.13	0.03
14	340	335	46	26	2.9	0.2	0.9	0.5	0.05	0.07
10	210	190	2	5	0.1	1.7	0.06	0.08	0.008	0.002
11.8	302	292	25.4	18.5	1.2	.9	0.4	0.3	0.03	0.02
16	340	335	31	44	0.2	6.1	0.9	0.8	0.08	0.08
12	230	240	5	12	0.1	0.9	0.02	0.2	0.02	0.0004
14	285	287	21.1	32			0.3	0.4	0.04	0.03

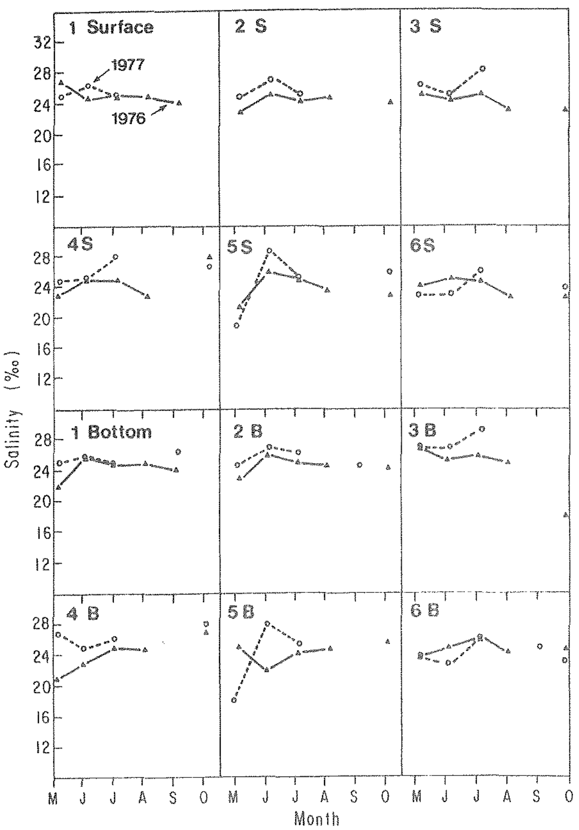

Fig. 7. Variations in salinity (o/oo) of the waters of Northumberland Strait during 1976 and 1977.

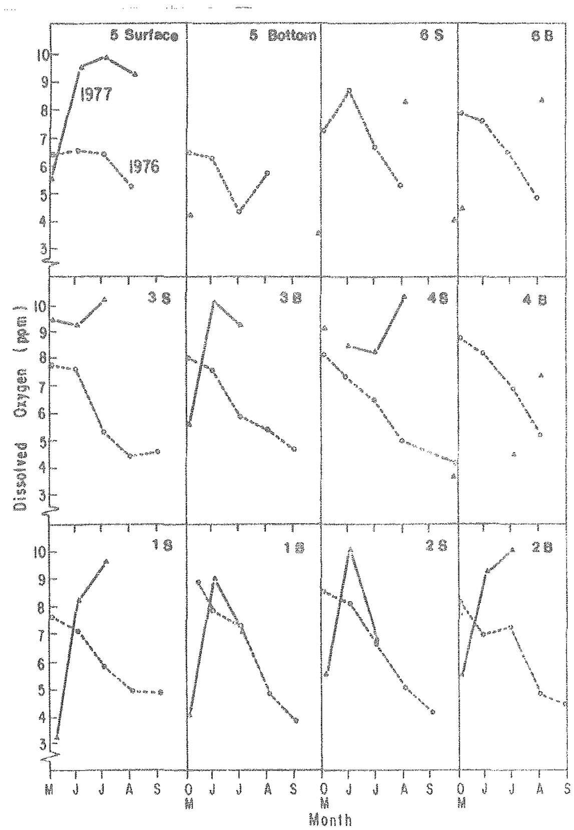

Fig. 8. Variations in dissolved oxygen (ppm) of the waters of Northumberland Strait during 1976 and 1977.

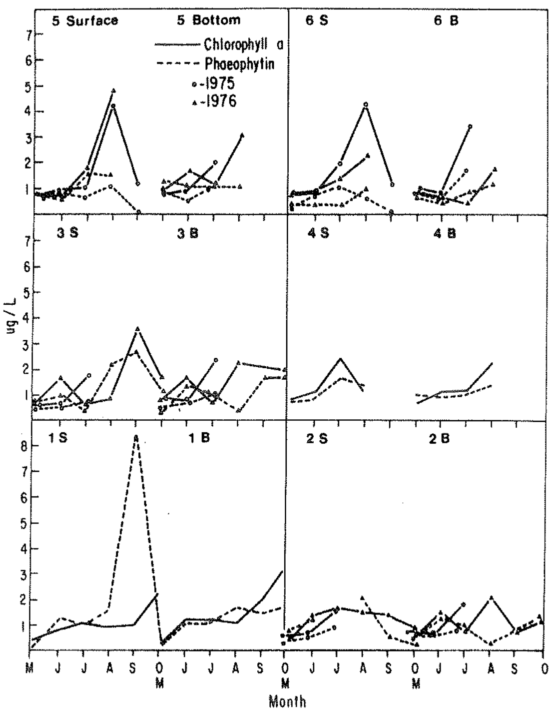

Fig. 9. Variations in chlorophyll *a* and phaeophytin (μg/L) in Northumberland Strait waters during 1975 and 1976.

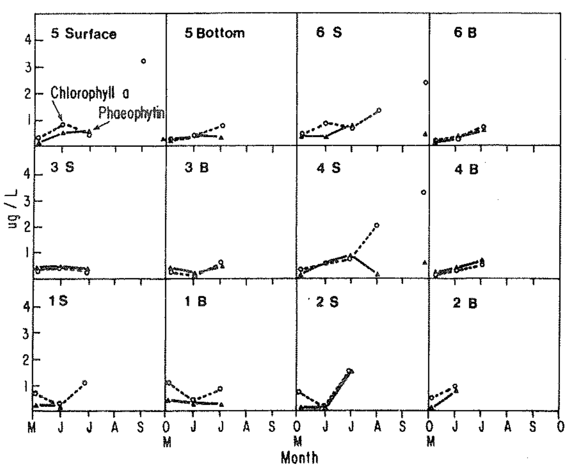

Fig. 10. Variations in chlorophyll *a* and phaeophytin (μg/L) in the waters of Northumberland Strait during 1977.

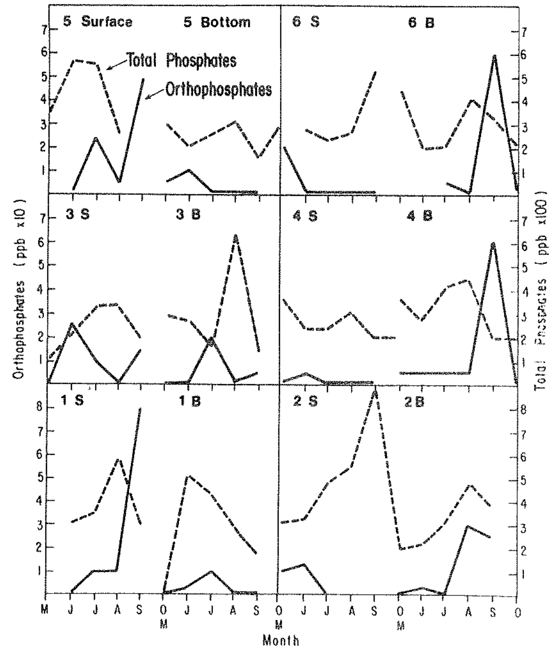

Fig. 11. Variations in total phosphates and orthophosphates in the waters of Northumberland Strait during 1976.

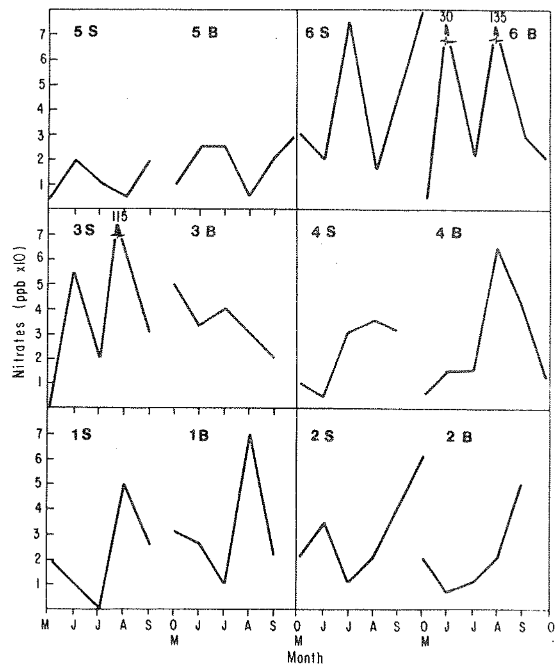

Fig. 12. Variations in nitrates in the waters of Northumberland Strait during 1976.

In surface waters chlorophyll *a* generally ranged between 0.02 and 4.73 μg/L. Average values for chlorophyll *a* indicated a definite reduction in biomass in 1977 compared to 1975 and 1976 (cf. Table 3). The Saint-Édouard-de-Kent waters showed higher phytoplankton populations and consequently higher chlorophyll *a* values. Usually July and August showed greater chlorophyll *a* concentrations. Intensive grazing was indicated by high phaeophytin concentrations during late August and September. Nearshore increase in chlorophyll *a* occurred during June at some sampling stations (Fig. 9, 10). Total phosphate (6-530 ppb) and orthophosphate (trace-80 ppb) reflected changes in the chlorophyll *a* concentrations (Fig. 11). The nitrate nitrogen concentrations were lower (trace to 0.4 ppb) in 1977 than in 1976 when a value up to 30 ppb was recorded (Fig. 12). This may be due to the change of method of estimation during 1977. The nitrite nitrogen varied between traces and 0.68 ppb. Variations in nitrogen fractions were irregular and did not show any definite correlation with those of chlorophyll *a*.

The total carbon of surface water ranged between 30 and 48 ppm at Cap Pelé and 37 and 80 ppm at Saint-Édouard-de-Kent. Transparencies of the water were comparatively lower in 1976 than in 1977, indicating thereby greater production of phytoplankton in 1976. The most common genera of phytoplankton found were: *Euglena*, *Chilomonas*, *Rhodomonas*, *Exuviaella*, *Prorocentrum*, *Dinophysis*, *Gymnodinium*, *Glenodinium*, *Peridinium*, *Gonyaulax*, *Oxytoxum*, *Pyrocystis*, *Acanthoica*, *Phaeocystis*, *Pontosphaera*, *Syracosphaera*, *Coccolithus*, *Dictyocha*, *Phalacroma*, *Dinophysis* and *Distephanus* and many diatoms.

The concentration levels and distribution of iron, manganese, copper, nickel, zinc, lead and cadmium are shown in Table 4. No unusual concentration of cadmium occurred. Copper, zinc, lead, nickel, manganese and iron showed levels characteristic of coastal waters. Although copper (0.8 μg/L) showed the same level as zinc (0.9 μg/L) during 1976, in 1977 the samples showed high levels (17.0 μg/L). Iron (300-600 μg/L), manganese (60-80 μg/L), and lead (2.0-6.0 μg/L) showed unusually high concentrations in 1977 (Table 5). This may be due to low salinity and pH, and also all samples show total iron as they were not filtered. In general, differences in the concentration of trace metals between inshore and offshore stations seem insignificant. Probably this may be due to the extension of shore-waters to the offshore waters and a favourable circulation pattern for mixing of both. These results indicate that their distribution is probably controlled both by allochthonous input and water circulation.

The distribution of lobster larvae off Cap Pelé and Saint-Édouard-de-Kent is shown in Tables 6 and 7 (Varma, pers. comm.). A total of 113 larvae were captured off Cap Pelé during sampling on six occasions from May 18 to July 27, 1976, of which stages I, II and III were represented by 98, 12 and 3 larvae respectively. From Côte Ste-Anne in five samplings from May 26 to July 20 a total of 42 larvae were captured of which 41 were stage I and 1 stage II. Fifty larvae from Cap Pelé (35 stage I, 12 stage II, 3 stage III) and 25 larvae from Côte Ste-Anne were examined for their stomach contents. All larval stages contained planktonic algae, copepods, organic matter and 40-50% inorganic matter.

DISCUSSION

Waters of Northumberland Strait are subjected to pollution from fresh water, natural drainage, sewage and other industrial wastes of local communities in the southern and northern regions. For example, Culligan and Baxter (1973) reported bacterial contamination of the Cocagne river and estuary in Kent County. The shore regions are subjected to tidal current velocities of 0.5 knots and higher, and the estuaries trap most of the sediment load (Farquharson 1962; Kranck 1971). The waters showed varied transparencies and were well oxygenated. Bacon (1977) reported dissolved oxygen values above 5 ppm in Northumberland Strait waters and that the waters were isothermal and isohaline with thermal stratification at some stations only during November, April, May and June. The present studies showed distinct differences in water temperatures and salinities of Saint-Édouard-de-Kent and Cap Pelé, the latter with higher values.

Templeman (1936) reported faster development of lobster larvae at higher temperatures (24°C), with salinities of 31 o/oo most suitable while 28 o/oo and lower were slightly unfavourable. Stewart et al. (1972) stated that in lobsters changes in muscle content and serum protein concentration were strictly temperature dependent in starved populations while hemolymph carbohydrate values are more directly related to temperature than food quantities. Templeman (1936) suggested that reduction in plankton food supply for lobster larvae lengthens their stage periods and reduces the chances of survival. Although the data on lobster larvae populations in 1976 are not sufficient to draw comparisons with the findings of Scarratt (1964, 1974), it is possible that the lobster larvae were unable to ingest sufficient food resulting in slower growth and exposure to predation and other unfavourable environmental conditions (Varma, pers. comm.).

The algal biomass showed higher average values (1.1-1.8 μg/L) in the Cap Pelé waters during 1975 and 1977 than off Saint-Édouard-de-Kent. In 1976 both regions had similar quantities of algal biomass (1.2-1.23 μg/L). The 1976 values for lobster larval populations indicated a high incidence in Cap Pelé waters. Vézina

Table 3. Chlorophyll *a* during 1975, 1976 and 1977 in the coastal waters of Northumberland Strait (mean value in μg/L).

Sample station	Year 1975	1976	1977
1	0.82	1.03	0.40
2	-	1.22	0.50
3	0.94	1.47	0.30
4	1.71	1.35	1.20
5	-	2.0	1.0
6	2.0	1.31	1.20

Table 4. Concentration of heavy metals in the coastal waters of Northumberland Strait, 1976.

	$\bar{X}$		Max		Min		S.D.		N	
Metal	S	B	S	B	S	B	S	B	S	B
Fe	2.8	2.5	6.0	3.8	1.8	1.2	0.16	0.49	46	45
Mn	1.8	1.9	5.0	5.0	0.8	0.6	0.3	0.29	41	33
Cu	0.8	1.1	1.4	2.3	0.4	0.4	0.01	0.31	46	44
Ni	14.6	14.1	20.0	20.0	10.0	10.0	0.3	0.75	45	44
Zn	0.9	0.8	2.8	1.8	0.3	0.4	0.19	0.12	46	45
Pb	3.5	4.01	6.0	6.4	2.5	2.5	0.3	0.23	46	45
Cd	0.6	0.7	0.8	1.0	0.5	0.6	0.03	0.06	46	45

S = surface; B = bottom; $\bar{X}$ = mean; N = number of samples analyzed; S.D. = standard deviation. All values expressed in parts per billion.

Table 5. Concentration of heavy metals in the coastal waters of Northumberland Strait (mean values in μg/L).

	1976						1977					
	$\bar{X}$		Max		Min		X		Max		Min	
Metal	S	B	S	B	S	B	S	B	S	B	S	B
Fe	2.8	2.5	6.0	3.8	1.8	1.2	350	43	600	-	300	-
Mn	1.8	1.9	5.0	5.0	0.8	0.6	70	-	80	-	60	-
Cu	0.8	1.1	1.4	2.3	0.4	0.4	17	-	50	-	4	-
Ni	14.6	14.9	20	20	10	10	-	-	-	-	-	-
Zn	0.9	0.8	2.8	1.8	0.3	0.4	4	-	50	-	2	-
Pb	3.5	4.0	6.0	6.4	2.5	2.5	2.0	-	6.0	-	2.5	-
Cd	0.6	0.7	0.8	1.0	0.5	0.6	1.0	-	3.0	-	0.6	-

S = surface; B = bottom; $\bar{X}$ = mean; Max = maximum; Min = minimum; - not estimated.

Table 6. Distribution of various stages of lobster larvae at different stations during summer 1976 off Cap-Pelé.

Stages	I			II			III			IV			
Stations	1	2	3	1	2	3	1	2	3	1	2	3	
Dates													Total
May 18	0	0	0	0	0	0	0	0	0	0	0	0	0
June 1	0	0	0	0	0	0	0	0	0	0	0	0	0
June 15	0	0	0	0	0	0	0	0	0	0	0	0	0
June 28	0	3	6	0	0	1	0	0	0	0	0	0	10
July 12	12	22	15	2	3	2	0	1	2	0	0	0	65
July 27	10	15	9	0	2	2	0	0	0	0	0	0	38
August 9	BAD WEATHER												

Table 7. Distribution of the various stages of lobster larvae at different stations during summer 1976 off Côte Ste-Anne.

Stages	I			II			III			IV			
Stations	4	5	6	4	5	6	4	5	6	4	5	6	
Dates													Total
May 26	0	0	0	0	0	0	0	0	0	0	0	0	0
June 8	0	0	0	0	0	0	0	0	0	0	0	0	0
June 21	0	1	0	0	0	0	0	0	0	0	0	0	1
July 6	3	0	0	0	0	0	0	0	0	0	0	0	3
July 20	8	15	14	0	1	0	0	0	0	0	0	0	38

(1977) indicated the lobster abundance and diminution at both Saint-Édouard-de-Kent and Cap Pelé. This coincided generally with variations in temperature and salinity but not with the biomass there.

The values for chlorophyll *a* were in general agreement with those of Steven et al. (1971), Platt (1971) and Platt and Subba Rao (1975). The ratio of fluorescence values of unacidified to acidified extracts is comparable to the values for natural populations of Yentsch and Menzel (1963). The phytoplankton was dominated by diatoms like that shown by Bacon (1977) while the nannoplankton was also significantly represented. Bacon (1977) reported detectable total phosphorous all during the year in the study area. The present results indicate nutrient enrichment with a probable trend for future higher accumulations of nutrients and heavy metals in Northumberland Strait waters.

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DISCUSSION OF OTHER PAPERS PRESENTED WHICH HAVE BEEN PUBLISHED ELSEWHERE

Estimates of pre-causeway flow through the Strait of Canso
D. J. Lawrence and D. Greenberg[1]

Scarratt: There is no doubt in your mind that this net flow in an outward direction in the Atlantic does exist?

Greenberg: It certainly exists at times although if you looked at the average over a few weeks it could be zero, or sometimes it could even be reversed.

Scarratt: You suggested that the surface 25 m of St. Georges Bay would be transported from one end of the Strait to the other in a period of about 30 d?

Greenberg: My estimate is 1½ to 2 mo.

Muir: With the barrier there, what is the difference in level between the head on the two sides?

Greenberg: The 6-mo average in 1955 was 0.2 ft, but that could vary from year to year.

Muir: The question that has been raised and that we may have to eventually consider is whether it would be better to remove the whole Causeway, cut a hole in it, or install a siphon-type system.

Greenberg: We can probably say categorically that a siphon system wouldn't work, and that a hole probably wouldn't.

Muir: On what basis?

Greenberg: The flow through wouldn't allow sufficient flow to drain the whole of St. Georges Bay.

Muir: But for siphoning off some portion of the top few meters of water that might contain larvae?

Dadswell: I would think there might be a major danger there, in that you wouldn't generate enough current to carry the larvae out the southern end of the Strait and that they might then end up outside the pulp mill.

The influence of a causeway on oceanography and Foraminifera in the Strait of Canso
G. Vilks, C. T. Schafer, and D. A. Walker[2]

Sandeman: Was there any indication of a northward movement of species adapted to a colder environment?

Vilks: No.

Question: Are there any comparable data for the central part of St. Georges Bay?

Vilks: Yes, but they were taken since construction of the Causeway.

Question: How do they compare?

Vilks: Not very well. It seems that all cases show more sediment on top. They are not dated but are being processed now.

Sandeman: How much of the splitting of the two groups is attributable to *Ammonia beccarii*?

Vilks: This could be the most important factor.

Dadswell: Are all the Foraminifera on the surface of the mud?

Vilks: Yes, essentially on the surface, they are stationary - don't migrate.

The effects of the Canso Causeway on the marine environment of the Strait of Canso and adjacent bays
D. E. Buckley

Question: Do we know anything about possible contaminants in material dredged from behind the NSFI wharf?

Buckley: Little environmental monitoring was done as the Ocean Dumping Act was not yet in force.

Cook: Were metal bottles used to collect samples from the Port Hawkesbury area prior to dredging?

Buckley: Yes, however, the dredged material was 80% organic (wood fiber) that contains mercury and other contaminants.

Cook: Dumping of wastes with a high level of heavy metal contamination wouldn't be allowed now. They would have to look for a land disposal site.

Wilson: There is some information available on composition of the benthos there. Samples were collected in August 1973 using a suction dredge and only one of the eight samples was free of molluscs.

Buckley: Molluscs were found inshore but the deeper area in the centre of the channel was barren.

Dadswell: Could this be due to a difference in sampling technique? (Subsequent discussions showed that the two data sets were in agreement. However, site locations are critical as there are spatial gradients in mollusc populations.)

Sandeman: What species were found inshore?

Wilson: At least half a dozen. They are listed in the Machell, Spencer, and Pelly report.

Surficial geology of Canso Bank and adjacent areas
B. MacLean, B. B. Fader, and L. H. King

Question: What is the depth of water in Canso Strait?

MacLean: Thirty meters minimum up to 50 m maximum.

Question: The Nova Scotia government sponsored a survey of bottom deposits in the Strait. Did they decide that the glacial till was dredgeable?

MacLean: Yes, the till is dredgeable but there has been a temporary lull in the interest in a super-port.

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[1]Paper presented by D. Greenberg
[2]Paper presented by G. Vilks